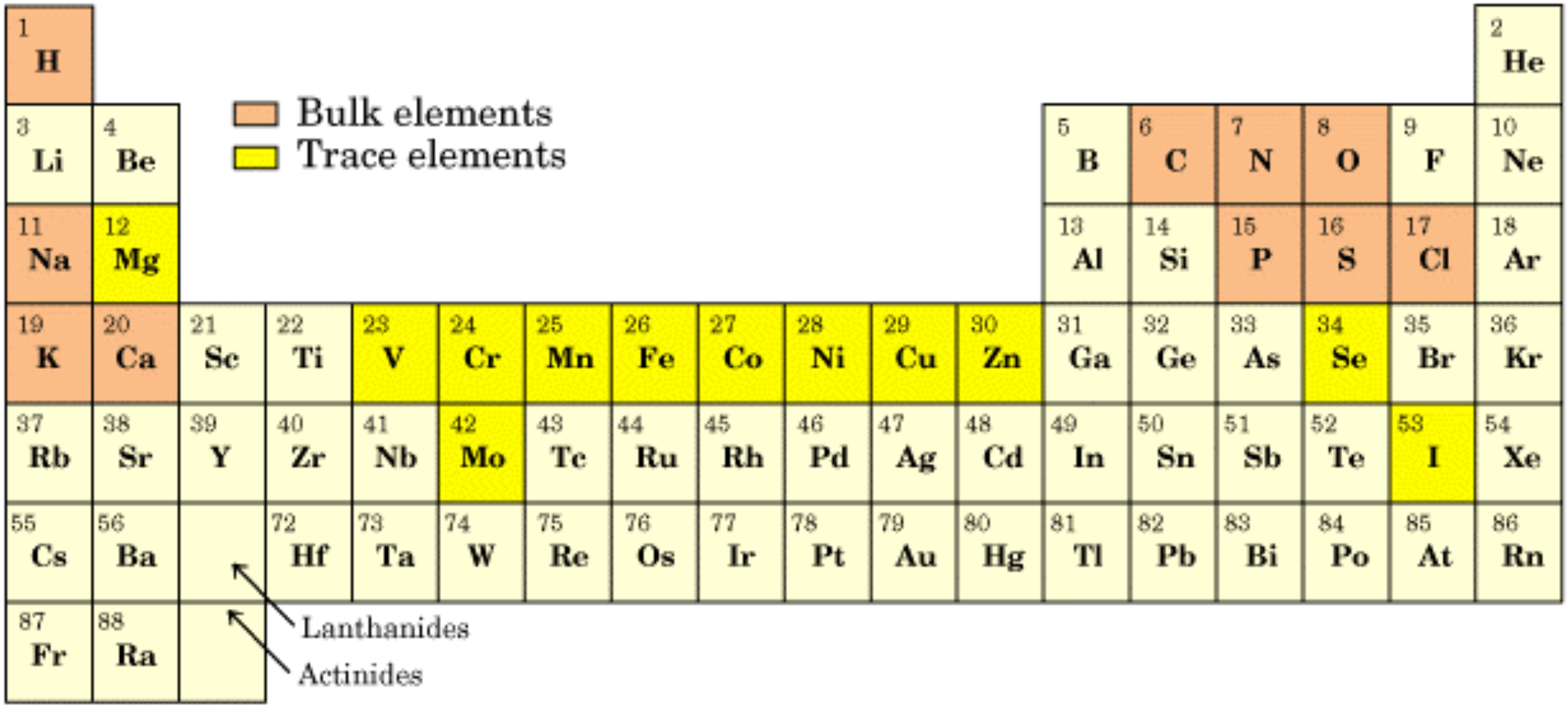
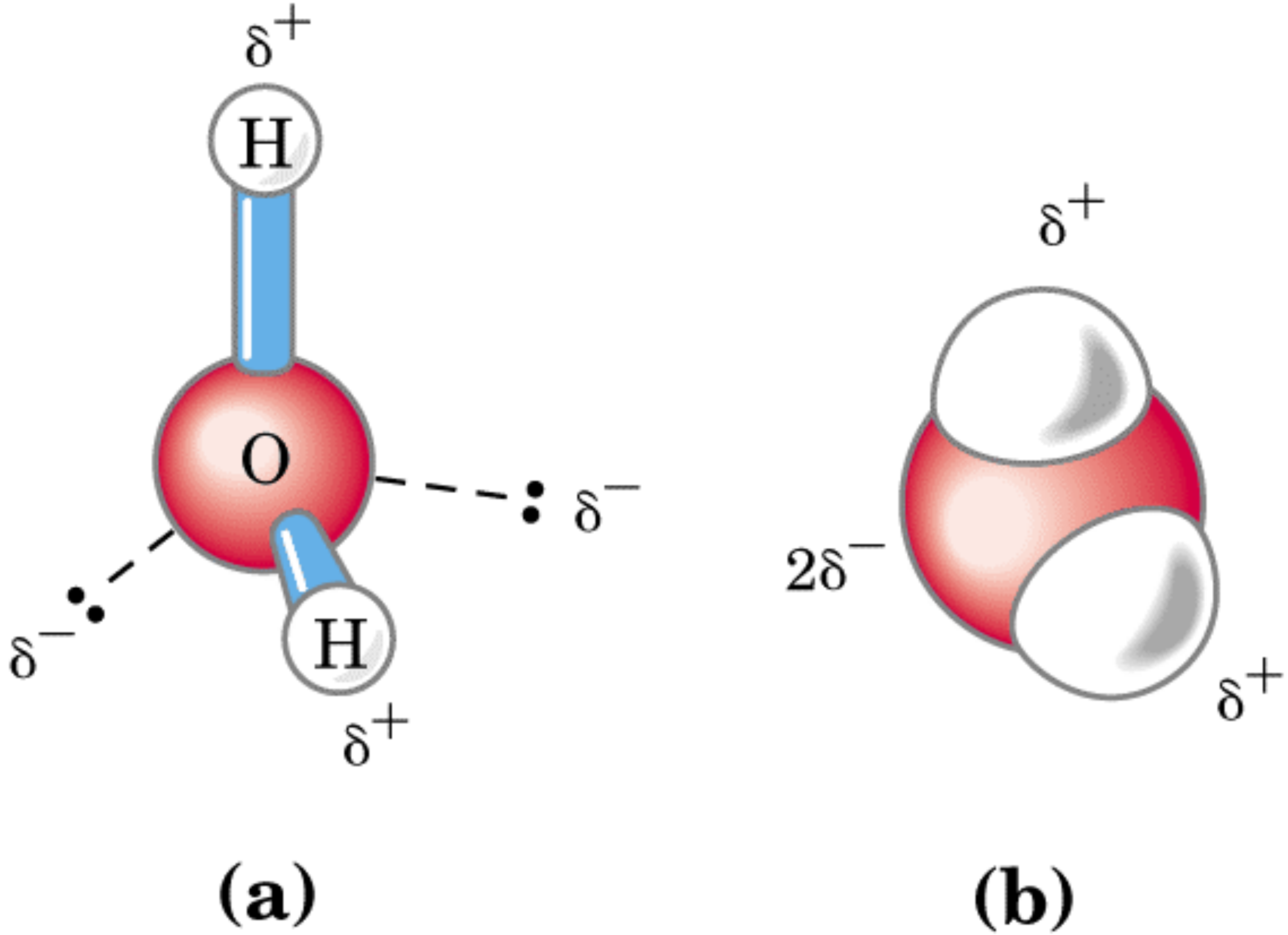
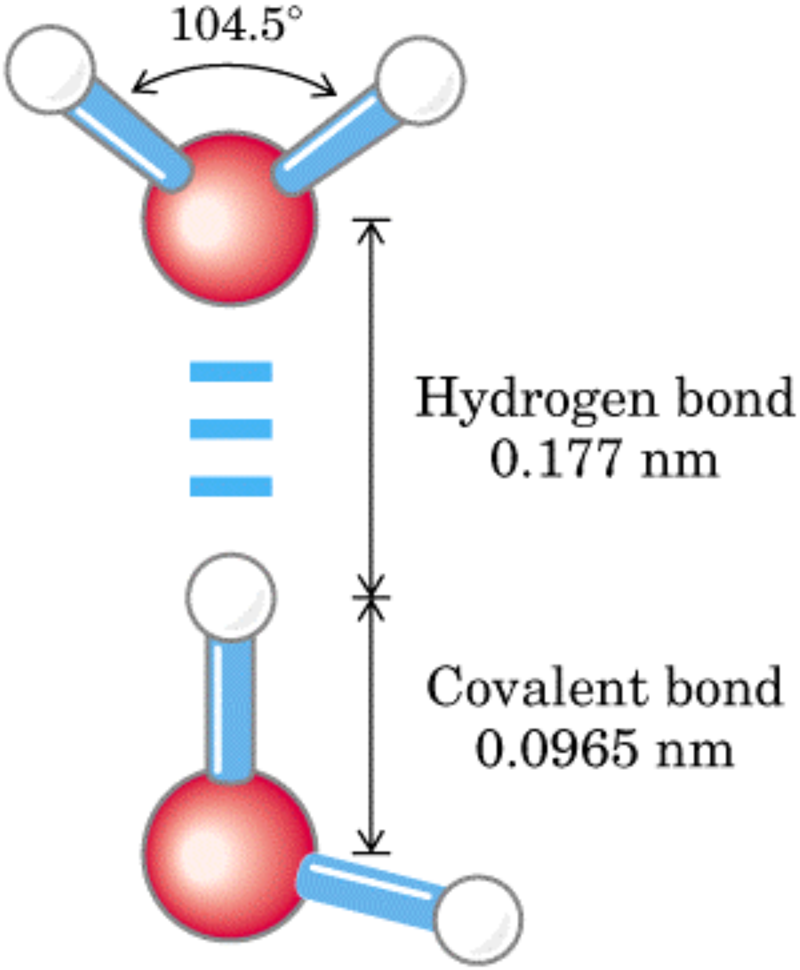
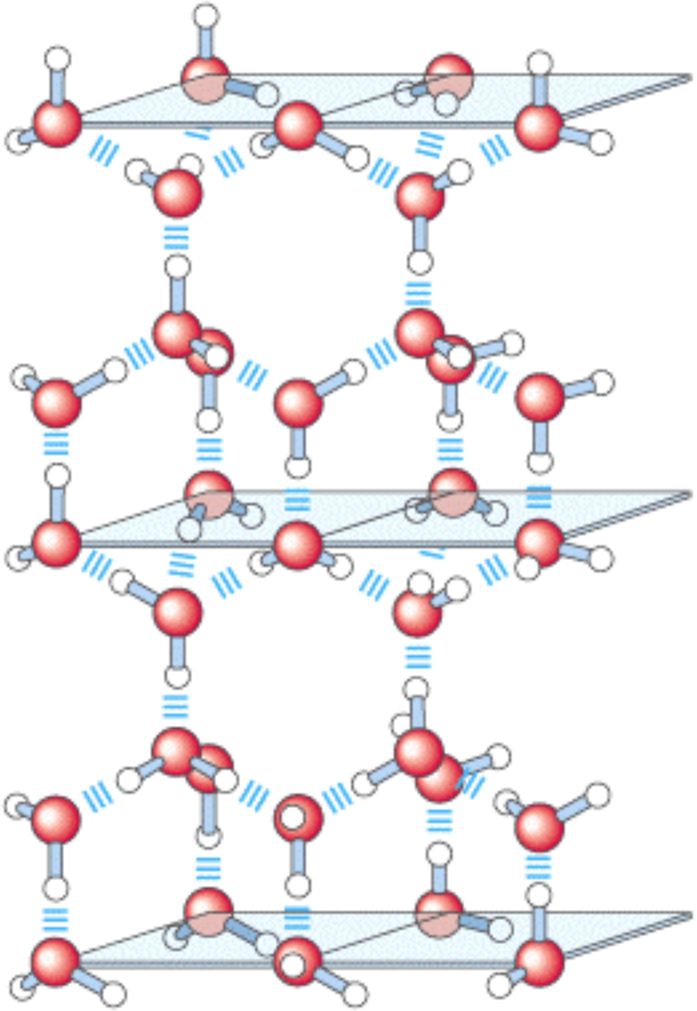
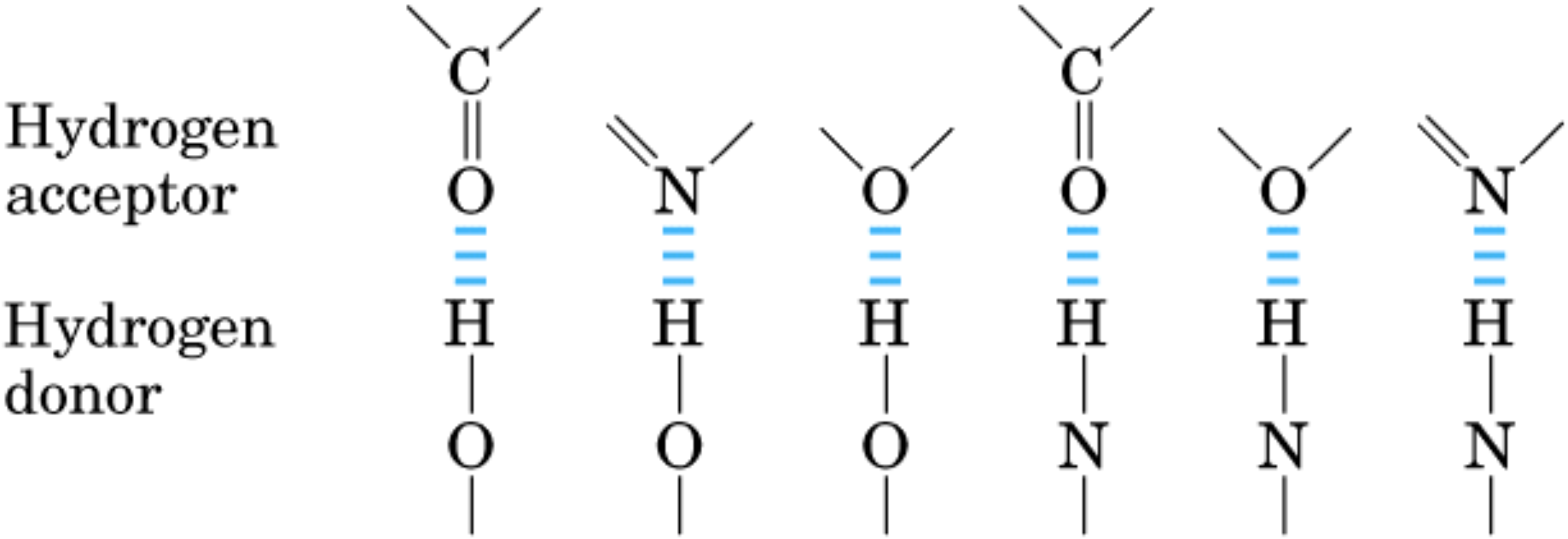

Bulk elements
Trace elements
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
Lanthanides
Actinides


δ⁺
H
O
δ⁻
δ⁻
H
δ⁺
(a)
δ⁺
2δ⁻
δ⁺
(b)



(c)




Hydrogen acceptor
Hydrogen donor
C
O
H
O
N
H
O
O
H
O
C
O
H
N
O
H
N
N
H
N

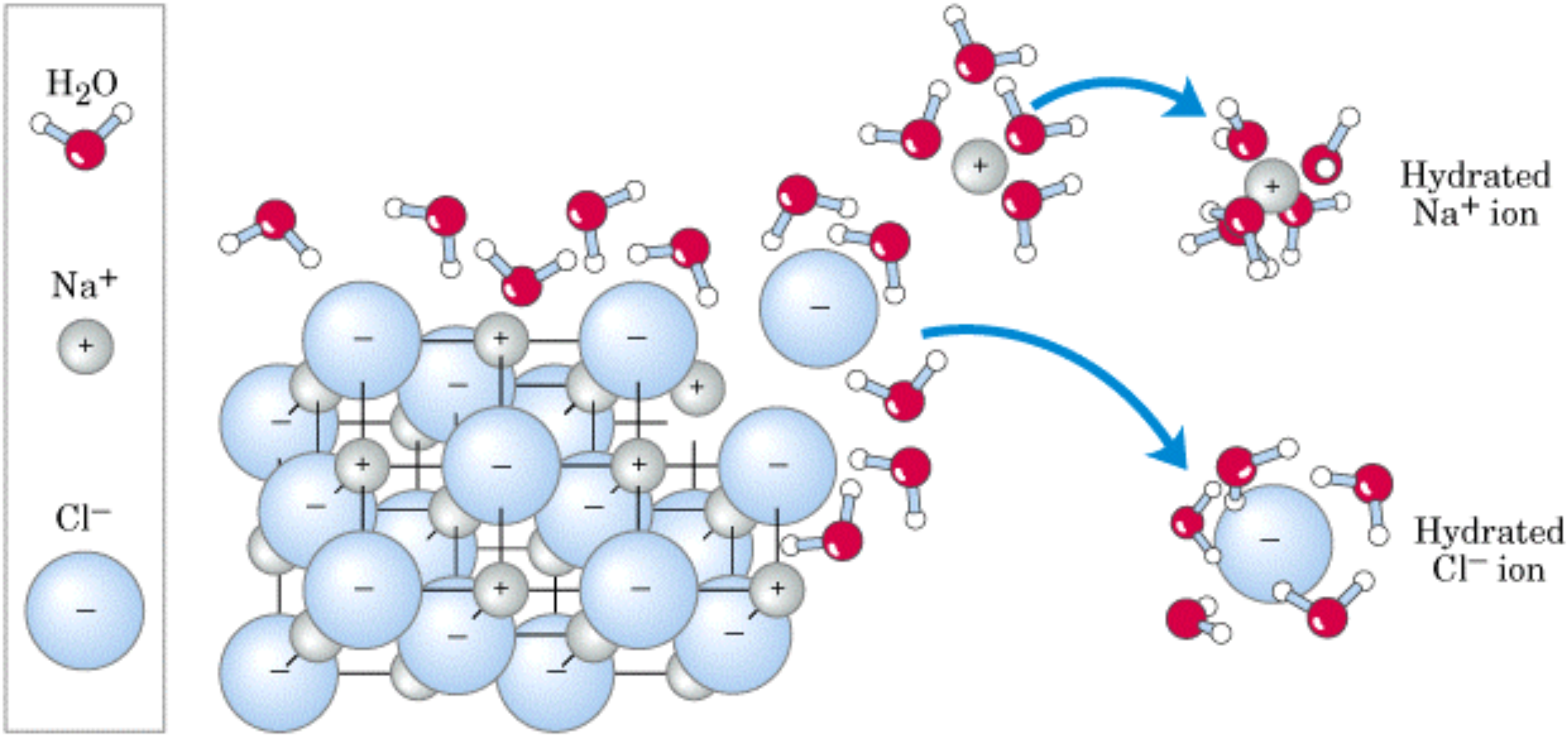
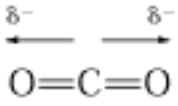
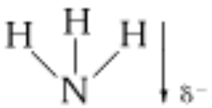
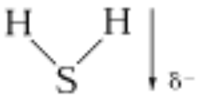

H2O
Na+
Cl−
Hydrated Na+ ion
Hydrated Cl− ion

table 4–3

Solubilities of Some Gases in Water

Gas	Structure*	Polarity	Solubility in water (g/L)[†]
Nitrogen	N≡N	Nonpolar	0.018 (40 °C)
Oxygen	O=O	Nonpolar	0.035 (50 °C)
Carbon dioxide	 $\overset{\delta^-}{\longleftarrow}\quad\overset{\delta^-}{\longrightarrow}$ O=C=O	Nonpolar	0.97 (45 °C)
Ammonia		Polar	900 (10 °C)
Hydrogen sulfide		Polar	1,860 (40 °C)

*The arrows represent electric dipoles; there is a partial negative charge (δ^-) at the head of the arrow, a partial positive charge (δ^+; not shown here) at the tail.

[†] Note that polar molecules dissolve far better even at low temperatures than do nonpolar molecules at relatively high temperatures.

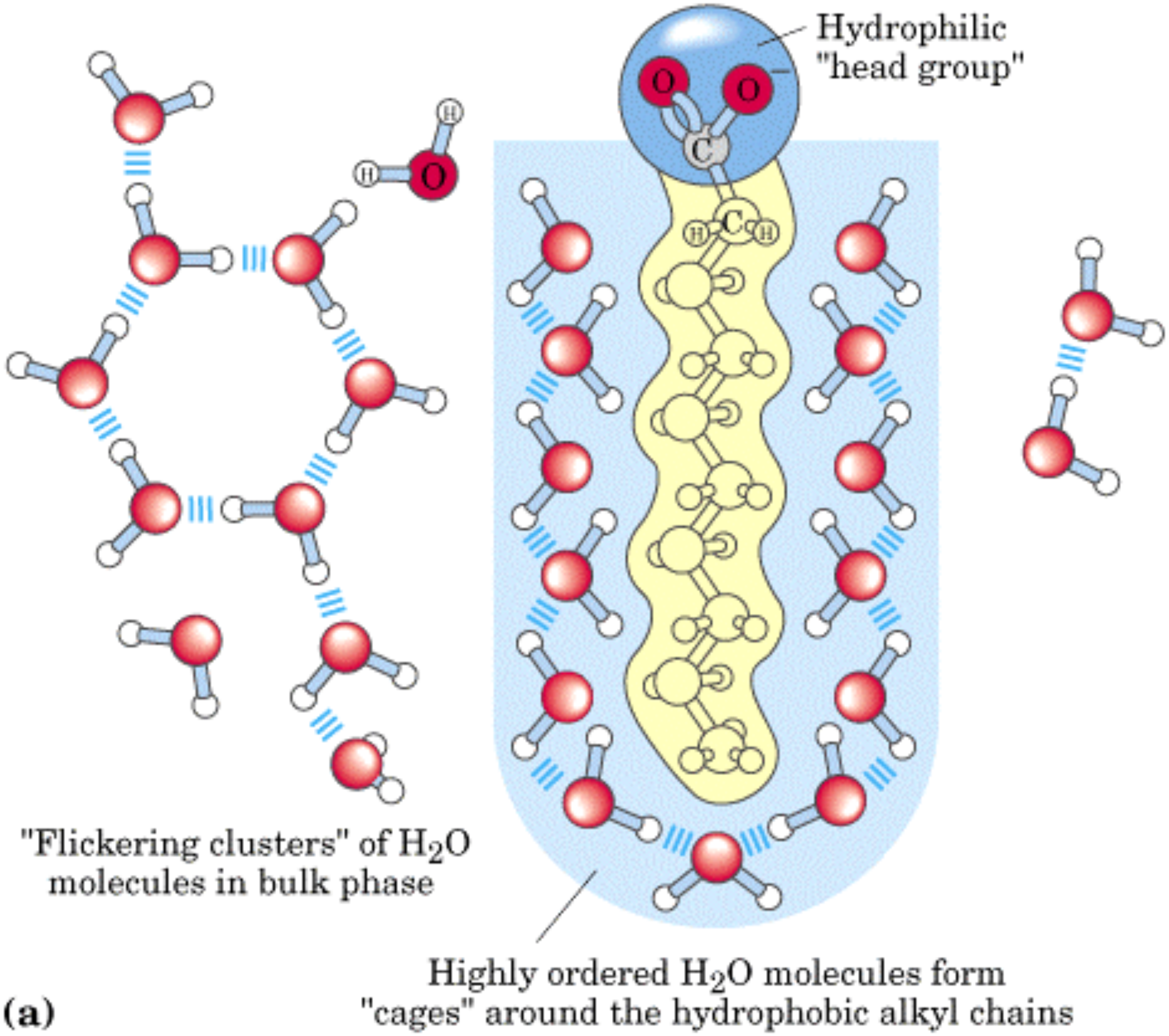

Hydrophilic "head group"
O
O
C
C
H
H
H
O
"Flickering clusters" of H_2O molecules in bulk phase
Highly ordered H_2O molecules form "cages" around the hydrophobic alkyl chains
(a)

table 4–4

Four Types of Noncovalent ("Weak") Interactions among Biomolecules in Aqueous Solvent

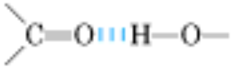
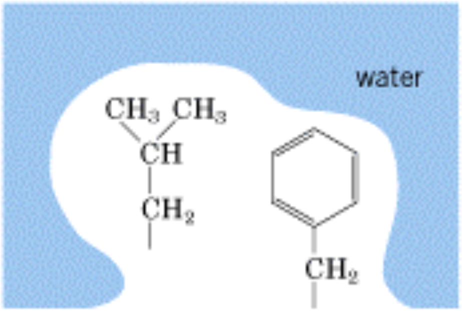
Hydrogen bonds	
Between neutral groups	
Between peptide bonds	
Ionic interactions	
Attraction	 $-{}^{+}NH_3 \rightarrow\leftarrow {}^{-}O-\overset{O}{\overset{\parallel}{C}}-$
Repulsion	$-{}^{+}NH_3 \longleftrightarrow H_3N^{+}-$
Hydrophobic interactions	
Van der Waals interactions	Any two atoms in close proximity

Table 2–1 Covalent and Noncovalent Chemical Bonds

		STRENGTH (kcal/mole)	
BOND TYPE	**LENGTH (nm)**	**IN VACUUM**	**IN WATER**
Covalent	0.15	90	90
Noncovalent: ionic*	0.25	80	3
hydrogen	0.30	4	1
van der Waals attraction (per atom)	0.35	0.1	0.1

*An ionic bond is an electrostatic attraction between two fully charged atoms.

