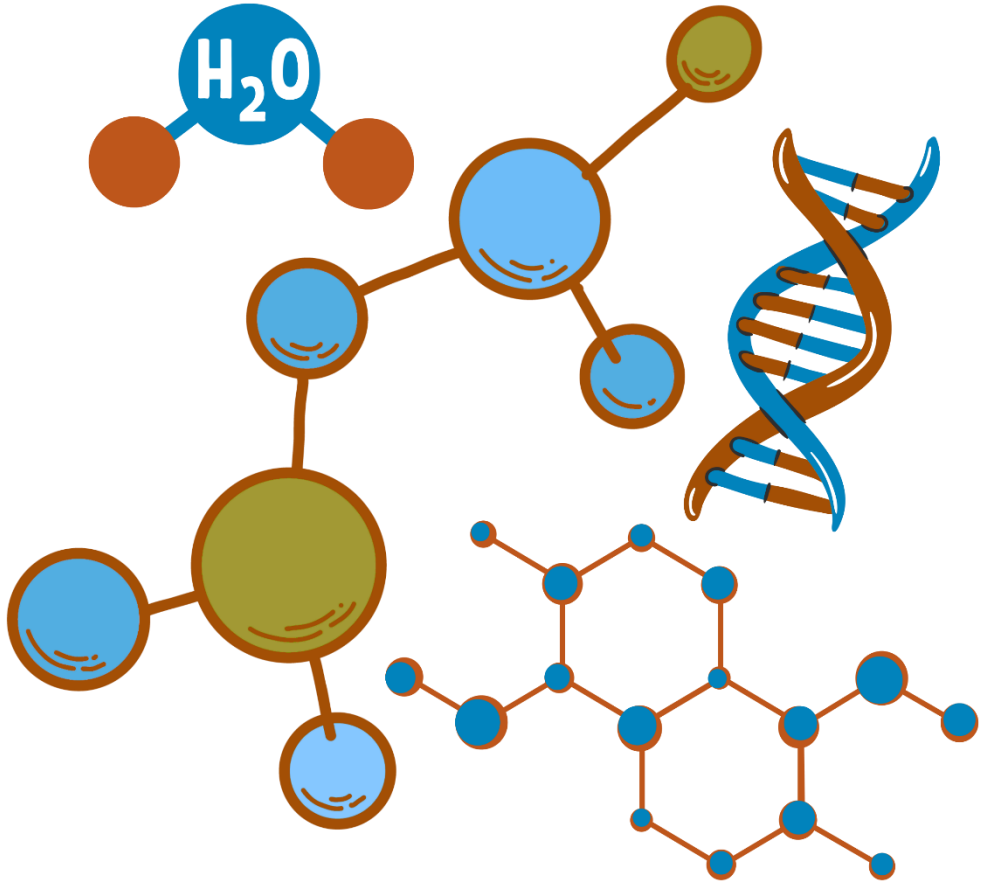
Introduction to Organic Chemistry
CHEM 108

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Chapter 6: Chemistry of Biomolecules



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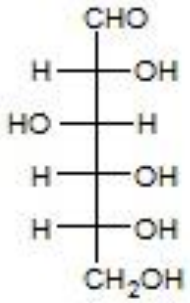
Carbohydrates

Chapter 6: Chemistry of Biomolecules

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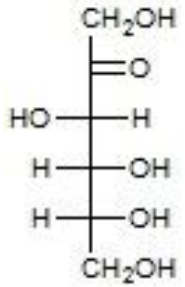
6.1. Carbohydrates

- **Carbohydrates** are polyhydroxy aldehydes or ketones, or compounds that can be hydrolyzed to produce such molecules.
- **Carbohydrates** typically follow the general chemical formula $C_x(H_2O)_y$. i.e. carbohydrate can be expressed as hydrates of carbon
- *Example;* Glucose has the molecular formula $C_6H_{12}O_6$, which might be written as $C_6(H_2O)_6$.



D-Glucose

polyhydroxyaldehydes



D-Fructose

polyhydroxyketones

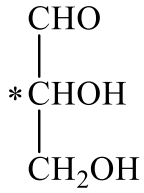
6.1.1. Classification of Carbohydrates

- **Monosaccharides** are the simplest carbohydrates and cannot be further hydrolyzed into smaller carbohydrate units.
- **Disaccharides** can be broken down by hydrolysis into two monosaccharide units.
- **Oligosaccharides** produce between two and ten monosaccharides upon hydrolysis.
- **Polysaccharides** yield more than ten monosaccharides when hydrolyzed.

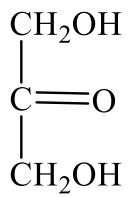
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6.1.2. Monosaccharides

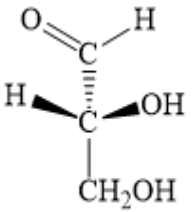
- Glyceraldehyde is the simplest aldose, and dihydroxyacetone is the simplest ketose.
- Each is related to glycerol in that each has a carbonyl group in place of one of the hydroxyl groups.



Glyceraldehyde (an aldotriose)

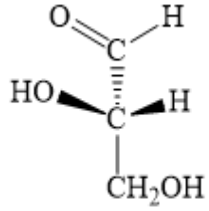


Dihydroxyacetone (a ketotriose)



D-(+)-Glyceraldehyde

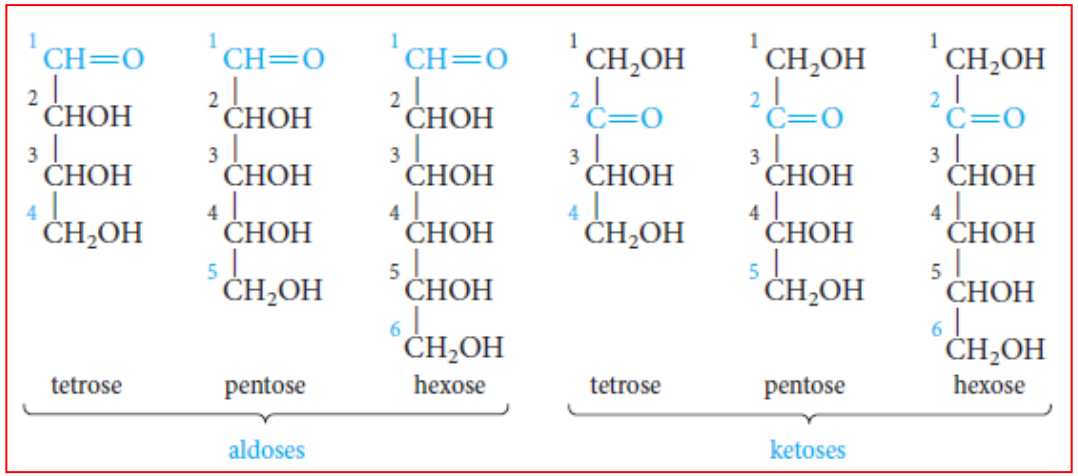
and



L-(-)-Glyceraldehyde

6.1.2.1. Classification of Monosaccharides

- **Monosaccharides** are classified based on two main features:
  1. The number of carbon atoms they contain (triose, tetrose, pentose, and hexose).
  2. The type of carbonyl group present — either an aldehyde or a ketone group.

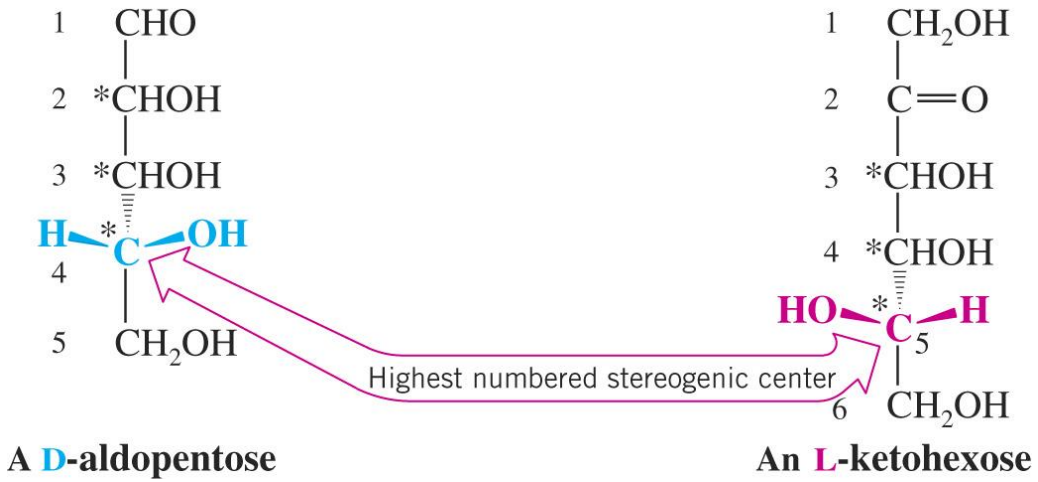


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6.1.2. Monosaccharides

6.1.2.2. D- and L- Designations of Monosaccharides

- Chiral (asymmetric) carbon atom bonded to four different groups.
- The simplest carbohydrates are glyceraldehyde, which is chiral and assigned as L or D-configuration, and dihydroxyacetone, which is achiral.
- D-sugar if its highest-numbered chiral center has the same configuration as D-(+)-glyceraldehyde.
- L-sugar if its highest-numbered chiral center shares the same configuration as L-(–)-glyceraldehyde.



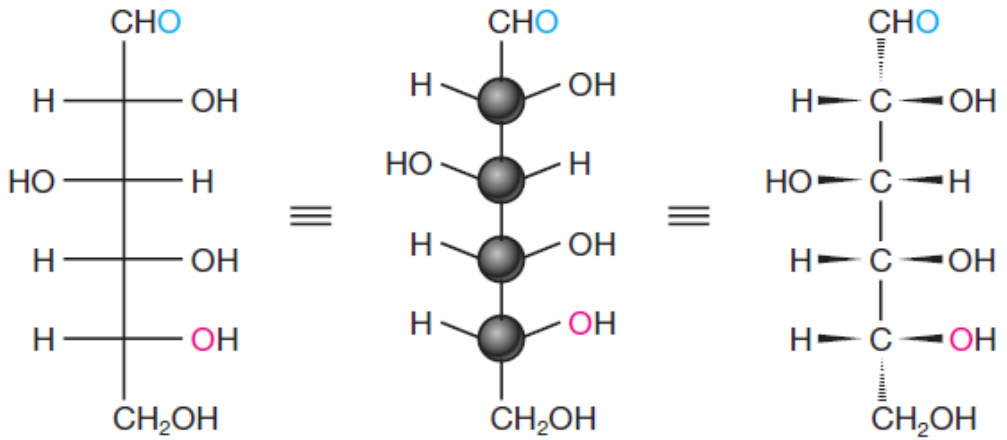
A D-aldopentose **An L-ketohexose**

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6.1.2. Monosaccharides

6.1.2.3. Structural Formulas for Monosaccharides

- **Fischer projection**
  - Represents sugar stereochemistry in the open-chain form.
  - Horizontal lines → bonds projecting out of the plane (toward the viewer).
  - Vertical lines → bonds behind the plane (away from the viewer).
  - The –CHO group is placed at the top, and the –CH_2OH group at the bottom.

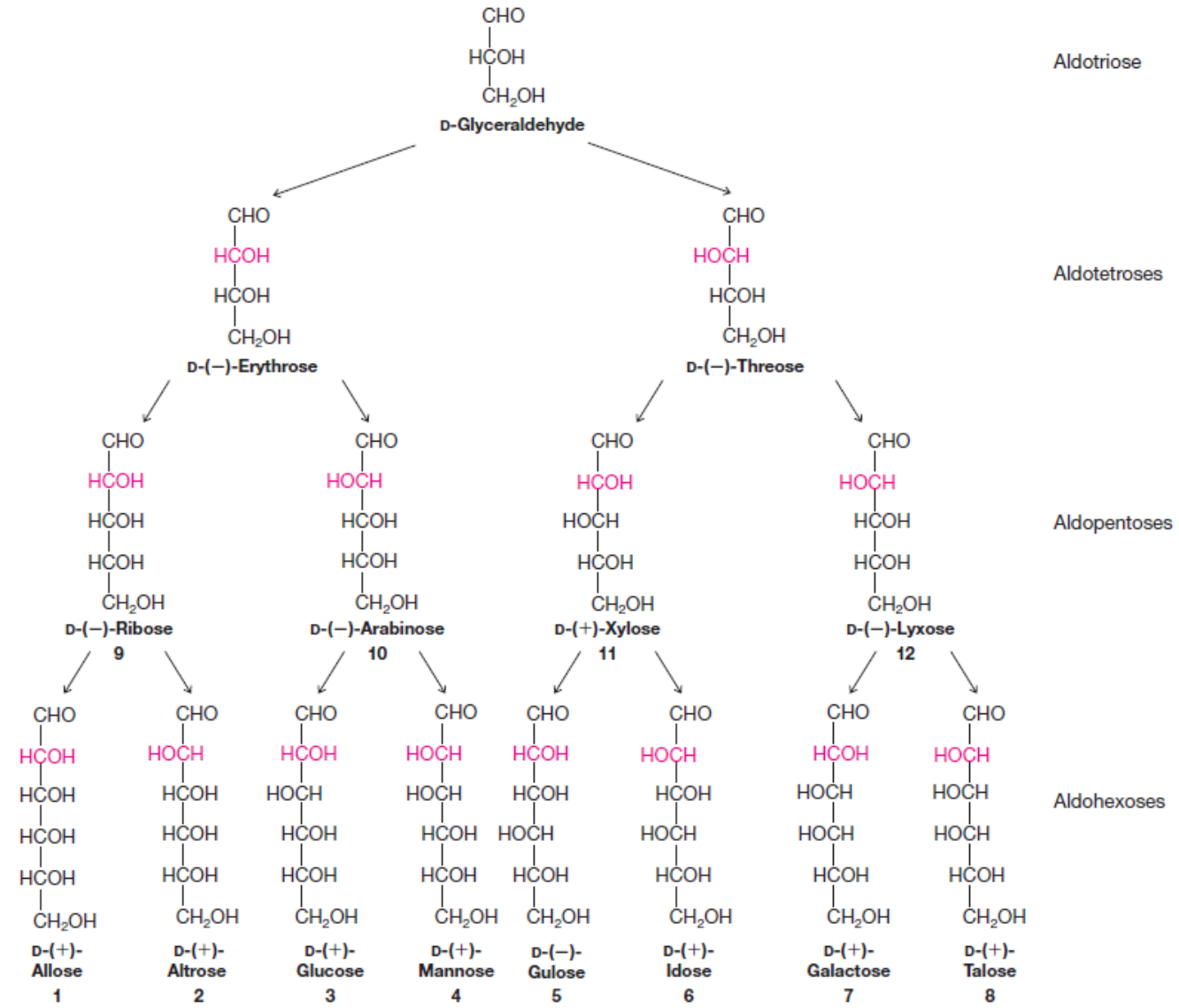


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6.1.2. Monosaccharides

6.1.2.3. Structural Formulas for Monosaccharides

- The Ruff degradation and the Kiliani–Fischer synthesis allow us to place all of the aldoses into families or "family trees" based on their relation to D- or L-glyceraldehyde.
- Most, but not all, of the naturally occurring aldoses belong to the D family, with D-(+)-glucose being by far the most common.

