Laboratoř růstových regulátorů

Miroslav Strnad

Složení rostlinného těla, základní organické komponenty [kap. 00]

- Univerzita Palackého & Ústav experimentální botaniky AV CR

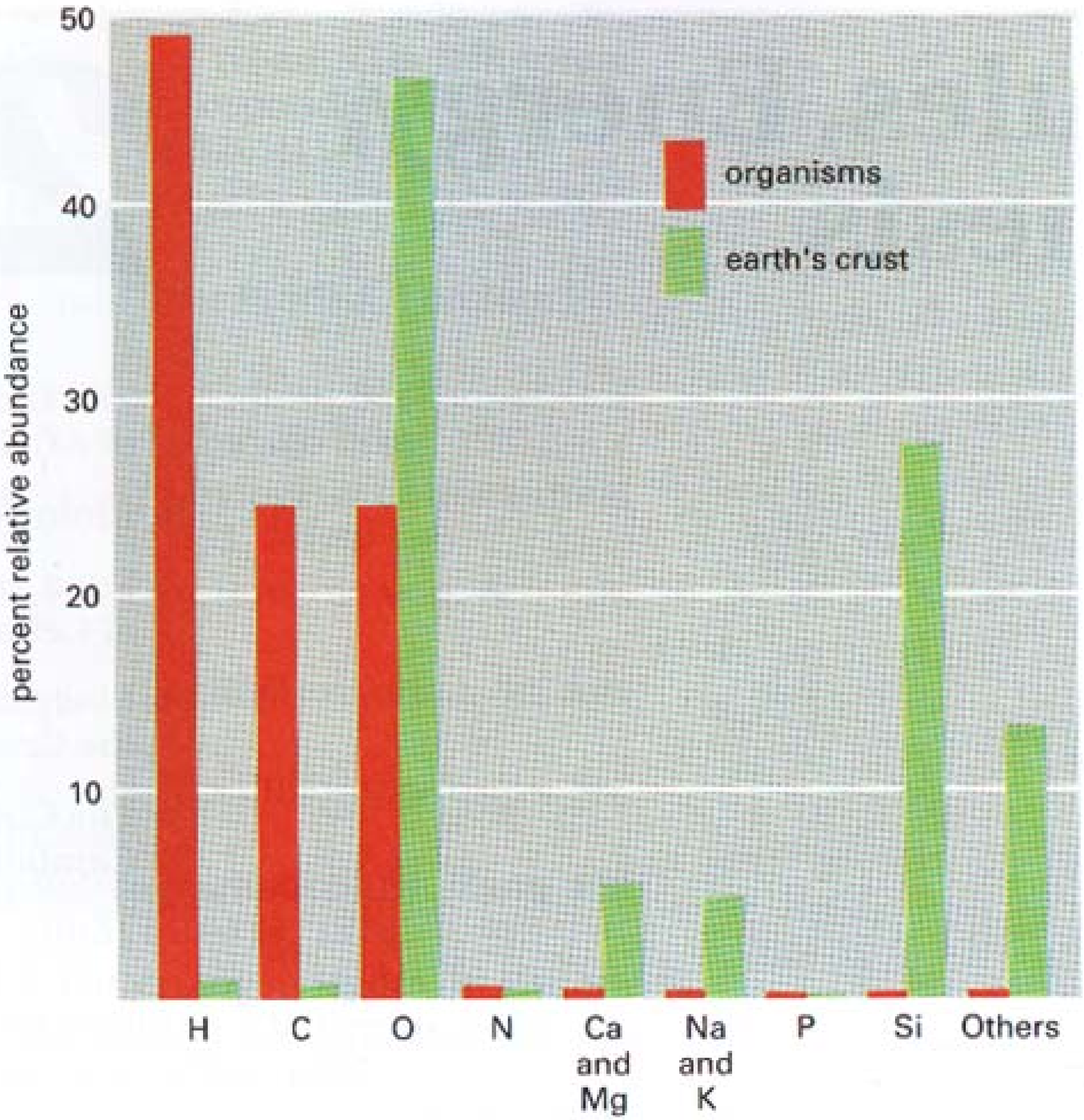


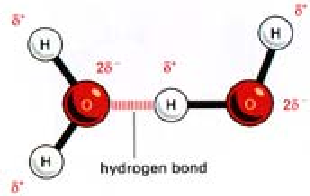
Figure 2–1 The relative abundance of chemical elements found in the earth's crust (the nonliving world) compared to that in the soft tissues of living organisms. The relative abundance is expressed as a percentage of the total *number* of atoms present. Thus, for example, nearly 50% of the atoms in living organisms are hydrogen atoms.

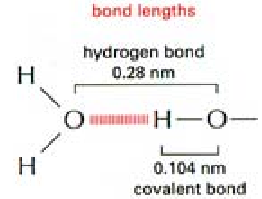
Table 2–1 **The Approximate Chemical Composition of a Bacterial Cell**

	Percent 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, and polysaccharides)	26	~3000

HYDROGEN BONDS

Because they are polarized, two adjacent H_2O molecules can form a linkage known as a hydrogen bond. Hydrogen bonds have only about 1/20 the strength of a covalent bond.

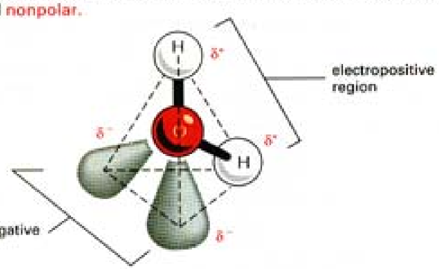




Hydrogen bonds are strongest when the three atoms lie in a straight line.

WATER

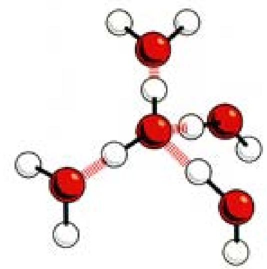
Two atoms, connected by a covalent bond, may exert different attractions for the electrons of the bond. In such cases the bond is dipolar, with one end slightly negatively charged (δ^-) and the other slightly positively charged (δ^+). A bond in which both atoms are the same, or in which they attract electrons equally, is called nonpolar.



Although a water molecule has an overall neutral charge (having the same number of electrons and protons), the electrons are asymmetrically distributed, which makes the molecule polar. The oxygen nucleus draws electrons away from the hydrogen nuclei, leaving these nuclei with a small net positive charge. The excess of electron density on the oxygen atom creates weakly negative regions at the other two corners of an imaginary tetrahedron.

WATER STRUCTURE

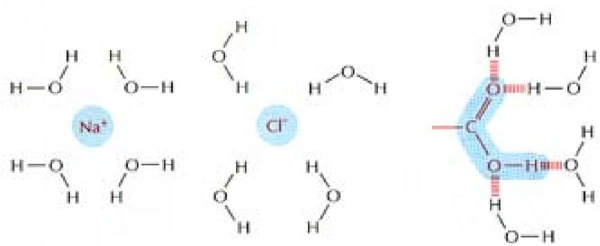
Molecules of water join together transiently in a hydrogen-bonded lattice. Even at 37°C, 15% of the water molecules are joined to four others in a short-lived assembly known as a "flickering cluster."



The cohesive nature of water is responsible for many of its unusual properties, such as high surface tension, specific heat, and heat of vaporization.

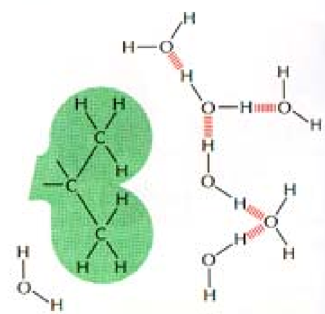
HYDROPHILIC AND HYDROPHOBIC MOLECULES

Because of the polar nature of water molecules, they will cluster around ions and other polar molecules.



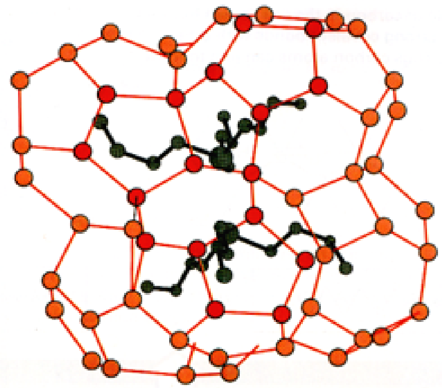
Molecules that can thereby be accommodated in water's hydrogen-bonded structures are hydrophilic and relatively water-soluble.

Nonpolar molecules interrupt the H-bonded structure of water without forming favorable interactions with water molecules. They are therefore hydrophobic and quite insoluble in water.



