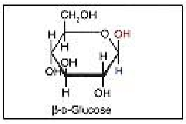
Appendix— Review of Organic Chemistry

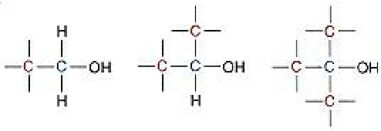
Carol N. Angstadt



Functional Groups

Alcohols

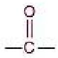
The general formula of **alcohols** is R–OH, where R equals an alkyl or aryl group. They are classified as *primary, secondary*, or *tertiary*, according to whether the hydroxyl (OH)-bearing carbon is bonded to no carbon or one, two, or three other carbon atoms:



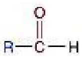
Primary Secondary Tertiary

Aldehydes and Ketones

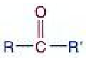
Aldehydes and **ketones** contain a carbonyl group:



Aldehydes are

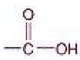


and a *ketone* has two alkyl groups at the carbonyl group



Acids and Acid Anhydrides

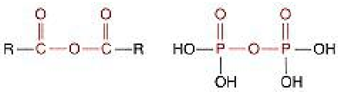
Carboxylic acids contain the functional group



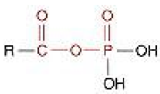
(–COOH). Dicarboxylic and tricarboxylic acids contain two or three carboxyl groups. A carboxylic acid ionizes in water to a negatively charged carboxylate ion:

Carboxylic acid Carboxylate ion

Names of carboxylic acids usually end in -ic and the carboxylate ion in -ate. **Acid anhydrides** are formed when two molecules of acid react with loss of a molecule of water. An acid anhydride may form between two organic acids, two inorganic acids, or an organic and an inorganic acid:



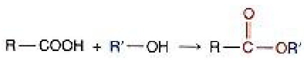
Organic anhydride Inorganic anhydride



Organic–inorganic anhydride

Esters

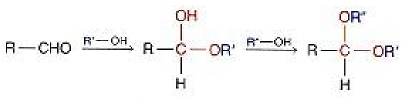
Esters form in the reaction between a carboxylic acid and an alcohol:



Esters may form between an inorganic acid and an organic alcohol, for example, glucose 6-phosphate.

Hemiacetals, Acetals, and Lactones

A reaction between an aldehyde and an alcohol gives a **hemiacetal,** which may react with another molecule of alcohol to form an **acetal:**



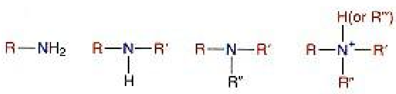
Lactones are cyclic esters formed when an acid and an alcohol group on the same molecule react and usually require that a five- or six-membered ring be formed.

Unsaturated Compounds

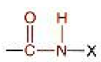
Unsaturated compounds are those containing one or more carbon–carbon multiple bonds, for example, a double bond: –C=C–

Amines and Amides

Amines, R–NH_2, are organic derivatives of NH_3 and are classified as *primary, secondary*, or *tertiary*, depending on the number of alkyl groups (R) bonded to the nitrogen. When a fourth substituent is bonded to the nitrogen, the species is positively charged and called a *quaternary ammonium ion:*



Amides contain the functional group

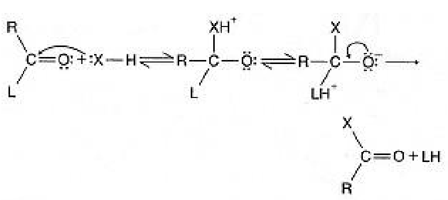


where X can be H (simple) or R (*N* substituted). The carbonyl group is from an acid, and the *N* is from an amine. If both functional groups are from amino acids, the amide bond is referred to as a **peptide bond.**

Types of Reactions

Nucleophilic Substitutions at an Acyl Carbon

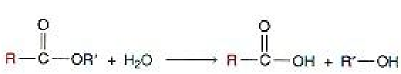
If the acyl carbon is on a carboxylic group, the leaving group is water. Nucleophilic substitution on carboxylic acids usually



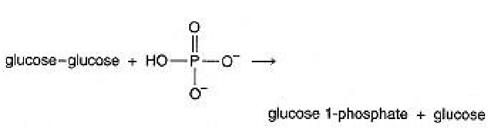
requires a catalyst or conversion to a more reactive intermediate; biologically this occurs via enzyme catalysis. X–H may be an alcohol (R–OH), ammonia, amine (R–NH_2), or another acyl compound. Types of nucleophilic substitutions include *esterification, peptide bond* formation, and *acid anhydride* formation.

Hydrolysis and Phosphorolysis Reactions

Hydrolysis is the cleavage of a bond by water:



Hydrolysis is often catalyzed by either acid or base. *Phosphorolysis* is the cleavage of a bond by inorganic phosphate:

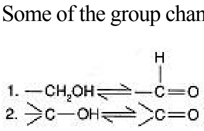


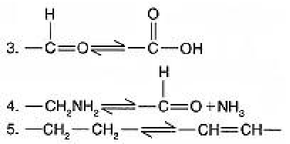
Oxidation–Reduction Reactions

Oxidation is the loss of electrons; **reduction** is the gain of electrons. Examples of oxidation are as follows:

1. Fe^{2+} + acceptor → Fe^{3+} + acceptor · e^-
2. S(ubstrate) + O_2 + DH_2 → S—OH + H_2O + D
3. S—H_2 + acceptor → S + acceptor · H_2

Some of the group changes that occur on oxidation-reduction are:

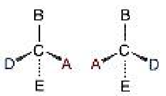




Stereochemistry

Stereoisomers are compounds with the same molecular formulas and order of attachment of constituent atoms but with different arrangements of these atoms in space.