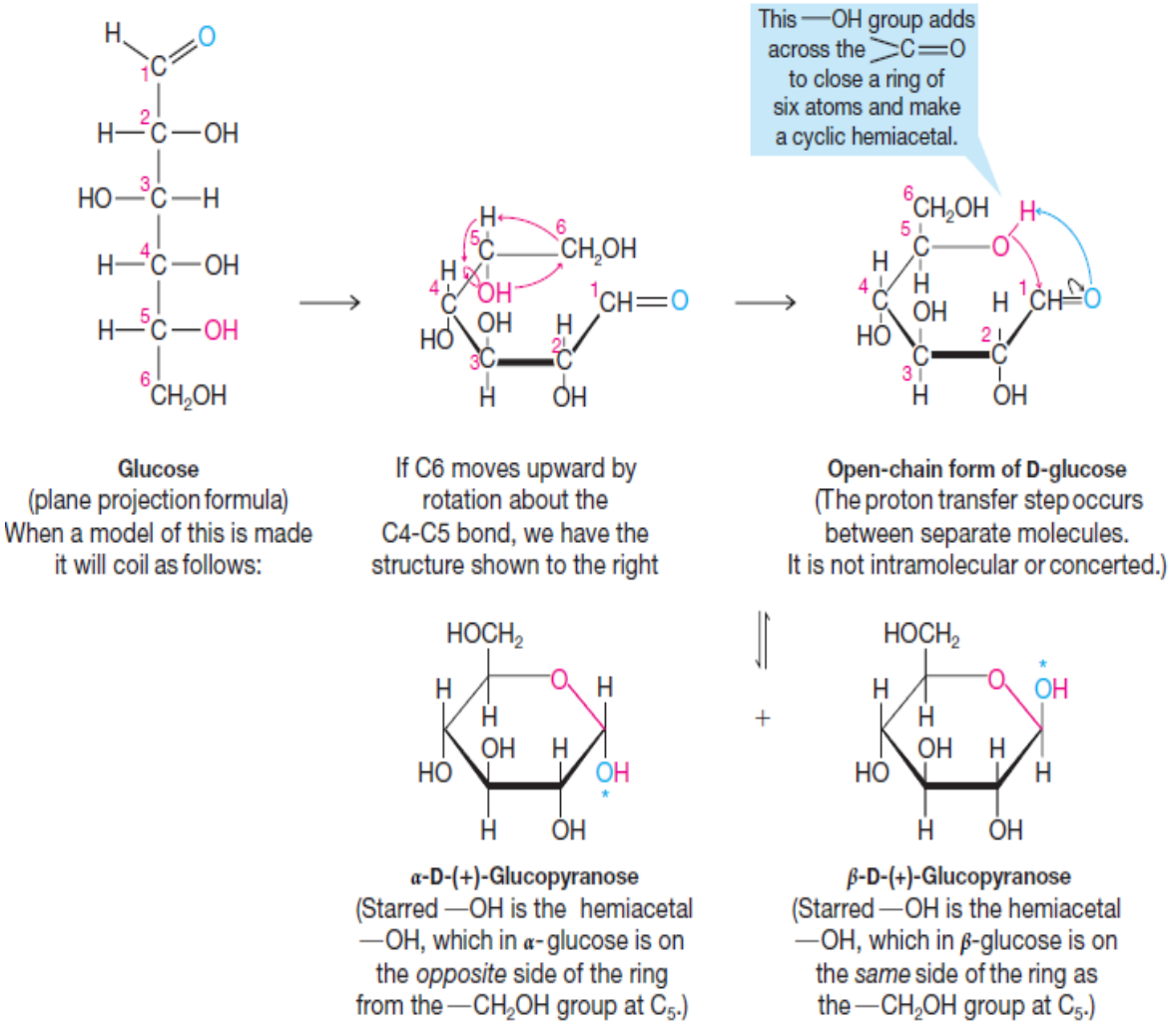


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6.1.2. Monosaccharides

6.1.2.3. Structural Formulas for Monosaccharides

- **Haworth formulas**
  - Represent sugar stereochemistry in the cyclic form, which exists in equilibrium with the open-chain form.
  - The cyclic (hemiacetal) forms are produced by an intramolecular reaction between the –OH group at C5 and the aldehyde group at C1.
  - Cyclization creates a new chiral center at C1, explaining the existence of two cyclic forms.
  - These two forms are differing only in the configuration at C1 (the anomeric carbon).
    - α-anomer → the hemiacetal –OH is *trans* to the –CH_2OH group.
    - β-anomer → the hemiacetal –OH is *cis* to the –CH_2OH group.



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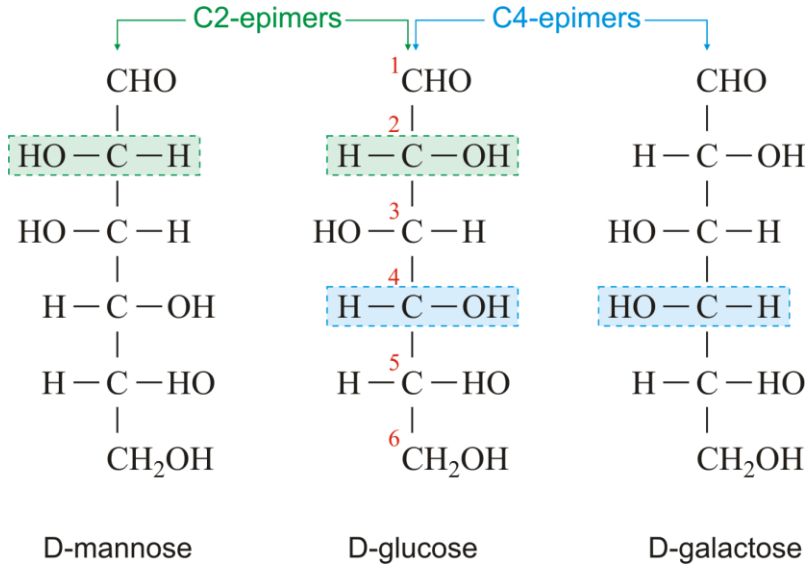
6.1.2. Monosaccharides

6.1.2.4. Isomerization

Enantiomers

- **Stereogenic centers** are mostly carbon atoms (*asymmetric carbon*) that bind four different groups.
- **Stereoisomers = 2^n** (n = number of stereogenic centers).

- **Epimers:** A special name is given to diastereomers that differ in configuration at only one stereogenic center as shown.



D-glucose and D-mannose are epimers (at C-2).

D-glucose and D-galactose are epimers (at C-4).

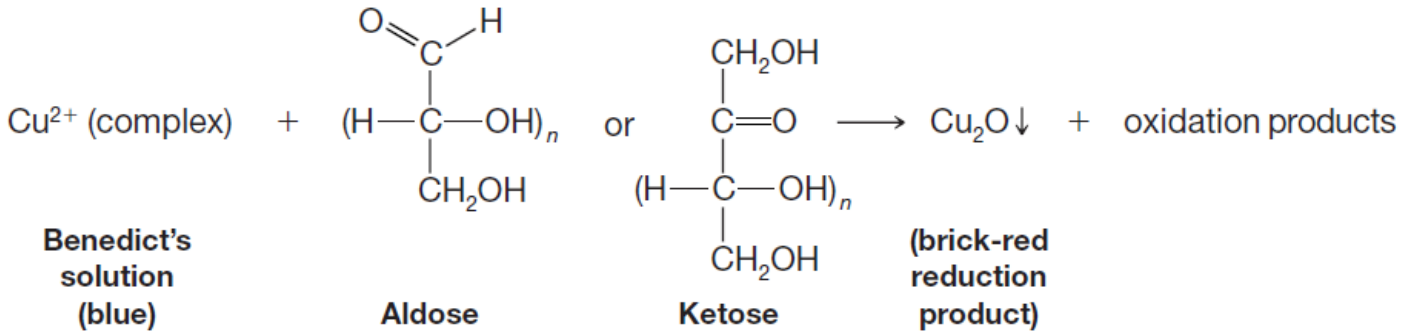
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6.1.2. Monosaccharides

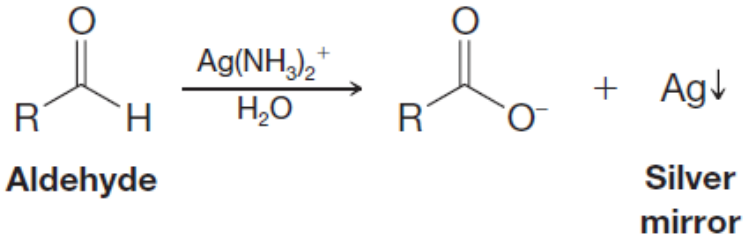
6.1.2.5. Oxidation Reactions of Monosaccharides

A) Benedict's or Tollens' Reagents: Reducing Sugars

- **Benedict's reagent:** an alkaline solution containing a cupric citrate complex ion.



- **Tollens' solution:** $[Ag(NH_3)_2\bar{O}H]$



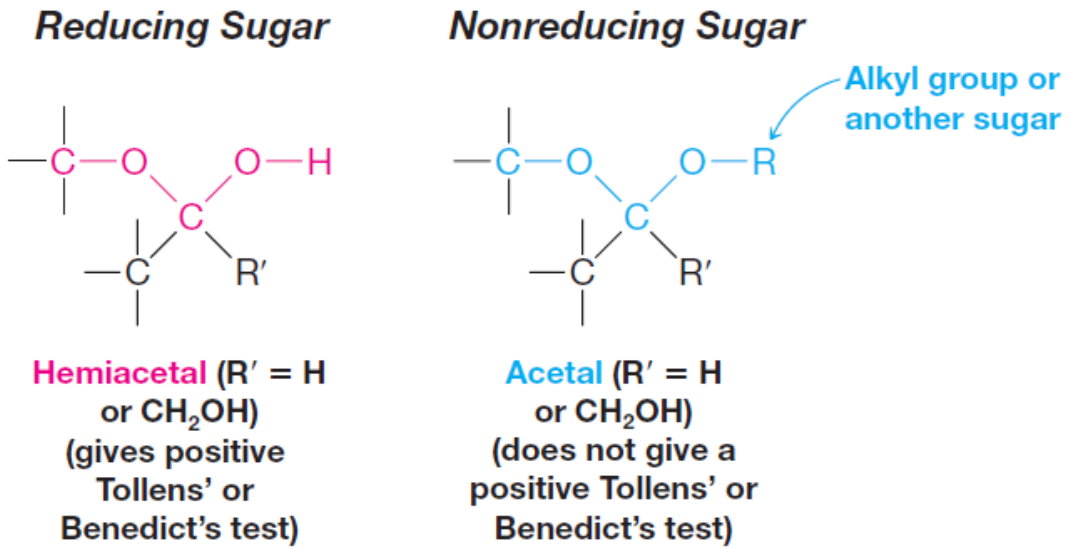
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6.1.2. Monosaccharides

6.1.2.5. Oxidation Reactions of Monosaccharides

A) Benedict's or Tollens' Reagents: Reducing Sugars

- They both oxidize and give positive tests with aldoses and ketoses even those that exist primarily as cyclic hemiacetals.
- Carbohydrates that contain hemiacetal groups give positive tests with Benedict's or Tollens' solutions, and they are called *reducing sugars*.
- Carbohydrates that contain only acetal groups do not give positive tests with Benedict's or Tollens' solutions, and they are called *nonreducing sugars*.



