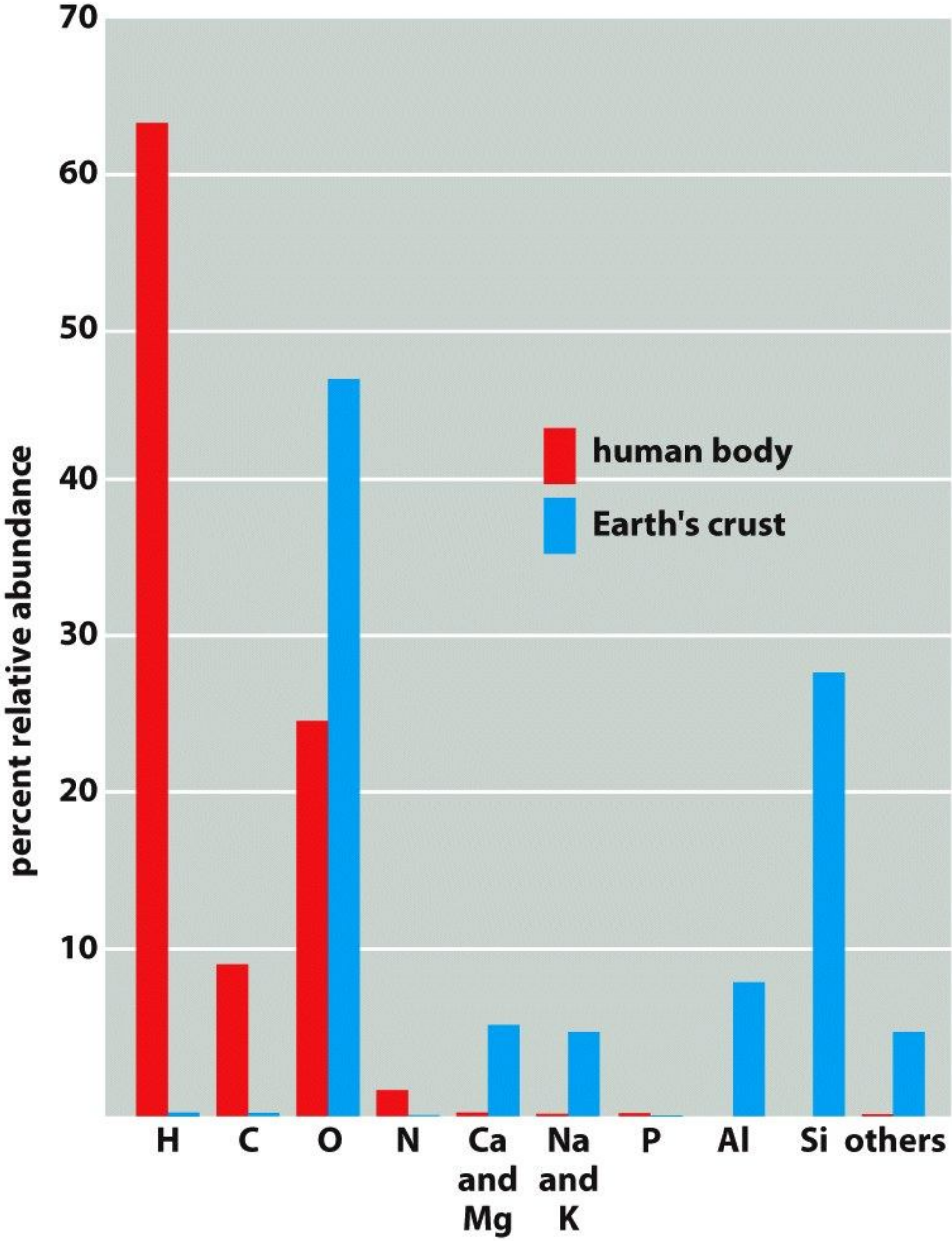
Chemical components of the cell

Biomolecules

Living system chemistry

1. Carbon based
2. Water environment & temperature special range
3. Complicated processes
4. Polymeric molecules
5. Well programmed & controled


70
60
50
40
30
20
10
percent relative abundance
human body
Earth's crust
H
C
O
N
Ca and Mg
Na and K
P
Al
Si
others

Carbon

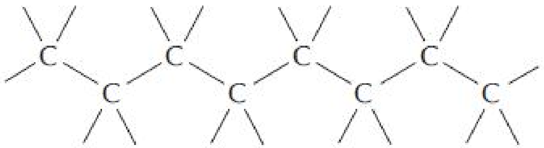
- In all biomolecules
- 4 binding sites
- Chain & cycle formation
- Large molecule production
- No limitation in size

Organic molecules

Carbon skeleton

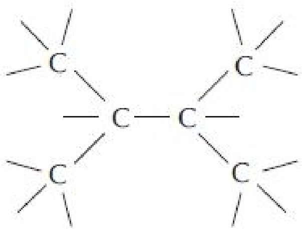
CARBON SKELETONS

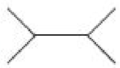
Carbon has a unique role in the cell because of its ability to form strong covalent bonds with other carbon atoms. Thus carbon atoms can join to form chains



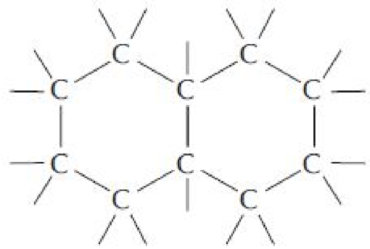
also written as 

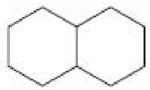
or branched trees



also written as 

or rings.



also written as 

COVALENT BONDS

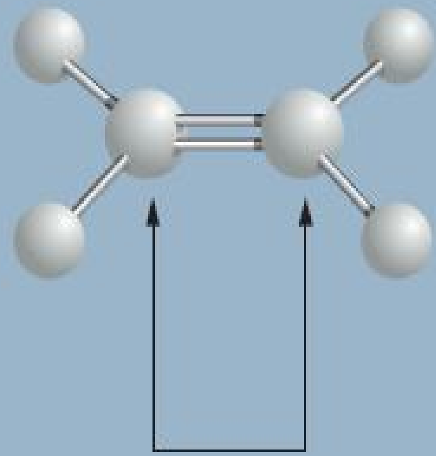
A covalent bond forms when two atoms come very close together and share one or more of their electrons.

Each atom forms a fixed number of covalent bonds in a defined spatial arrangement.

SINGLE BONDS: two electrons shared per bond

DOUBLE BONDS: four electrons shared per bond

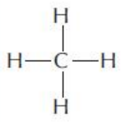
The precise spatial arrangement of covalent bonds influence the three-dimentional structure—and chemistry—of molecules. In this review panel, we see how covalent bonds are used in a variety of biological molecules.



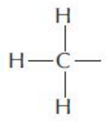
Atoms joined by two or more covalent bonds cannot rotate freely around the bond axis. This restriction has a major influence on the three-dimensional shape of many macromolecules.

C–H COMPOUNDS

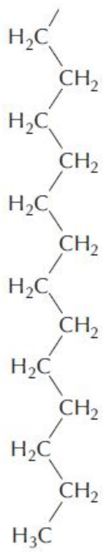
Carbon and hydrogen together make stable compounds (or groups) called hydrocarbons. These are nonpolar, do not form hydrogen bonds, and are generally insoluble in water.



methane



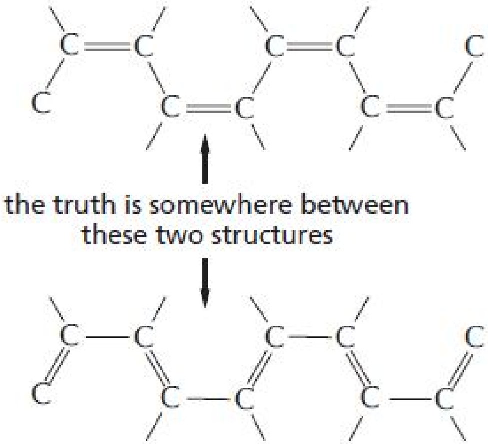
methyl group



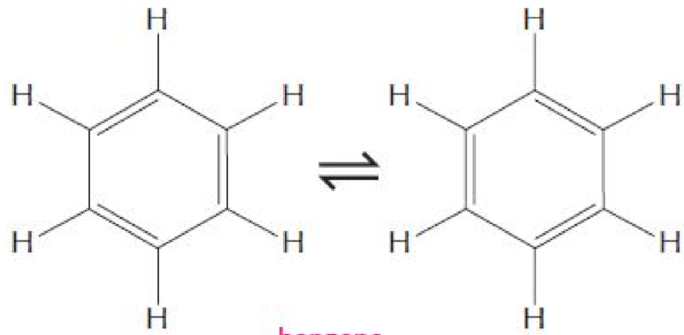
part of the hydrocarbon "tail" of a fatty acid molecule

ALTERNATING DOUBLE BONDS

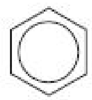
A carbon chain can include double bonds. If these are on alternate carbon atoms, the bonding electrons move within the molecule, stabilizing the structure by a phenomenon called resonance.



Alternating double bonds in a ring can generate a very stable structure.



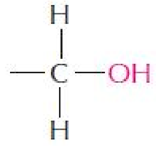
benzene

often written as 

C–O COMPOUNDS

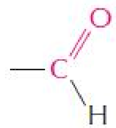
Many biological compounds contain a carbon bonded to an oxygen. For example,

alcohol

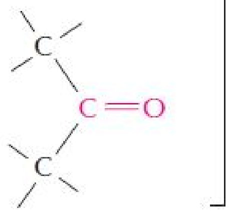


The –OH is called a hydroxyl group.

aldehyde

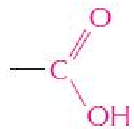


ketone



The C=O is called a carbonyl group.

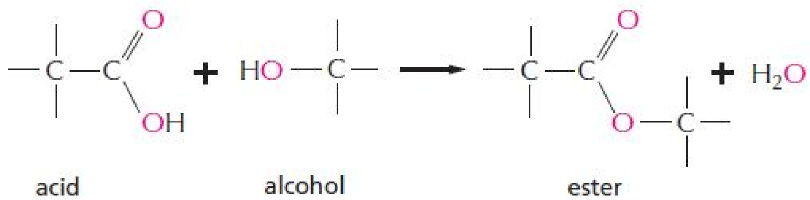
carboxylic acid



The –COOH is called a carboxyl group. In water this loses an H^+ ion to become $-COO^-$.

esters

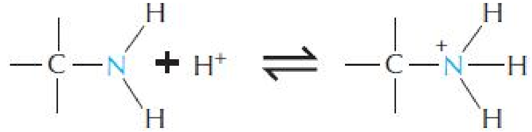
Esters are formed by combining an acid and an alcohol.



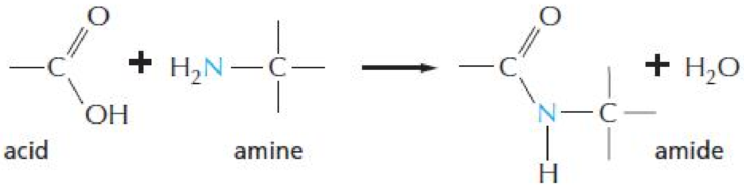
C–N COMPOUNDS

Amines and amides are two important examples of compounds containing a carbon linked to a nitrogen.

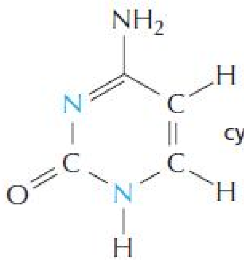
Amines in water combine with an H^+ ion to become positively charged.



Amides are formed by combining an acid and an amine. Unlike amines, amides are uncharged in water. An example is the peptide bond that joins amino acids in a protein.



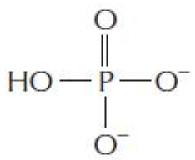
Nitrogen also occurs in several ring compounds, including important constituents of nucleic acids: purines and pyrimidines.



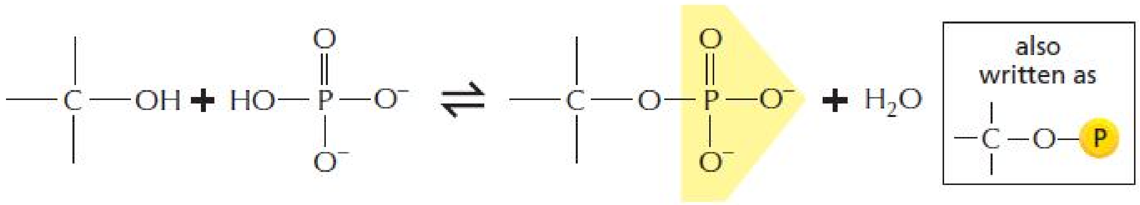
cytosine (a pyrimidine)

PHOSPHATES

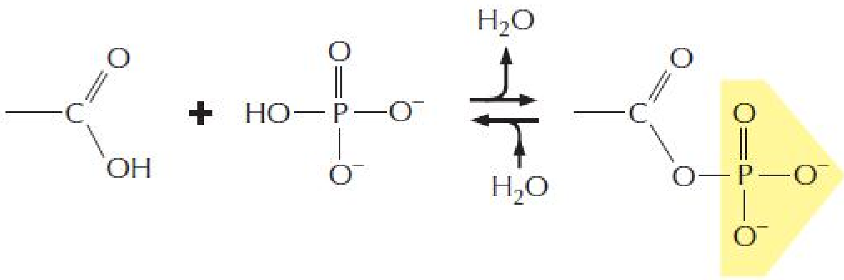
Inorganic phosphate is a stable ion formed from phosphoric acid, H_3PO_4. It is often written as P_i.



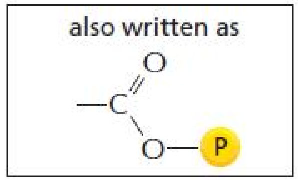
Phosphate esters can form between a phosphate and a free hydroxyl group. Phosphoryl groups are often attached to proteins in this way.

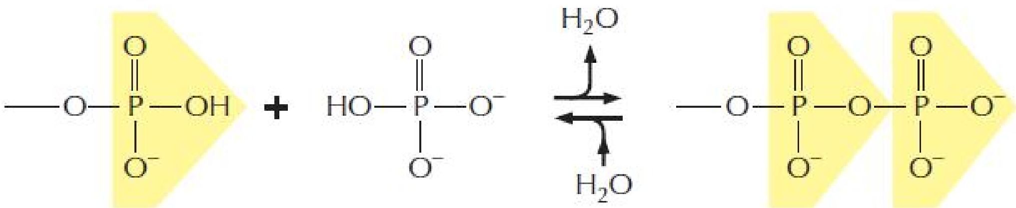


The combination of a phosphate and a carboxyl group, or two or more phosphate groups, gives an acid anhydride.

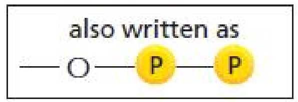


high-energy acyl phosphate bond (carboxylic–phosphoric acid anhydride) found in some metabolites





phosphoanhydride—a high-energy bond found in molecules such as ATP

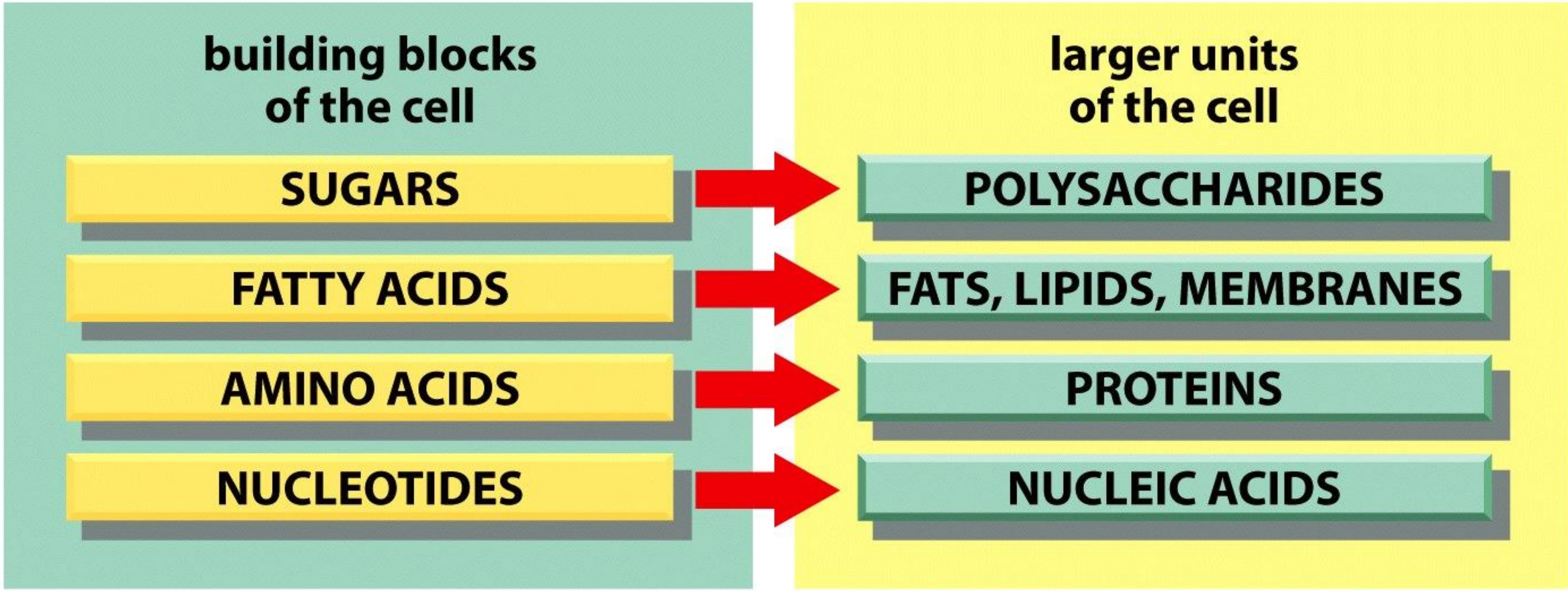


Small organic molecules

- 100-1000s Daltones
- 30 C atoms or more
- Monomeric form
- Polimerization

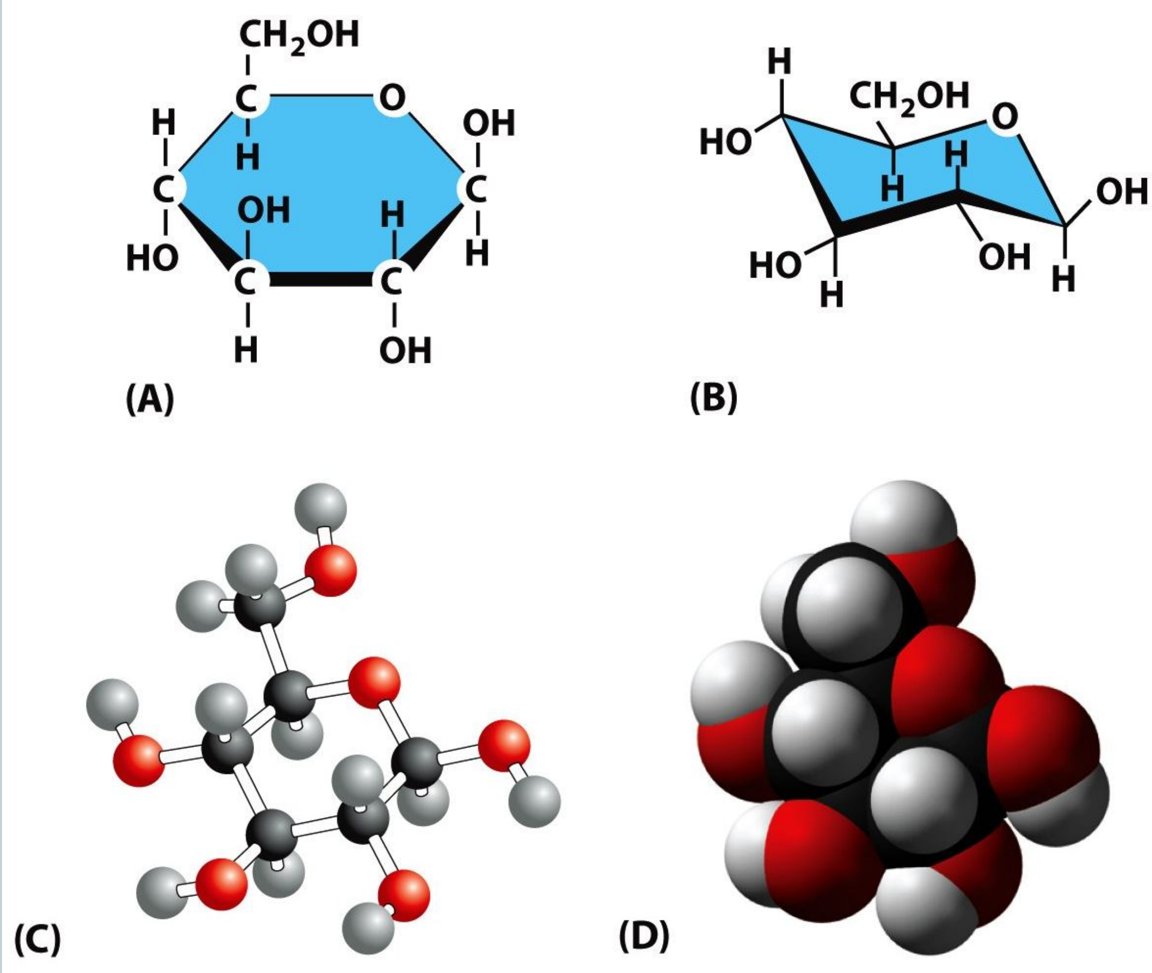
TABLE 2–2 THE APPROXIMATE CHEMICAL COMPOSITION OF A BACTERIAL CELL

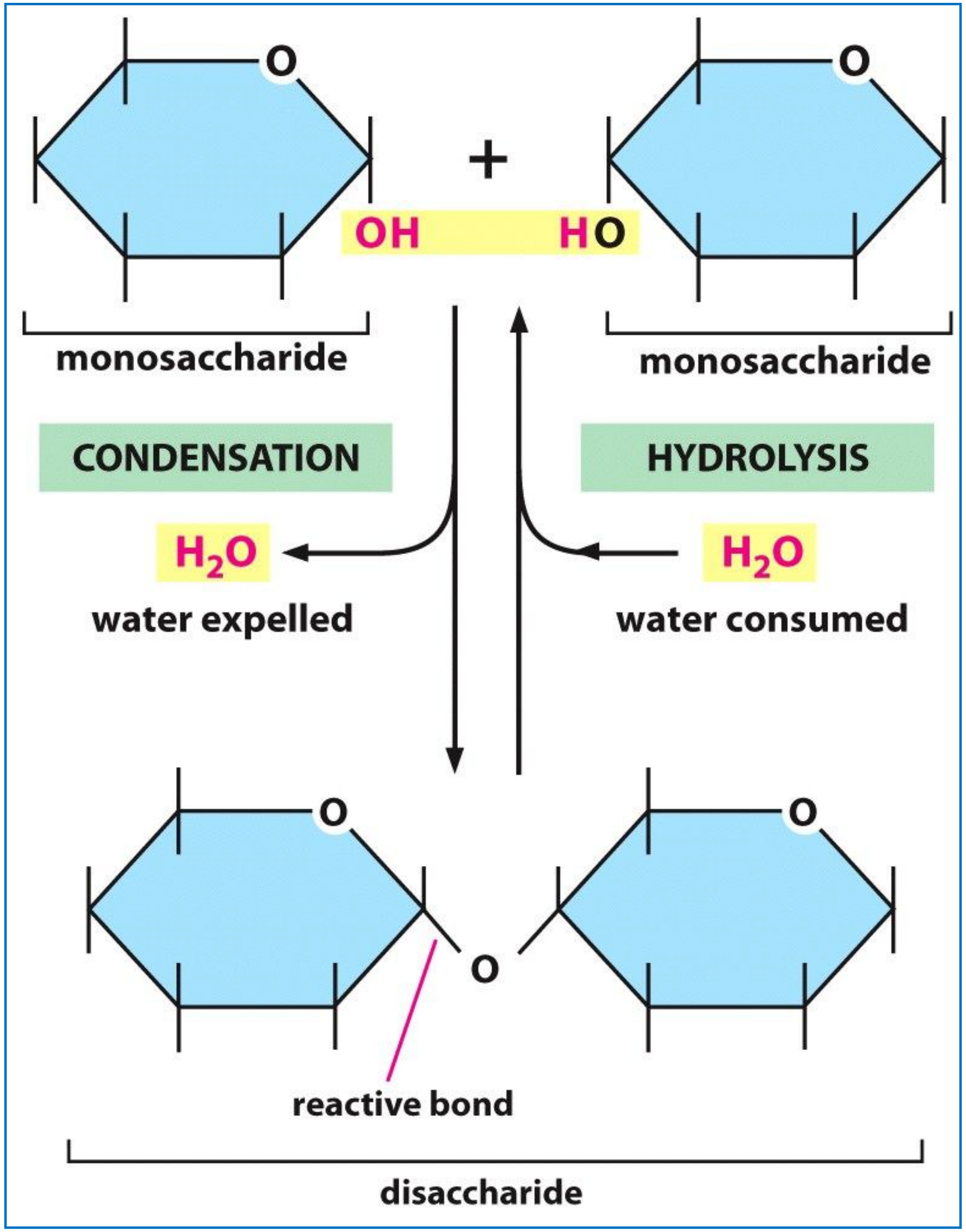
	PERCENTAGE OF TOTAL CELL WEIGHT	NUMBER OF TYPES OF EACH MOLECULE
Water	70	1
Inorganic ions	1	20
Sugars and precursors	1	250
Amino acids and precursors	0.4	100
Nucleotides and precursors	0.4	100
Fatty acids and precursors	1	50
Other small molecules	0.2	~300
Macromolecules (proteins, nucleic acids, polysaccharides, and phospholipids)	26	~3000


building blocks of the cell
larger units of the cell
SUGARS
POLYSACCHARIDES
FATTY ACIDS
FATS, LIPIDS, MEMBRANES
AMINO ACIDS
PROTEINS
NUCLEOTIDES
NUCLEIC ACIDS

