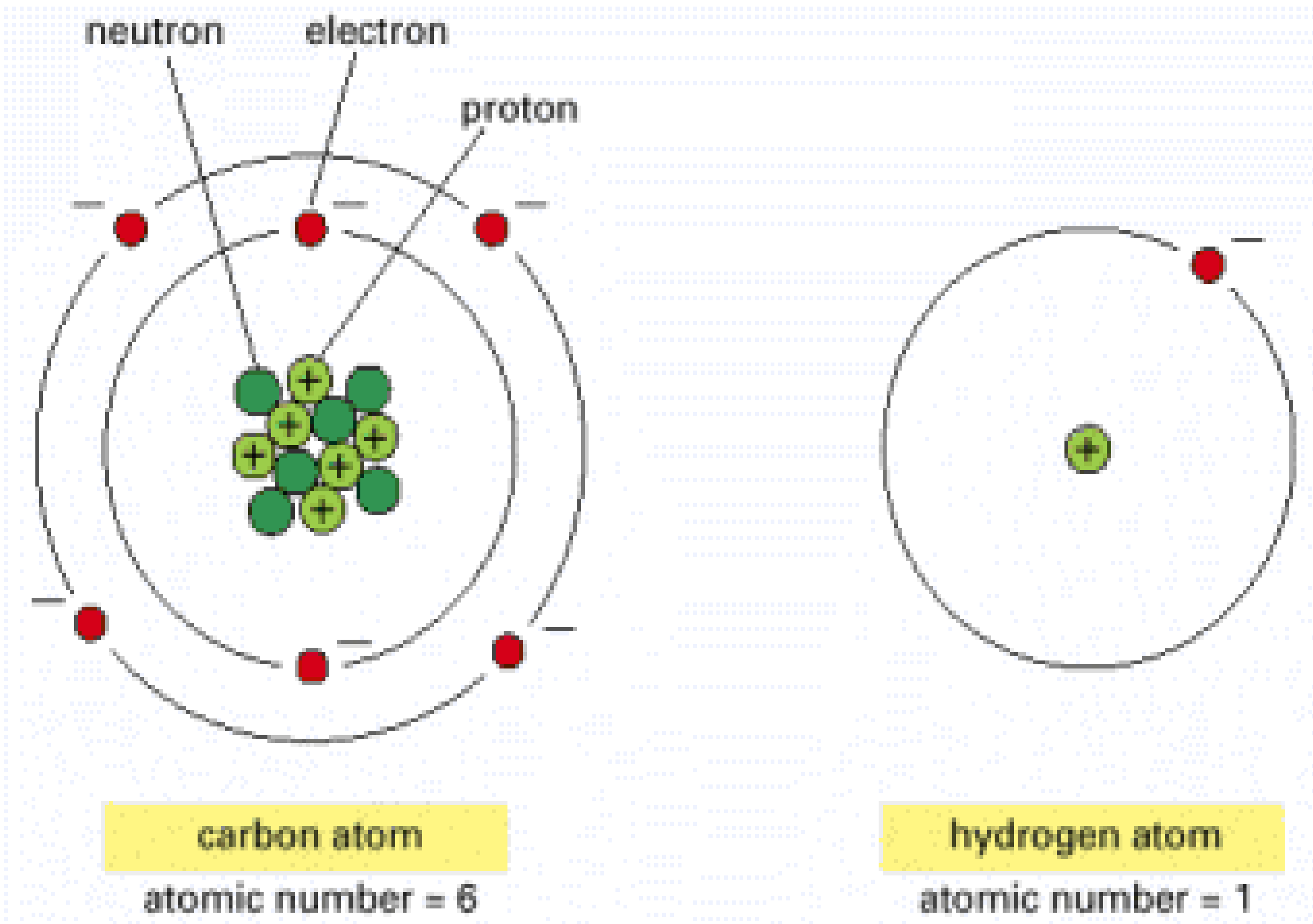
The chemical components of the cell

Dr. C Basumata

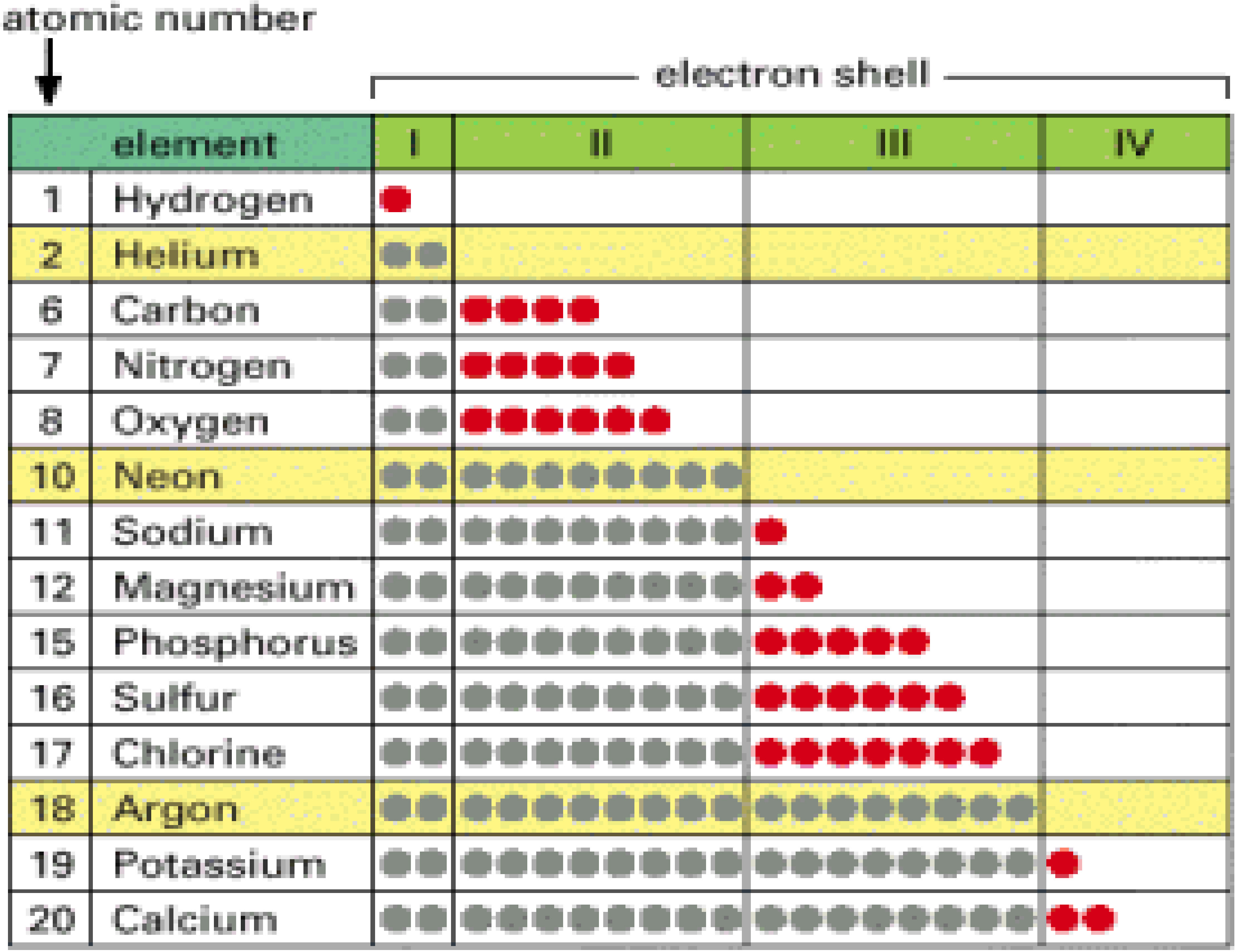
Cells Are Made From a Few Types of Atoms

- The structure of atoms
  - Protons, neutrons, electrons etc.
- Atomic weight
- Mole
- Cells are made of only a small selection of these elements.