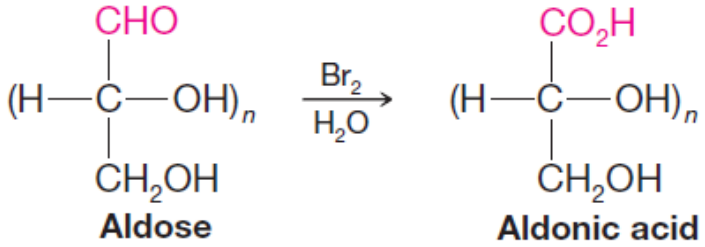
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6.1.2. Monosaccharides

6.1.2.5. Oxidation Reactions of Monosaccharides

B) Bromine Water: The Synthesis of Aldonic Acids

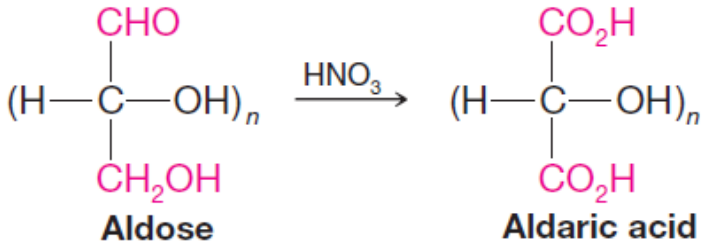
- Bromine water is a general reagent that selectively oxidizes the −CHO group to a $-CO_2H$ group, thus converting an aldose to an **aldonic acid**.



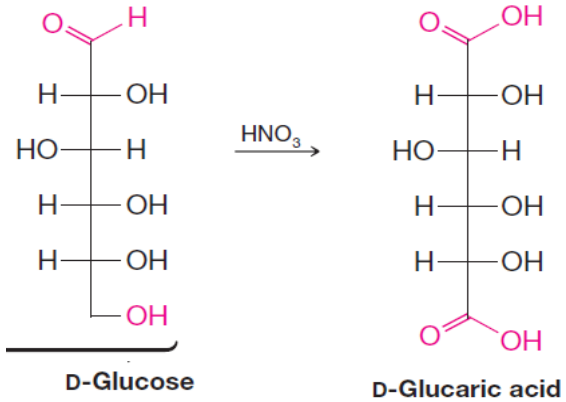
Aldose → Aldonic acid

C) Nitric Acid Oxidation: Aldaric Acids

- Dilute nitric acid is a stronger oxidizing agent than bromine water , it oxidizes both the −CHO group and the terminal $-CH_2OH$ group of an aldose to $-CO_2H$ groups, forming dicarboxylic acids are known as **aldaric acids**.



Aldose → Aldaric acid



D-Glucose → D-Glucaric acid

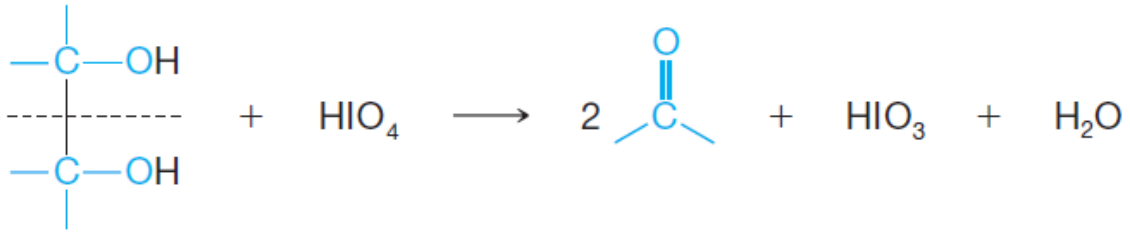
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6.1.2. Monosaccharides

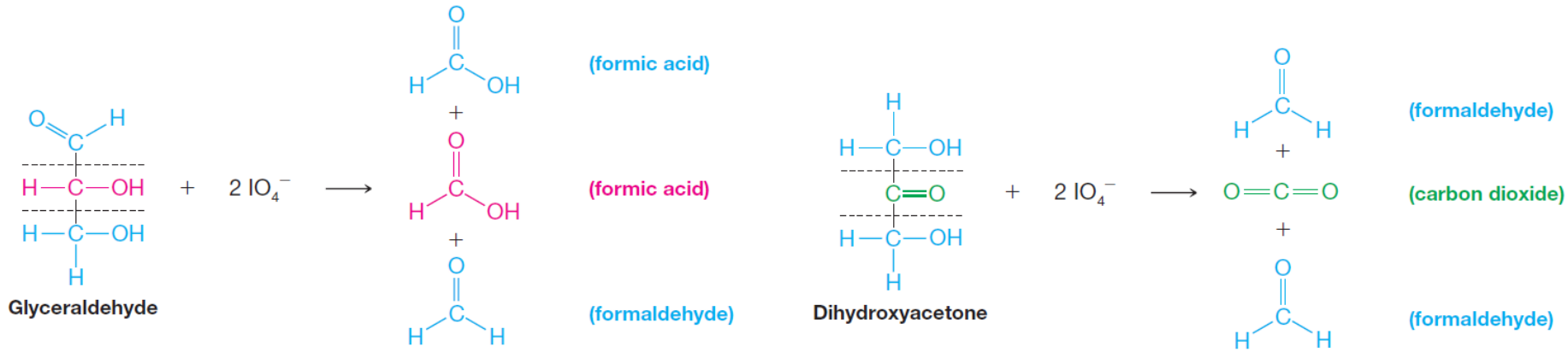
6.1.2.5. Oxidation Reactions of Monosaccharides

D) Periodate Oxidations: Oxidative Cleavage of Polyhydroxy Compounds

- Compounds with adjacent hydroxyl groups (vicinal diols) undergo oxidative cleavage by aqueous periodic acid (HIO_4), breaking the C–C bond to yield carbonyl compounds (aldehydes, ketones, or carboxylic acids).



- In chains with three or more contiguous –CHOH groups, the internal ones produce formic acid.
- Cleavage also occurs when an –OH group is adjacent to the carbonyl of an aldehyde or ketone (but not acids or esters).

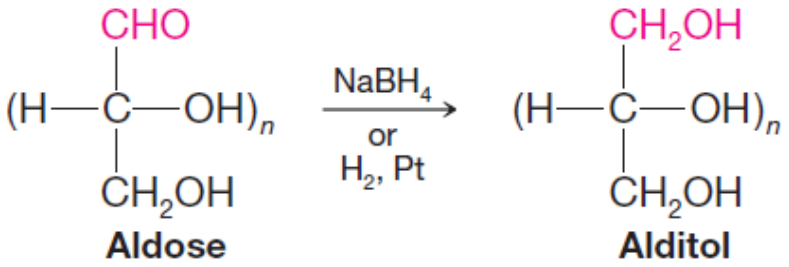


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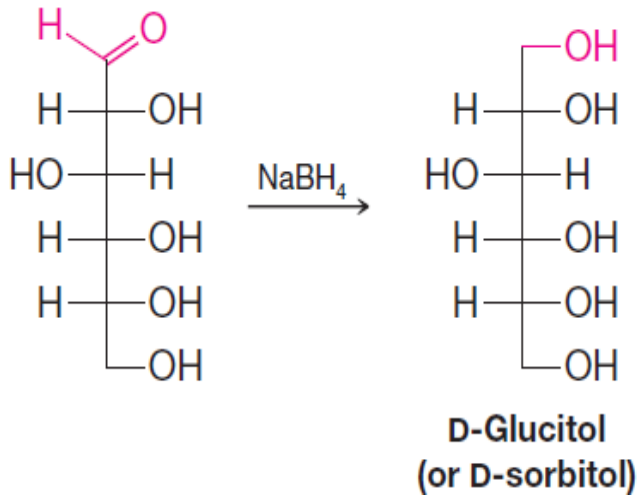
6.1.2. Monosaccharides

6.1.2.6. Reduction of Monosaccharides: Alditols

- Aldoses (and ketoses) can be reduced with sodium borohydride to give compounds called **alditols**.



- Example; Reduction of D-glucose, yields D-glucitol.

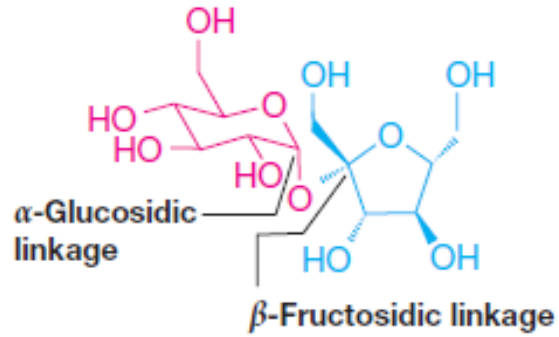


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6.1.3. Disaccharides

6.1.3.1. Sucrose

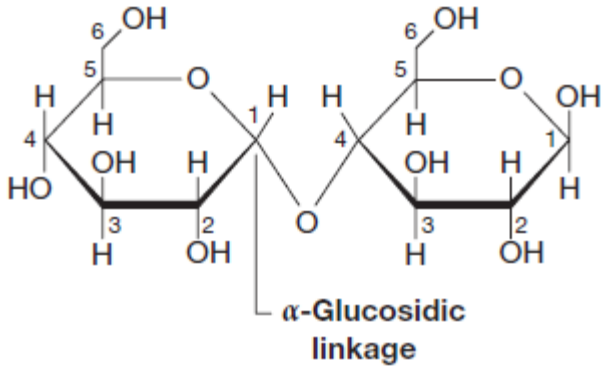
- Sucrose is the most widely occurring disaccharide, obtained commercially from sugarcane or sugar beets.
- It is a nonreducing sugar and has the molecular formula $C_{12}H_{22}O_{11}$.
- Acid-catalyzed hydrolysis of 1 mole of sucrose yields 1 mole of D-glucose and 1 mole of D-fructose.



(+)-Sucrose
α-D-Glucopyranosyl-(1→2)-β-D-fructofuranoside

6.1.3.2. Maltose

- Partial hydrolysis of starch gives Maltose.
- When 1 mol of maltose is subjected to acid-catalyzed hydrolysis, it yields 2 mol of D-(+)-glucose.
- Maltose is a reducing sugar; it gives positive tests with Benedict's, and Tollens' solutions.



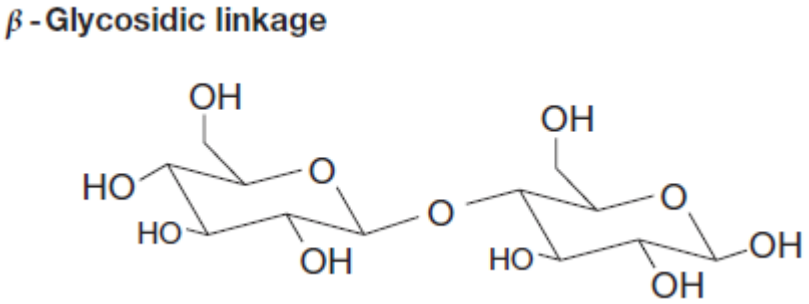
(+)-maltose,
α-D-Glucopyranosyl-(1→4)- β- D-glucopyranose

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6.1.3. Disaccharides

6.1.3.3. Cellobiose

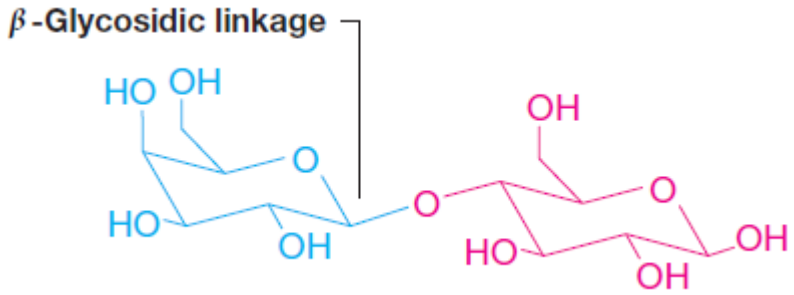
- Partial hydrolysis of cellulose gives cellobiose.
- Cellobiose resembles maltose in every respect except one: the configuration of its 1→4 glycosidic linkage.
- Cellobiose is a reducing sugar that, on acid-catalyzed hydrolysis, yields two molar equivalents of D-glucose



Cellobiose,
β-D-Glucopyranosyl-(1→4)- β-D-glucopyranose

6.1.3.4. Lactose

- Lactose is a disaccharide present in the milk of humans, cows, and almost all other mammals.
- Lactose is a reducing sugar that hydrolyzes to yield D-glucose and D-galactose; the 1→4 glycosidic linkage is β.



Lactose,
β-D-Galactopyranosyl-(1→4)-β-D-glucopyranose

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6.1.4. Polysaccharides

- Polysaccharides are polymers consisting of monosaccharides joined together by glycosidic linkages.
- Homopolysaccharides are polymers made of a single type of monosaccharide.
- Heteropolysaccharides are polymers made of more than one type of monosaccharide.