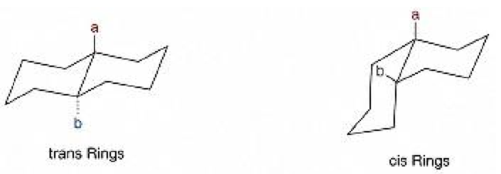
Enantiomers are stereoisomers in which one isomer is the mirror image of the other and requires the presence of a chiral atom. A chiral carbon (also called an asymmetric carbon) is one that is attached to four different groups:



Enantiomers will be distinguished from each other by the designations *R* and *S* or D and L. The maximum number of stereoisomers possible is 2^n, where n is the number of chiral carbon atoms. A molecule with more than one chiral center will be an achiral molecule if it has a point or plane of symmetry.

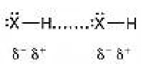
Diastereomers are stereoisomers that are not mirror images of each other and need not contain chiral atoms. **Epimers** are diastereomers that contain more than one chiral carbon and differ in configuration about *only one* asymmetric carbon.

Anomers are a special form of carbohydrate epimers in which the difference is specifically about the anomeric carbon (see p. 1140). Diastereomers can also occur with molecules in which there is restricted rotation about carbon–carbon bonds. Double bonds exhibit **cis–trans isomerism.** The double bond is in the cis configuration if the two end groups are on the same side and is trans if the two ends of the longest chain are on opposite sides. Fused ring systems, such as those found in steroids (see p. 1145), also exhibit cis–trans isomerism.



Types of Forces Involved in Macromolecular Structures

A **hydrogen bond** is a dipole–dipole attraction between a hydrogen atom attached to an electronegative atom and a nonbonding electron pair on another electronegative atom: Hydrogen bonds of importance in macromolecular structures occur between two nitrogen atoms, two oxygen atoms, or an oxygen and a nitrogen atom.



A **hydrophobic interaction** is the association of nonpolar groups in a polar medium. *Van der Waals* forces consist of dipole and induced-dipole interactions between two nonpolar groups. A nonpolar residue dissolved in water induces a highly ordered, thermodynamically unfavorable, solvation shell. Interaction of nonpolar residues with each other, with the exclusion of water, increases the entropy of the system and is thermodynamically favorable.

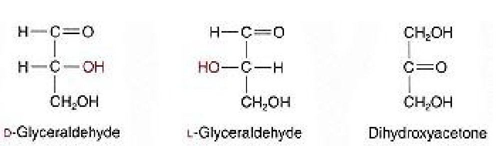
Ionic (electrostatic) interactions between charged groups can be attractive if the charges are of opposite signs or repulsive if they are of the same sign. The strength of an electrostatic interaction in the interior of a protein molecule may be high. Most charged groups on the surface of a protein molecule interact with water rather than with each other.

A **disulfide bond** (S–S) is a covalent bond formed by the oxidation of two sulfhydryl (SH) groups.

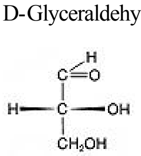
Carbohydrates

Carbohydrates are polyhydroxy aldehydes or ketones or their derivatives. **Monosaccharides** (simple sugars) are those carbohydrates that cannot be hydrolyzed into simpler compounds. The generic name of a monosaccharide includes the type of function, a Greek prefix indicating the number of carbon atoms, and the ending -ose; for example, *aldohexose* is a six-carbon aldehyde and *ketopentose* is a five-carbon ketone. Monosaccharides may react with each other to form larger molecules. With fewer than eight monosaccharides, either a Greek prefix indicating the number or the general term *oligosaccharide* may be used. **Polysaccharide** refers to a polymer with more than eight monosaccharides. Oligo- and polysaccharides may be either homologous or mixed.

Most *monosaccharides* are asymmetric, an important consideration since enzymes usually work on only one isomeric form. The simplest carbohydrates are glyceraldehyde and dihydroxyacetone, whose structures, shown as Fischer projections, are as follows:

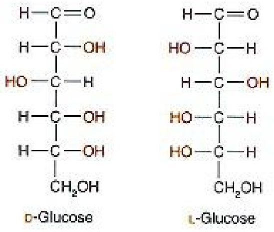


D-Glyceraldehyde may also be written as follows:

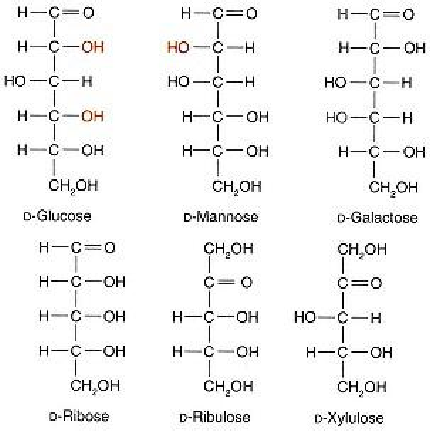


In the Cahn–Ingold–Prelog system, the designations are (*R*) (rectus; right) and (*S*) (sinister, left).

