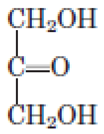
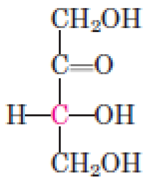
Monosaccharides

Three carbons



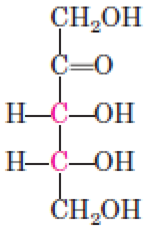
Dihydroxyacetone

Four carbons

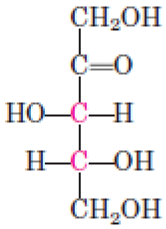


D-Erythrulose

Five carbons

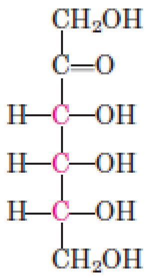


D-Ribulose

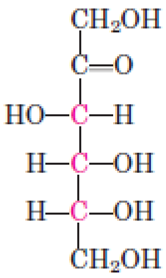


D-Xylulose

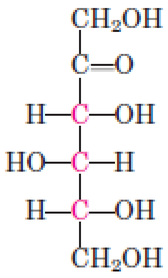
Six carbons



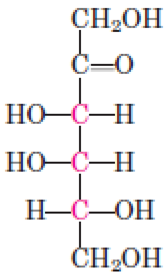
D-Psicose



D-Fructose



D-Sorbose

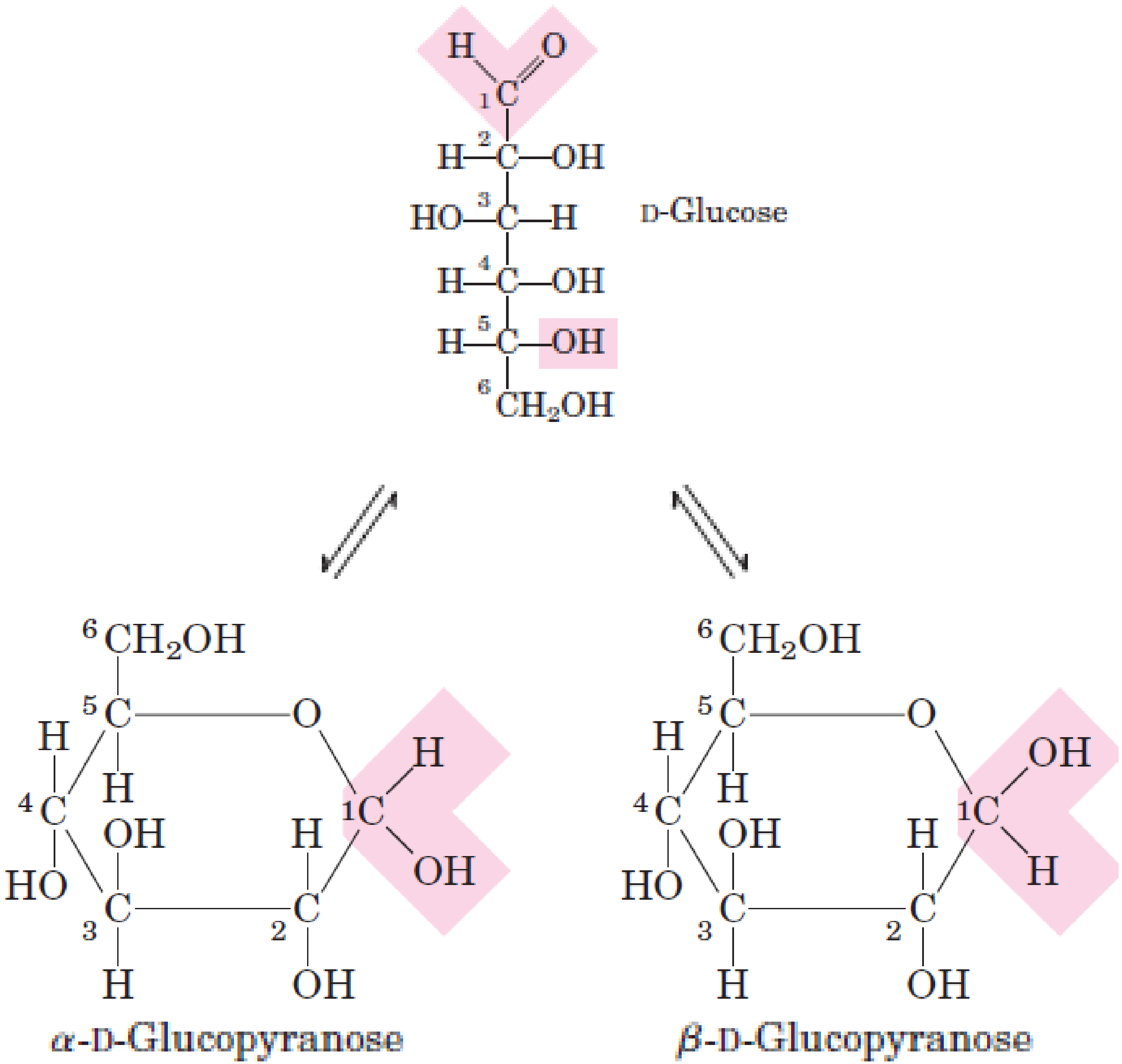


D-Tagatose

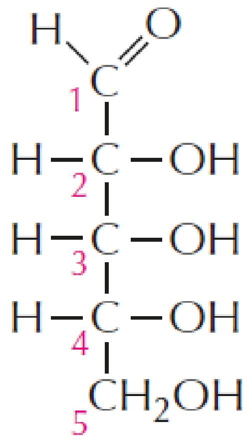
D-Ketoses

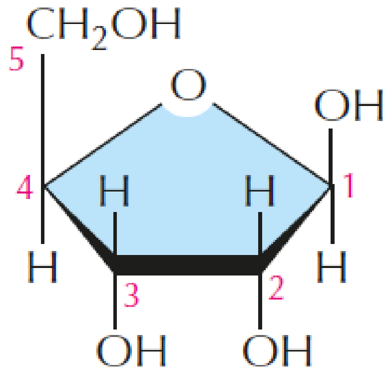
Monosaccharides

Formation of the two cyclic forms of D-glucose



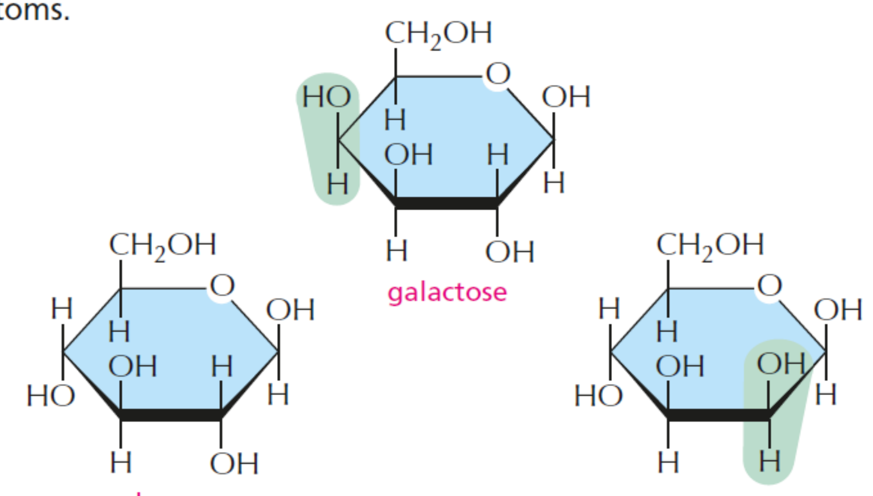
Monosaccharides

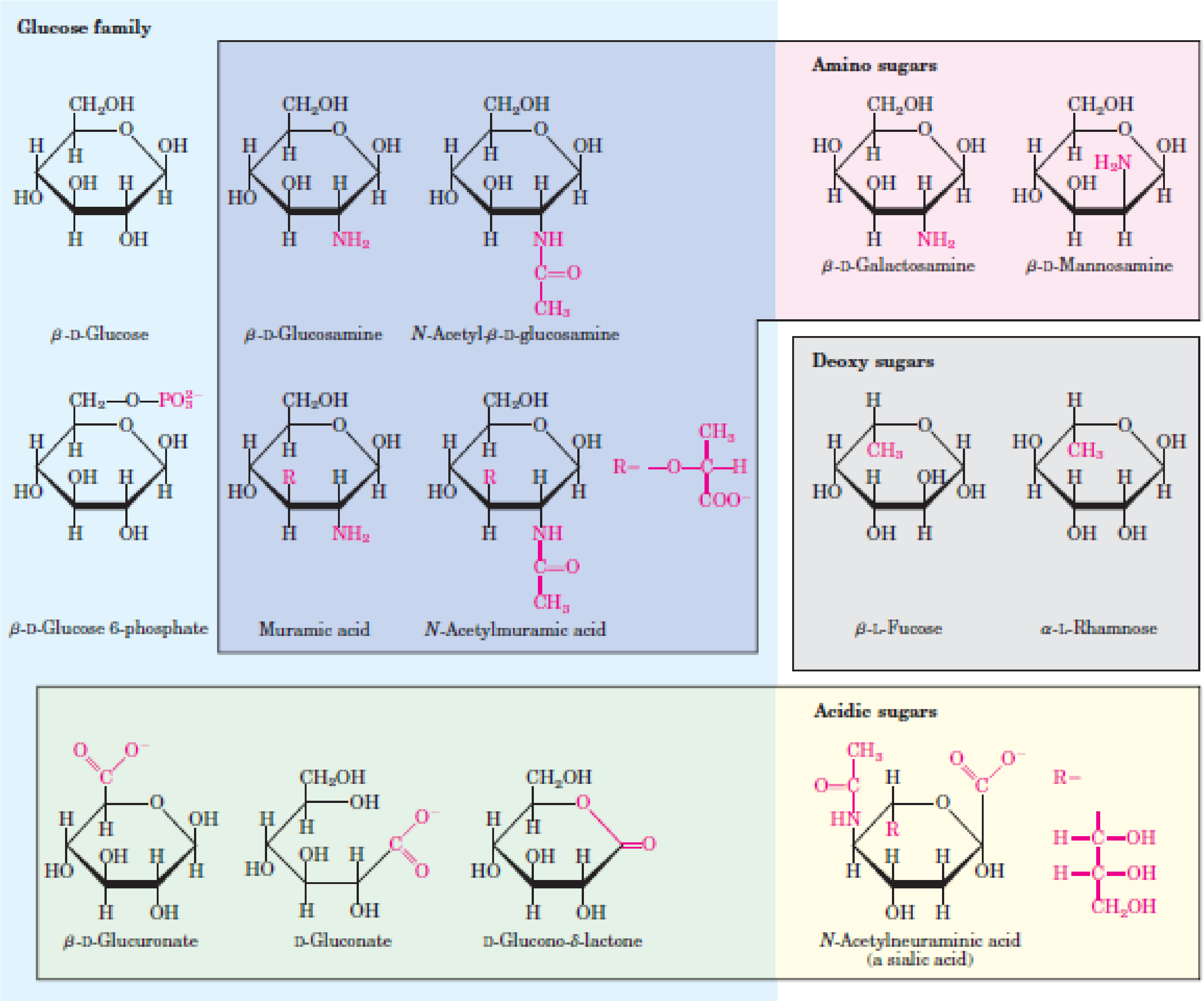




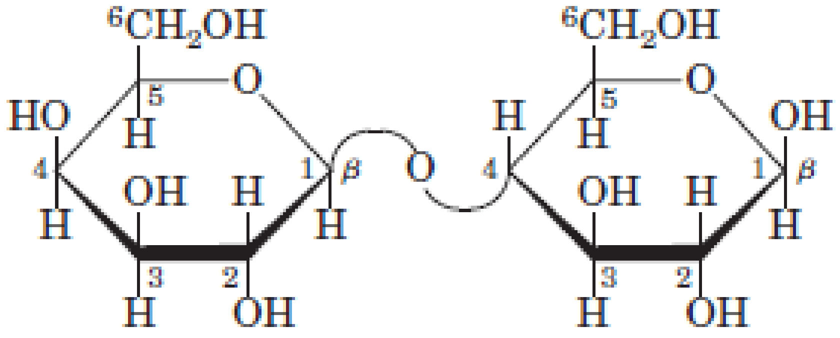
ribose

Many monosaccharides differ only in the spatial arrangement of atoms—that is, they are isomers. For example, glucose, galactose, and mannose have the same formula ($C_6H_{12}O_6$) but differ in the arrangement of groups around one or two carbon atoms.

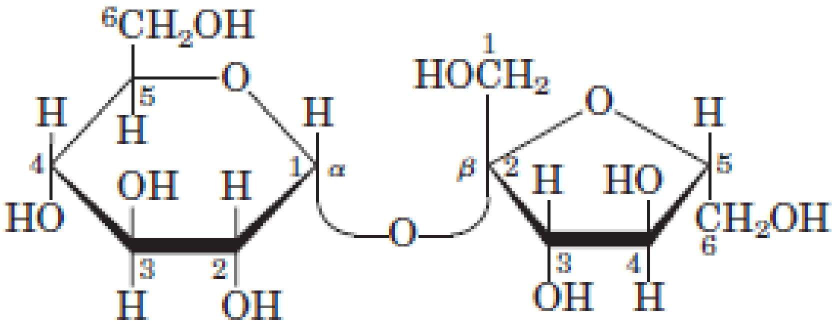



Glucose family
Amino sugars
β-D-Glucose
β-D-Glucosamine
N-Acetyl-β-D-glucosamine
β-D-Galactosamine
β-D-Mannosamine
Deoxy sugars
β-D-Glucose 6-phosphate
Muramic acid
N-Acetylmuramic acid
β-L-Fucose
α-L-Rhamnose
Acidic sugars
β-D-Glucuronate
D-Gluconate
D-Glucono-δ-lactone
N-Acetylneuraminic acid
(a sialic acid)

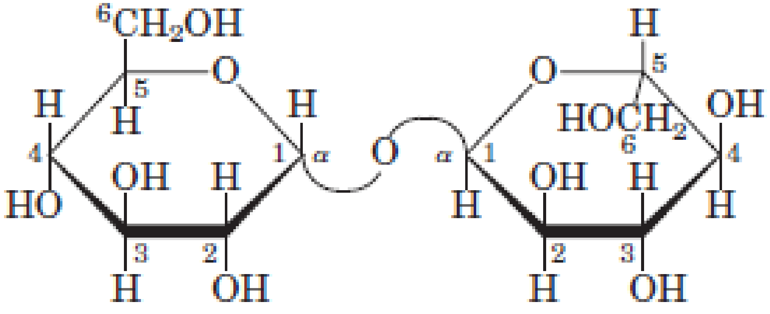
Disaccharides



Lactose (β form)



Sucrose



Trehalose

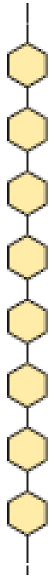
Three common disaccharides are

maltose (glucose + glucose)
lactose (galactose + glucose)
sucrose (glucose + fructose)

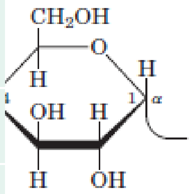
Polysaccharides

Homopo

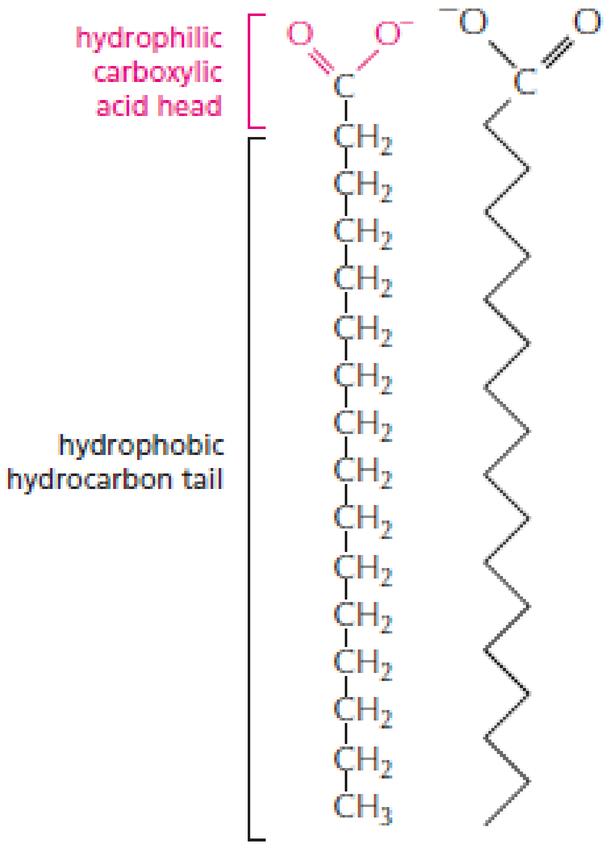
Unbranc

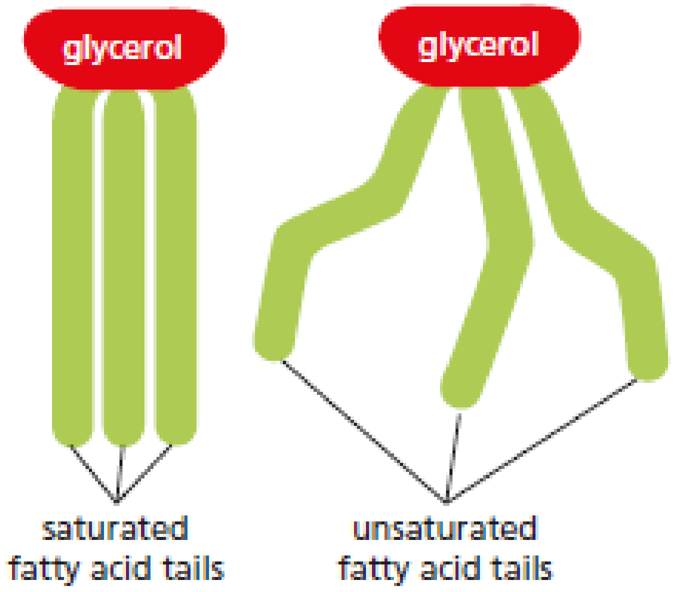


Polymer	Type*	Repeating unit†	Size (number of monosaccharide units)	Roles/significance
Starch				Energy storage: in plants
Amylose	Homo-	(α1→4)Glc, linear	50–5,000	
Amylopectin	Homo-	(α1→4)Glc, with (α1→6)Glc branches every 24–30 residues	Up to 10^6	
Glycogen	Homo-	(α1→4)Glc, with (α1→6)Glc branches every 8–12 residues	Up to 50,000	Energy storage: in bacteria and animal cells
Cellulose	Homo-	(β1→4)Glc	Up to 15,000	Structural: in plants, gives rigidity and strength to cell walls
Chitin	Homo-	(β1→4)GlcNAc	Very large	Structural: in insects, spiders, crustaceans, gives rigidity and strength to exoskeletons
Dextran	Homo-	(α1→6)Glc, with (α1→3) branches	Wide range	Structural: in bacteria, extracellular adhesive
Peptidoglycan	Hetero-; peptides attached	4)Mur2Ac(β1→4) GlcNAc(β1	Very large	Structural: in bacteria, gives rigidity and strength to cell envelope
Agarose	Hetero-	3)D-Gal(β1→4)3,6-anhydro-L-Gal(α1	1,000	Structural: in algae, cell wall material
Hyaluronan (a glycosamino-glycan)	Hetero-; acidic	4)GlcA(β1→3) GlcNAc(β1	Up to 100,000	Structural: in vertebrates, extracellular matrix of skin and connective tissue; viscosity and lubrication in joints



Fats - depend on the length and saturation of the fatty acid chains they carry



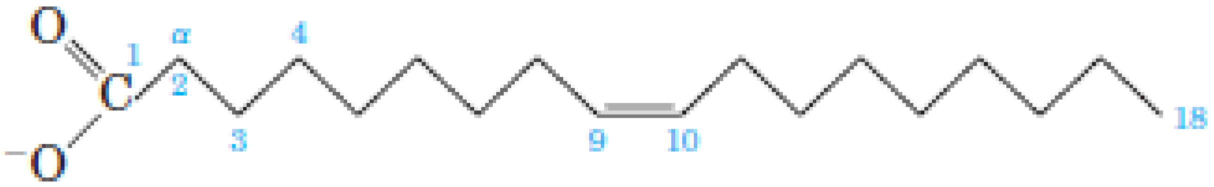


Fatty acids are stored in the cytoplasm of many cells in the form of droplets of *triacylglycerol* molecules

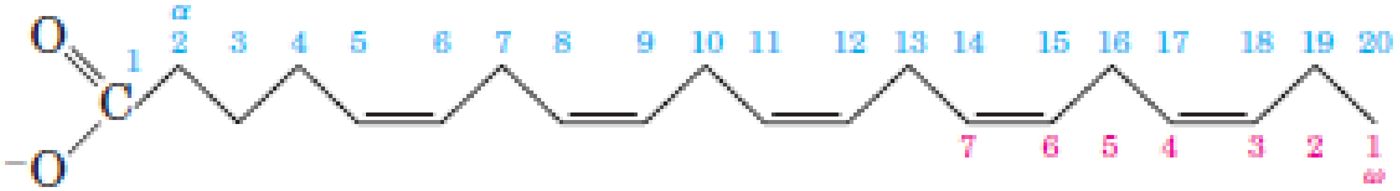
Saturated fats are found in meat and dairy products

Plant oils, such as corn oil, contain unsaturated fatty acids

Fatty acids are carboxylic acids with hydrocarbon chains ranging from 4 to 36 carbons long (C4 to C36).



