Biomolecules

Short Course

CARBOHYDRATES
AMINO ACIDS, PEPTIDES, PROTEINS
NUCLEIC ACID

Prof. Salem S. Al-Theyab

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King Saud University
Department
Chemistry & College
of Science

BIOPOLYMERS

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Chapter 1: CARBOHYDRATES

Chapter 2: AMINO ACIDS, PEPTIDES and PROTEINS

Chapter 3: NUCLEIC ACID

Chapter 1

CARBOHYDRATES

Definition

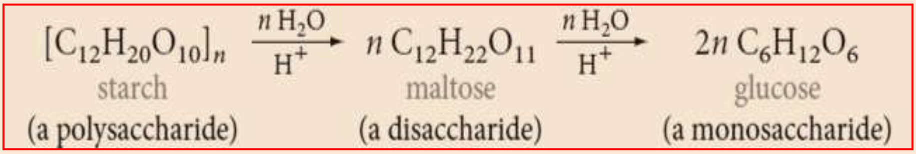
- Carbohydrates are a group of naturally occurring Compounds that contain carbonyl group and several hydroxyl groups and may also include their derivatives formed from them. The word *carbohydrate* can be expressed as *hydrates* of *carbon* because of the molecular formulas of these compounds *which is as follow* $C_n(H_2O)_n$.

Example:

Glucose has the molecular formula **$C_6H_{12}O_6$,** which might be written as **$C_6(H_2O)_6$**.

- *Carbohydrates* are polyhydroxyaldehydes, polyhydroxyketones, or substances that give such compounds on hydrolysis.
- The chemistry of *carbohydrates* is mainly the combined chemistry of two functional groups: the hydroxyl group and the carbonyl group.
- *Carbohydrates* are usually classified according to their structure as monosaccharides, oligosaccharides, or polysaccharides.
- The term *saccharide* comes from Latin (*saccharum,* sugar) and refers to the sweet taste of some simple carbohydrates.
- The three classes of carbohydrates are related to each other through hydrolysis.

$$\text{polysaccharide} \xrightarrow[H^+]{H_2O} \text{oligosaccharides} \xrightarrow[H^+]{H_2O} \text{monosaccharides}$$



$$[C_{12}H_{20}O_{10}]_n \xrightarrow[H^+]{n\,H_2O} n\,C_{12}H_{22}O_{11} \xrightarrow[H^+]{n\,H_2O} 2n\,C_6H_{12}O_6$$

- ***Monosaccharides*** **(or simple sugars)**

  Monosaccharides are carbohydrates that cannot be hydrolyzed to simpler compounds.

- ***Oligosaccharides***

  Oligosaccharides (from the Greek *oligos*, few) contain at least two and generally no more than a few linked monosaccharide units. They may be called disaccharides, trisaccharides, and so on, depending on the number of units, which may be the same or different.

Example:

Maltose is a disaccharide made of two glucose units.
Sucrose is made of two different monosaccharide units:

- ***Polysaccharides***

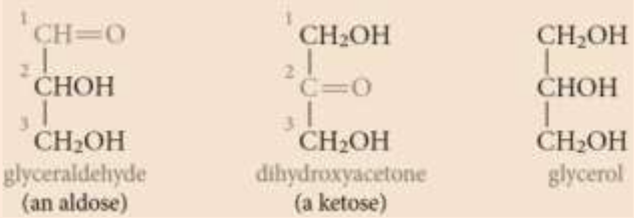
  Polysaccharides contain many monosaccharide units - sometimes hundreds or even thousands. Usually, but not always, the units are identical.