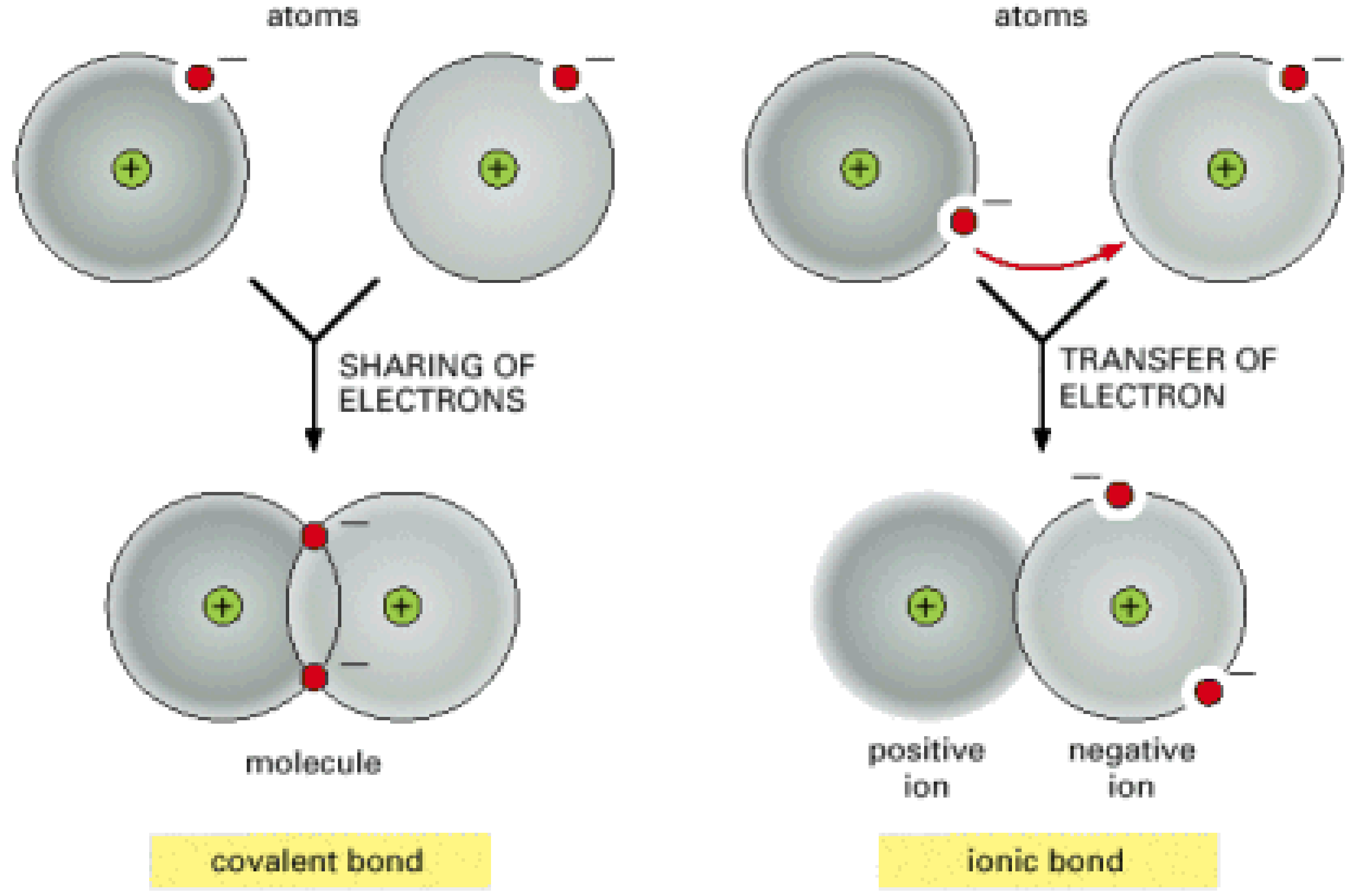

neutron
electron
proton
carbon atom
atomic number = 6
hydrogen atom
atomic number = 1

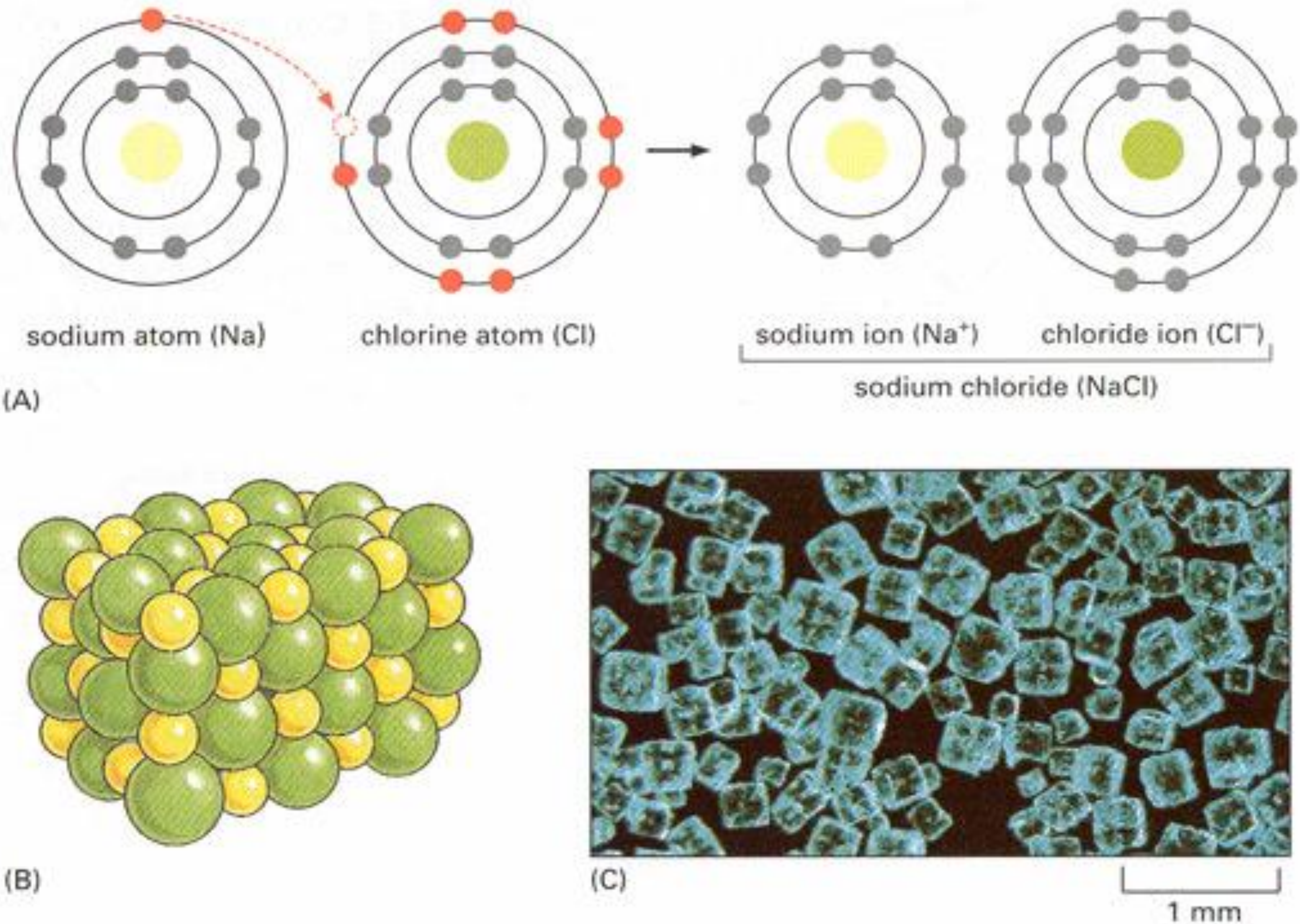
How Atoms Interact: atomic bonds

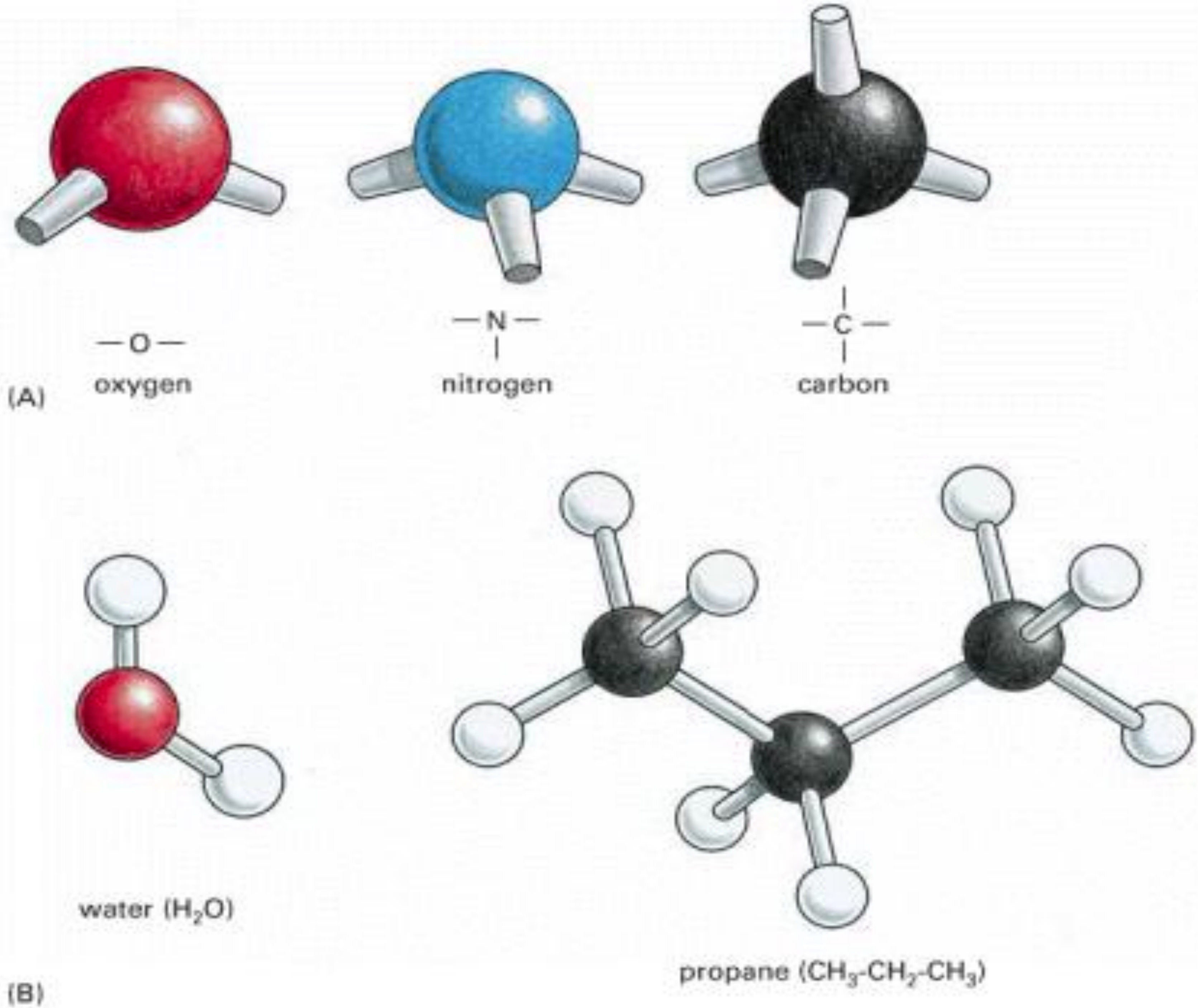
- Electrons are in continuous motion around the nucleus, following rules of quantum physics.
  - They occupy discrete states: electron shell
- An atom whose outermost shell is entirely filled with electrons is especially stable and therefore chemically unreactive.
  - Inert gases: Helium (2 electrons), neon (2 + 8), and argon (2 + 8 + 8)
  - Hydrogen: only one electron and only a half-filled shell, is highly reactive