Table 2-1 *Molecular Biology of the Cell* (© Garland Science 2008)

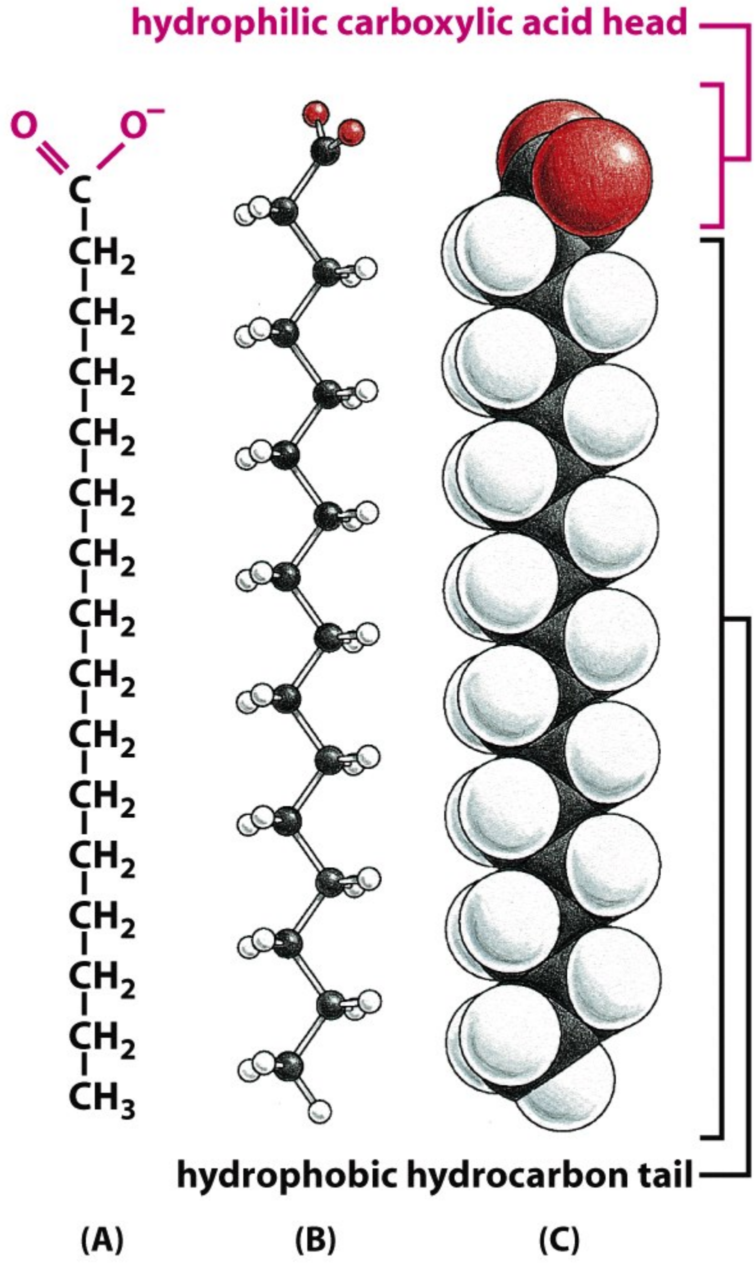


Figure 2-21 *Molecular Biology of the Cell* (© Garland Science 2008)

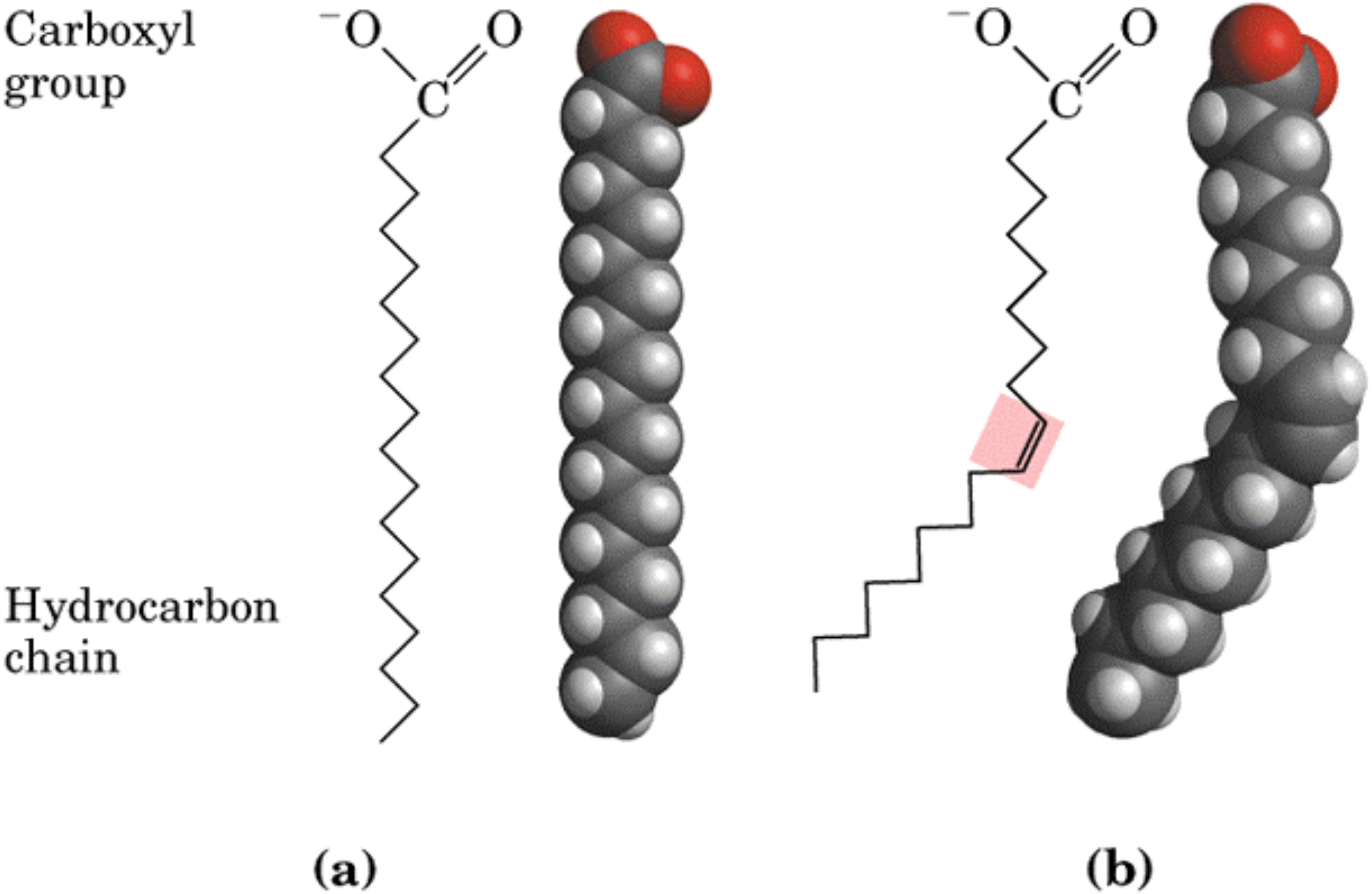

Carboxyl group
Hydrocarbon chain
⁻O
O
C
⁻O
O
C
(a)
(b)

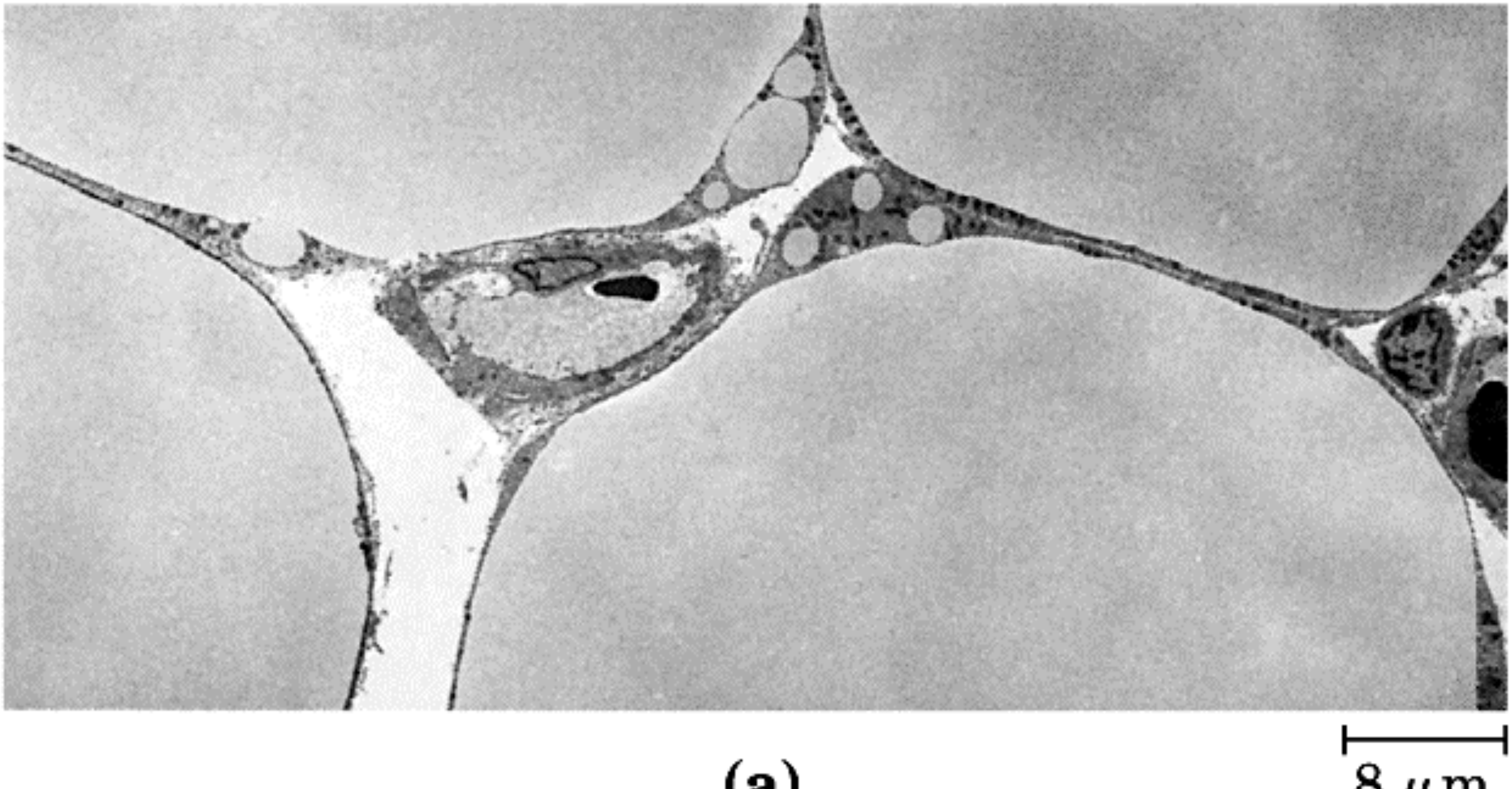
table 11–1

Some Naturally Occurring Fatty Acids

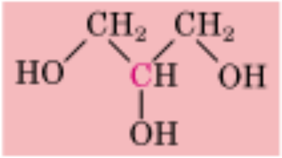
					Solubility at 30 °C (mg/g solvent)	
Carbon skeleton	Structure*	Systematic name†	Common name (derivation)	Melting point (°C)	Water	Benzene
12:0	$CH_3(CH_2)_{10}COOH$	*n*-Dodecanoic acid	Lauric acid (Latin *laurus*, "laurel plant")	44.2	0.063	2,600
14:0	$CH_3(CH_2)_{12}COOH$	*n*-Tetradecanoic acid	Myristic acid (Latin *Myristica*, nutmeg genus)	53.9	0.024	874
16:0	$CH_3(CH_2)_{14}COOH$	*n*-Hexadecanoic acid	Palmitic acid (Latin *palma*, "palm tree")	63.1	0.0083	348
18:0	$CH_3(CH_2)_{16}COOH$	*n*-Octadecanoic acid	Stearic acid (Greek *stear*, "hard fat")	69.6	0.0034	124
20:0	$CH_3(CH_2)_{18}COOH$	*n*-Eicosanoic acid	Arachidic acid (Latin *Arachis*, legume genus)	76.5		
24:0	$CH_3(CH_2)_{22}COOH$	*n*-Tetracosanoic acid	Lignoceric acid (Latin *lignum*, "wood" + *cera*, "wax")	86.0		
$16{:}1(\Delta^{9})$	$CH_3(CH_2)_5CH{=}CH(CH_2)_7COOH$	*cis*-9-Hexadecenoic acid	Palmitoleic acid	−0.5		
$18{:}1(\Delta^{9})$	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	*cis*-9-Octadecenoic acid	Oleic acid (Latin *oleum*, "oil")	13.4		
$18{:}2(\Delta^{9,12})$	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	*cis*-,*cis*-9,12-Octadecadienoic acid	Linoleic acid (Greek *linon*, "flax")	−5		
$18{:}3(\Delta^{9,12,15})$	$CH_3CH_2CH{=}CHCH_2CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	*cis*-,*cis*-,*cis*-9,12,15-Octadecatrienoic acid	α-Linolenic acid	−11		
$20{:}4(\Delta^{5,8,11,14})$	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CHCH_2CH{=}CHCH_2CH{=}CH(CH_2)_3COOH$	*cis*-,*cis*-,*cis*-,*cis*-5,8,11,14-Icosatetraenoic acid	Arachidonic acid	−49.5		

*All acids are shown in their nonionized form. At pH 7, all free fatty acids have an ionized carboxylate. Note that numbering of carbon atoms begins at the carboxyl carbon.

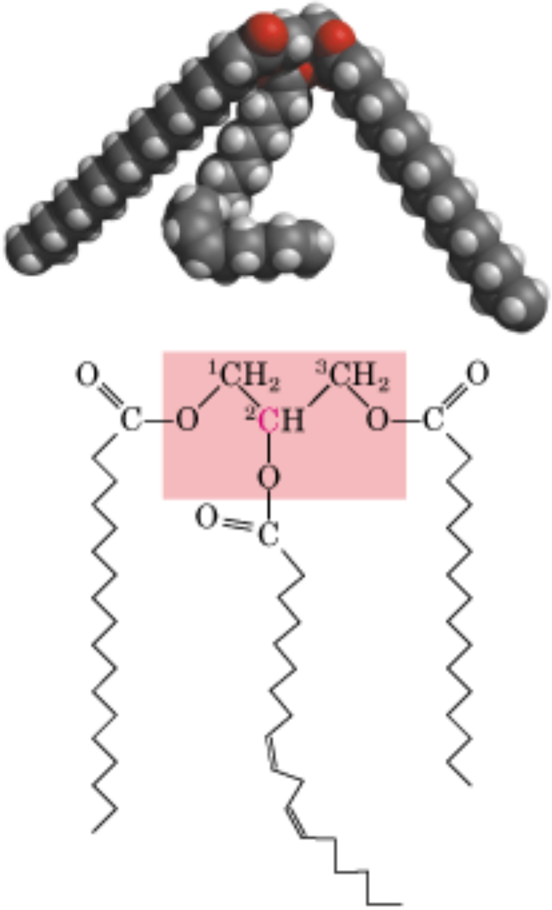
†The prefix *n*- indicates the "normal" unbranched structure. For instance, "dodecanoic" simply indicates 12 carbon atoms, which could be arranged in a variety of branched forms; "*n*-dodecanoic" specifies the linear, unbranched form. For unsaturated fatty acids, the configuration of each double bond is indicated; in biological fatty acids the configuration is almost always cis.



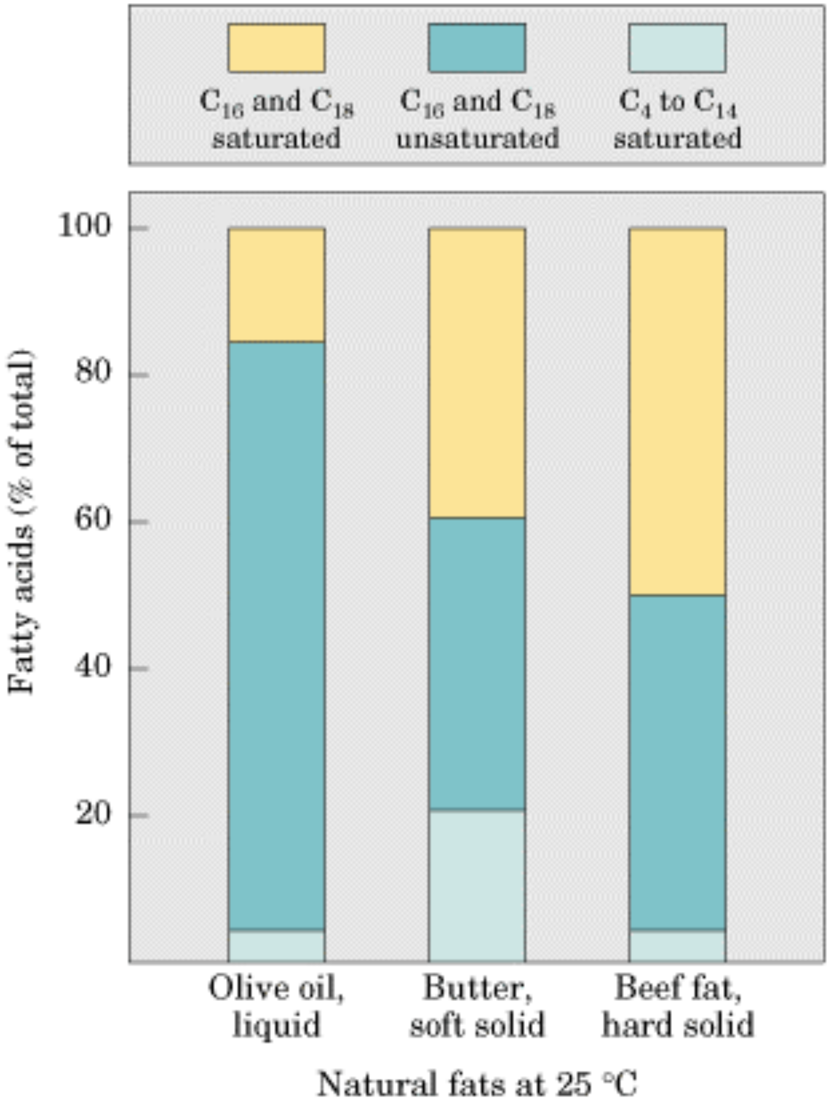
(a)



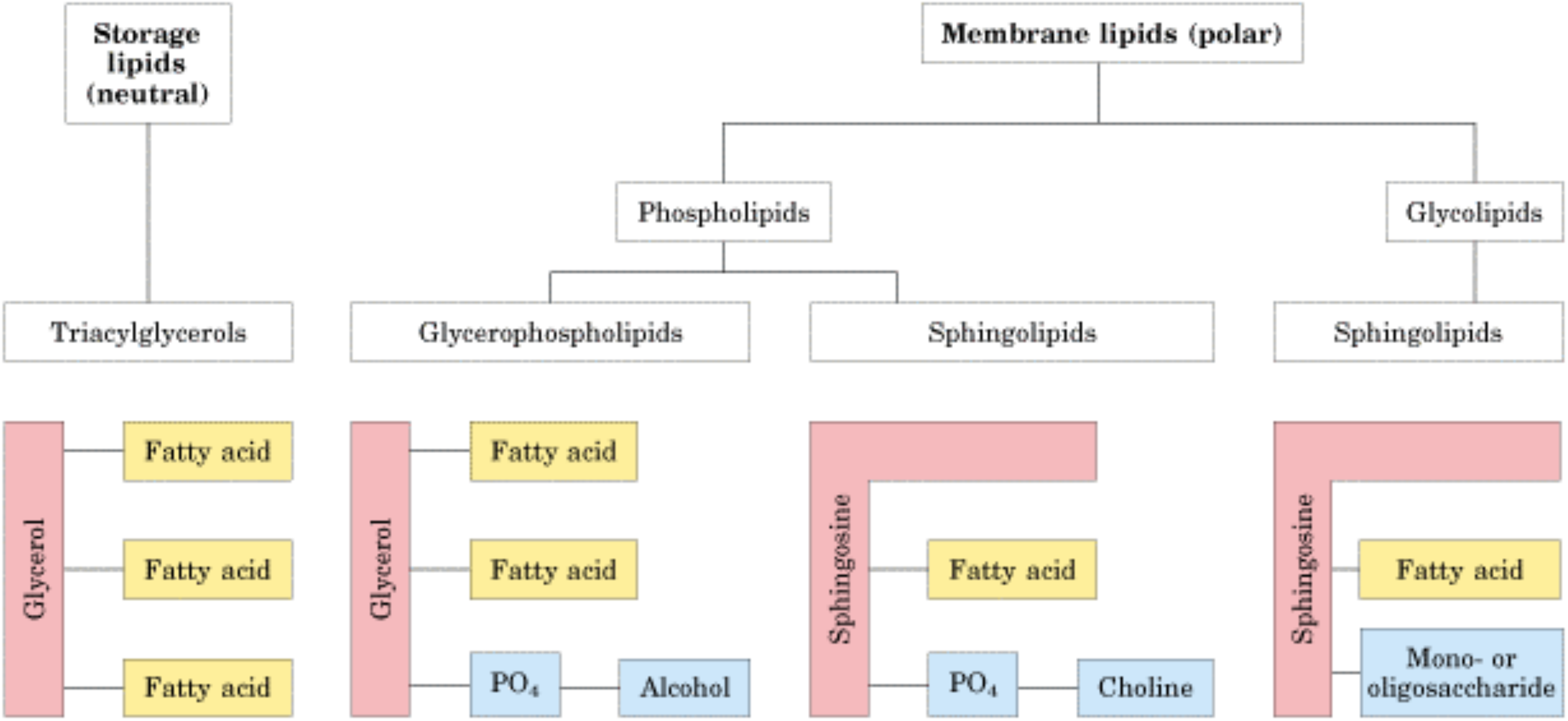
Glycerol



1-Stearoyl, 2-linoleoyl, 3-palmitoyl glycerol,
a mixed triacylglycerol



C_{16} and C_{18} saturated
C_{16} and C_{18} unsaturated
C_4 to C_{14} saturated
Fatty acids (% of total)
100
80
60
40
20
Olive oil, liquid
Butter, soft solid
Beef fat, hard solid
Natural fats at 25 °C