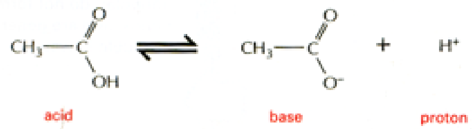
HYDROPHOBIC MOLECULES AND CLATHRATE WATER STRUCTURES

Molecules that are nonpolar and cannot form hydrogen bonds—such as hydrocarbons—have only limited solubility in water and are called hydrophobic. In water, ordered cages of water molecules are formed around hydrocarbons. These icelike cages, called "clathrate structures," are relatively more ordered than water and cause an entropy decrease of the mixture. Part of a clathrate cage (*red*) surrounding a hydrocarbon (*black*) is shown. In the intact cage, each oxygen atom (*red circles*) would be tetrahedrally coordinated to four others.



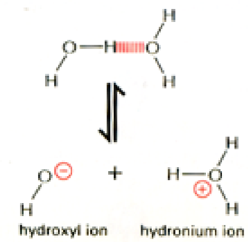
ACIDS AND BASES

An acid is a molecule that releases an H^+ ion (proton) in solution. For example,



A base is a molecule that accepts an H^+ ion (proton) in solution. For example,

Water itself has a slight tendency to ionize and can act both as a weak acid and as a weak base. When it acts as an acid, it releases a proton to form a hydroxyl ion. When it acts as a base, it accepts a proton to form a hydronium ion. Most protons in aqueous solutions exist as hydronium ions.



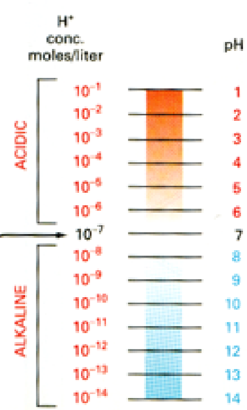
pH

The acidity of a solution is defined by the concentration of H^+ ions it possesses. For convenience we use the pH scale where

$pH = -\log_{10}[H^+]$

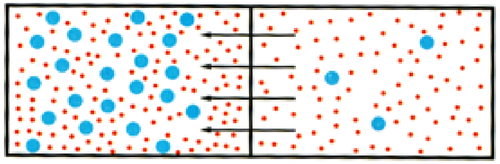
For pure water

$[H^+] = 10^{-7}$ moles/liter



OSMOSIS

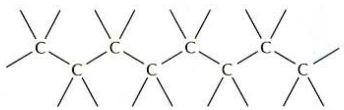
If two aqueous solutions are separated by a membrane that allows only water molecules to pass, water will move into the solution containing the greatest concentration of solute molecules by a process known as osmosis.



This movement of water from a hypotonic to a hypertonic solution can cause an increase in hydrostatic pressure in the hypertonic compartment. Two solutions that have identical solute concentrations and are therefore osmotically balanced are said to be isotonic.

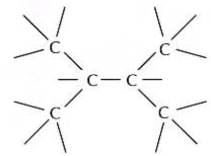
CARBON SKELETONS

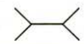
The unique role of carbon in the cell comes from its ability to form strong covalent bonds with other carbon atoms. Thus carbon atoms can join to form chains.



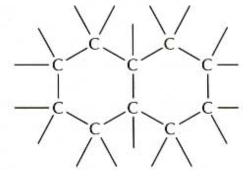
also written as 

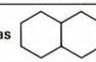
or branched trees



also written as 

or rings



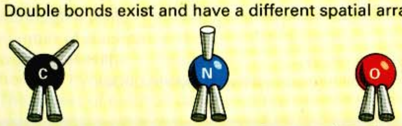
also written as 

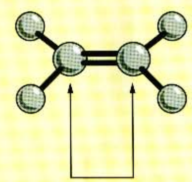
COVALENT BONDS

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.

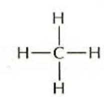




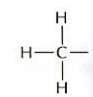
Atoms joined by two or more covalent bonds cannot rotate freely about the bond axis. This restriction is a major influence on the three-dimensional shape of many macromolecules.

HYDROCARBONS

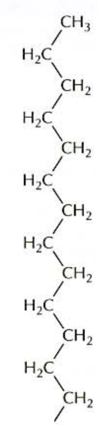
Carbon and hydrogen together make stable compounds called hydrocarbons. These are nonpolar, do not form hydrogen bonds, and are generally insoluble in water.



methane



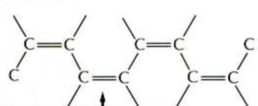
methyl group



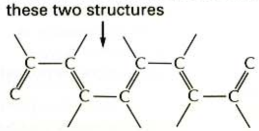
part of a fatty acid chain

RESONANCE AND AROMATICITY

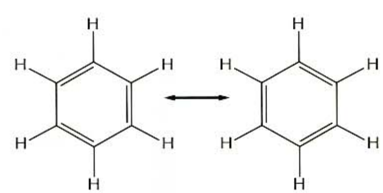
The carbon chain can include double bonds. If these are on alternate carbon atoms, the bonding electrons move within the molecule, stabilizing the structure by a phenomenon called resonance.

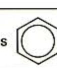


the truth is somewhere between these two structures



When resonance occurs throughout a ring compound, an aromatic ring is generated.

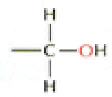


often written as 

C—O COMPOUNDS

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

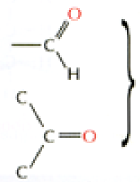
alcohol



The —OH is called a hydroxyl group.

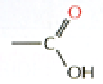
aldehyde

ketone



The C═O is called a carbonyl group.

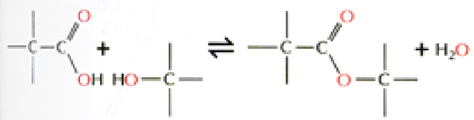
carboxylic acid



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.



acid alcohol ester

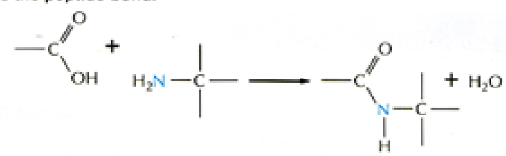
C—N COMPOUNDS

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

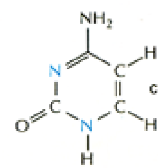
Amines in water combine with an H^+ ion to become positively charged.

They are therefore basic.

Amides are formed by combining an acid and an amine. They are more stable than esters. Unlike amines, they are uncharged in water. An example is the peptide bond.



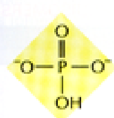
Nitrogen also occurs in several ring compounds, including important constituents of nucleic acids: purines and pyrimidines.



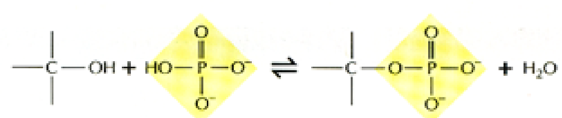
cytosine (a pyrimidine)

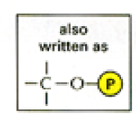
PHOSPHATES

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

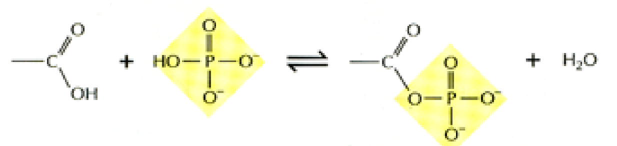


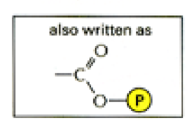
Phosphate esters can form between a phosphate and a free hydroxyl group.





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

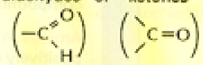




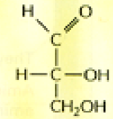
Cukry = Mono-, oligo- a polysacharidy

MONOSACCHARIDES

Monosaccharides are aldehydes or ketones



that also have two or more hydroxyl groups. Their general formula is $(CH_2O)_n$. The simplest are trioses ($n = 3$) such as



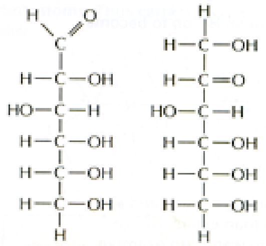
glyceraldehyde (an aldose)

dihydroxyacetone (a ketose)

HEXOSES $n = 6$

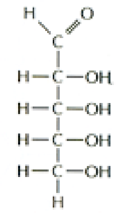
Two common hexoses are

glucose fructose



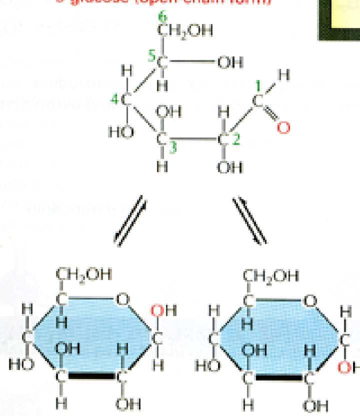
PENTOSES $n = 5$

A common pentose is



ribose

D-glucose (open-chain form)



β-D-glucose α-D-glucose

STEREOISOMERS

RING FORMATION

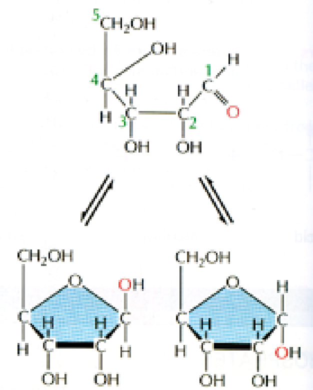
The aldehyde or ketone group of a sugar can react with a hydroxyl group

For the larger sugars ($n > 4$) this happens within the same molecule to form a 5- or 6-membered ring.