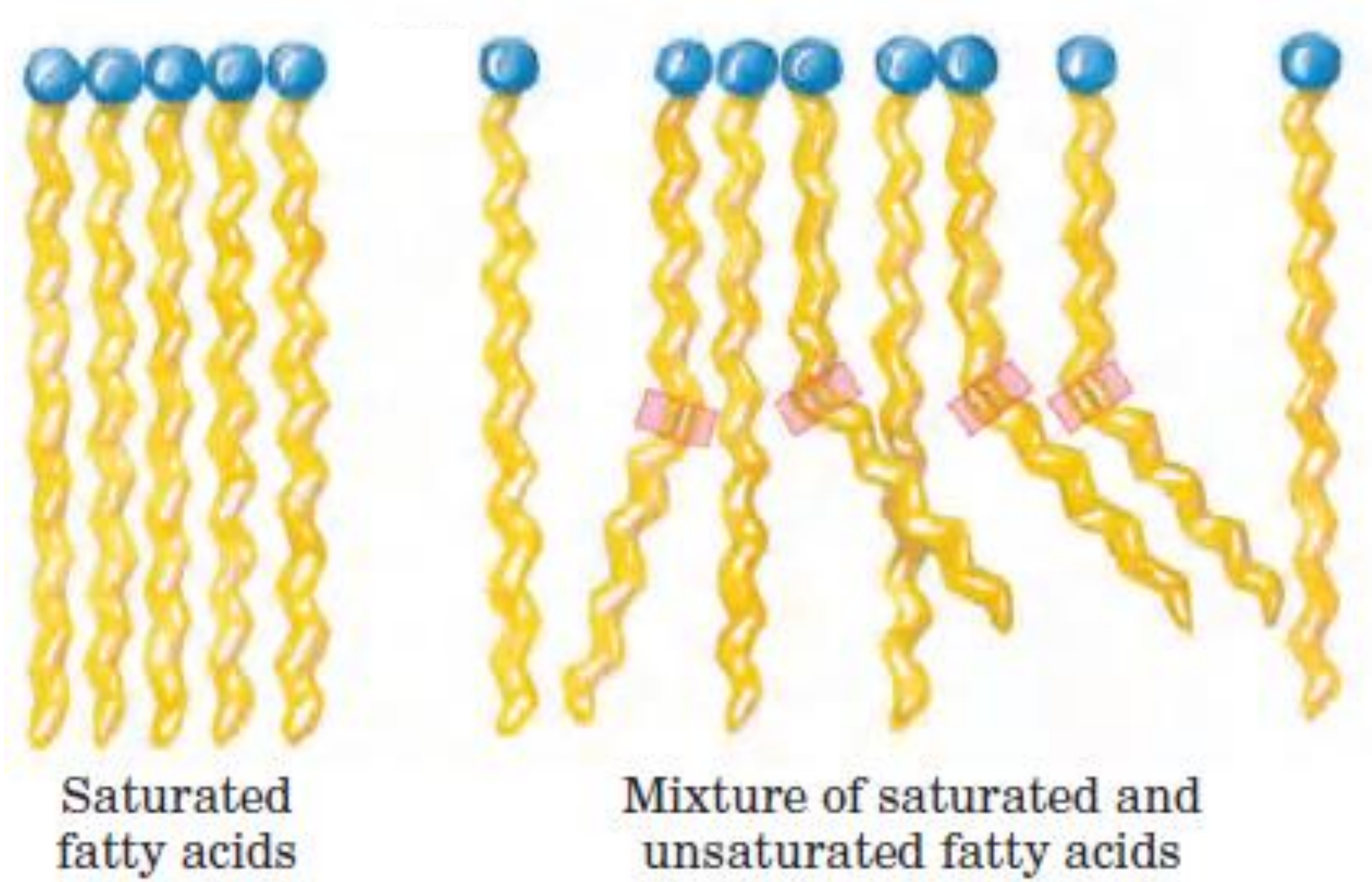
(a) 18:1(Δ^9) *cis*-9-Octadecenoic acid



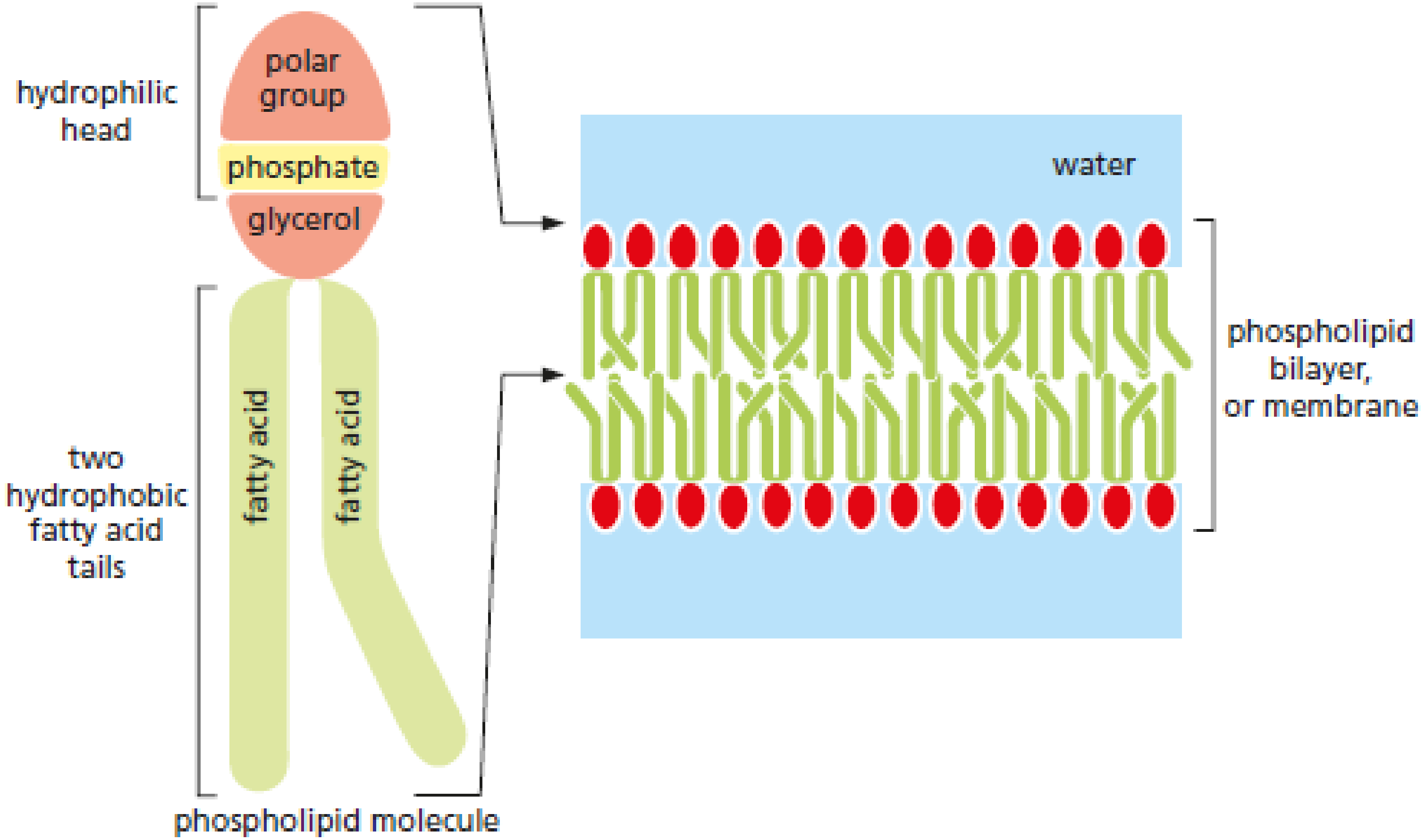
(b) 20:5($\Delta^{5,8,11,14,17}$) Eicosapentaenoic acid (EPA), an omega-3 fatty acid

Carbon skeleton	Structure*	Systematic name†	Common name (derivation)
12:0	$CH_3(CH_2)_{10}COOH$	*n*-Dodecanoic acid	Lauric acid (Latin *laurus*, "laurel plant")
14:0	$CH_3(CH_2)_{12}COOH$	*n*-Tetradecanoic acid	Myristic acid (Latin *Myristica*, nutmeg genus)
16:0	$CH_3(CH_2)_{14}COOH$	*n*-Hexadecanoic acid	Palmitic acid (Latin *palma*, "palm tree")
18:0	$CH_3(CH_2)_{16}COOH$	*n*-Octadecanoic acid	Stearic acid (Greek *stear*, "hard fat")
20:0	$CH_3(CH_2)_{18}COOH$	*n*-Eicosanoic acid	Arachidic acid (Latin *Arachis*, legume genus)
24:0	$CH_3(CH_2)_{22}COOH$	*n*-Tetracosanoic acid	Lignoceric acid (Latin *lignum*, "wood" + *cera*, "wax")
16:1(Δ^9)	$CH_3(CH_2)_5CH{=}CH(CH_2)_7COOH$	*cis*-9-Hexadecenoic acid	Palmitoleic acid
18:1(Δ^9)	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	*cis*-9-Octadecenoic acid	Oleic acid (Latin *oleum*, "oil")
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")
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
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

The packing of fatty acids into stable aggregates



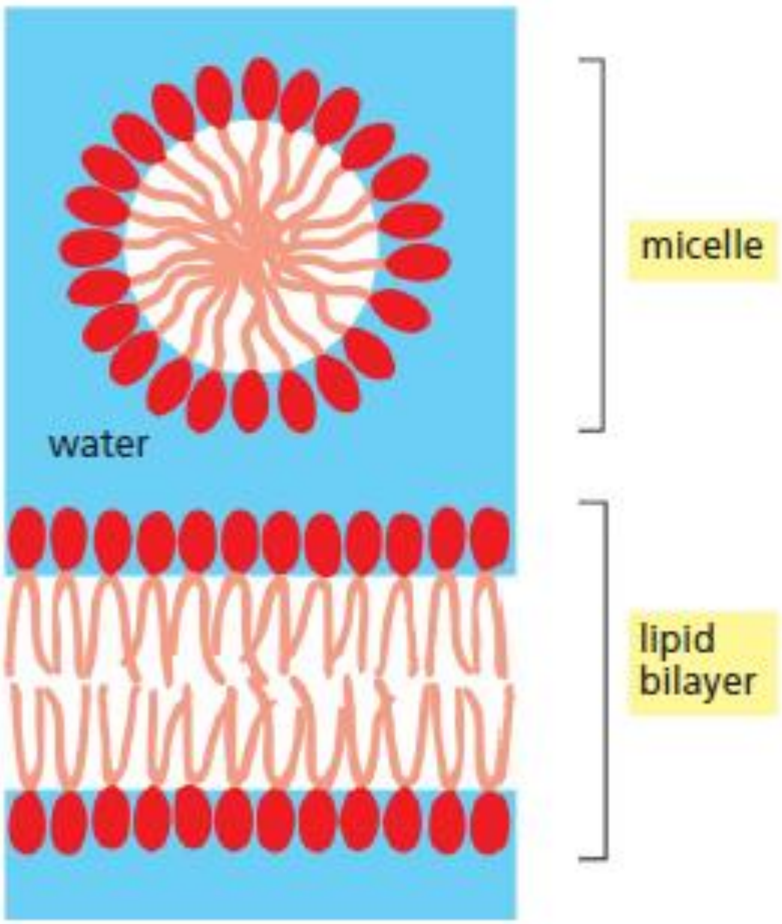
Phospholipid - Lipid Bilayer

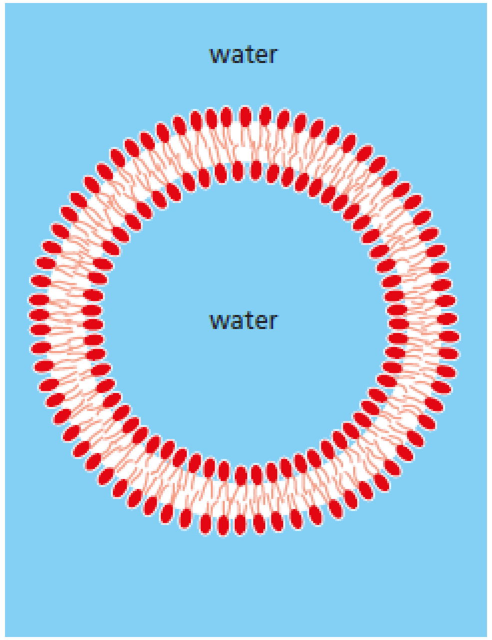


Glycerol is joined to two fatty acid chains.

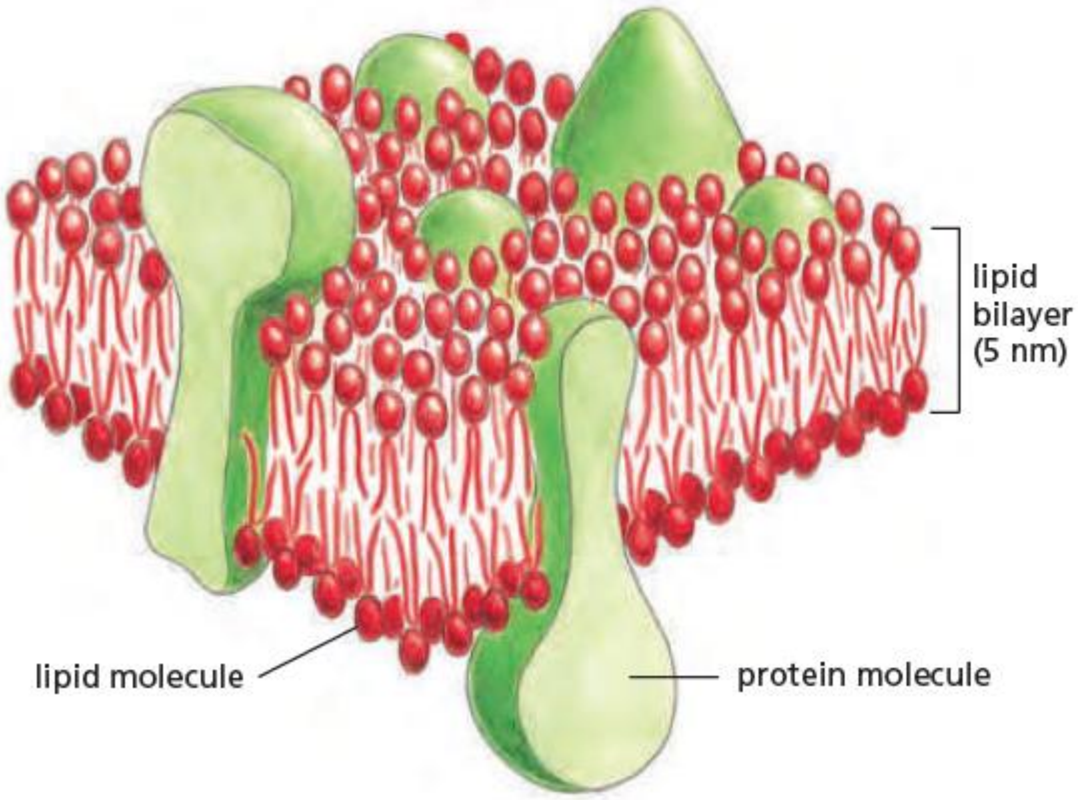
The remaining –OH group on the glycerol is linked to a hydrophilic phosphate group, which in turn is attached to a small hydrophilic compound such as choline.

Phospholipids Spontaneously Form Bilayers

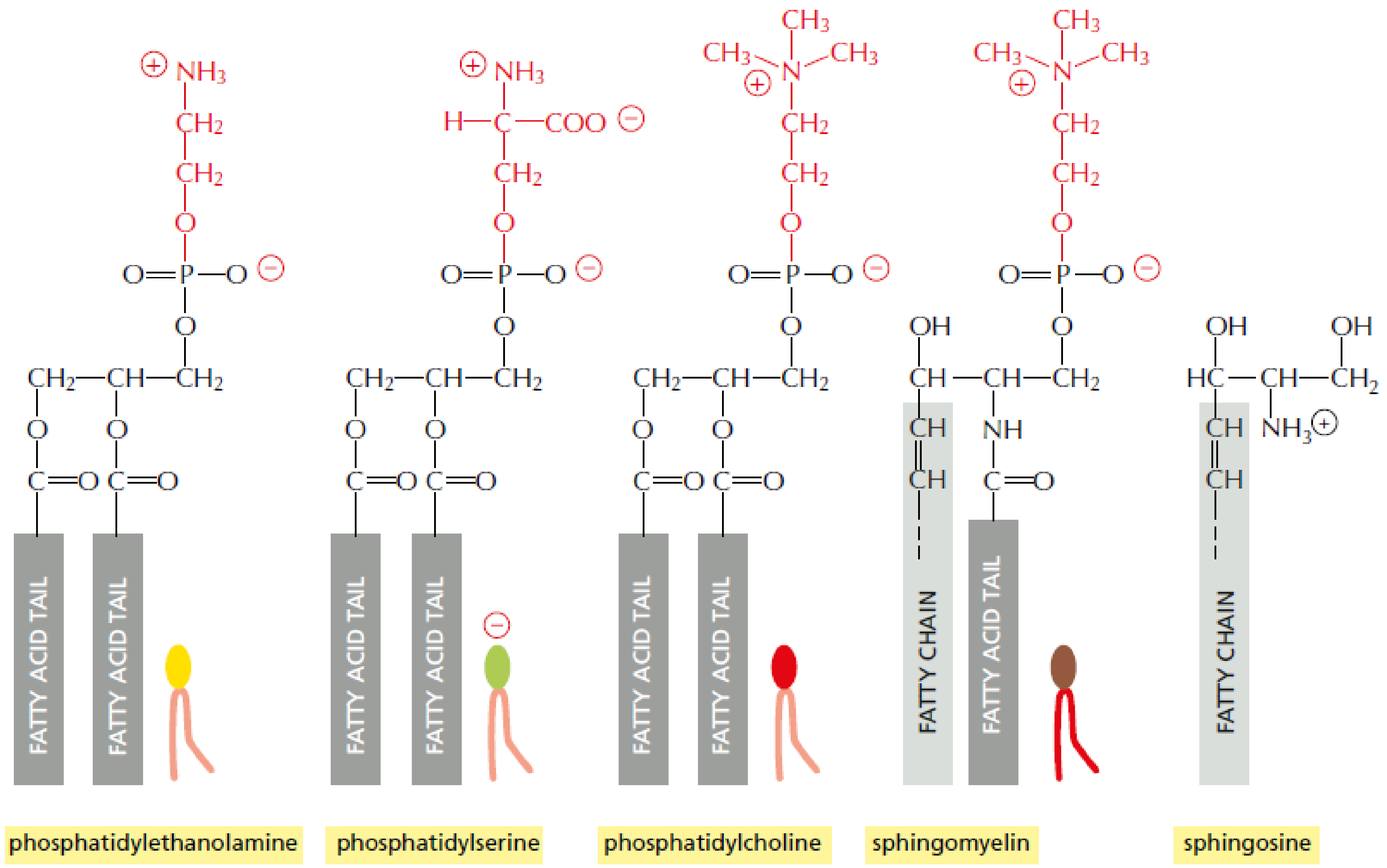




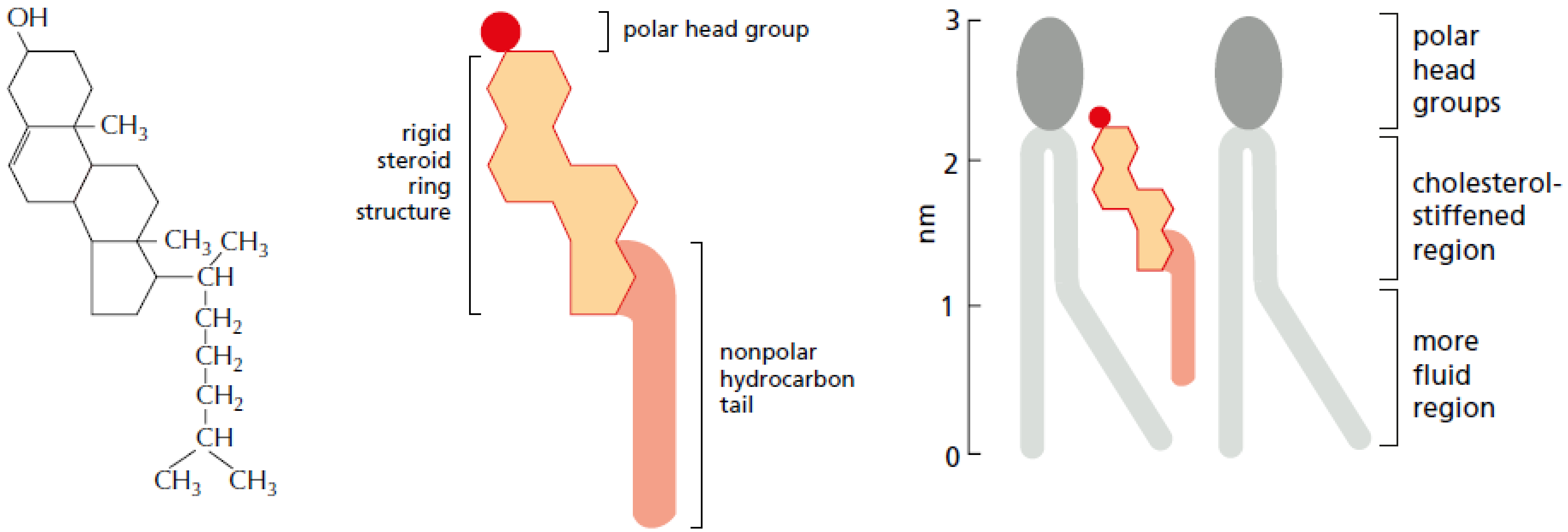
A three-dimensional schematic view of a cell membrane