Storage lipids (neutral)

Triacylglycerols

Glycerol – Fatty acid, Fatty acid, Fatty acid

Membrane lipids (polar)

Phospholipids

Glycerophospholipids

Glycerol – Fatty acid, Fatty acid, PO_4 – Alcohol

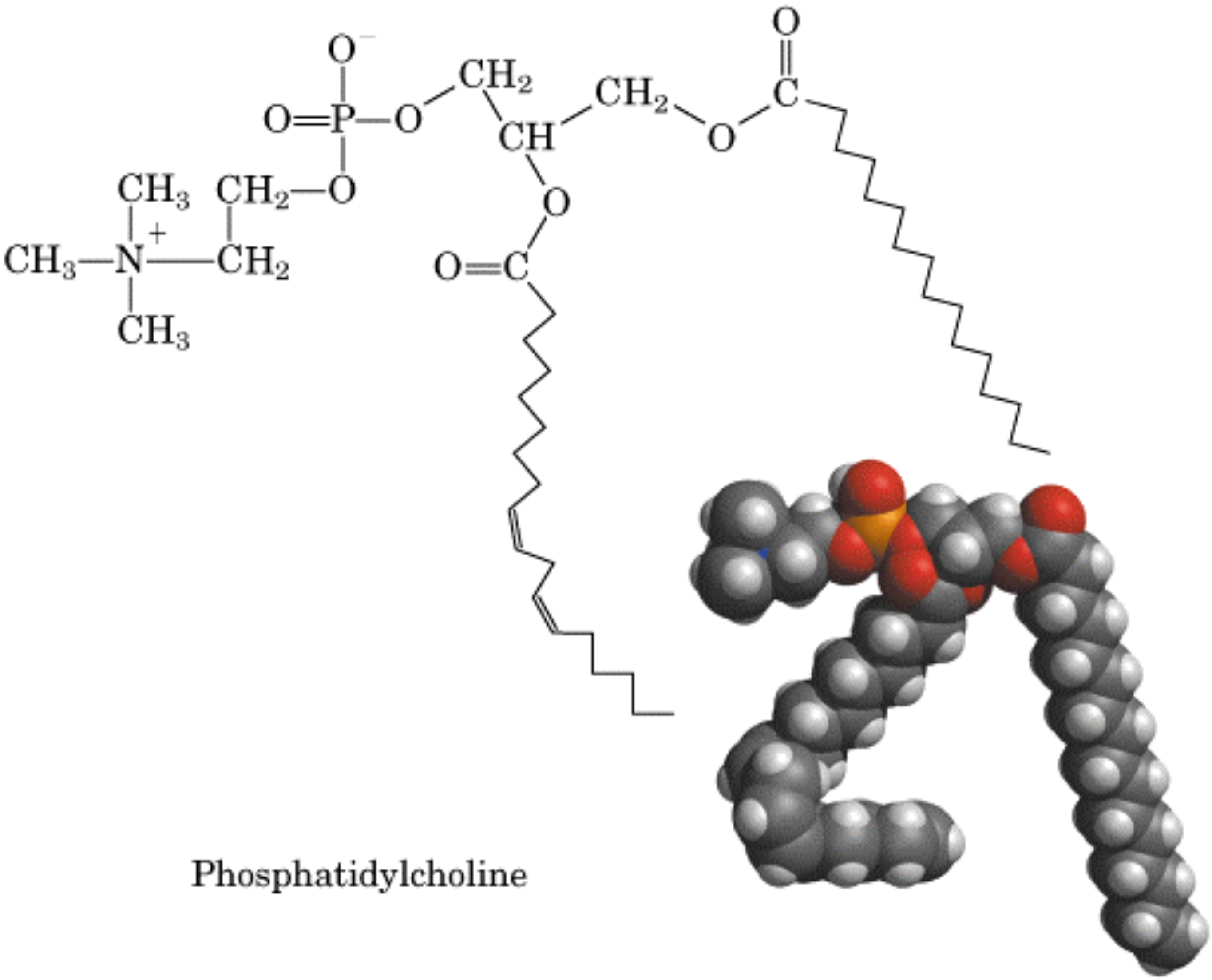
Sphingolipids

Sphingosine – Fatty acid, PO_4 – Choline

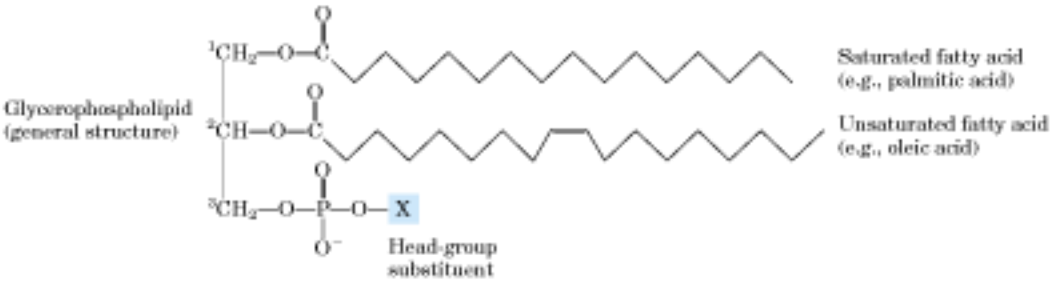
Glycolipids

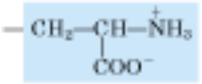
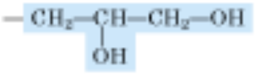
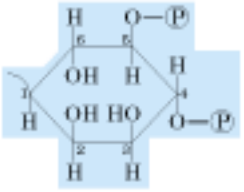
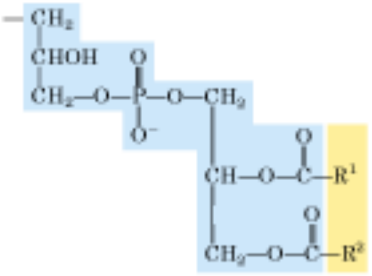
Sphingolipids

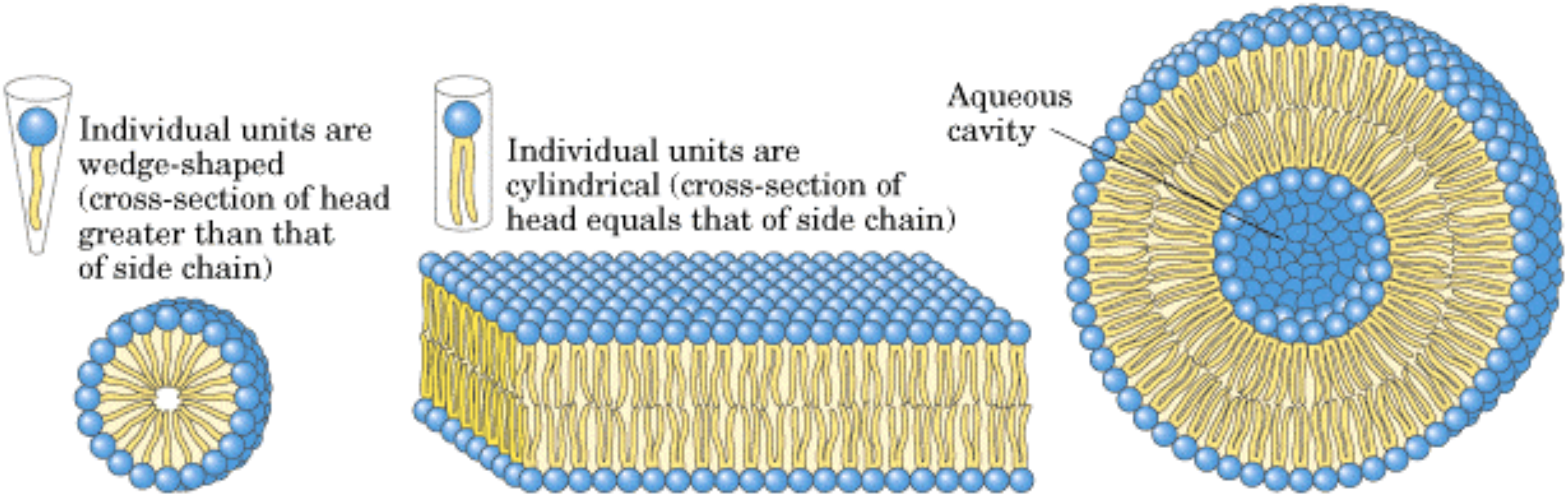
Sphingosine – Fatty acid, Mono- or oligosaccharide



Phosphatidylcholine



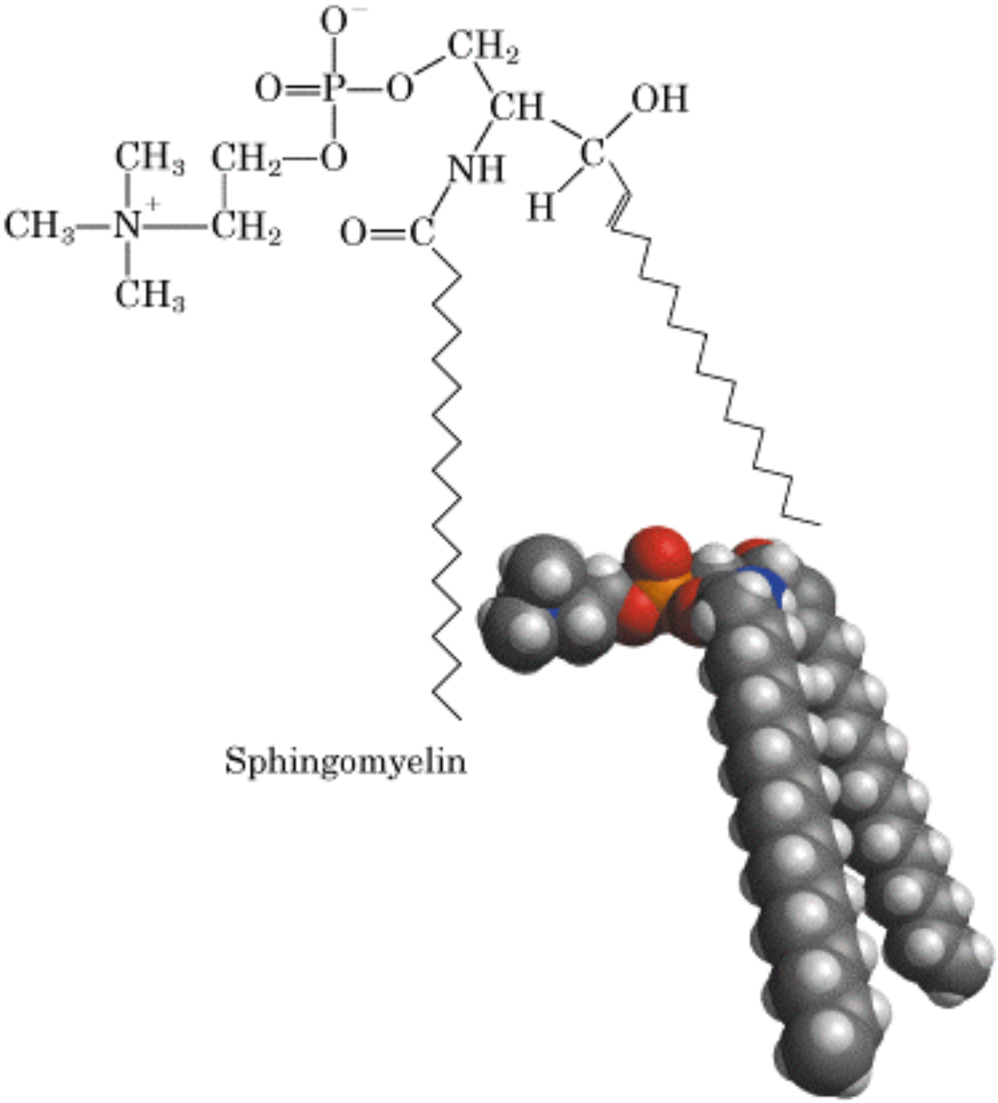
Name of glycerophospholipid	Name of X	Formula of X	Net charge (at pH 7)
Phosphatidic acid	—	$-H$	−1
Phosphatidylethanolamine	Ethanolamine	$-CH_2-CH_2-\overset{+}{N}H_3$	0
Phosphatidylcholine	Choline	$-CH_2-CH_2-\overset{+}{N}(CH_3)_3$	0
Phosphatidylserine	Serine	 $-CH_2-\underset{COO^-}{CH}-\overset{+}{N}H_3$	−1
Phosphatidylglycerol	Glycerol	 $-CH_2-\underset{OH}{CH}-CH_2-OH$	−1
Phosphatidylinositol 4,5-bisphosphate	*myo*-Inositol 4,5-bisphosphate		−4
Cardiolipin	Phosphatidyl-glycerol		−2



Micelle
(a)

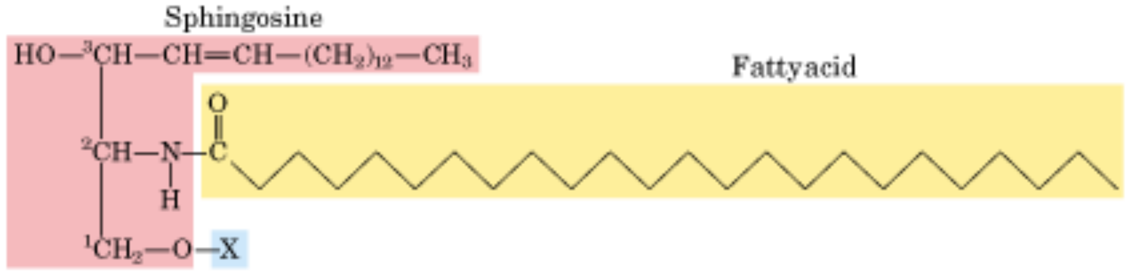
Bilayer
(b)

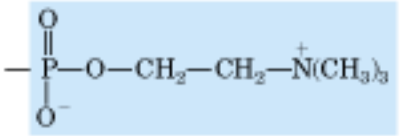
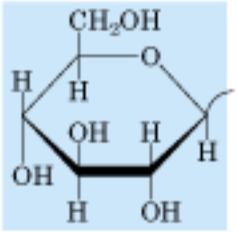
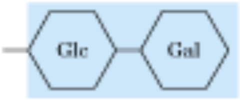
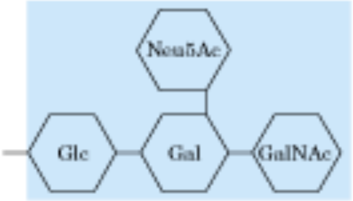
Liposome
(c)

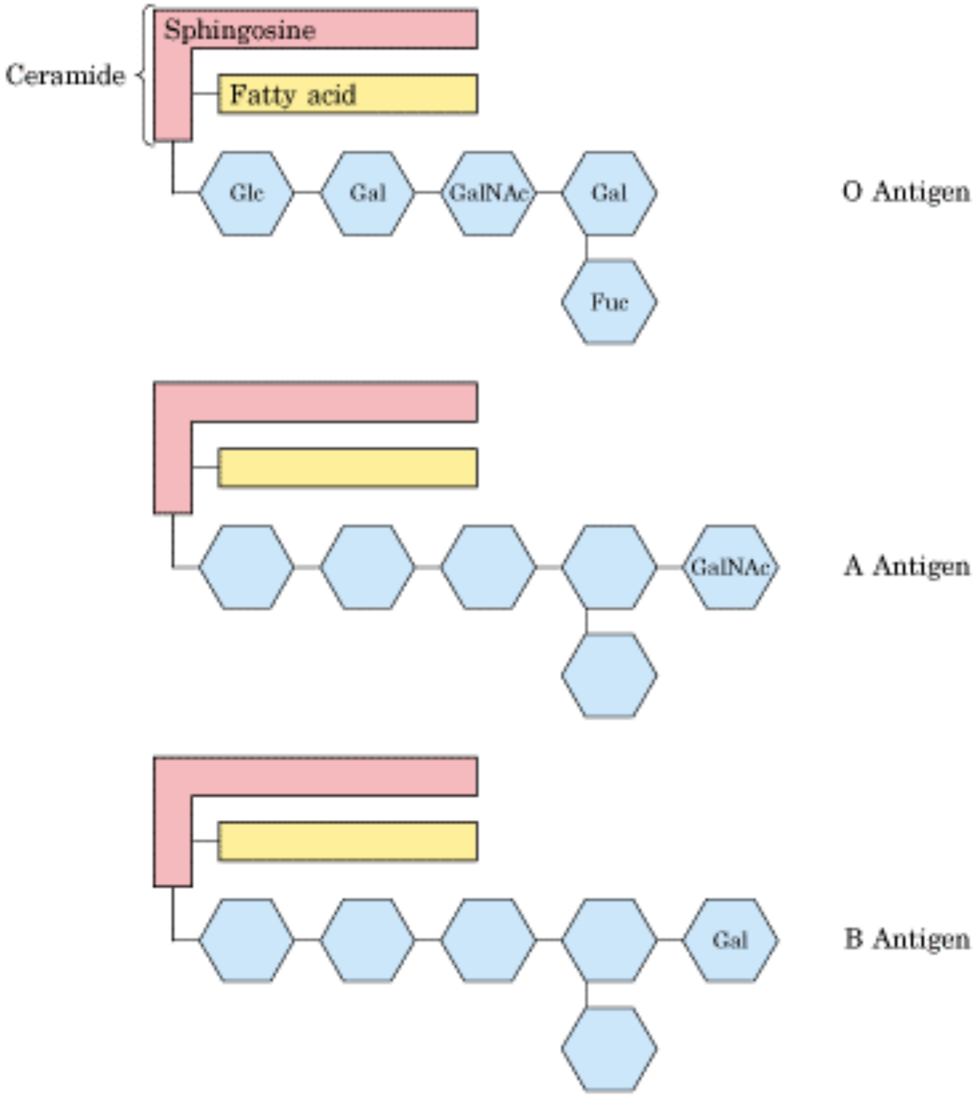


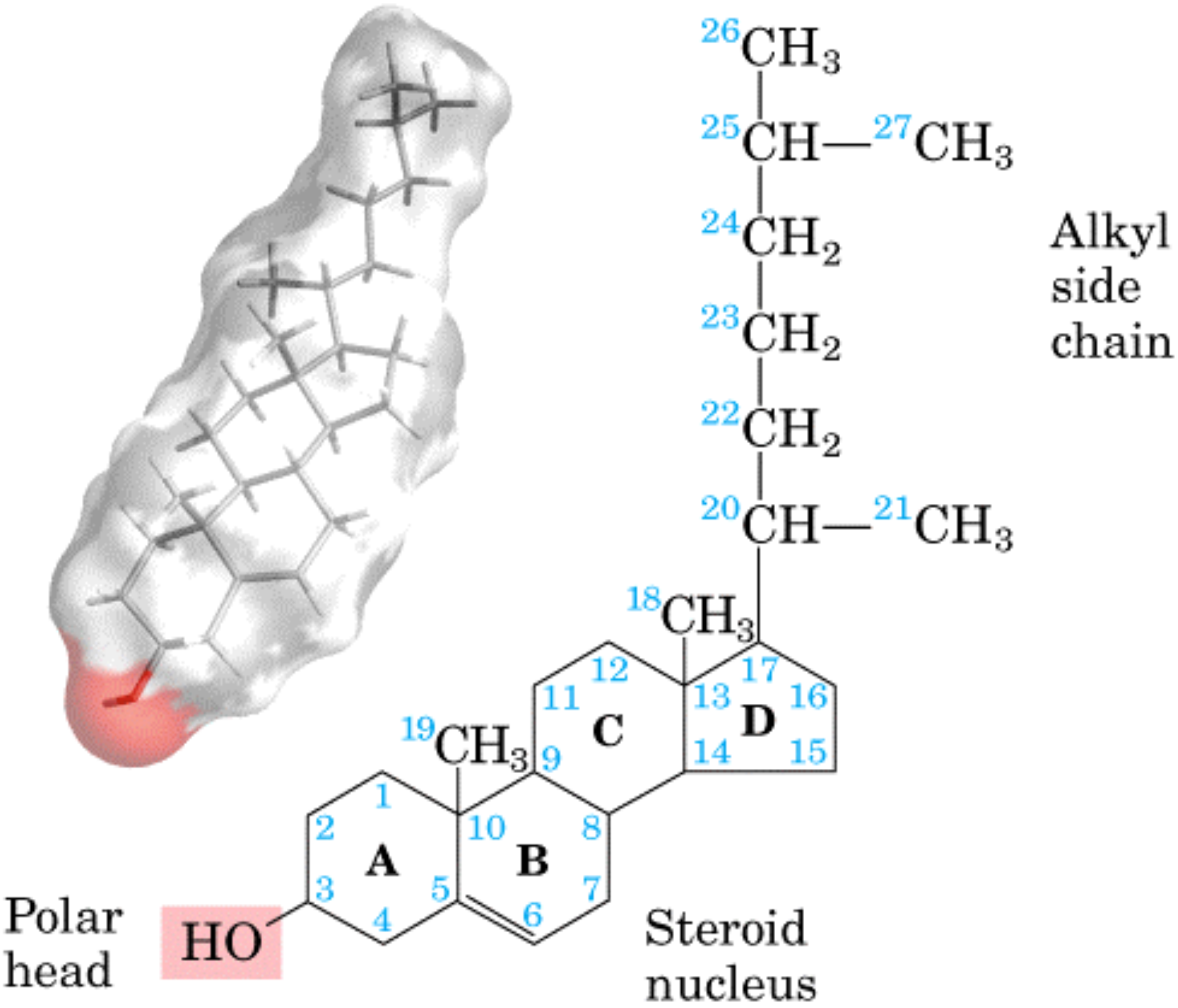
Sphingomyelin

Sphingolipid
(general
structure)