NUMBERING

The carbon atoms of a sugar are numbered from the end closest to the aldehyde or ketone.

D-ribose (open-chain form)

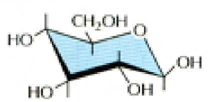


β-D-ribose α-D-ribose

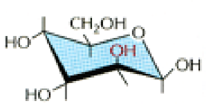
STEREOISOMERS

ISOMERS

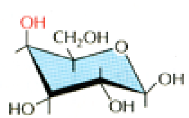
Monosaccharides have many isomers that differ only in the orientation of their hydroxyl groups—e.g., glucose, mannose, and galactose are isomers of each other.



glucose



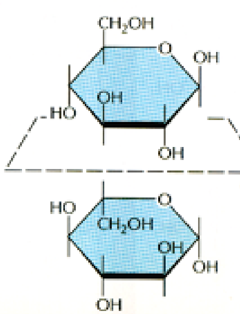
mannose



galactose

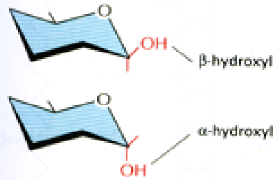
D AND L FORMS

Two isomers that are mirror images of each other have the same chemistry and therefore are given the same name and distinguished by the prefix D or L.



α- AND β-LINKS

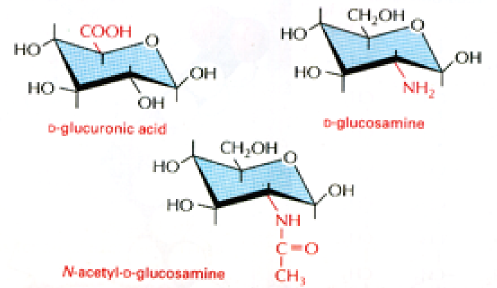
The hydroxyl group on the carbon that carries the aldehyde or ketone can rapidly change from one position to another. These two positions are called α- and β-.



As soon as one sugar is linked to another, the α- or β-form is frozen.

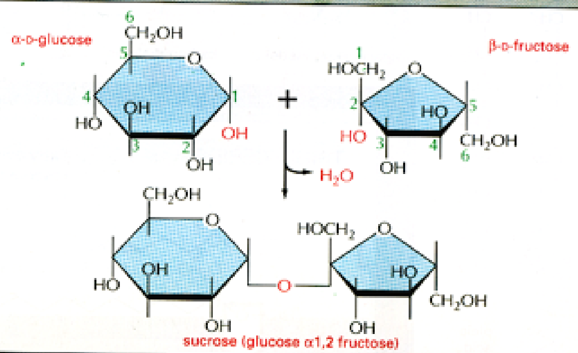
SUGAR DERIVATIVES

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



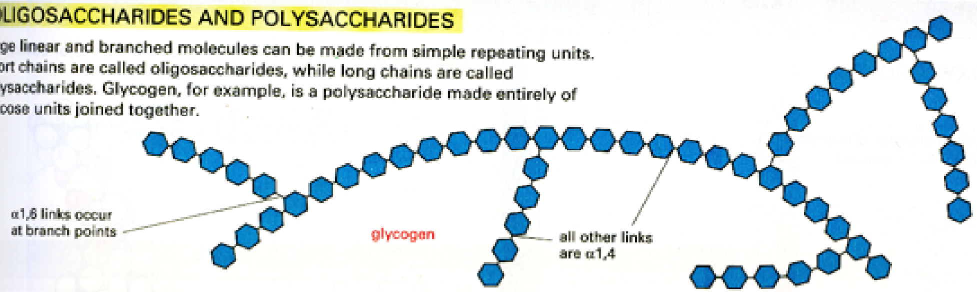
DISACCHARIDES

The carbon that carries the aldehyde or the ketone can react with any hydroxyl group on a second sugar molecule to form a glycosidic bond. Three common disaccharides are maltose (glucose α1,4 glucose), lactose (galactose β1,4 glucose), and sucrose (glucose α1,2 fructose). Sucrose is shown here.



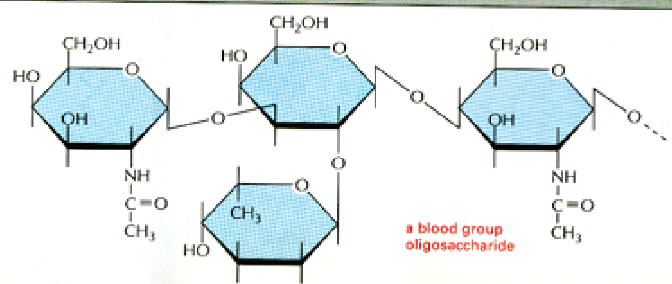
OLIGOSACCHARIDES AND POLYSACCHARIDES

Large linear and branched molecules can be made from simple repeating units. Short chains are called oligosaccharides, while 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.



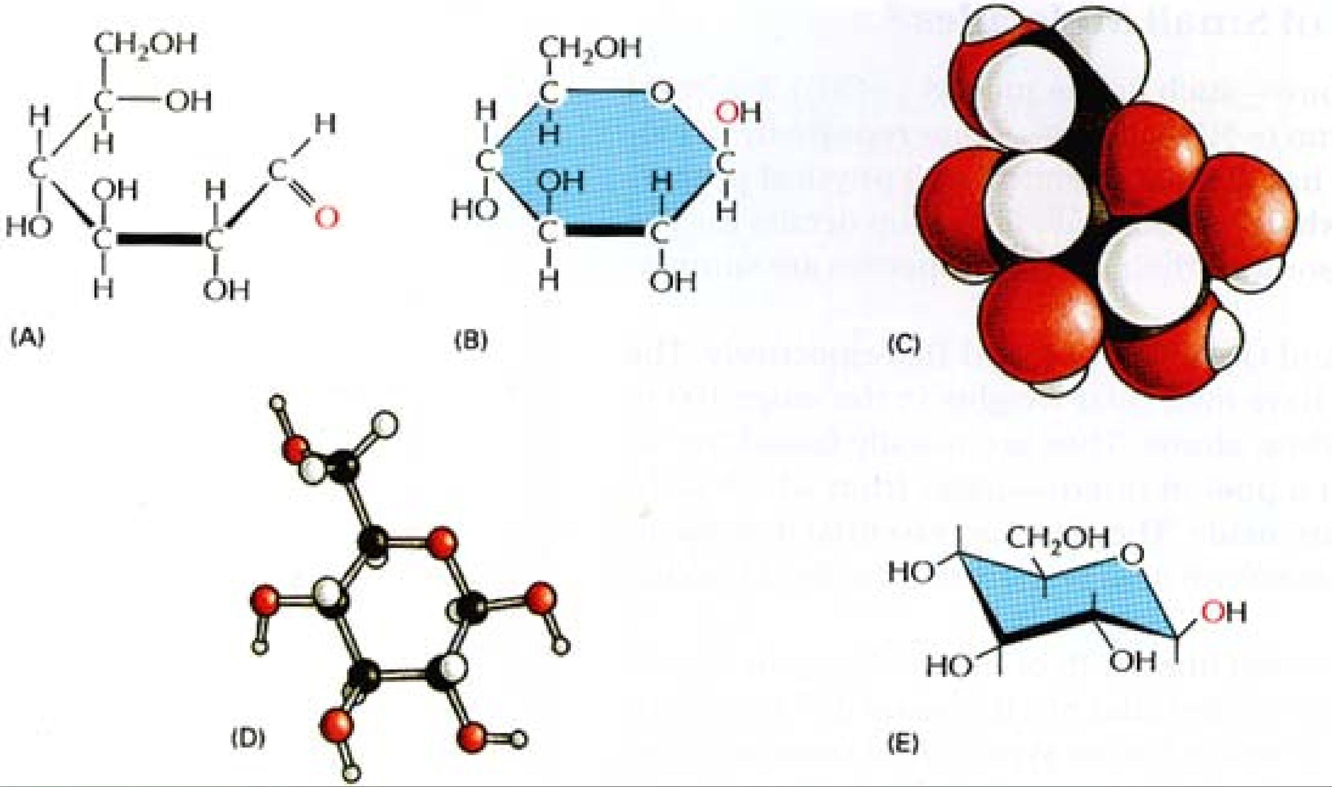


Figure 2–3 The structure of the monosaccharide glucose, a common hexose sugar. (A) is the open-chain form of this sugar, which is in equilibrium with the more stable cyclic or ring form in (B). (C) and (D) are space-filling and ball-and-stick models, respectively, of this cyclic form (β-∂-glucose). The chair form (E) is an alternative representation of the cyclic form that is frequently used because it more accurately reflects the structure. In (A), (B), and (E) the *red* O denotes the oxygen atom of the aldehyde group. For an outline of sugar structures and chemistry, see Panel 2–3 (pp. 52–53).