6.1.4.1. Starch

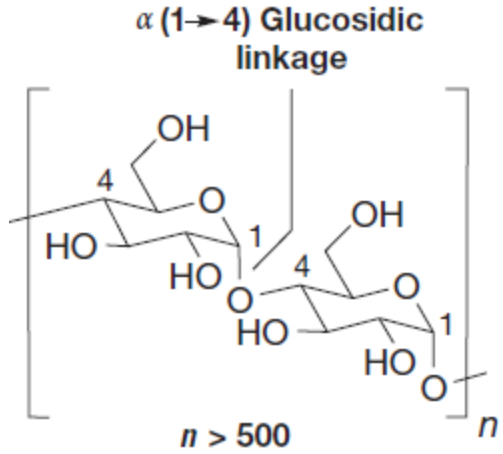
- Starch occurs as microscopic granules in roots, tubers, and seeds (e.g., corn, potatoes, wheat, rice).
- Heating starch with water swells the granules, forming a colloidal suspension.
- Starch is a nonreducing polysaccharide composed of amylose (10–20%) and amylopectin (80–90%).

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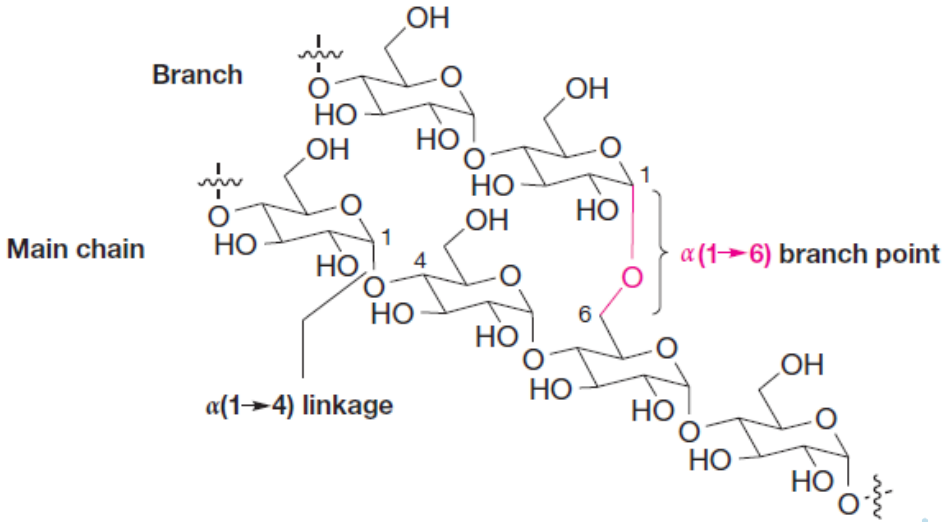
6.1.4. Polysaccharides

6.1.4.1. Starch

- **Amylose** typically consists of more than 1000 D-glucopyranoside units connected in α linkages between C1 of one unit and C4 of the next.
- **Amylopectin** has a structure similar to amylose, with $\alpha(1\rightarrow4)$ glycosidic links in the linear chains, but its structure is branched by $\alpha(1\rightarrow6)$ glycosidic bonds.
- The branching occurs between C6 of one glucose unit and C1 of another.
- Branch points appear approximately every 20–25 glucose units.
- **Amylopectin** has a molecular weight of 1–6 million, consisting of hundreds of interconnected chains, each containing about 20–25 glucose units.



Partial structure of Amylose



Partial structure of Amylopectin

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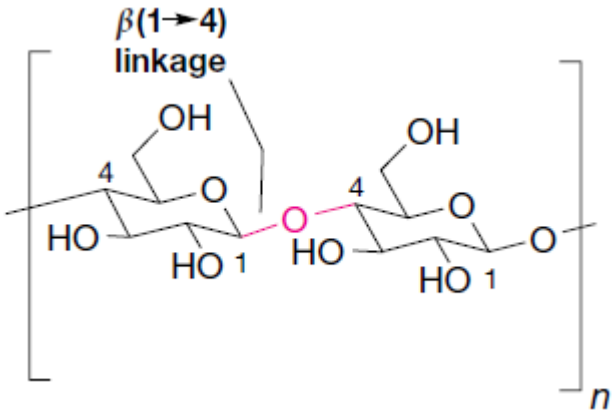
6.1.4. Polysaccharides

6.1.4.2. Glycogen

- Glycogen has a structure very much like that of amylopectin; however, in glycogen the chains are much more highly branched.
- Glycogen has a very high molecular weight, and samples isolated under conditions minimizing hydrolysis show molecular weights as high as 100 million.

6.1.4.3. Cellulose

- Cellulose consists of D-glucopyranose units linked by β(1→4) glycosidic bonds forming very long, unbranched chains.
- The β-linkages make cellulose chains linear, unlike the helical α(1→4) chains in starch and glycogen.
- Hydroxyl (–OH) groups on adjacent chains form extensive hydrogen bonds, producing a rigid, insoluble, fibrous structure.
- The precise stereochemistry of D-glucose allows the formation of strong linear fibers ideal for plant cell walls.



Partial structure of Cellulose

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Lipids

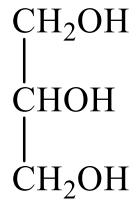
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6.2. Lipids

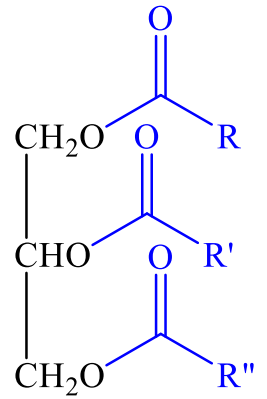
- **Lipids** are compounds of biological origin that dissolve in nonpolar solvents, such as chloroform and diethyl ether.
- The name lipid comes from the Greek word *lipos*, for fat.

6.2.1. Fatty Acids and Triacylglycerols

- **Triacylglycerols (Triglycerides)** are the oils of plants and the fats of animal origin.
- **Triacylglycerols** are carboxylic acids of biological origin that are found as esters of glycerol.
- The groups R, R′, and R″ are usually long chain alkyl groups that may also contain one or more carbon–carbon double bonds and may all be different.
- **Triacylglycerols** include such common substances as peanut oil, soybean oil, corn oil, sunflower oil, butter, lard, and tallow.



Glycerol

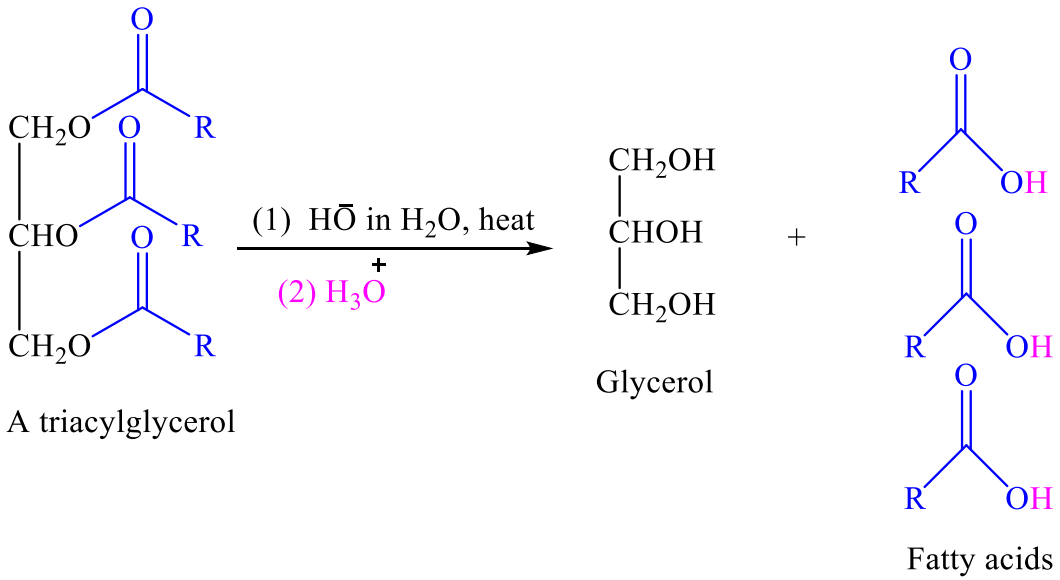


A triacylglycerol

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6.2.1. Fatty Acids and Triacylglycerols

- **Triacylglycerols** are known as oils and fats.
- **Fats** are solid at room temperature due to saturated fatty acids.
- **Oils** are liquid because of higher unsaturation.
- **Triacylglycerols** can be
  - **Simple triacylglycerols**; all three acyl groups are the same.
  - **Mixed triacylglycerols**; the acyl groups are different.
- Hydrolysis of fats or oils yields fatty acids that are typically unbranched and contain an even number of carbon atoms.

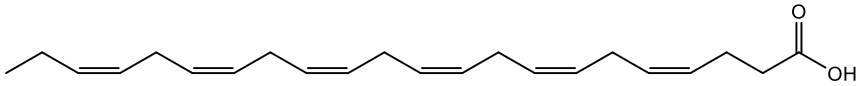


A triacylglycerol

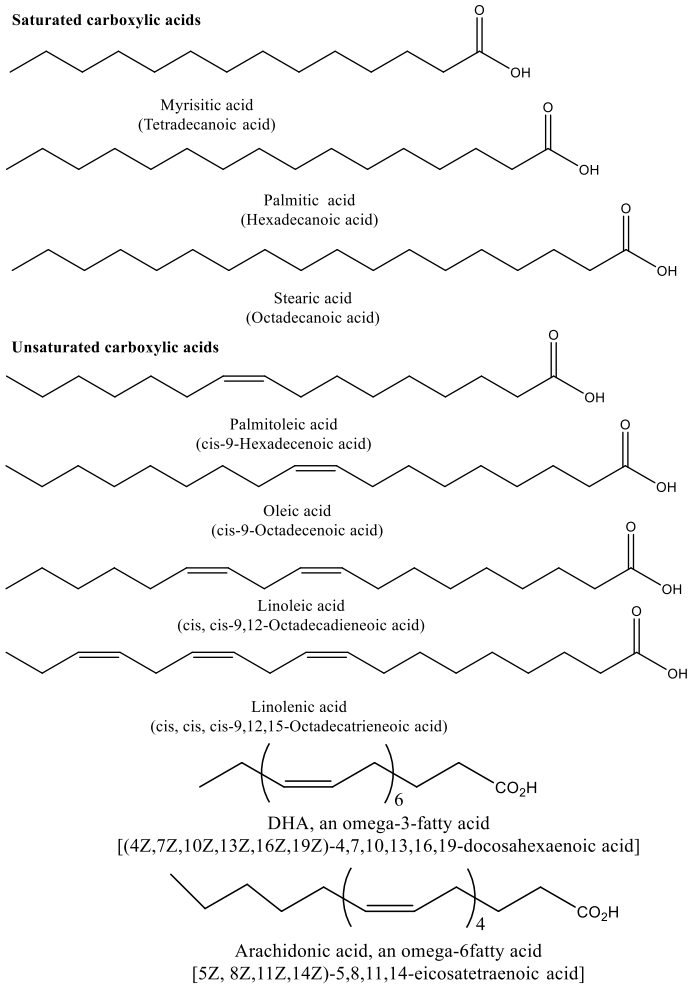
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6.2.1. Fatty Acids and Triacylglycerols

- **Unsaturated fatty acids,**
  - Unsaturated fatty acids contain *cis* double bonds.
  - Many of them have two or three double bonds.
  - Such fats are called polyunsaturated fats or oils.
  - The first double bond usually occurs between C9 and C10
- **Saturated fatty acids** have relatively high melting points.
- **Omega-3 fatty acids** are those where the third to last carbon in the chain is part of a carbon–carbon double bond.



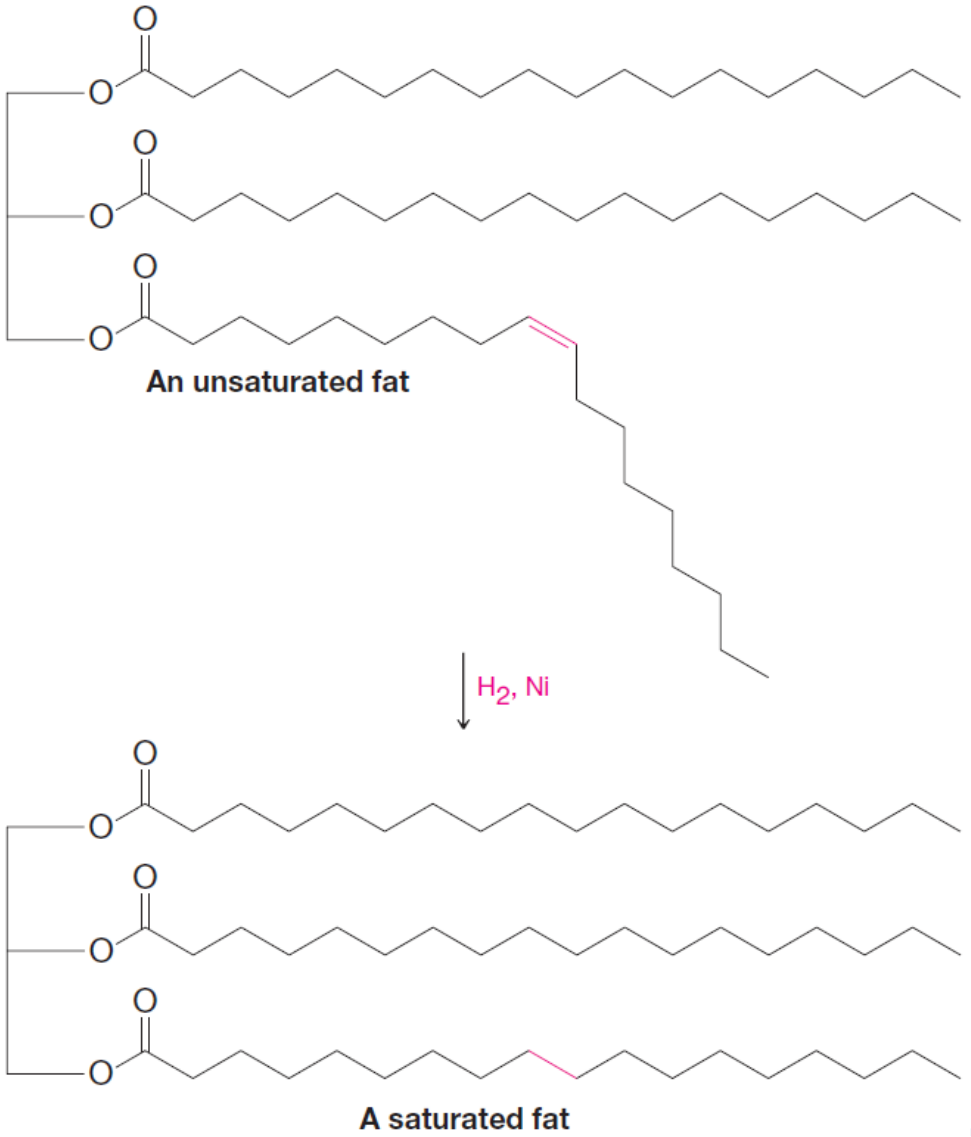
DHA, an omega-3-fatty acid
[(4Z,7Z,10Z,13Z,16Z,19Z)-4,7,10,13,16,19-docosahexaenoic acid]