Name of sphingolipid	Name of X	Formula of X
Ceramide	—	—H
Sphingomyelin	Phosphocholine	 $-\overset{O}{\underset{O^-}{\overset{\|}{\underset{\|}{P}}}}-O-CH_2-CH_2-\overset{+}{N}(CH_3)_3$
Neutral glycolipids Glucosylcerebroside	Glucose	
Lactosylceramide (a globoside)	Di-, tri-, or tetrasaccharide	
Ganglioside GM2	Complex oligosaccharide	


Ceramide
Sphingosine
Fatty acid
Glc
Gal
GalNAc
Gal
Fuc
O Antigen
GalNAc
A Antigen
Gal
B Antigen


26 CH3
25 CH
27 CH3
24 CH2
23 CH2
22 CH2
20 CH
21 CH3
18 CH3
19 CH3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
A
B
C
D
HO
Alkyl side chain
Polar head
Steroid nucleus

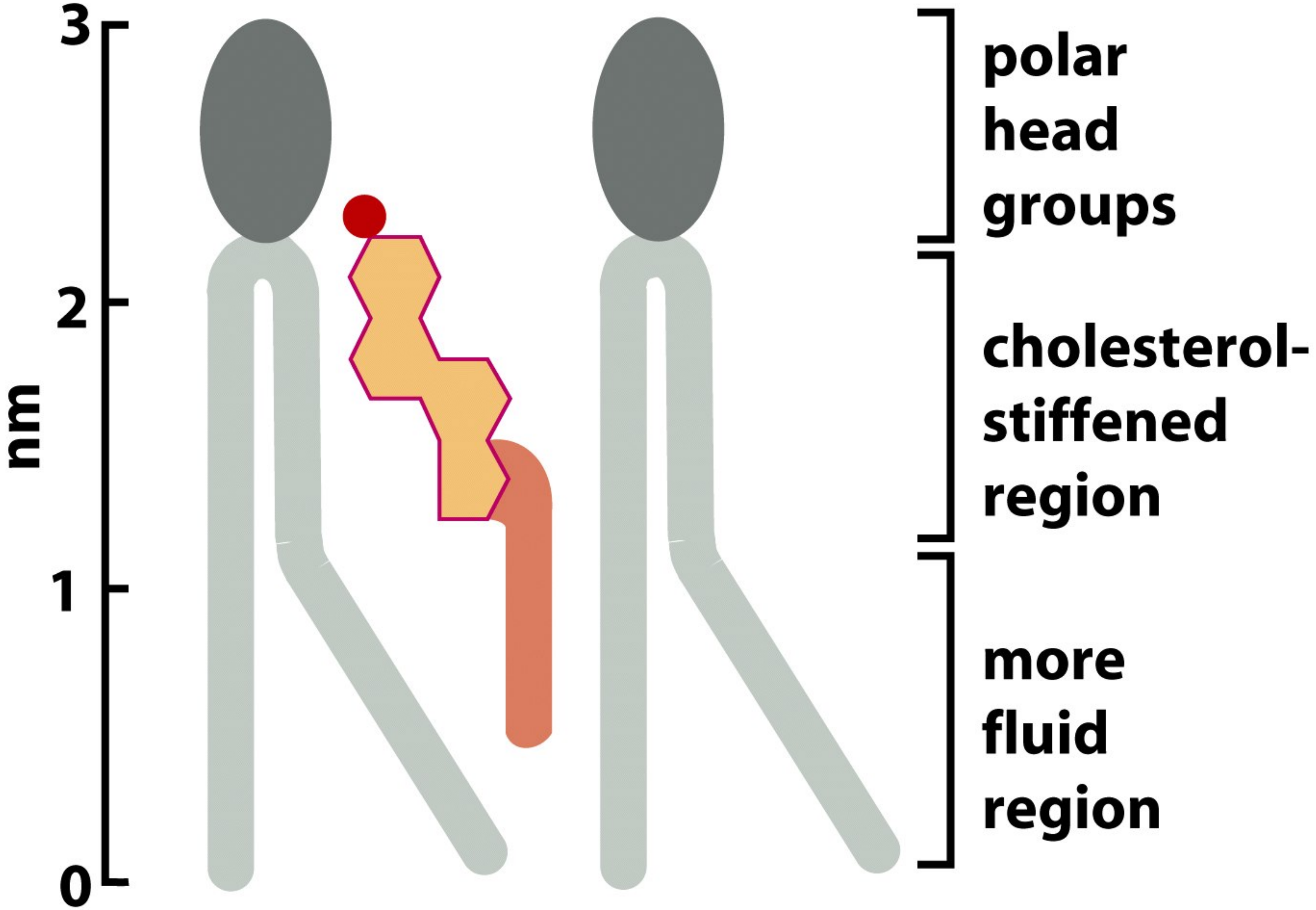
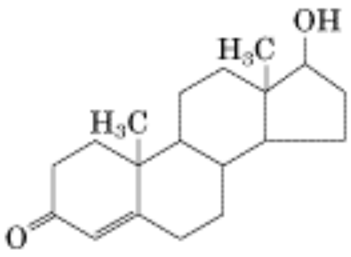
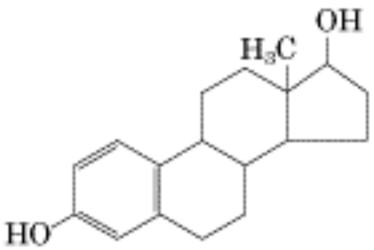


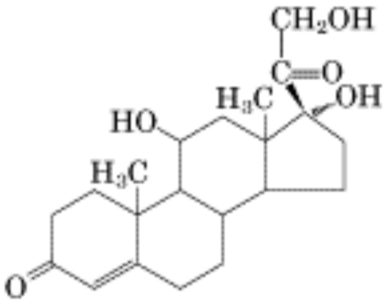
Figure 10-5 *Molecular Biology of the Cell* (© Garland Science 2008)



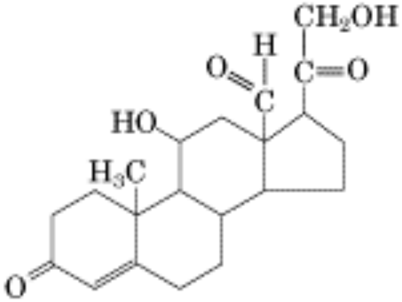
Testosterone



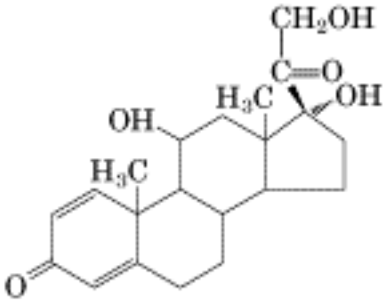
Estradiol



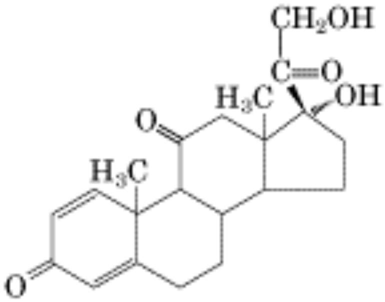
Cortisol



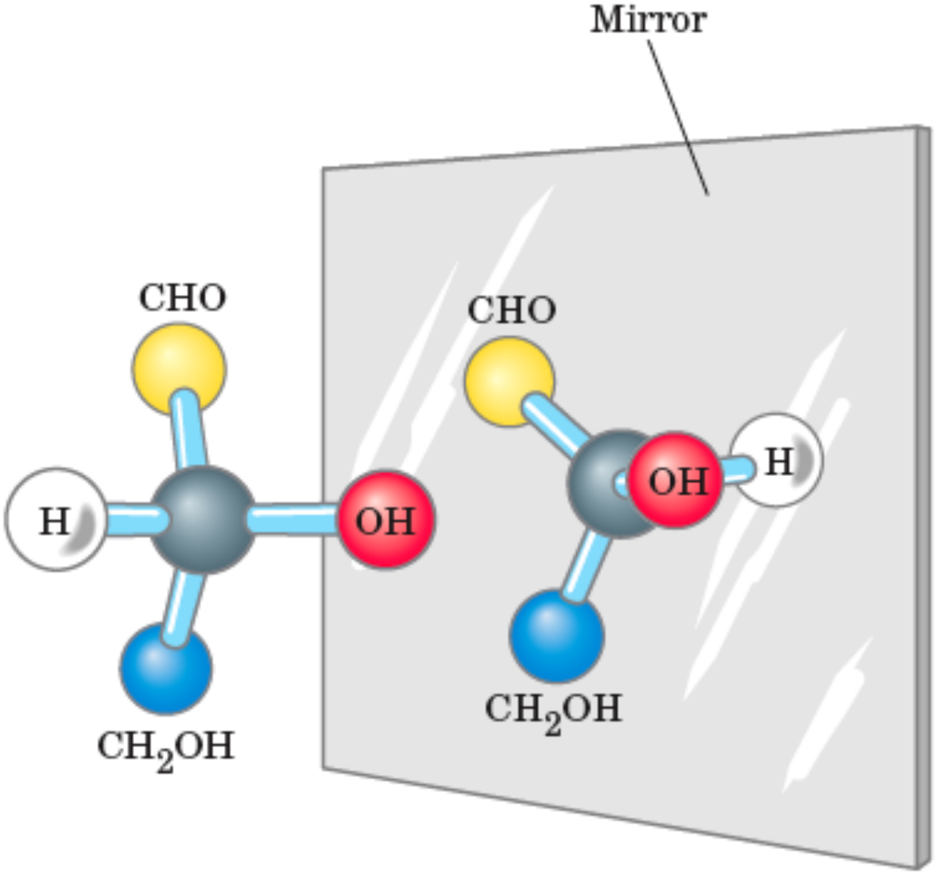
Aldosterone



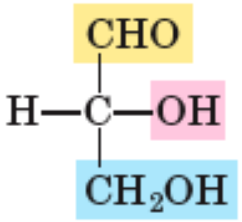
Prednisolone



Prednisone

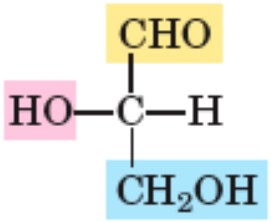


Ball-and-stick models



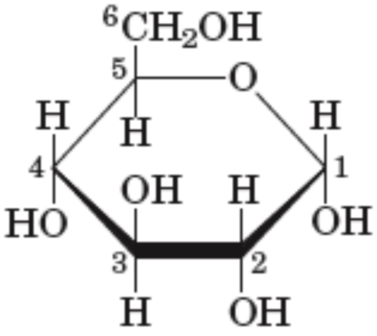
$$\begin{array}{c} \text{CHO} \\ | \\ \text{H}-\text{C}-\text{OH} \\ | \\ \text{CH}_2\text{OH} \end{array}$$

D-Glyceraldehyde

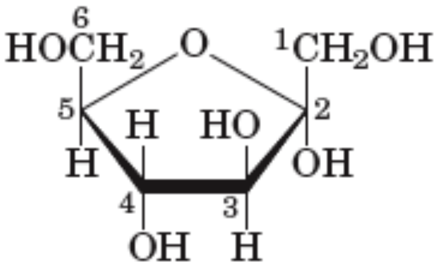


$$\begin{array}{c} \text{CHO} \\ | \\ \text{HO}-\text{C}-\text{H} \\ | \\ \text{CH}_2\text{OH} \end{array}$$

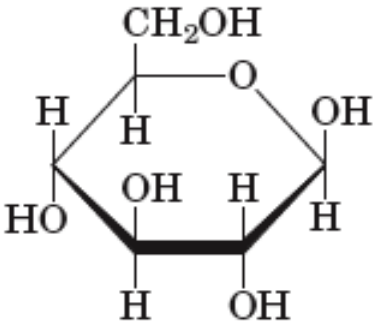
L-Glyceraldehyde



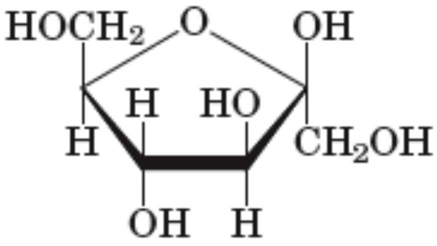
α-D-Glucopyranose



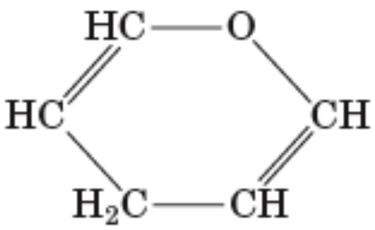
α-D-Fructofuranose



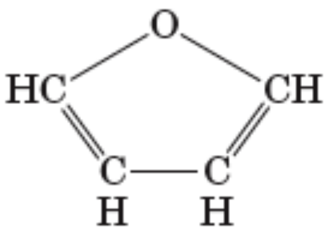
β-D-Glucopyranose



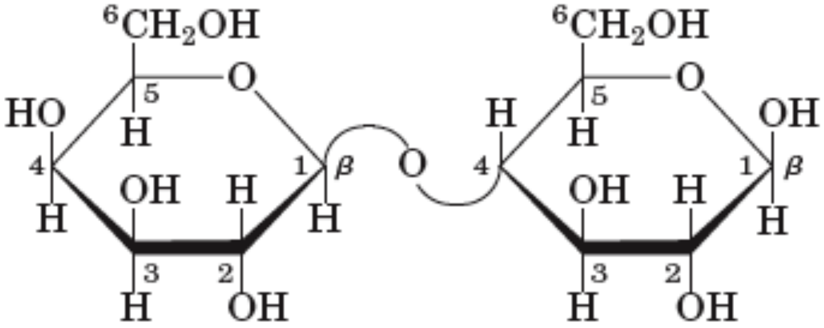
β-D-Fructofuranose



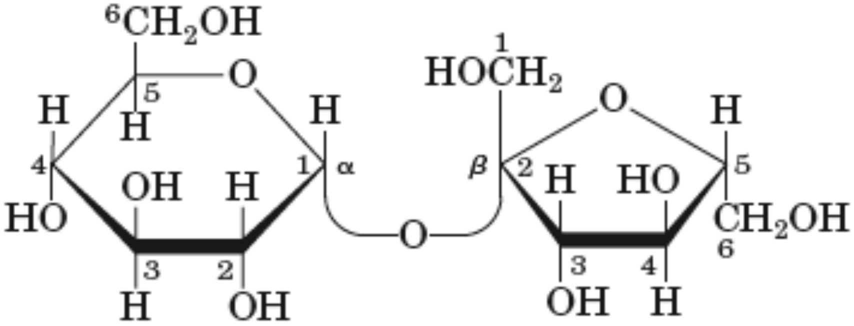
Pyran



Furan



Lactose (*β* form)
β-D-galactopyranosyl-(1→4)-*β*-D-glucopyranose
Gal(*β*1→4)Glc



Sucrose
α-D-glucopyranosyl *β*-D-fructofuranoside
Glc(*α*1↔2*β*)Fru

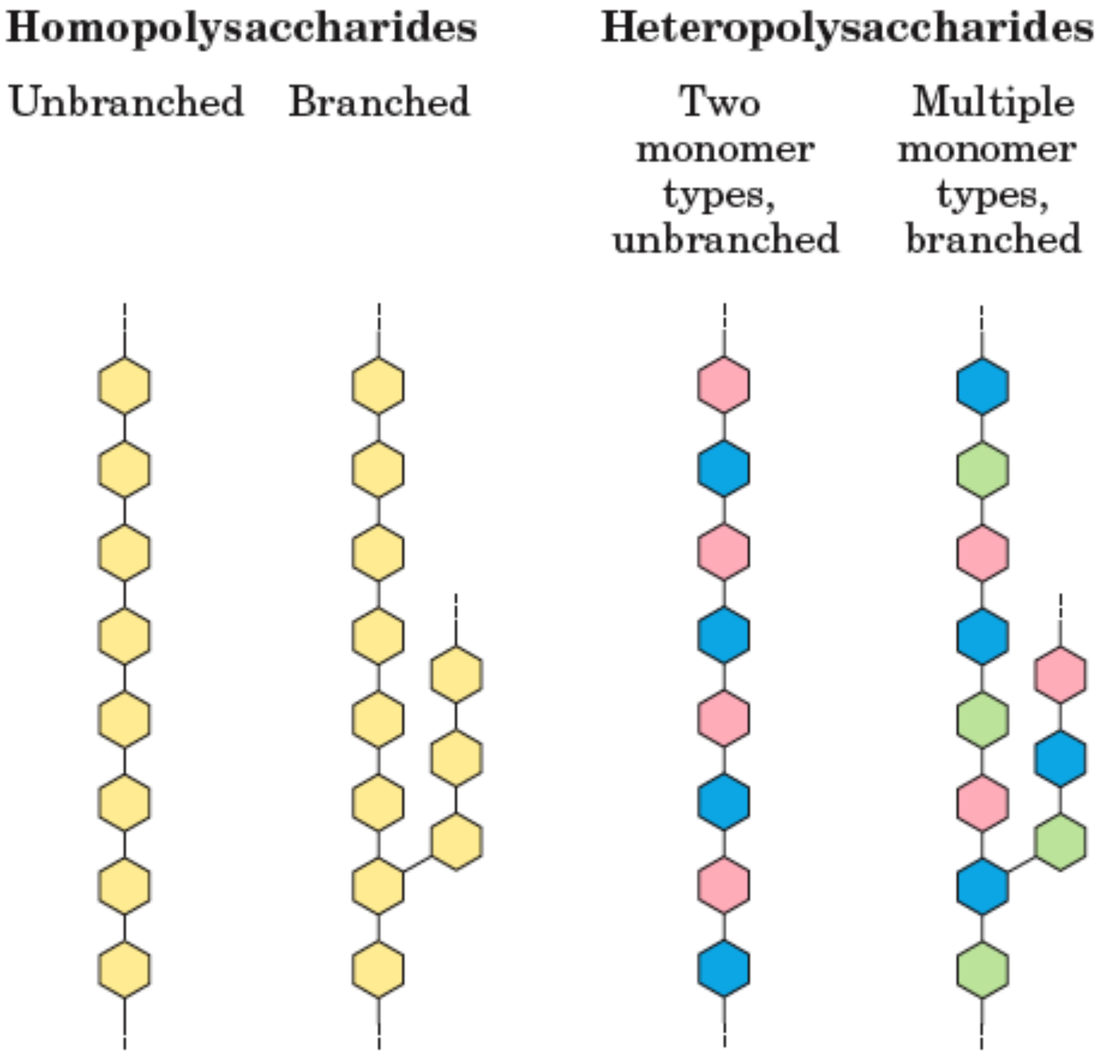
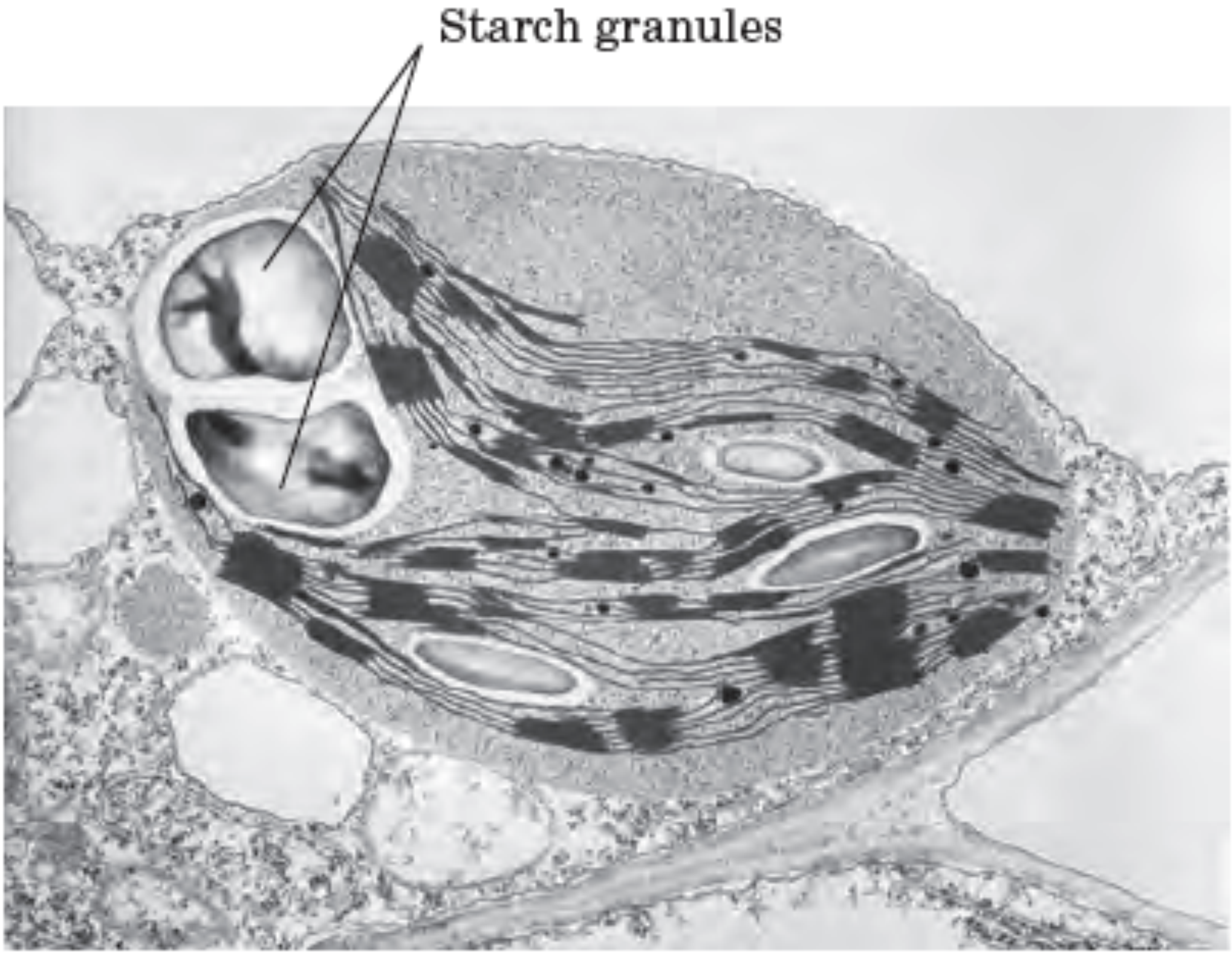


FIGURE 7–13 **Homo- and heteropolysaccharides.** Polysaccharides may be composed of one, two, or several different monosaccharides, in straight or branched chains of varying length.