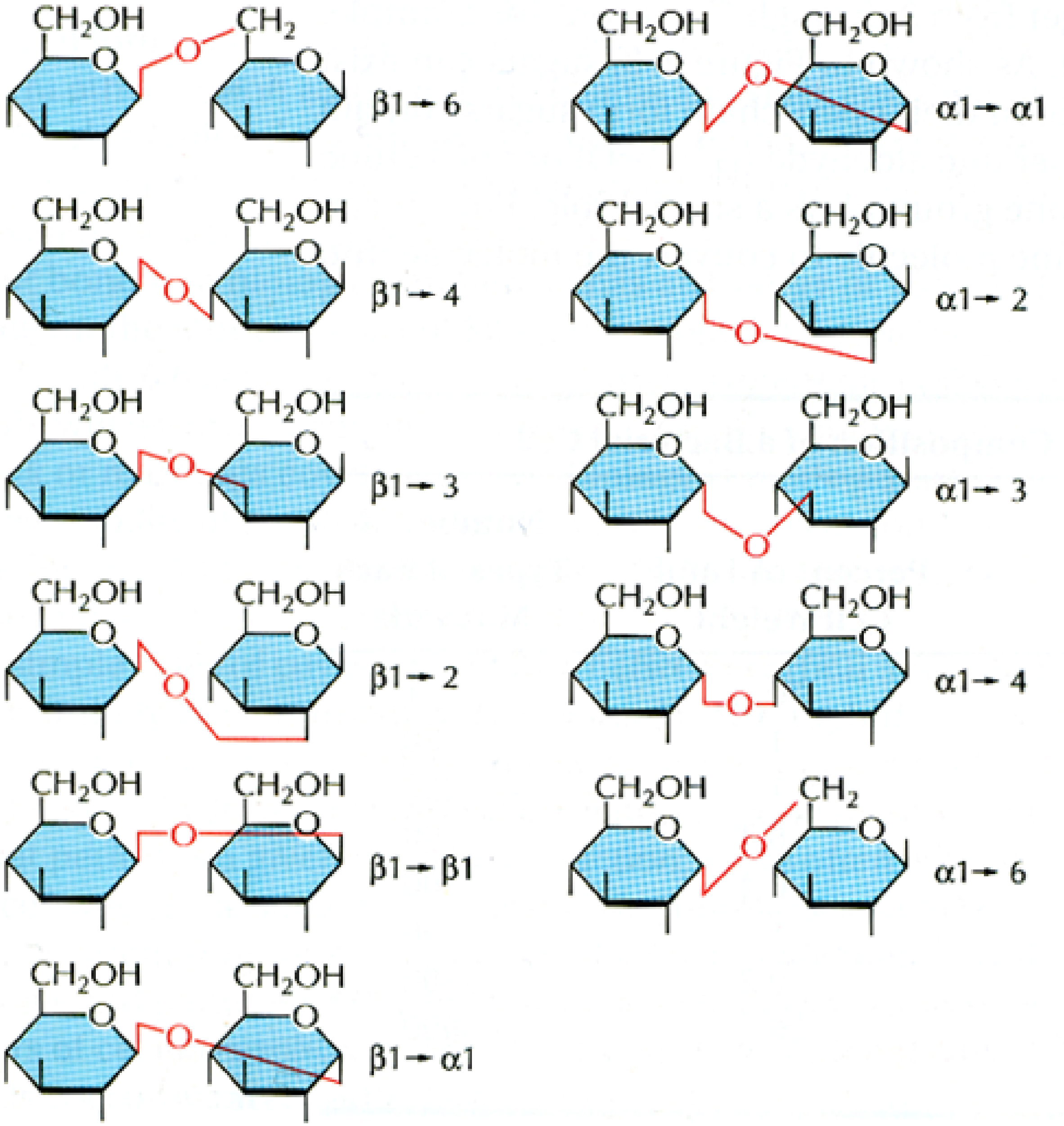


Figure 2–4 Eleven disaccharides consisting of two ∂-glucose units. Although these differ only in the type of linkage between the two glucose units, they are chemically distinct. Since the oligosaccharides associated with proteins and lipids may have six or more different kinds of sugar joined in both linear and branched arrangements through linkages such as those illustrated here, the number of distinct types of oligosaccharides that can be used in cells is extremely large.

Mastné kyseliny a tuky

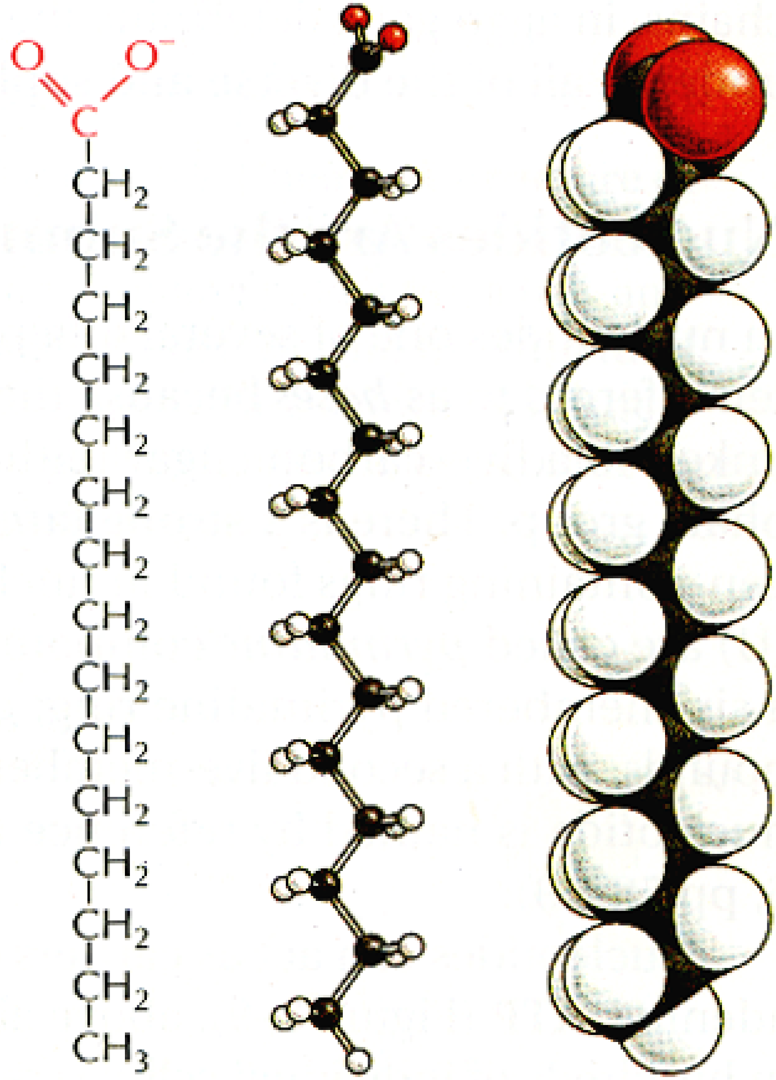
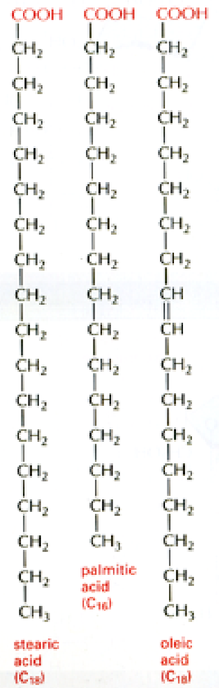


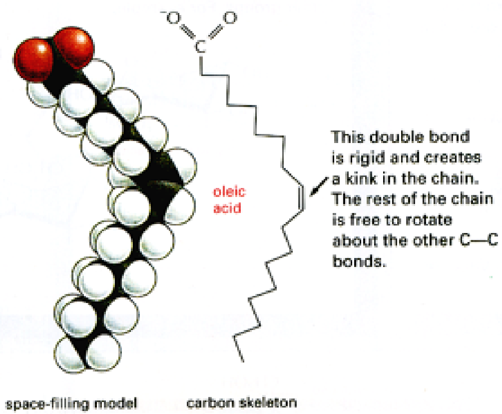
Figure 2–5 Palmitic acid. The carboxylic acid group (*red*) is shown in its ionized form. A ball-and-stick model (*center*) and a space-filling model (*right*) are also shown.

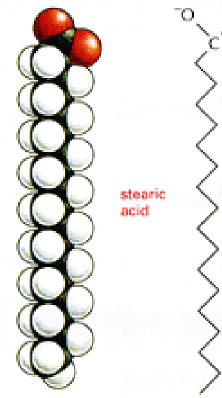
COMMON FATTY ACIDS

These are carboxylic acids with long hydrocarbon tails.