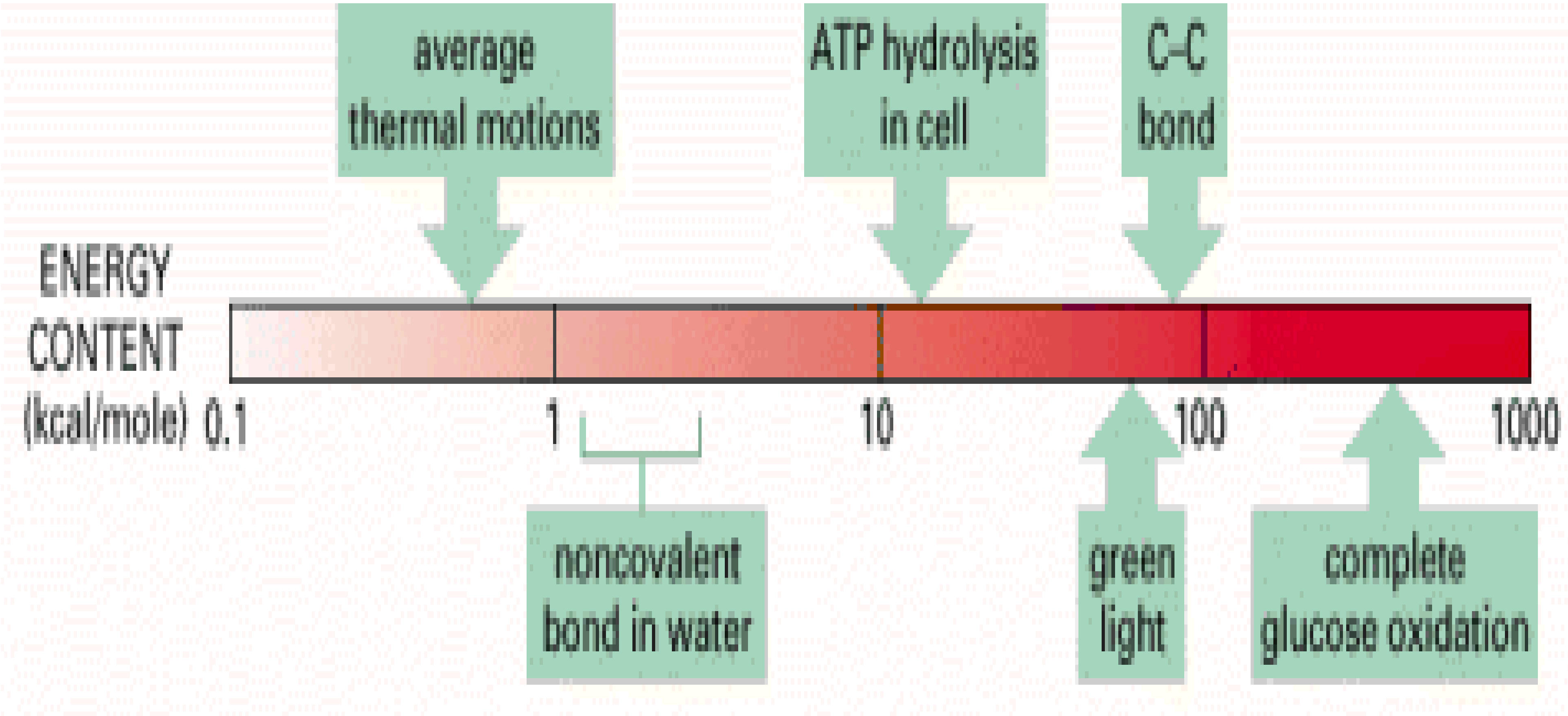

atomic number
electron shell
element
I
II
III
IV
1 Hydrogen
2 Helium
6 Carbon
7 Nitrogen
8 Oxygen
10 Neon
11 Sodium
12 Magnesium
15 Phosphorus
16 Sulfur
17 Chlorine
18 Argon
19 Potassium
20 Calcium

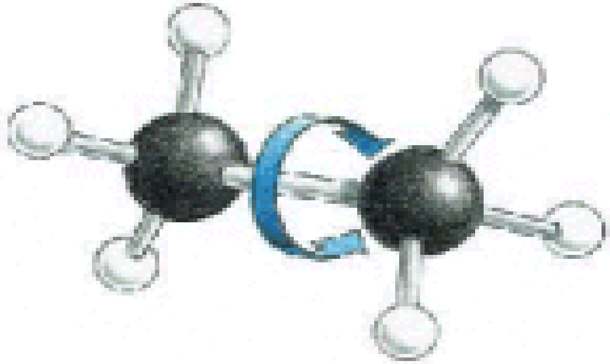
Chemical bonds: covalent and ionic



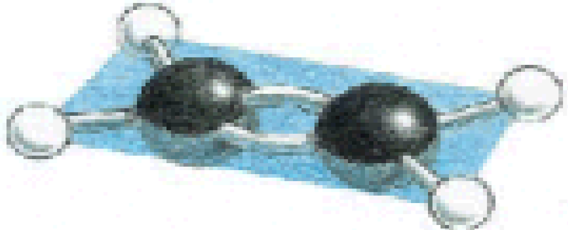

sodium atom (Na)
chlorine atom (Cl)
sodium ion (Na⁺)
chloride ion (Cl⁻)
sodium chloride (NaCl)
(A)
(B)
(C)
1 mm


—O—
oxygen
—N—
nitrogen
—C—
carbon
(A)
water (H_2O)
propane (CH_3-CH_2-CH_3)
(B)


average
thermal motions
ATP hydrolysis
in cell
C–C
bond
ENERGY
CONTENT
(kcal/mole) 0.1
1
10
100
1000
noncovalent
bond in water
green
light
complete
glucose oxidation



(A) ethane



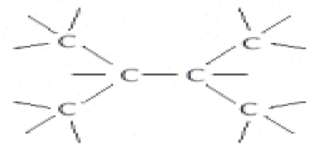
(B) ethene

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.

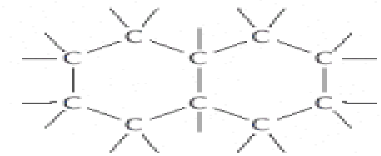
also written as 

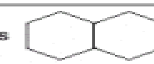
or branched trees



also written as 

or rings



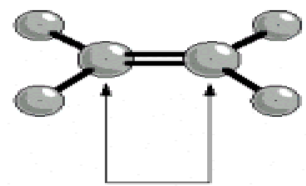
also written as 

COVALENT BONDS

A covalent bond forms when two atoms come very close together and share one or more of their electrons. In a single bond one electron from each of the two atoms is shared; in a double bond a total of four electrons are shared.

Each atom forms a fixed number of covalent bonds in a defined spatial arrangement. For example, carbon forms four single bonds arranged tetrahedrally, whereas nitrogen forms three single bonds and oxygen forms two single bonds arranged as shown below.

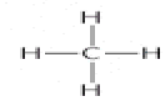
Double bonds exist and have a different spatial arrangement.



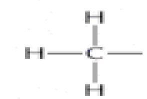
Atoms joined by two or more covalent bonds cannot rotate freely around the bond axis. This restriction is a major influence on the three-dimensional shape of many macromolecules.

HYDROCARBONS

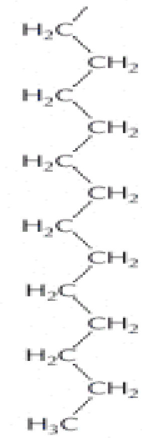
Carbon and hydrogen combine together to make stable compounds (or chemical groups) called hydrocarbons. These are nonpolar, do not form hydrogen bonds, and are generally insoluble in water.



methane



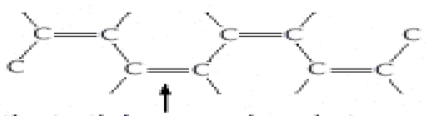
methyl group



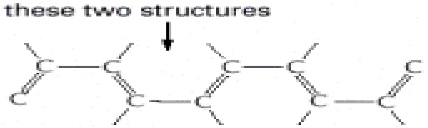
part of the hydrocarbon "tail" of a fatty acid molecule

ALTERNATING DOUBLE BONDS

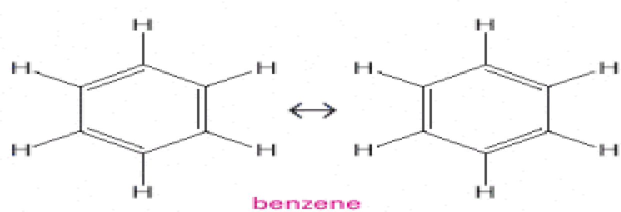
The carbon chain can include double bonds. If these are on alternate carbon atoms, the bonding electrons move within the molecule, stabilizing the structure by a phenomenon called resonance.