TABLE 7–2 Structures and Roles of Some Polysaccharides

Polymer	*Type*[*]	*Repeating unit*[†]	*Size (number of monosaccharide units)*	*Roles/significance*
Starch				Energy storage: in plants
Amylose	Homo-	$(\alpha1\rightarrow4)$Glc, linear	50–5,000	
Amylopectin	Homo-	$(\alpha1\rightarrow4)$Glc, with $(\alpha1\rightarrow6)$Glc branches every 24–30 residues	Up to 10^6	
Glycogen	Homo-	$(\alpha1\rightarrow4)$Glc, with $(\alpha1\rightarrow6)$Glc branches every 8–12 residues	Up to 50,000	Energy storage: in bacteria and animal cells
Cellulose	Homo-	$(\beta1\rightarrow4)$Glc	Up to 15,000	Structural: in plants, gives rigidity and strength to cell walls
Chitin	Homo-	$(\beta1\rightarrow4)$GlcNAc	Very large	Structural: in insects, spiders, crustaceans, gives rigidity and strength to exoskeletons
Dextran	Homo-	$(\alpha1\rightarrow6)$Glc, with $(\alpha1\rightarrow3)$ branches	Wide range	Structural: in bacteria, extracellular adhesive
Peptidoglycan	Hetero-; peptides attached	4)Mur2Ac$(\beta1\rightarrow4)$GlcNAc$(\beta1$	Very large	Structural: in bacteria, gives rigidity and strength to cell envelope
Agarose	Hetero-	3)D-Gal$(\beta1\rightarrow4)$3,6-anhydro-L-Gal$(\alpha1$	1,000	Structural: in algae, cell wall material
Hyaluronate (a glycosaminoglycan)	Hetero-; acidic	4)GlcA$(\beta1\rightarrow3)$GlcNAc$(\beta1$	Up to 100,000	Structural: in vertebrates, extracellular matrix of skin and connective tissue; viscosity and lubrication in joints


Starch granules

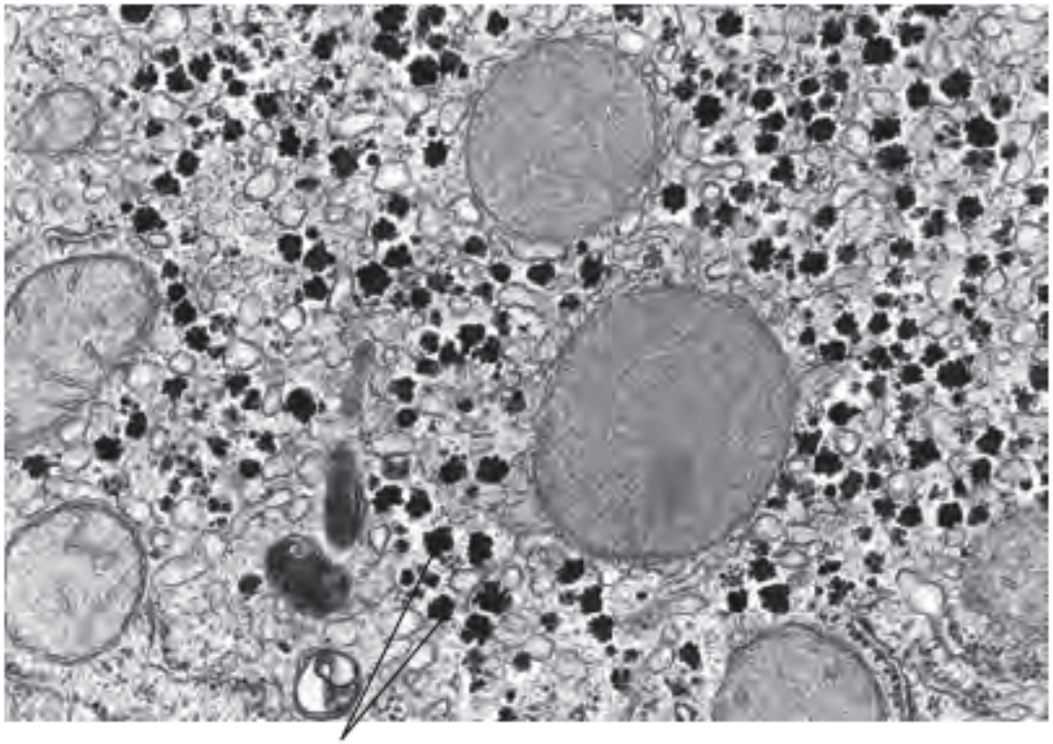
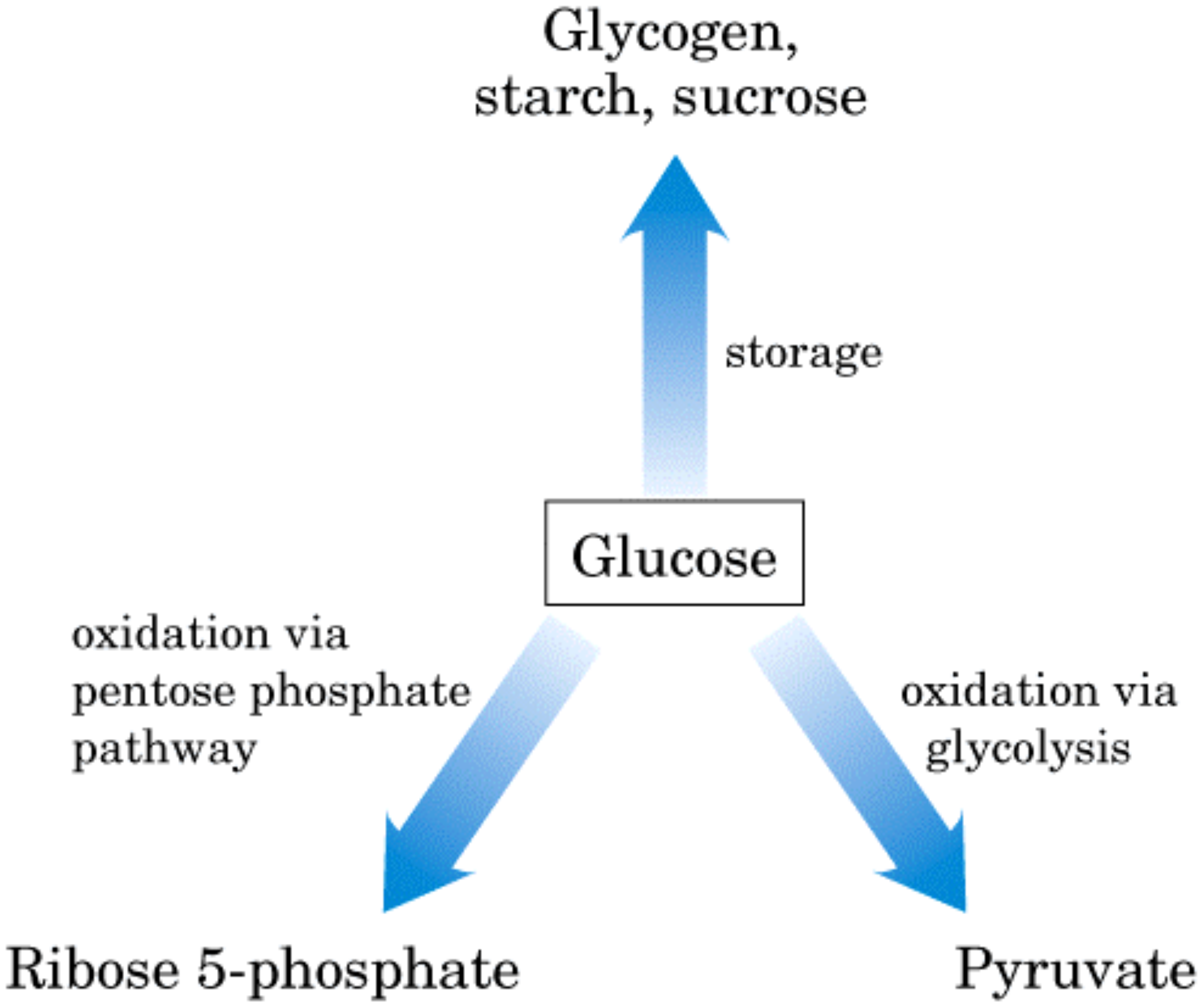

Glycogen granules

FIGURE 7–17 **Cellulose breakdown by wood fungi.** A wood fungus growing on an oak log. All wood fungi have the enzyme cellulase, which breaks the (β1→4) glycosidic bonds in cellulose, such that wood is a source of metabolizable sugar (glucose) for the fungus. The only vertebrates able to use cellulose as food are cattle and other ruminants (sheep, goats, camels, giraffes). The extra stomach compartment (rumen) of a ruminant teems with bacteria and protists that secrete cellulase.



Glycogen,
starch, sucrose

storage

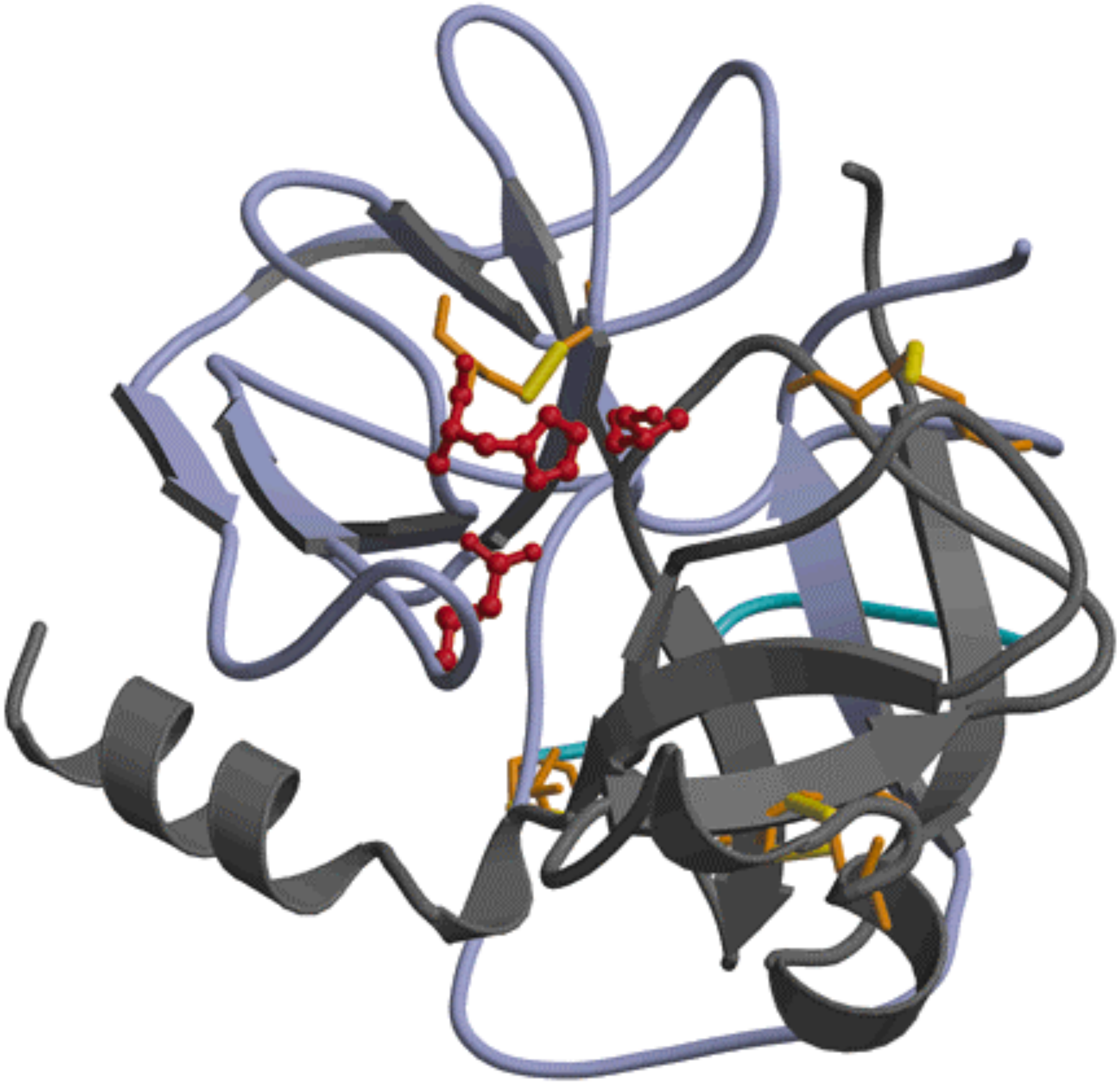
Glucose

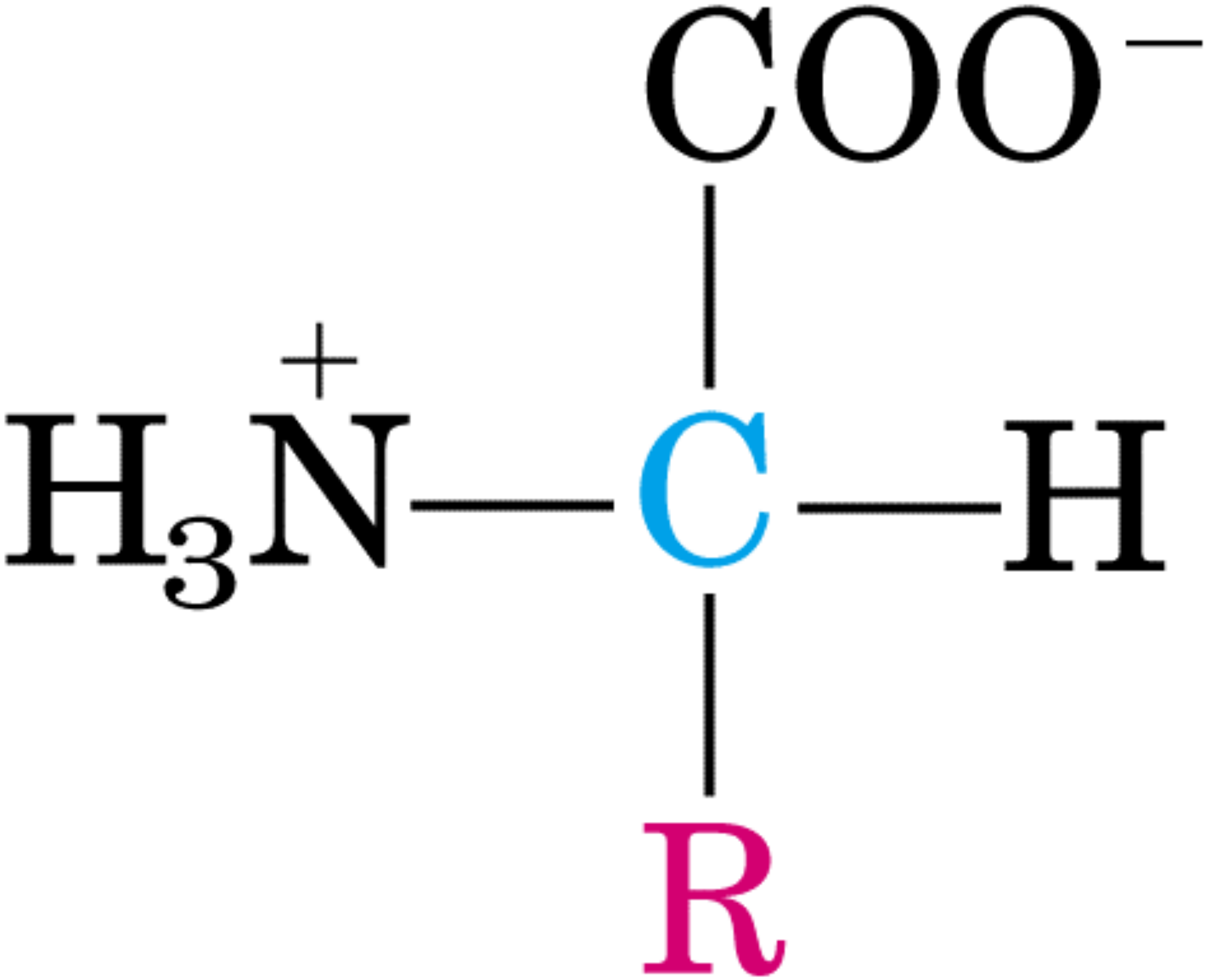
oxidation via
pentose phosphate
pathway

oxidation via
glycolysis

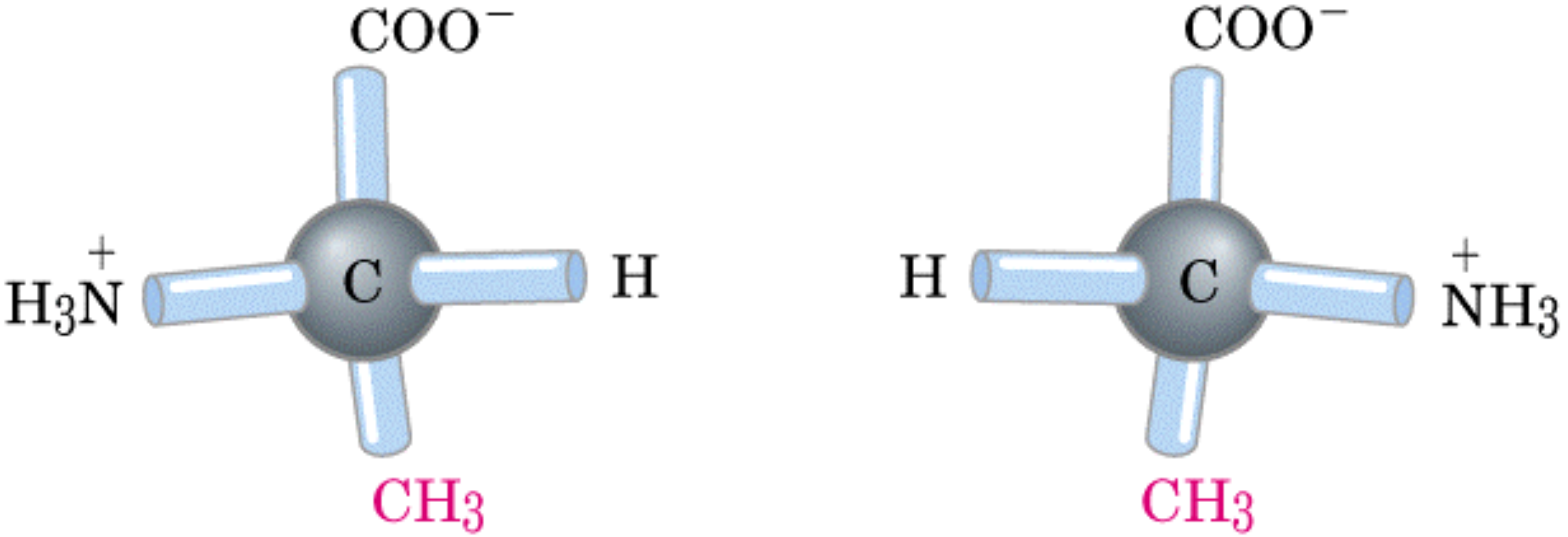
Ribose 5-phosphate

Pyruvate



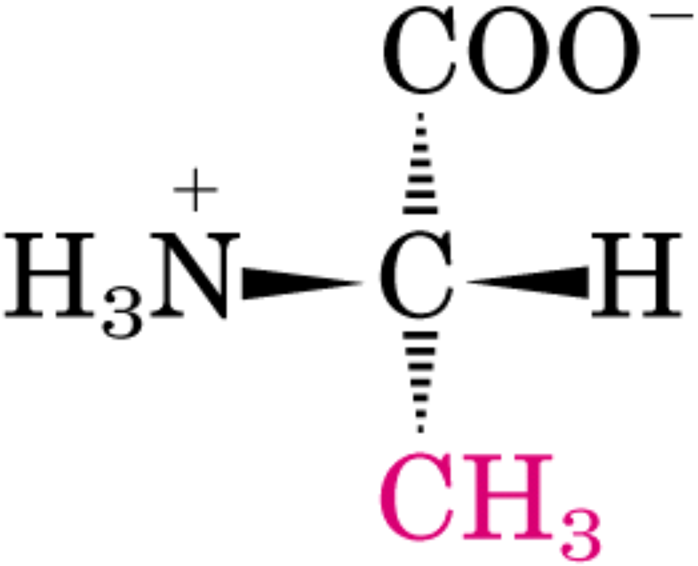


$$\begin{array}{ccccc} & & \mathrm{COO^-} & & \\ & & | & & \\ \mathrm{H_3\overset{+}{N}} & - & \mathrm{C} & - & \mathrm{H} \\ & & | & & \\ & & \mathrm{R} & & \end{array}$$

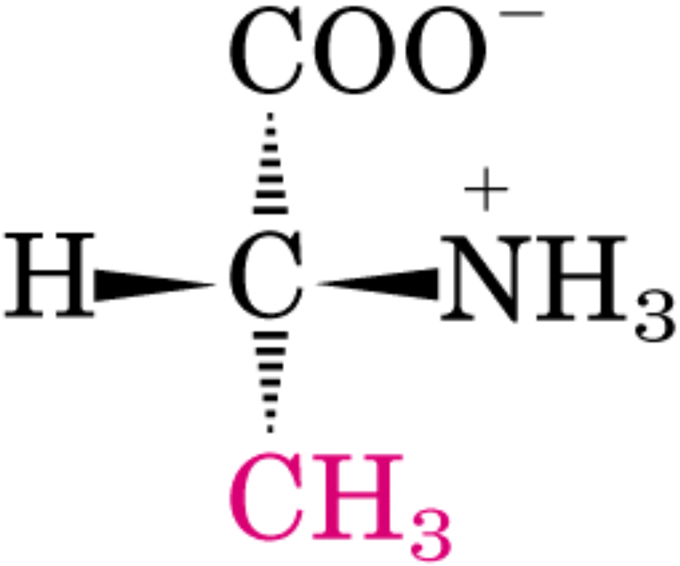


L-Alanine D-Alanine

(a)