Four major phospholipids in mammalian plasma membranes



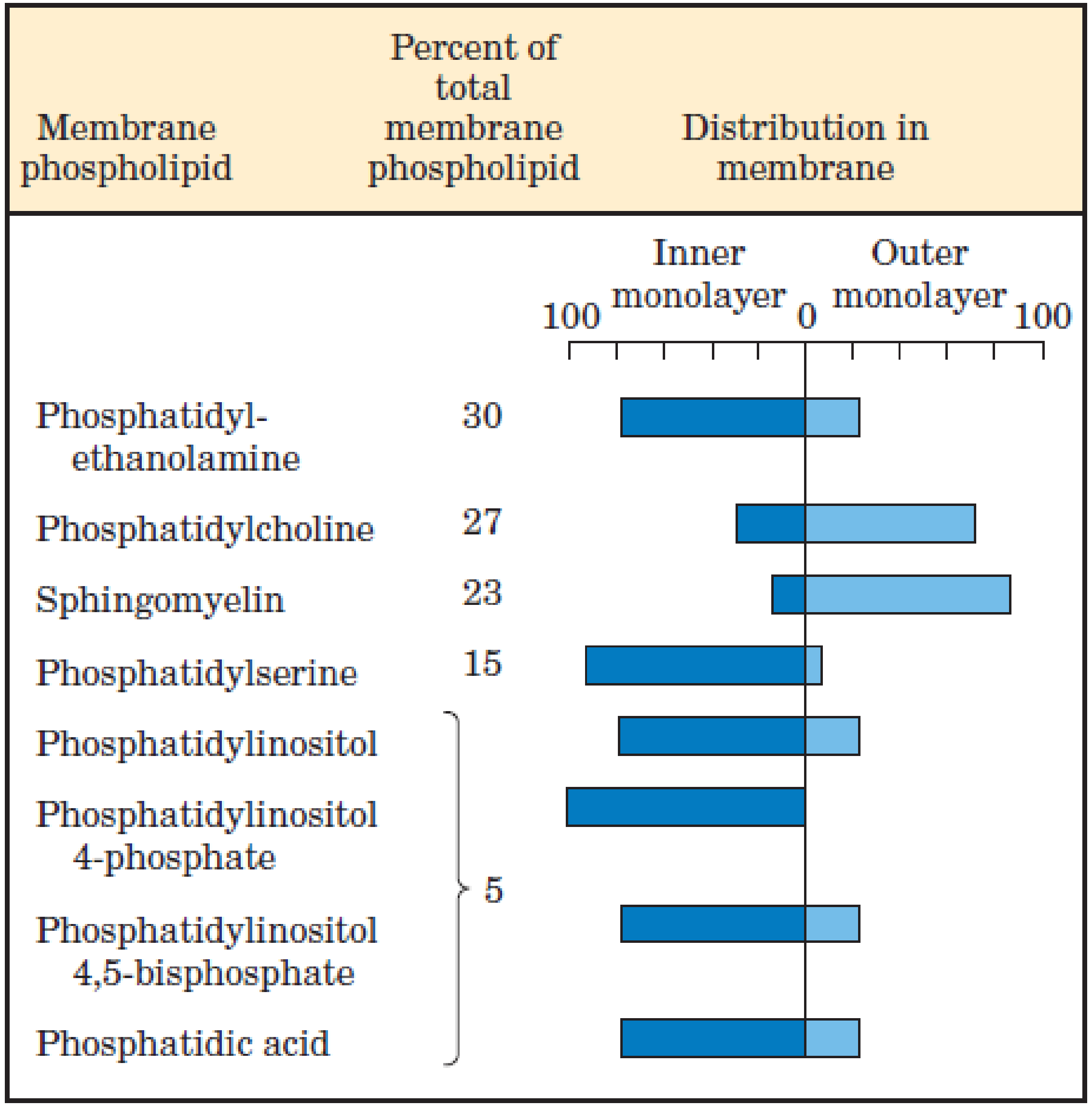
The structure of cholesterol



Lipid composition of the plasma membrane and organelle membranes of a hepatocyte

Lipid	Percentage of total lipid by weight					
	Liver cell plasma membrane	Red blood cell plasma membrane	Myelin	Mitochondrion (inner and outer membranes)	Endoplasmic reticulum	*E. coli* bacterium
Cholesterol	17	23	22	3	6	0
Phosphatidylethanolamine	7	18	15	28	17	70
Phosphatidylserine	4	7	9	2	5	trace
Phosphatidylcholine	24	17	10	44	40	0
Sphingomyelin	19	18	8	0	5	0
Glycolipids	7	3	28	trace	trace	0
Others	22	14	8	23	27	30

Distribution of phospholipids between the inner and outer monolayers



Proteins

ENZYMES

function: Catalyze covalent bond breakage or formation.

examples: Living cells contain thousands of different enzymes, each of which catalyzes (speeds up) one particular reaction. Examples include: *tryptophan synthetase*—makes the amino acid tryptophan; *pepsin*—degrades dietary proteins in the stomach; *ribulose bisphosphate carboxylase*—helps convert carbon dioxide into sugars in plants; *DNA polymerase*—copies DNA; *protein kinase*—adds a phosphate group to a protein molecule.

STRUCTURAL PROTEINS

function: Provide mechanical support to cells and tissues.

examples: Outside cells, *collagen* and *elastin* are common constituents of extracellular matrix and form fibers in tendons and ligaments. Inside cells, *tubulin* forms long, stiff microtubules, and *actin* forms filaments that underlie and support the plasma membrane; *keratin* forms fibers that reinforce epithelial cells and is the major protein in hair and horn.

TRANSPORT PROTEINS

function: Carry small molecules or ions.

examples: In the bloodstream, *serum albumin* carries lipids, *hemoglobin* carries oxygen, and *transferrin* carries iron. Many proteins embedded in cell membranes transport ions or small molecules across the membrane. For example, the bacterial protein *bacteriorhodopsin* is a light-activated proton pump that transports H^+ ions out of the cell; *glucose carriers* shuttle glucose into and out of cells; and a *Ca^{2+} pump* clears Ca^{2+} from a muscle cell's cytosol after the ions have triggered a contraction.

MOTOR PROTEINS

function: Generate movement in cells and tissues.

examples: *Myosin* in skeletal muscle cells provides the motive force for humans to move; *kinesin* interacts with microtubules to move organelles around the cell; *dynein* enables eukaryotic cilia and flagella to beat.

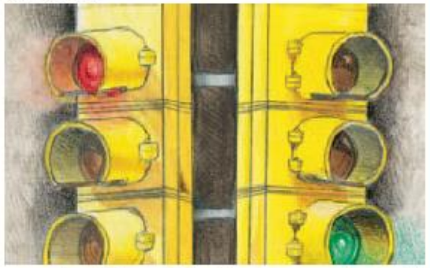
STORAGE PROTEINS

function: Store amino acids or ions.

examples: Iron is stored in the liver by binding to the small protein *ferritin*; *ovalbumin* in egg white is used as a source of amino acids for the developing bird embryo; *casein* in milk is a source of amino acids for baby mammals.

SIGNAL PROTEINS

function: Carry extracellular signals from cell to cell.



examples: Many of the hormones and growth factors that coordinate physiological functions in animals are proteins; *insulin*, for example, is a small protein that controls glucose levels in the blood; *netrin* attracts growing nerve cell axons to specific locations in the developing spinal cord; *nerve growth factor* (*NGF*) stimulates some types of nerve cells to grow axons; *epidermal growth factor* (*EGF*) stimulates the growth and division of epithelial cells.

RECEPTOR PROTEINS

function: Detect signals and transmit them to the cell's response machinery.

examples: *Rhodopsin* in the retina detects light; the *acetylcholine receptor* in the membrane of a muscle cell is activated by acetylcholine released from a nerve ending; the *insulin receptor* allows a cell to respond to the hormone insulin by taking up glucose; the *adrenergic receptor* on heart muscle increases the rate of the heartbeat when it binds to adrenaline.

GENE REGULATORY PROTEINS

function: Bind to DNA to switch genes on or off.

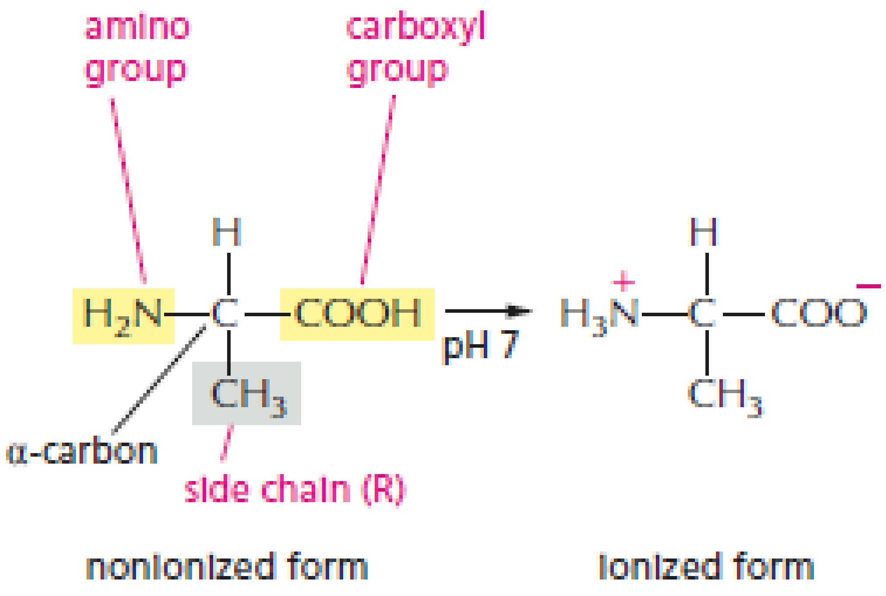
examples: The *lactose repressor* in bacteria silences the genes for the enzymes that degrade the sugar lactose; many different *homeodomain proteins* act as genetic switches to control development in multicellular organisms, including humans.

SPECIAL-PURPOSE PROTEINS

function: Highly variable.

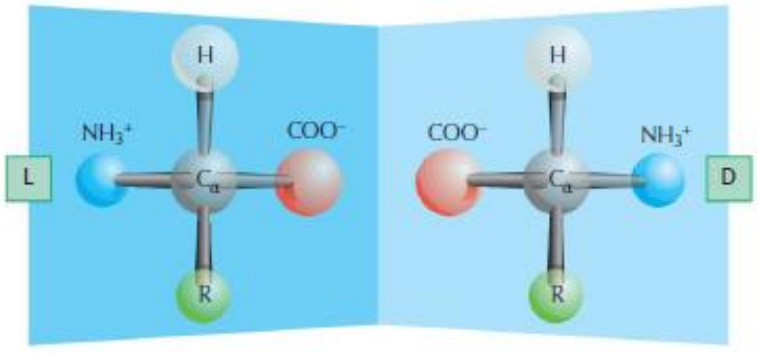
examples: Organisms make many proteins with highly specialized properties. These molecules illustrate the amazing range of functions that proteins can perform. The *antifreeze proteins* of Arctic and Antarctic fishes protect their blood against freezing; *green fluorescent protein* from jellyfish emits a green light; *monellin*, a protein found in an African plant, has an intensely sweet taste; mussels and other marine organisms secrete *glue proteins* that attach them firmly to rocks, even when immersed in seawater.

Amino acids



OPTICAL ISOMERS

The α-carbon atom is asymmetric, which allows for two mirror images (or stereo-) isomers, L and D.



Proteins consist exclusively of L-amino acids.

FAMILIES OF AMINO ACIDS

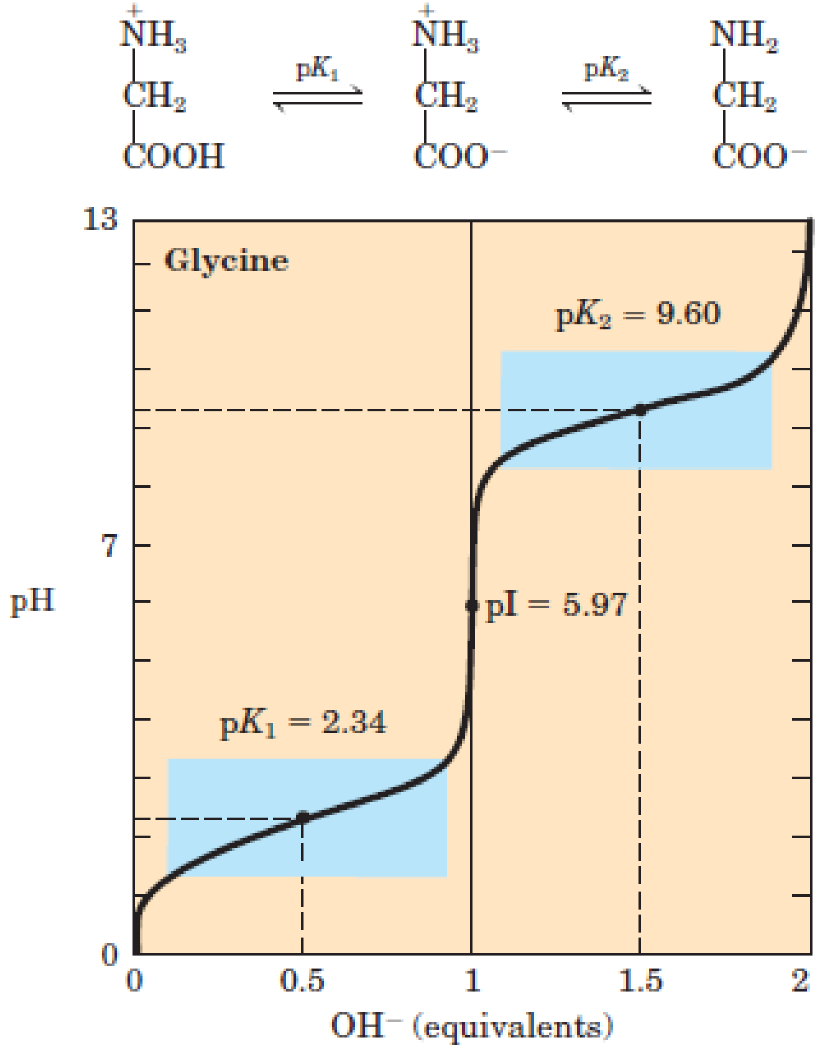
The common amino acids are grouped according to whether their side chains are

- acidic
- basic
- uncharged polar
- nonpolar

These 20 amino acids are given both three-letter and one-letter abbreviations.

Thus: alanine = Ala = A

Amino Acids Have Characteristic Titration Curves



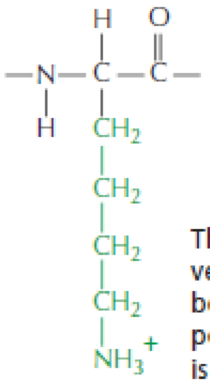
Amino Acids Can Act as Acids and Bases

Amino acids

BASIC SIDE CHAINS

lysine

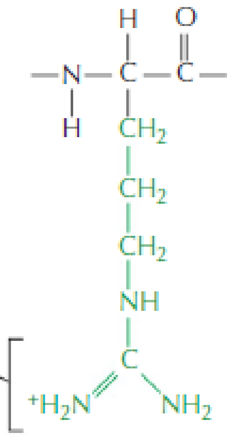
(Lys, or K)



This group is very basic because its positive charge is stabilized by resonance (see Panel 2–1).

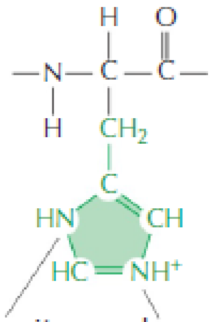
arginine

(Arg, or R)



histidine

(His, or H)

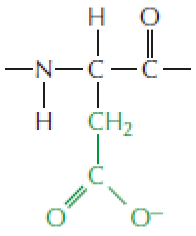


These nitrogens have a relatively weak affinity for an H^+ and are only partly positive at neutral pH.

ACIDIC SIDE CHAINS

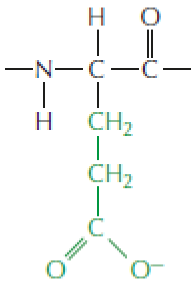
aspartic acid

(Asp, or D)

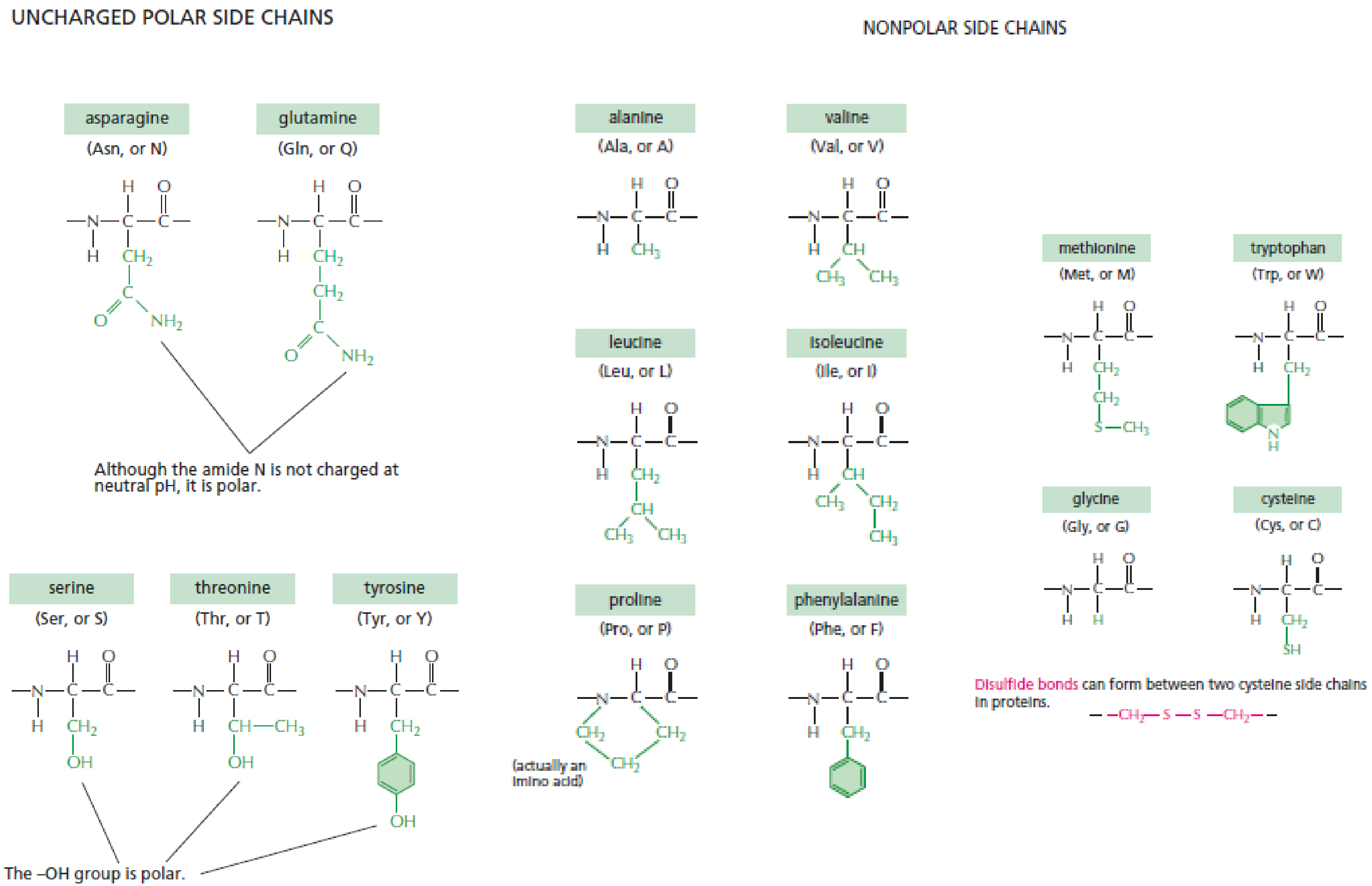


glutamic acid

(Glu, or E)



Amino acids



UNCHARGED POLAR SIDE CHAINS
asparagine
(Asn, or N)
glutamine
(Gln, or Q)
Although the amide N is not charged at neutral pH, it is polar.
serine
(Ser, or S)
threonine
(Thr, or T)
tyrosine
(Tyr, or Y)
The –OH group is polar.
NONPOLAR SIDE CHAINS
alanine
(Ala, or A)
valine
(Val, or V)
leucine
(Leu, or L)
isoleucine
(Ile, or I)
proline
(Pro, or P)
(actually an imino acid)
phenylalanine
(Phe, or F)
methionine
(Met, or M)
tryptophan
(Trp, or W)
glycine
(Gly, or G)
cysteine
(Cys, or C)
Disulfide bonds can form between two cysteine side chains in proteins.