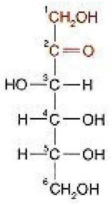
The configuration of monosaccharides is determined by the stereochemistry at the asymmetric carbon furthest from the carbonyl carbon (number 1 for an aldehyde; lowest possible number for a ketone). Based on the *position* of the OH on the highest number asymmetric carbon, a monosaccharide is D if the OH projects to the *right* and L if it projects to the *left*. The D and L monosaccharides with the same name are *enantiomers*, and the substituents on all asymmetric carbon atoms are reversed as in



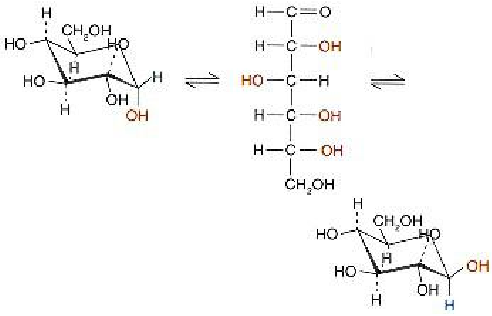
Epimers (e.g., glucose and mannose) are stereoisomers that differ in the configuration about *only one* asymmetric carbon. The relationship of OH groups to *each other* determines the specific monosaccharide. Three aldohexoses and three pentoses of importance are



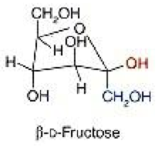
Fructose, a ketohexose, differs from glucose only on carbon atoms 1 and 2:



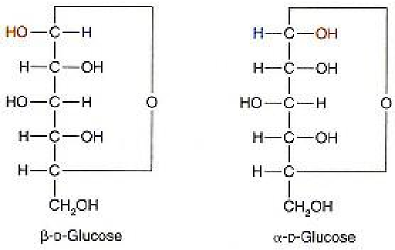
Five- and six-carbon monosaccharides form **cyclic hemiacetals** or *hemiketals* in solution. A new asymmetric carbon is generated so two isomeric forms are possible:



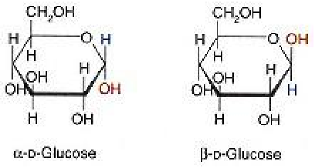
Both five-membered (furanose) and six-membered (pyranose) ring structures are possible, although pyranose rings are more common. A furanose ring is written as follows:

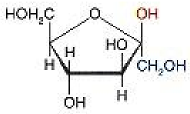


The isomer is designated α if the OH group and the CH_2OH group on the two carbon atoms linked by the oxygen are trans to each other and β if they are cis. The hemiacetal or hemiketal forms may also be written as modified *Fischer projection formulas*: α if OH on the acetal or ketal carbon projects to the same side as the ring and β if on the opposite side:



Haworth formulas are used most commonly:





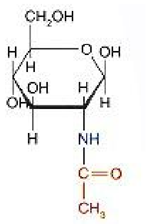
β-D-Fructose

The ring is perpendicular to the plane of the paper with the oxygen written to the back (upper) right, C-1 to the right, and substituents above or below the plane of the ring. The OH at the acetal or ketal carbon is below in the α isomer and above in the β. Anything written to the right in the Fischer projection is written down in the Haworth formula.

The α and β forms of the same monosaccharide are special forms of epimers called *anomers*, differing only in the configuration about the anomeric (acetal or ketal) carbon. Monosaccharides exist in solution primarily as a mixture of the hemiacetals (or hemiketals) but react chemically as aldehydes or ketones. *Mutarotation* is the equilibration of α and β forms through the free aldehyde or ketone. Substitution of the H of the anomeric OH prevents mutarotation and fixes the configuration in either the α or β form.

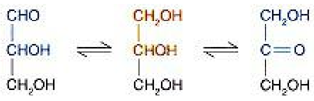
Monosaccharide Derivatives

A **deoxymonosaccharide** is one in which an OH has been replaced by H. In biological systems, this occurs at C-2 unless otherwise indicated. An **amino monosaccharide** is one in which an OH has been replaced by NH_2, again at C-2 unless otherwise specified. The amino group of an amino sugar may be *acetylated*:

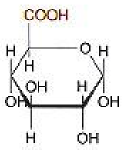


β-*N*-Acetylglucosamine

An aldehyde is reduced to a primary and a ketone to a secondary **monosaccharide alcohol (alditol).** Alcohols are named with the base name of the sugar plus the ending -*itol* or with a trivial name (glucitol = sorbitol). Monosaccharides that differ around only two of the first three carbon atoms yield the same alditol. D-Glyceraldehyde and dihydroxyacetone give glycerol:

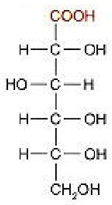


D-Glucose and D-fructose give D-sorbitol; D-fructose and D-mannose give D-mannitol. Oxidation of the terminal CH_2OH, but not of the CHO, yields a-**uronic acid,** a *monosaccharide acid:*

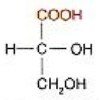


D-Glucuronic acid

Oxidation of the CHO, but not the CH_2OH, gives an -**onic acid:**

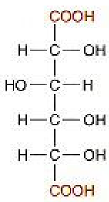


D-Gluconic acid



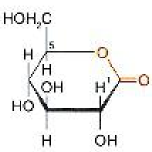
D-Glyceric acid

Oxidation of both the CHO and CH_2OH gives an -**aric acid**:

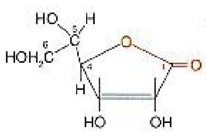


D-Glucaric acid

Ketones do not form acids. Both -onic and -uronic acids can react with an OH in the same molecule to form a **lactone** (see p. 1138):



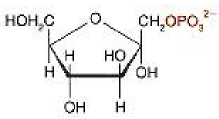
D-Glucono-5-lactone

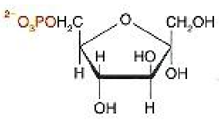


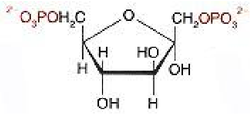
L-Ascorbic acid
(derivative of L-gulose)