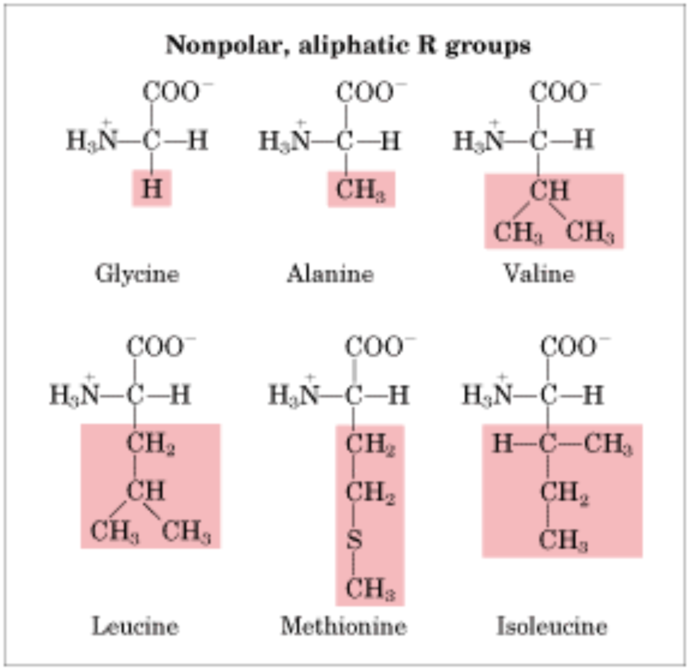


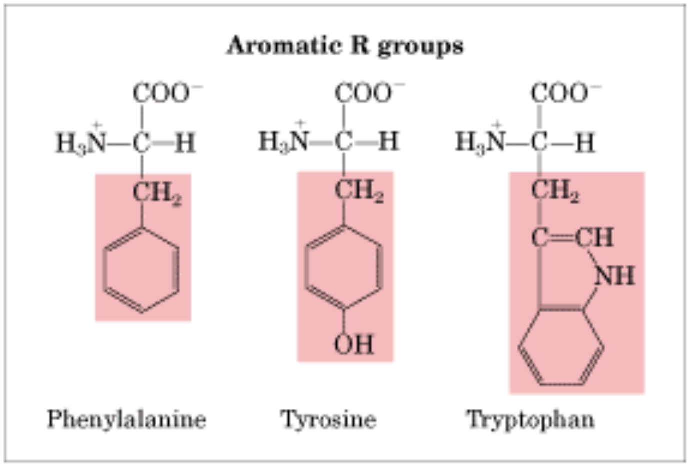
L-Alanine

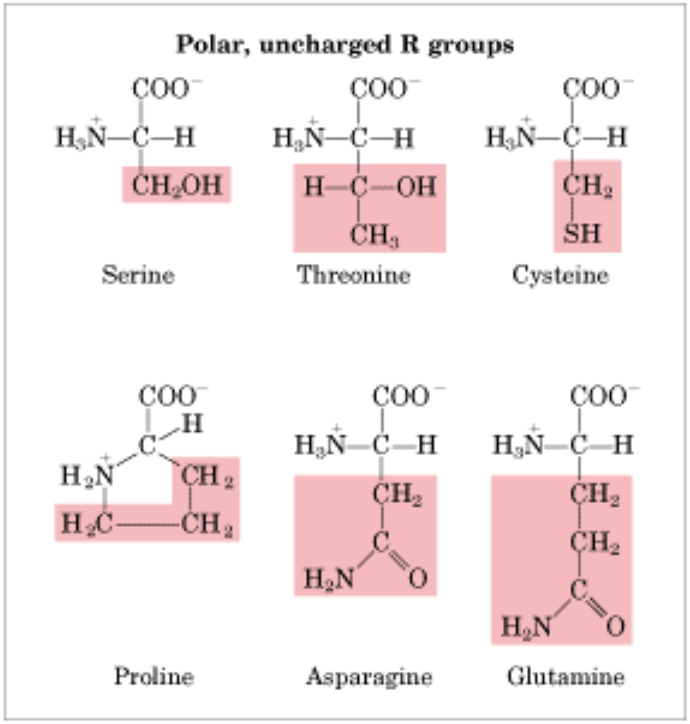


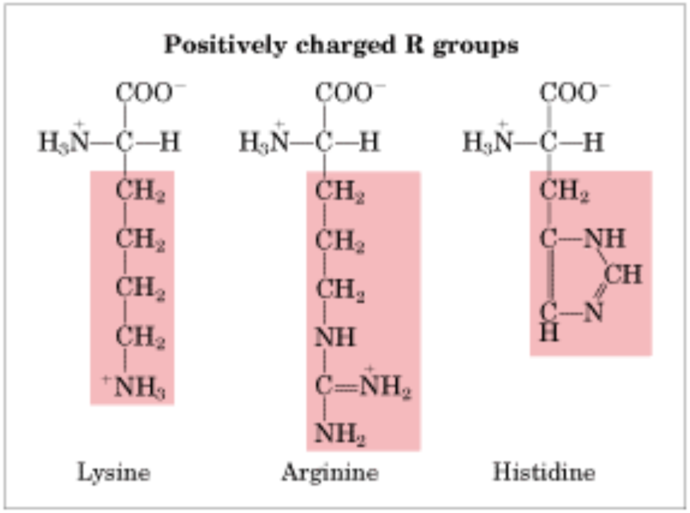
D-Alanine

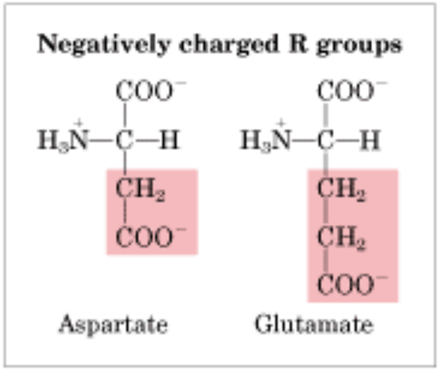
(b)


Nonpolar, aliphatic R groups
Glycine
Alanine
Valine
Leucine
Methionine
Isoleucine


Aromatic R groups
Phenylalanine
Tyrosine
Tryptophan


Polar, uncharged R groups
Serine
Threonine
Cysteine
Proline
Asparagine
Glutamine


Positively charged R groups
Lysine
Arginine
Histidine


Negatively charged R groups
Aspartate
Glutamate

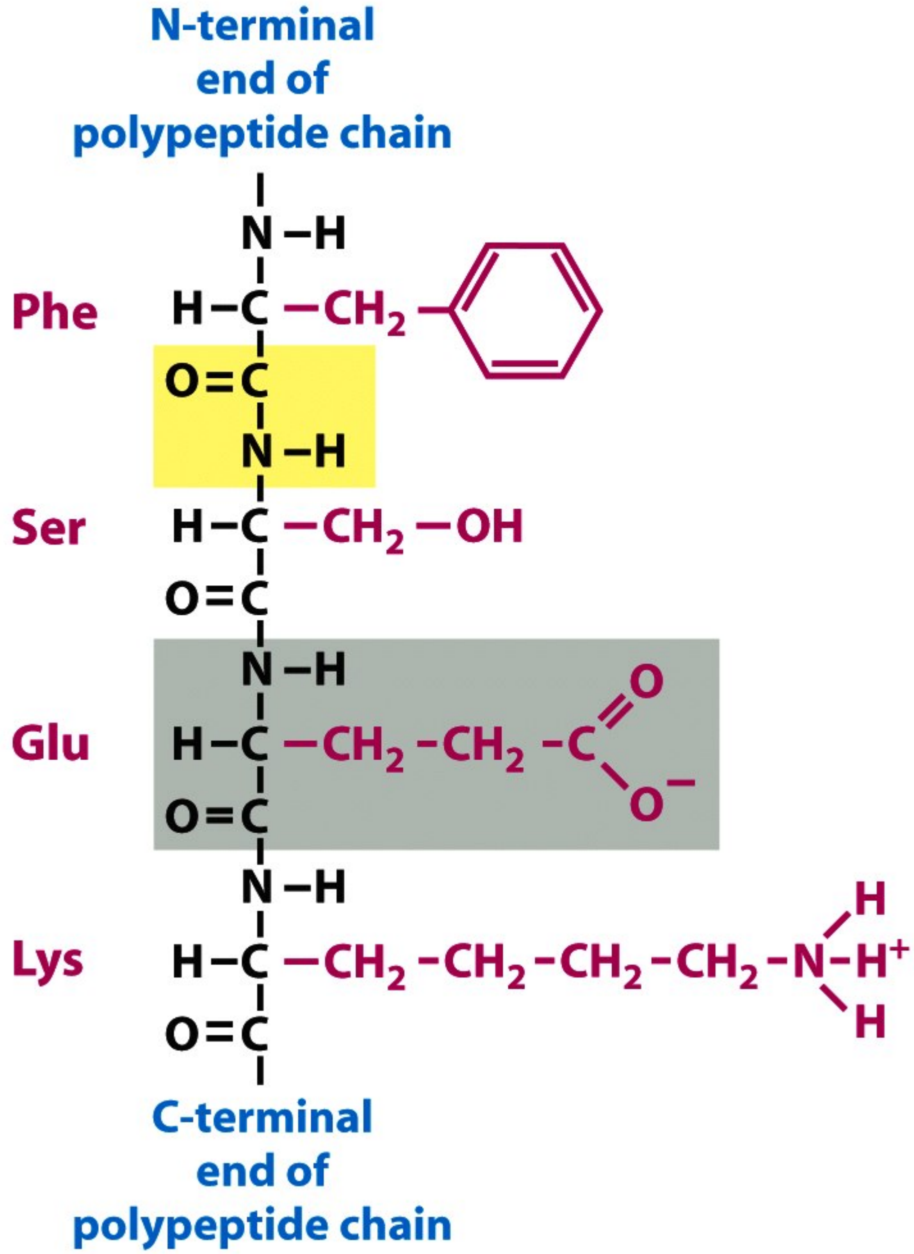
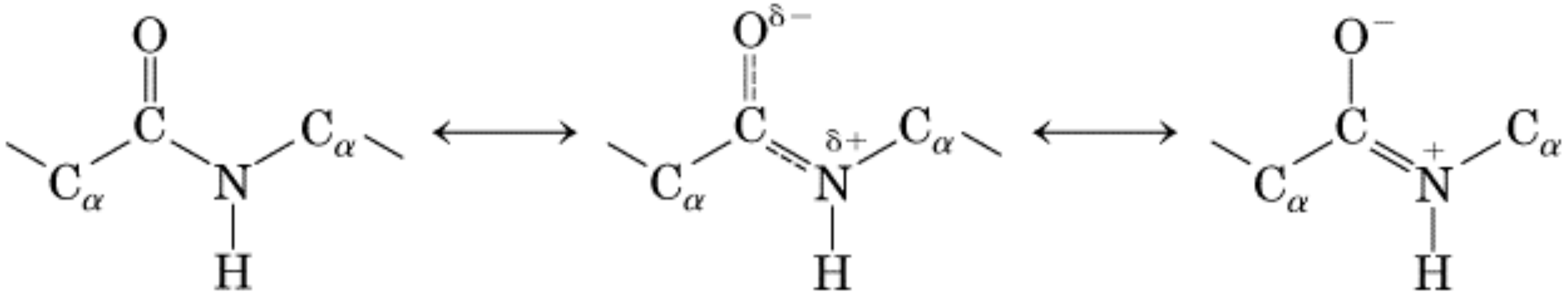
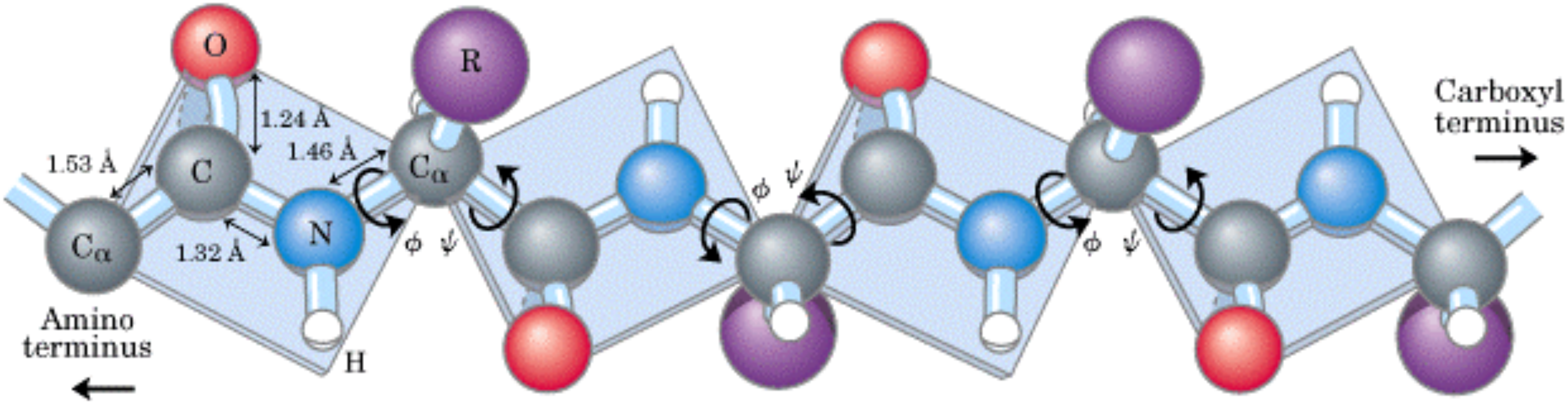


Figure 2-24 *Molecular Biology of the Cell* (© Garland Science 2008)

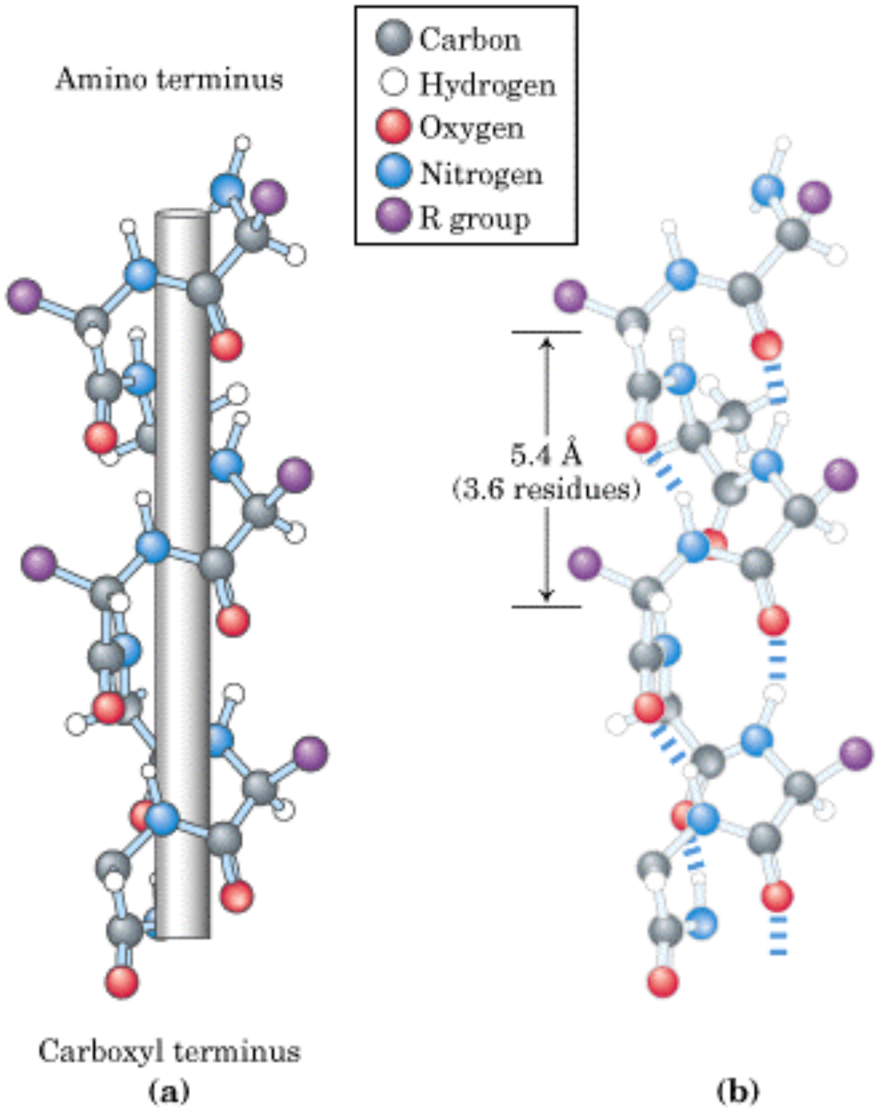
The carbonyl oxygen has a partial negative charge and the amide nitrogen a partial positive charge, setting up a small electric dipole. Virtually all peptide bonds in proteins occur in this trans configuration; an exception is noted in Figure 6–8b.

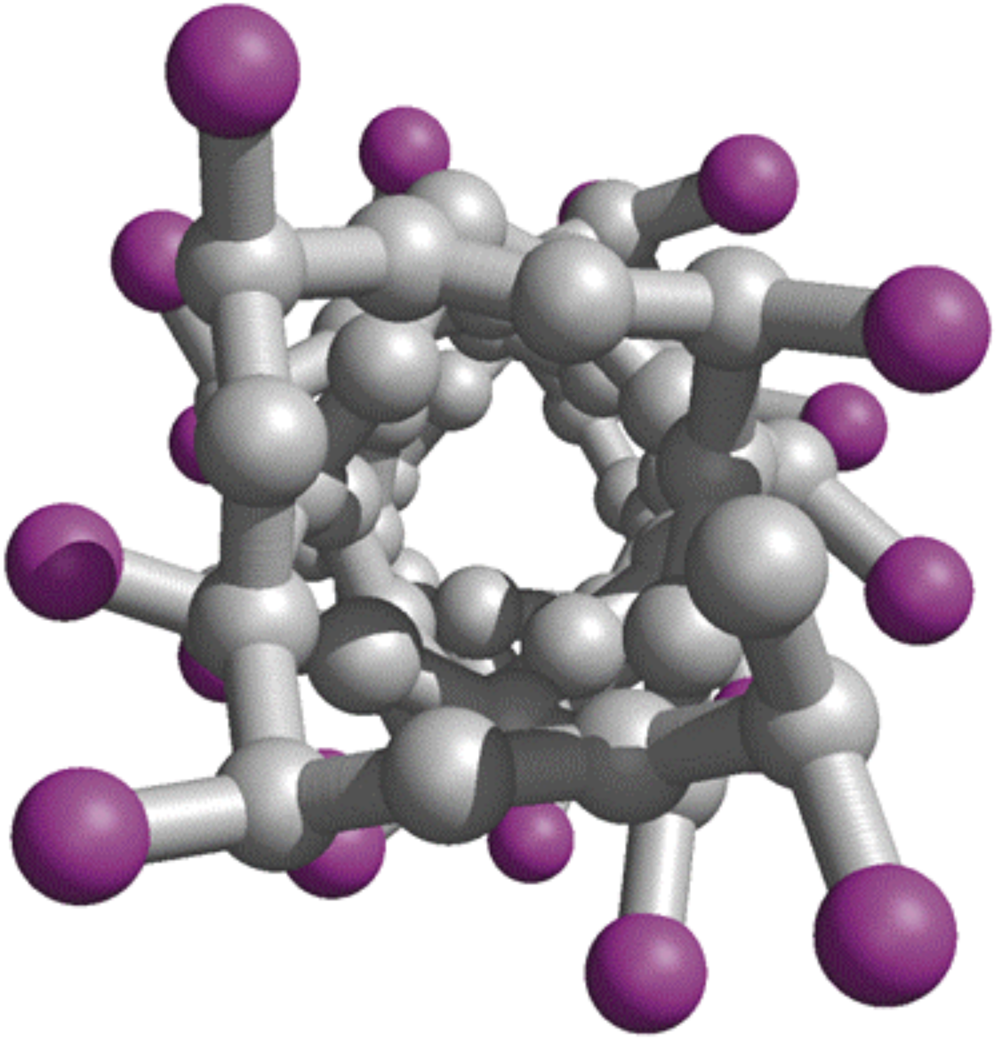


(a)

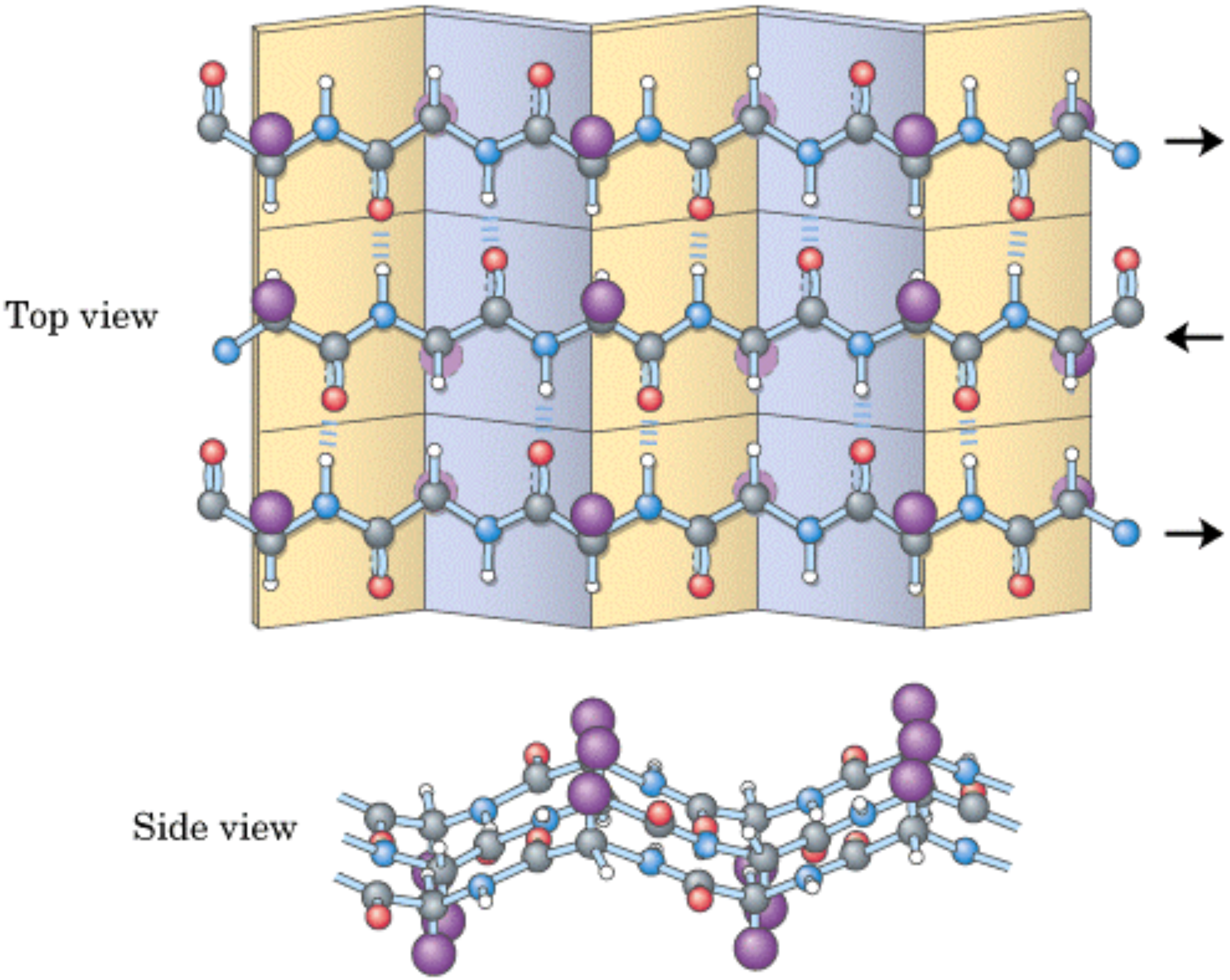

O
R
1.24 Å
1.46 Å
1.53 Å
C
Cα
Cα
1.32 Å
N
H
ϕ
ψ
ϕ
ψ
ϕ
ψ
Amino terminus
Carboxyl terminus

(b)


Carbon
Hydrogen
Oxygen
Nitrogen
R group
Amino terminus
5.4 Å
(3.6 residues)
Carboxyl terminus
(a)
(b)