Sugars

- CH2o
- Monosaccharide




O
O
+
OH
HO
monosaccharide
monosaccharide
CONDENSATION
HYDROLYSIS
H2O
H2O
water expelled
water consumed
O
O
O
reactive bond
disaccharide

Sugars

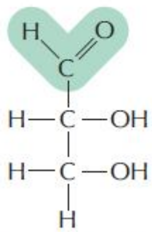
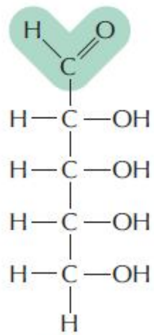
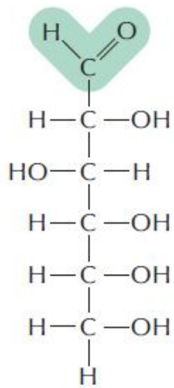
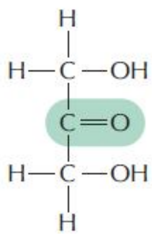
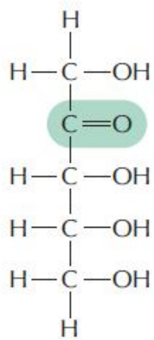
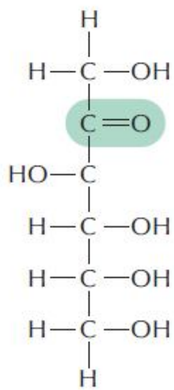
1. **Monosacharides** (glucose, fructose, galactose)
2. **Disacharides** (mannose, lactose, sucrose)
3. **Polysacharides**

- Oligosacharides (3-50)

- Glycogen
- starch
- Cellulose
- chitin

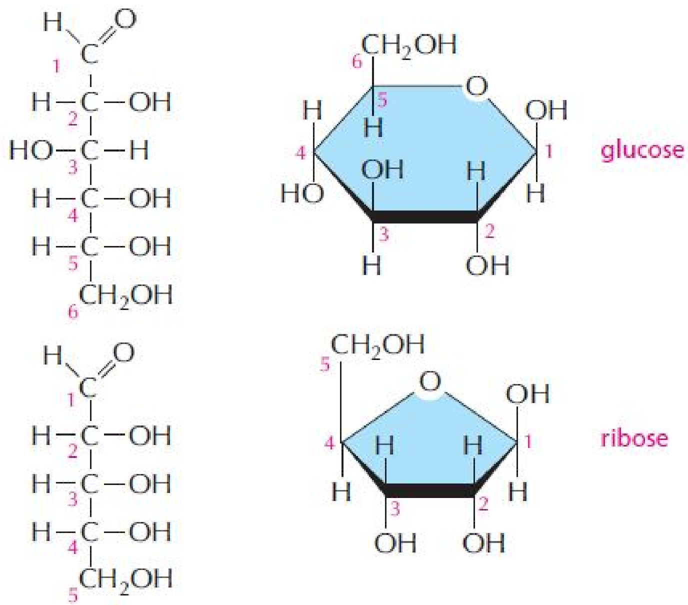
MONOSACCHARIDES

Monosaccharides usually have the general formula $(CH_2O)_n$, where *n* can be 3, 4, 5, or 6, and have two or more hydroxyl groups. They either contain an aldehyde group ($-C\langle^{O}_{H}$) and are called aldoses, or a ketone group ($\rangle C{=}O$) and are called ketoses.

	3-carbon (TRIOSES)	5-carbon (PENTOSES)	6-carbon (HEXOSES)
ALDOSES	 glyceraldehyde	 ribose	 glucose
KETOSES	 dihydroxyacetone	 ribulose	 fructose

RING FORMATION

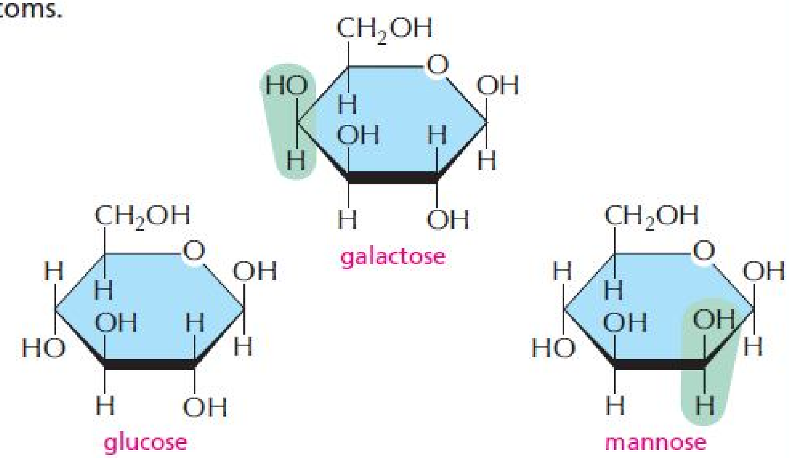
In aqueous solution, the aldehyde or ketone group of a sugar molecule tends to react with a hydroxyl group of the same molecule, thereby closing the molecule into a ring.



Note that each carbon atom has a number.

ISOMERS

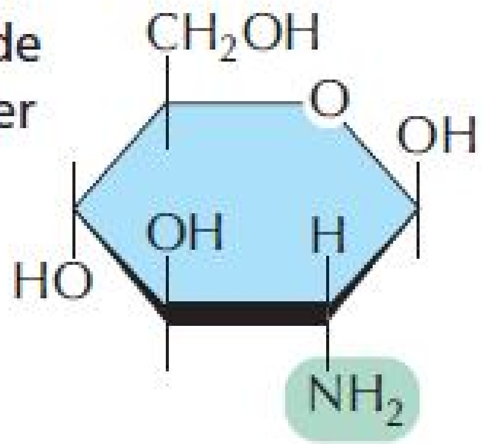
Many monosaccharides differ only in the spatial arrangement of atoms—that is, they are isomers. For example, glucose, galactose, and mannose have the same formula ($C_6H_{12}O_6$) but differ in the arrangement of groups around one or two carbon atoms.



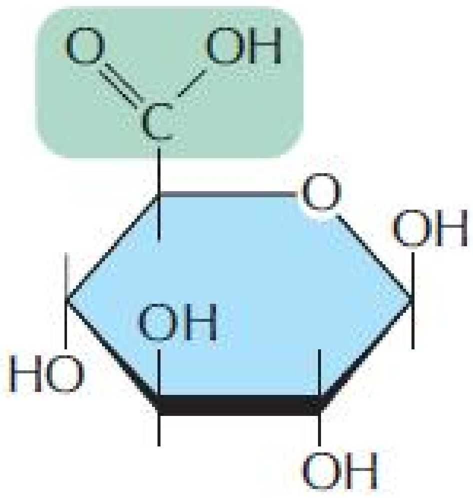
These small differences make only minor changes in the chemical properties of the sugars. But they are recognized by enzymes and other proteins and therefore can have important biological effects.

SUGAR DERIVATIVES

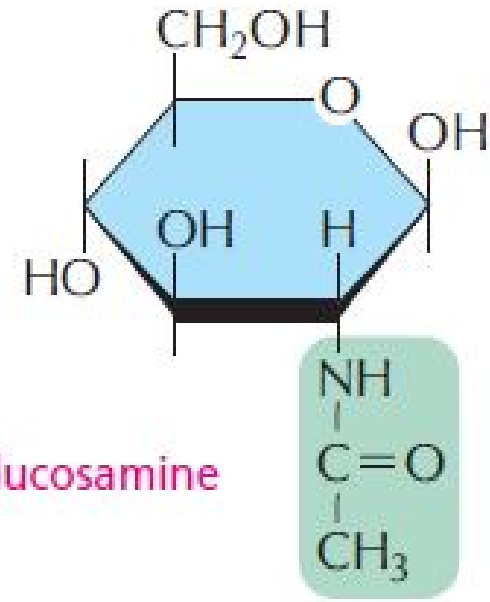
The hydroxyl groups of a simple monosaccharide can be replaced by other groups. For example,



glucosamine



glucuronic acid



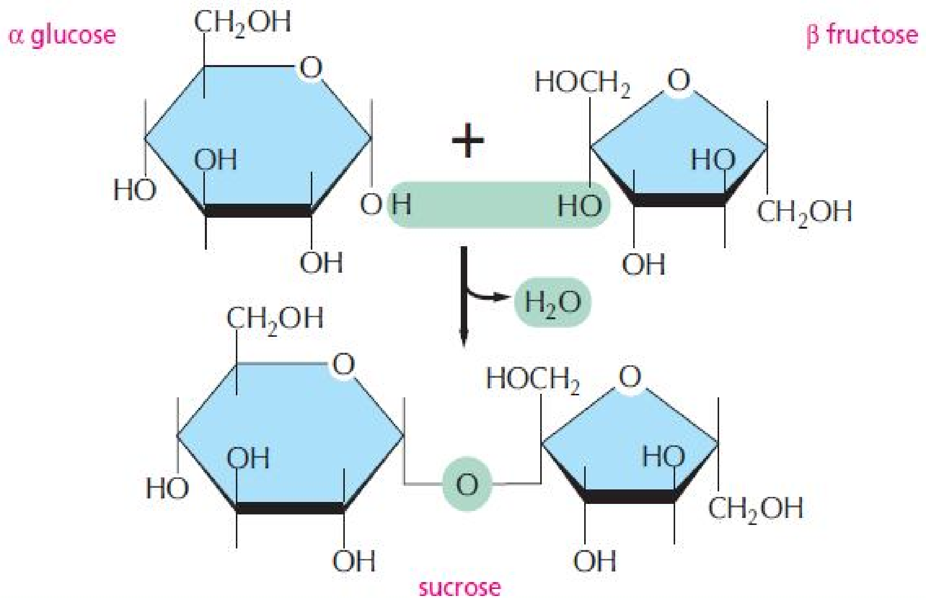
N-acetylglucosamine

DISACCHARIDES

The carbon that carries the aldehyde or the ketone can react with any hydroxyl group on a second sugar molecule to form a disaccharide. Three common disaccharides are

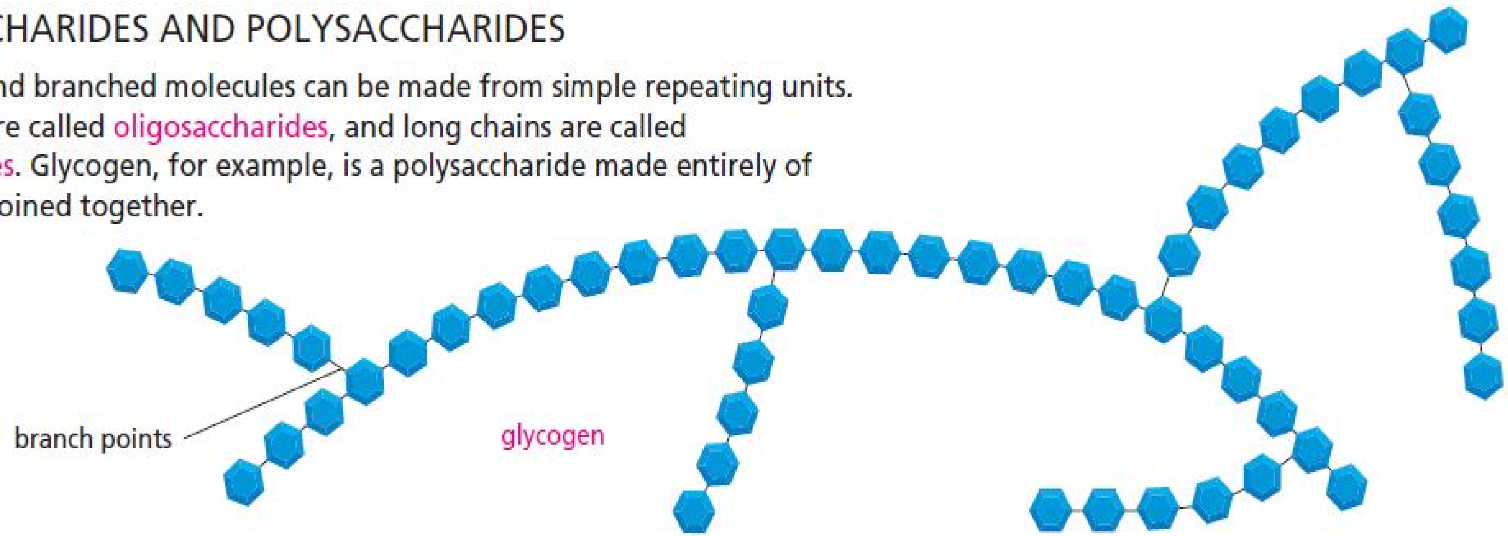
- maltose (glucose + glucose)
- lactose (galactose + glucose)
- sucrose (glucose + fructose)

The reaction forming sucrose is shown here.



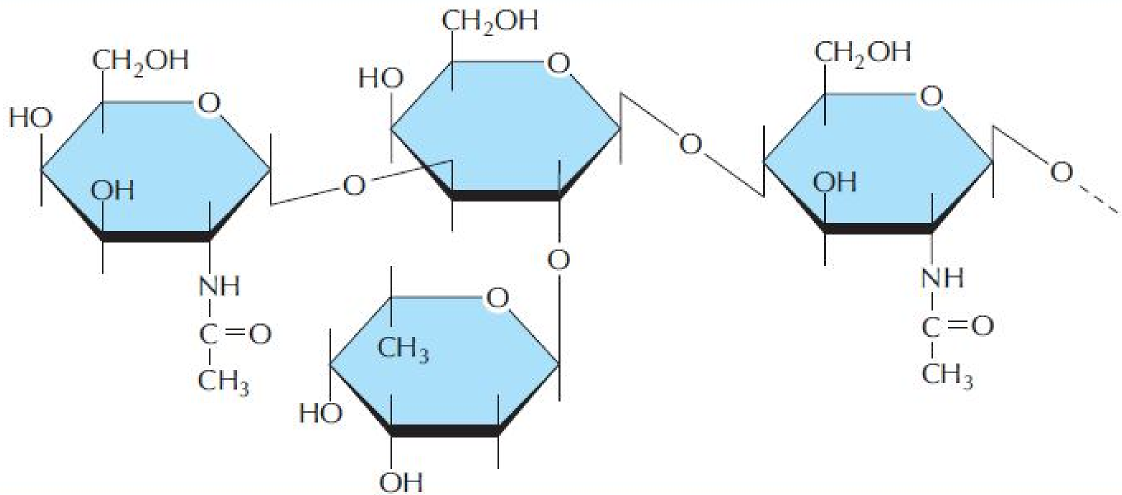
OLIGOSACCHARIDES AND POLYSACCHARIDES

Large linear and branched molecules can be made from simple repeating units. Short chains are called oligosaccharides, and long chains are called polysaccharides. Glycogen, for example, is a polysaccharide made entirely of glucose units joined together.



COMPLEX OLIGOSACCHARIDES

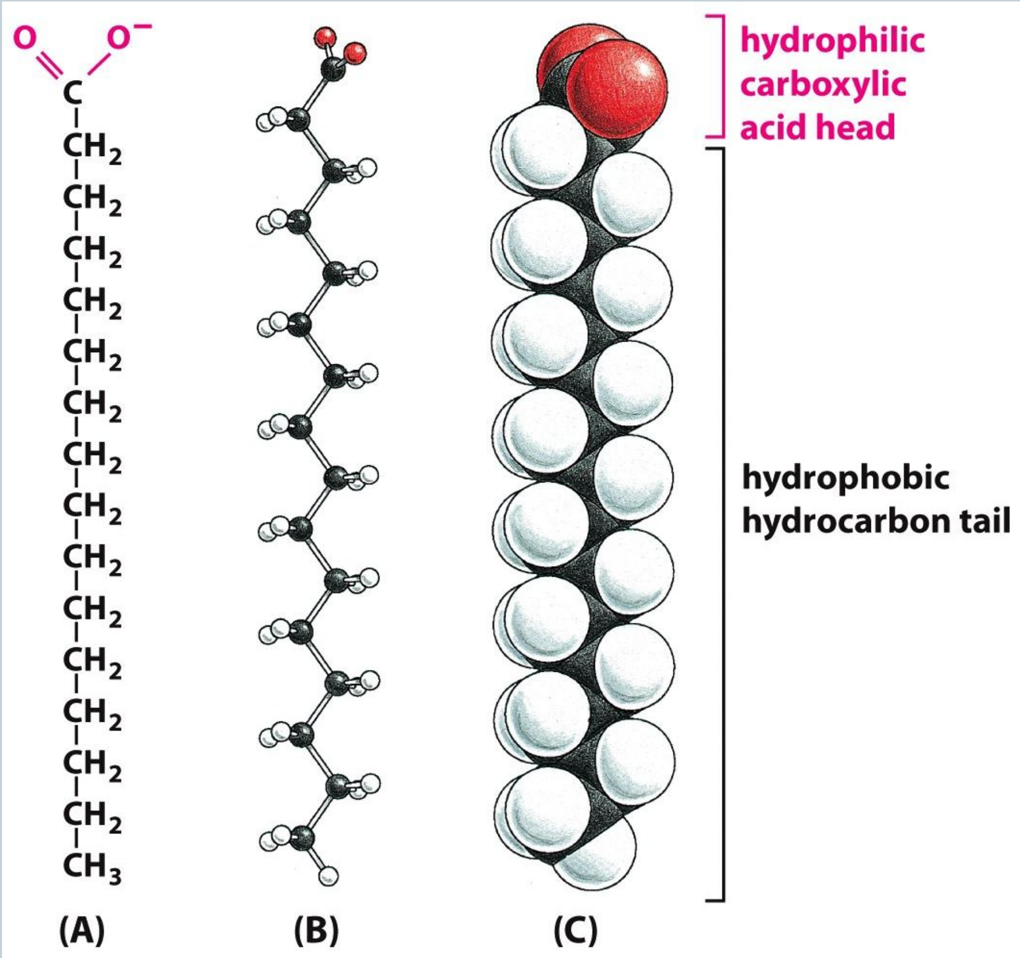
In many cases a sugar sequence is nonrepetitive. Many different molecules are possible. Such complex oligosaccharides are usually linked to proteins or to lipids, as is this oligosaccharide, which is part of a cell-surface molecule, that defines a particular blood group.



Lipids

- Fatty acids
- Triglyserids
- Phospholipids
- Polyisopernoids
- Waxes
- Steroids
- glycolipids

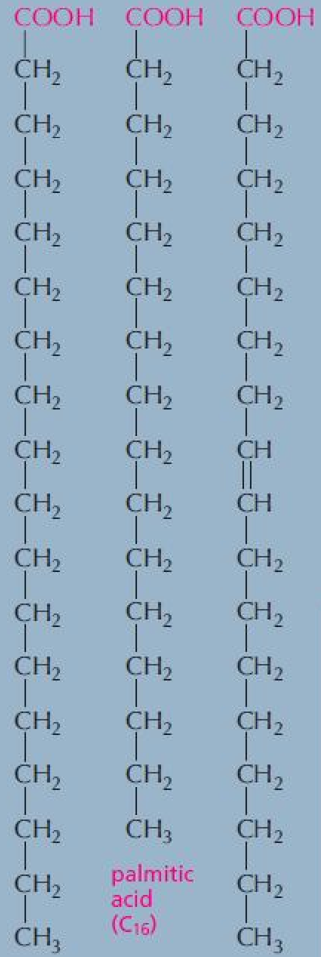
Fatty acids



O
O−
C
CH2
CH3
hydrophilic carboxylic acid head
hydrophobic hydrocarbon tail
(A)
(B)
(C)

FATTY ACIDS

All fatty acids have carboxyl groups with long hydrocarbon tails.

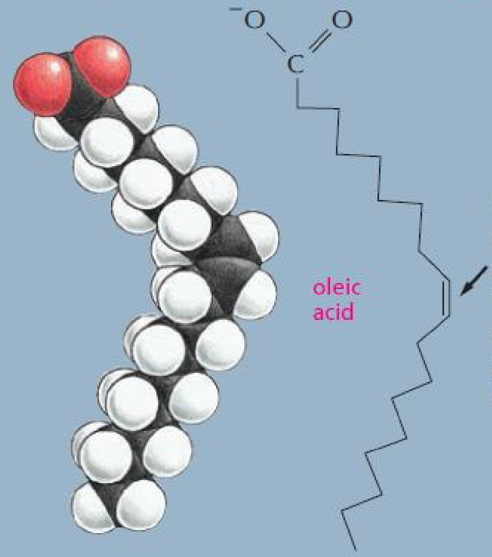


stearic acid (C_{18})

palmitic acid (C_{16})

oleic acid (C_{18})

Hundreds of different kinds of fatty acids exist. Some have one or more double bonds in their hydrocarbon tail and are said to be unsaturated. Fatty acids with no double bonds are saturated.