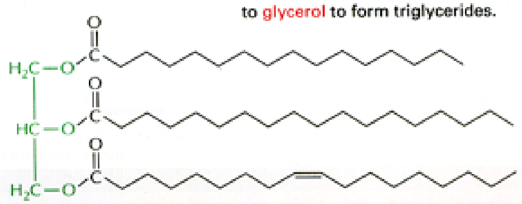
Hundreds of different kinds of fatty acids exist. Some have one or more double bonds and are said to be unsaturated.

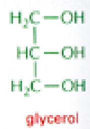




TRIGLYCERIDES

Fatty acids are stored as an energy reserve (fat) through an ester linkage to glycerol to form triglycerides.

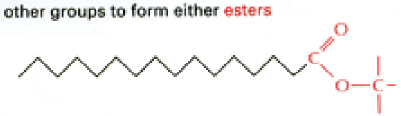




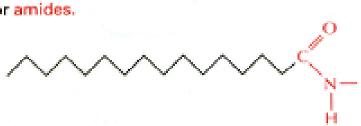
CARBOXYL GROUP

If free, the carboxyl group of a fatty acid will be ionized.

But more usually it is linked to other groups to form either esters

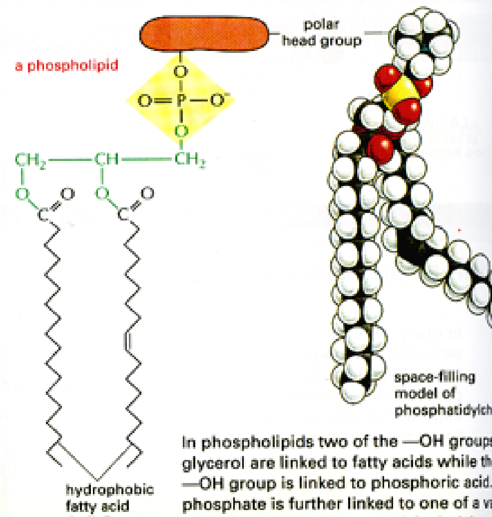


or amides.



PHOSPHOLIPIDS

Phospholipids are the major constitue of cell membranes.

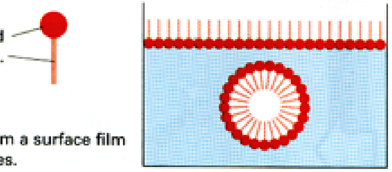


In phospholipids two of the —OH groups glycerol are linked to fatty acids while the —OH group is linked to phosphoric acid. T phosphate is further linked to one of a va of small polar head groups (alcohols).

LIPID AGGREGATES

Fatty acids have a hydrophilic head and a hydrophobic tail.

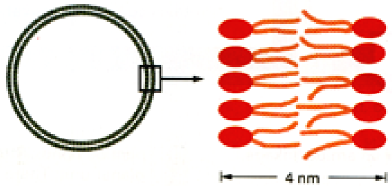
In water they can form a surface film or form small micelles.



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

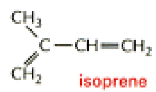
Triglycerides form large spherical fat droplets in the cell cytoplasm.

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



OTHER LIPIDS

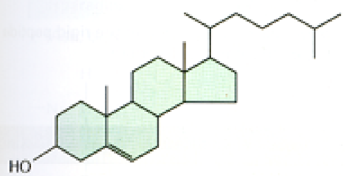
Lipids are defined as the water-insoluble molecules in cells that are soluble in organic solvents. Two other common types of lipids are steroids and polyisoprenoids. Both are made from isoprene units.



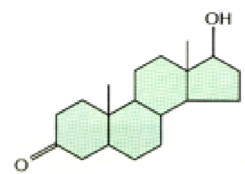
isoprene

STEROIDS

Steroids have a common multiple-ring structure.



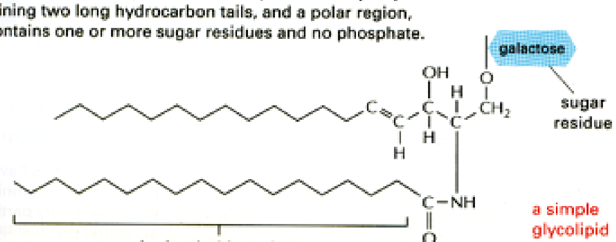
cholesterol—found in many membranes



testosterone—male steroid hormone

GLYCOLIPIDS

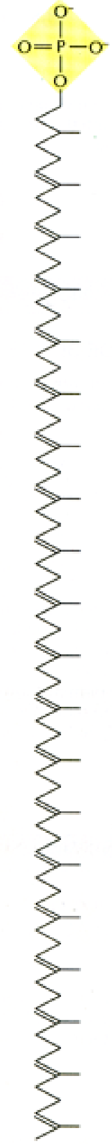
Like phospholipids, these compounds are composed of a hydrophobic region, containing two long hydrocarbon tails, and a polar region, which now contains one or more sugar residues and no phosphate.



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

Aminokyseliny a bílkoviny

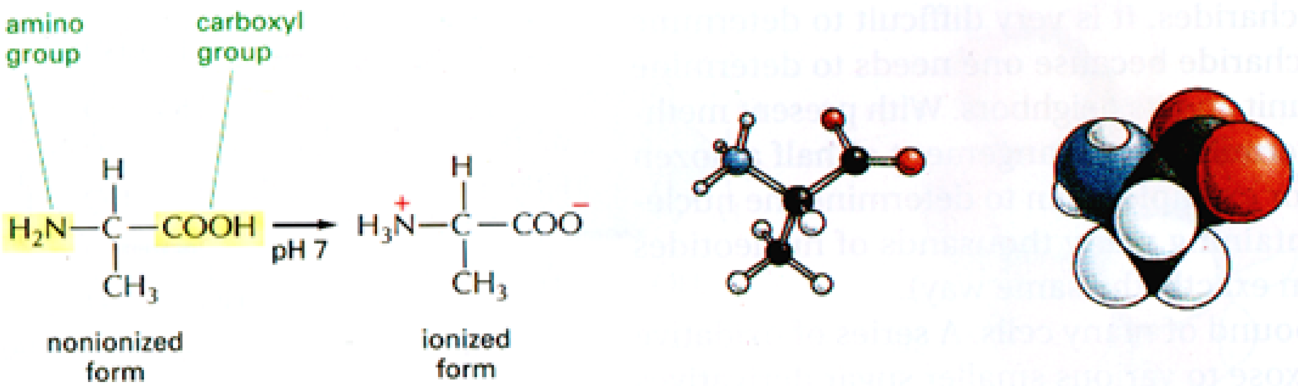
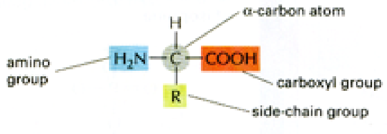


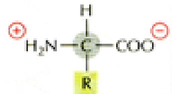
Figure 2–6 The amino acid alanine. In the cell, where the pH is close to 7, the free amino acid exists in its ionized form; but when it is incorporated into a polypeptide chain, the charges on the amino and carboxyl groups disappear. A ball-and-stick model and a space-filling model are shown to the right of the structural formulas. For alanine, the side chain is a $-CH_3$ group.

THE AMINO ACID

The general formula of an amino acid is

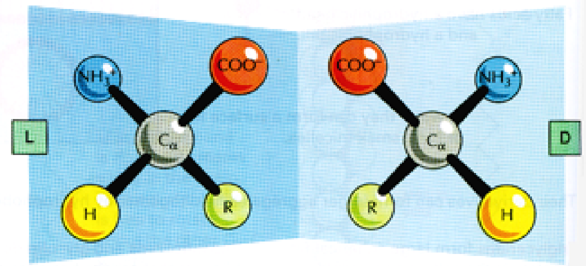


R is commonly one of 20 different side chains. At pH 7 both the amino and carboxyl groups are ionized.



OPTICAL ISOMERS

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

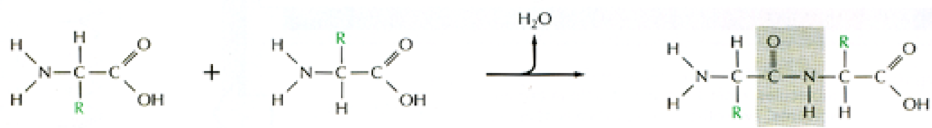


Proteins consist exclusively of L-amino acids.

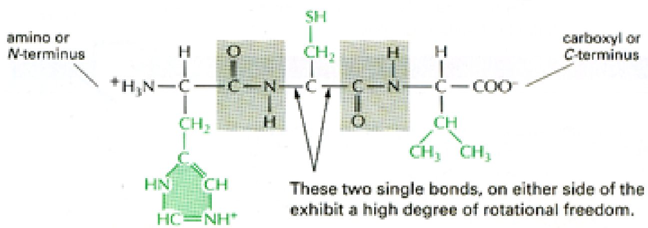
PEPTIDE BONDS

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

peptide bond: The four atoms in each *gray box* form a rigid planar unit. There is no freedom of rotation about the C—N b



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 His Cys Val.