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6.2.2. Hydrogenation of Triacylglycerols

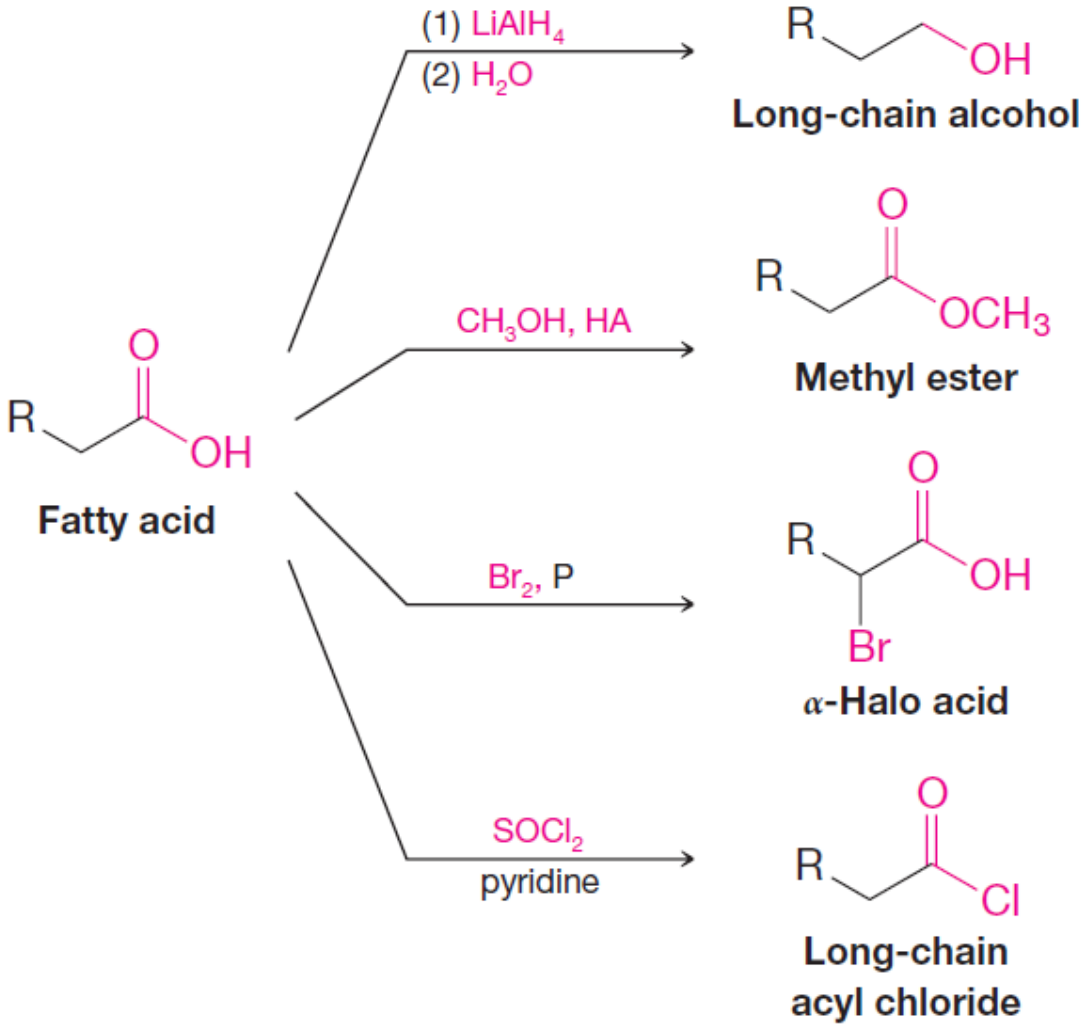
- **Fats:** Triacylglycerols high in saturated fatty acids → *solid at room temperature, high melting points*.
- **Oils:** Triacylglycerols high in unsaturated/polyunsaturated fatty acids → *liquid at room temperature, lower melting points*.
- Catalytic hydrogenation converts unsaturated triacylglycerols into more saturated forms.
- Commercial solid fats are produced by partial hydrogenation of vegetable oils, while complete hydrogenation is avoided because fully saturated triacylglycerols are hard and brittle.



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6.2.3. Reactions of the Carboxyl Group of Fatty Acids

- **Fatty acids** undergo reactions typical of carboxylic acids.
  - They react with $LiAlH_4$ to form alcohols,
  - They react with alcohols and mineral acid to form esters,
  - They react with bromine and phosphorus to form α-halo acids,
  - They react with thionyl chloride to form acyl chlorides



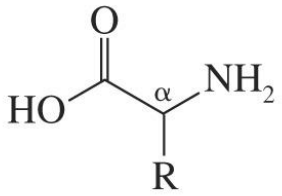
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Amino Acids and Proteins

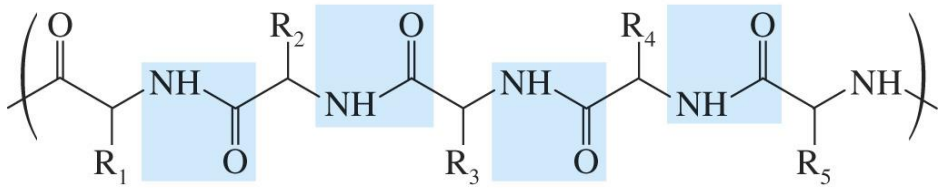
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6.3. Amino Acids and Proteins

- **Proteins** have many diverse functions; they are major components of the following biomolecules.
  - Enzymes and hormones which catalyze and regulate biological reactions.
  - Muscles and tendons which provide the body with means for movement.
  - Hemoglobin which carries oxygen to all parts of the body.
  - Antibodies they are integral parts of the immune system.
- **The 20 α-amino acids** are the essential building blocks of proteins and peptides, forming polyamides through peptide bonds.



An α-amino acid
***R* is a side chain at the α carbon that determines the identity of the amino acid (Table 24.1).**



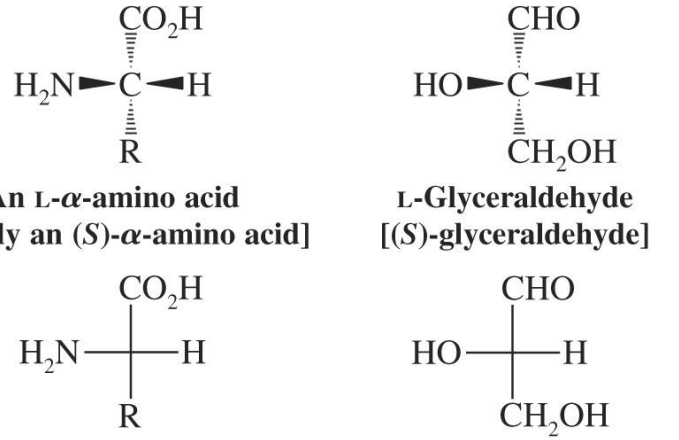
A portion of a protein molecule
Amide (peptide) linkages are shaded.
R_1–R_5 may be any of the possible side chains.

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6.3.1. Amino acids

6.3.1.1. Structure and Names

- **All natural occurring amino acids** are chiral (except glycine which is achiral) and have the L-configuration (as related to glyceraldehyde) at the α-carbon.



An L-α-amino acid [usually an (*S*)-α-amino acid] **L-Glyceraldehyde [(*S*)-glyceraldehyde]**

Fischer projections for an L-α-amino acid and L-glyceraldehyde

- **Nomenclature and Classification of amino acids:**
  - The 20 amino acids are known by their common names (IUPAC nomenclature could be applied).
  - Abbreviated by **three letter** based on its common name, which is used when writing the formulas of peptides.
  - **One-letter** abbreviation used to describe the amino acid sequence in a protein.
  - **Example;** Glycine = Gly or (G); Alanine = Ala or (A); Valine = Val or (V), etc..

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6.3.1. Amino acids

6.3.1.2. Classification of amino acids

- **Amino acids are classified according to the structure of R group:**

1. The acidity of R group: neutral or acidic or basic.
   - *Neutral R Group*: are those which containing one amino group and one carboxylic group.

     The majority of amino acids contain neutral R group.
   - *Acidic R group*: are those amino acids that contain more than one carboxylic group.

     Example; Aspartic, Glutamic --------"**hydrophilic"**
   - *Basic R group*: are those amino acids that contain more than one N atom.

     Example; Lysine, Arginine ---------"**hydrophilic"**
2. Polarity of the R group: Amino acid could be classified into polar (hydrophilic) or non-polar (hydrophobic).

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6.3.1. Amino acids

6.3.1.2. Classification of amino acids

- **Essential and non-essential amino acid:**
  - *Essential amino acid:* amino acids, which cannot be synthesized by adult humans and therefore must be included in the diet in the form of proteins.

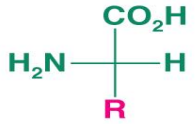
    Eight amino acids; Valine. Leucine, Isoleucine, Threonine, Methionine, Phenylalanine, Tryptophan, and Lysine.
  - *Non-essential amino acids:* amino acids, which can be synthesized in the body from other foods.

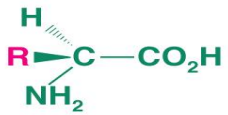
    Twelve amino acids; Glycine, Alanine, Serine, Cysteine, Proline, Tyrosine, Aspartic acid, Glutamic acid, Asparagine, Glutamine, Arginine, and Histidine.

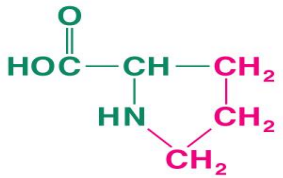
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6.3.1. Amino acids

6.3.1.2. Classification of amino acids



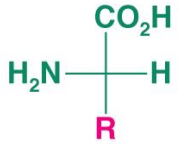


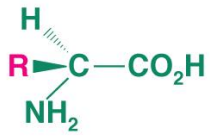
Structure of R	Name	Abbreviations[a]	pK_{a_1} α-CO_2H	pK_{a_2} α-NH_3^+	pK_{a_3} R group	pI
Neutral Amino Acids						
—H	Glycine	G or Gly	2.3	9.6		6.0
—CH_3	Alanine	A or Ala	2.3	9.7		6.0
—$CH(CH_3)_2$	Valine[b]	V or Val	2.3	9.6		6.0
—$CH_2CH(CH_3)_2$	Leucine[b]	L or Leu	2.4	9.6		6.0
—$CHCH_2CH_3$ CH_3	Isoleucine[b]	I or Ile	2.4	9.7		6.1
—CH_2 	Phenylalanine[b]	F or Phe	1.8	9.1		5.5
—CH_2CONH_2	Asparagine	N or Asn	2.0	8.8		5.4
—$CH_2CH_2CONH_2$	Glutamine	Q or Gln	2.2	9.1		5.7
—CH_2 	Tryptophan[b]	W or Trp	2.4	9.4		5.9
 (complete structure)	Proline	P or Pro	2.0	10.6		6.3

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6.3.1. Amino acids

6.3.1.2. Classification of amino acids





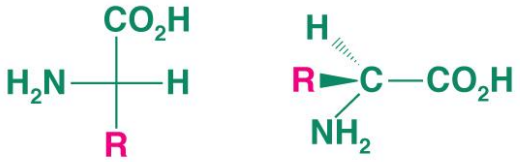
Structure of R	Name	Abbreviations[a]	pK_{a_1} α-CO_2H	pK_{a_2} α-NH_3^+	pK_{a_3} R group	p*I*
Neutral Amino Acids						
—CH_2OH	Serine	S or Ser	2.2	9.2		5.7
—CHOH CH_3	Threonine[b]	T or Thr	2.6	10.4		6.5
—CH_2—⟨benzene⟩—OH	Tyrosine	Y or Tyr	2.2	9.1	10.1	5.7
HOC(=O)—CH(NH—CH_2—CH_2)—CH(OH)	Hydroxyproline	Hyp	1.9	9.7		6.3
—CH_2SH	Cysteine	C or Cys	1.7	10.8	8.3	5.0
—CH_2—S —CH_2—S	Cystine	Cys-Cys	1.6 2.3	7.9 9.9		5.1
—$CH_2CH_2SCH_3$	Methionine[b]	M or Met	2.3	9.2		5.8