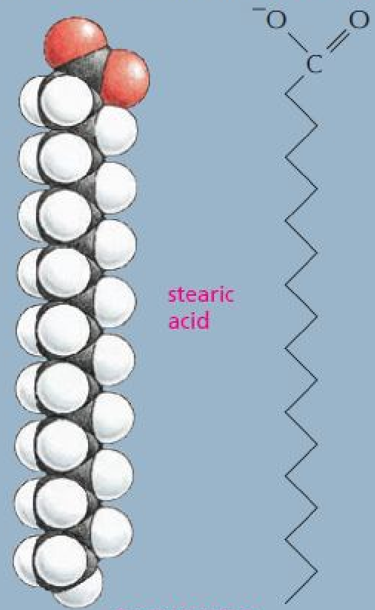


This double bond is rigid and creates a kink in the chain. The rest of the chain is free to rotate about the other C–C bonds.

space-filling model

carbon skeleton

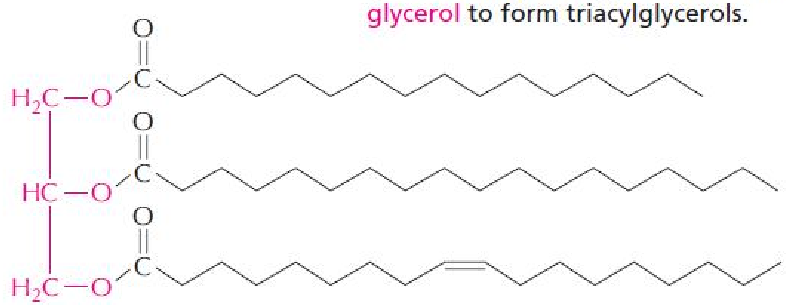
UNSATURATED

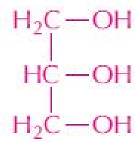


SATURATED

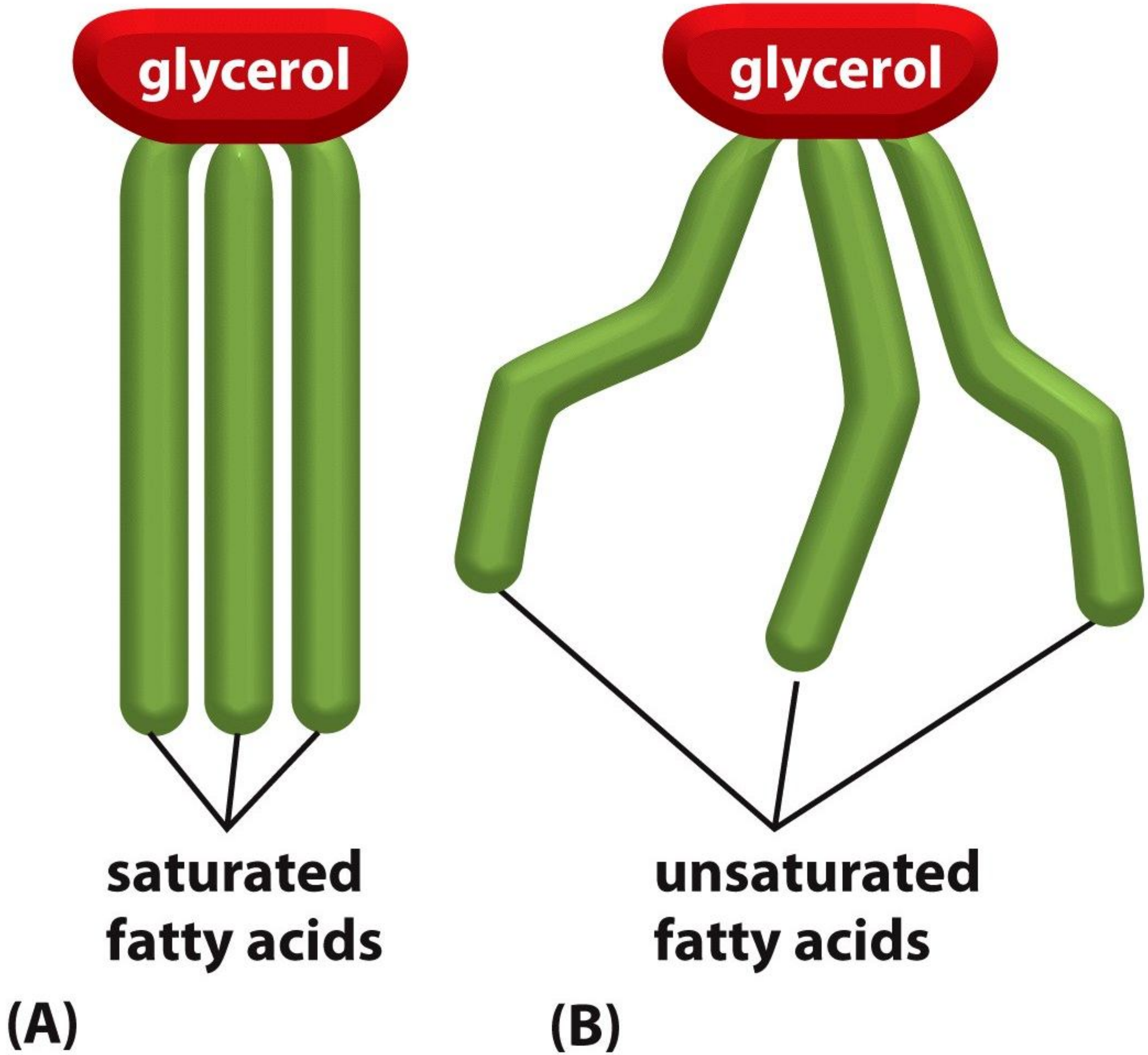
TRIACYLGLYCEROLS

Fatty acids are stored as an energy reserve (fats and oils) through an ester linkage to glycerol to form triacylglycerols.



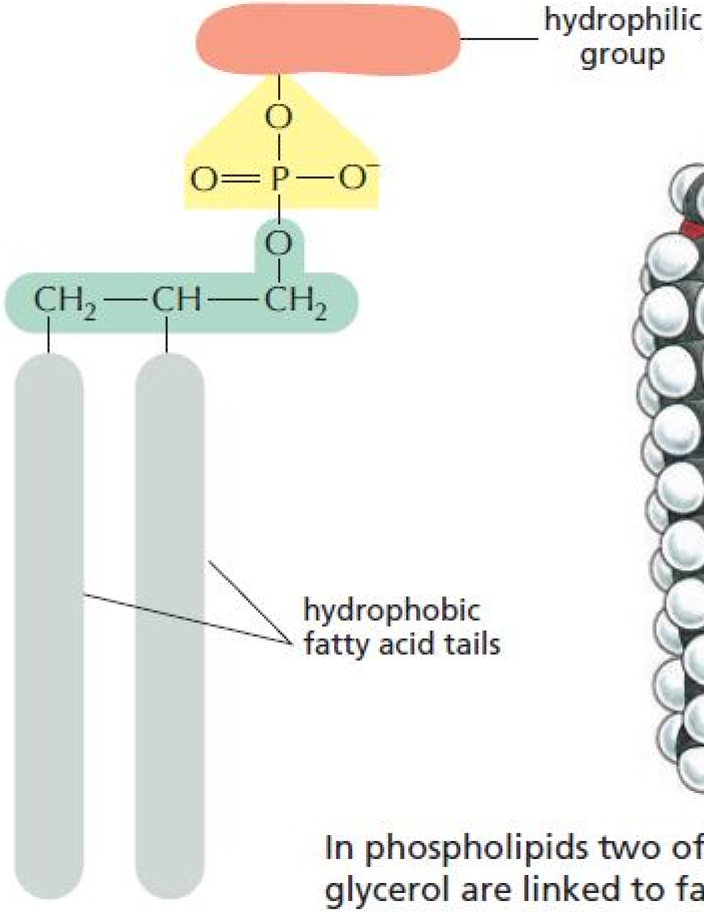


glycerol

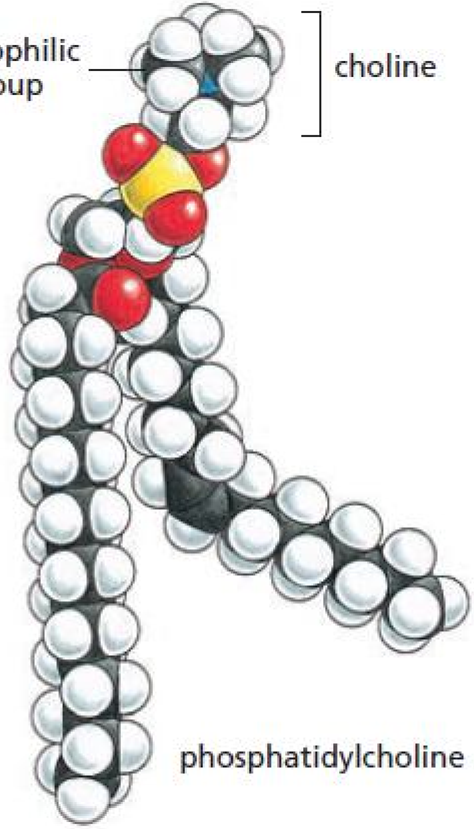

glycerol
glycerol
saturated
fatty acids
unsaturated
fatty acids
(A)
(B)

PHOSPHOLIPIDS

Phospholipids are the major constituents of cell membranes.

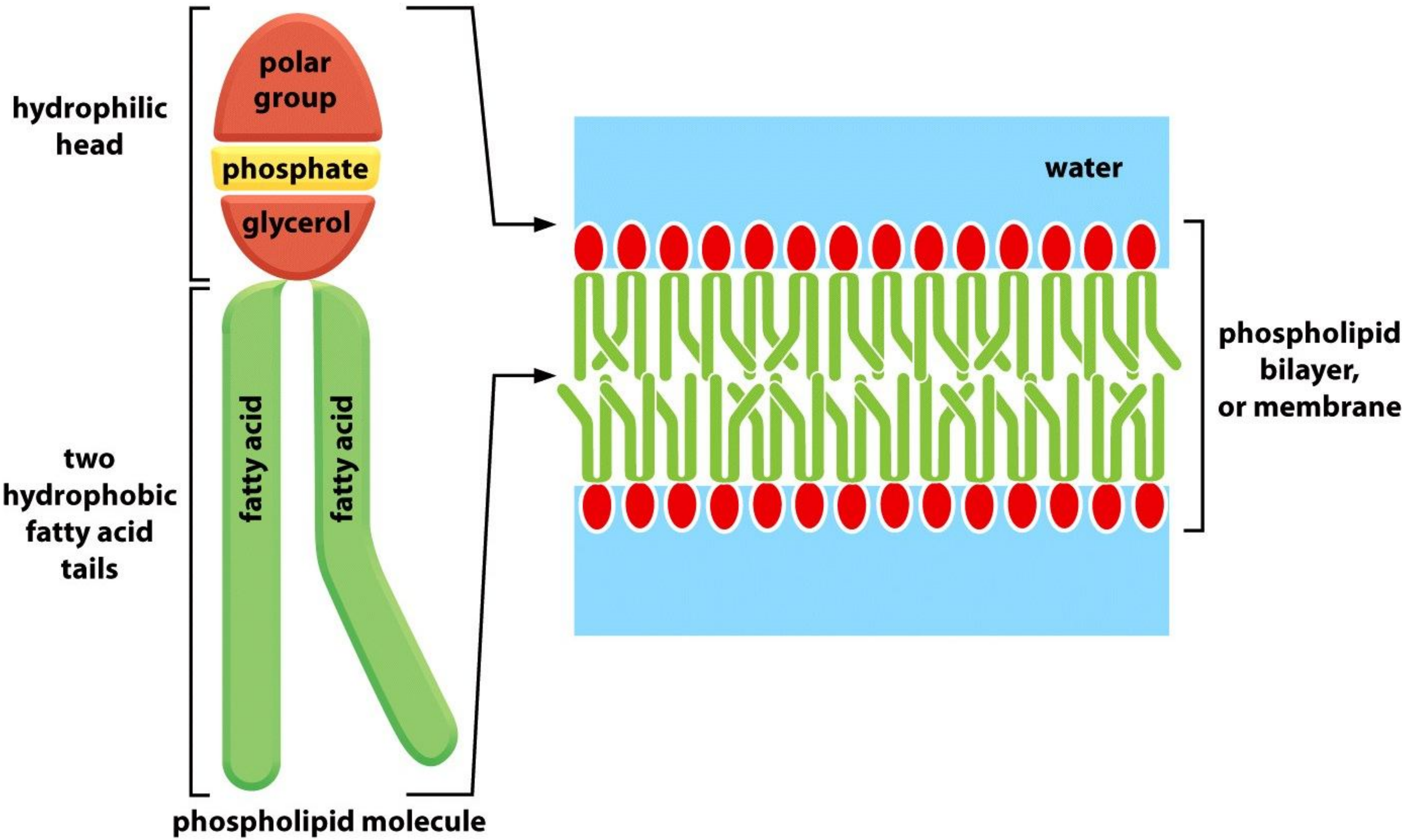


general structure of a phospholipid



phosphatidylcholine

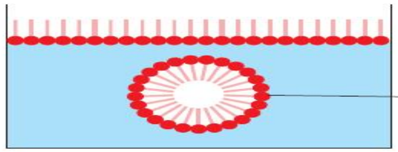
In phospholipids two of the –OH groups in glycerol are linked to fatty acids, while the third –OH group is linked to phosphoric acid. The phosphate is further linked to one of a variety of small polar groups (alcohols).


hydrophilic head
polar group
phosphate
glycerol
two hydrophobic fatty acid tails
fatty acid
fatty acid
phospholipid molecule
water
phospholipid bilayer, or membrane

LIPID AGGREGATES

Fatty acids have a hydrophilic head and a hydrophobic tail.

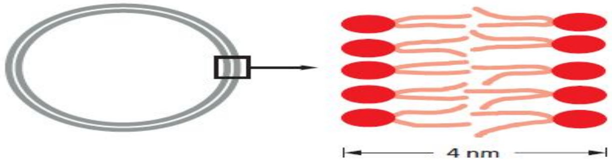
In water they can form a surface film or form small micelles.



Their derivatives can form larger aggregates held together by hydrophobic forces:

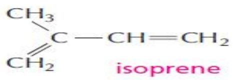
Triacylglycerols form large spherical fat droplets in the cell cytoplasm.

Phospholipids and glycolipids form self-sealing lipid bilayers that are the basis for all cellular membranes.



OTHER LIPIDS

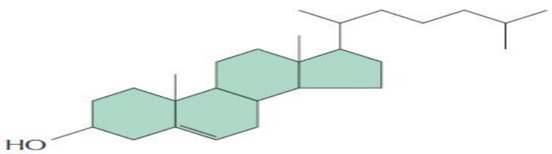
Lipids are defined as the water-insoluble molecules in cells that are soluble in organic solvents. Two other common types of lipids are steroids and polyisoprenoids. Both are made from isoprene units.



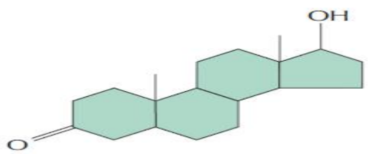
isoprene

STEROIDS

Steroids have a common multiple-ring structure.



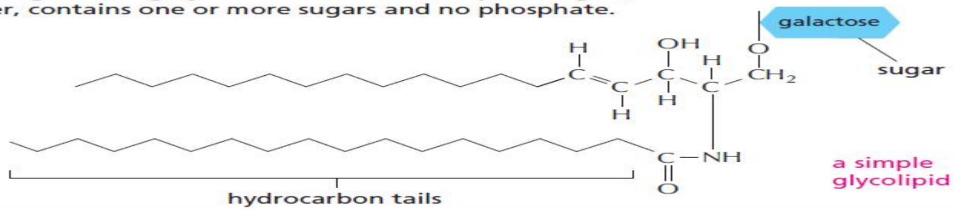
cholesterol—found in many membranes



testosterone—male steroid hormone

GLYCOLIPIDS

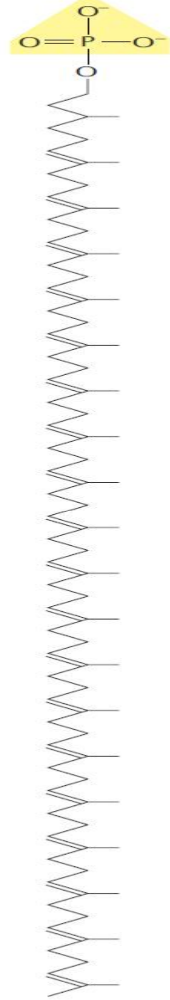
Like phospholipids, these compounds are composed of a hydrophobic region, containing two long hydrocarbon tails, and a polar region, which, however, contains one or more sugars and no phosphate.



a simple glycolipid

POLYISOPRENOIDS

long-chain polymers of isoprene

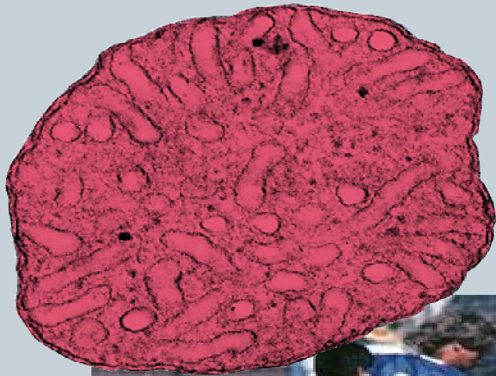


dolichol phosphate—used to carry activated sugars in the membrane-associated synthesis of glycoproteins and some polysaccharides

Importance; Biological Role

- Used to store energy (approx 36 kj/gram)

Lipids are often stored in special **adipose tissue**, within large fat cells

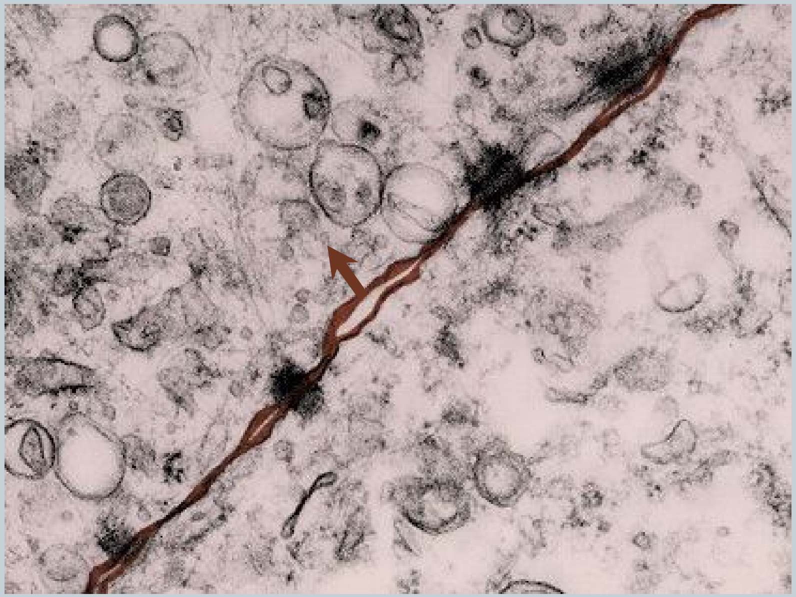


Mitochondrion
(false color TEM)

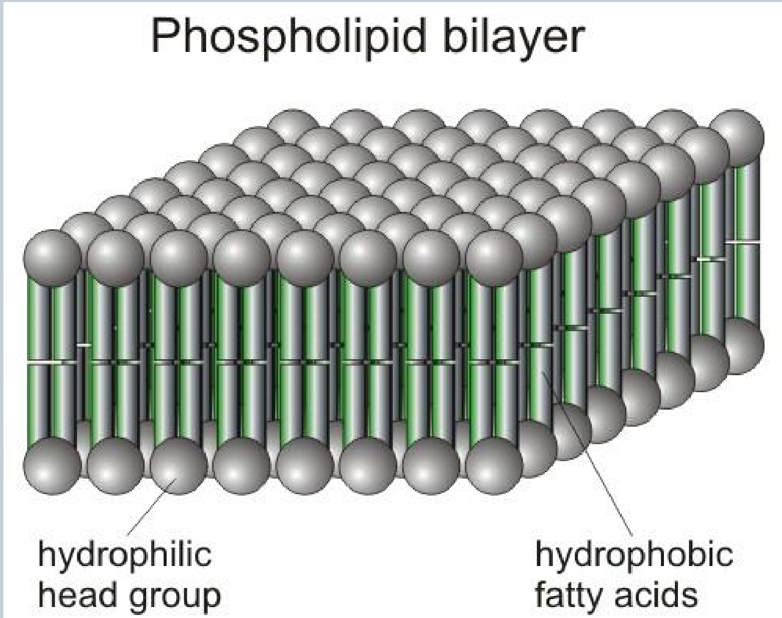
Lipids are concentrated sources of **energy** and can be broken down (through fatty acid oxidation in the mitochondria) to provide fuel for aerobic respiration

Importance; Biological Role

- An important structural component of membranes

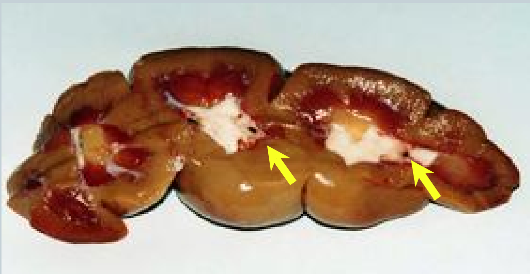


Phospholipids are the primary structural component of all cellular membranes, such as the plasma membrane (false color TEM above).



Importance; Biological Role

- acts as a shock absorber and good insulator



The white fat tissue (arrows) is visible in this ox kidney

Fat **absorbs shocks**. Organs that are prone to bumps and shocks (e.g. kidneys) are cushioned with a relatively thick layer of fat.

Stored lipids provide **insulation** in extreme environments. Increased body fat levels in winter reduce heat losses to the environment.

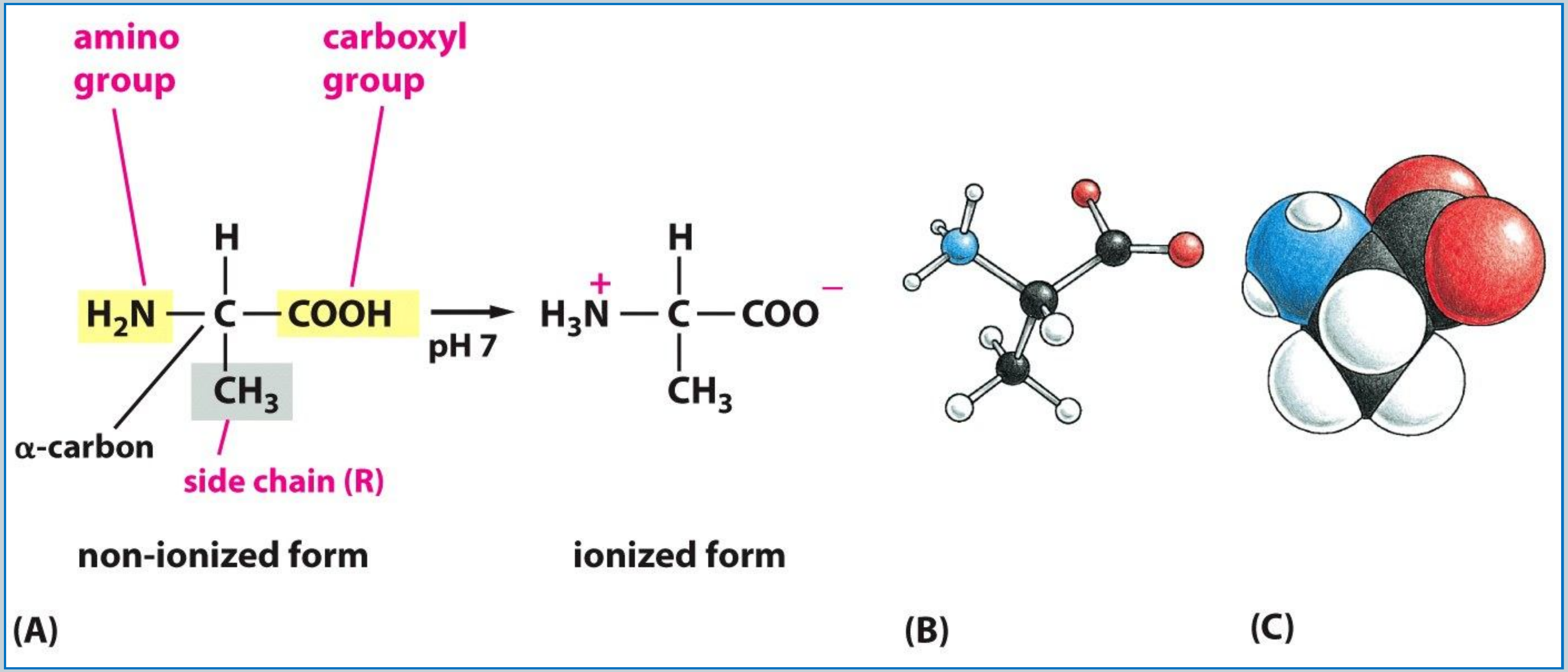
Importance; Biological Role

- Water proofing of some surfaces

- Transmission of chemical messages via hormones

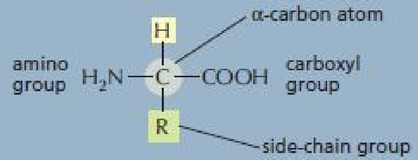
Waxes and oils, when secreted on to surfaces provide **waterproofing** in plants and animals.