Reactions of Monosaccharides

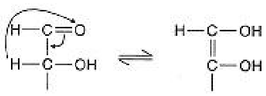
The most common *esters* of monosaccharides are phosphate esters at carbon atoms 1 and/or 6:



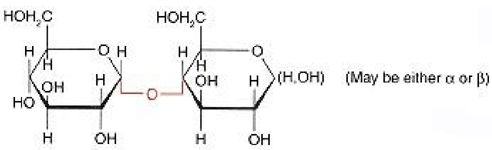




To be a **reducing sugar,** mutarotation must be possible. In alkali, enediols form that may migrate to 2,3 and 3,4 positions:



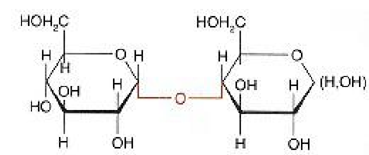
Enediols may be oxidized by O_2, CU^{2+}, Ag^+, and Hg^{2+}. Reducing ability is more important in the laboratory than physiologically. A hemiacetal or hemiketal may react with the OH of another monosaccharide to form a disaccharide (*acetal: glycoside*) (see below):



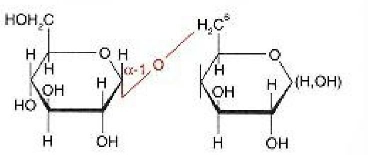
One monosaccharide still has a free anomeric carbon and can react further. Reaction of the anomeric OH may be with any OH on the other monosaccharide, including the anomeric one. The anomeric OH that has reacted is fixed as either α or β and cannot mutarotate or reduce. If the glycosidic bond is not between two anomeric carbon atoms, one of the units will still be free to mutarotate and reduce.

Oligo- and Polysaccharides

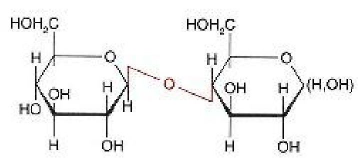
Disaccharides have two monosaccharides, either the same or different, in glycosidic linkage. If the glycosidic linkage is between the two anomeric carbon atoms, the disaccharide is nonreducing:



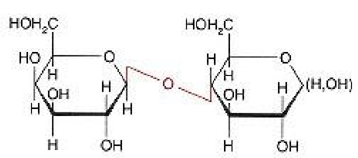
Maltose



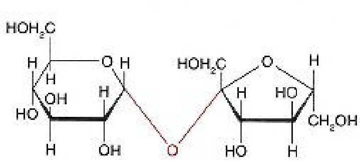
Isomaltose



Cellobiose



Lactose



Sucrose

Maltose = 4-*O*-(α-D-glucopyranosyl)D-glucopyranose; reducing

Isomaltose = 6-*O*-(α-D-glucopyranosyl)D-glucopyranose; reducing

Cellobiose = 4-*O*-(β-D-glucopyranosyl)D-glucopyranose; reducing

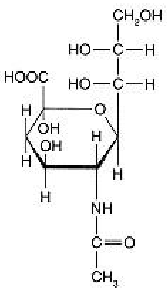
Lactose = 4-*O*-(β-D-galactopyranosyl)D-glucopyranose; reducing

Sucrose = α-D-glucopyranosyl-β-D-fructofuranoside; non-reducing

As many as thousands of monosaccharides, either the same or different, may be joined by glycosidic bonds to form *polysaccharides*. The anomeric carbon of one unit is usually joined to C-4 or C-6 of the next unit. The ends of a polysaccharide are not identical (reducing end = free anomeric carbon; nonreducing = anomeric carbon linked to next unit; branched polysaccharide = more than one nonreducing end). The most common carbohydrates are homopolymers of glucose; for example, starch, glycogen, and cellulose. Plant starch is a mixture of **amylose,** a linear polymer of maltose units, and **amylopectin,** branches of repeating maltose units (glucose–glucose in α-1,4 linkages) joined via isomaltose linkages. **Glycogen,** the storage form of carbohydrate in animals, is similar to amylopectin, but the branches are shorter and occur more frequently. **Cellulose,** in plant cell walls, is a linear polymer of repeating cellobioses (glucose–glucose in β-1,4 linkages).

Mucopolysaccharides contain amino sugars, free and acetylated, uronic acids, sulfate esters, and sialic acids in addition to the simple monosaccharides. **N-Acetylneur-**

aminic acid, a sialic acid, is



Lipids

Lipids are a diverse group of chemicals related primarily because they are insoluble in water, soluble in nonpolar solvents, and found in animal and plant tissues.

Saponifiable lipids yield salts of fatty acids upon alkaline hydrolysis. *Acylglycerols* = glycerol + fatty acid(s); *phosphoacylglycerols* = glycerol + fatty acids + HPO_4^{2-} + alcohol; *sphingolipids* = sphingosine + fatty acid + polar group (phosphorylalcohol or carbohydrate); *waxes* = long-chain alcohol + fatty acid. *Nonsaponifiable lipids* (*terpenes, steroids, prostaglandins,* and related compounds) are not usually subject to hydrolysis. *Ampbipathic* lipids have both a polar "head" group and a nonpolar "tail." Amphipathic molecules can stabilize emulsions and are responsible for the lipid bilayer structure of membranes.