These two single bonds, on either side of the rigid peptide u exhibit a high degree of rotational freedom.

FAMILIES OF AMINO ACIDS

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

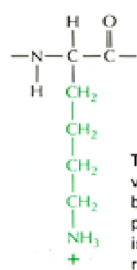
- acidic
- basic
- uncharged polar
- nonpolar

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

Thus: alanine = Ala = A

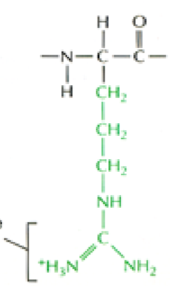
BASIC SIDE CHAINS

lysine (Lys, or K)

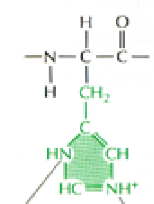


This group is very basic because its positive charge is stabilized by resonance.

arginine (Arg, or R)



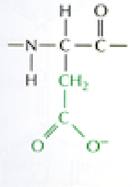
histidine (His, or H)



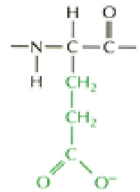
These nitrogens have a relatively weak affinity for an H⁺ and are only partly positive at neutral pH.

ACIDIC SIDE CHAINS

aspartic acid (Asp, or D)



glutamic acid (Glu, or E)



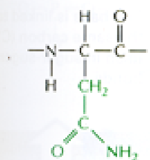
Amino acids with uncharged polar side chains are relatively hydrophilic and are usually on the outside of proteins, while the side chains on nonpolar amino acids tend to cluster together on the inside. Amino acids with basic or acidic side chains are very polar, and they are nearly always found on the outside of protein molecules.

The one letter code in alphabetical order:

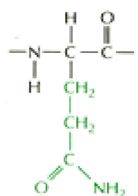
A = Ala	G = Gly	M = Met	S = Ser
C = Cys	H = His	N = Asn	T = Thr
D = Asp	I = Ileu	P = Pro	V = Val
E = Glu	K = Lys	Q = Gln	W = Trp
F = Phe	L = Leu	R = Arg	Y = Tyr

UNCHARGED POLAR SIDE CHAINS

asparagine (Asn, or N)

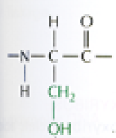


glutamine (Gln, or Q)

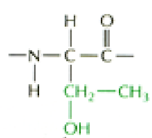


Although the amide N is not charged at neutral pH, it is polar.

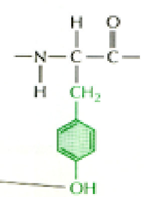
serine (Ser, or S)



threonine (Thr, or T)

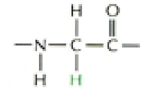


tyrosine (Tyr, or Y)



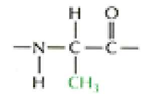
The —OH group is polar.

NONPOLAR SIDE CHAINS

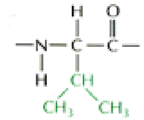


glycine (Gly, or G)

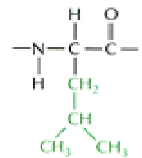
alanine (Ala, or A)



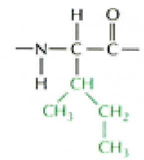
valine (Val, or V)



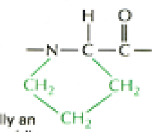
leucine (Leu, or L)



isoleucine (Ileu, or I)

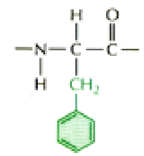


proline (Pro, or P)

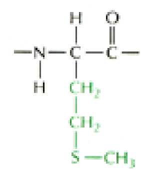


(actually an imino acid)

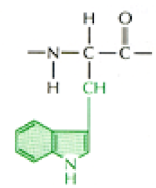
phenylalanine (Phe, or F)

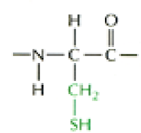


methionine (Met, or M)



tryptophan (Trp, or W)





cysteine (Cys, or C)

Paired cysteines allow disulfide bonds to form in proteins.

— $-CH_2-S-S-CH_2-$ —

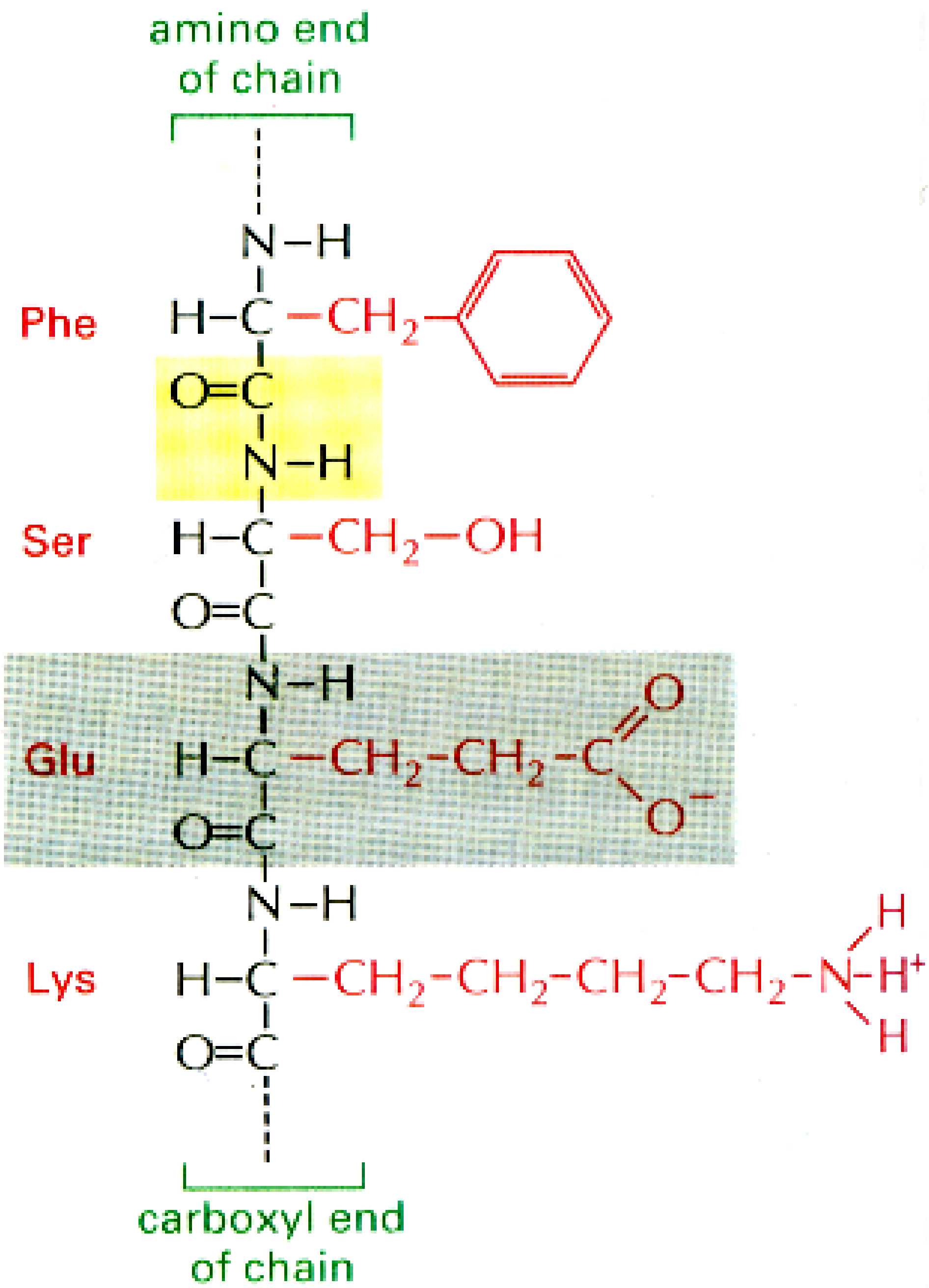


Figure 2–7 A small part of a protein molecule, showing four amino acids. Each amino acid is linked to the next by a covalent *peptide bond*, one of which is shaded *yellow*. A protein is therefore also sometimes referred to as a *polypeptide*. The amino acid *side chains* are shown in *red*, and the atoms of one amino acid (glutamic acid) are outlined by the *gray box*.