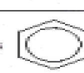
the truth is somewhere between these two structures



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



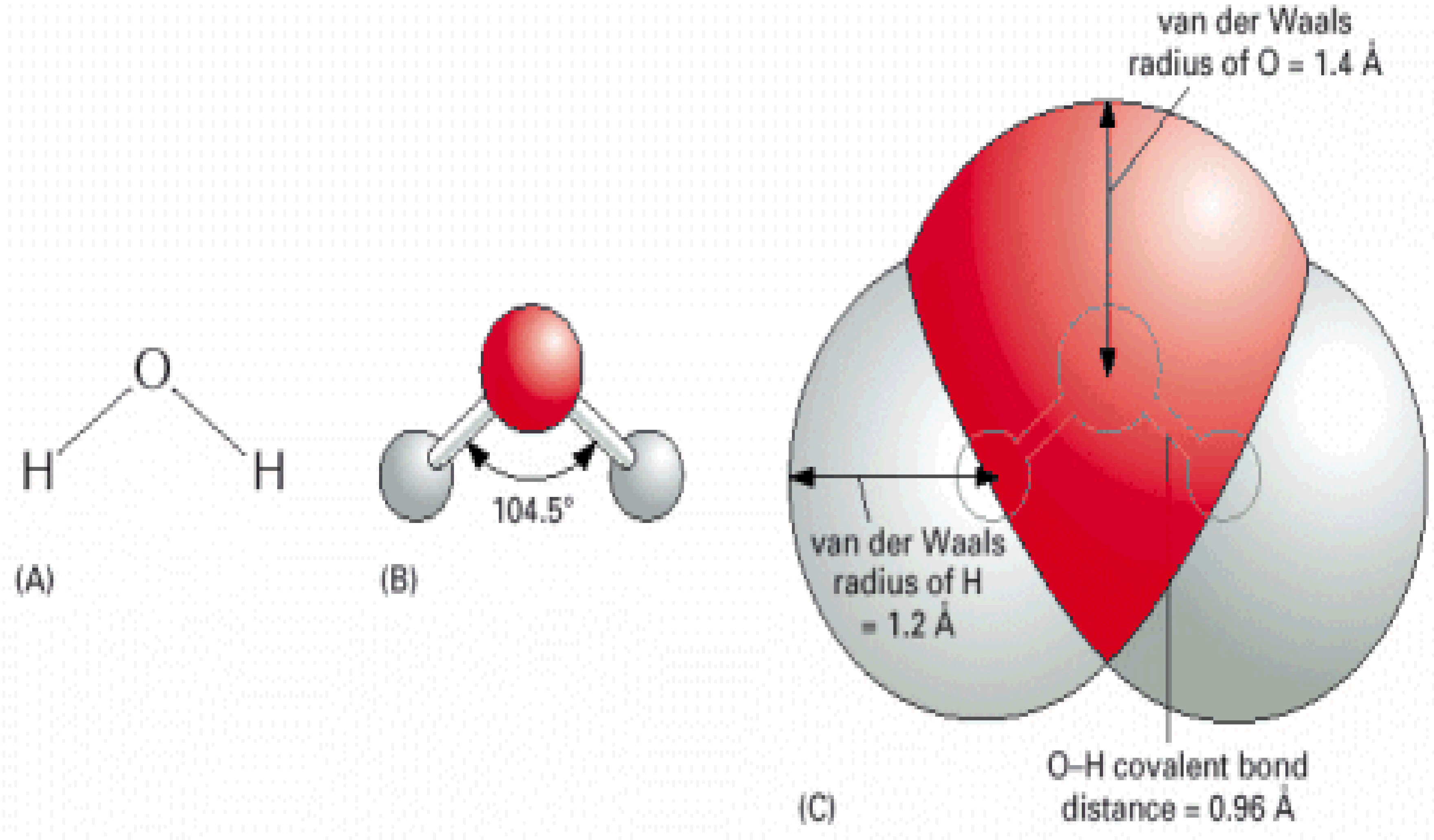
benzene

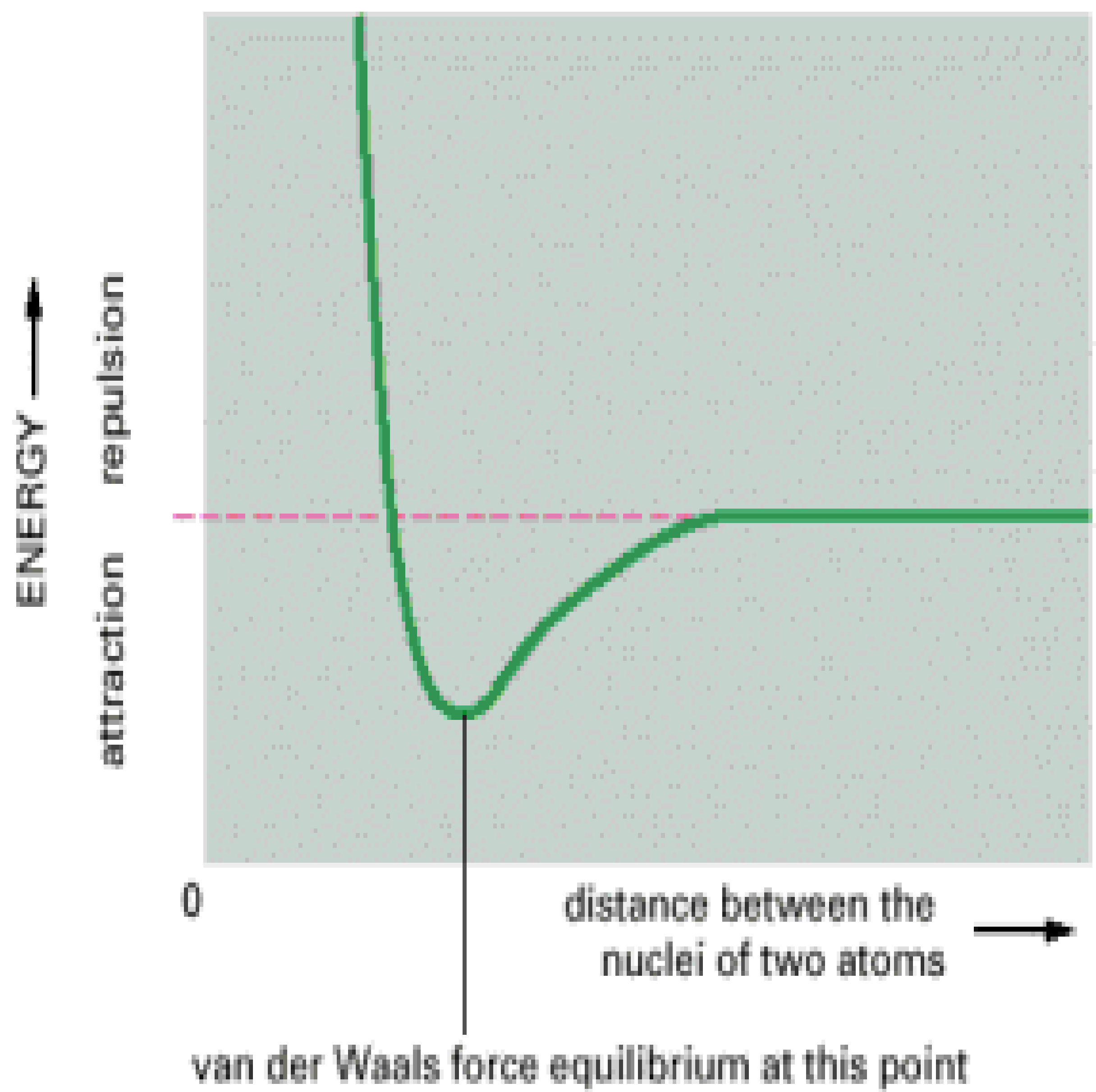
often written as 

Non-covalent Interactions Help Bring Molecules Together in Cells

- Ionic bonds.
- Hydrogen bonds.
- van der Waals attractions
- Hydrophobic force

BOND TYPE	LENGTH (nm)	STRENGTH (kcal/mole) 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


O
H
H
(A)
104.5°
(B)
van der Waals
radius of O = 1.4 Å
van der Waals
radius of H
= 1.2 Å
(C)
O–H covalent bond
distance = 0.96 Å