Amino acids

AMINO ACID			SIDE CHAIN
Aspartic acid	Asp	D	negative
Glutamic acid	Glu	E	negative
Arginine	Arg	R	positive
Lysine	Lys	K	positive
Histidine	His	H	positive
Asparagine	Asn	N	uncharged polar
Glutamine	Gln	Q	uncharged polar
Serine	Ser	S	uncharged polar
Threonine	Thr	T	uncharged polar
Tyrosine	Tyr	Y	uncharged polar

POLAR AMINO ACIDS

AMINO ACID			SIDE CHAIN
Alanine	Ala	A	nonpolar
Glycine	Gly	G	nonpolar
Valine	Val	V	nonpolar
Leucine	Leu	L	nonpolar
Isoleucine	Ile	I	nonpolar
Proline	Pro	P	nonpolar
Phenylalanine	Phe	F	nonpolar
Methionine	Met	M	nonpolar
Tryptophan	Trp	W	nonpolar
Cysteine	Cys	C	nonpolar

NONPOLAR AMINO ACIDS

Six amino acids (CHIMSV), the first letter of the amino acid name is unique

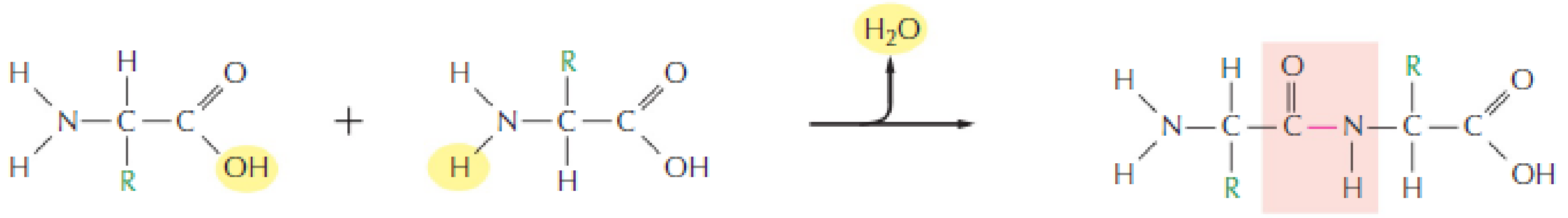
Phonetically suggestive - RFYW: aRginine, Fenylalanine, tYrosine, tWiptophan.

Proteins

PEPTIDE BONDS

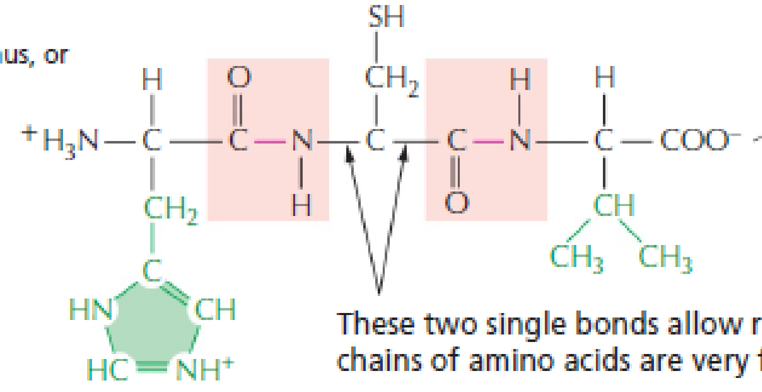
In proteins, amino acids are commonly joined together by an amide linkage, called a peptide bond.

The four atoms in each peptide bond *(red box)* form a rigid planar unit. There is no rotation around the C–N bond.



Proteins are long polymers of amino acids linked by peptide bonds, and they are always written with the N-terminus toward the left. Peptides are shorter, usually fewer than 50 amino acids long. The sequence of this tripeptide is histidine-cysteine-valine.

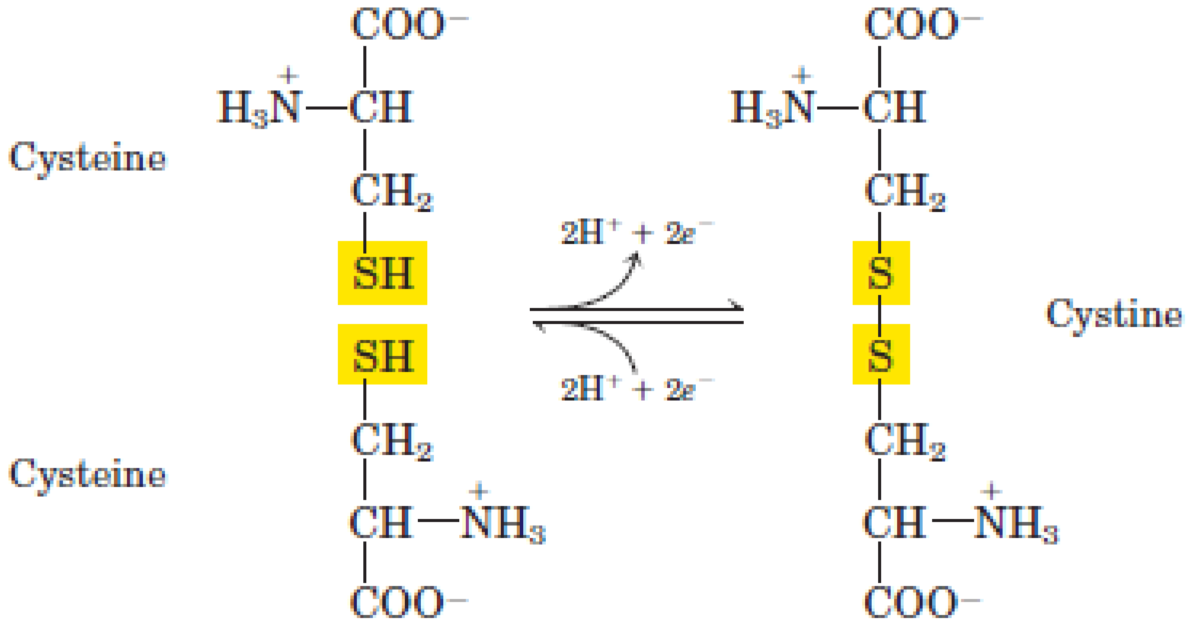
amino terminus, or N-terminus



carboxyl terminus, or C-terminus

These two single bonds allow rotation, so that long chains of amino acids are very flexible.

Reversible formation of a disulfide bond by the oxidation of two molecules of cysteine



Molecular Data on Some Proteins

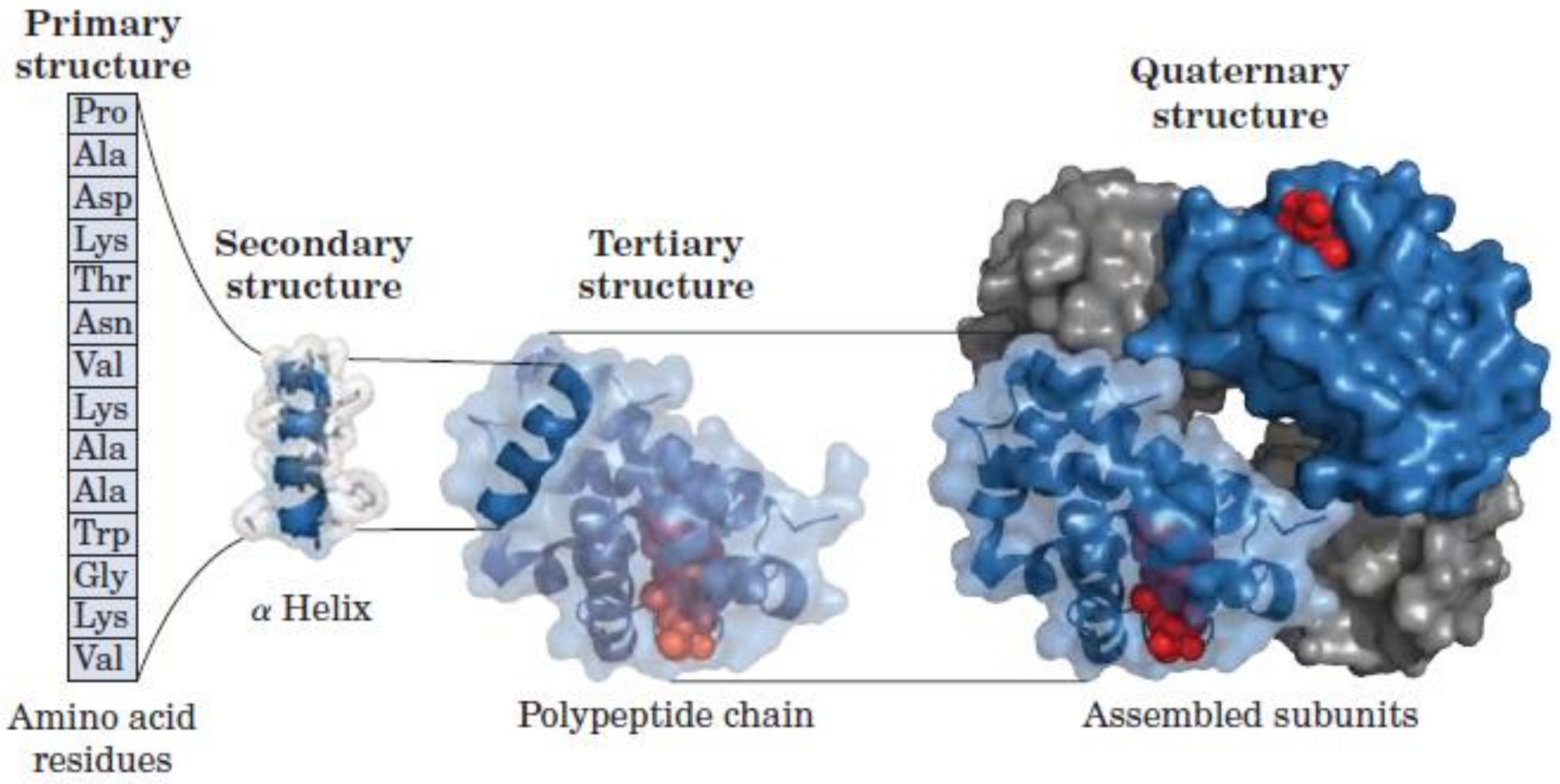
	Molecular weight	Number of residues	Number of polypeptide chains
Cytochrome *c* (human)	12,400	104	1
Ribonuclease A (bovine pancreas)	13,700	124	1
Lysozyme (chicken egg white)	14,300	129	1
Myoglobin (equine heart)	16,700	153	1
Chymotrypsin (bovine pancreas)	25,200	241	3
Chymotrypsinogen (bovine)	25,700	245	1
Hemoglobin (human)	64,500	574	4
Serum albumin (human)	66,000	609	1
Hexokinase (yeast)	107,900	972	2
RNA polymerase (*E. coli*)	450,000	4,158	5
Apolipoprotein B (human)	513,000	4,536	1
Glutamine synthetase (*E. coli*)	619,000	5,628	12
Titin (human)	2,993,000	26,926	1

Some Proteins Contain Chemical Groups Other Than Amino Acids

Class	Prosthetic group	Example
Lipoproteins	Lipids	β_1-Lipoprotein of blood
Glycoproteins	Carbohydrates	Immunoglobulin G
Phosphoproteins	Phosphate groups	Casein of milk
Hemoproteins	Heme (iron porphyrin)	Hemoglobin
Flavoproteins	Flavin nucleotides	Succinate dehydrogenase
Metalloproteins	Iron	Ferritin
	Zinc	Alcohol dehydrogenase
	Calcium	Calmodulin
	Molybdenum	Dinitrogenase
	Copper	Plastocyanin

Conjugated Proteins

The Structure of Proteins

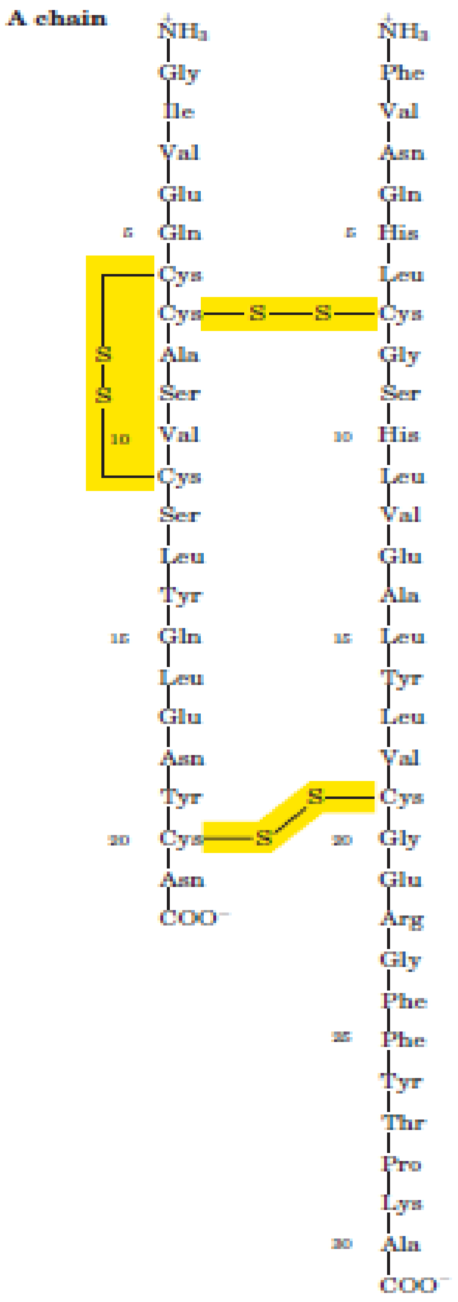


Aligning protein sequences

```
E. coli      TGNRTIAVYDLGGGTFDISIIEIDEVDGEKTFEVLATNGDTHLGGEDFDSRLIHYL
B. subtilis  DEDQTILLYDLGGGTFDVSILELGDG----TFEVRSTAGDNRLGGDDFDQVIIDHL
```

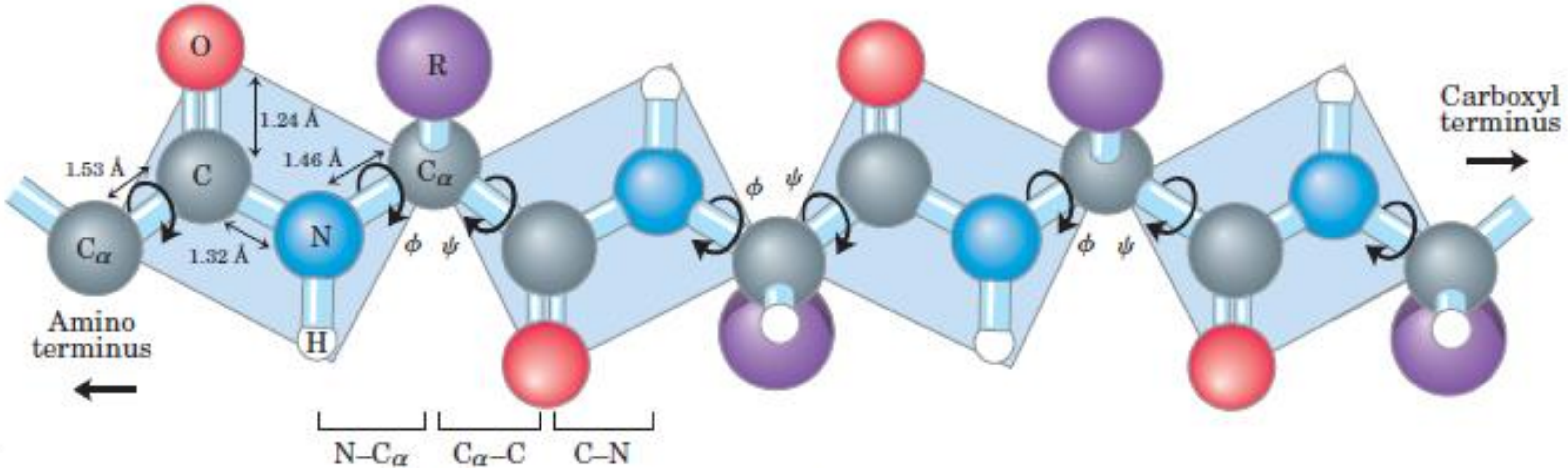
Gap

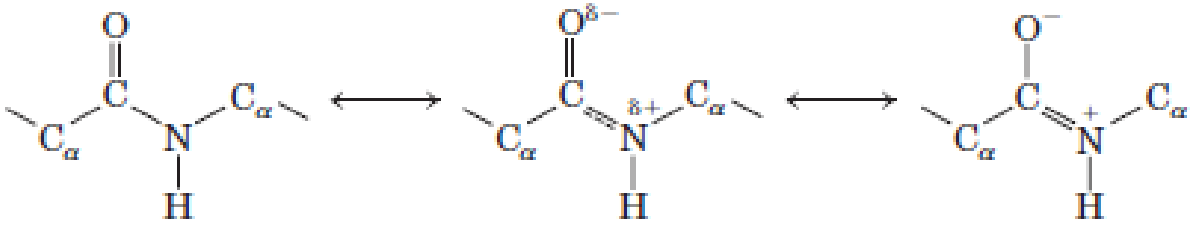
Amino acid sequence of bovine insulin



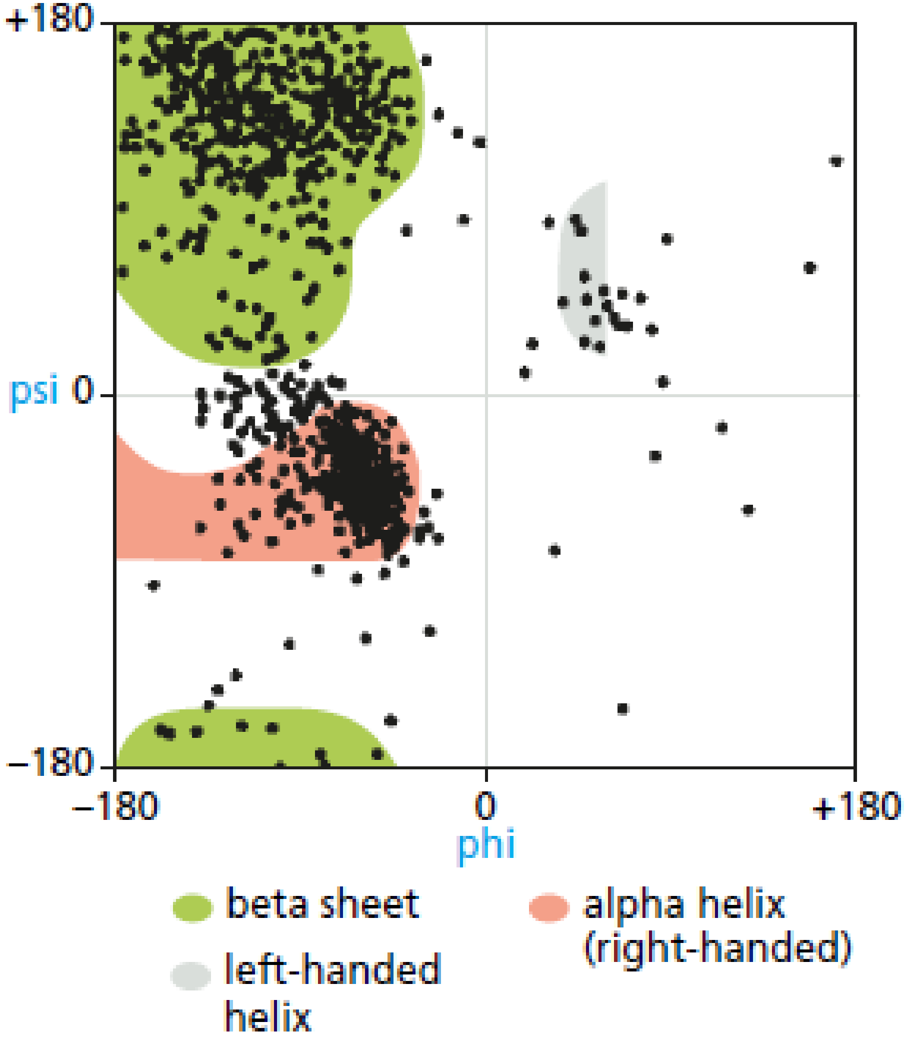
Frederick Sanger worked out the sequence of amino acid residues in the polypeptide chains of the hormone insulin