Proteins

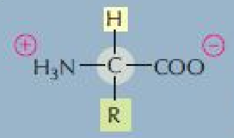

amino group
carboxyl group
H
H2N
C
COOH
CH3
α-carbon
side chain (R)
pH 7
H3N
+
C
COO
–
CH3
non-ionized form
ionized form
(A)
(B)
(C)

THE AMINO ACID

The general formula of an amino acid is



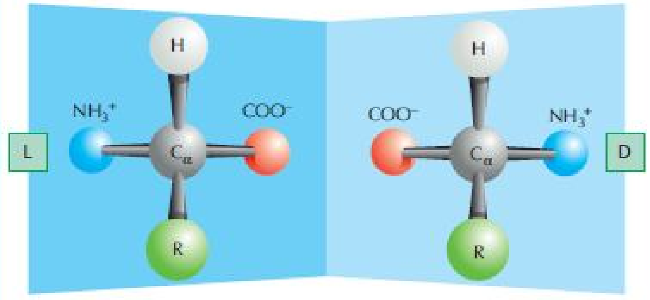
R is commonly one of 20 different side chains. At pH 7 both the amino and carboxyl groups are ionized.



These pages present the amino acids found in proteins and show how they are linked to form them.

OPTICAL ISOMERS

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

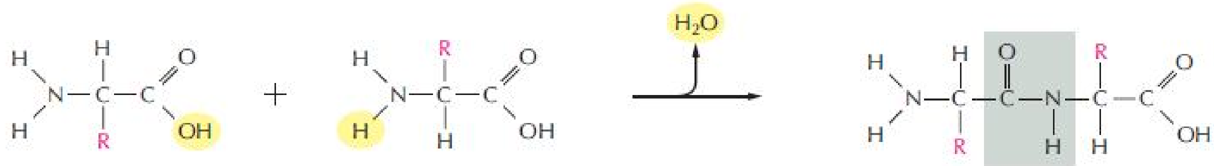


Proteins consist exclusively of L-amino acids.

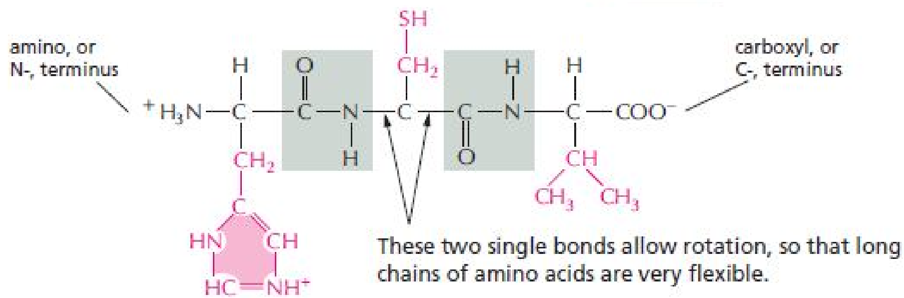
PEPTIDE BONDS

Amino acids are commonly joined together by an amide linkage, called a peptide bond.

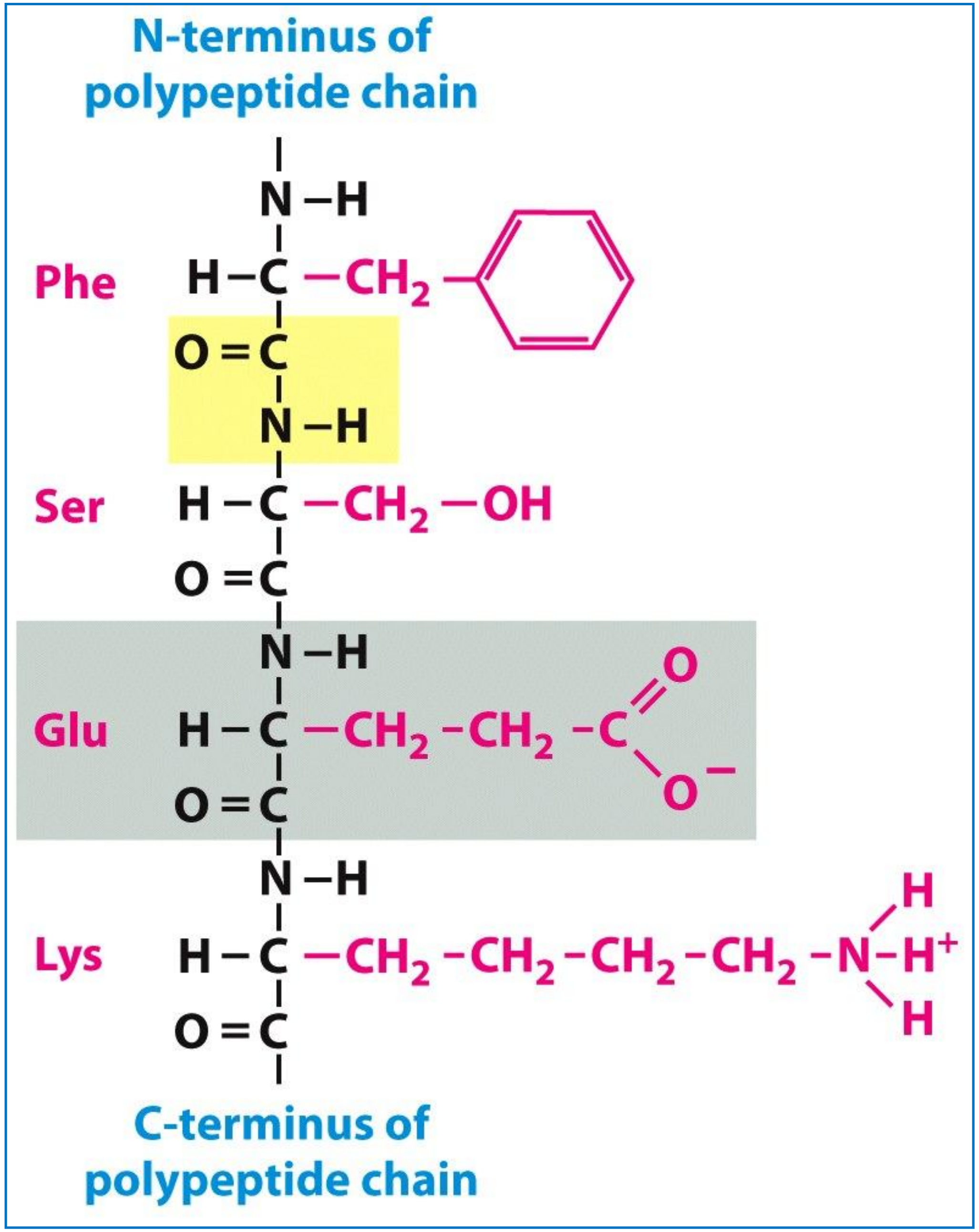
The four atoms in each peptide bond *(gray box)* form a rigid planar unit. There is no rotation around the C–N bond.



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



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



N-terminus of
polypeptide chain
Phe
Ser
Glu
Lys
C-terminus of
polypeptide chain

FAMILIES OF AMINO ACIDS

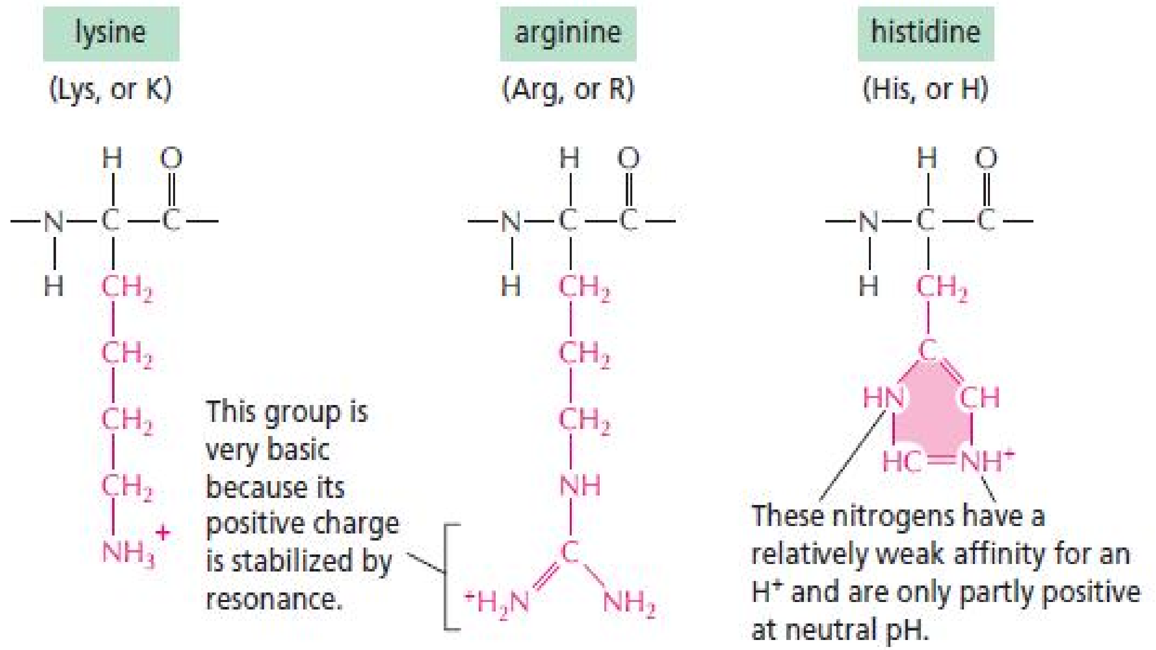
The common amino acids are grouped according to whether their side chains are

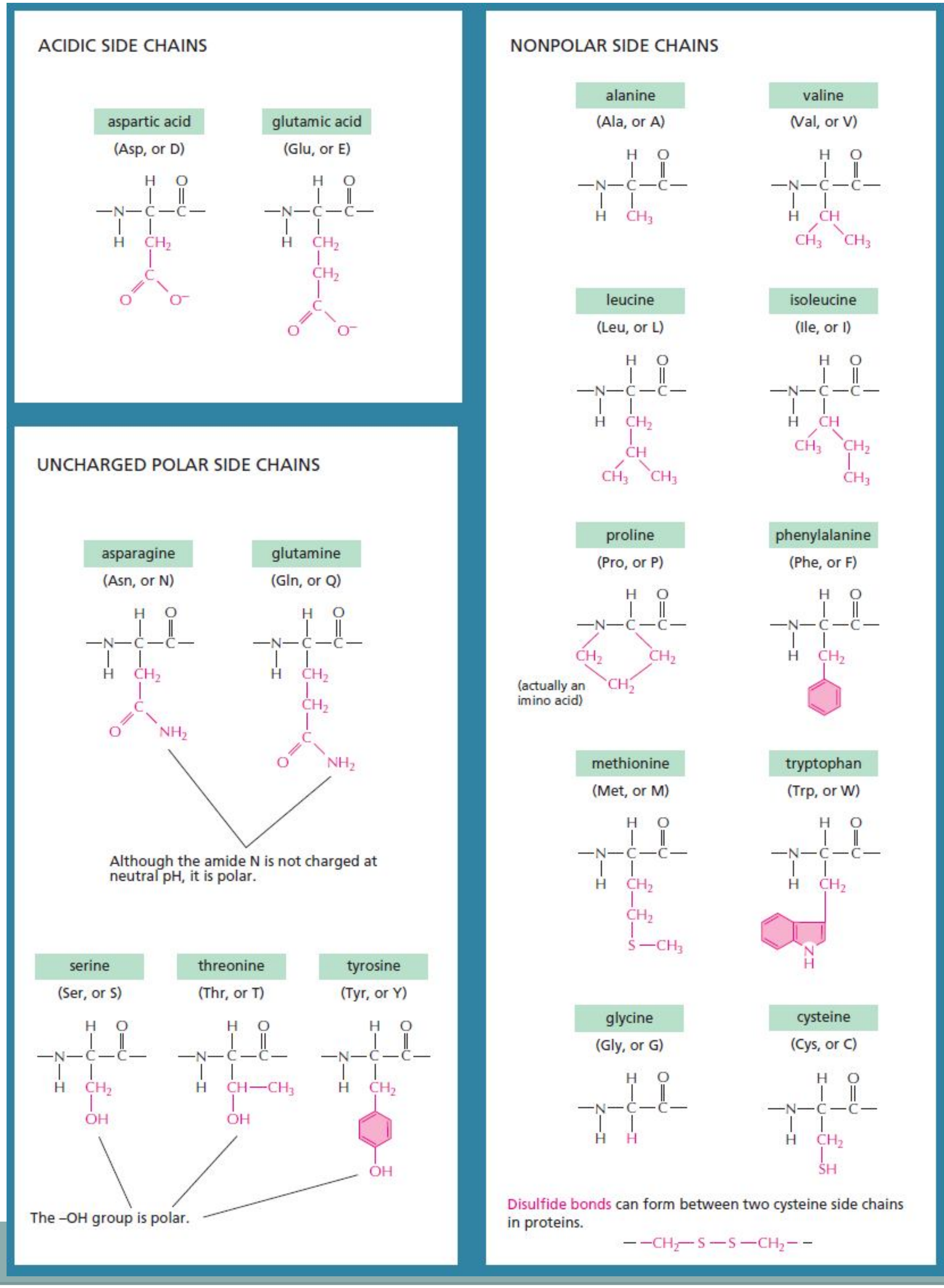
- acidic
- basic
- uncharged polar
- nonpolar

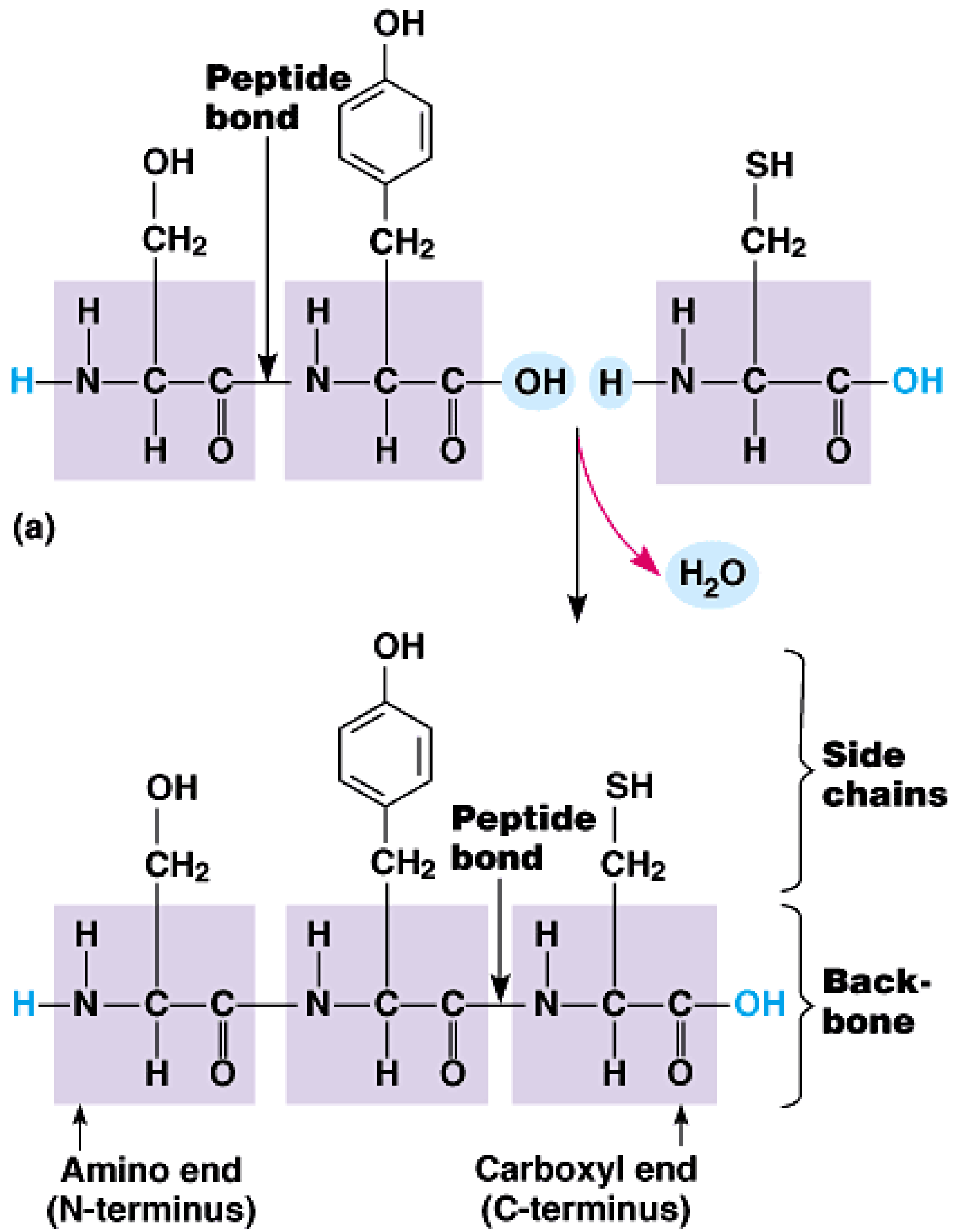
These 20 amino acids are given both three-letter and one-letter abbreviations.

Thus: alanine = Ala = A

BASIC SIDE CHAINS




ACIDIC SIDE CHAINS
aspartic acid
(Asp, or D)
glutamic acid
(Glu, or E)
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.


Peptide bond
(a)
H₂O
Side chains
Peptide bond
Back-bone
Amino end (N-terminus)
Carboxyl end (C-terminus)

Folding of polypetides to form Proteins

- Shape of a proteins are important because
    - This determines how they interact with other molecules
    - This determines their particular function

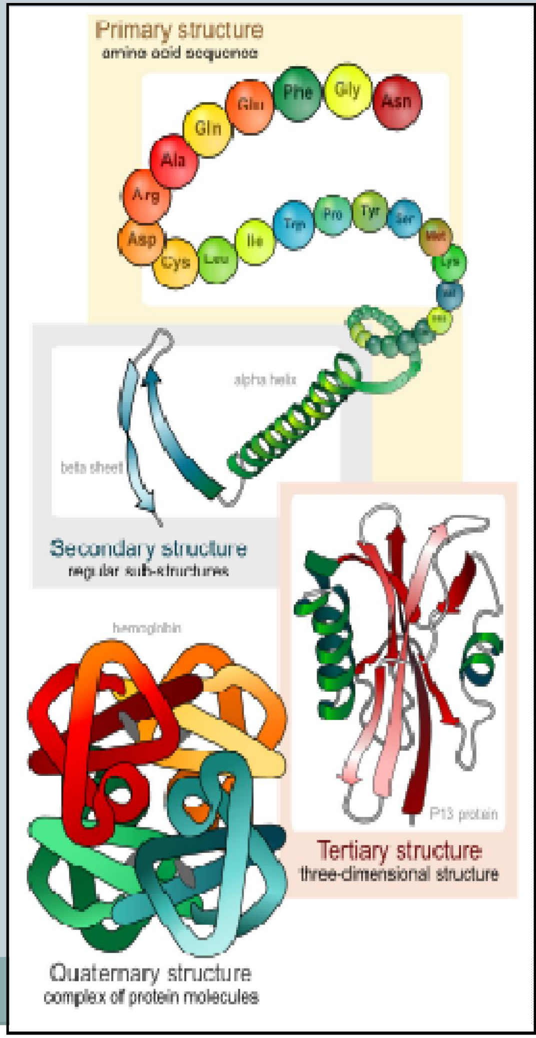
protein structure

Primary structure
(Amino acid sequence)
↓

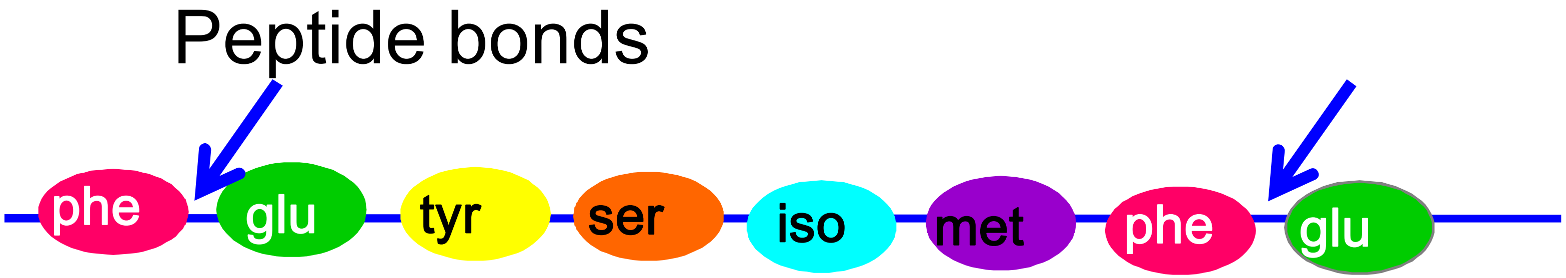
Secondary structure
(α-helix, β-sheet)
↓

Tertiary structure
(Three-dimensional structure formed by assembly of secondary structures)
↓

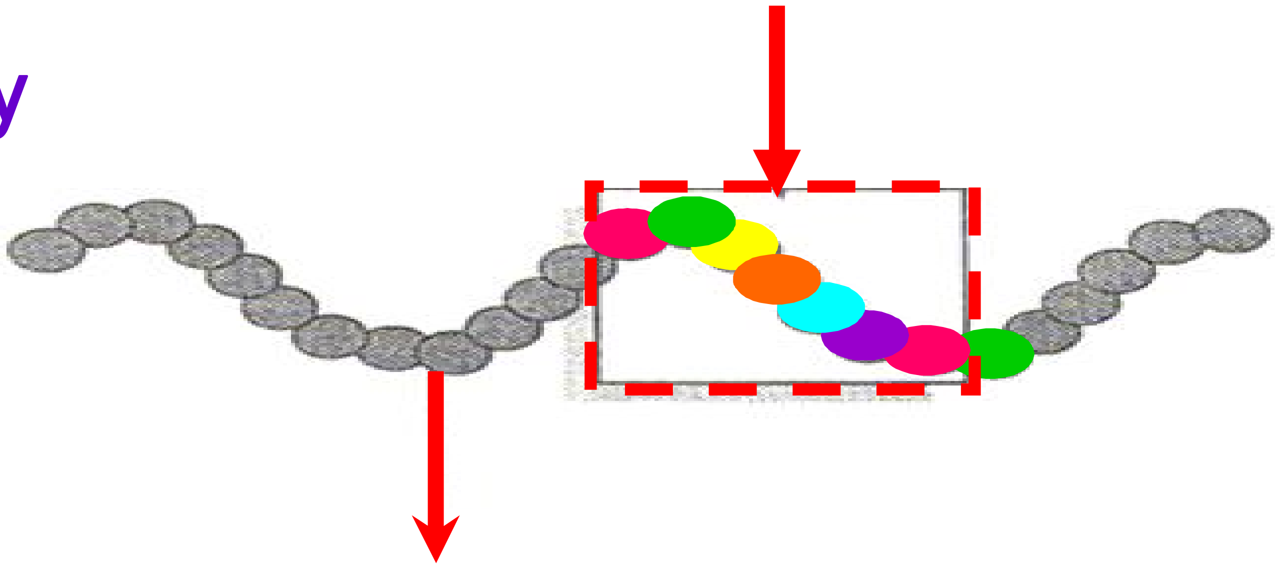
Quaternary structure
(Structure formed by more than one polypeptide chains)