Example:

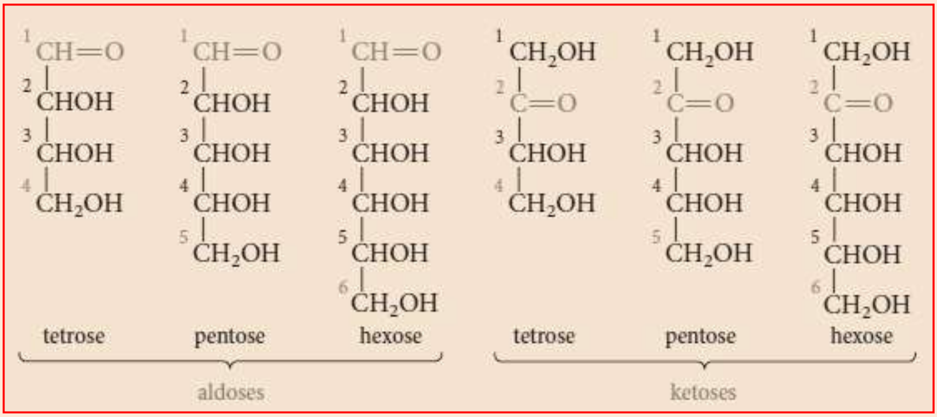
Starch and cellulose, contain linked units of the same monosaccharide, glucose.

Monosaccharides

- **Monosaccharides are classified according to:**
  - **The number of carbon atoms present (triose, tetrose, pentose, hexose, and so on).**
  - **Whether the carbonyl group is present as an aldehyde (aldose) or as a ketone (ketose).**
- **There are only two trioses: glyceraldehyde and dihydroxyacetone.**
- **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.**



- **Other aldoses or ketoses can be derived from glyceraldehyde or dihydroxyacetone by adding carbon atoms, each with a hydroxyl group.**
- **In aldoses, the chain is numbered from the aldehyde carbon.**
- **In most ketoses, the carbonyl group is located at C-2.**



Chirality in Monosaccharides.

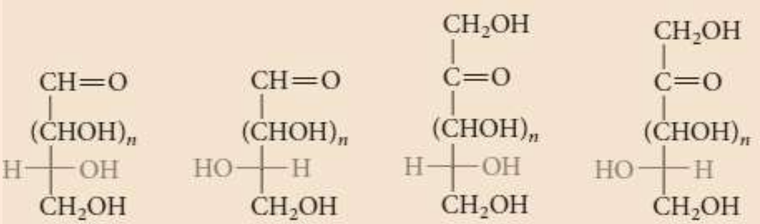
Fischer Projection Formulas and D, L-Sugars