The Peptide Bond Is Rigid and Planar

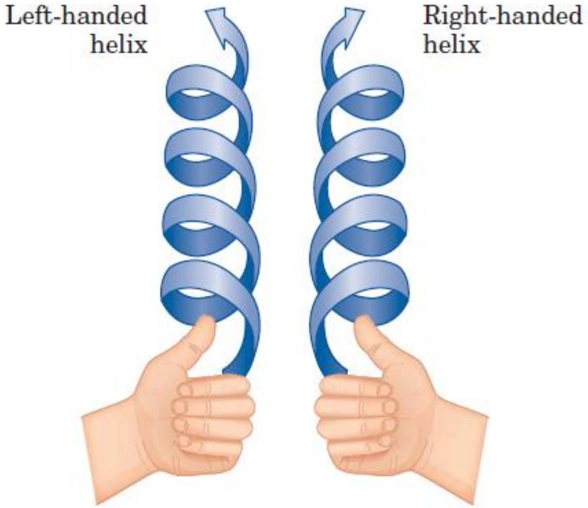




Steric limitations on the bond angles in a polypeptide chain

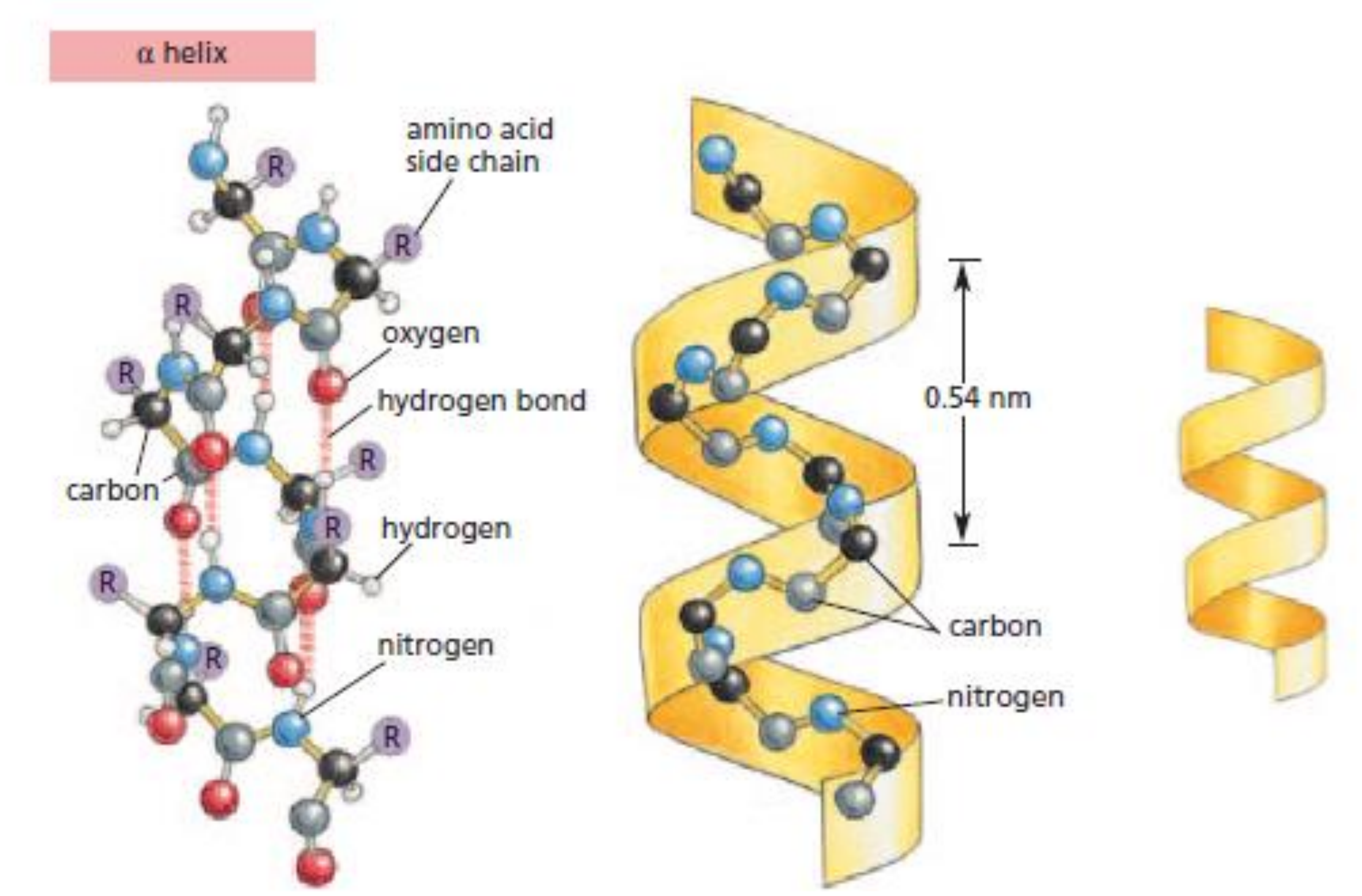


Ramachandran plot



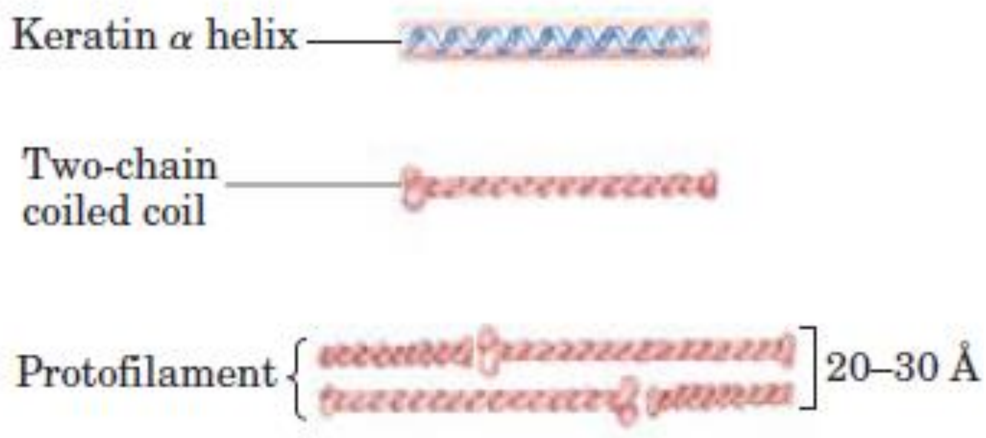
Each dot represents an observed pair of angles in a protein.

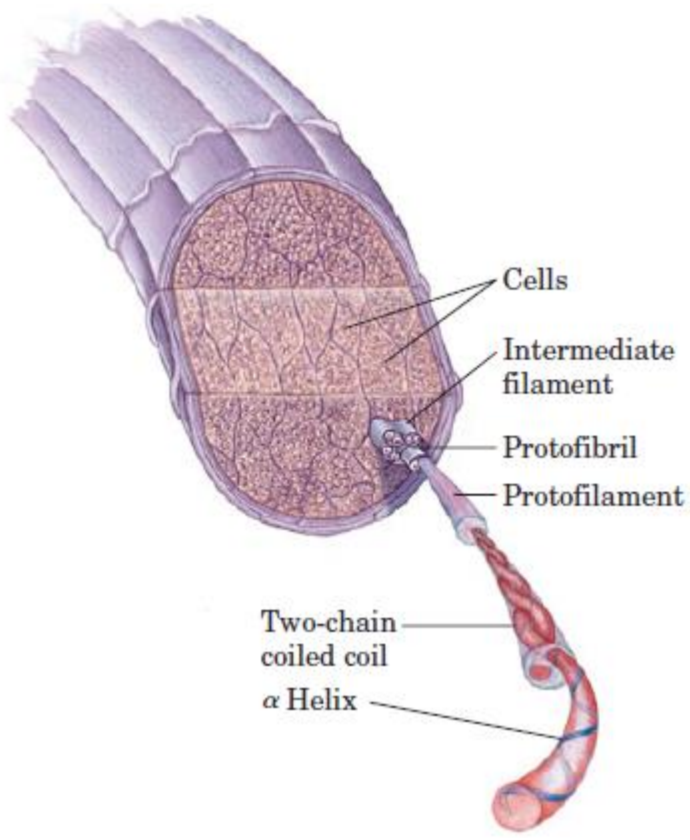
The regular conformation of the polypeptide backbone in the α helix



The N–H of every peptide bond is hydrogen-bonded to the C=O of a neighboring peptide bond located four peptide bonds away in the same chain

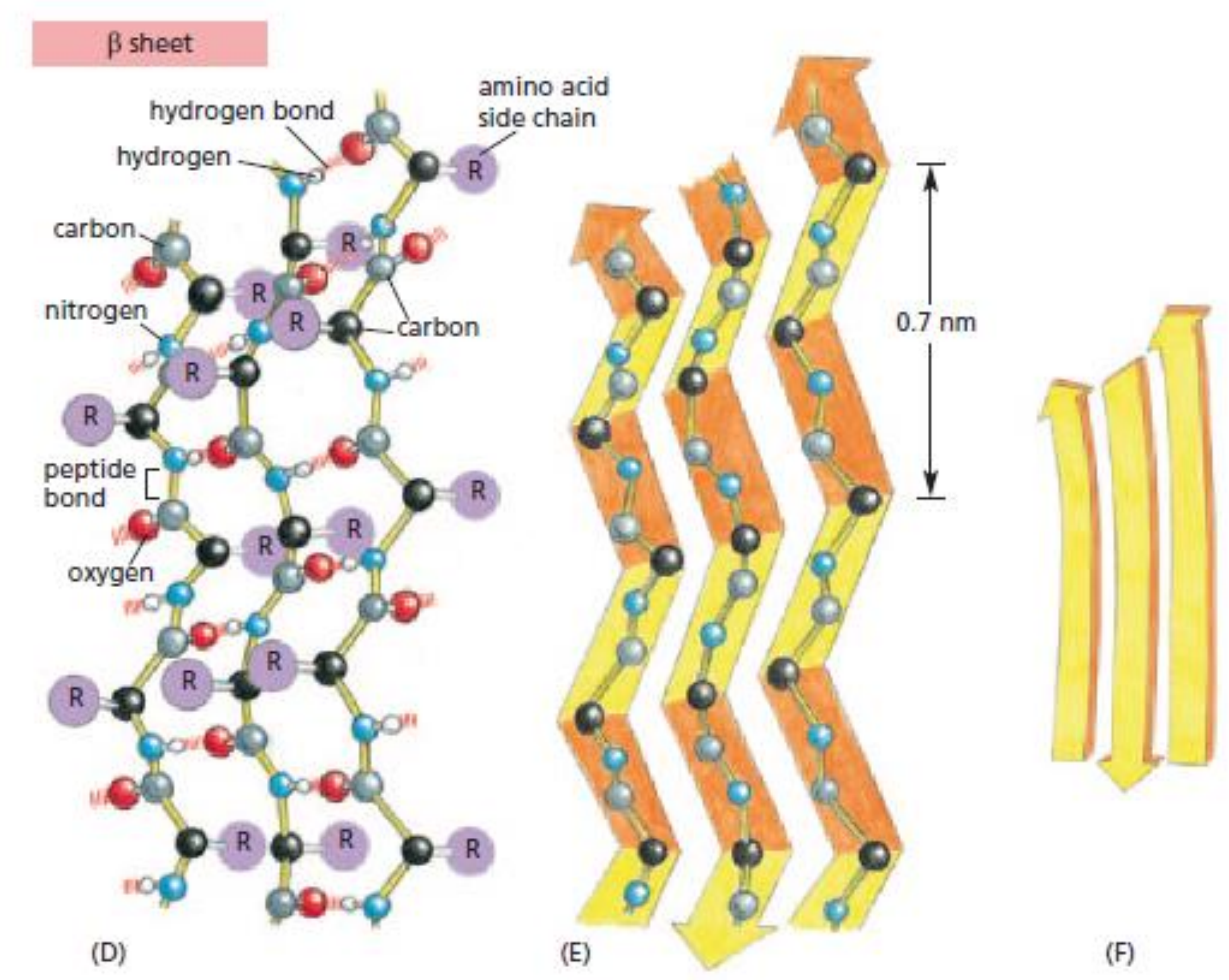
Fibrous Protein



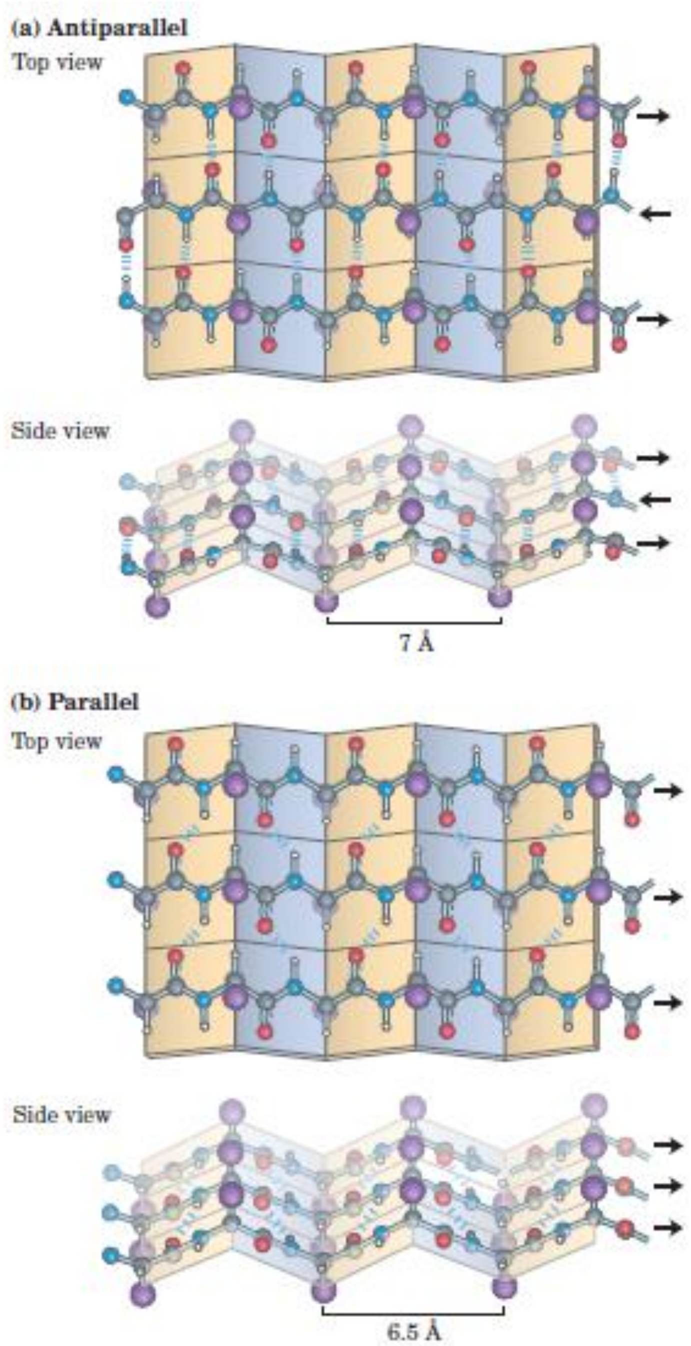


Cross section of a hair

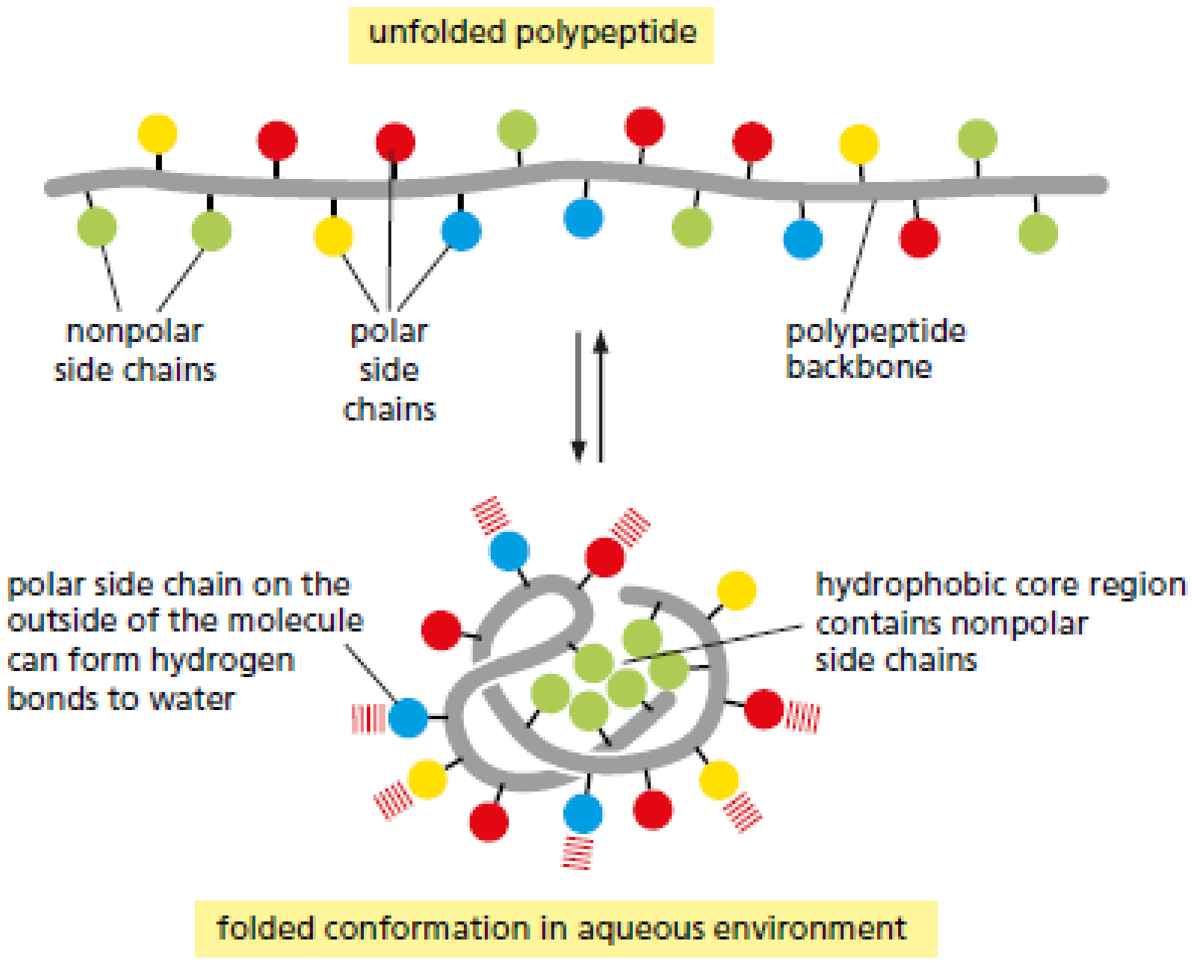
The regular conformation of the polypeptide backbone in the β sheet



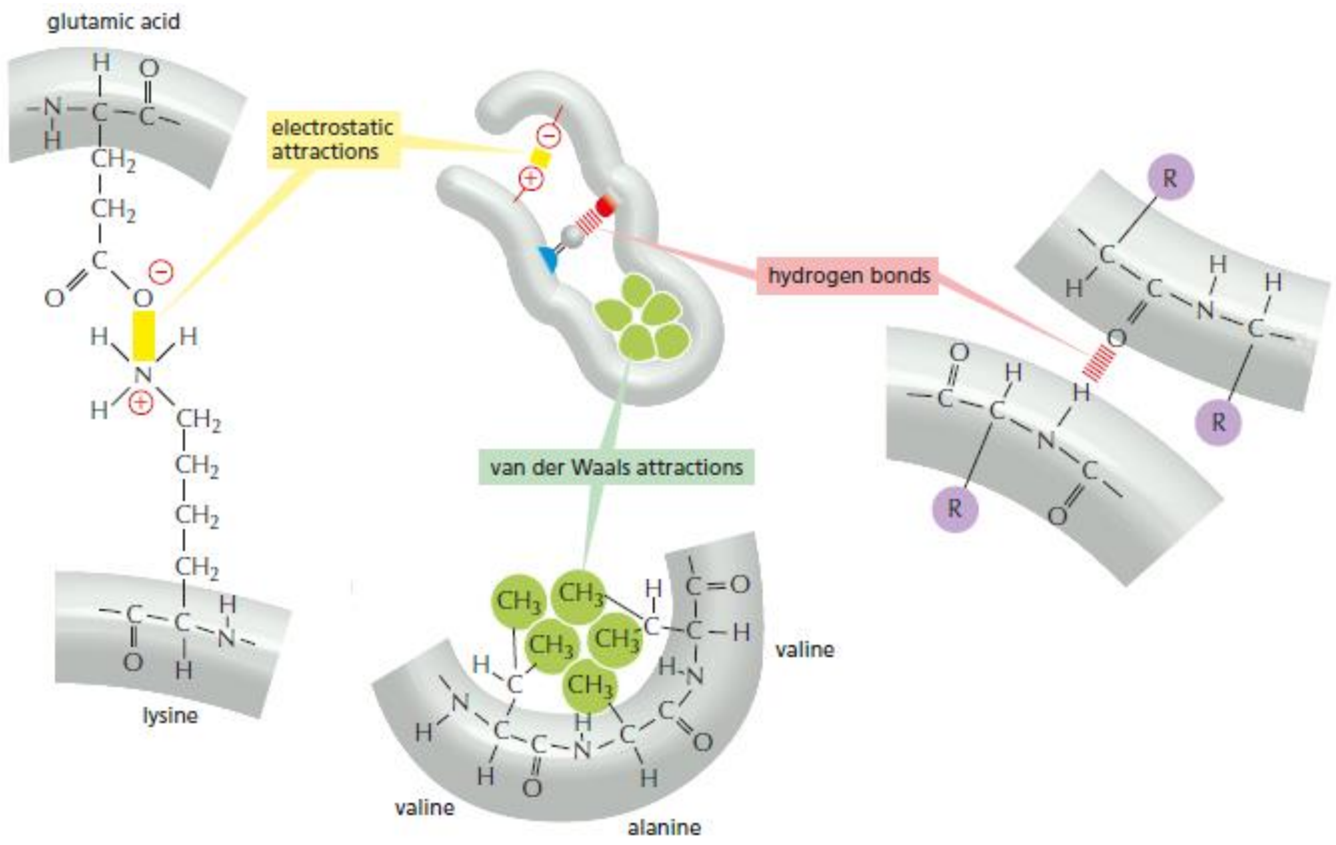
β sheet


(a) Antiparallel
Top view
Side view
7 Å
(b) Parallel
Top view
Side view
6.5 Å

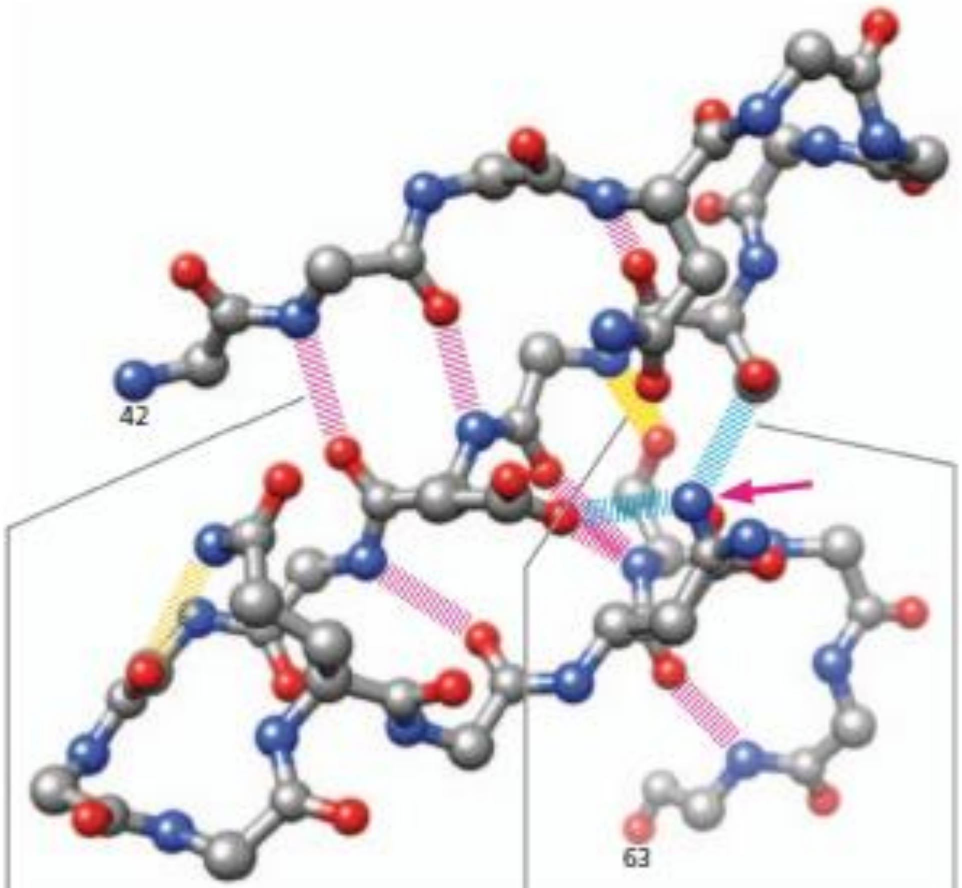
How a protein folds into a compact conformation