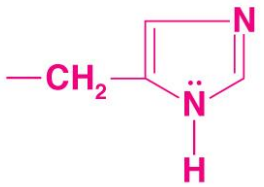
(complete structure)

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6.3.1. Amino acids

6.3.1.2. Classification of amino acids



Structure of R	Name	Abbreviations[a]	pK_{a_1} α-CO_2H	pK_{a_2} α-NH_3^+	pK_{a_3} R group	p*I*
R Contains an Acidic (Carboxyl) Group						
$-CH_2CO_2H$	Aspartic acid	D or Asp	2.1	9.8	3.9	3.0
$-CH_2CH_2CO_2H$	Glutamic acid	E or Glu	2.2	9.7	4.3	3.2
R Contains a Basic Group						
$-CH_2CH_2CH_2CH_2NH_2$	Lysine[b]	K or Lys	2.2	9.0	10.5[c]	9.8
$-CH_2CH_2CH_2NH-C(=NH)-NH_2$	Arginine	R or Arg	2.2	9.0	12.5[c]	10.8
	Histidine	H or His	1.8	9.2	6.0[c]	7.6

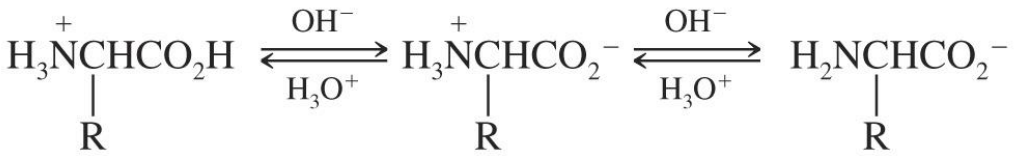
[a]Single-letter abbreviations are now the most commonly used form in current biochemical literature.
[b]An essential amino acid.
[c]pK_a is of protonated amine of R group.

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6.3.1. Amino acids

6.3.1.3. Amino acids as dipolar ions

- In the dry solid state amino acids exist as dipolar ions (zwittrions or inner salts).
- In aqueous solutions an equilibrium exists between the dipolar ion, the cationic and the anionic forms of the amino acid.
- The predominant form depends on the pH of the solution.
  - At low pH, the amino acid exists primarily in the cationic form.
  - At high pH, the amino acid exists primarily in the anionic form.
  - At some intermediate pH, called the P*I* (*isoelectric point*), the concentration of the dipolar ion is at maximum, and the concentrations of anionic and cationic forms are equal
- Each individual amino acid has a characteristic P*I*.



Cationic form (predominant in strongly acidic solutions, e.g., at pH 0) | **Dipolar ion** | **Anionic form (predominant in strongly basic solutions, e.g., at pH 14)**

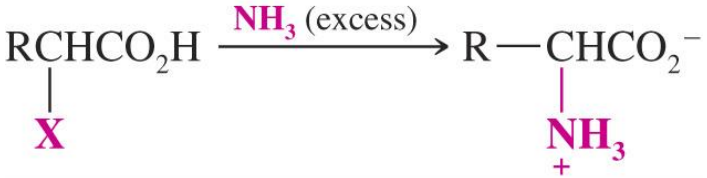
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6.3.1. Amino acids

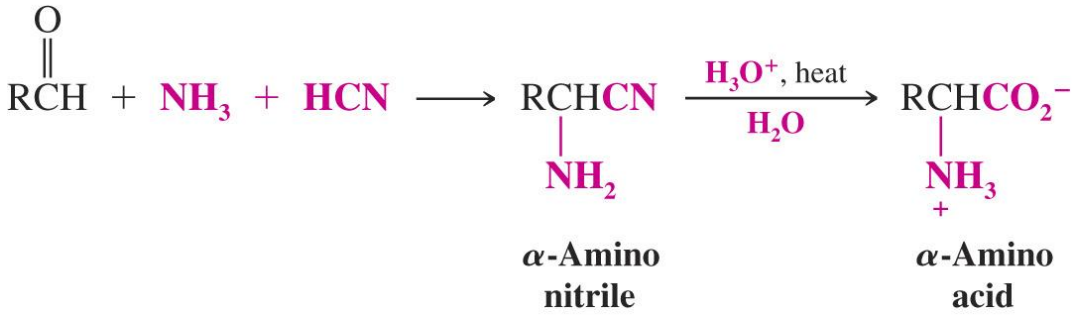
6.3.1.4. Synthesis of Amino acids

- There are many methods to prepare amino acids, two methods will be mentioned here.

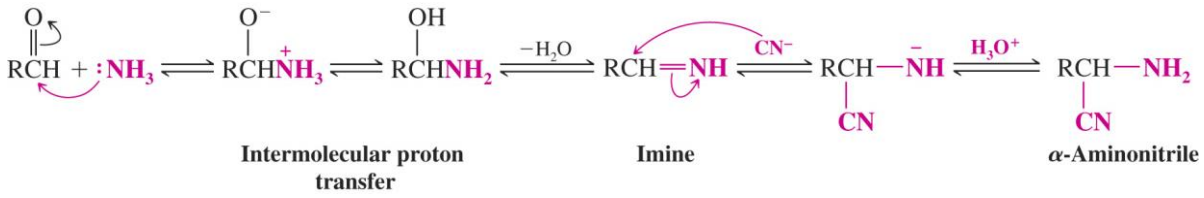
1. **Direct Ammonolysis** of α-halo-carboxylic acid with this method, yields tend to be poor.



2. **The Strecker Synthesis** (Reductive amination) treatment of an aldehyde with ammonia and hydrogen cyanide yields an α-aminonitrile, which is hydrolyzed to the α-amino acid.



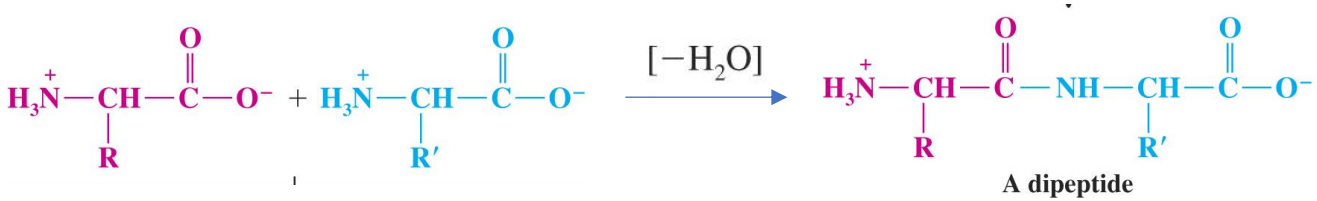
The mechanism proceeds via an intermediate imine



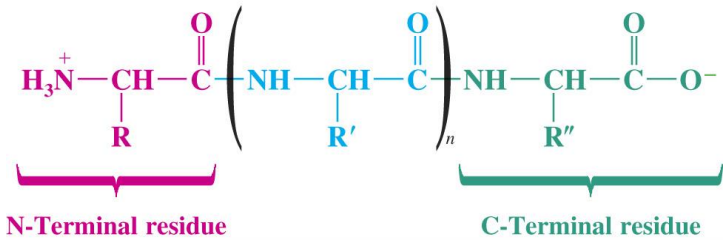
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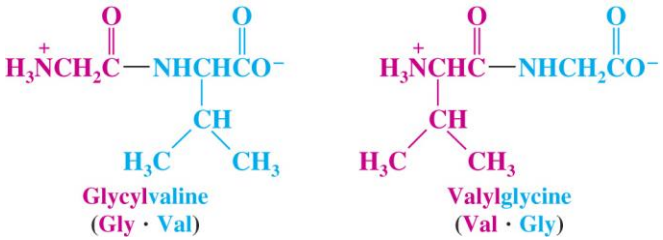
6.3.2. Polypeptides and Proteins

- Enzymes polymerize amino acids by forming amide linkages.
- The polymer is called a peptide, and the amide linkages are called peptide bonds or peptide linkages.
- Each amino acid in the peptide is called an amino acid residue.
- Proteins can contain one or more peptide chains and others associated molecules or metal ions.



- **Polypeptides** are linear polymers.
- One end of a polypeptide chain in an amino acid residue has a free amino group -NH3, the other terminate in amino acid residue with free carboxylic group –CO2. These two groups are called the N-terminal and the C-terminal residues, respectively.
- **Polypeptides** are usually written with the N-terminal residue to the left and the C-terminal residue to the right.





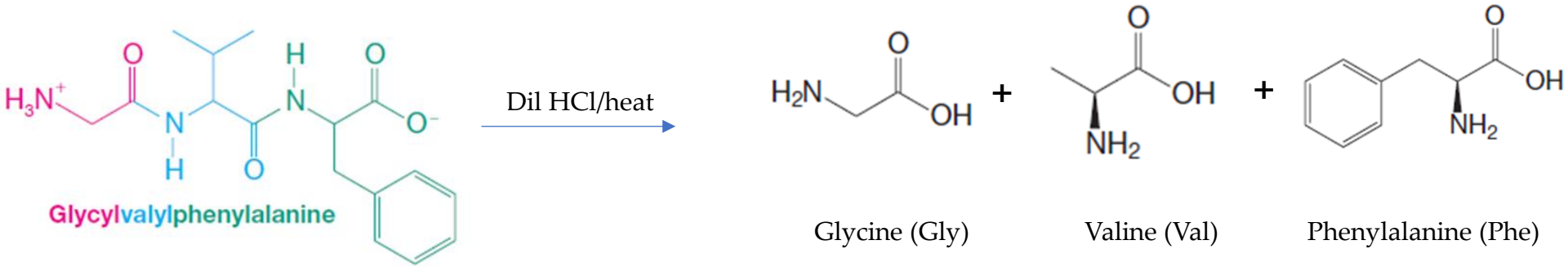
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6.3.2. Polypeptides and Proteins

6.3.2.1. Hydrolysis of Polypeptides

- Hydrolysis of all amide linkages of a protein or polypeptide usually takes place by refluxing with 6M HCl for 24 hours.
- This hydrolysis results in the liberation of amino acids.
- The individual amino acids can be separated from each other using chromatographic methods.
- Example;

The complete hydrolysis of the tripeptide Glycylvalylpheneylalanine (Gly-Val-Phe) will give the three amino acids glycine, valine, and phenylalanine.

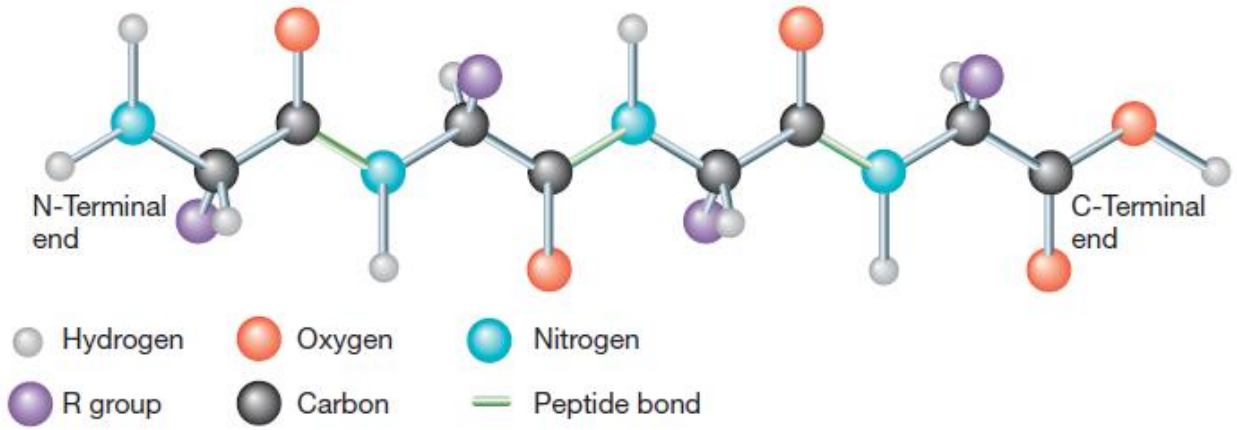


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6.3.2. Polypeptides and Proteins

6.3.2.2. Primary Structure of Polypeptides and Proteins

- Primary structure; specific sequence of amino acid residues in a polypeptide or protein
- Determining the exact sequence is very important.
- First step: Identify the N-terminal and C-terminal residues.