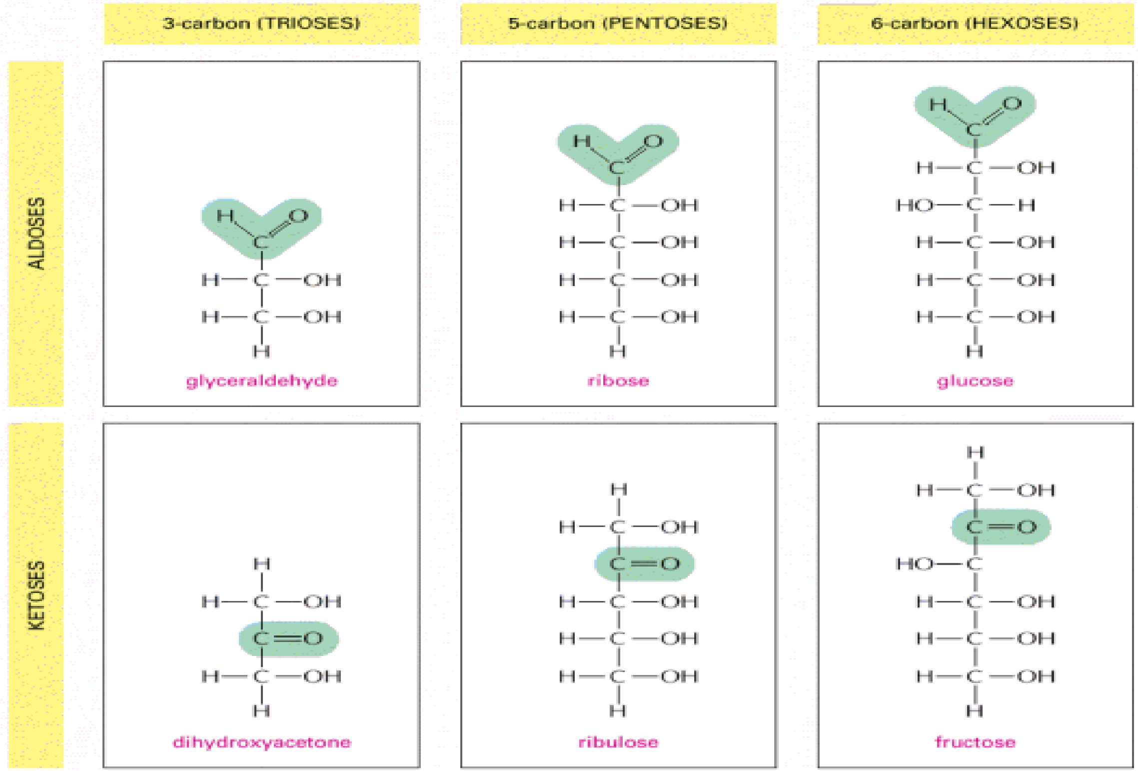
ENERGY
repulsion
attraction
0
distance between the nuclei of two atoms
van der Waals force equilibrium at this point

Cells Contain Four Major Families of Small Organic Molecules

- Sugars Provide an Energy Source for Cells and Are the Subunits of Polysaccharides
- Fatty Acids Are Components of Cell Membranes
- Amino Acids Are the Subunits of Proteins
- Nucleotides Are the Subunits of DNA and RNA

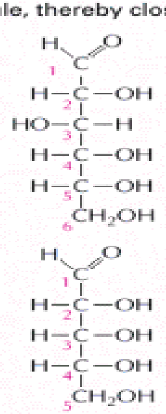
MONOSACCHARIDES

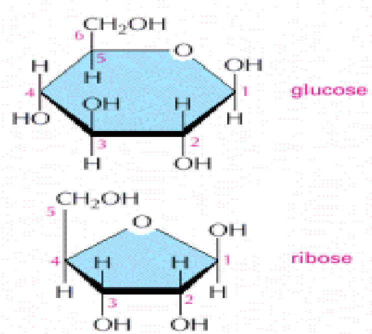
Monosaccharides usually have the general formula $(CH_2O)_n$, where *n* can be 3, 4, 5, 6, 7, or 8, and have two or more hydroxyl groups. They either contain an aldehyde group ($-C\lesssim^{O}_{H}$) and are called aldoses or a ketone group ($>C=O$) and are called ketoses.



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.

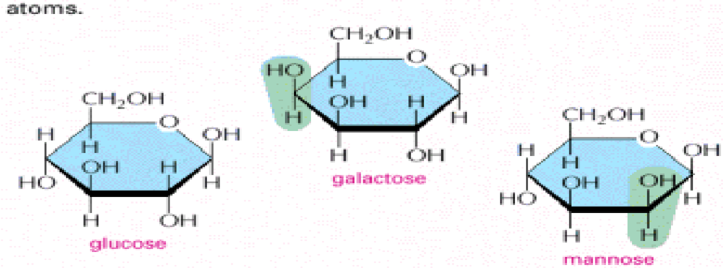




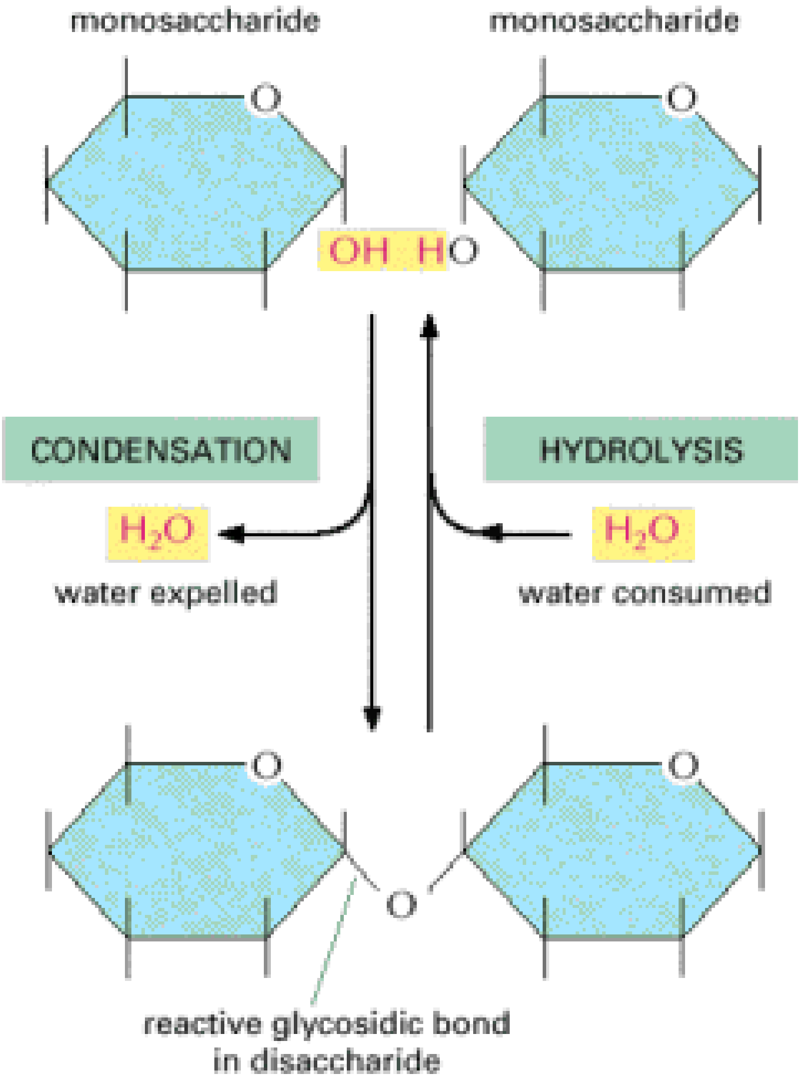
Note that each carbon atom has a number.

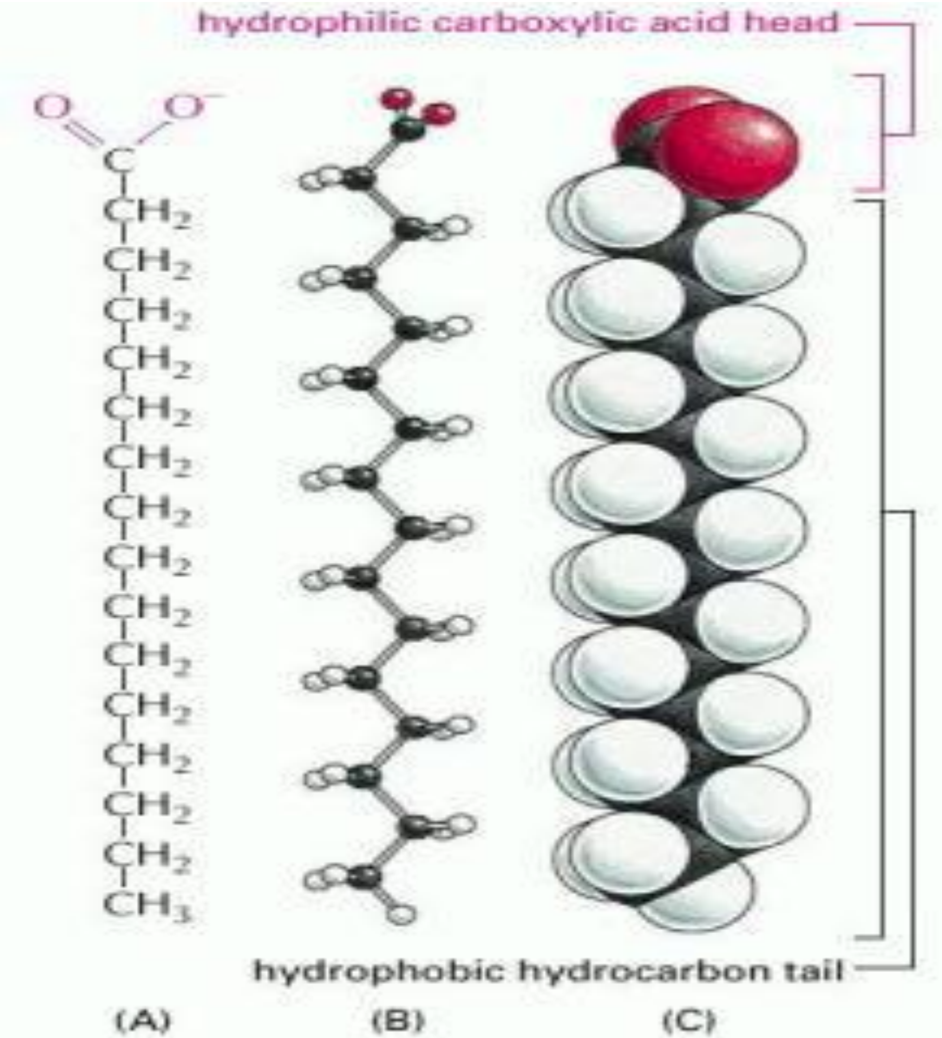
ISOMERS

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.