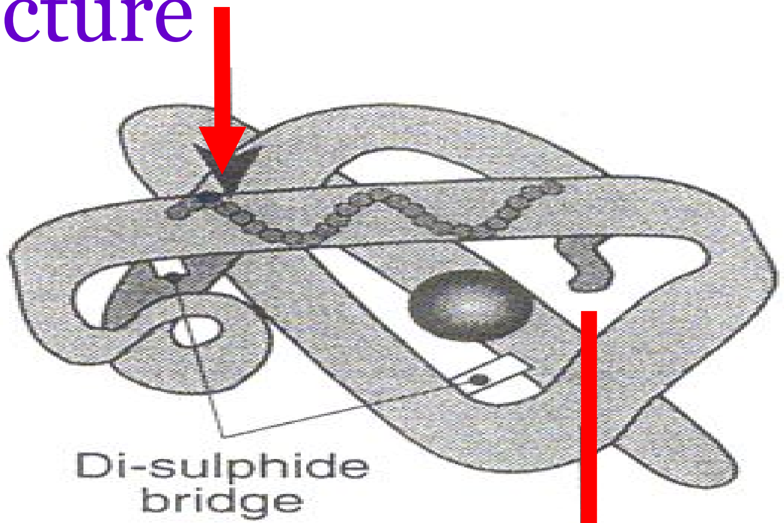
Primary Structure



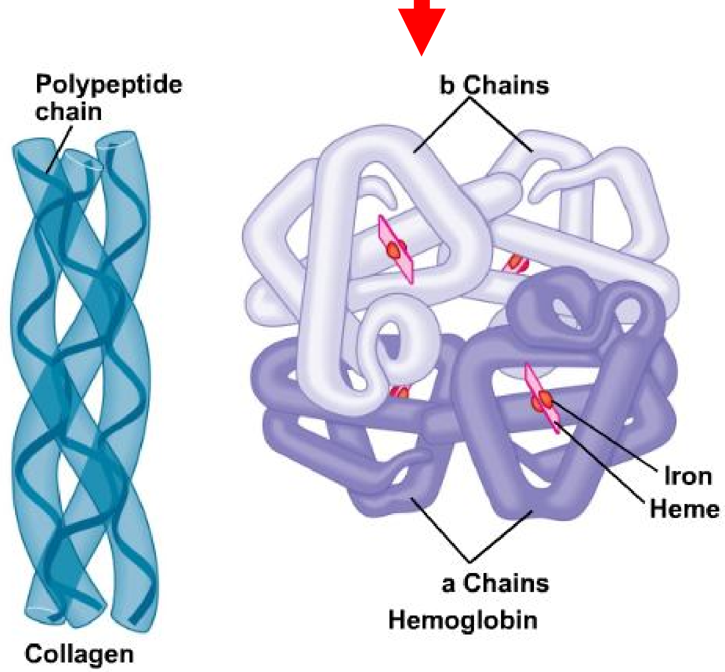
secondary Structure



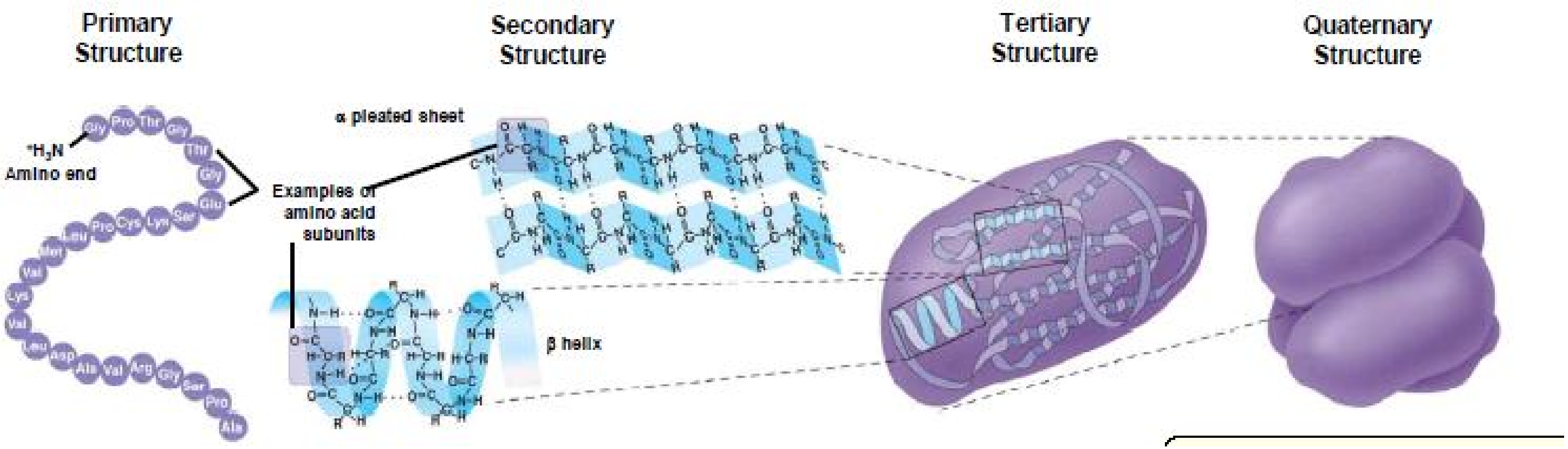
Tertiary Structure



Quaternary Structure



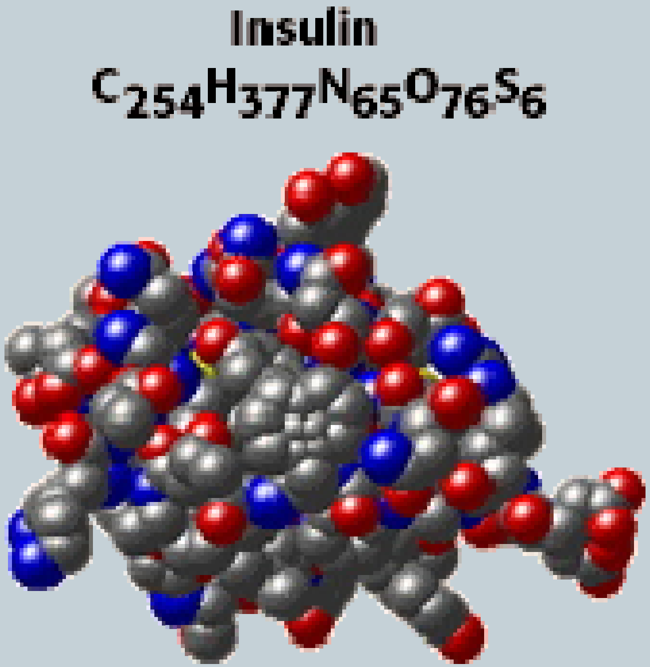
Summary


Primary Structure
Secondary Structure
Tertiary Structure
Quaternary Structure
α pleated sheet
^+H_3N Amino end
Examples of amino acid subunits
β helix

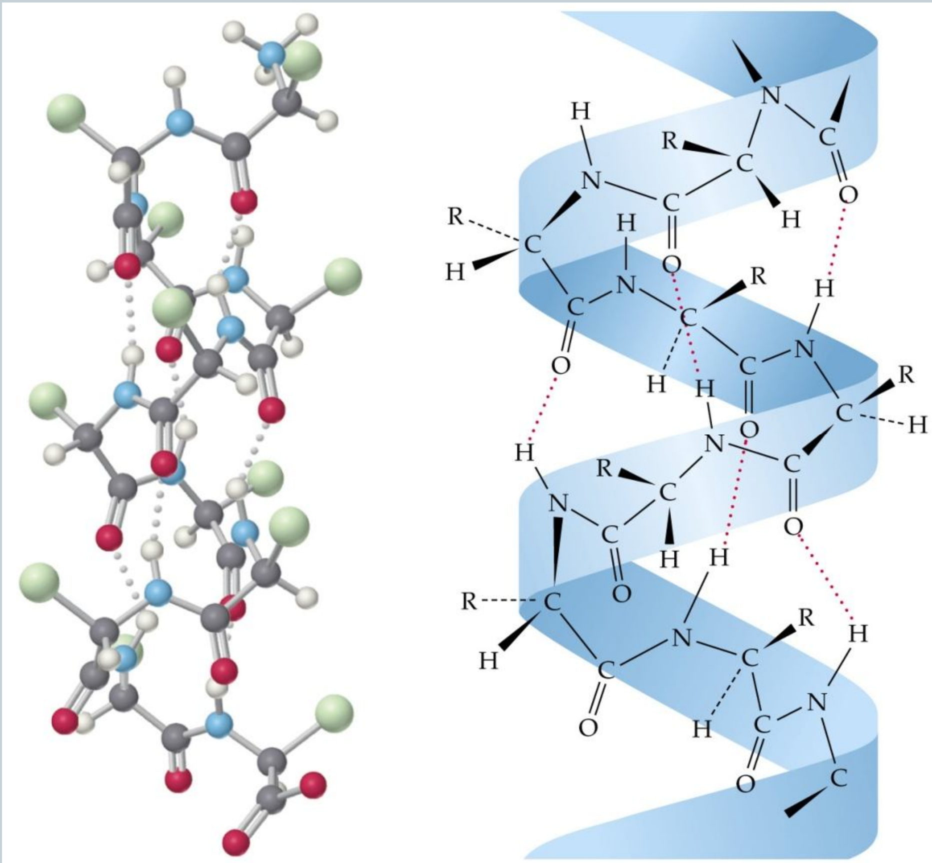
CATALYSTS eg. lipase

REGULATION(hormones)

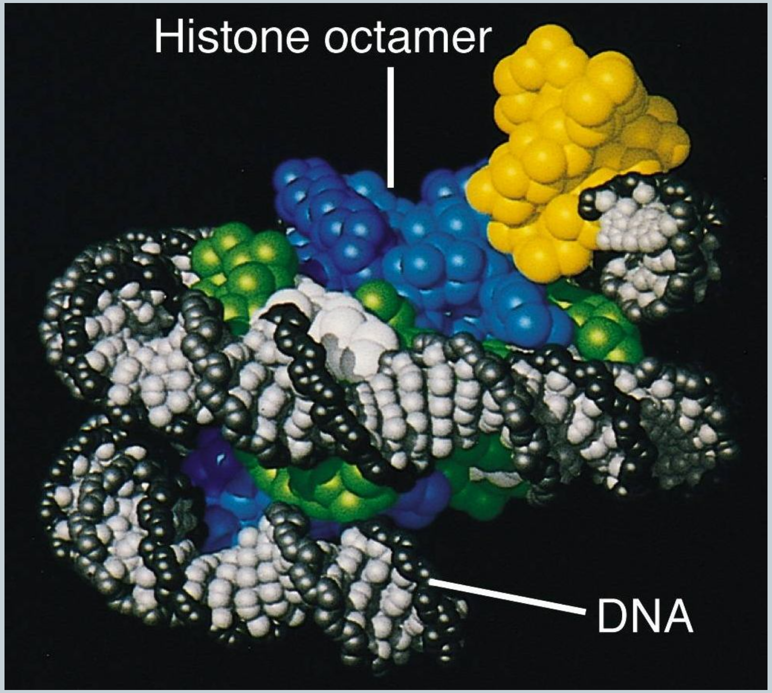
- Insulin



STRUCTURAL eg.Keratin



STRUCTURAL eg. Histone Protein



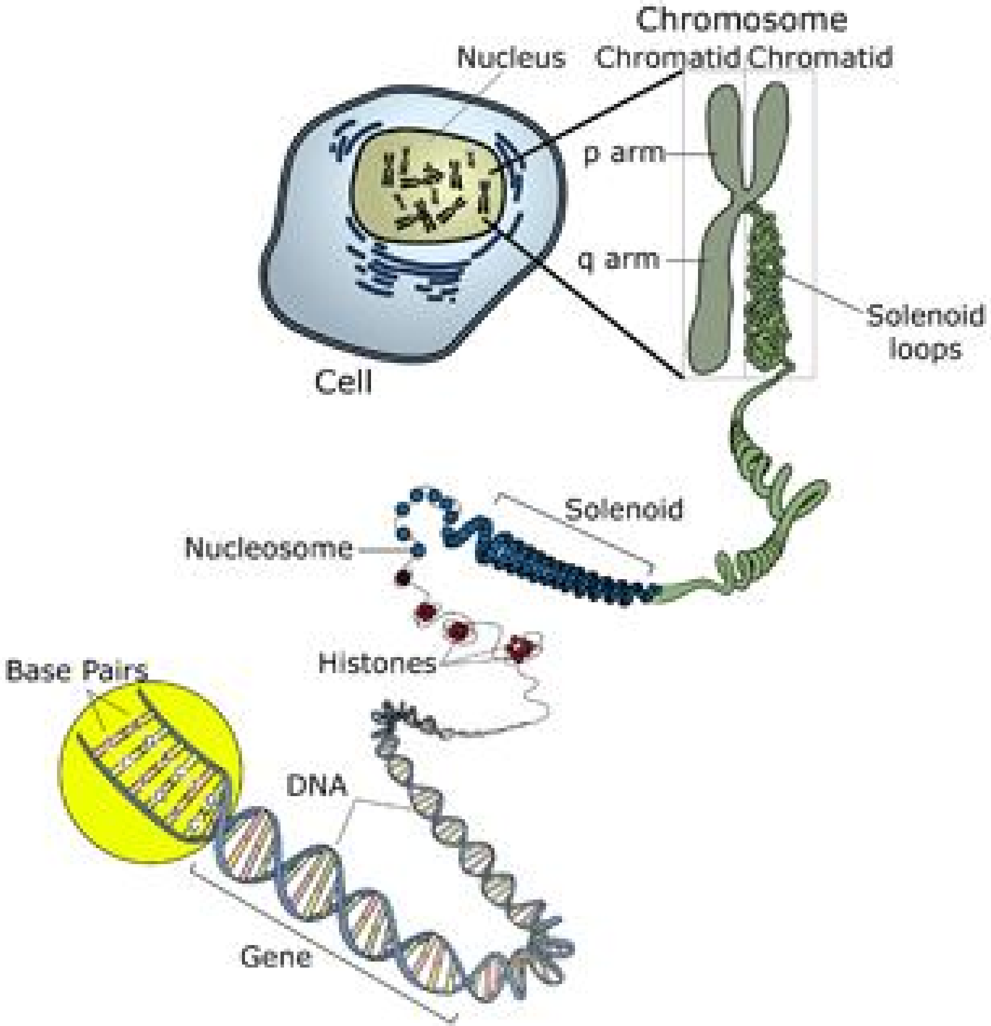
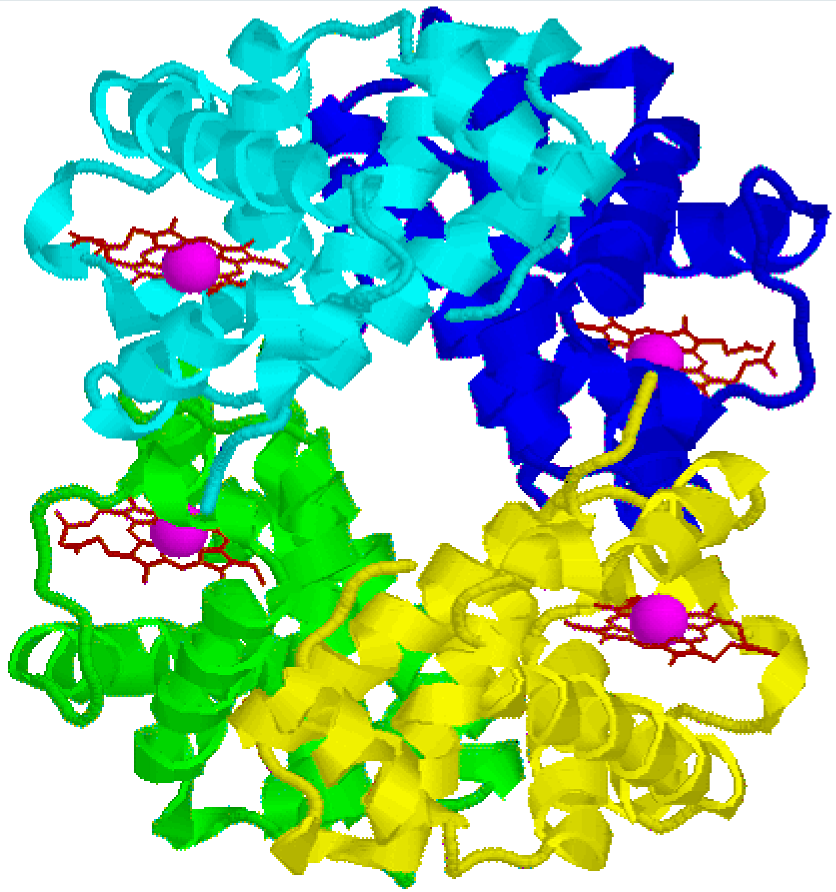
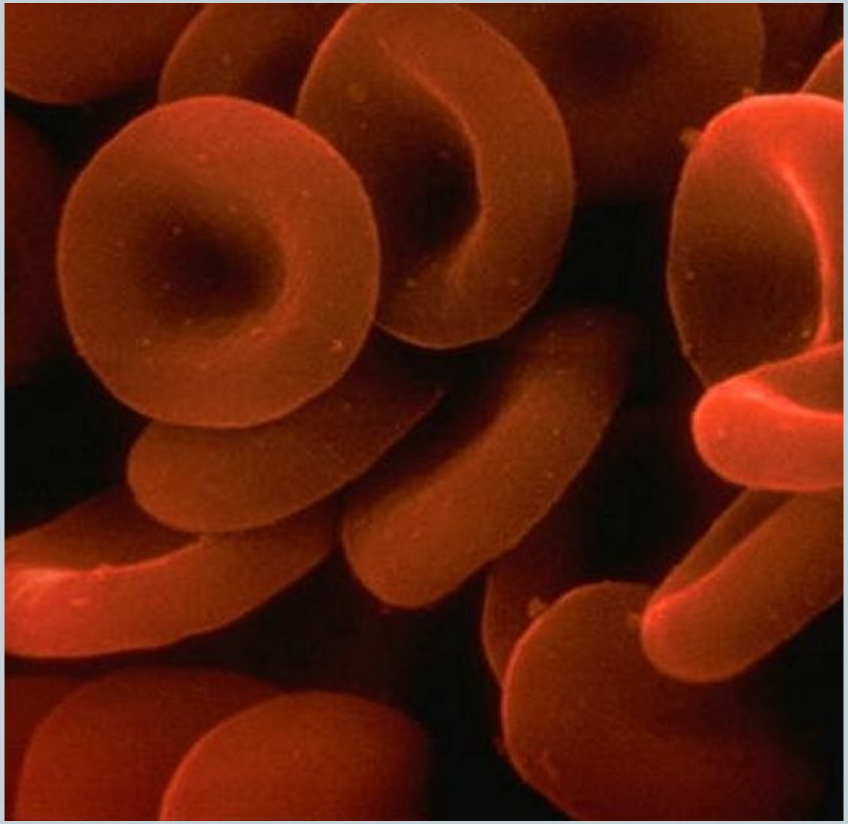


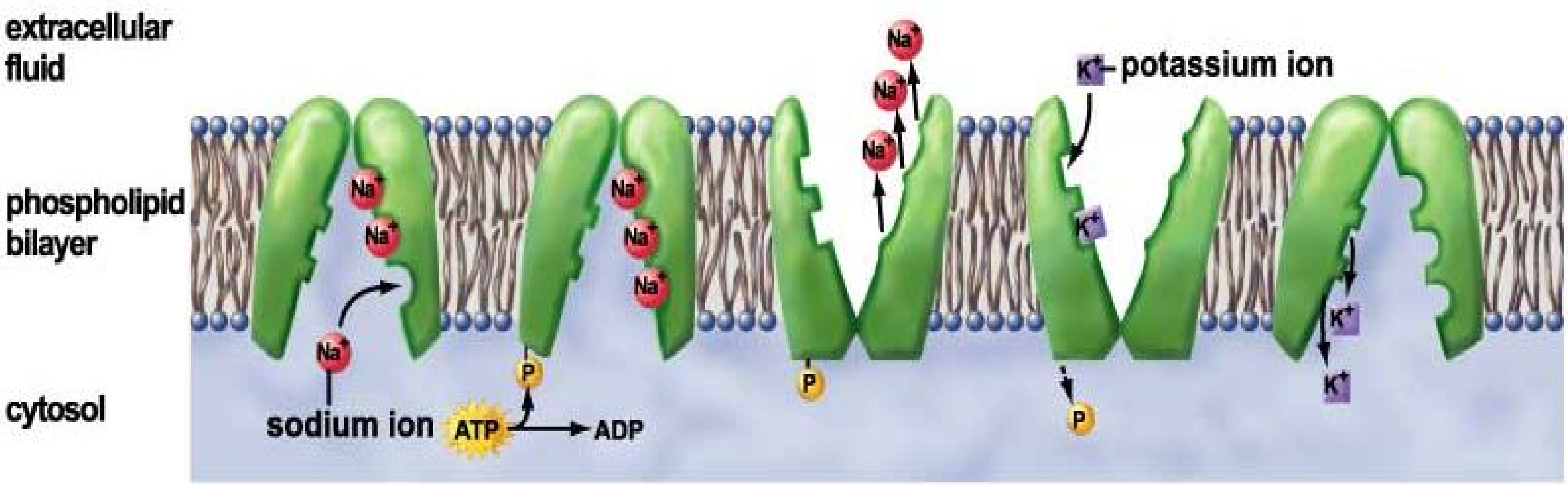
Image adapted from: National Human Genome Research Institute.

TRANSPORT: eg haemoglobin

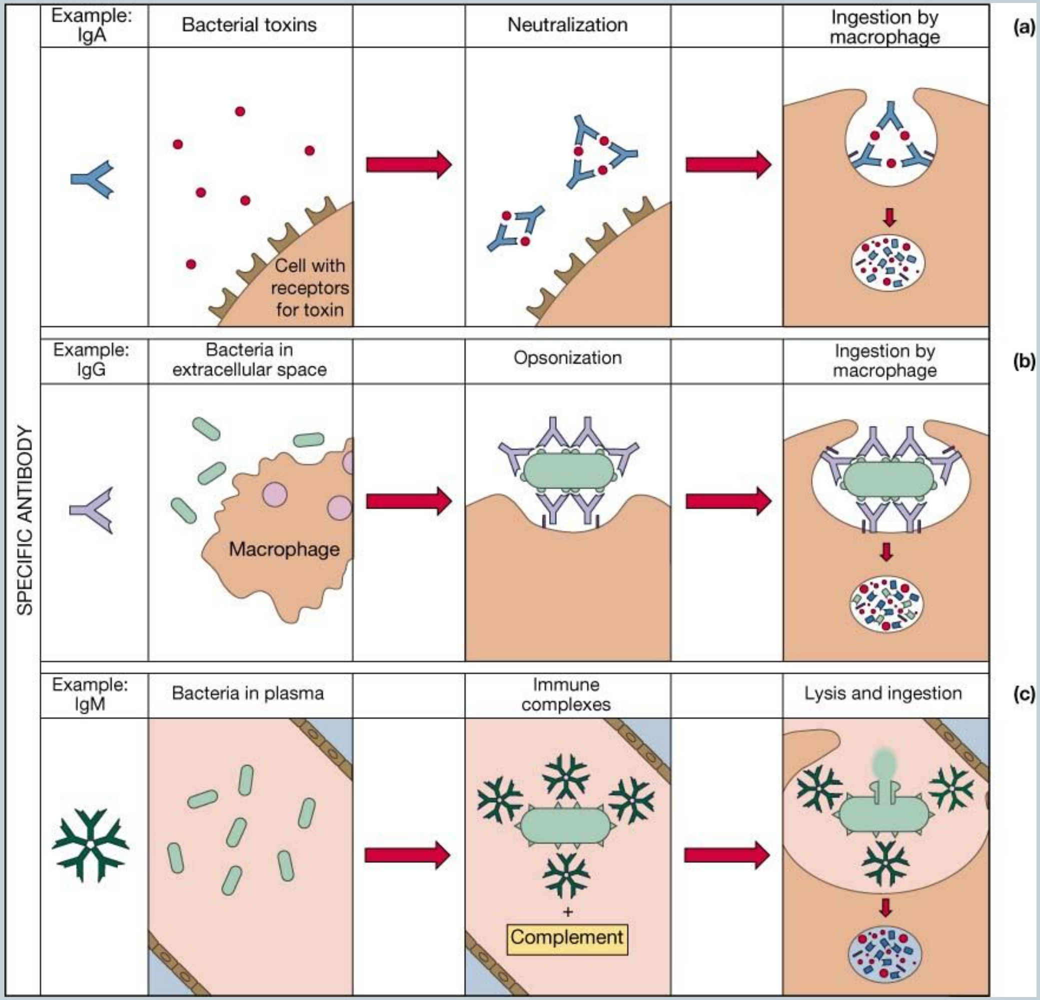




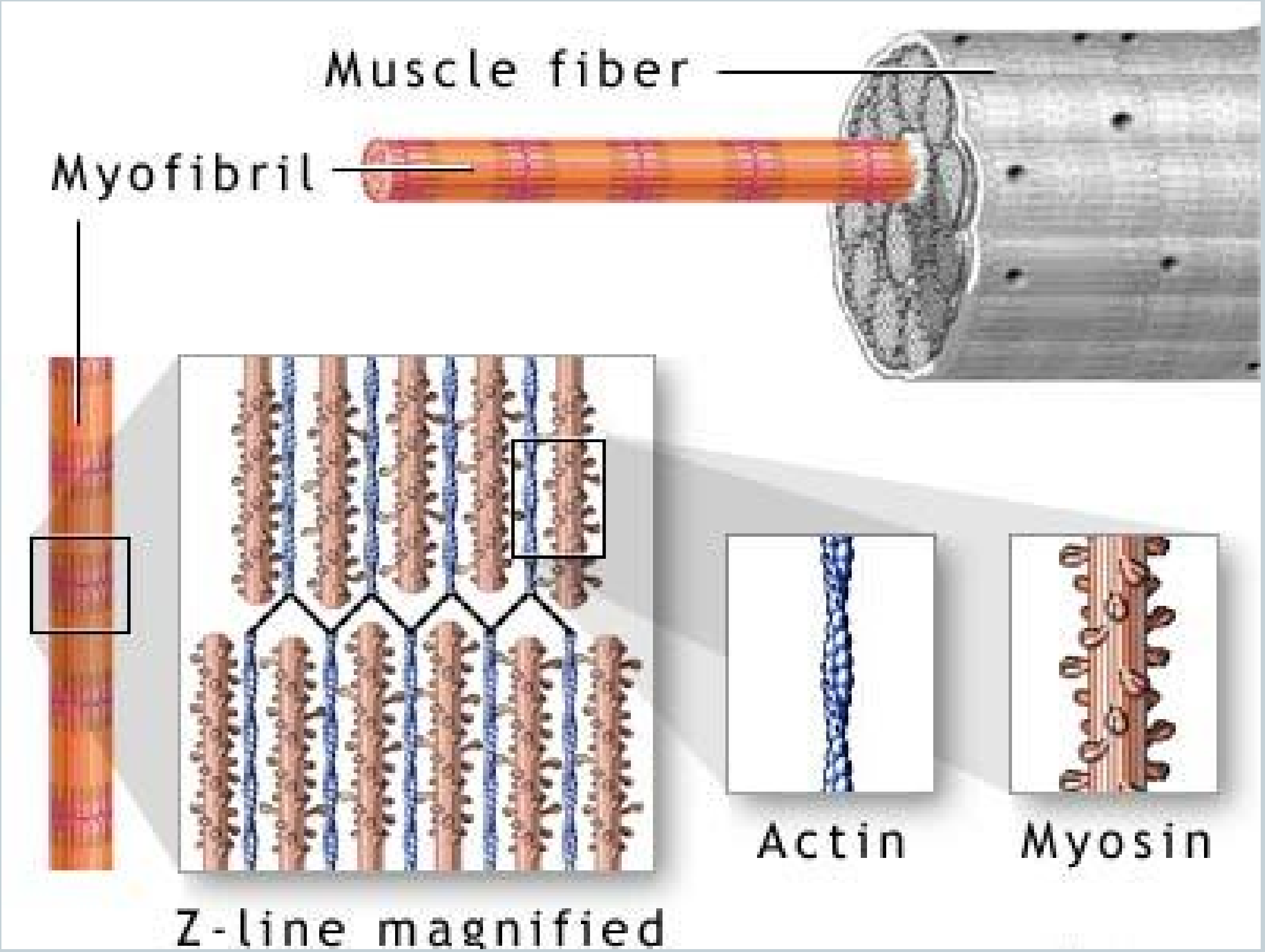
TRANSPORT: protein channels or carrier proteins