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Nucleic Acids

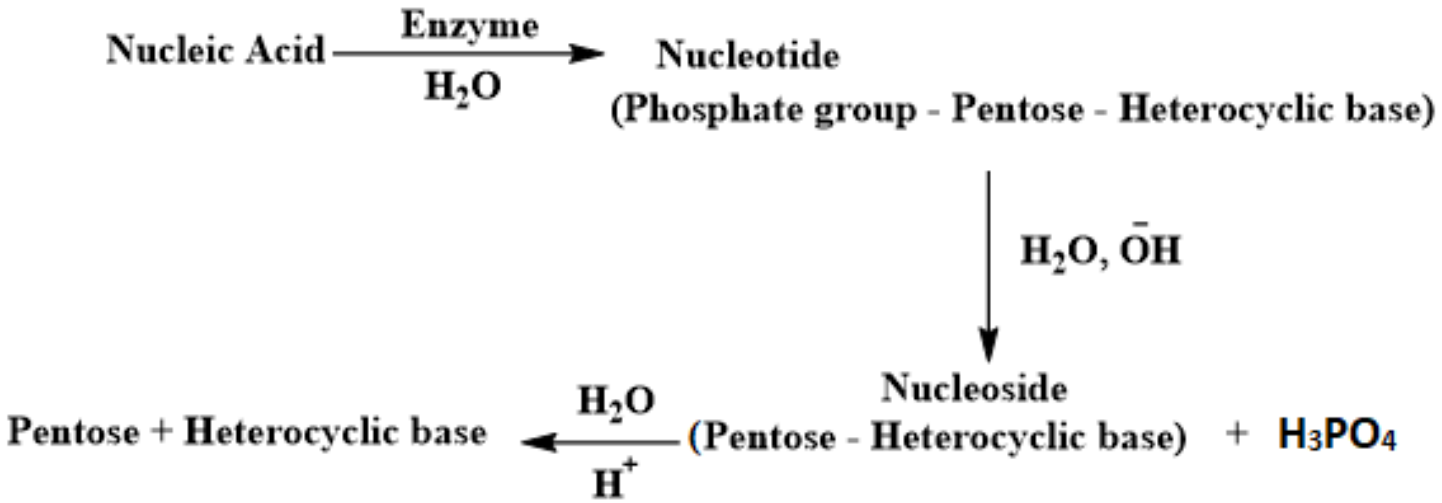
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6.4. Nucleic Acids

- Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are molecules that carry genetic information in cells.
- DNA is the molecular archive of instructions for protein synthesis.
- RNA molecules transcribe and translate the information from DNA for the mechanics of protein synthesis.

6.4.1. The General Structure of Nucleic acids; Nucleotides and Nucleosides

- Nucleic acids are linear polymers made up of nucleotide units.
- Hydrolysis of nucleic acids releases nucleotides, the basic building blocks of these molecules.



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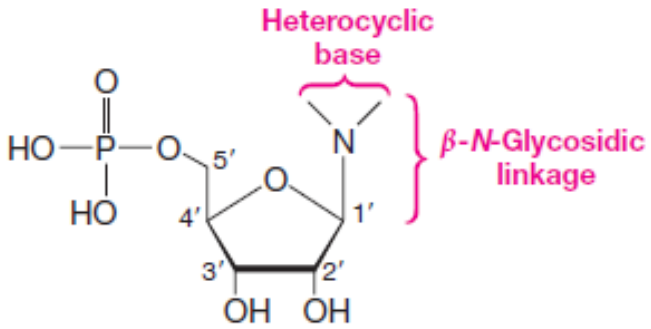
6.4.1. The General Structure of Nucleic acids; Nucleotides and Nucleosides

6.4.1.1. Nucleotides

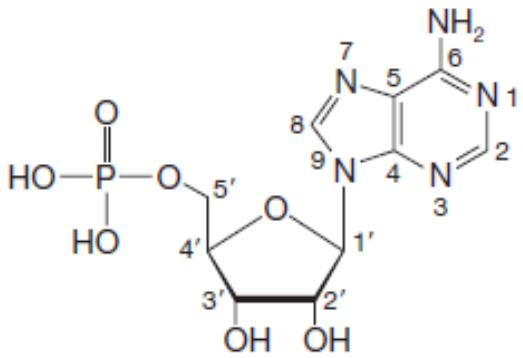
- The Nucleotide Unit is composed of:
  1. A heterocyclic base from either the purine or pyrimidine family.

     The heterocyclic base of a nucleotide is attached through an *N*-glycosidic linkage to C1′ of the ribose or deoxyribose unit, and this linkage is always β.
  2. A five-carbon monosaccharide that is either d-ribose or deoxy-d-ribose.
  3. A phosphate ion.

     The phosphate group of a nucleotide is present as a phosphate ester and may be attached at C5′ or C3′.



A nucleotide



Adenylic acid

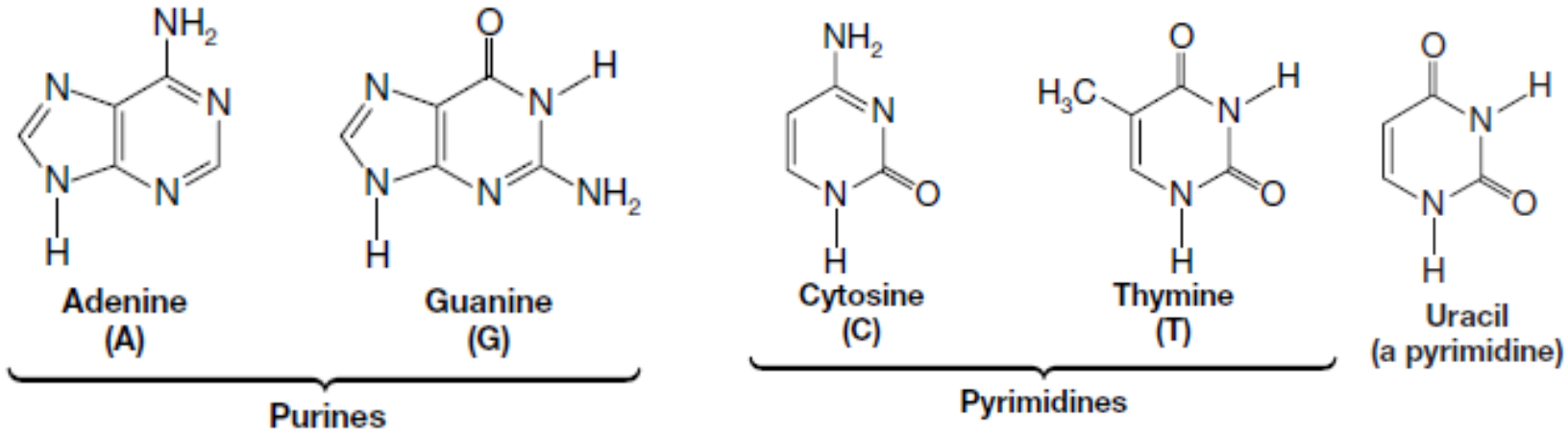
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6.4.1. The General Structure of Nucleic acids; Nucleotides and Nucleosides

6.4.1.1. Nucleotides

A) Heterocyclic Bases

- The nitrogenous base—either a purine or a pyrimidine—is linked to the 1′-carbon of the pentose sugar via replacement of the hydroxyl group.
- Uracil replaces thymine in an RNA nucleoside (or nucleotide).



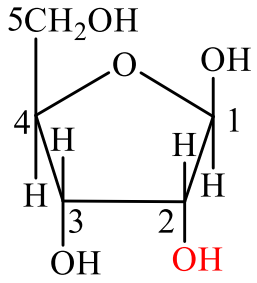
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6.4.1. The General Structure of Nucleic acids; Nucleotides and Nucleosides

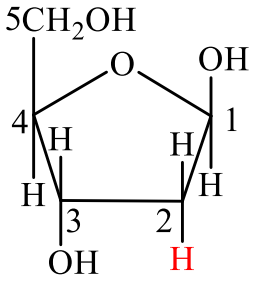
6.4.1.1. Nucleotides

B) A five-carbon monosaccharide

- The five-carbon monosaccharide in nucleic acids is either ribose or 2-deoxyribose, which are found in RNA and DNA, respectively.
- The key structural difference is at the C2′ carbon: ribose contains a hydroxyl (–OH) group, whereas in deoxyribose this group is replaced by hydrogen (–H).



D-ribose



2-deoxy-D-ribose

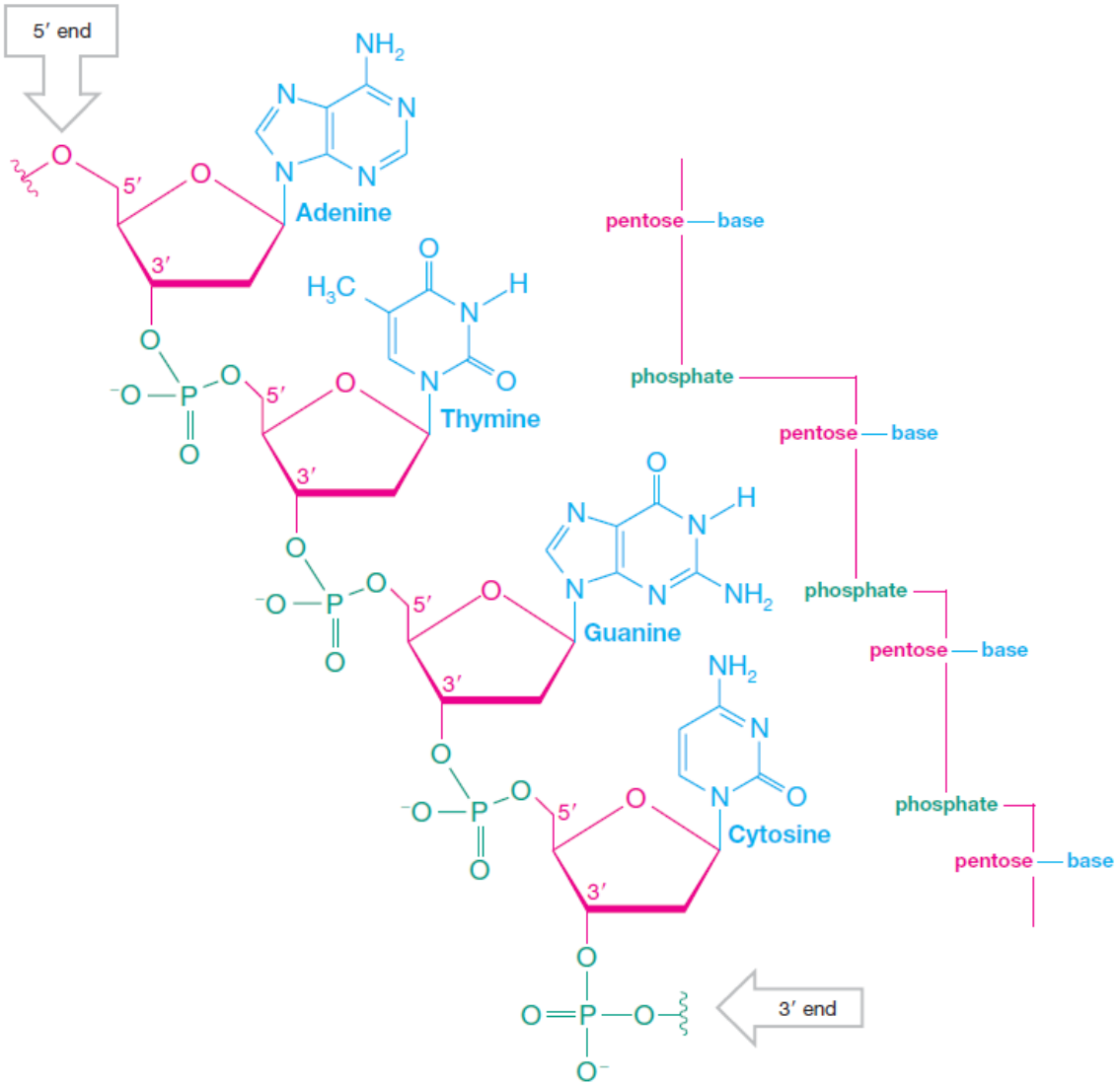
C) Phosphate group

- Phosphate groups link nucleotides through 3′–5′ phosphodiester bonds, forming the sugar–phosphate backbone of nucleic acids.
- The phosphate is attached to the 5′-carbon of one sugar and the 3′-hydroxyl of the next.

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6.4.1. The General Structure of Nucleic acids; Nucleotides and Nucleosides

6.4.1.2. Polynucleotides

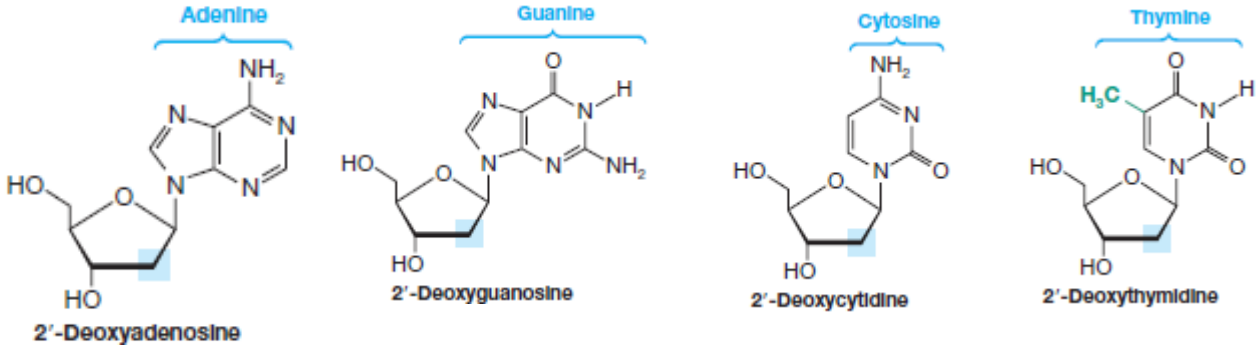


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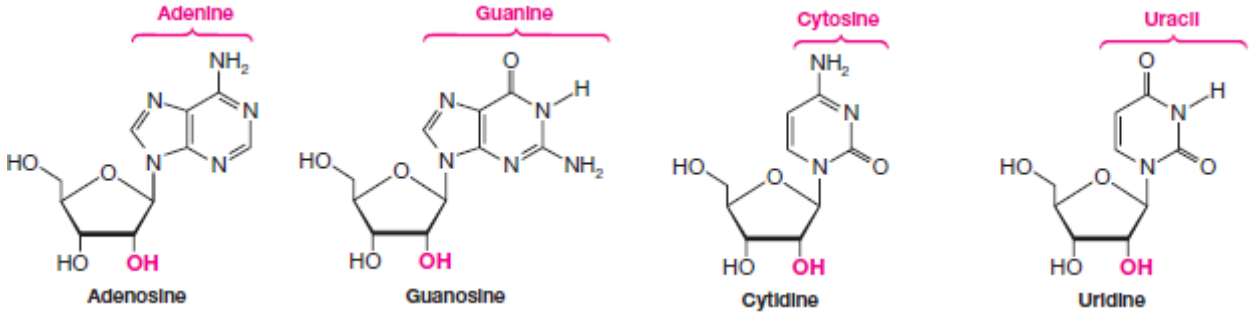
6.4.1. The General Structure of Nucleic acids; Nucleotides and Nucleosides

6.4.1.3. Nucleosides

- Removal of the phosphate group of a nucleotide converts it to a compound known as **a nucleoside**.
- DNA-derived nucleosides consist of 2-deoxy-D-ribose and one of four bases: adenine, guanine, cytosine, or thymine.
- RNA nucleosides contain D-ribose and uracil instead of thymine, which is the main structural difference from DNA.