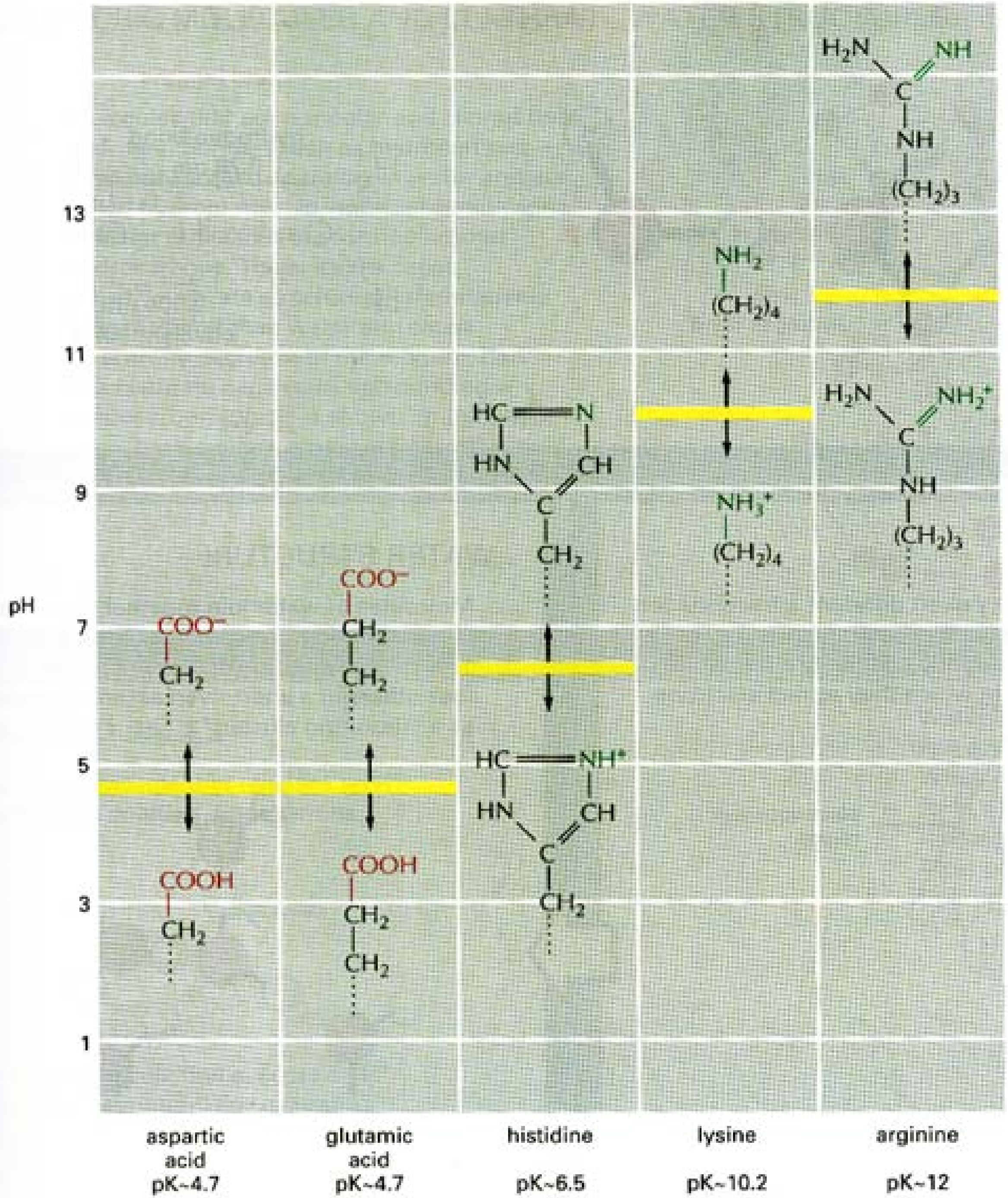
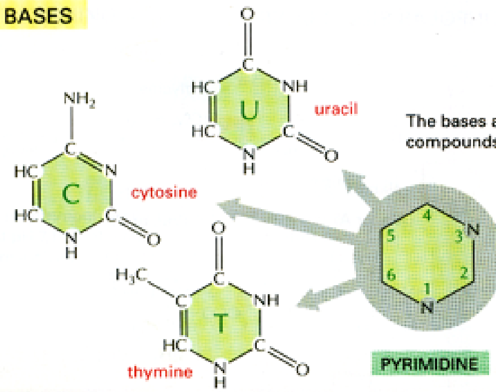


Figure 2–8 The charge on amino acid side chains depends on the pH. Carboxylic acids readily lose H^+ in aqueous solution to form a negatively charged ion, which is denoted by the suffix "-ate," as in aspart*ate* or glutam*ate*. A comparable situation exists for amines, which in aqueous solution take up H^+ to form a positively charged ion (which does not have a special name). These reactions are rapidly reversible, and the amounts of the two forms, charged and uncharged, depend on the pH of the solution. At a high pH, carboxylic acids tend to be charged and amines uncharged. At a low pH, the opposite is true—the carboxylic acids are uncharged and amines are charged. The pH at which exactly *half* of the carboxylic acid or amine residues are charged is known as the pK of that amino acid side chain.

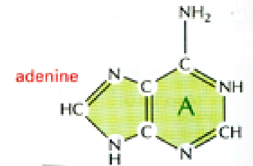
In the cell the pH is close to 7, and almost all carboxylic acids and amines are in their fully charged form.

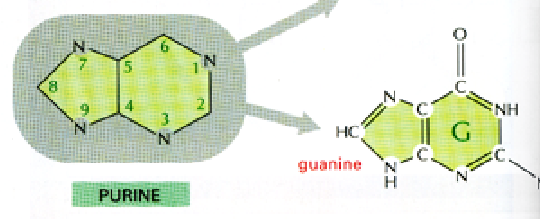
Nukleotidy a polynukleotidy

BASES



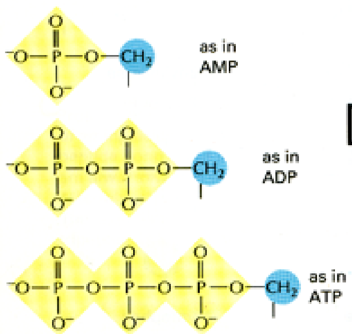
The bases are nitrogen-containing ring compounds, either purines or pyrimidines.





PHOSPHATES

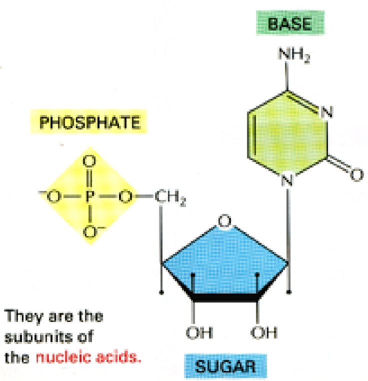
The phosphates are normally joined to the C5 hydroxyl of the ribose or deoxyribose sugar. Mono-, di-, and triphosphates are common.



The phosphate makes a nucleotide negatively charged.

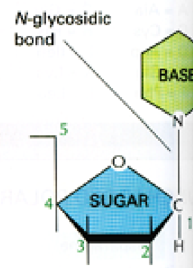
NUCLEOTIDES

A nucleotide consists of a nitrogen-containing base, a 5-carbon sugar, and one or more phosphate groups.



They are the subunits of the nucleic acids.

BASIC SUGAR LINKAGE

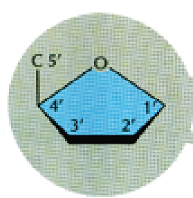


The base is linked to the same carbon (C1) used in sugar-sugar bonds.