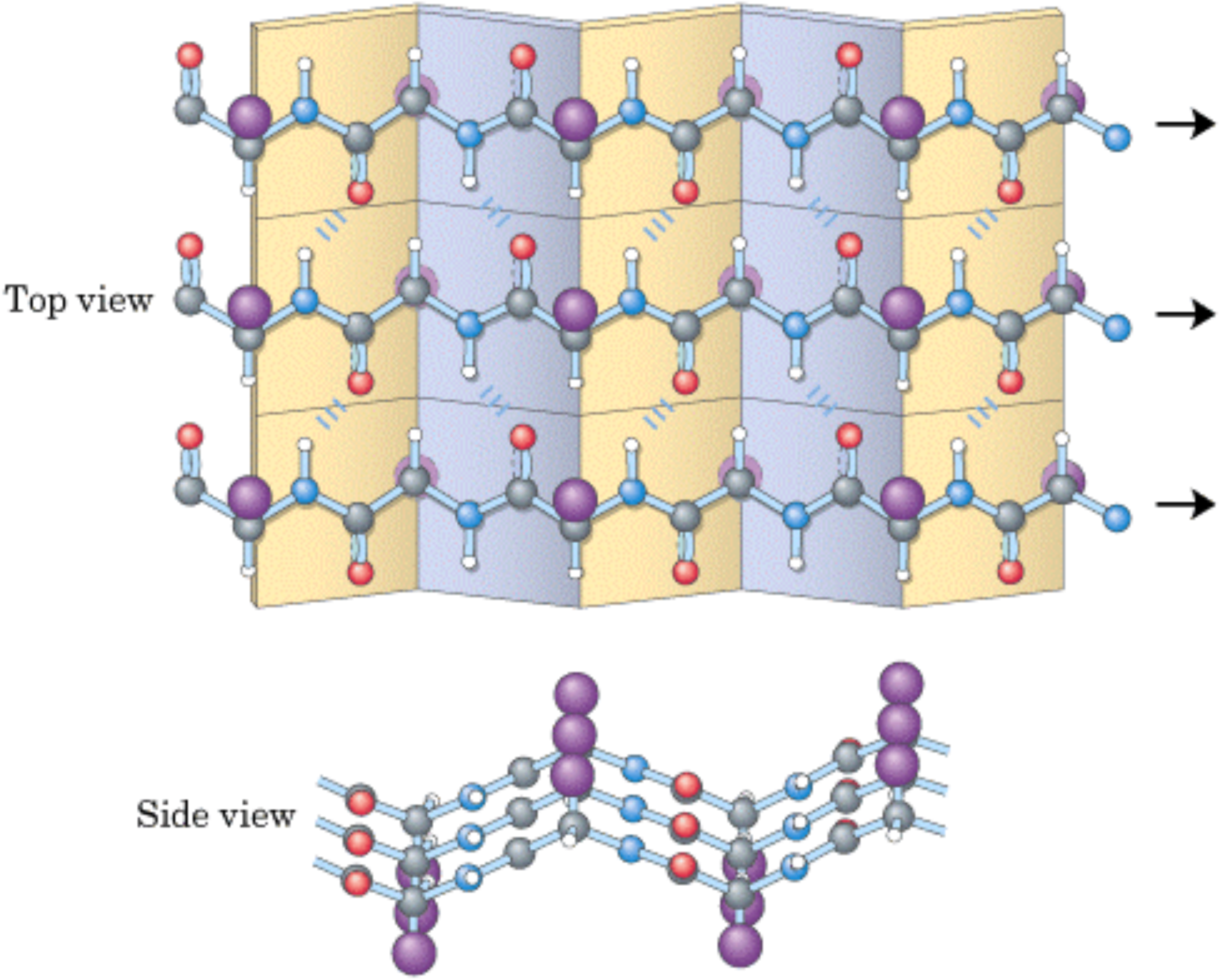


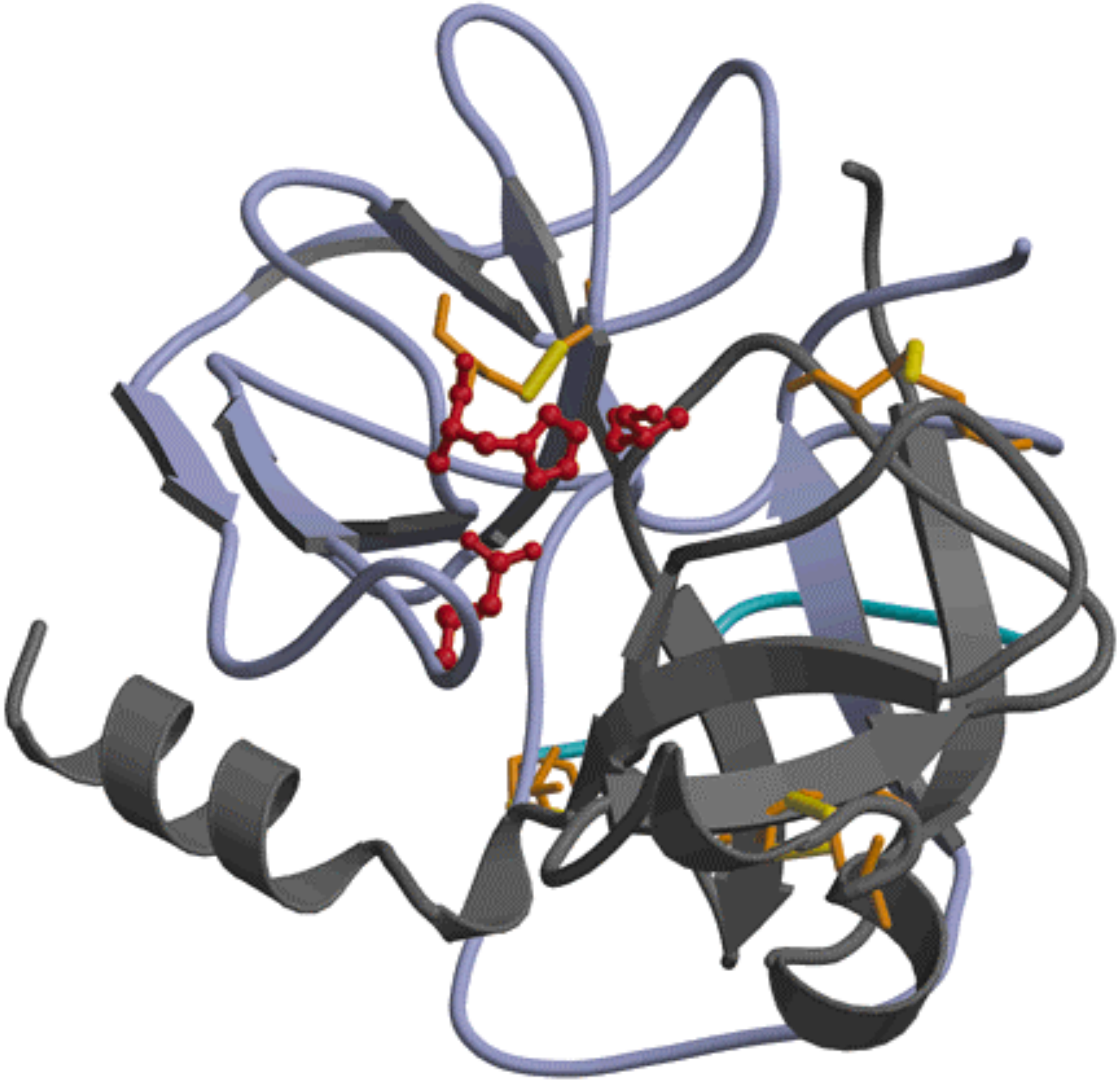
(c)

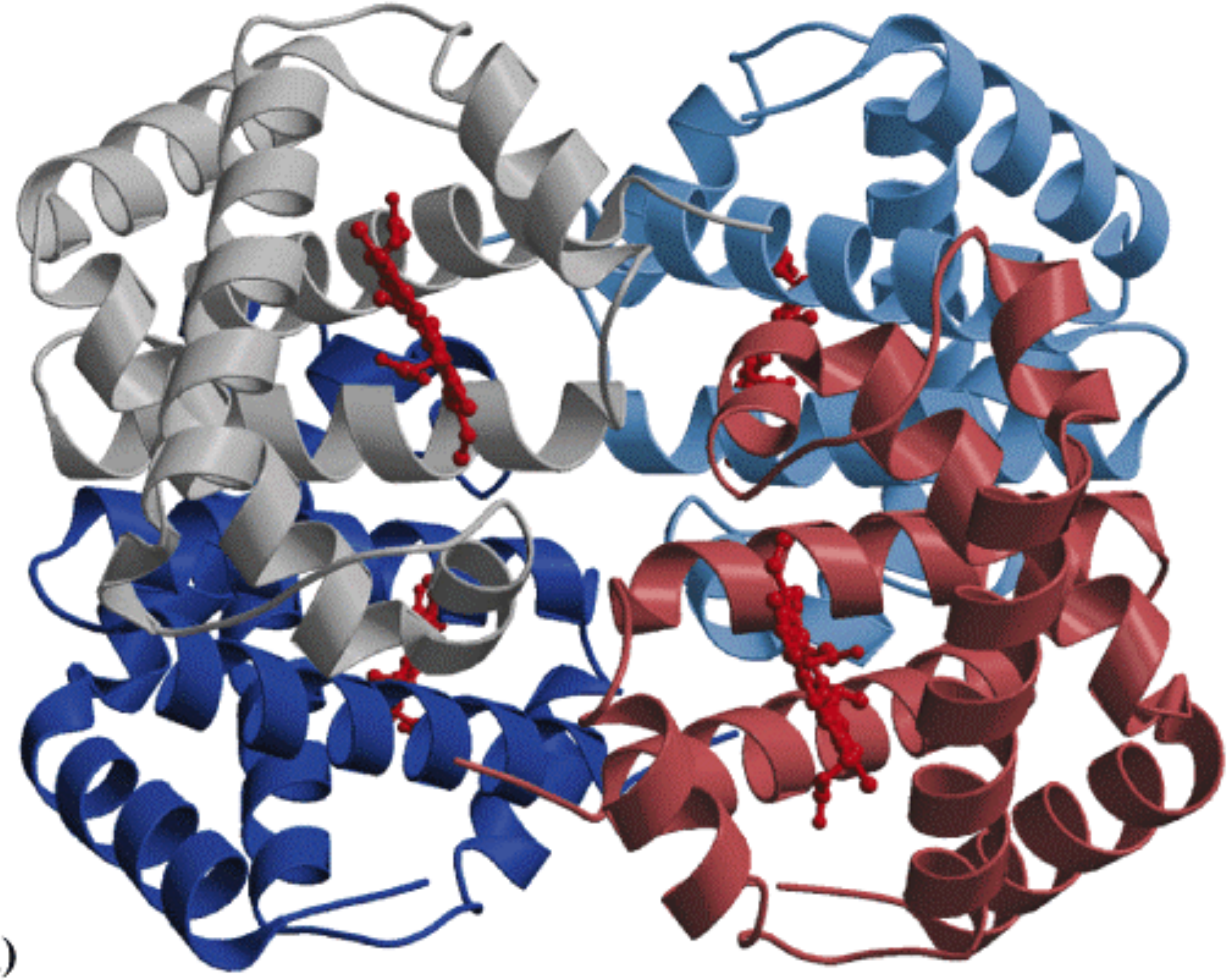


(a) Antiparallel

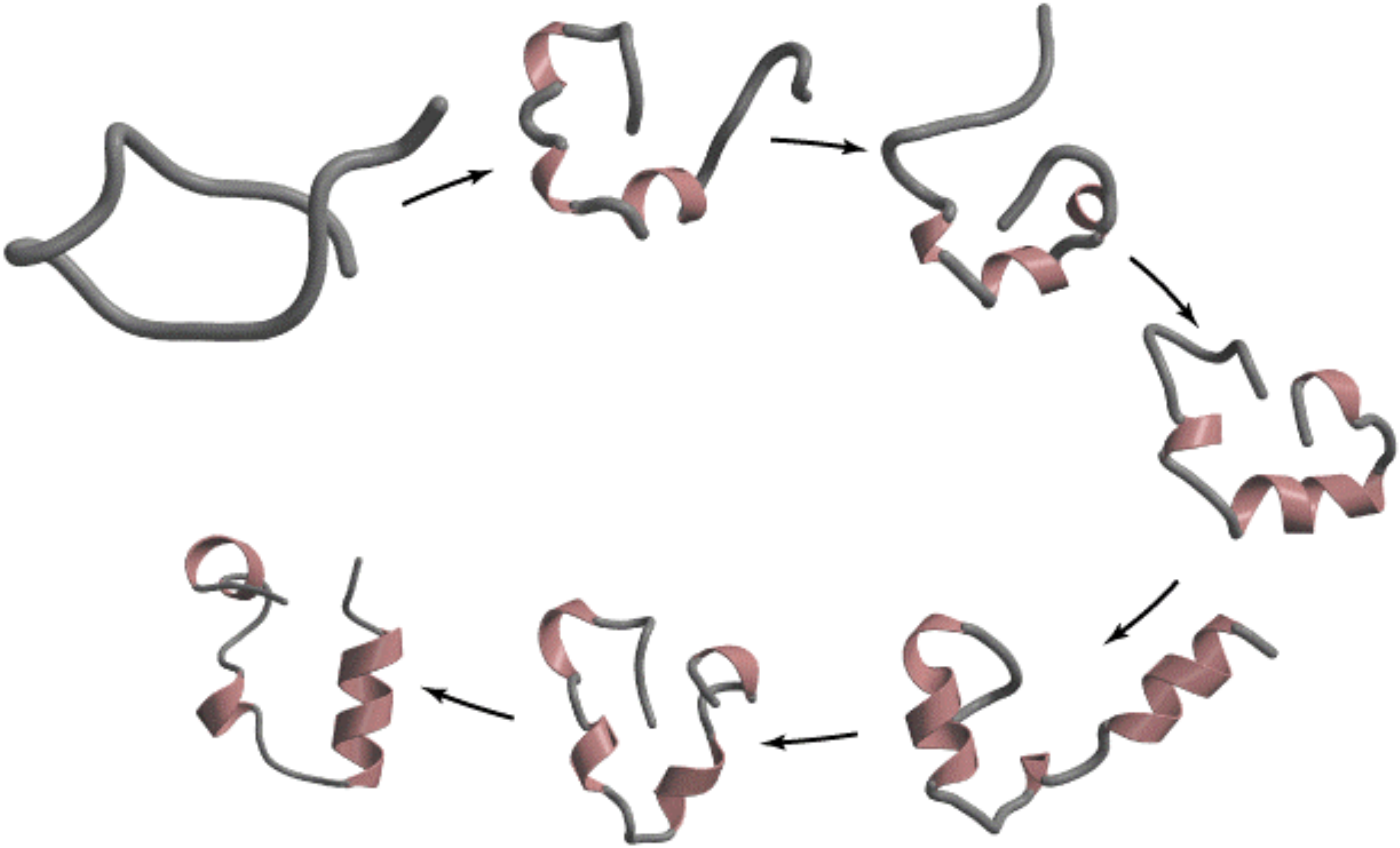
(b) Parallel

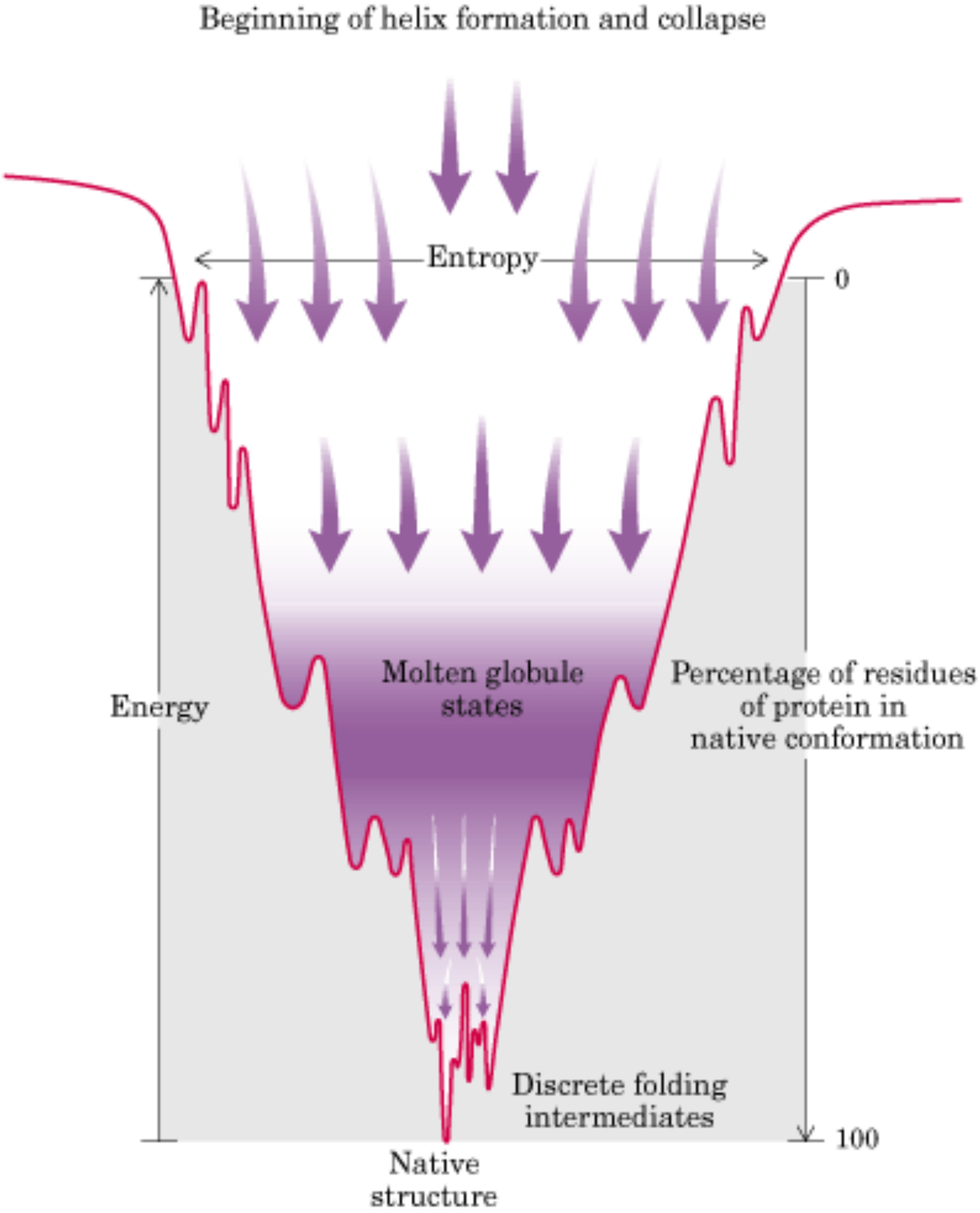


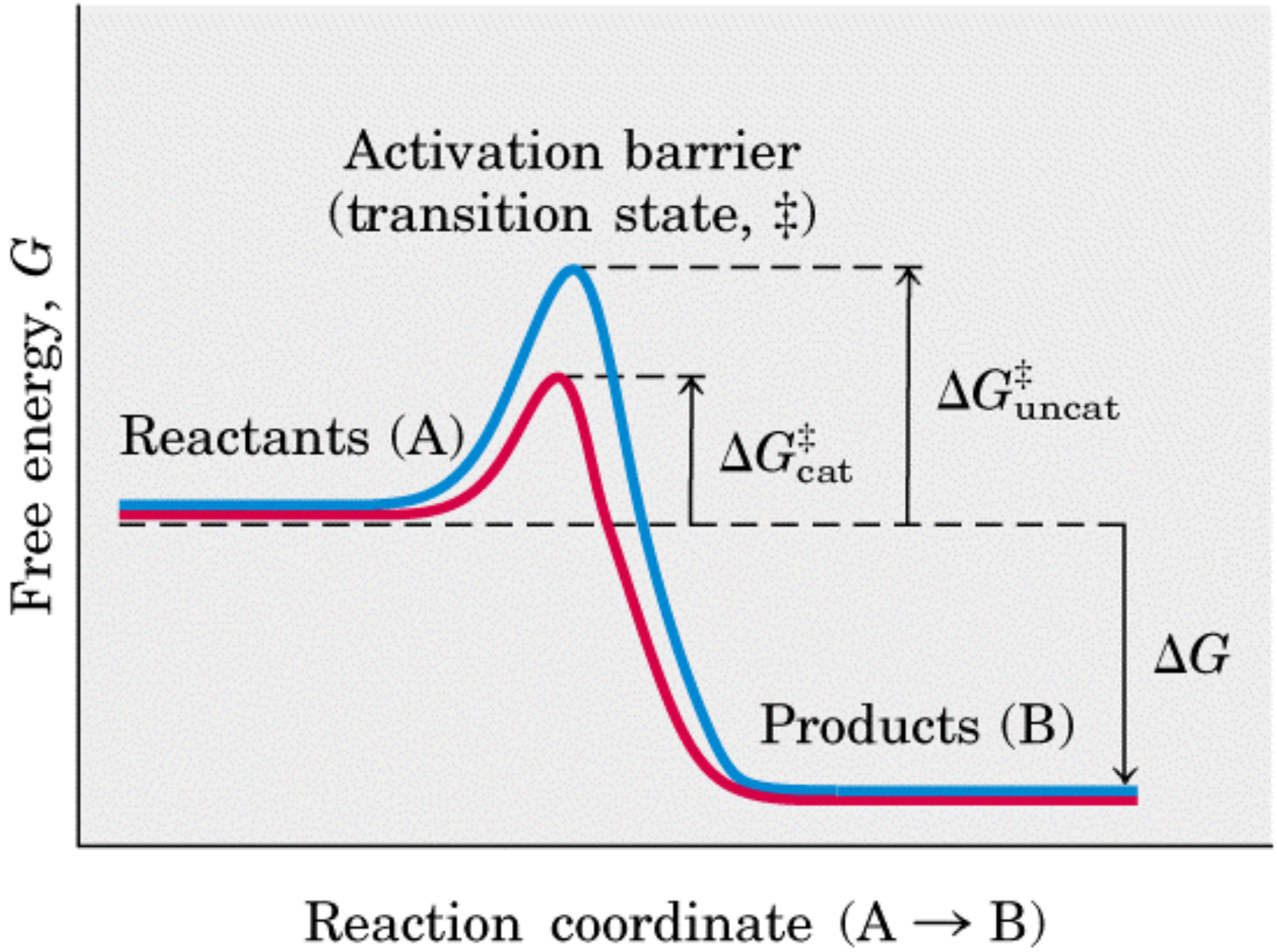


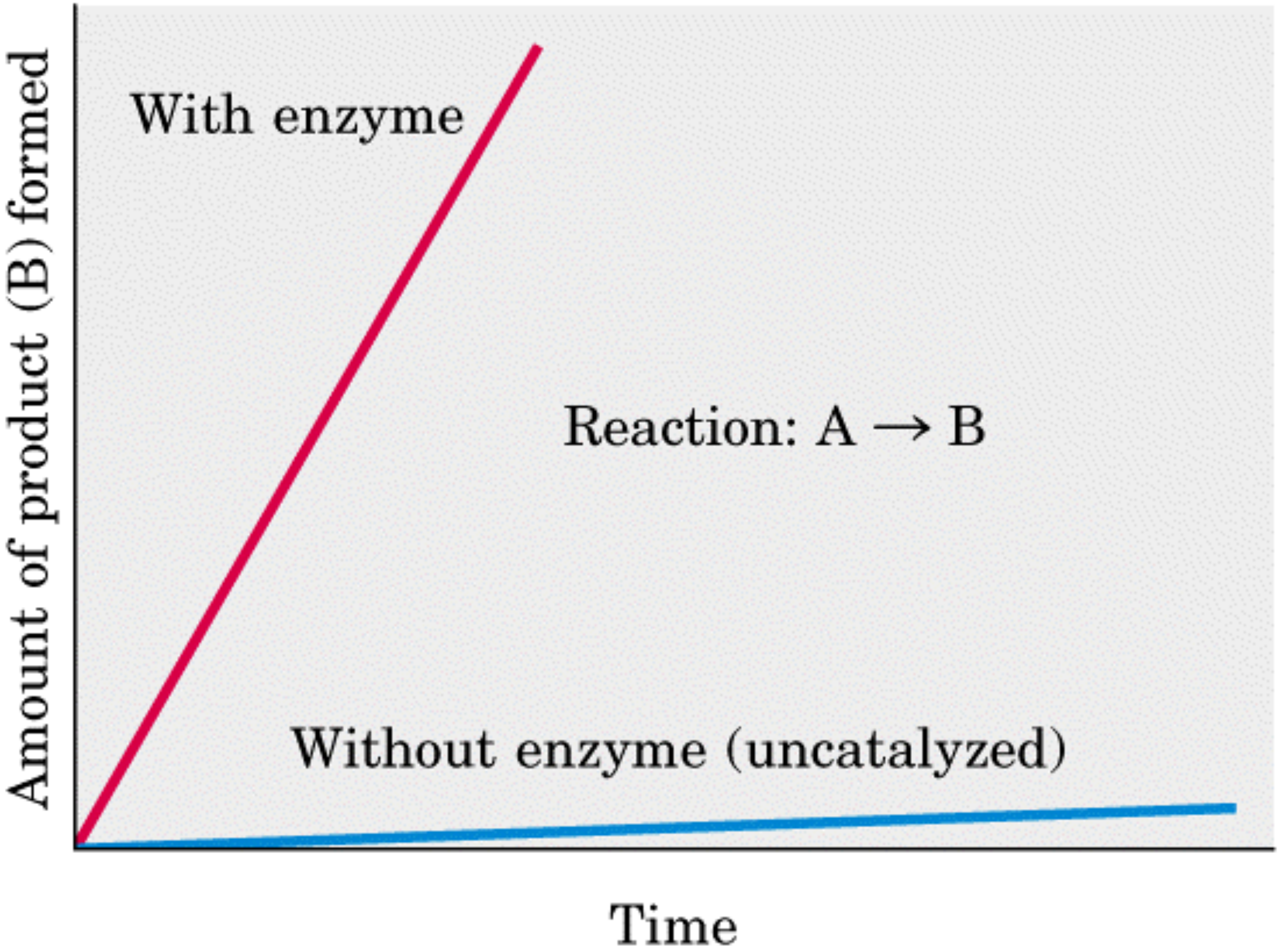


(a)