R-(+)-glyceraldehyde

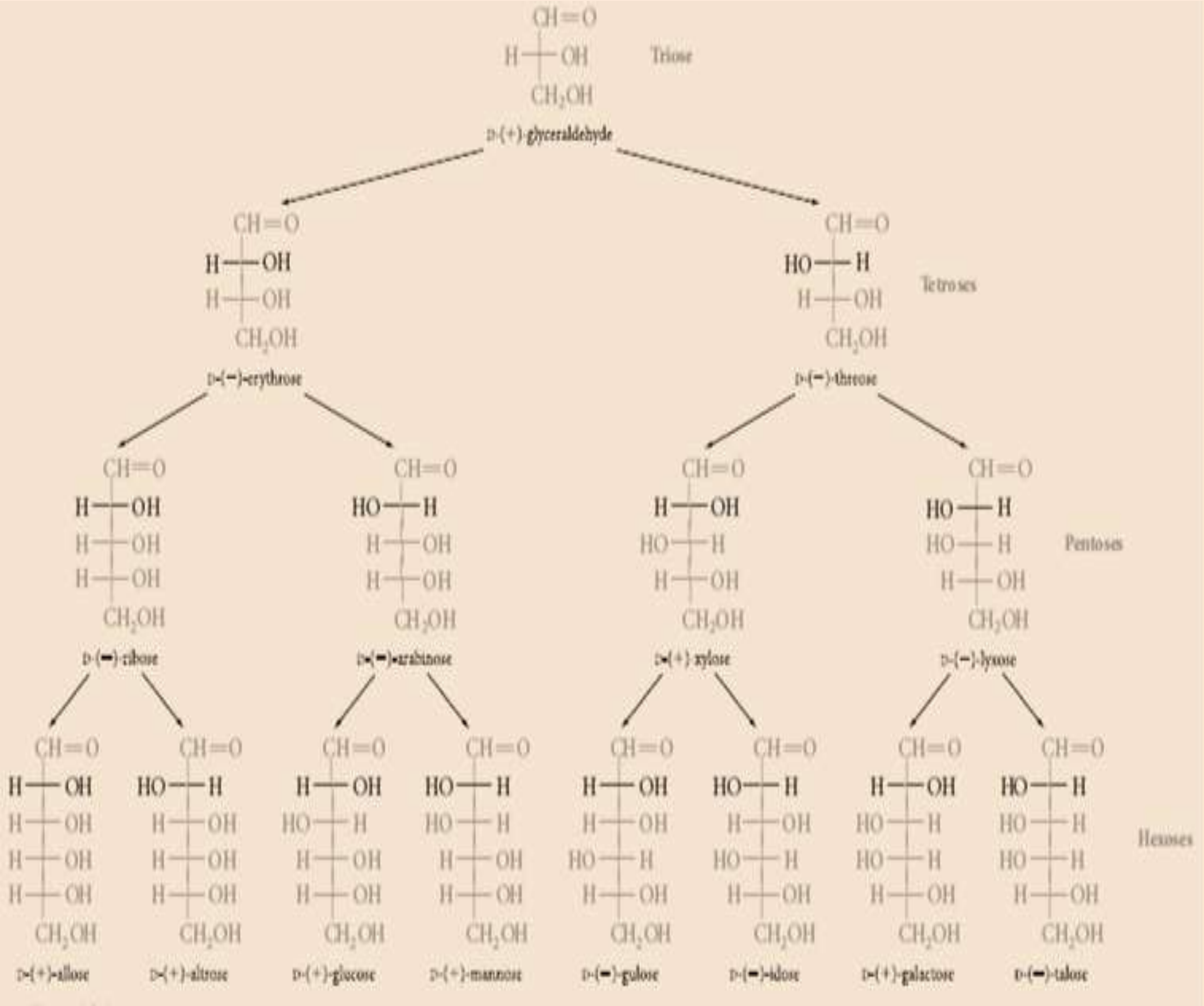
Fischer projection formula for R-(+)-glyceraldehyde

- He used a small capital d to represent the configuration of (+)-glyceraldehyde, with the hydroxyl group on the *right;* its enantiomer, with the hydroxyl group on the *left*, was designated L-(2)-glyceraldehyde.
  The most oxidized carbon (CHO) was placed at the top.

D-(+)-glyceraldehyde L-(−)-glyceraldehyde



a D-aldose an L-aldose a D-ketose an L-ketose


Triose
D-(+)-glyceraldehyde
Tetroses
D-(−)-erythrose
D-(−)-threose
Pentoses
D-(−)-ribose
D-(−)-arabinose
D-(+)-xylose
D-(−)-lyxose
Hexoses
D-(+)-allose
D-(+)-altrose
D-(+)-glucose
D-(+)-mannose
D-(−)-gulose
D-(−)-idose
D-(+)-galactose
D-(−)-talose

- **Diastereomers**

  when two or more stereoisomers of a compound have different configurations at one or more (but not all) of the equivalent (related) stereocenters and are not mirror images of each other.

- ***Epimers***

  A special name is given to diastereomers that differ in configuration *at only one stereogenic center*.

  Each pair has the same configurations at all stereogenic centers except one.