Fatty acids are monocarboxylic acids with a short (<6 carbon atoms), medium (8–14 carbon atoms), or long (>14 carbon atoms) aliphatic chain. Biologically important ones are usually linear molecules with an even number of carbon atoms (16–20). Fatty acids are numbered using either arabic numbers (COOH is 1) or the Greek alphabet (COOH is not given a symbol; adjacent carbon atoms are α, β, γ, etc.). **Saturated fatty acids** have the general formula $CH_3CH_2)_nCOOH$. (*Palmitic acid* = C_{16}; stearic acid = C_{18}.) They tend to be extended chains and solid at room temperature unless the chain is short. Both trivial and systematic (prefix indicating number of carbon atoms + *anoic acid*) names are used. $CH_3(CH_2)_{14}COOH$ = palmitic acid or hexadecanoic acid.

Unsaturated fatty acids have one or more double bonds. Most naturally occurring fatty acids have cis double bonds and are usually liquid at room temperature. Fatty acids with trans double bonds tend to have higher melting points. A double bond is indicated by ^{n}, where *n* is the number of the first carbon of the bond. *Palmitoleic* = ^{9}-hexadecenoic acid; *oleic* = ^{9}-octadecenoic acid; *linoleic* = ^{9,12}-octadecadienoic acid; *linolenic* = ^{9,12,15}-octadecatrienoic acid; *arachidonic* = ^{5,8,11,14}-eicosatetraenoic acid. Since fatty acids are elongated *in vivo* from the carboxyl end, biochemists use alternate terminology to assign these fatty acids to families: omega ( ) minus *x* (or *n* – *x*), where *x* is the number of carbon atoms from the methyl end where a double bond is first encountered. *Palmitoleic* is an – 7 and *oleic* is an – 9 acid, *linoleic* and *arachidonic* are – 6 acids, and *linolenic* is an – 3 acid. Addition of carbon atoms does not change the family to which an unsaturated fatty acid belongs.

Since the p*K* values of fatty acids are about 4–5, in physiological solutions, they exist primarily in the ionized form, called salts or "soaps." Long-chain fatty acids are insoluble in water, but soaps form micelles. Fatty acids form esters with alcohols and thioesters with CoA.

The following are biochemically significant reactions of unsaturated fatty acids:

1. *Reduction*

$$-CH{=}CH- + XH_2 \rightarrow -CH_2CH_2- + X$$

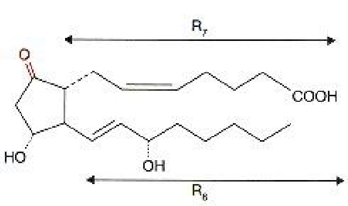
2. *Addition of water*

$$-CH{=}CH- + H_2O \rightarrow -CH(OH)-CH_2-$$

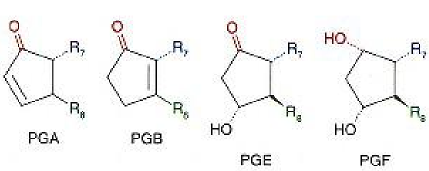
3. *Oxidation*

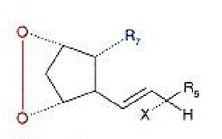
$$R-CH{=}CH-R' \rightarrow R-CHO + R'-CHO$$

Prostaglandins, thromboxanes, and *leukotrienes* are derivatives of C_{20}, polyunsaturated fatty acids, especially arachidonic acid. Prostaglandins have the general structure:

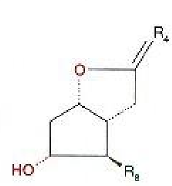


The series differ from each other in the substituents on the ring and whether C-15 contains an OH or O · OH group. The subscript indicates the number of double bonds in the side chains. Substituents indicated by –(β) are above the plane of the ring; . . . (α) below:

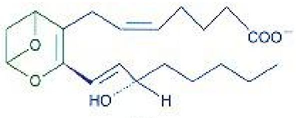




PGG(X=OH); PGH(X=OOH)

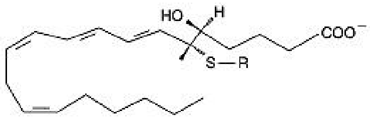


Thromboxanes have an oxygen incorporated to form a six-membered ring:



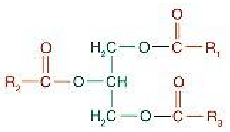
TXA_2

Leukotrienes are substituted derivatives of arachidonic acid in which no internal ring has formed; R is variable:



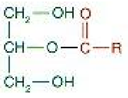
Leukotriene C, D, or E

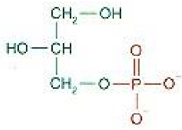
Acylglycerols are compounds in which one or more of the three OH groups of glycerol are esterified. In **triacylglycerols** (triglycerides) all three OH groups are esterified to fatty acids. At least two of the three R groups are usually different. If R_1 is not equal to R_3, the molecule is asymmetric and of the L configuration:



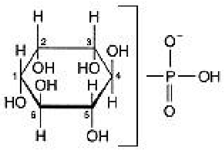
The properties of the triacylglycerols are determined by those of the fatty acids they contain, with *oils* being liquid at room temperature (preponderance of short-chain and/or cis-unsaturated fatty acids) and *fats* being solid (preponderance of long-chain, saturated, and/or trans-unsaturated).

Triacylglycerols are hydrophobic and do not form stable micelles. They may be hydrolyzed to glycerol and three fatty acids by strong alkali or enzymes (lipases). *Mono-* [usually with the fatty acid in the β(2) position] and *diacylglycerols* also exist in small amounts as metabolic intermediates. Mono- and diacylglycerols are slightly more polar than triacylglycerols. *Phosphoacylglycerols* are derivatives of L-α-glycerolphosphate (L-glycerol 3-phosphate):

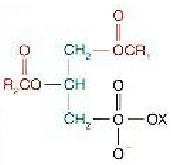




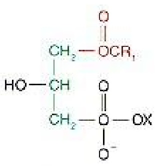
The parent compound, **phosphatidic acid** (two OH groups of L-α-glycerolphosphate esterified to fatty acids), has its phosphate esterified to an alcohol (XOH) to form several series of phosphoacylglycerols. These are amphipathic molecules, but the net charge at pH 7.4 depends on the nature of X–OH.