Beginning of helix formation and collapse
Entropy
0
Energy
Molten globule states
Percentage of residues of protein in native conformation
Discrete folding intermediates
100
Native structure


Activation barrier
(transition state, ‡)
Reactants (A)
$\Delta G^{\ddagger}_{\text{cat}}$
$\Delta G^{\ddagger}_{\text{uncat}}$
ΔG
Products (B)
Free energy, G
Reaction coordinate (A → B)


With enzyme
Reaction: A → B
Without enzyme (uncatalyzed)
Amount of product (B) formed
Time

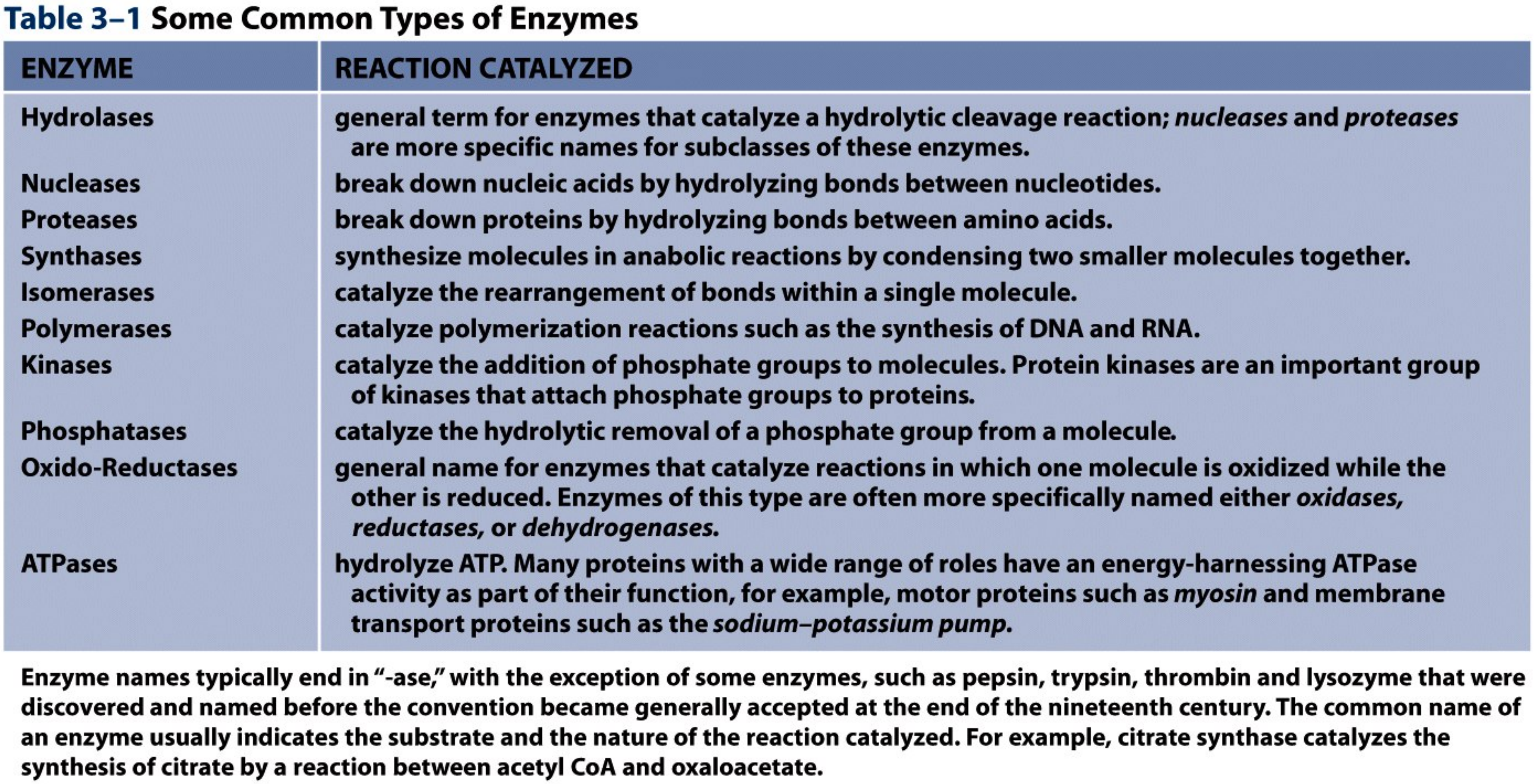


Table 3–1 Some Common Types of Enzymes

ENZYME	REACTION CATALYZED
Hydrolases	general term for enzymes that catalyze a hydrolytic cleavage reaction; *nucleases* and *proteases* are more specific names for subclasses of these enzymes.
Nucleases	break down nucleic acids by hydrolyzing bonds between nucleotides.
Proteases	break down proteins by hydrolyzing bonds between amino acids.
Synthases	synthesize molecules in anabolic reactions by condensing two smaller molecules together.
Isomerases	catalyze the rearrangement of bonds within a single molecule.
Polymerases	catalyze polymerization reactions such as the synthesis of DNA and RNA.
Kinases	catalyze the addition of phosphate groups to molecules. Protein kinases are an important group of kinases that attach phosphate groups to proteins.
Phosphatases	catalyze the hydrolytic removal of a phosphate group from a molecule.
Oxido-Reductases	general name for enzymes that catalyze reactions in which one molecule is oxidized while the other is reduced. Enzymes of this type are often more specifically named either *oxidases, reductases,* or *dehydrogenases.*
ATPases	hydrolyze ATP. Many proteins with a wide range of roles have an energy-harnessing ATPase activity as part of their function, for example, motor proteins such as *myosin* and membrane transport proteins such as the *sodium–potassium pump.*

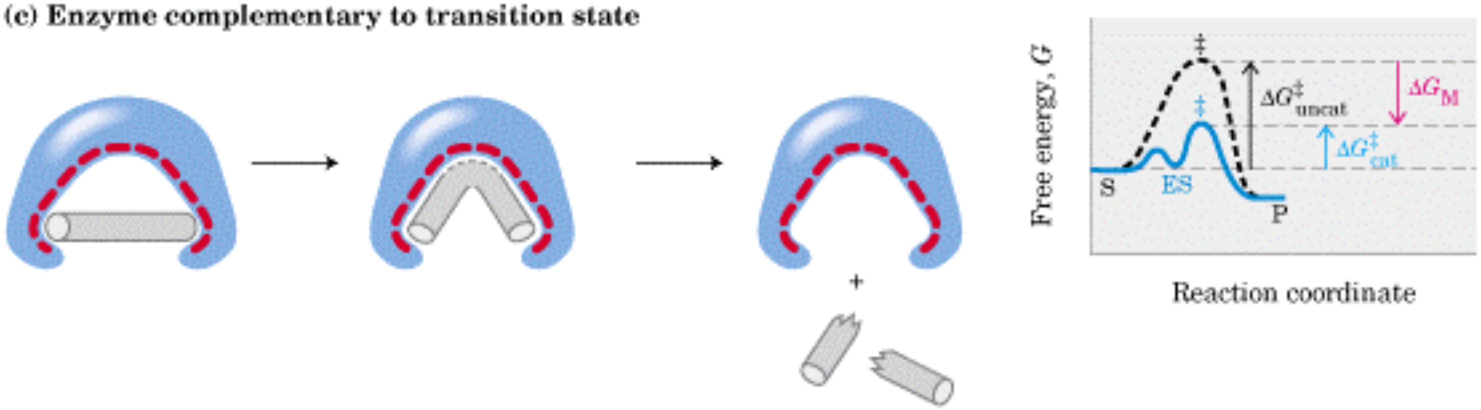
Enzyme names typically end in "-ase," with the exception of some enzymes, such as pepsin, trypsin, thrombin and lysozyme that were discovered and named before the convention became generally accepted at the end of the nineteenth century. The common name of an enzyme usually indicates the substrate and the nature of the reaction catalyzed. For example, citrate synthase catalyzes the synthesis of citrate by a reaction between acetyl CoA and oxaloacetate.

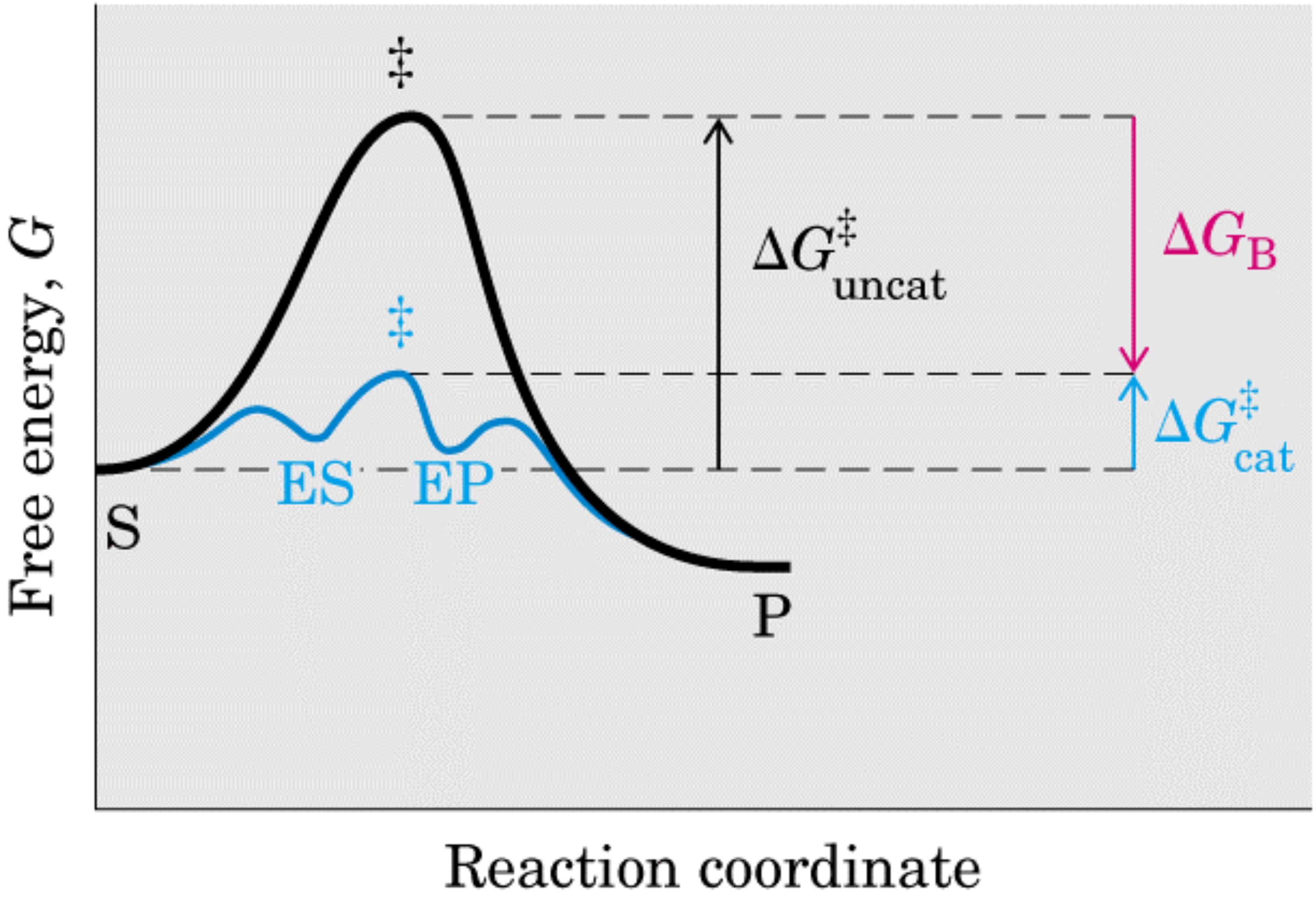
Table 3-1 *Molecular Biology of the Cell* (© Garland Science 2008)

(a) No enzyme

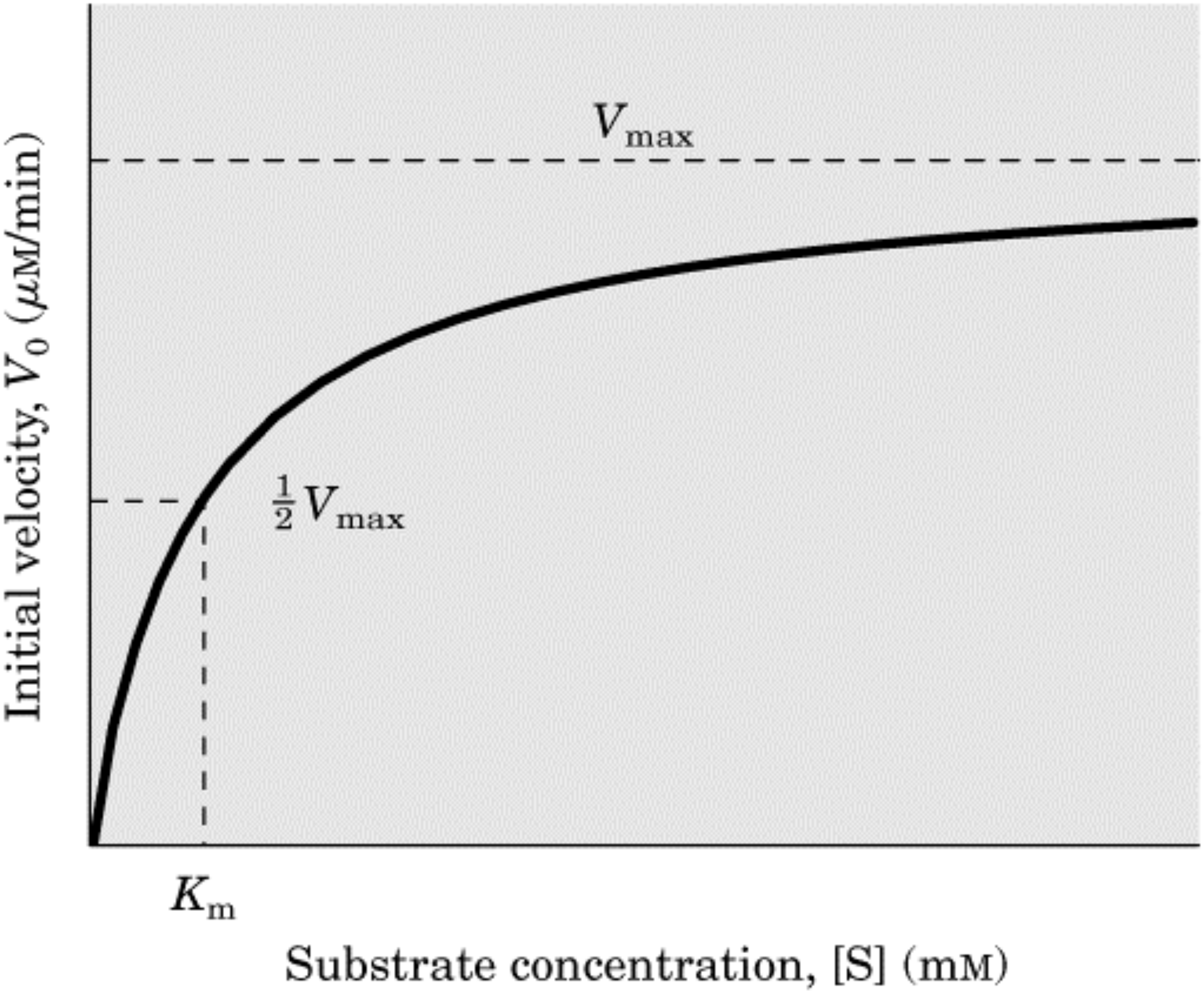
(b) Enzyme complementary to substrate

(c) Enzyme complementary to transition state

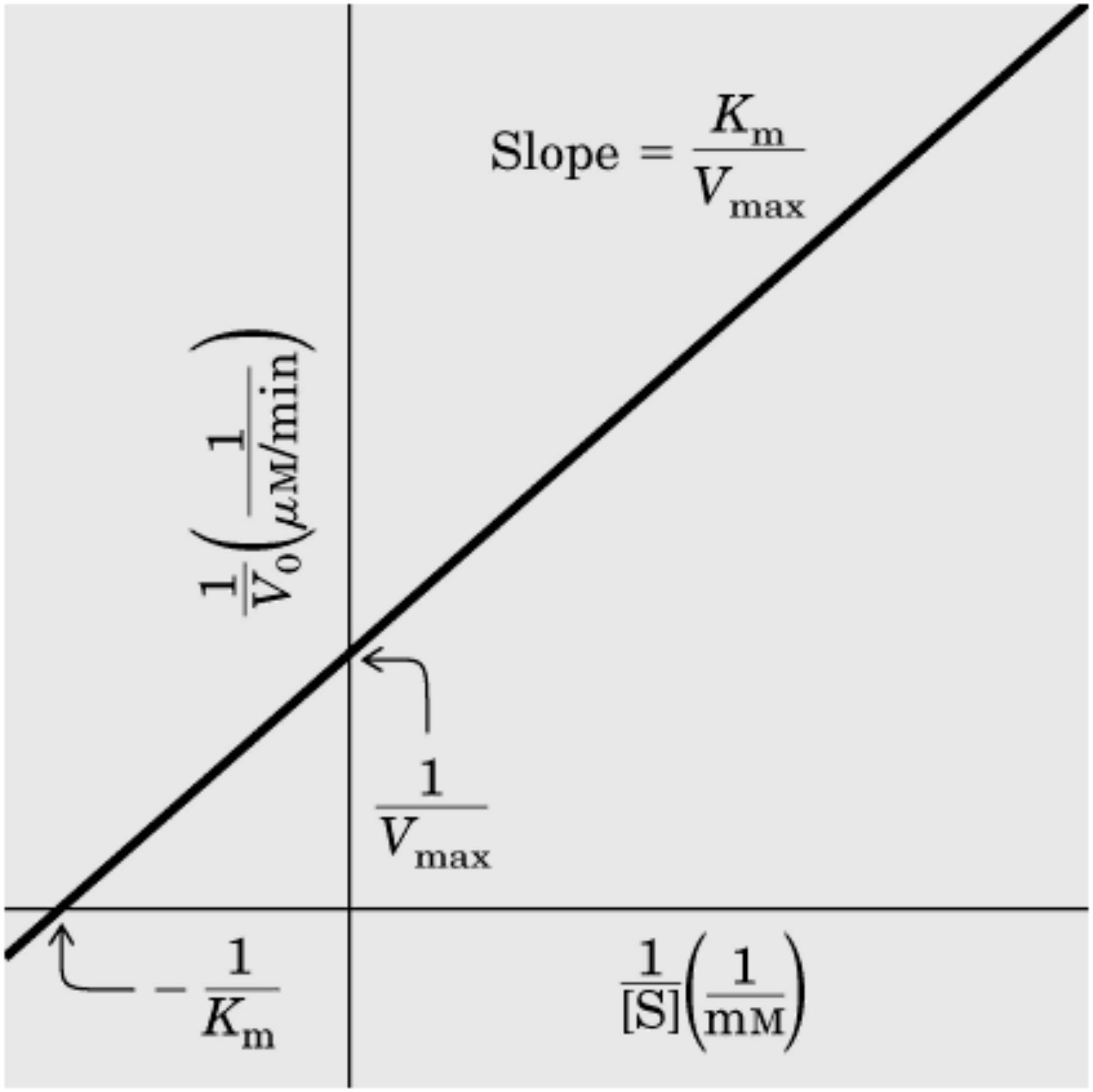



‡
‡
$\Delta G^{\ddagger}_{\text{uncat}}$
ΔG_{B}
$\Delta G^{\ddagger}_{\text{cat}}$
ES
EP
S
P
Free energy, G
Reaction coordinate

$$V_0 = \frac{V_{\mathrm{max}}[\mathrm{S}]}{K_{\mathrm{m}} + [\mathrm{S}]}$$


$V_{\max}$
$\frac{1}{2}V_{\max}$
K_m
Initial velocity, V_0 (μM/min)
Substrate concentration, [S] (mM)

$$\frac{1}{V_0} = \frac{K_{\mathrm{m}}}{V_{\mathrm{max}}[\mathrm{S}]} + \frac{1}{V_{\mathrm{max}}}$$


Slope = $\frac{K_m}{V_{max}}$
$\frac{1}{V_0}\left(\frac{1}{\mu M/min}\right)$
$\frac{1}{V_{max}}$
$-\frac{1}{K_m}$
$\frac{1}{[S]}\left(\frac{1}{mM}\right)$