Three types of noncovalent bonds help proteins fold

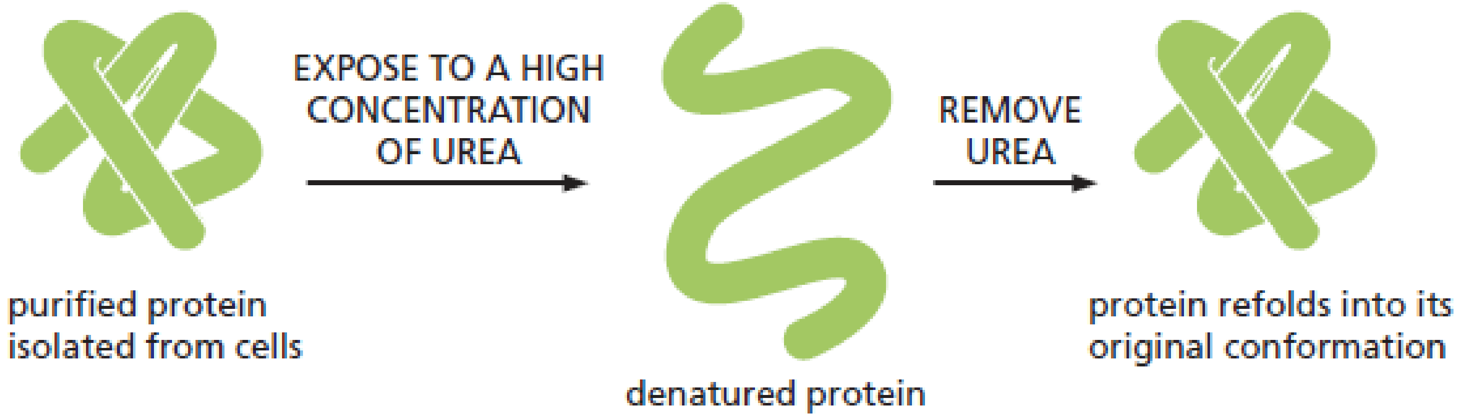


Hydrogen bonds within a protein molecule



backbone to backbone	backbone to side chain	side chain to side chain
hydrogen bond between atoms of two peptide bonds	hydrogen bond between atoms of a peptide bond and an amino acid side chain	hydrogen bond between two amino acid side chains

Denatured proteins can often recover their natural shapes

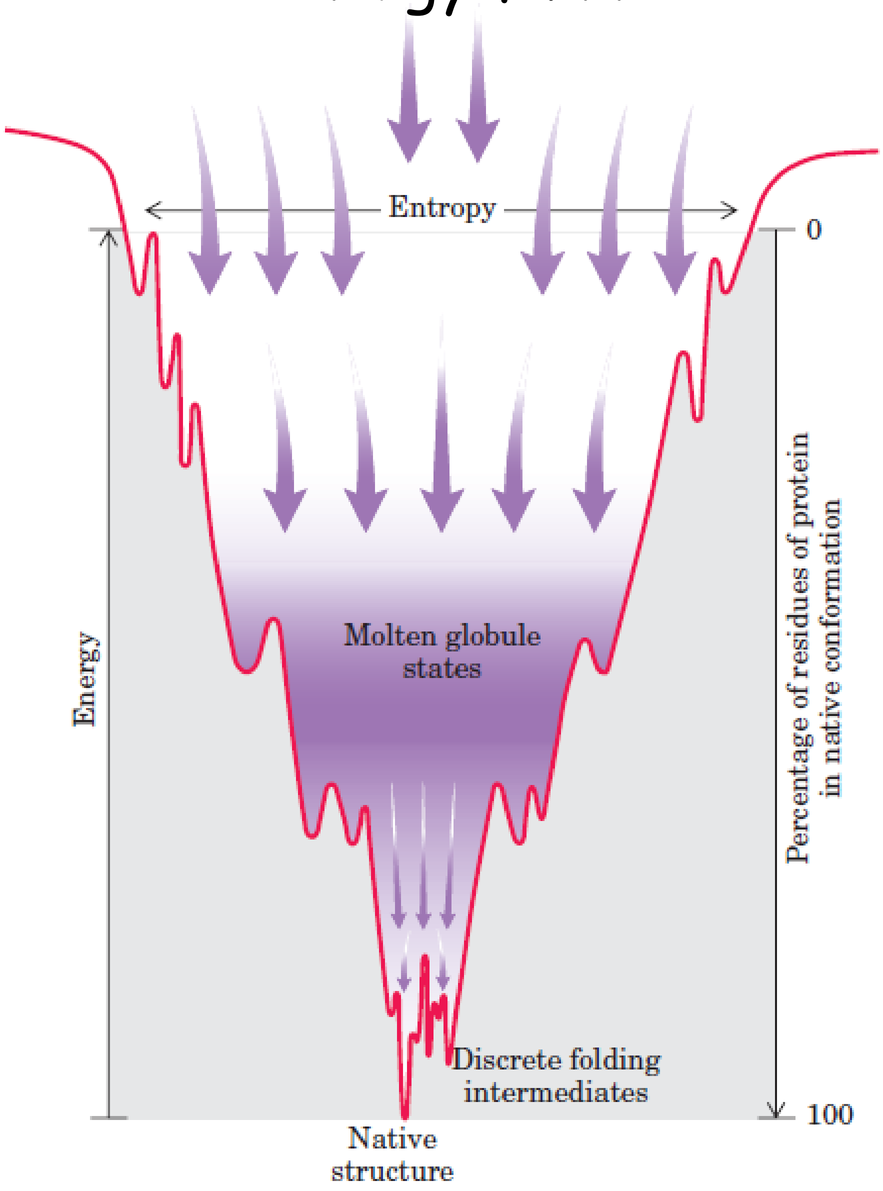


Levinthal's paradox

"Proteins have an incredible number of possible conformational states, yet they are able to fold very quickly"

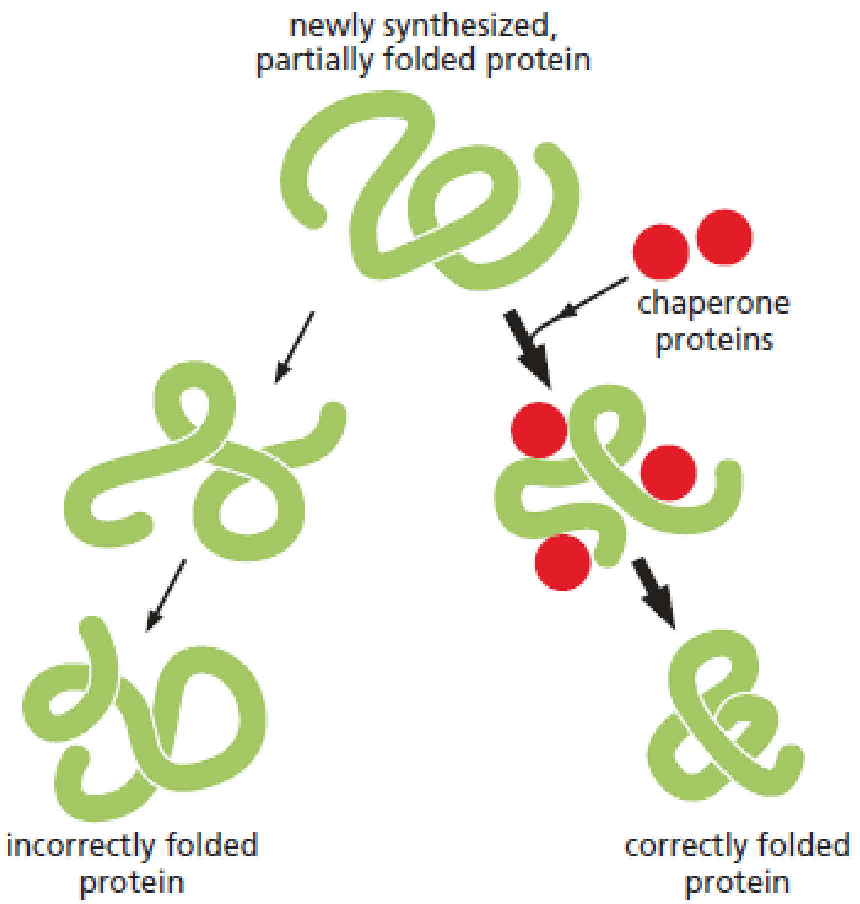
150 AA domain
10 different conformations per side chain
-------> 10^{150} possible conformations.

The thermodynamics of protein folding depicted as a free-energy funnel

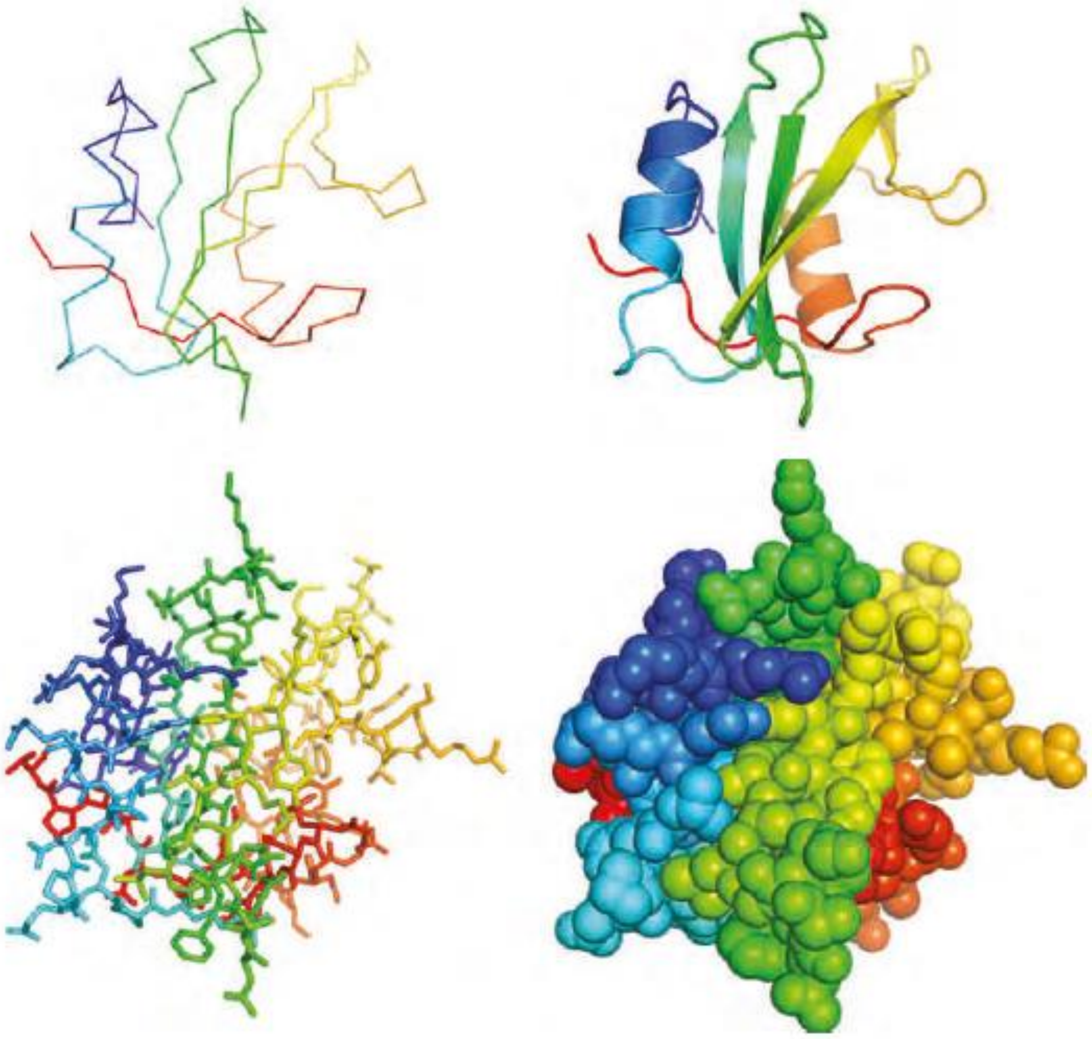


Polypeptides Fold Rapidly by a Stepwise Process

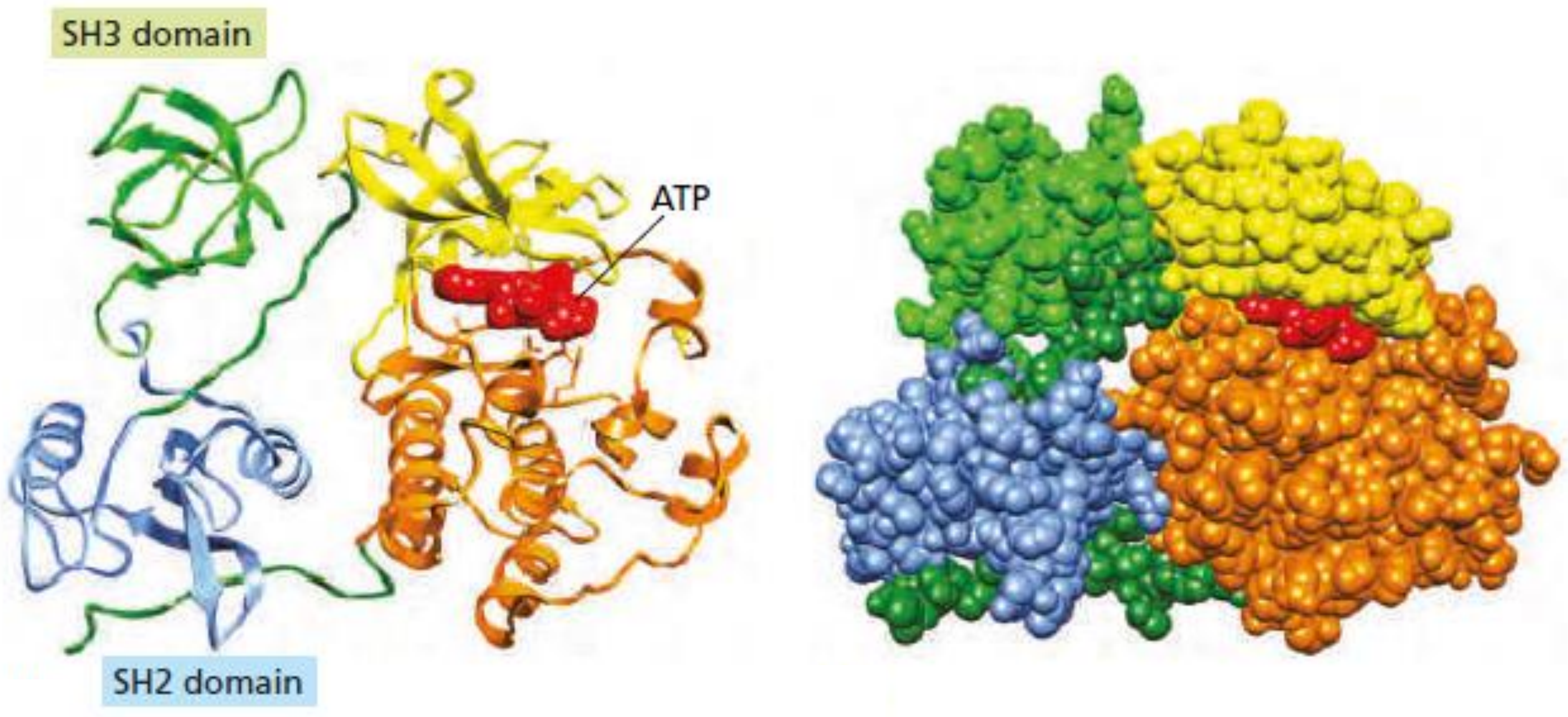
Chaperone proteins can guide the folding of a newly synthesized polypeptide chain



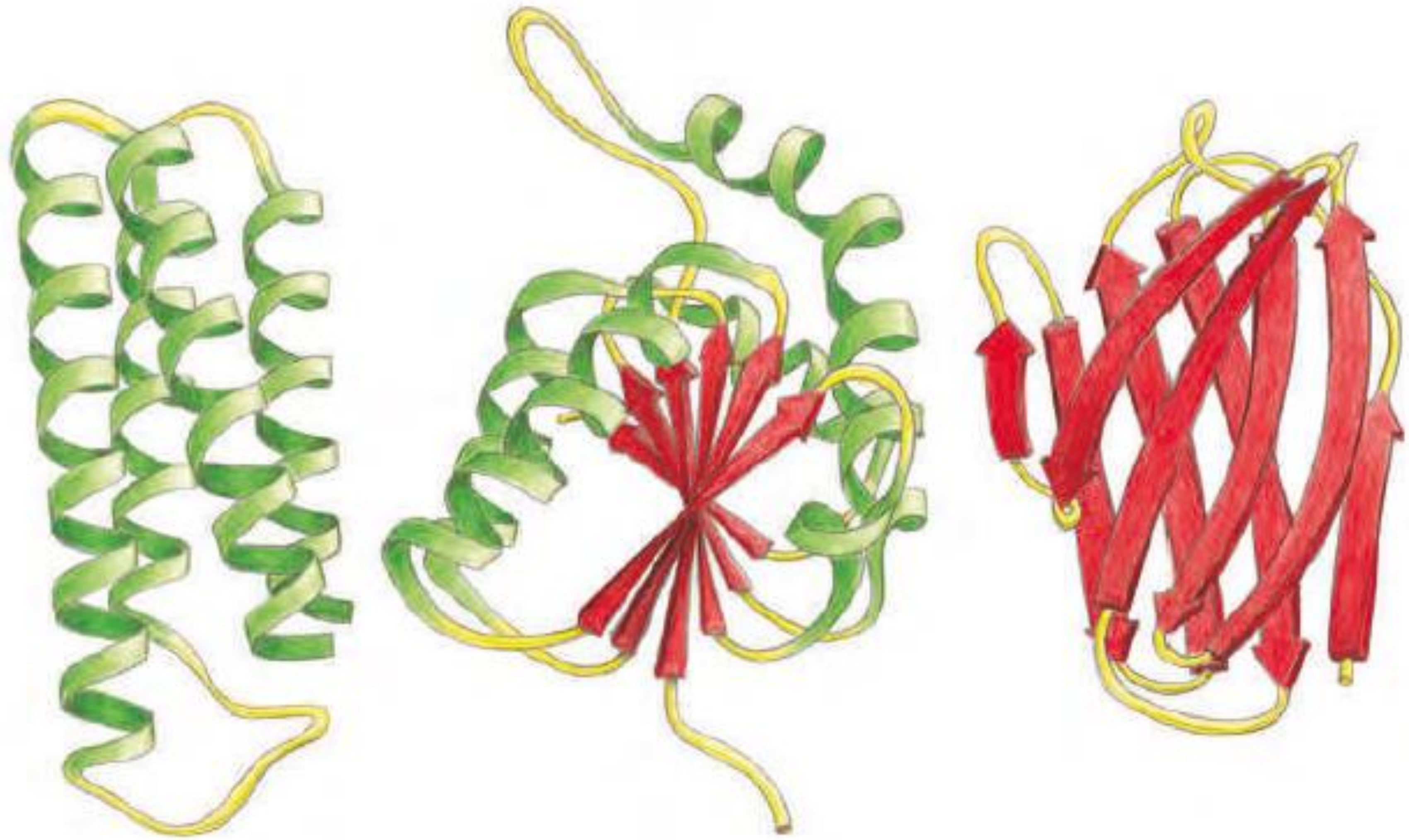
Four representations describing the structure of a small protein domain