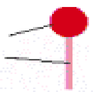
These small differences make only minor changes in the chemical properties of the sugars. But they are recognized by enzymes and other proteins and therefore can have important biological effects.


monosaccharide
monosaccharide
O
O
OH HO
CONDENSATION
HYDROLYSIS
H_2O
water expelled
H_2O
water consumed
O
O
O
reactive glycosidic bond
in disaccharide

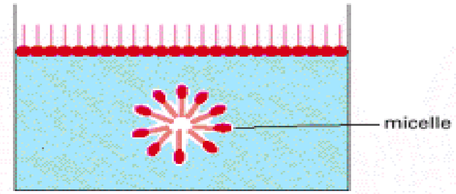

hydrophilic carboxylic acid head
hydrophobic hydrocarbon tail
(A)
(B)
(C)

LIPID AGGREGATES

Fatty acids have a hydrophilic head and a hydrophobic tail.



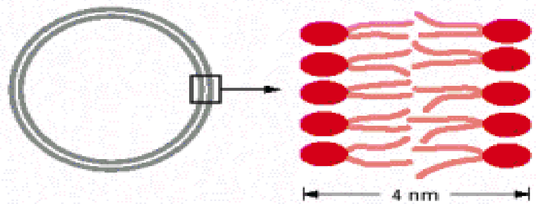
In water they can form a surface film or form small micelles.



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

Triglycerides can form large spherical fat droplets in the cell cytoplasm.

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



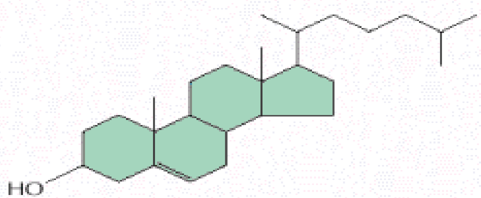
OTHER LIPIDS

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.

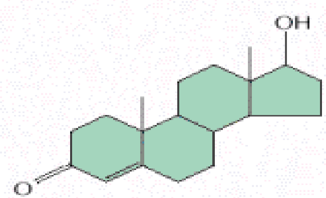
isoprene

STEROIDS

Steroids have a common multiple-ring structure.



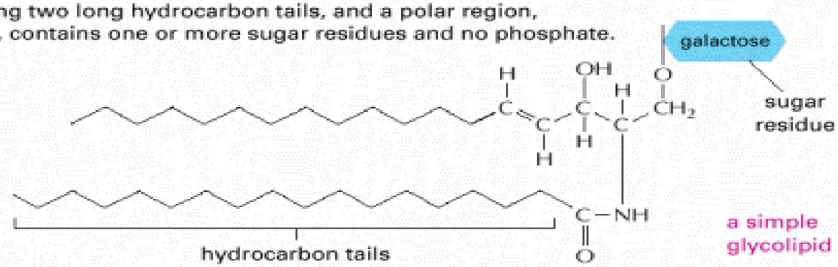
cholesterol—found in many membranes



testosterone—male steroid hormone

GLYCOLIPIDS

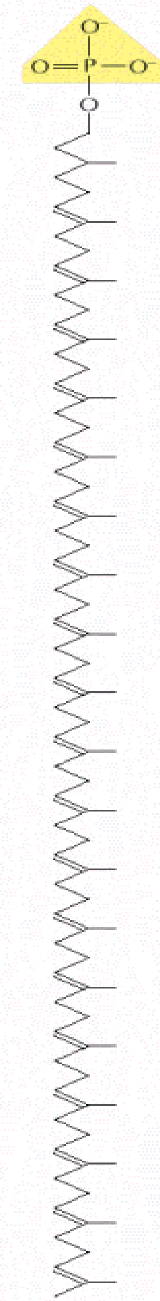
Like phospholipids, these compounds are composed of a hydrophobic region, containing two long hydrocarbon tails, and a polar region, which, however, contains one or more sugar residues and no phosphate.