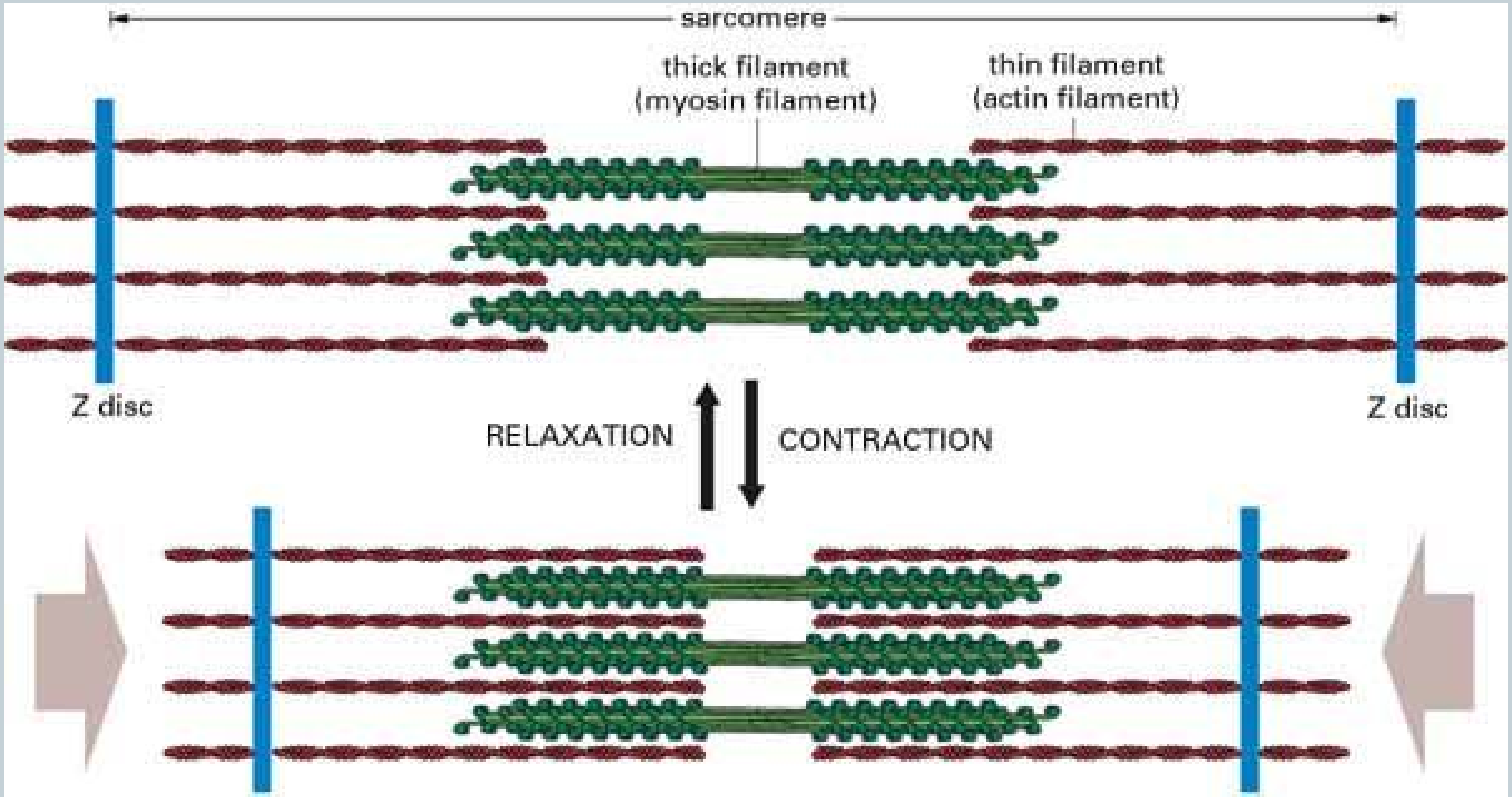
IMMUNITY: eg Antibodies



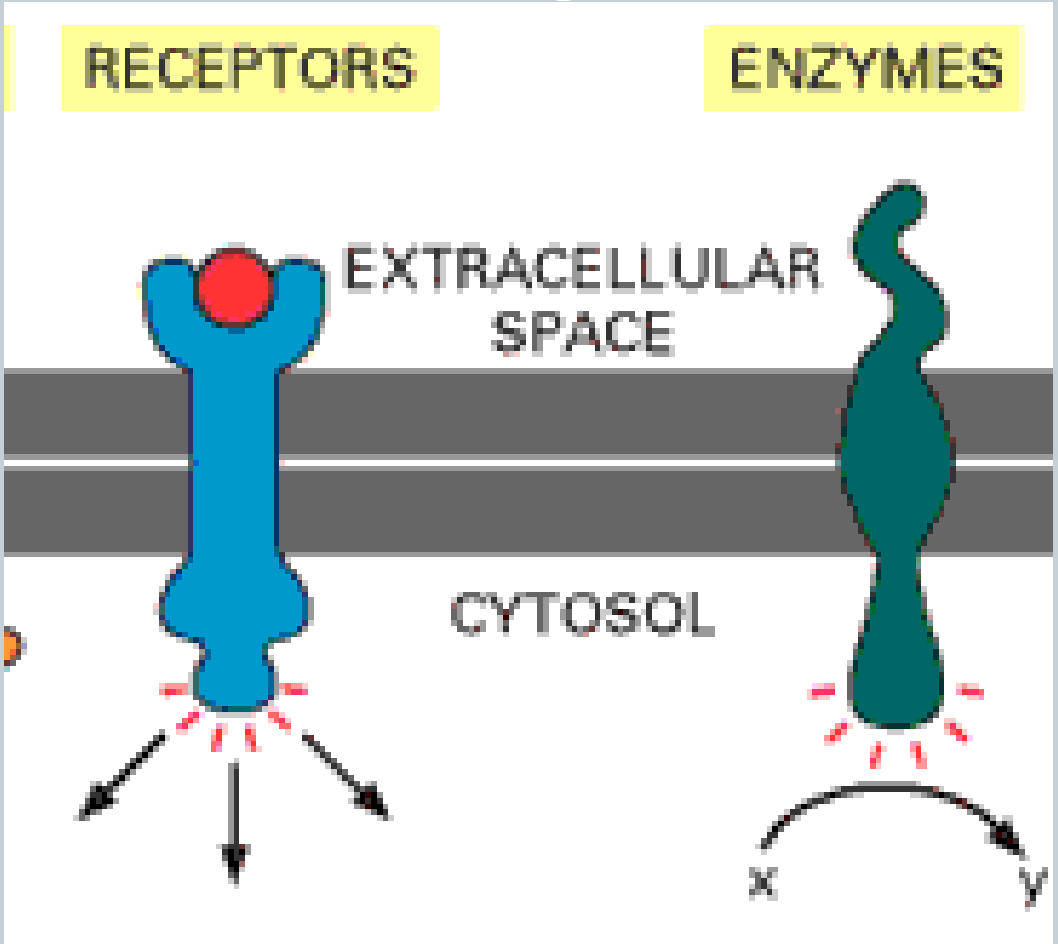
CONTRACTILE: eg Actin and Myosin



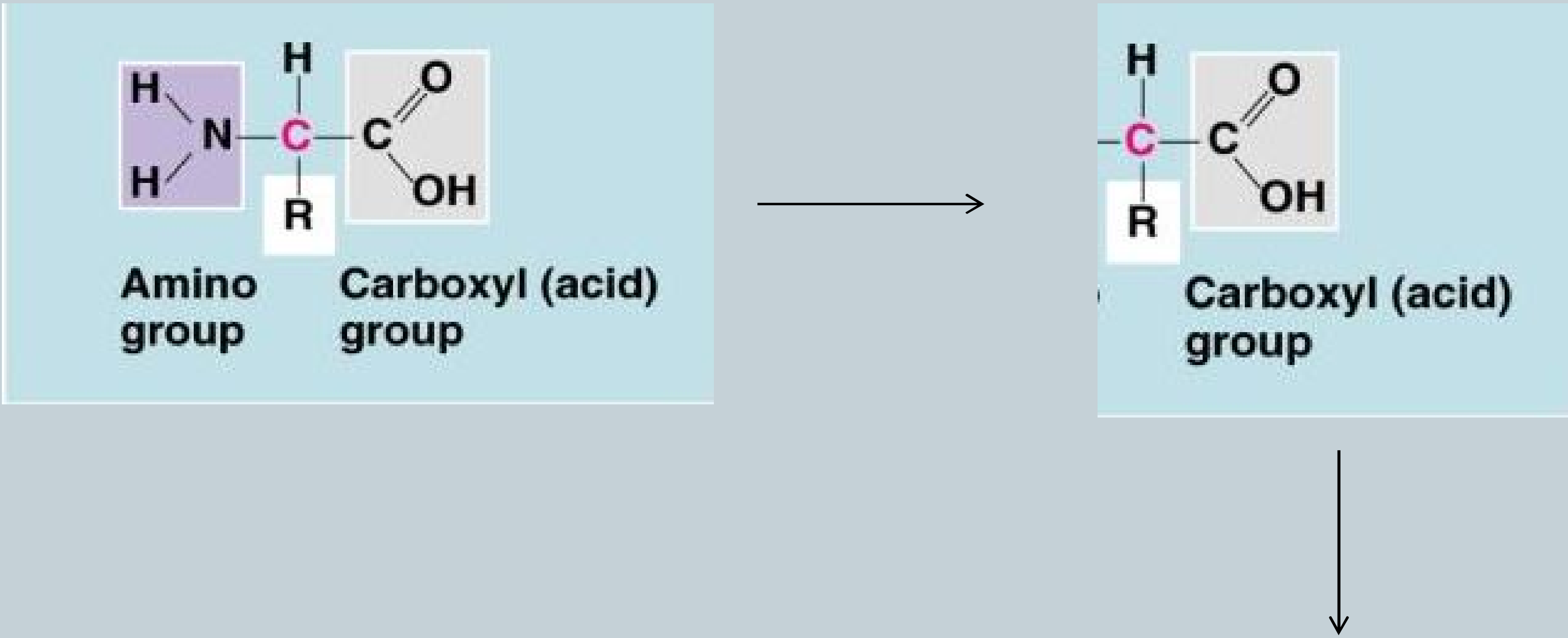
Muscle contraction &relaxation



Surface receptors



Secondary Energy source



respiration

FUNCTIONS OF PROTEIN

Antibodies

are specialized proteins involved in defending the body from antigens (foreign invaders). One way antibodies destroy antigens is by immobilizing them so that they can be destroyed by white blood cells.

Enzymes

are proteins that facilitate biochemical reactions. They are often referred to as catalysts because they speed up chemical reactions. Examples include the enzymes lactase and pepsin. Lactase breaks down the sugar lactose found in milk. Pepsin is a digestive enzyme that works in the stomach to break down proteins in food.

Hormonal Proteins

are messenger proteins which help to coordinate certain bodily activities. Examples include insulin, oxytocin, and somatotropin. Insulin regulates glucose metabolism by controlling the blood-sugar concentration. Oxytocin stimulates contractions in females during childbirth. Somatotropin is a growth hormone that stimulates protein production in muscle cells.

Contractile Protein

are responsible for movement. Examples include actin and myosin. These proteins are involved in muscle contraction and movement.

FUNCTIONS OF PROTEIN

Structural Proteins

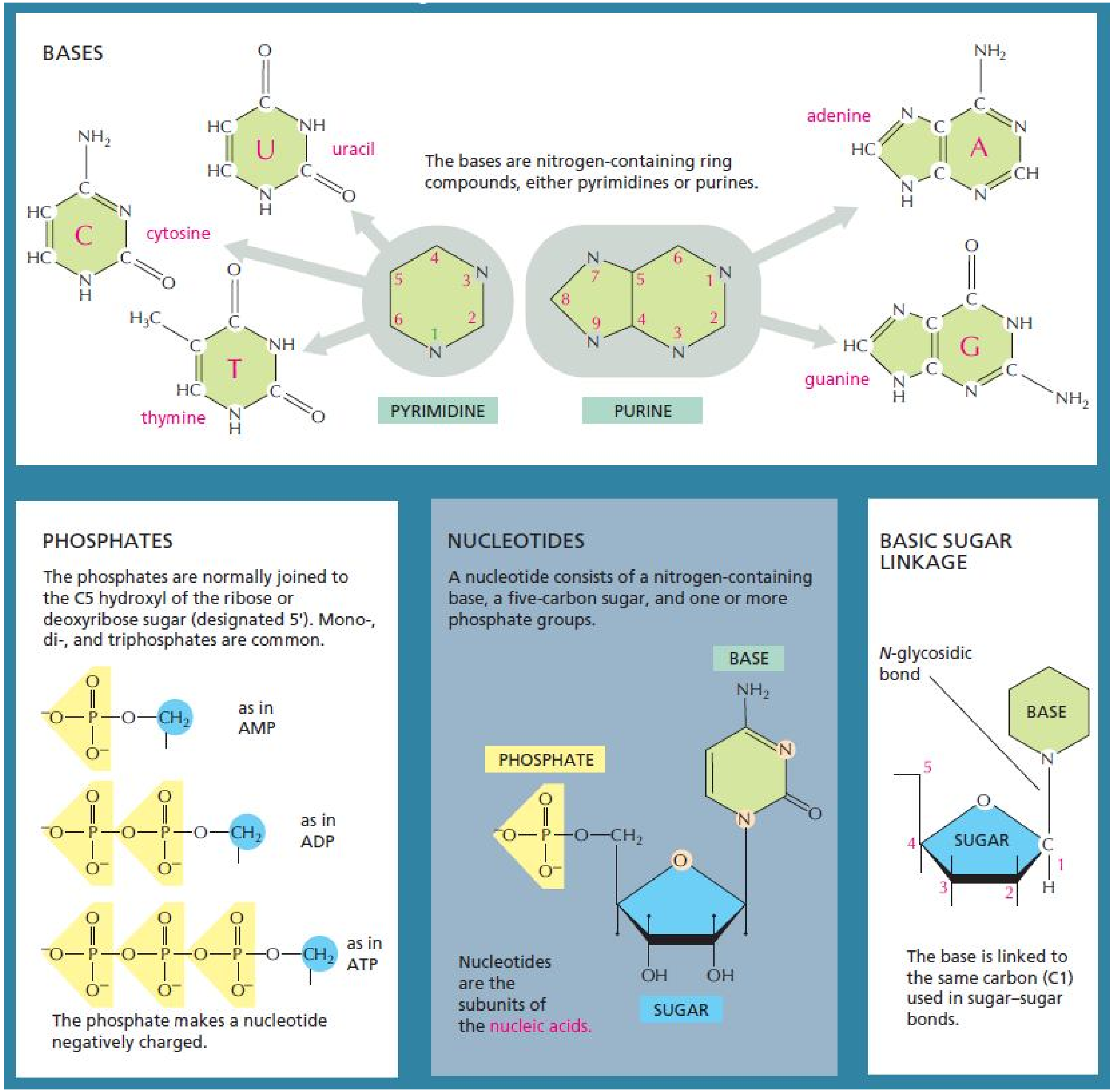
are fibrous and stringy and provide support. Examples include keratin, collagen, and elastin. Keratins strengthen protective coverings such as hair, quills, feathers, horns, and beaks. Collagens and elastin provide support for connective tissues such as tendons and ligaments.

Transport Proteins

are carrier proteins which move molecules from one place to another around the body. Examples include hemoglobin and cytochromes. Hemoglobin transports oxygen through the blood. Cytochromes operate in the electron transport chain as electron carrier proteins.

Storage Proteins

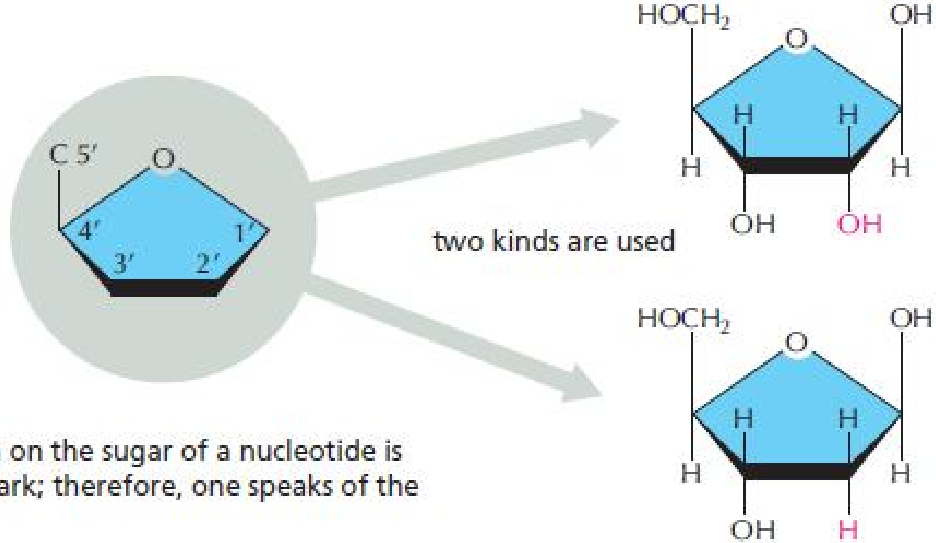
store amino acids. Examples include ovalbumin and casein. Ovalbumin is found in egg whites and casein is a milk-based protein.


BASES
uracil
cytosine
thymine
The bases are nitrogen-containing ring compounds, either pyrimidines or purines.
adenine
guanine
PYRIMIDINE
PURINE
PHOSPHATES
The phosphates are normally joined to the C5 hydroxyl of the ribose or deoxyribose sugar (designated 5'). Mono-, di-, and triphosphates are common.
as in AMP
as in ADP
as in ATP
The phosphate makes a nucleotide negatively charged.
NUCLEOTIDES
A nucleotide consists of a nitrogen-containing base, a five-carbon sugar, and one or more phosphate groups.
BASE
PHOSPHATE
SUGAR
Nucleotides are the subunits of the nucleic acids.
BASIC SUGAR LINKAGE
N-glycosidic bond
BASE
SUGAR
The base is linked to the same carbon (C1) used in sugar–sugar bonds.

SUGARS

PENTOSE

a five-carbon sugar



β-D-ribose
used in ribonucleic acid

β-D-2-deoxyribose
used in deoxyribonucleic acid

Each numbered carbon on the sugar of a nucleotide is followed by a prime mark; therefore, one speaks of the "5-prime carbon," etc.

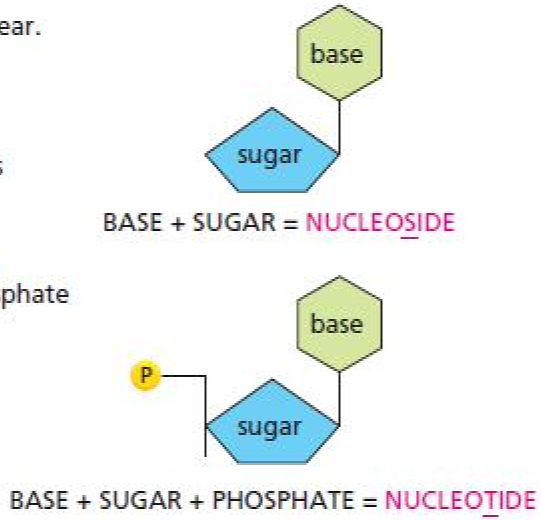
NOMENCLATURE

The names can be confusing, but the abbreviations are clear.