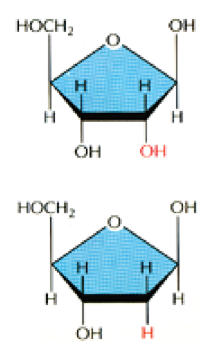
SUGARS

PENTOSE

a 5-carbon sugar



two kinds are used



β-D-RIBOSE
used in ribonucleic acid

β-D-2-DEOXYRIBOSE
used in deoxyribonucl

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

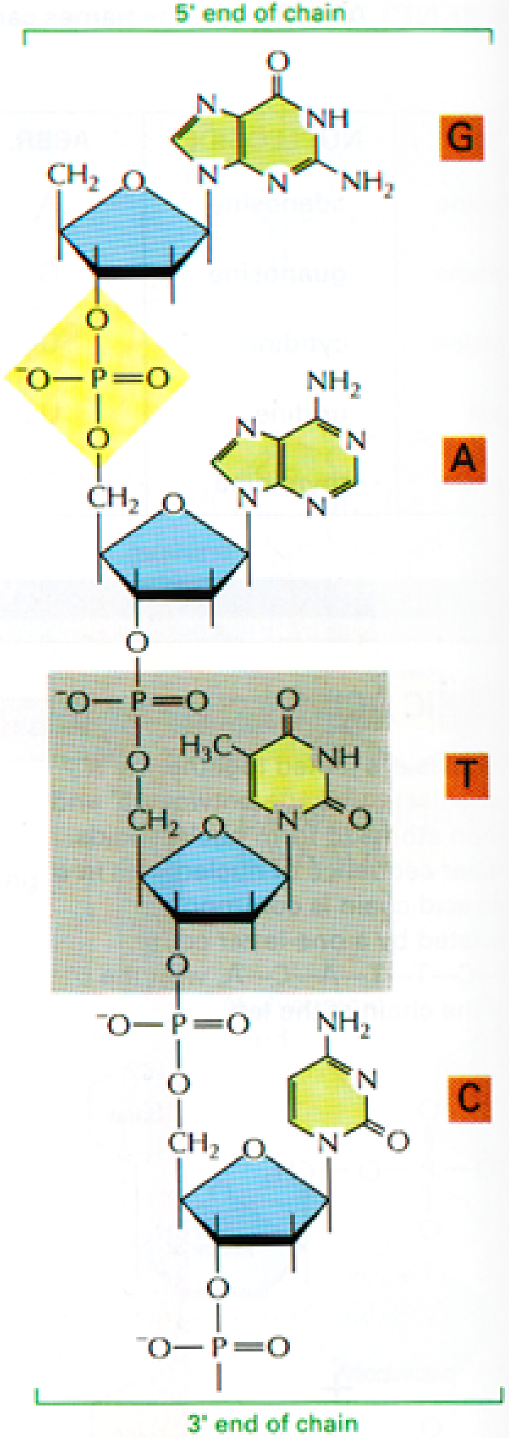
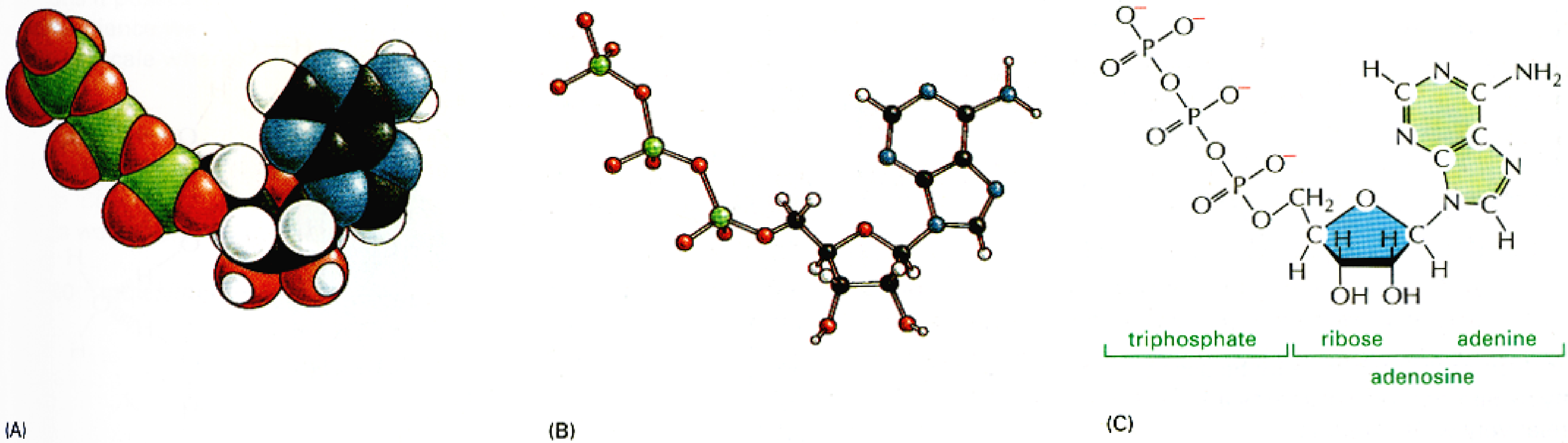


Figure 2–10 A short length of deoxyribonucleic acid (DNA), showing four nucleotides. One of the phosphodiester bonds that link adjacent nucleotides is shaded *yellow*, and one of the nucleotides is enclosed in a *gray box*. DNA and its close relative RNA are the nucleic acids of the cell.

containing adenine derivative, *cyclic AMP,* serves as a universal signaling molecule within cells.

The special significance of nucleotides is in the storage of biological information. Nucleotides serve as building blocks for the construction of **nucleic acids,** long polymers in which nucleotide subunits are covalently linked by the formation of a phosphate ester between the 3′-hydroxyl group on the sugar residue of one nucleotide and the 5′-phosphate group on the next nucleotide (Fig-

Figure 2–9 Chemical structure of adenosine triphosphate (ATP). A space-filling model (A), a ball-and-stick model (B), and the structural formula (C) are shown. Note the negative charges on each of the three phosphates.



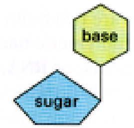
NOMENCLATURE

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

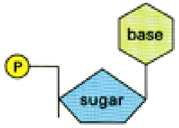
BASE	NUCLEOSIDE	ABBR.
adenine	adenosine	A
guanine	guanosine	G
cytosine	cytidine	C
uracil	uridine	U
thymine	thymidine	T

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

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



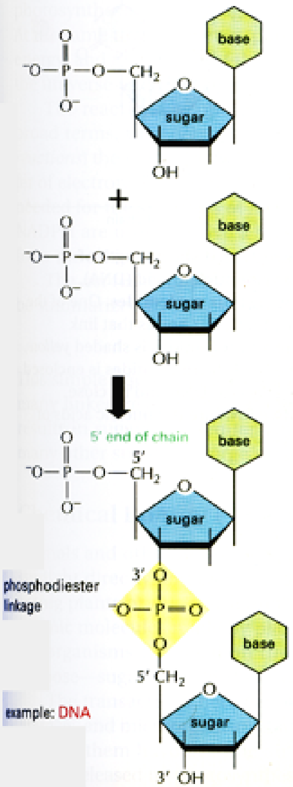
BASE + SUGAR = NUCLEOSIDE



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.

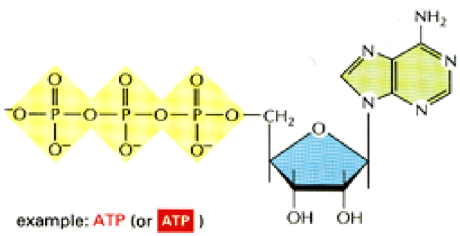


phosphodiester linkage

example: DNA

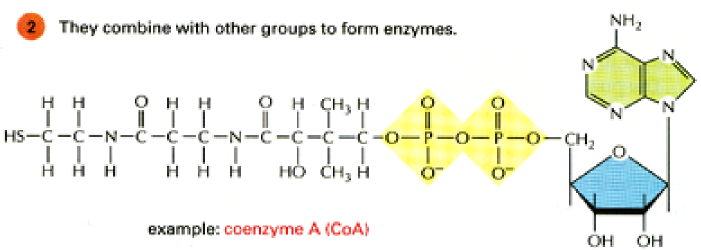
NUCLEOTIDES HAVE MANY OTHER FUNCTIONS

1. They carry chemical energy in their easily hydrolyzed acid-anhydride bonds.



example: ATP (or ATP)

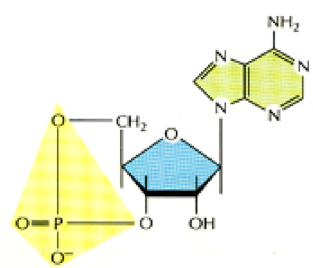
2. They combine with other groups to form enzymes.



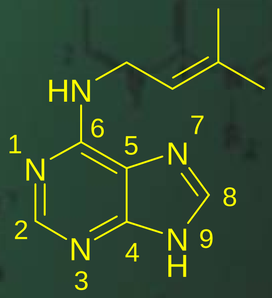
example: coenzyme A (CoA)

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

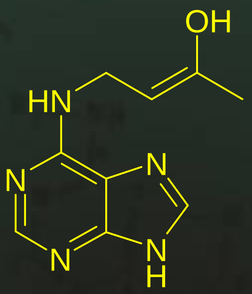
example:
cyclic AMP (cAMP)



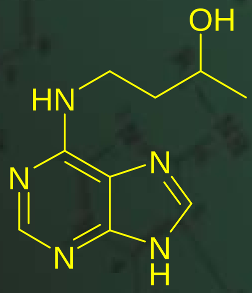
Isoprenoid and Aromatic Cytokinins



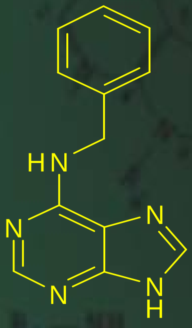
N^6-isopentenyladenine



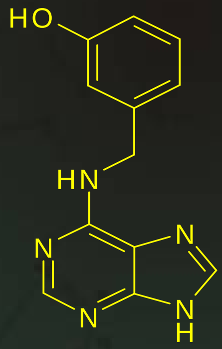
trans-zeatin



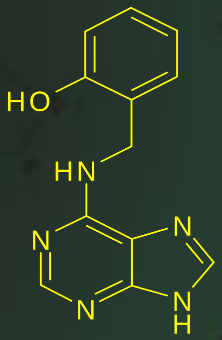
dihydrozeatin



N^6-benzyladenine



meta-topolin



ortho-topolin