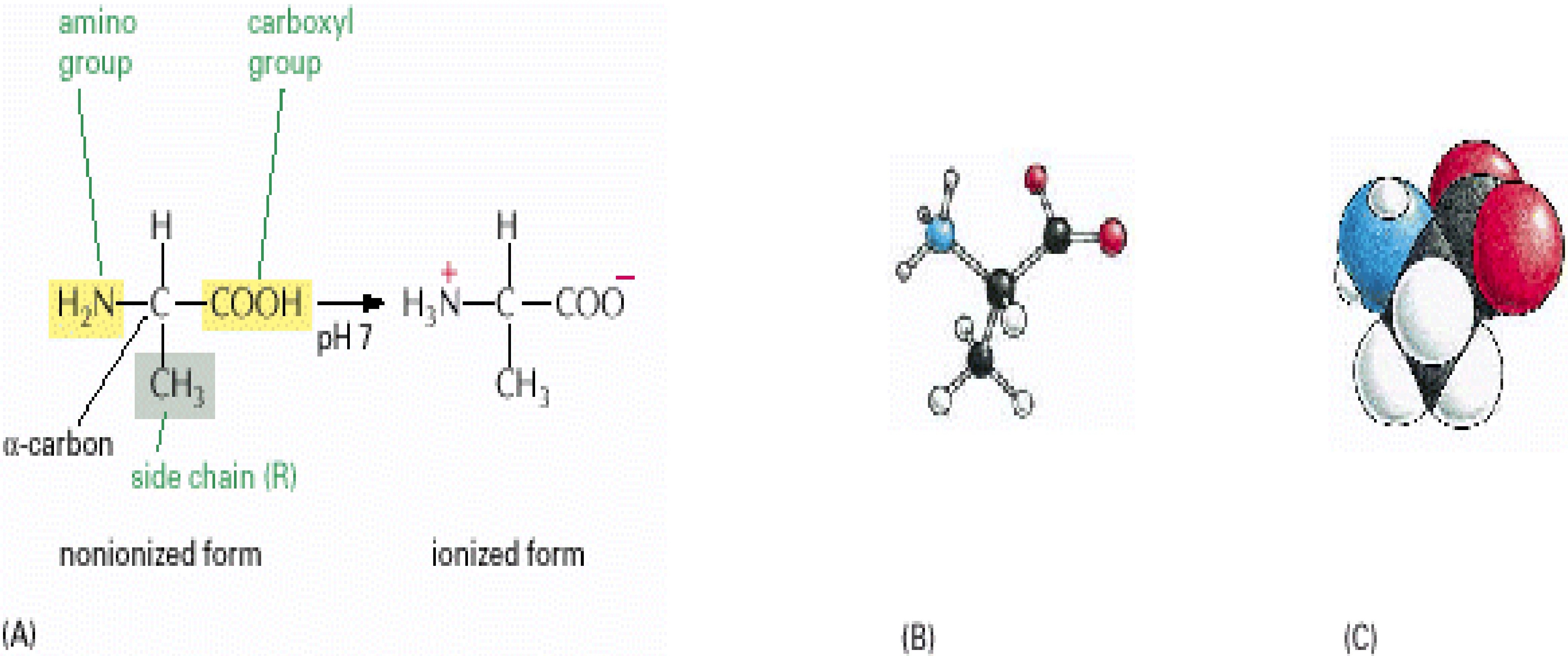
a simple glycolipid

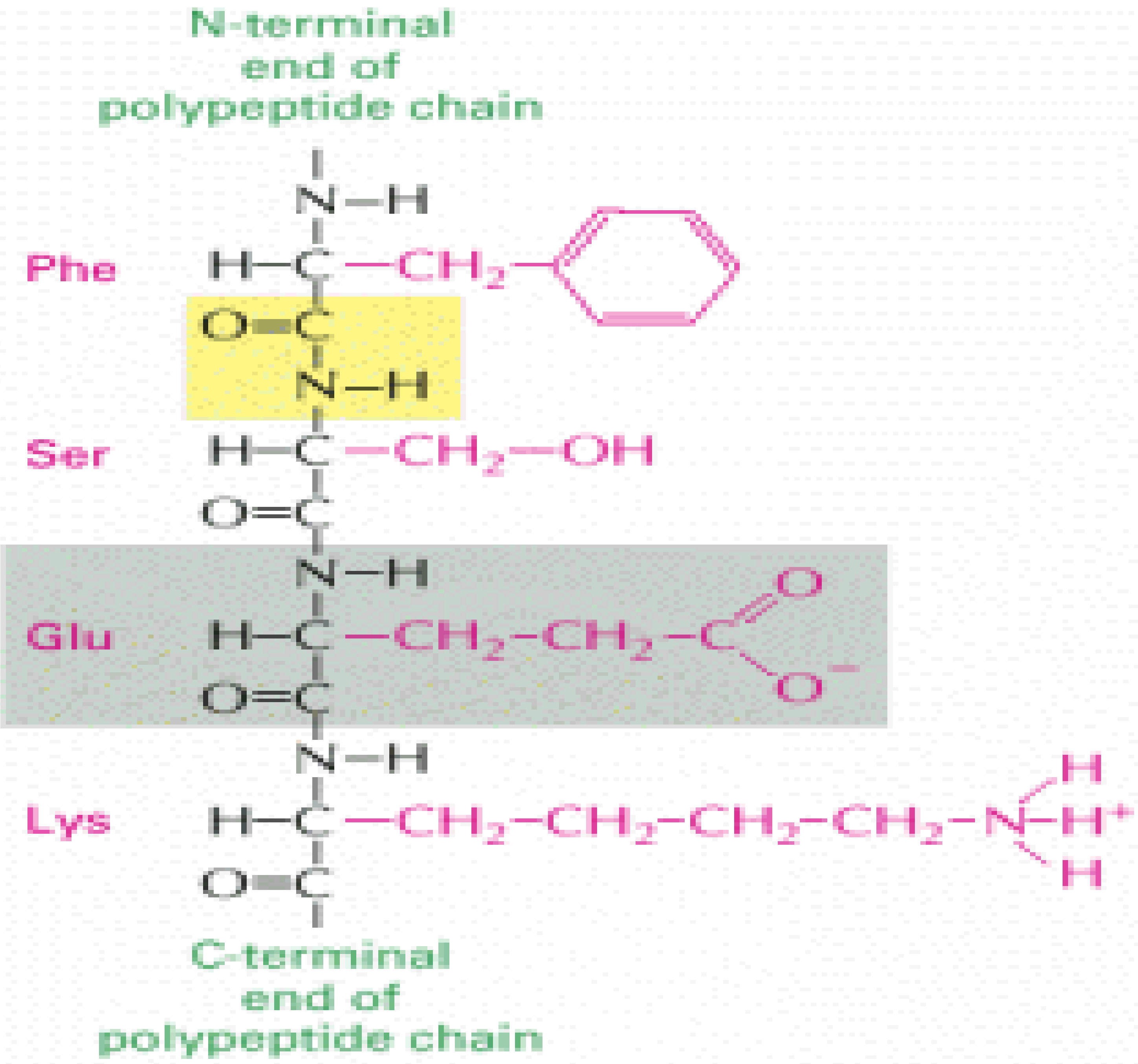
POLYISOPRENOIDS

long-chain polymers of isoprene



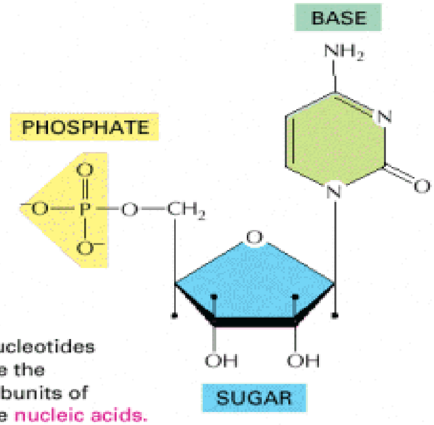
dolichol phosphate—used to carry activated sugars in the membrane-associated synthesis of glycoproteins and some polysaccharides


amino group
carboxyl group
$H_2N-C-COOH$
H
CH_3
pH 7
$H_3\overset{+}{N}-C-COO^-$
H
CH_3
α-carbon
side chain (R)
nonionized form
ionized form
(A)
(B)
(C)


N-terminal
end of
polypeptide chain
Phe
Ser
Glu
Lys
C-terminal
end of
polypeptide chain

NUCLEOTIDES

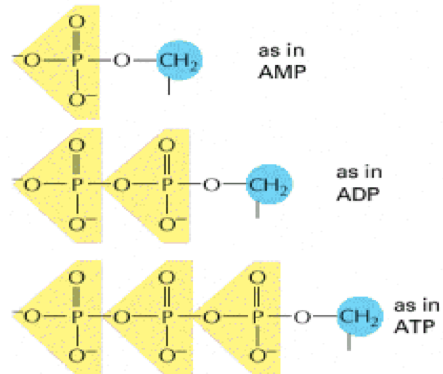
A nucleotide consists of a nitrogen-containing base, a five-carbon sugar, and one or more phosphate groups.



Nucleotides are the subunits of the nucleic acids.

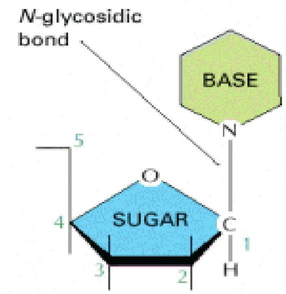
PHOSPHATES

The phosphates are normally joined to the C5 hydroxyl of the ribose or deoxyribose sugar (designated 5′). Mono-, di-, and triphosphates are common.



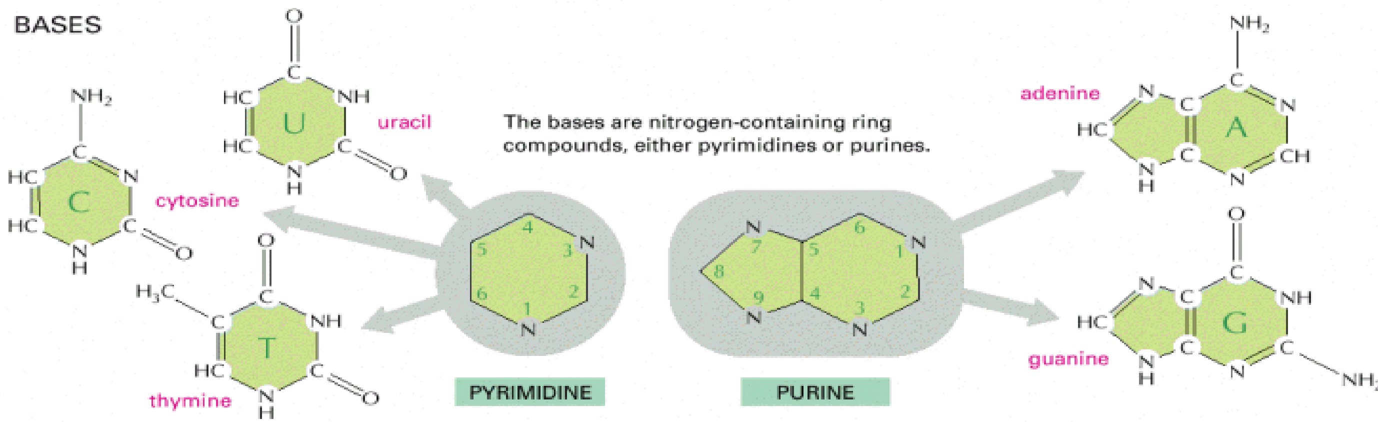
The phosphate makes a nucleotide negatively charged.

BASIC SUGAR LINKAGE



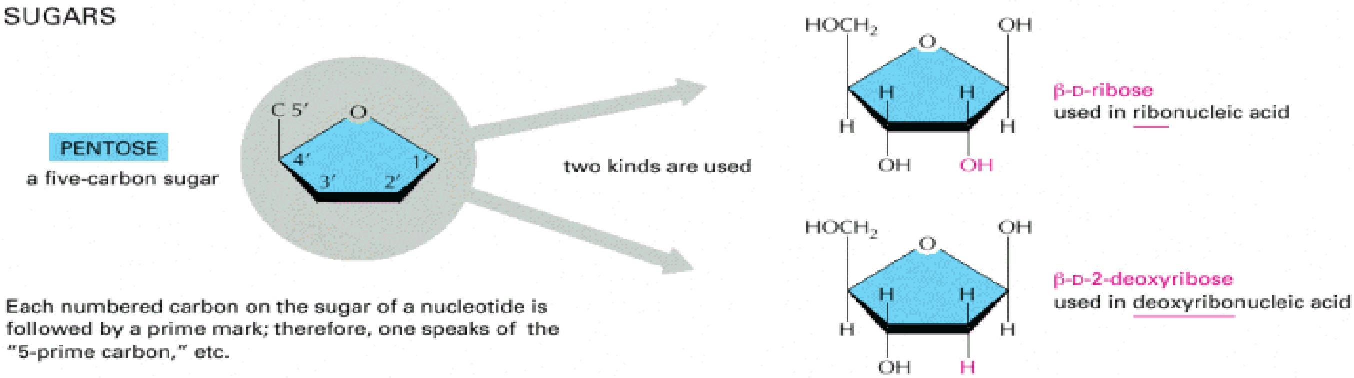
The base is linked to the same carbon (C1) used in sugar–sugar bonds.

BASES



The bases are nitrogen-containing ring compounds, either pyrimidines or purines.

SUGARS



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

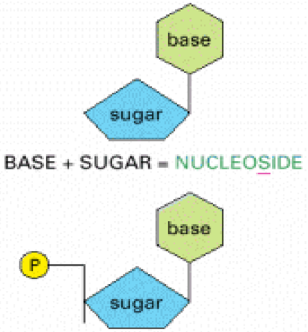
NOMENCLATURE

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

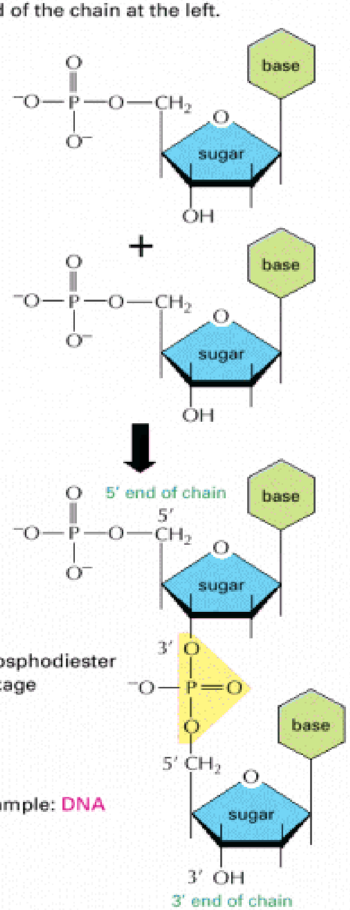


BASE + SUGAR = NUCLEOSIDE

BASE + SUGAR + PHOSPHATE = NUCLEOTIDE

NUCLEIC ACIDS

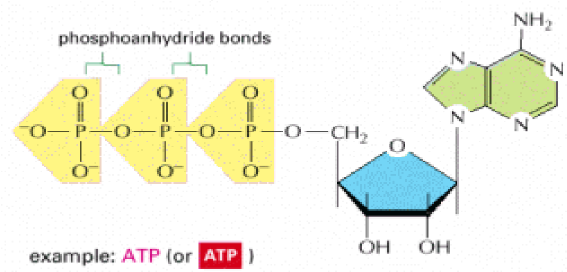
Nucleotides are joined together by a phosphodiester linkage between 5′ and 3′ carbon atoms to form nucleic acids. The linear sequence of nucleotides in a nucleic acid chain is commonly abbreviated by a one-letter code, A—G—C—T—T—A—C—A, with the 5′ end of the chain at the left.