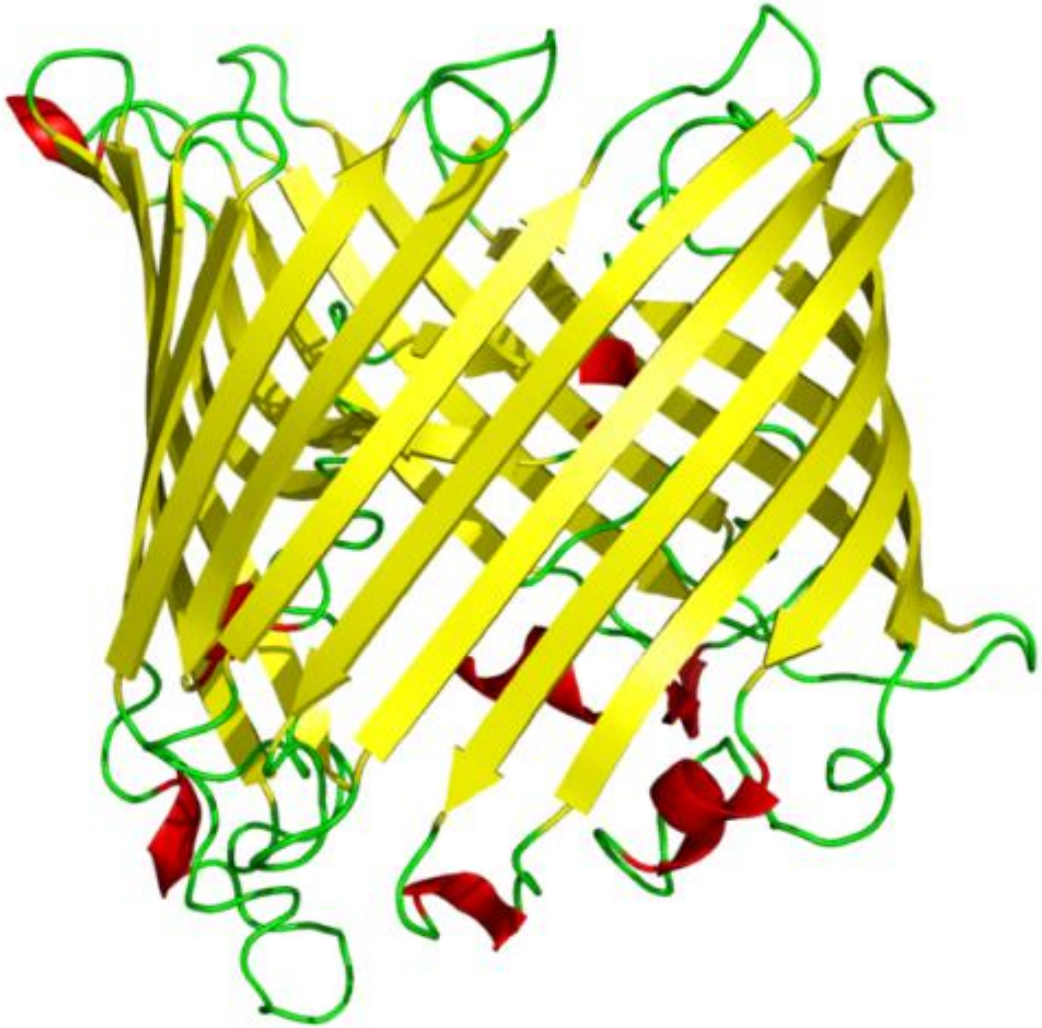
Protein Domains Are Modular Units from Which Larger Proteins Are Built



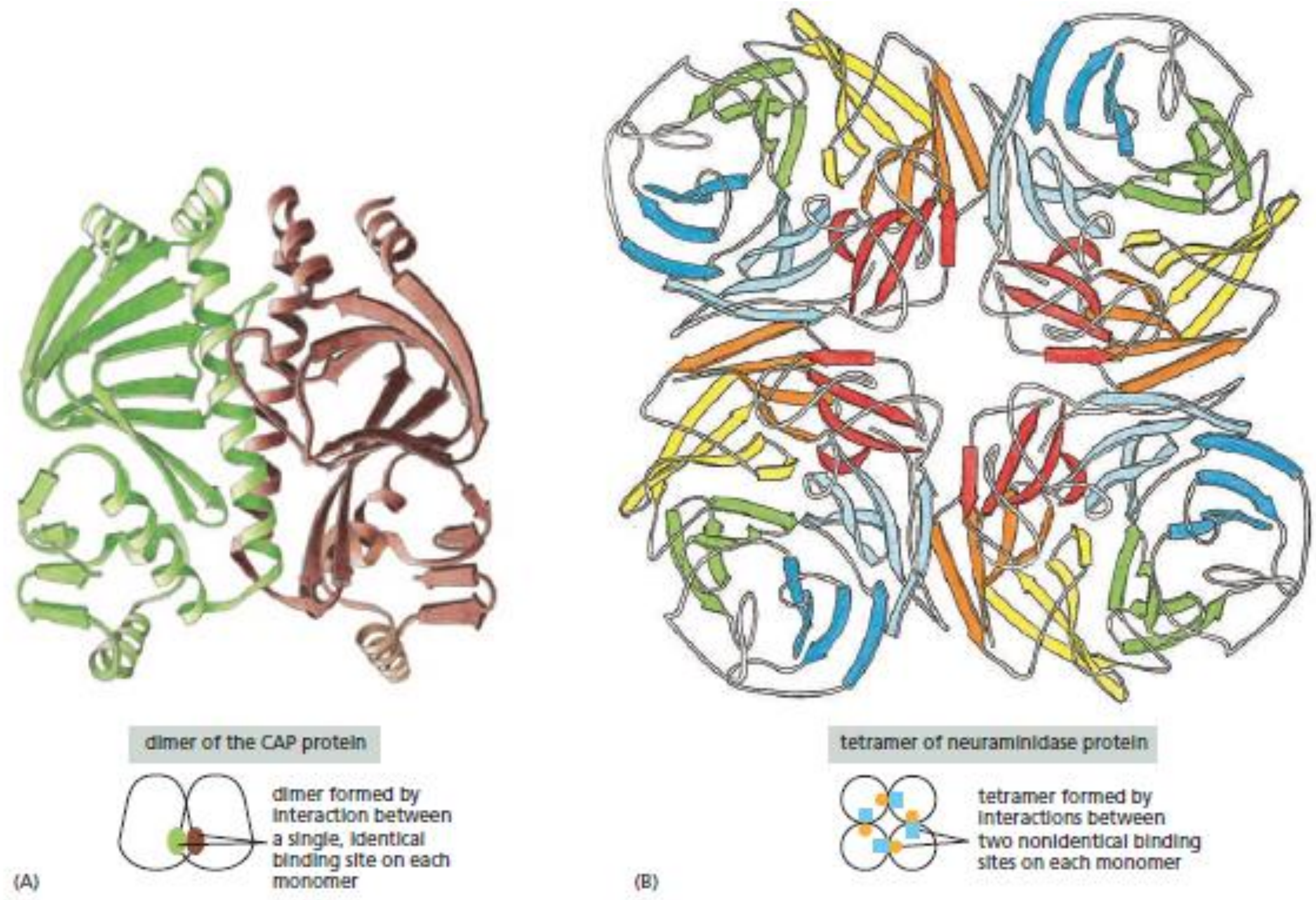
Three differently organized protein domains



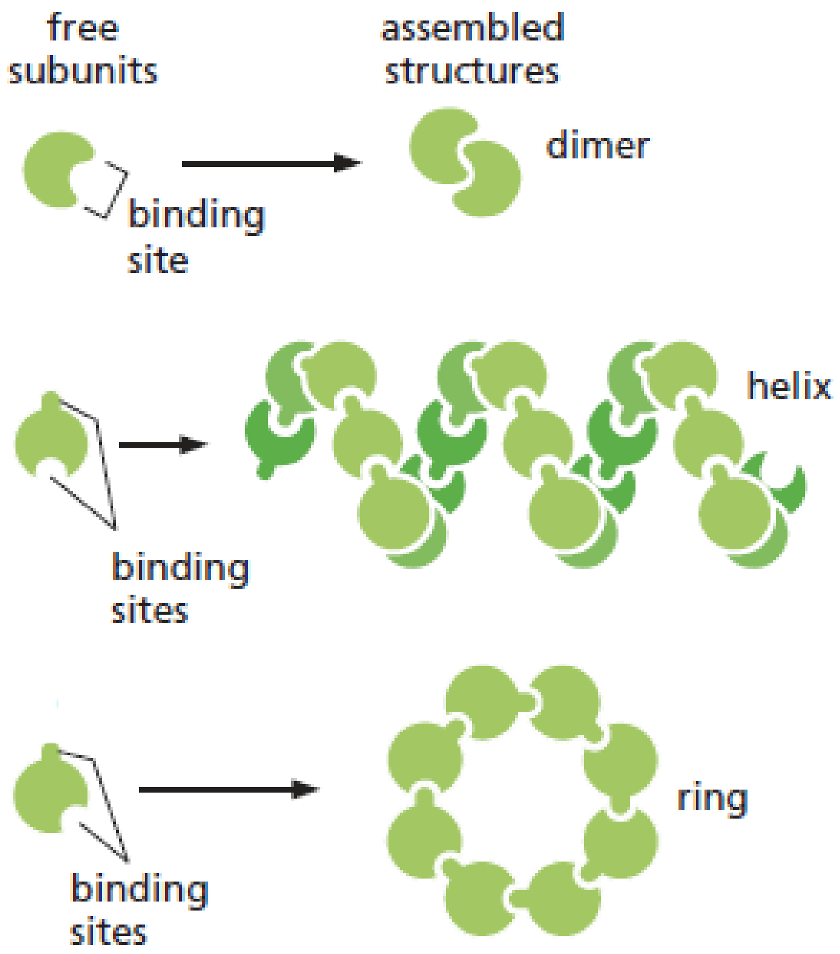
β Barrel



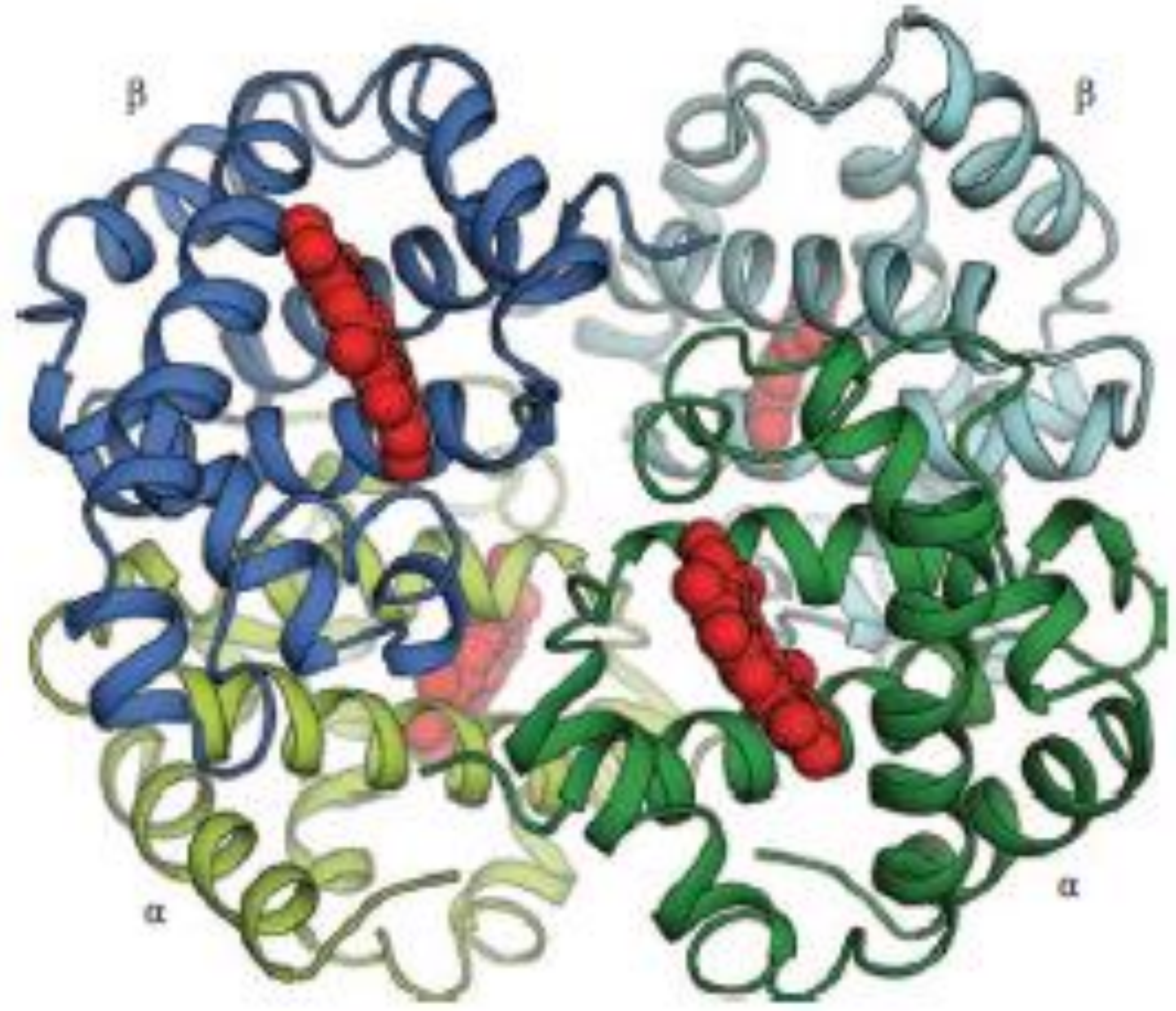
Large Protein Molecules Often Contain More Than One Polypeptide Chain



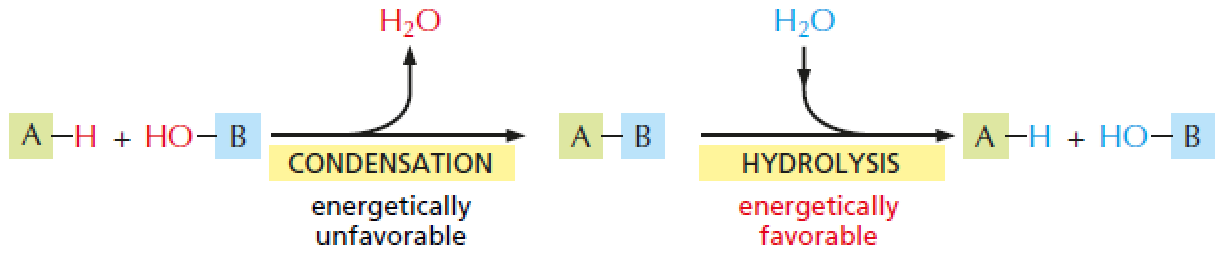
Identical protein subunits can assemble into complex structures

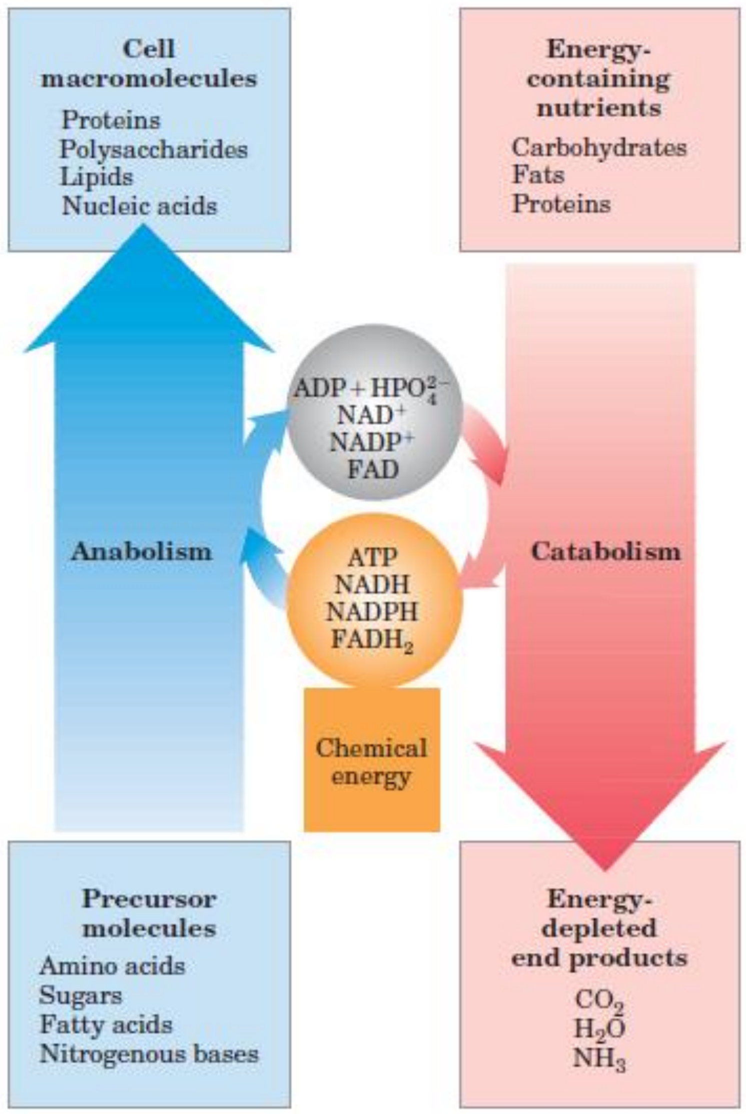


Some proteins are formed as a symmetrical assembly of two different subunits



Catalysis and use of energy by cells

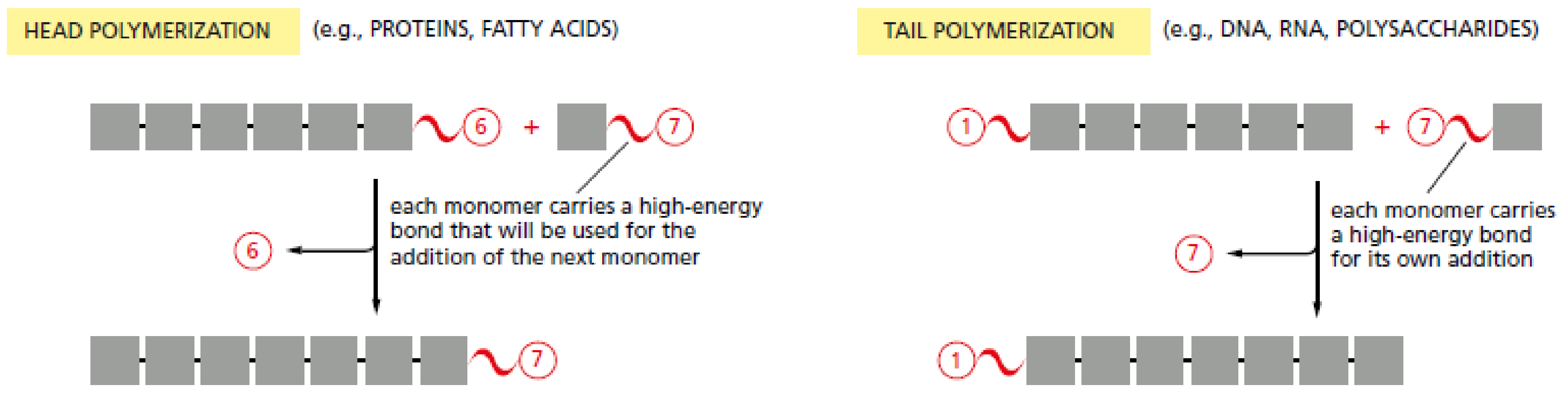




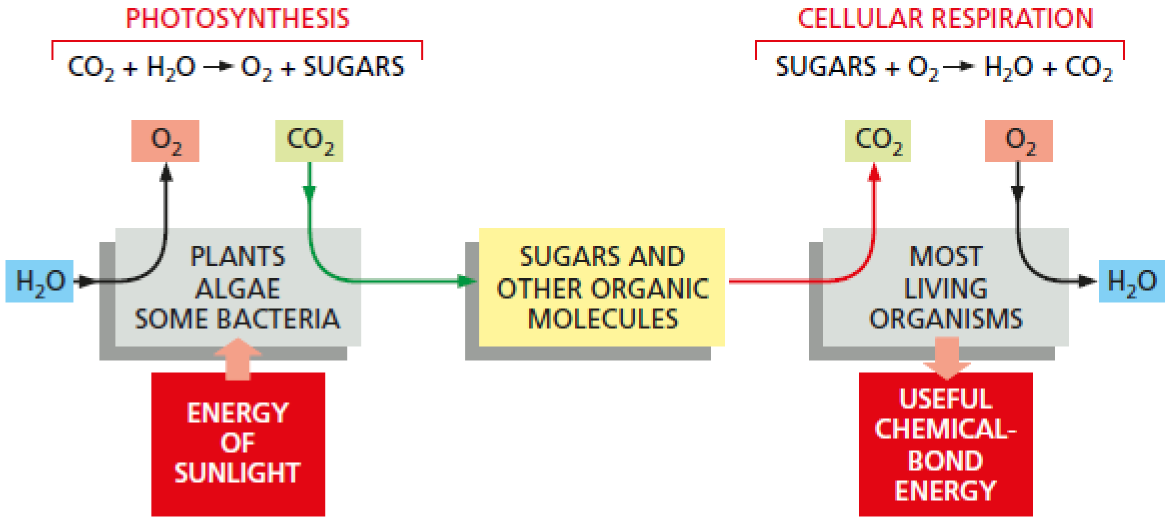
Some Activated Carrier Molecules Widely Used in Metabolism