X—OH	Phosphoacylglycerol
$HO—CH_2—CH_2—\overset{+}{N}—(CH_3)_3$	Phosphatidylcholines (lecithins)
$HO—CH_2—CH_2—\overset{+}{N}H_3$	Phosphatidylethanolamines (cephalins)
$HO—CH_2—CH(\overset{+}{N}H_3)—COO^-$	Phosphatidylserines
	Phosphatidylinositols phosphate on 4, or 4 and 5

In **plasmalogens,** the OH on C-1 is in *ether*, rather than ester, linkage to an alkyl group. If *one* fatty acid (usually β) has been hydrolyzed from a phosphoacylglycerol, the compound is a *lyso*-compound; for example, lyso-phosphatidylcholine (lysolecithin):

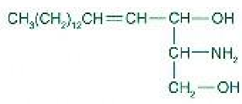


A phosphoacylglycerol

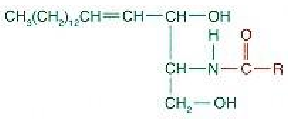


A lyso-compound

Sphingolipids are complex lipids based on the C-18, unsaturated alcohol, sphingosine. In *ceramides*, a long-chain fatty acid is in amide linkage to sphingosine:

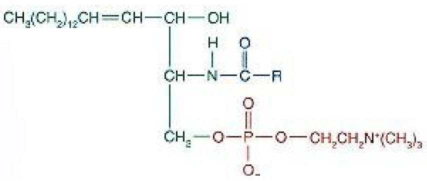


Sphingosine

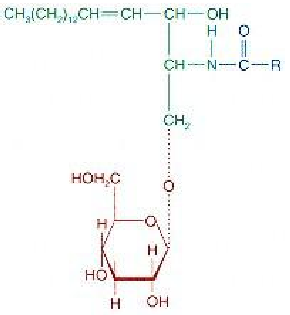


A ceramide

Sphingomyelins, the most common Sphingolipids, are a family of compounds in which the primary OH group of a ceramide is esterified to phosphorylcholine (phosphorylethanolamine):



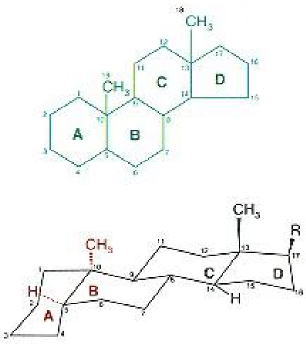
They are amphipathic molecules, existing as zwitterions at pH 7.4 and the only sphingolipids that contain phosphorus. *Glycosphingolipids* do not contain phosphorus but contain carbohydrate in glycosidic linkage to the primary alcohol of a ceramide. They are amphipathic and either neutral or acidic if the carbohydrate moiety contains an acidic group. **Cerebrosides** have a single glucose or galactose linked to a ceramide. *Sulfatides* are galactosylceramides esterified with sulfate at C-3 of the galactose:



Glucosylceramide (glucocerebroside)

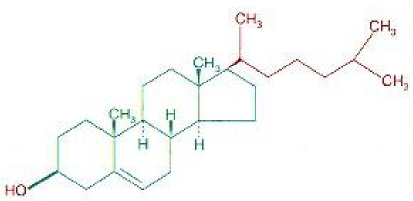
Globosides (ceramide oligosaccharides) are ceramides with two or more neutral monosaccharides, whereas **ganglio-sides** are an oligosaccharide containing one or more sialic acids.

Steroids are derivatives of cyclopentanoperhydrophe-nanthrene. The steroid nucleus is a rather rigid, essentially planar structure with substituents above or in the plane of the rings designated β (solid line) and those below called α (dotted line):

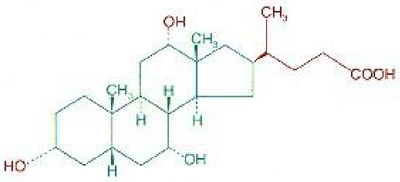


A and B rings—cis;
the others—trans

Most steroids in humans have methyl groups at positions 10 and 13 and frequently a side chain at position 17. *Sterols* contain one or more OH groups, free or esterified to a fatty acid. Most steroids are nonpolar. In a liposome or cell membrane, **cholesterol** orients with the OH toward any polar groups; cholesterol esters do not. **Bile acids** (e.g., cholic acid) have a polar side chain and so are amphipathic:

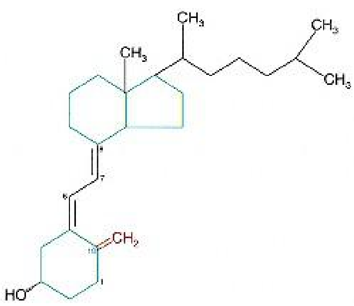


Cholesterol



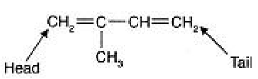
Cholic acid

Steroid hormones are oxygenated steroids of 18–21 carbon atoms. *Estrogens* have 18 carbon atoms, an aromatic ring A, and no methyl at C-10. *Androgens* have 19 carbon atoms and no side chain at C-17. *Glucocorticoids* and *mineralocorticoids* have 21 carbon atoms, including a C_2, of oxygenated side chain at C-17. *Vitamin D_3 (cholecalciferol)* is not a sterol but is derived from 7-dehydrocholesterol in humans:

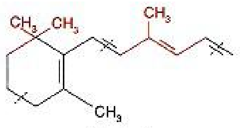


Cholecalciferol

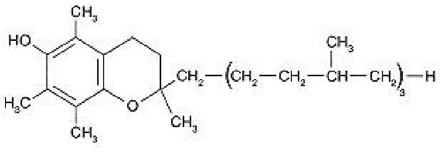
Terpenes are polymers of two or more isoprene units. **Isoprene** is



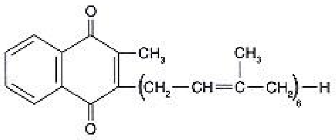
Terpenes may be linear or cyclic, with the isoprenes usually linked head to tail and most double bonds trans (but may be cis as in vitamin A). *Squalene,* the precursor of cholesterol, is a linear terpene of six isoprene units. Fat-soluble *vitamins* (A, D, E, and K) contain isoprene units:



Vitamin A



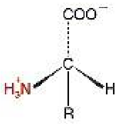
Vitamin E (α-tocopherol)



Vitamin K_2

Amino Acids

Amino acids contain both an *amino* (NH_2) and a *carboxylic acid* (COOH) group. Biologically important amino acids are usually α-amino acids with the formula



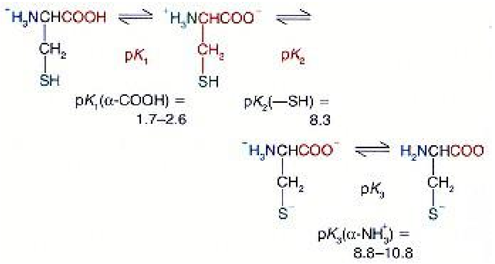
L-α-Amino acid

The amino group, with an unshared pair of electrons, is basic, with a pK_a of about 9.5, and exists primarily as $-NH_{3+}$ at pH values near neutrality. The carboxylic acid group (pK 2.3) exists primarily as a carboxylate ion. If R is anything but H, the molecule is asymmetric with most naturally occurring ones of the L configuration (same relative configuration as L-glyceraldehyde: see p. 1139).

The *polarity* of amino acids is influenced by their side chains (R groups) (see p. XX for complete structures). *Nonpolar* amino acids include those with large, aliphatic, aromatic, or undissociated sulfur groups (aliphatic = Ala, Ile, Leu, Val; aromatic = Phe, Trp; sulfur = Cys, Met). *Intermediate* polarity amino acids include Gly, Pro, Ser, Thr, and Tyr (undissociated).

Amino acids with ionizable side chains are *polar*. The pK values of the side groups of arginine, lysine, glutamate, and aspartate are such that these are nearly always charged at physiological pH, whereas the side groups of histidine (pK = 6.0) and cysteine (pK = 8.3) exist as both charged and uncharged species at pH 7.4 (acidic = Glu, Asp, Cys; basic = Lys, Arg, His). Although undissociated cysteine is nonpolar, cysteine in dissociated form is polar.

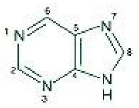
All amino acids are at least *dibasic acids* because of the presence of both the α-amino and α-carboxyl groups, the ionic state being a function of pH. The presence of another ionizable group will give a tribasic acid as shown for cysteine.



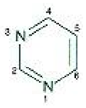
The **zwitterionic form** is the form in which the *net* charge is zero. The *isoelectric point* is the average of the two pK values involved in the formation of the zwitterionic form. In the above example this would be the average of pK_1 + pK_2.

Purines and Pyrimidines

Purines and **pyrimidines,** often called *bases*, are nitrogen-containing heterocyclic compounds with the structures



Purine

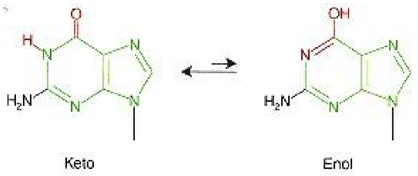


Pyrimidine

Major bases found in nucleic acids and as cellular nucleo-tides are the following:

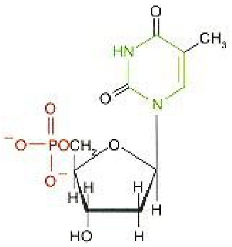
Purines	*Pyrimidines*
Adenine: 6-amino	Cytosine: 2-oxy, 4-amino
Guanine: 2-amino, 6-oxy	Uracil: 2,4-dioxy
	Thymine: 2,4-dioxy, 5-methyl
Other important bases found primarily as intermediates of synthesis and/or degradation are	
Hypoxanthine: 6-oxy	Orotic acid: 2,4-dioxy, 6-carboxy
Xanthine: 2,6-dioxy	

Oxygenated purines and pyrimidines exist as *tautomeric* structures with the keto form predominating and involved in hydrogen bonding between bases in nucleic acids:



Nucleosides have either *β*-D-ribose or *β*-D-2-deoxyribose in an *N*-glycosidic linkage between C-1 of the sugar and N-9 (purine) or N-1 (pyrimidine).