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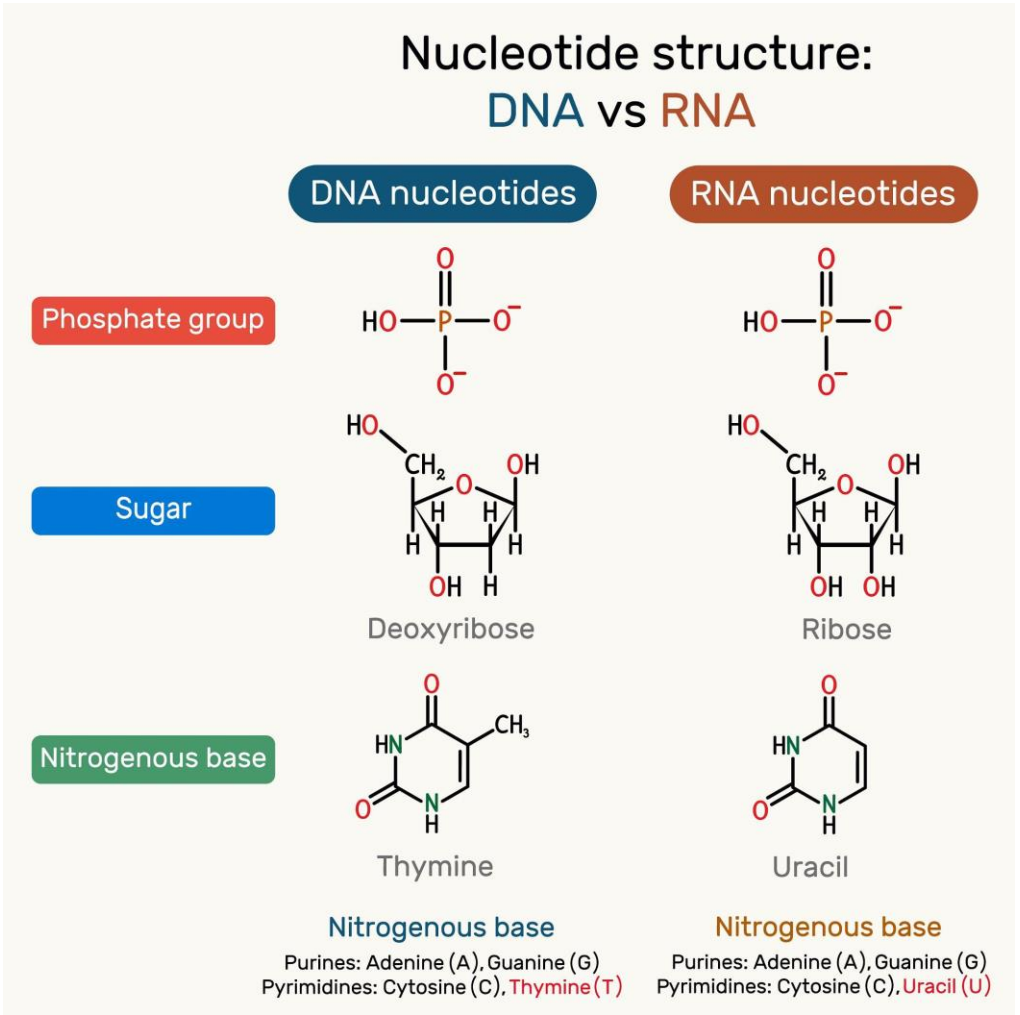


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6.4.1. The General Structure of Nucleic acids; Nucleotides and Nucleosides

6.4.1.4. The structural difference between DNA and RNA

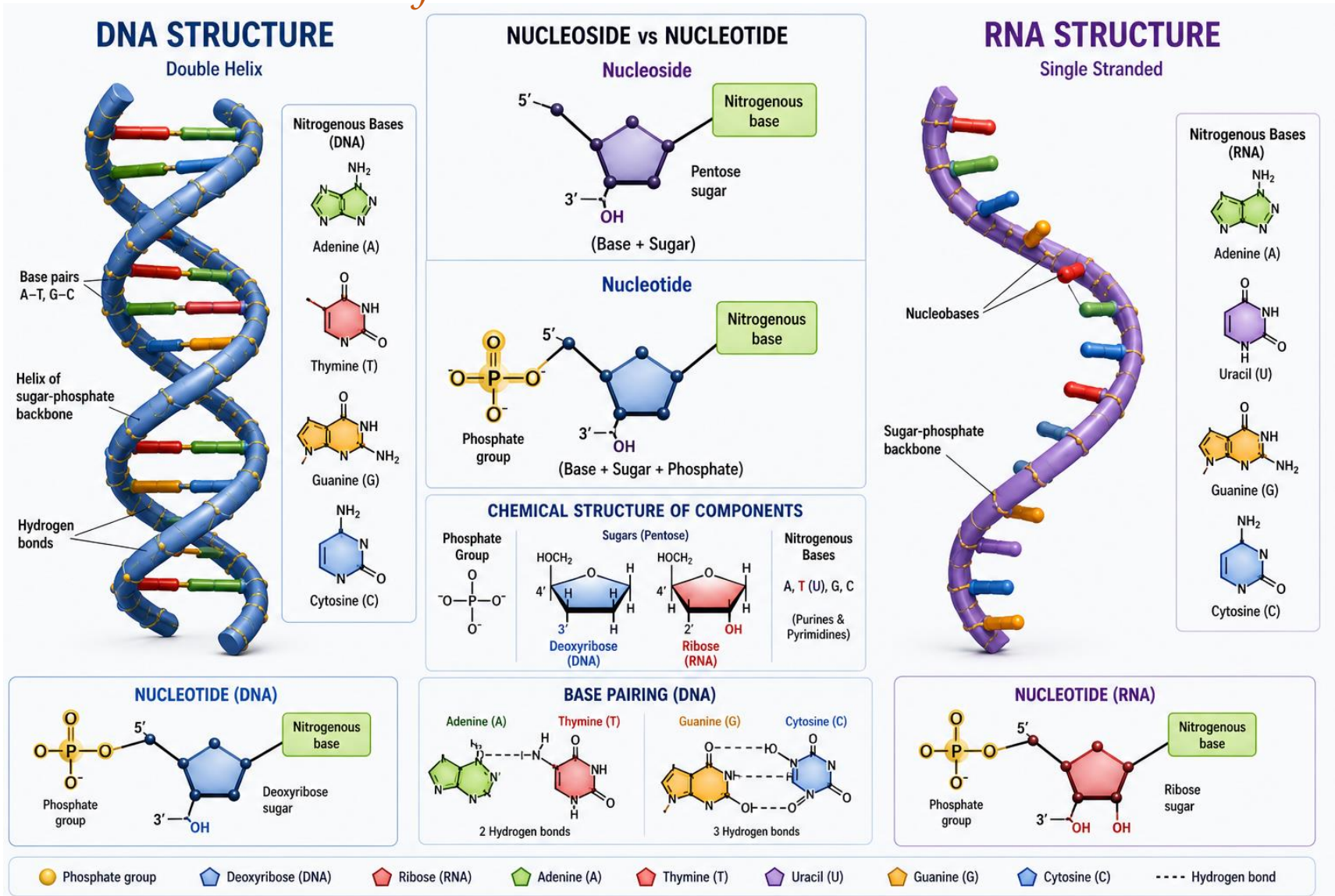
	DNA	RNA
Sugar	2-deoxy-D-ribose	D-ribose
A heterocyclic base	Adenine (A), Thymine (T), Guanine (G), Cytosine (C)	Adenine (A), Uracil (U), Guanine (G), Cytosine (C)
Number of strands	double-stranded (double helix)	single-stranded



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6.4.1. The General Structure of Nucleic acids; Nucleotides and Nucleosides

6.4.1.5. DNA and RNA – Distinctions Summary



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Practice Problems

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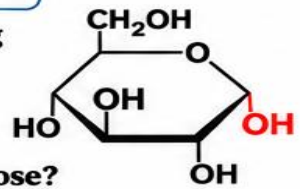
6.5. Practice Problems

A. Carbohydrates

1 Classify the following carbohydrates:

Compound	Classification
(a) Glucose	_____
(b) Sucrose	_____
(c) Starch	_____

2 Identify the anomer (α or β) of the following D-glucopyranose:



A. α-Anomer B. β-Anomer
C. Both α and β D. Neither

3 Which of the following is a ketose and a hexose?

A. Glucose C. Ribose
B. Fructose D. Glyceraldehyde

B. Lipids

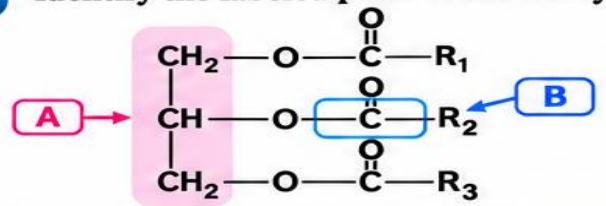
1 What is the major product of complete hydrolysis of a triacylglycerol?

A. Glycerol and three fatty acids B. Three alcohols only
C. One fatty acid and two glycerols D. Three fatty acids only

2 Classify the following fatty acids as saturated or unsaturated:

(a) $CH_3-(CH_2)_{16}-COOH$ → _____
(b) $CH_3-(CH_2)_7-CH=CH-(CH_2)_7-COOH$ → _____

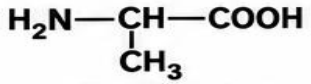
3 Identify the labeled parts of the triacylglycerol:



A. A = Glycerol backbone, B = Ester linkage
B. A = Fatty acid chain, B = Carbonyl group
C. A = Glycerol backbone, B = Fatty acid chain
D. A = Ester linkage, B = Glycerol backbone

C. Amino Acids

1 Identify the amino acid represented by the structure:



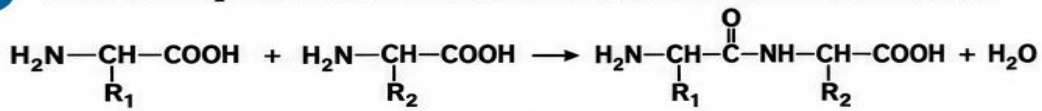
A. Glycine B. Alanine
C. Valine D. Serine

2 Arrange the following amino acids by increasing side-chain hydrophobicity:

Glycine (Gly)	Alanine (Ala)	Valine (Val)

A. Val < Ala < Gly B. Gly < Ala < Val
C. Ala < Gly < Val D. Gly < Val < Ala

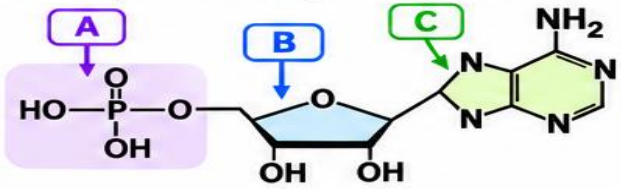
3 What is the product of condensation between two amino acids?



A. Ester B. Peptide bond C. Glycosidic bond D. Disulfide bond

D. Nucleic Acids

1 Identify the labeled parts of the nucleotide:



A. A = Phosphate, B = Pentose (ribose), C = Adenine
B. A = Base, B = Deoxyribose, C = Phosphate
C. A = Phosphate, B = Base, C = Ribose
D. A = Pentose, B = Phosphate, C = Adenine

2 Which base is found in DNA but not in RNA?

A. Uracil B. Thymine C. Cytosine D. Adenine

3 Which of the following statements describes DNA and RNA?

(1) DNA: _____
_____
(2) RNA: _____
_____

A. (1) Usually single-stranded; (2) Contains thymine
B. (1) Double-stranded helix; (2) Contains uracil
C. (1) Contains uracil; (2) Contains thymine
D. (1) Ribose sugar; (2) Deoxyribose sugar