Activated carrier	Group carried in high-energy linkage
ATP	Phosphate
NADH, NADPH, $FADH_2$	Electrons and hydrogens
Acetyl CoA	Acetyl group
Carboxylated biotin	Carboxyl group
S-Adenosylmethionine	Methyl group
Uridine diphosphate glucose	Glucose

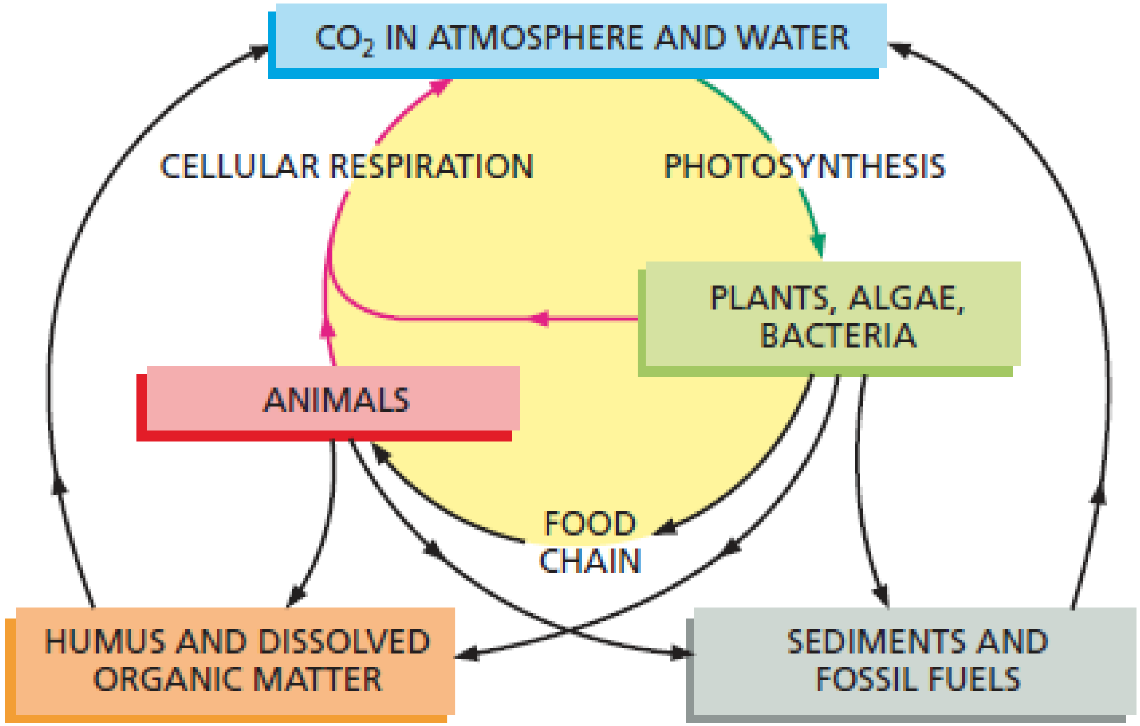
Anabolism - The orientation of the active intermediates



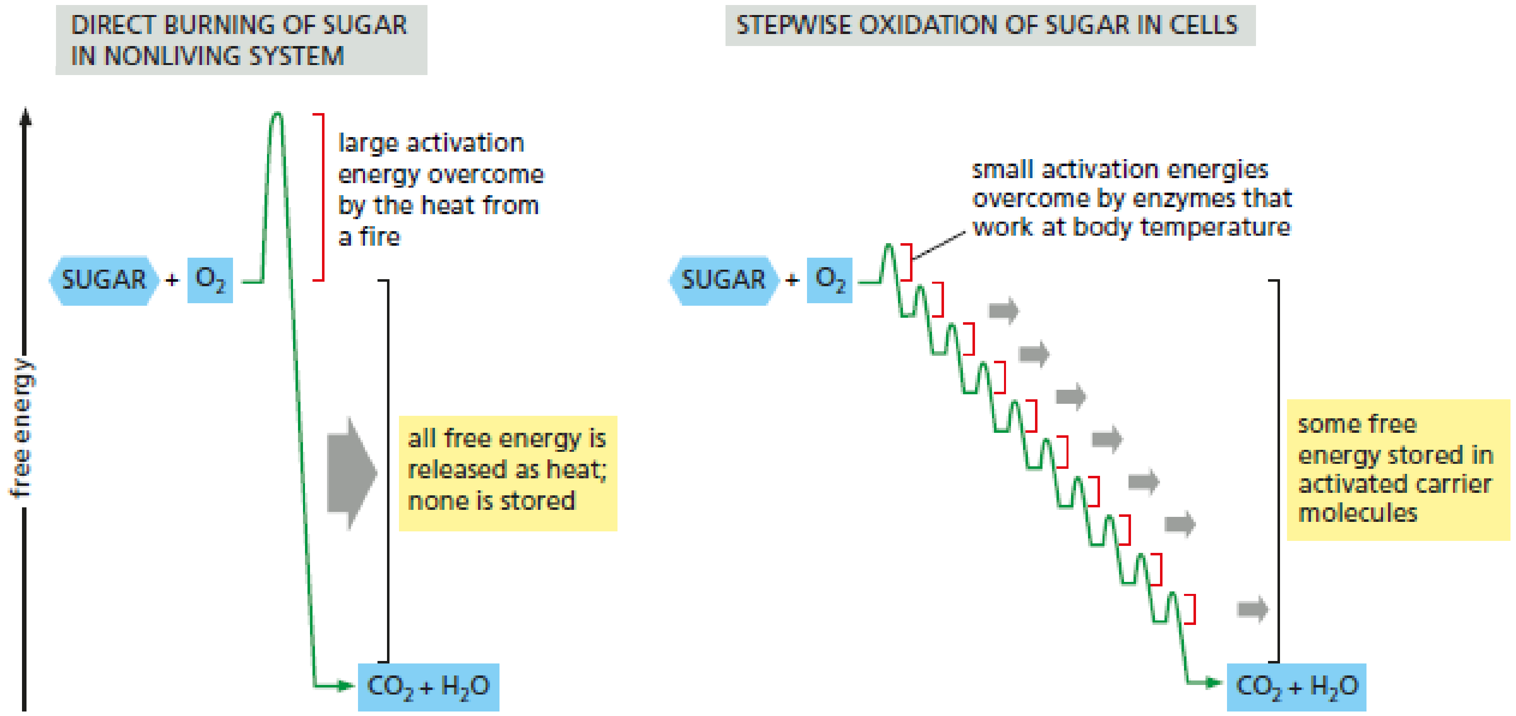
Photosynthesis and respiration as complementary processes in the living world.



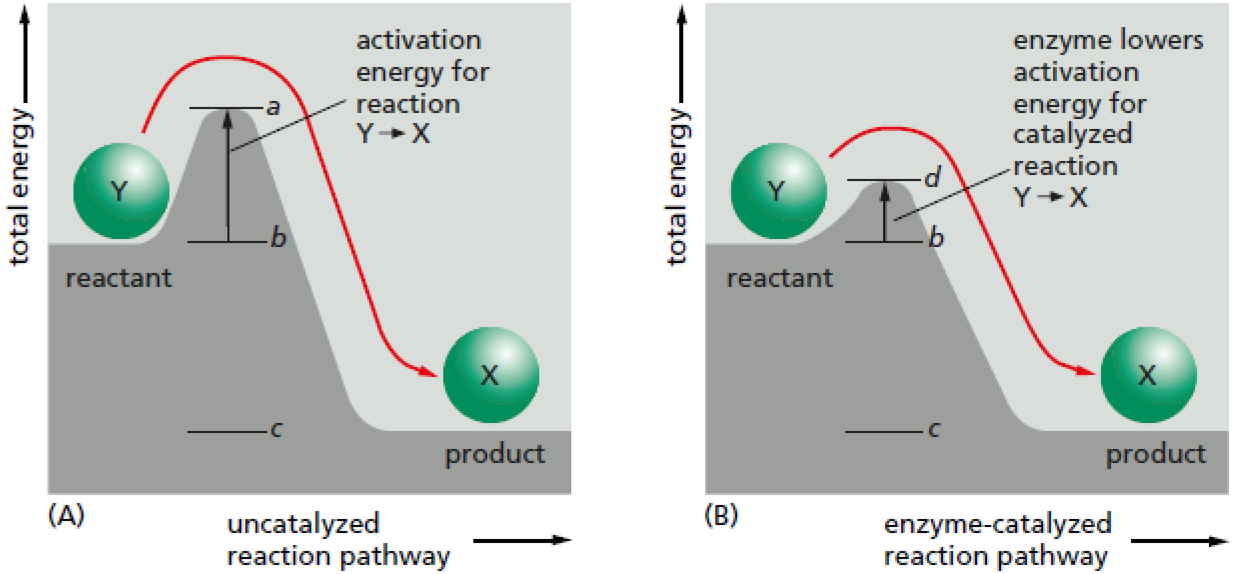
Carbon atoms cycle continuously through the biosphere



Catabolism - HOW CELLS OBTAIN ENERGY FROM FOOD ??



Principle of activation energy

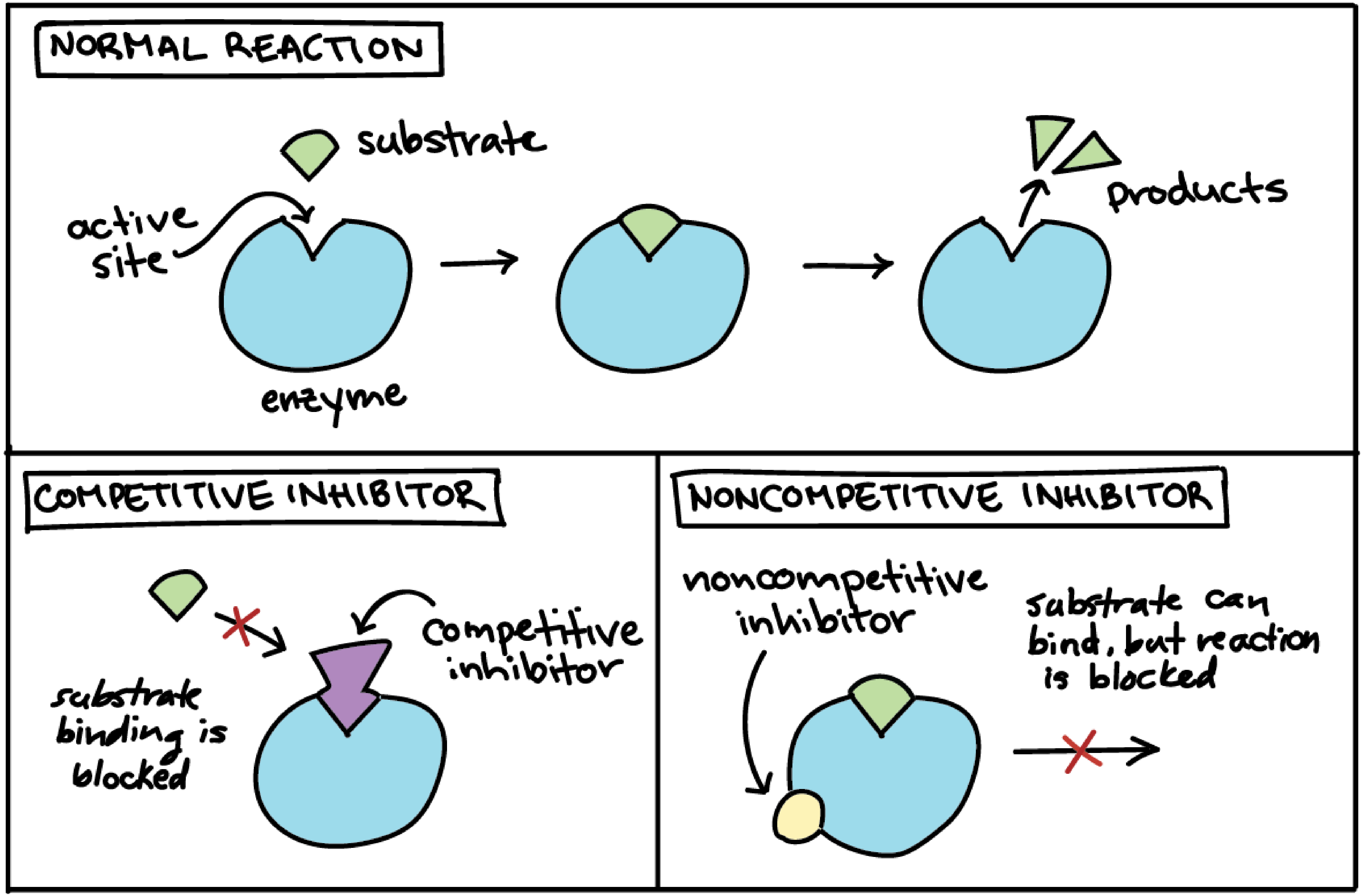


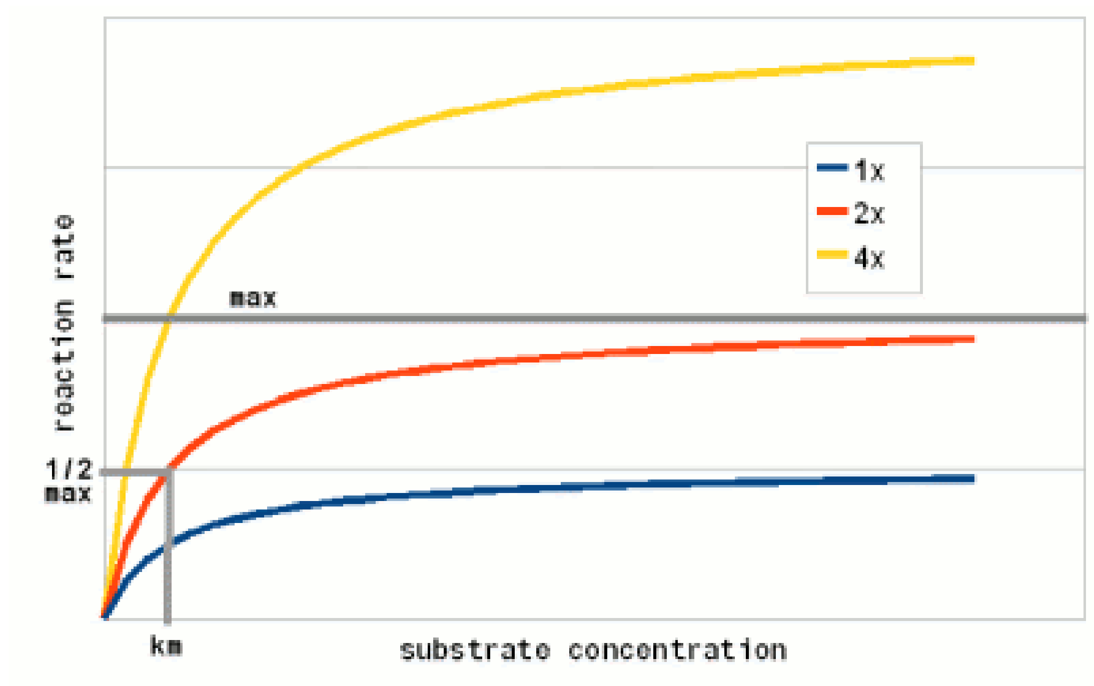
Predicting Reactions

driving force

$\Delta G°$ for some reactions

glucose-1-P $\longrightarrow$ glucose-6-P	–1.7 kcal/mole
sucrose $\longrightarrow$ glucose + fructose	–5.5 kcal/mole
ATP $\longrightarrow$ ADP + P_i	–7.3 kcal/mole
glucose + $6O_2$ $\longrightarrow$ $6CO_2$ + $6H_2O$	–686 kcal/mole


NORMAL REACTION
substrate
active site
enzyme
products
COMPETITIVE INHIBITOR
competitive inhibitor
substrate binding is blocked
NONCOMPETITIVE INHIBITOR
noncompetitive inhibitor
substrate can bind, but reaction is blocked



reaction rate
substrate concentration
max
1/2 max
km
1x
2x
4x

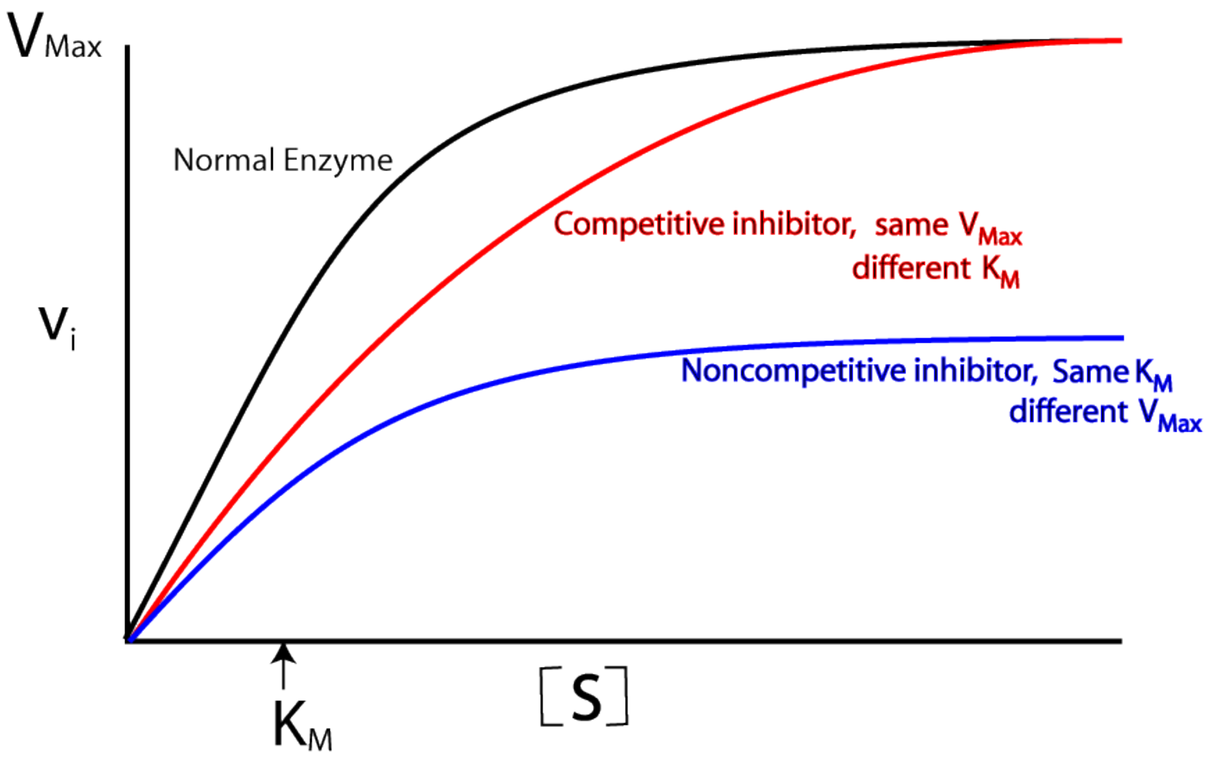

V_{Max}
v_i
Normal Enzyme
Competitive inhibitor, same V_{Max}
different K_M
Noncompetitive inhibitor, Same K_M
different V_{Max}
K_M
[S]

TABLE 6–3 International Classification of Enzymes

Class no.	Class name	Type of reaction catalyzed
1	Oxidoreductases	Transfer of electrons (hydride ions or H atoms)
2	Transferases	Group transfer reactions
3	Hydrolases	Hydrolysis reactions (transfer of functional groups to water)
4	Lyases	Addition of groups to double bonds, or formation of double bonds by removal of groups
5	Isomerases	Transfer of groups within molecules to yield isomeric forms
6	Ligases	Formation of C—C, C—S, C—O, and C—N bonds by condensation reactions coupled to cleavage of ATP or similar cofactor

Enzyme Commission number (E.C. number)

Enzymes

- All enzymes are assigned a number (EC number) which defines exactly which reaction is catalyzed by the enzyme.
- Example trypsin is **EC 3.4.21.4**

EC 3.4.21.4

3 describes the enzyme class (hydrolase)- hydrolysis reaction

4 is for the subclass (acts on peptide bonds, so it is a peptide hydrolase)

21 denotes its sub-subclass as a serine peptidase

4 because it is the 4th entry in this subclass

- Enzyme Nomenclature Database - http://expasy.org/enzyme