Nucleotides have one or more phosphate groups esterified to the sugar. Phosphates, if more than one are present, are usually attached to each other via phosphoanhydride bonds. Monophosphates may be designated as either the base monophosphate or as an -*ylic acid*(AMP: adenylic acid):



By conventional rules of *nomenclature*, the atoms of the base are numbered 1–9 in purines or 1–6 in pyrimidines and the carbon atoms of the sugar 1 –5 . A nucleoside with an unmodified name indicates that the sugar is ribose and the phosphate(s) is/are attached at C-5 of the sugar. Deoxy forms are indicated by the prefix d (dAMP = deoxyadenylic acid). If the phosphate is esterified at any position other than 5 , it must be so designated [3 -AMP; 3 -5 -AMP; (cyclic AMP = cAMP)]. The nucleosides and nucleotides (ribose form) are named as follows:

Base	***Nucleoside***	***Nucleotide***
Adenine	Adenosine	AMP, ADP, ATP
Guanine	Guanosine	GMP, GDP, GTP
Hypoxanthine	Inosine	IMP
Xanthine	Xanthosine	XMP
Cytosine	Cytidine	CMP, CDP, CTP
Uracil	Uridine	UMP, UDP, UTP
Thymine	dThymidine	dTMP, dTTP
Orotic acid	Orotidine	OMP

Minor (modified) bases and nucleosides also exist in nucleic acids. *Methylated* bases have a methyl group on an amino group (*N*-methyl guanine), a ring atom (1-methyl adenine), or on an OH group of the sugar (2 -*O*-methyl adenosine). *Dihydrouracil* has the 5–6 double bond saturated. In *pseudouridine*, the ribose is attached to C-5 rather than to N-1.

In **polynucleotides** (*nucleic acids*), the mononucleotides are joined by phosphodiester bonds between the 3 -OH of one sugar (ribose or deoxyribose) and the 5 -OH of the next (see p. 567 for the structure).

Index

HOW TO USE THIS INDEX. The letter "*f*" after a page number designates a figure; "*t*" designates tabular material; "cc" designates a Clinical Correlation **Boldface** page numbers show where terms are explained. "*See*" cross-references direct the reader to the synonymous term. "*See also*" cross-references direct the reader to (1) related topics or (2) the synonym under which a more detailed topic breakdown may be found.

D

G

N

Q

R

U

V

NORMAL CLINICAL VALUES: BLOOD*

INORGANIC SUBSTANCES

Ammonia	12–55 μmol/L
Bicarbonate	22–26 meq/L
Calcium	8.5–10.5 mg/dl
Carbon dioxide	24–30 meq/L
Chloride	100–106 meq/L
Copper	100–200 μg/dl
Iron	50–150 μg/dl
Lead	10 μg/dl or less
Magnesium	1.5–2.0 meq/L
Pco_2	35–45 mmHg 4.7–6.0 kPa
pH	7.35–7.45
Phosphorus	3.0–4.5 mg/dl
Po_2	75–100 mmHg 10.0–13.3 kPa
Potassium	3.5–5.0 meq/L
Sodium	135–145 meq/L

ORGANIC MOLECULES

Acetoacetate	negative
Ascorbic acid	0.4–15 mg/dl
Bilirubin	
Direct	0–0.4 mg/dl
Indirect	0.6 mg/dl
Carotenoids	0.8–4.0 μg/ml
Creatinine	0.6–1.5 mg/dl
Glucose	70–110 mg/dl
Lactic acid	0.5–2.2 meq/L
Lipids	
Total	450–1000 mg/dl
Cholesterol	120–220 mg/dl
Phospholipids	9–16 mg/dl as lipid P
Total fatty acids	190–420 mg/dl
Triglycerides	40–150 mg/dl
Phenylalanine	0–2 mg/dl
Pyruvic acid	0–0.11 meq/L
Urea nitrogen (BUN)	8–25 mg/dl
Uric acid	3.0–7.0 mg/dl
Vitamin A	0.15–0.6 μg/ml

PROTEINS

Total	6.0–8.4 g/dl
Albumin	3.1–4.3 g/dl
Ceruloplasmin	23–43 mg/dl
Globulin	2.6–4.1 g/dl
Insulin	0–29 μU/ml

ENZYMES

Aldolase	0–7 U/ml
Amylase	4–25 U/ml
Cholinesterase	0.5 pH U or more/h
Creatine kinase (CK)	40–150 U/L
Lactic dehydrogenase	110–210 U/L
Lipase	2 U/ml or less
Nucleotidase	1–11 U/L
Phosphatase (acid)	0.1–0.63 Sigma U/ml
Phosphatase (alkaline)	13–39 U/L
Transaminase (SGOT)	9–40 U/ml

PHYSICAL PROPTERTIES

Blood pressure	120/80 mmHg
Blood volume	8.5–9.0% of body weight in kg
Iron binding capacity	250–410 μg/dl
Osmolality	280–296 mOsm/kg H_2O
Hematocrit	37–52%

NORMAL CLINICAL VALUES: URINE*

Acetoacetate (acetone)	0
Amylase	24–76 U/ml
Calcium	0–300 mg/d
Copper	0–60 μg/d
Coproporphyrin	50–250 μg/d
Creatine	under 0.75 mmol/d
Creatinine	15–25 mg/kg body weight/d
5-Hydroxyindoleacetic acid	2–9 mg/d
Lead	120 μg/d or less
Phosphorus (inorganic)	varies; average 1 g/d
Porphobilinogen	0
Protein (quantitative)	less than 165 mg/d
Sugar	0
Titratable acidity	20–40 meq/d
Urobilinogen	up to 1.0 Ehrlich U
Uroporphyrin	0–30 μg/d

*Selected values are taken from normal reference laboratory values in use at the Massachusetts General Hospital and published in the *New England Journal of Medicine* 314:39, 1986 and 327:718, 1992. The reader is referred to the complete list of reference laboratory values in the literature citation for references to methods and units. dl, deciliters (100 ml); d, day.