BASE	NUCLEOSIDE	ABBR.
adenine	adenosine	A
guanine	guanosine	G
cytosine	cytidine	C
uracil	uridine	U
thymine	thymidine	T

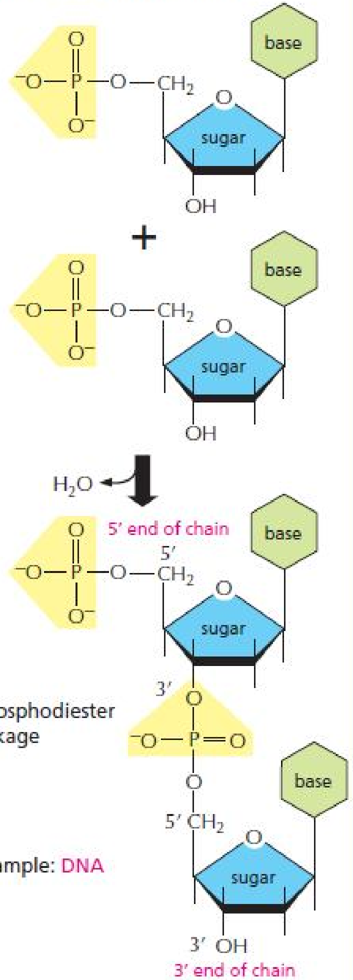
Nucleotides are abbreviated by three capital letters. Some examples follow:

AMP = adenosine monophosphate
dAMP = deoxyadenosine monophosphate
UDP = uridine diphosphate
ATP = adenosine triphosphate



NUCLEIC ACIDS

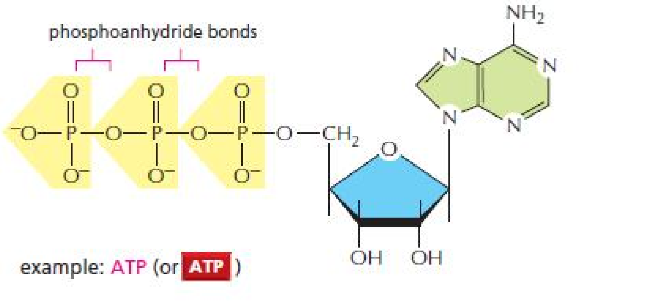
Nucleotides are joined together by a phosphodiester linkage between 5′ and 3′ carbon atoms to form nucleic acids. The linear sequence of nucleotides in a nucleic acid chain is commonly abbreviated by a one-letter code, A—G—C—T—T—A—C—A, with the 5′ end of the chain at the left.



example: DNA

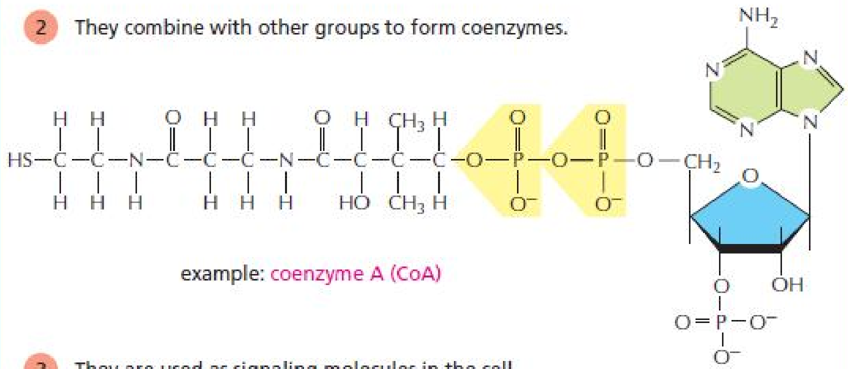
NUCLEOTIDES HAVE MANY OTHER FUNCTIONS

1 They carry chemical energy in their easily hydrolyzed phosphoanhydride bonds.



example: ATP (or ATP)

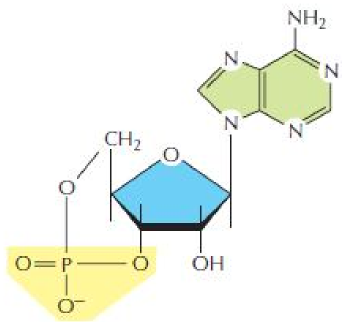
2 They combine with other groups to form coenzymes.

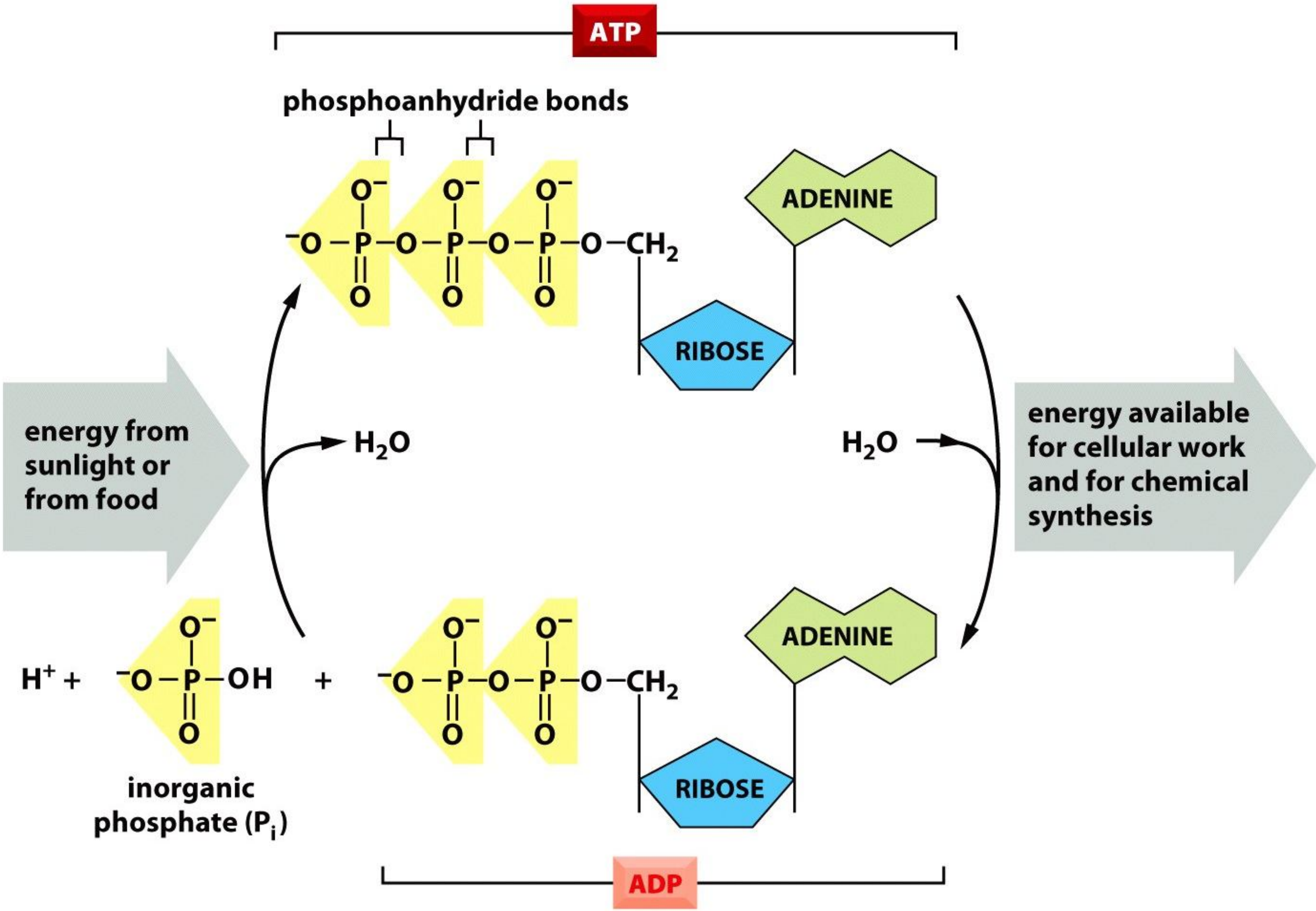


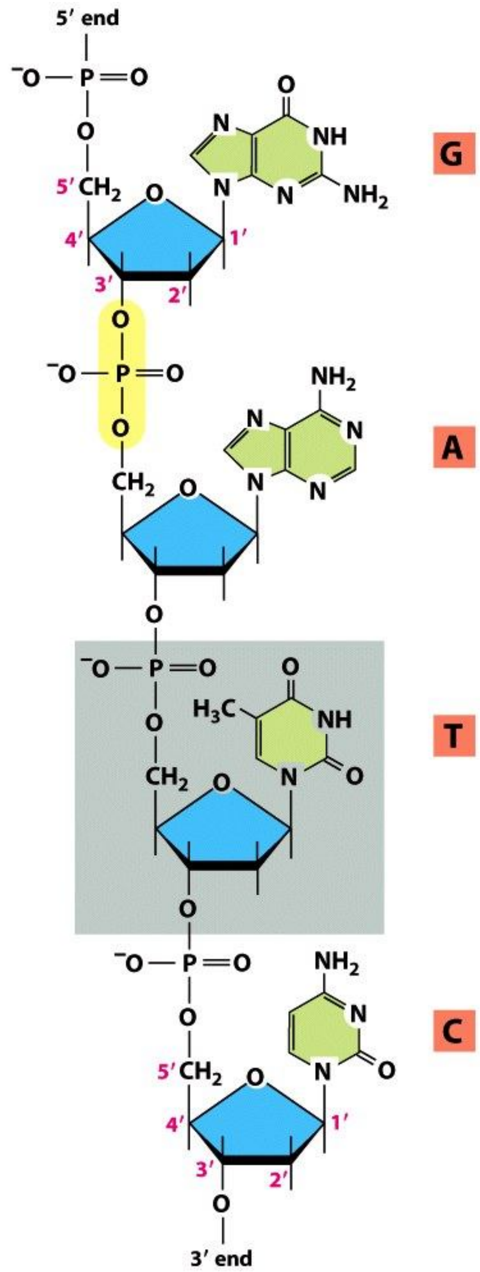
example: coenzyme A (CoA)

3 They are used as signaling molecules in the cell.

example: cyclic AMP




ATP
phosphoanhydride bonds
ADENINE
RIBOSE
energy from sunlight or from food
H_2O
H_2O
energy available for cellular work and for chemical synthesis
H^+ +
inorganic phosphate (P_i)
ADENINE
RIBOSE
ADP



5′ end
G
A
T
C
3′ end

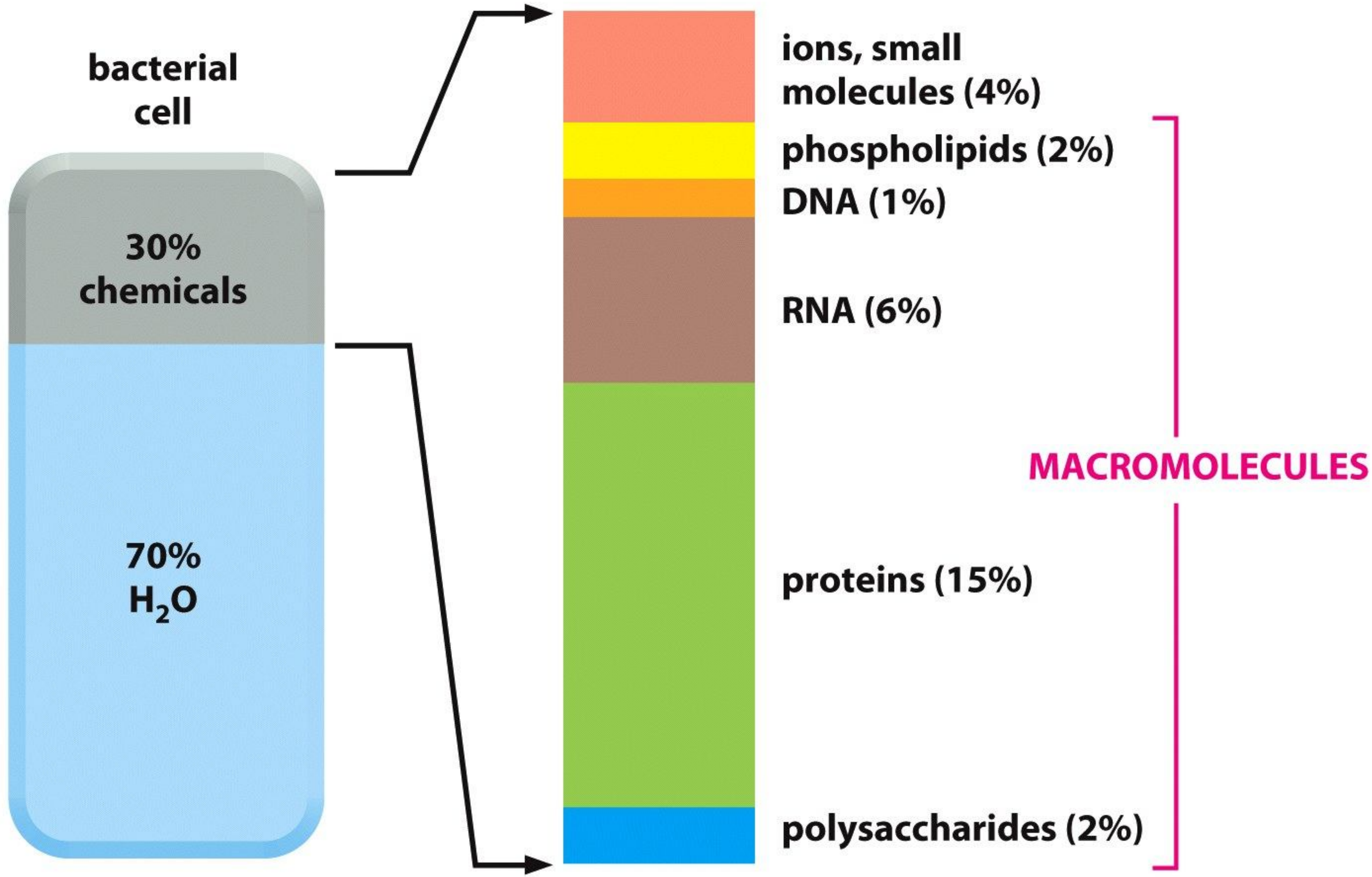
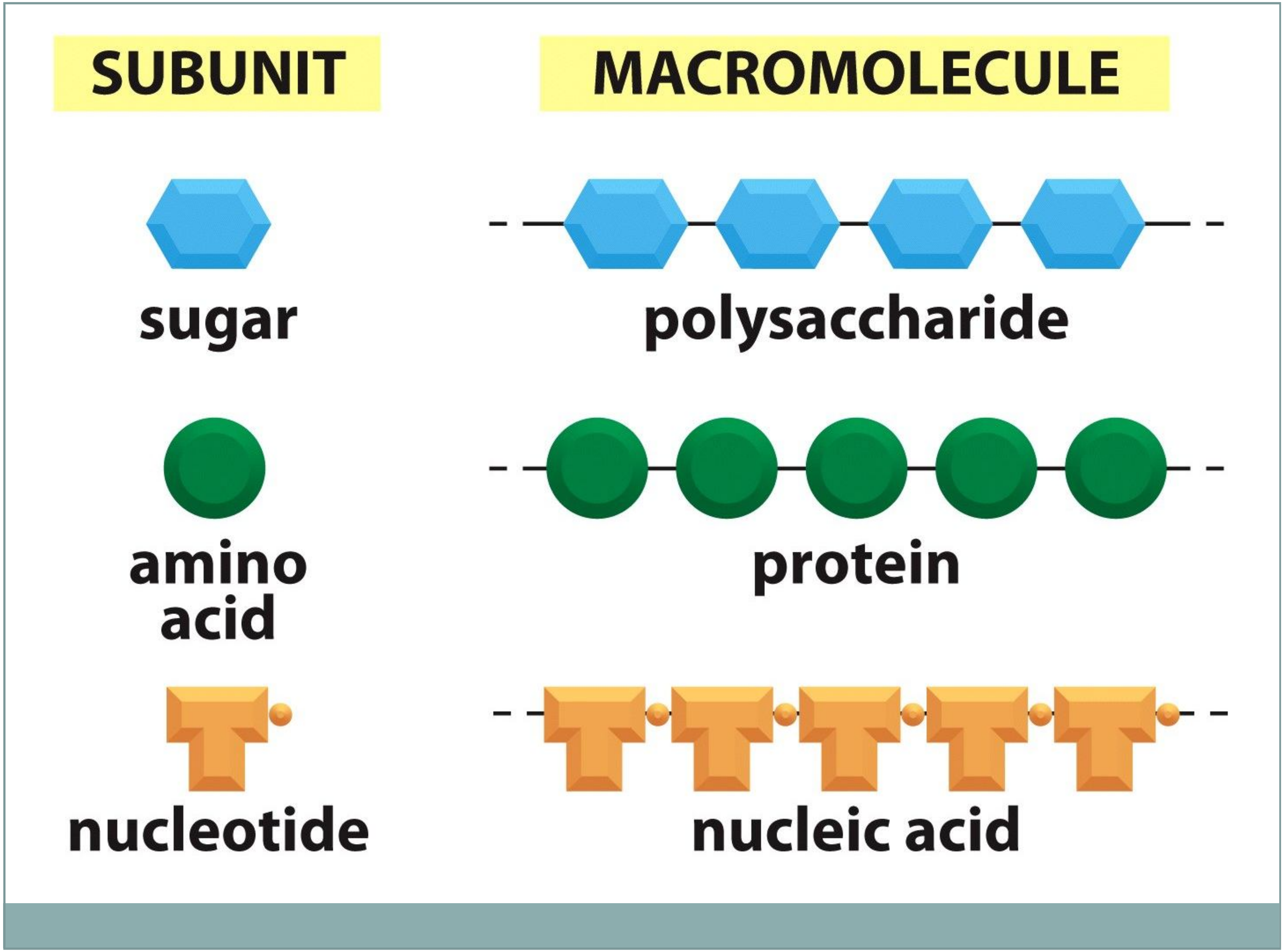
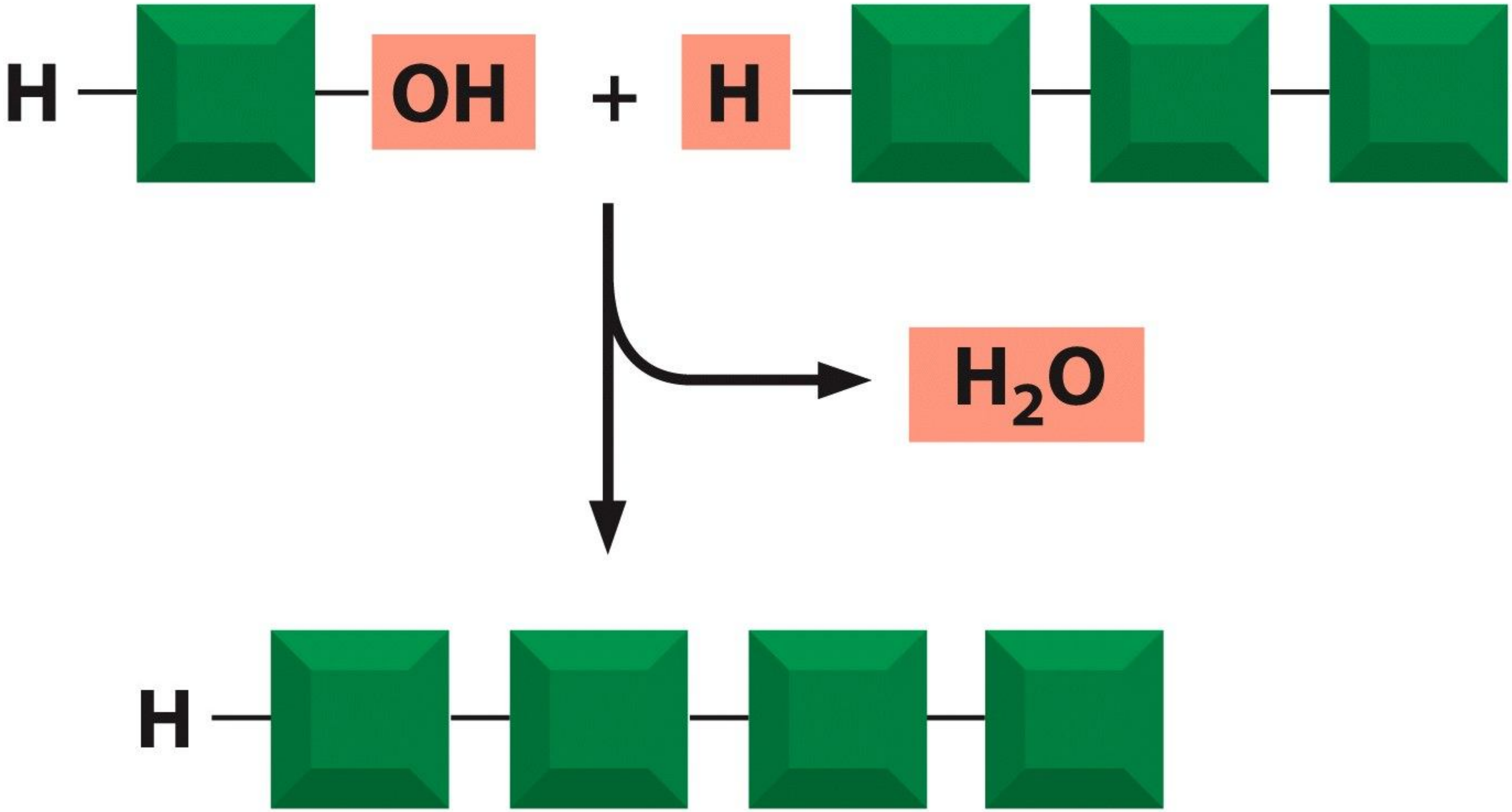
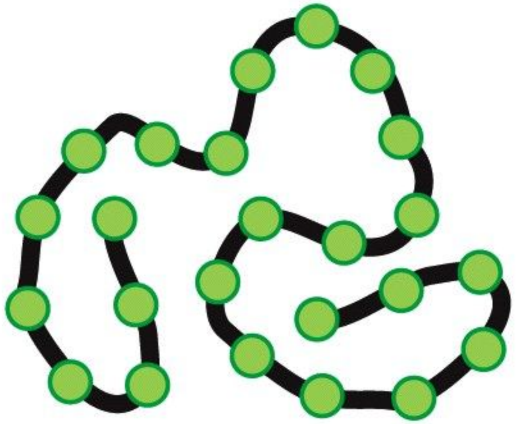


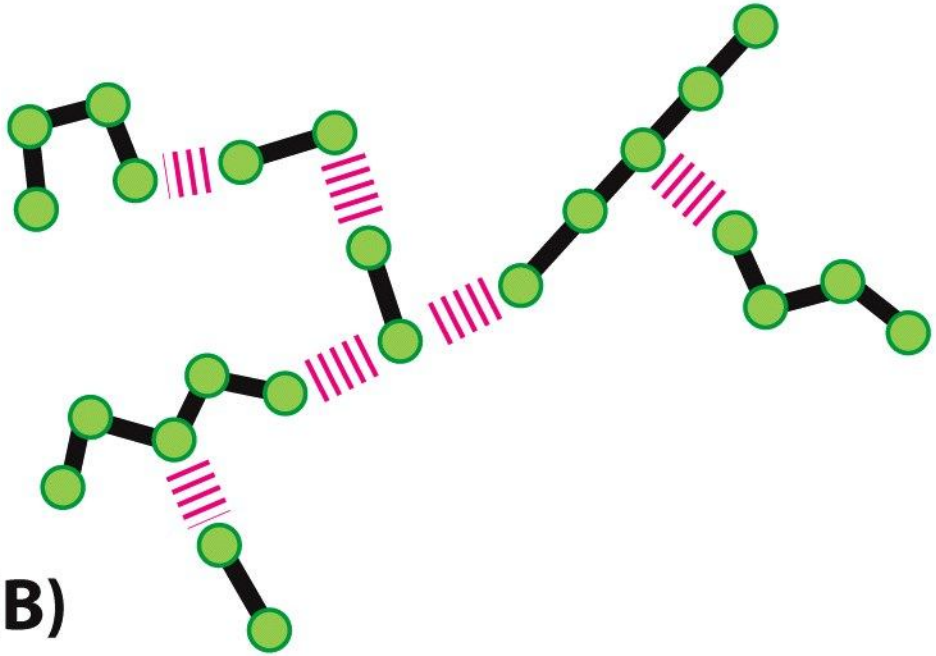
Figure 2-26 *Essential Cell Biology* (© Garland Science 2010)


SUBUNIT
MACROMOLECULE
sugar
polysaccharide
amino acid
protein
nucleotide
nucleic acid