example: DNA

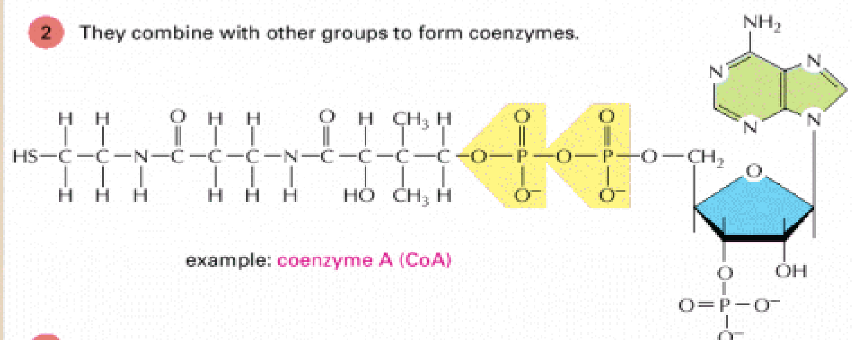
NUCLEOTIDES HAVE MANY OTHER FUNCTIONS

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



example: ATP (or ATP)

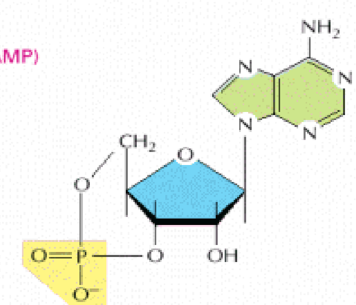
2 They combine with other groups to form coenzymes.

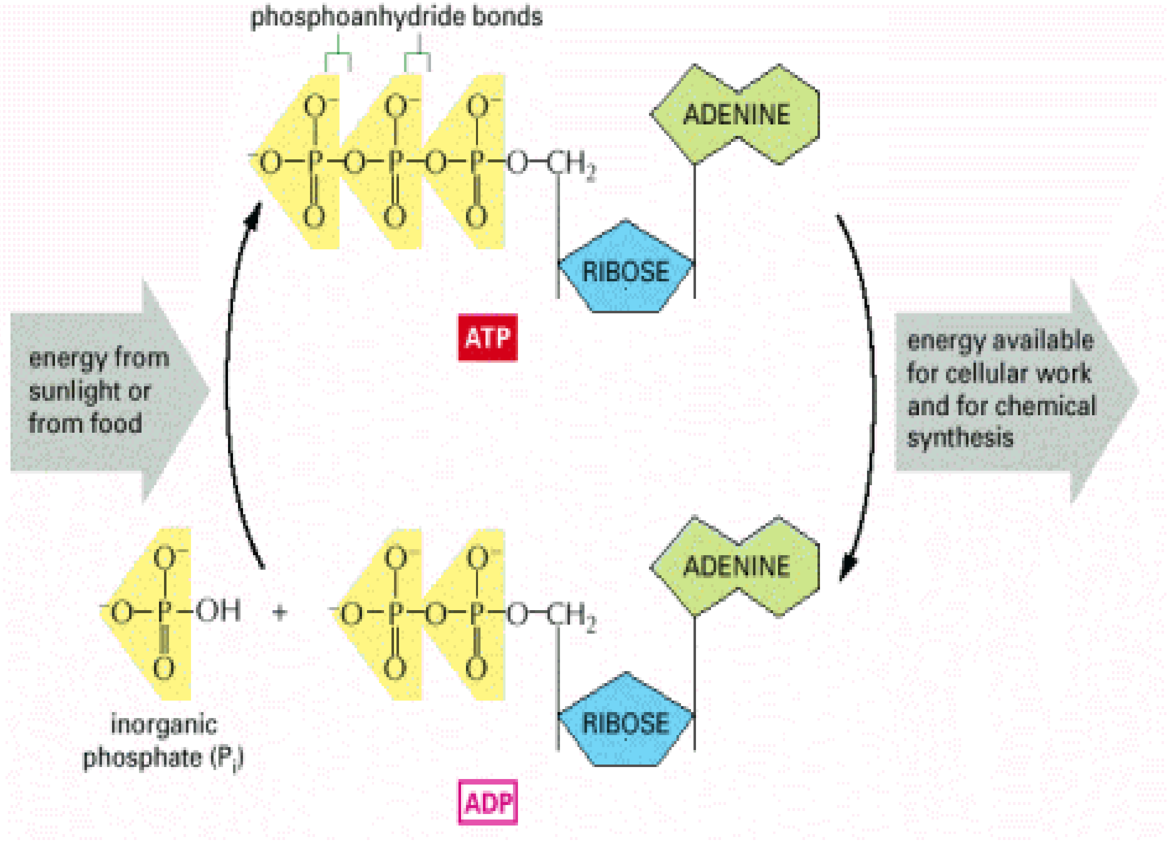


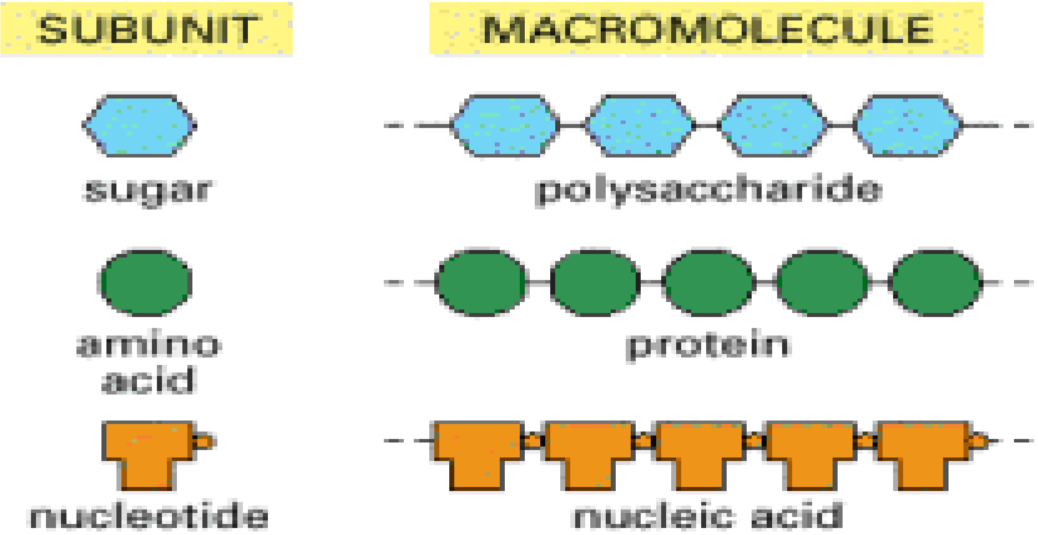
example: coenzyme A (CoA)

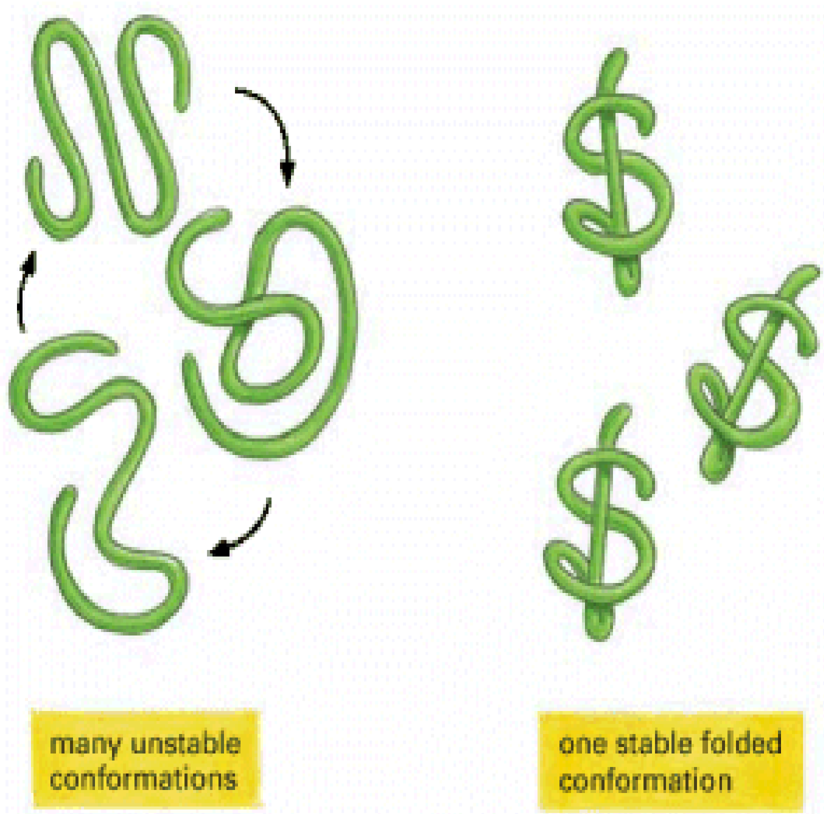
3 They are used as specific signaling molecules in the cell.

example: cyclic AMP (cAMP)




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


SUBUNIT
MACROMOLECULE
sugar
polysaccharide
amino acid
protein
nucleotide
nucleic acid


many unstable conformations
one stable folded conformation