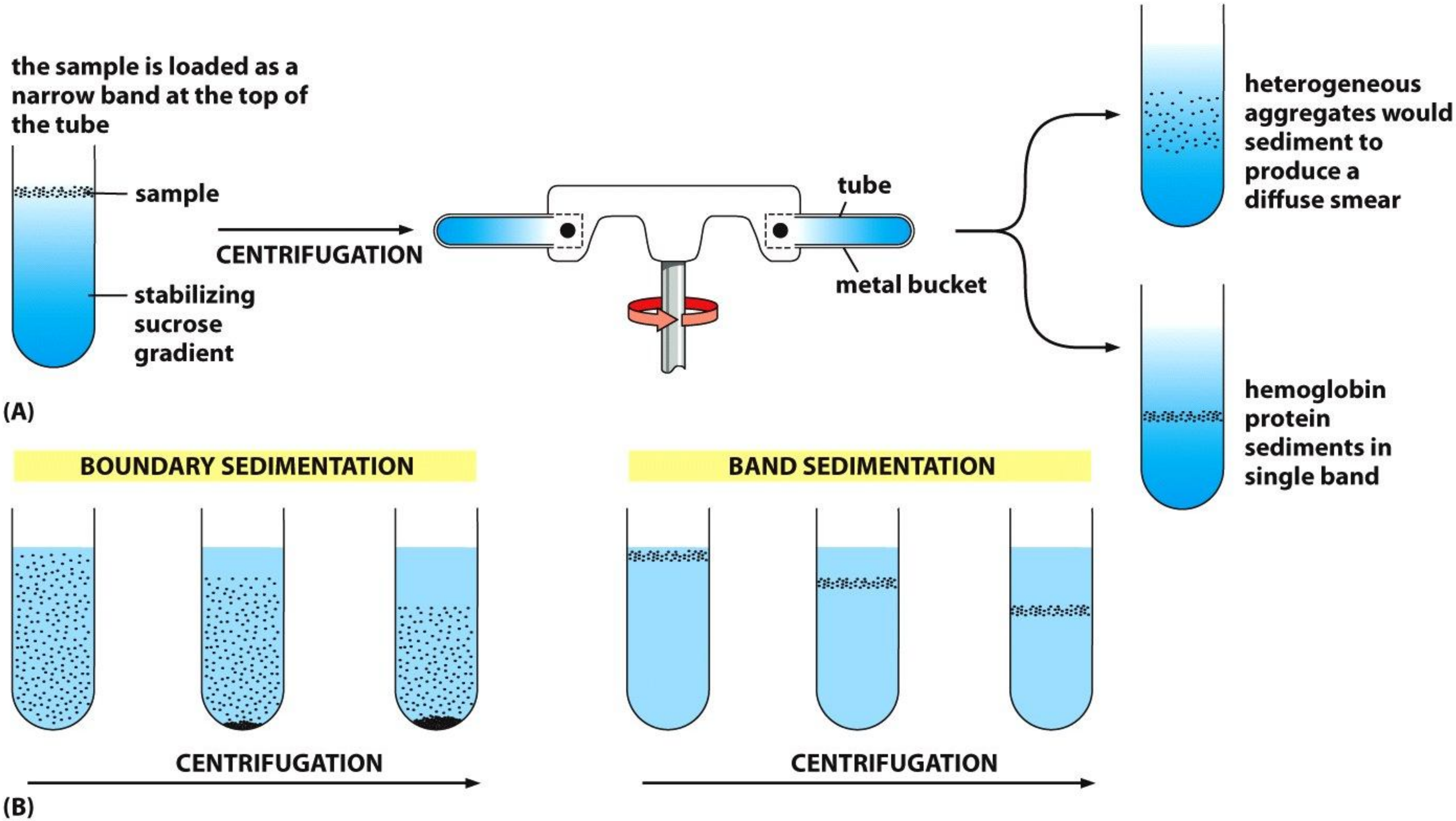

H
OH
+
H
H_2O
H



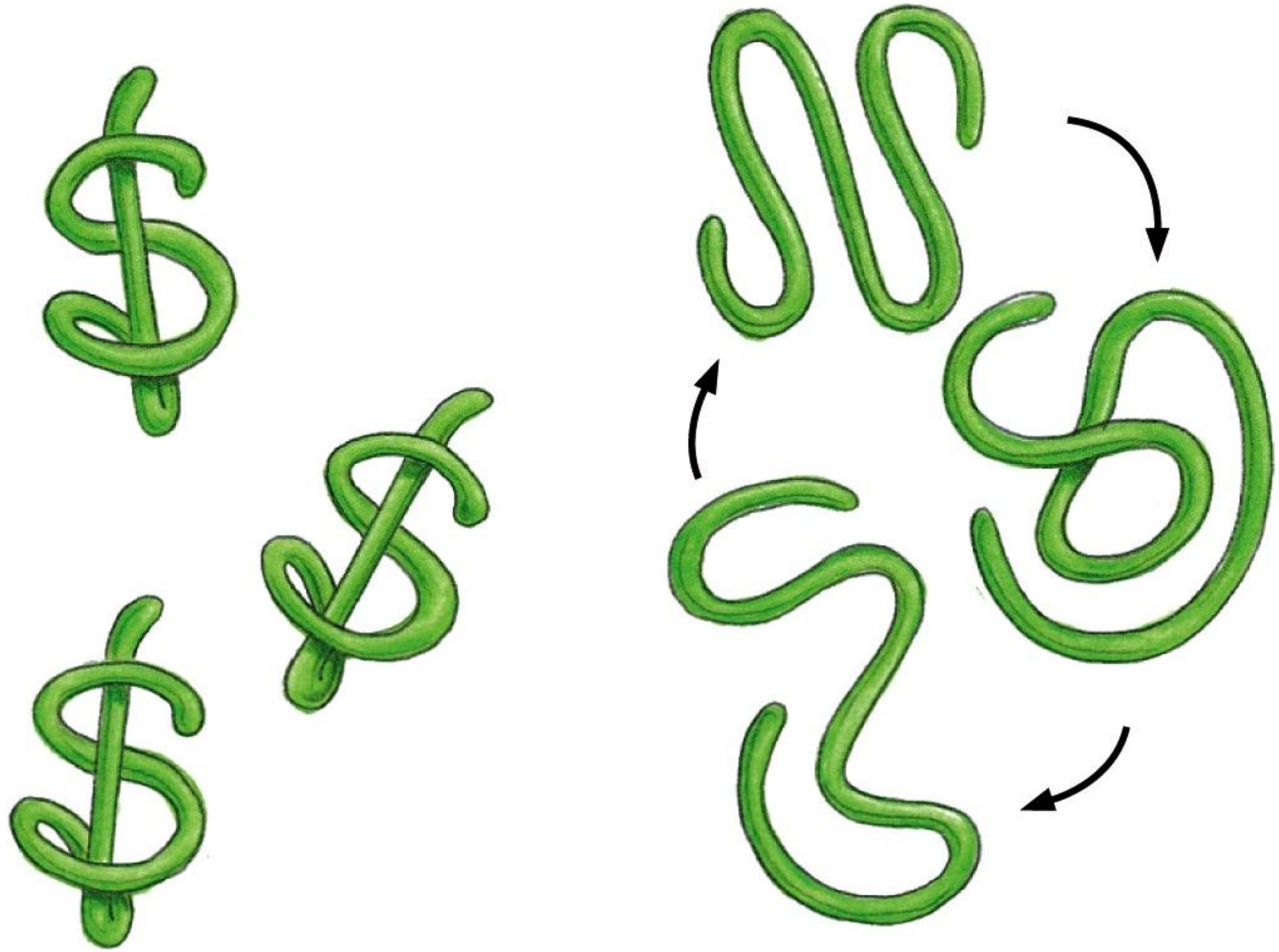
(A)



(B)

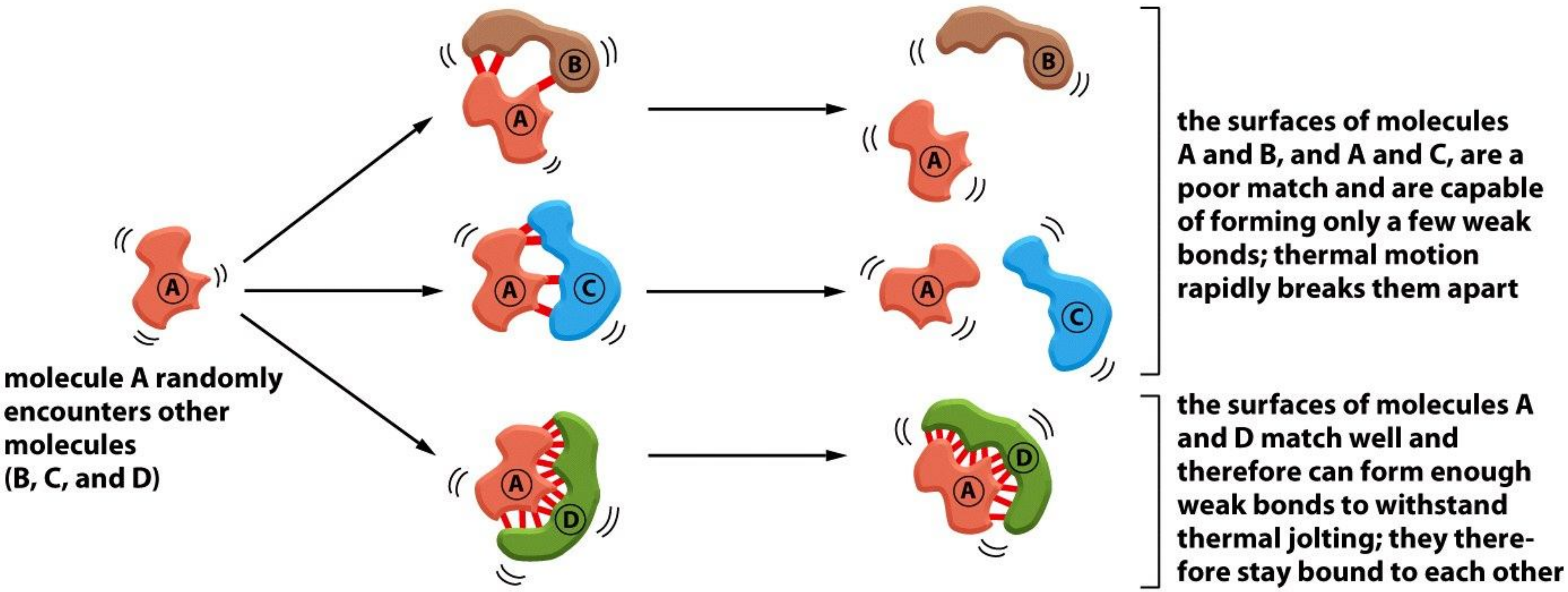


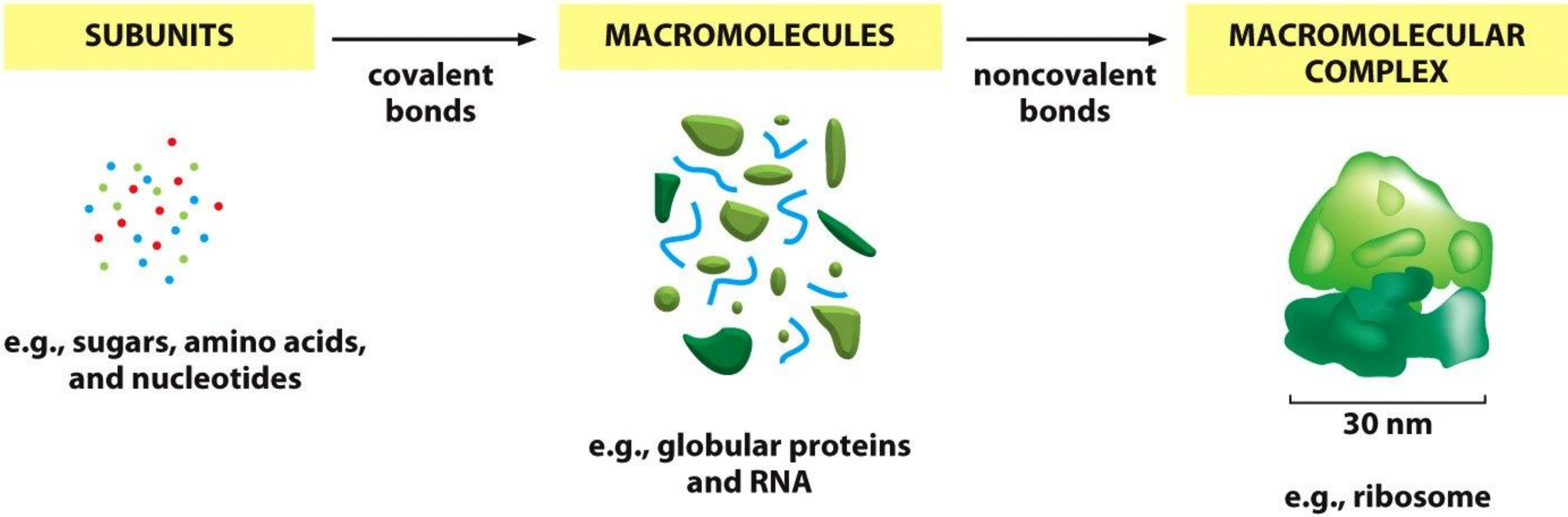
the sample is loaded as a narrow band at the top of the tube
sample
stabilizing sucrose gradient
CENTRIFUGATION
tube
metal bucket
heterogeneous aggregates would sediment to produce a diffuse smear
hemoglobin protein sediments in single band
(A)
BOUNDARY SEDIMENTATION
BAND SEDIMENTATION
CENTRIFUGATION
CENTRIFUGATION
(B)

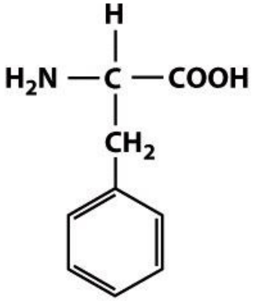


one stable folded conformation

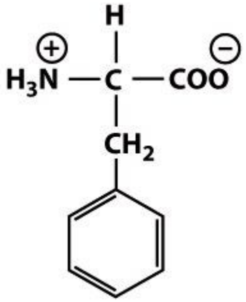
many unstable conformations


A
B
C
D
molecule A randomly encounters other molecules (B, C, and D)
the surfaces of molecules A and B, and A and C, are a poor match and are capable of forming only a few weak bonds; thermal motion rapidly breaks them apart
the surfaces of molecules A and D match well and therefore can form enough weak bonds to withstand thermal jolting; they therefore stay bound to each other

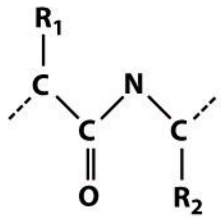

SUBUNITS
covalent bonds
MACROMOLECULES
noncovalent bonds
MACROMOLECULAR COMPLEX
e.g., sugars, amino acids, and nucleotides
e.g., globular proteins and RNA
30 nm
e.g., ribosome



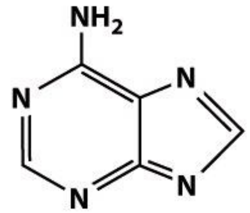
(A)



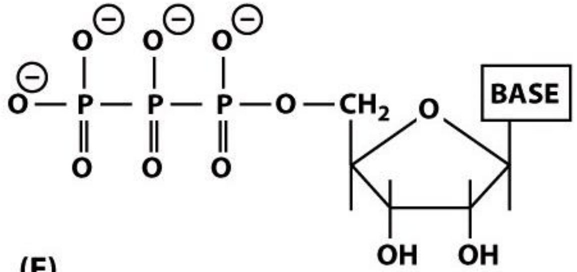
(B)



(C)



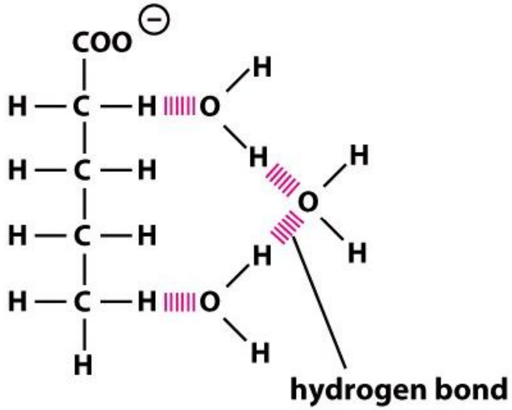
(D)



(E)

CH_3-CH_2-OH

(F)



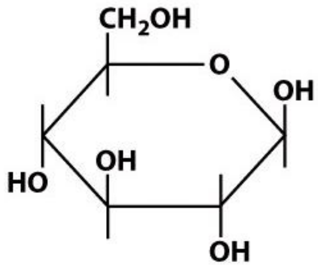
(G)

Na — Cl

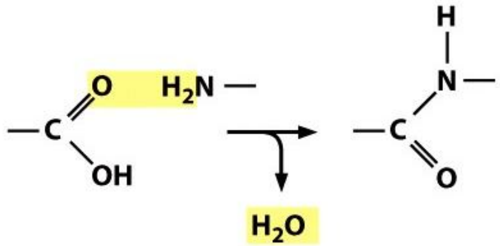
(H)

$\overset{\delta^+}{O}=\overset{\delta^-}{C}=\overset{\delta^+}{O}$

(I)



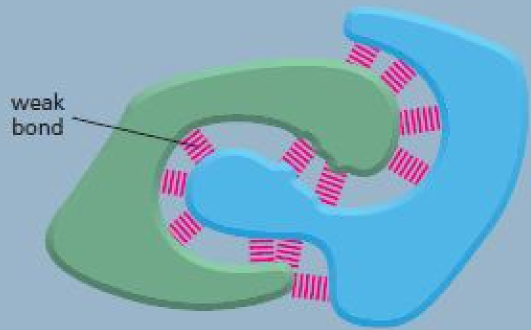
(J)



(K)

WEAK CHEMICAL BONDS

Organic molecules can interact with other molecules through three types of short-range attractive forces known as *noncovalent bonds:* van der Waals attractions, electrostatic attractions, and hydrogen bonds. The repulsion of hydrophobic groups from water is also important for ordering biological macromolecules.



Weak chemical bonds have less than 1/20 the strength of a strong covalent bond. They are strong enough to provide tight binding only when many of them are formed simultaneously.

HYDROGEN BONDS

As already described for water (see Panel 2–2, pp. 66–67) hydrogen bonds form when a hydrogen atom is "sandwiched" between two electron-attracting atoms (usually oxygen or nitrogen).

Hydrogen bonds are strongest when the three atoms are in a straight line:

VAN DER WAALS ATTRACTIONS

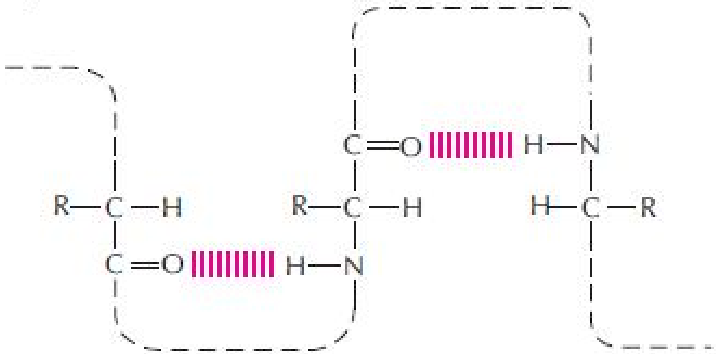
If two atoms are too close together they repel each other very strongly. For this reason, an atom can often be treated as a sphere with a fixed radius. The characteristic "size" for each atom is specified by a unique van der Waals radius. The contact distance between any two non-covalently bonded atoms is the sum of their van der Waals radii.

At very short distances any two atoms show a weak bonding interaction due to their fluctuating electrical charges. The two atoms will be attracted to each other in this way until the distance between their nuclei is approximately equal to the sum of their van der Waals radii. Although they are individually very weak, van der Waals attractions can become important when two macromolecular surfaces fit very close together, because many atoms are involved.

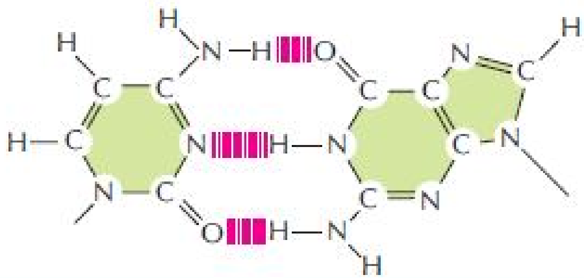
Note that when two atoms form a covalent bond, the centers of the two atoms (the two atomic nuclei) are much closer together than the sum of the two van der Waals radii. Thus,

Examples in macromolecules:

Amino acids in polypeptide chains hydrogen-bonded together.

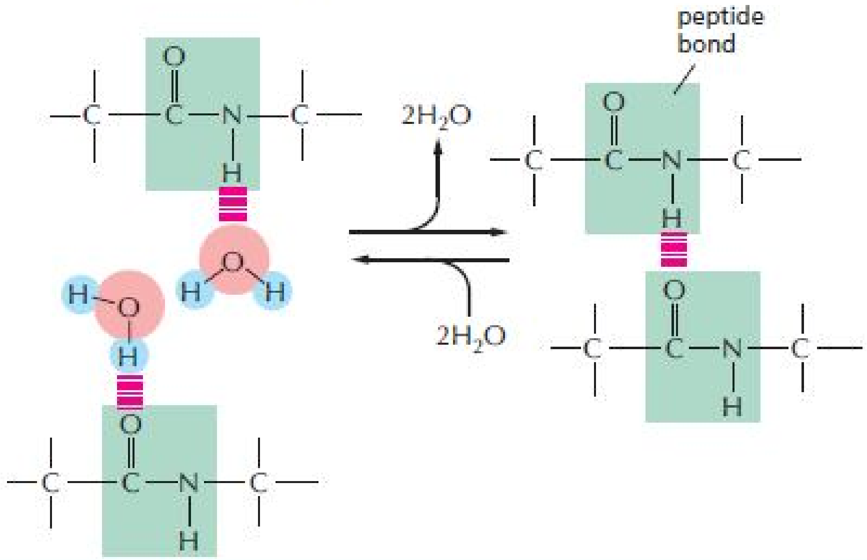


Two bases, G and C, hydrogen-bonded in DNA or RNA.

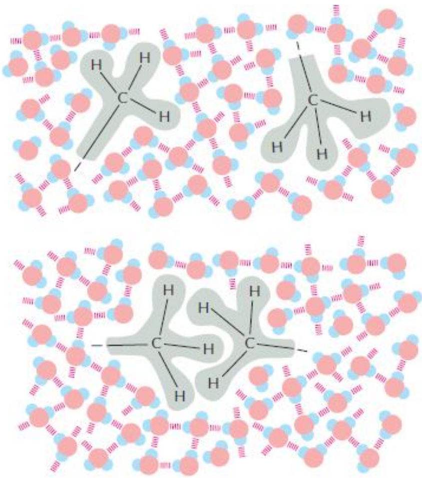


HYDROGEN BONDS IN WATER

Any molecules that can form hydrogen bonds to each other can alternatively form hydrogen bonds to water molecules. Because of this competition with water molecules, the hydrogen bonds formed between two molecules dissolved in water are relatively weak.



HYDROPHOBIC FORCES



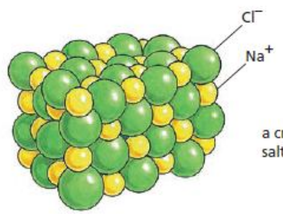
Water forces hydrophobic groups together in order to minimize their disruptive effects on the hydrogen-bonded water network. Hydrophobic groups held together in this way are sometimes said to be held together by "hydrophobic bonds," even though the attraction is actually caused by a repulsion from the water.

ELECTROSTATIC ATTRACTIONS

Attractive interactions occur both between fully charged groups (ionic bond) and between partially charged groups on polar molecules.

The force of attraction between the two charges, δ^{+} and δ^{-}, falls off rapidly as the distance between the charges increases.

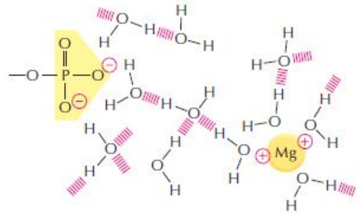
In the absence of water, electrostatic forces are very strong. They are responsible for the strength of such minerals as marble and agate, and for crystal formation in common table salt, NaCl.



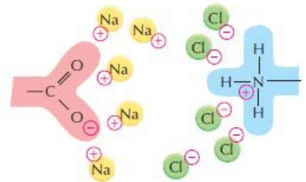
a crystal of salt, NaCl

ELECTROSTATIC ATTRACTIONS IN AQUEOUS SOLUTIONS

Charged groups are shielded by their interactions with water molecules. electrostatic attractions are therefore quite weak in water.



Similarly, ions in solution can cluster around charged groups and further weaken these attractions.



Despite being weakened by water and salt, electrostatic attractions are very important in biological systems. For example, an enzyme that binds a positively charged substrate will often have a negatively charged amino acid side chain at the appropriate place.