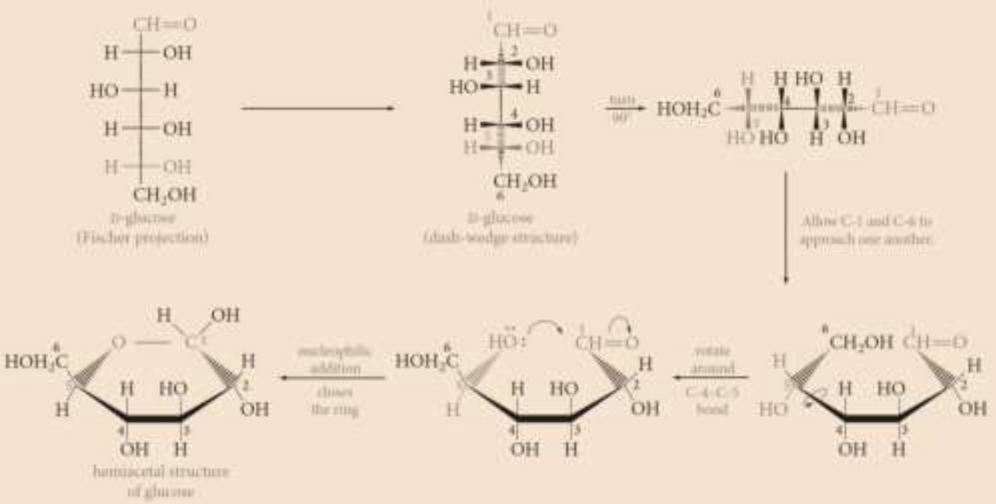
Examples:

- D- (-)-Erythrose and D-(-)-threose are not only diastereomers, they are epimers.
- D-glucose and D-mannose are epimers (at C-2).
- D-glucose and D-galactose are epimers (at C-4).

A compound may be labeled as Dextrorotary by using the " (+)-" or " d -" prefix. Likewise, a Levorotatory compound may be labeled using the " (−)-" or "l -" prefix.

The Cyclic Hemiacetal Structures of Monosaccharides

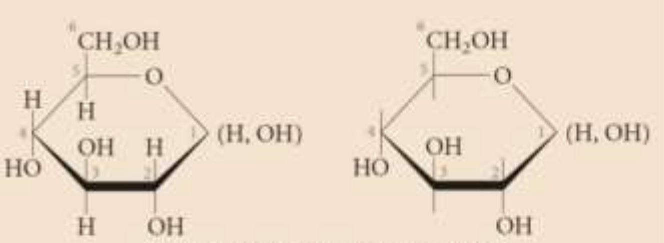
- *Monosaccharides exist mainly in cyclic, hemiacetal forms* and not in the acyclic aldo- or keto-forms.



Manipulation of the Fischer projection formula of D-glucose to bring the C-5 hydroxyl group in position for cyclization to the hemiacetal form.

Haworth Projection

- The carbons are arranged clockwise numerically, with C-1 at the right.
- Substituents attached to the ring lie above or below the plane.


Haworth projection formulas for D-glucose

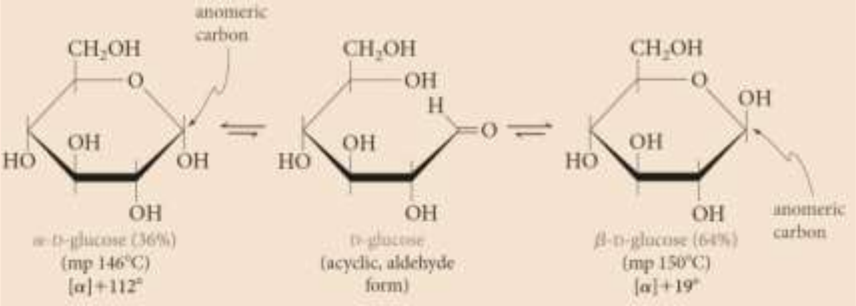
- **Carbons 1 through 5** are part of the ring structure, but carbon 6 (the -CH_2OH group) is a substituent on the ring.
- **C-1 is special**.

C-1 is the hemiacetal carbon (it carries a hydroxyl group, and it is also connected to C-5 by an ether linkage).

- **C-2**, **C-3**, and **C-4** are secondary alcohol carbons.
- **C-6** is a primary alcohol carbon.
- **Hydroxyl groups on the *right*** in the Fischer projection are *down* in the Haworth projection (and conversely.
- **Hydroxyl groups on the *left*** in the Fischer projection are *up* in the Haworth projection).
- For **D-sugars**, the terminal -CH_2OH group is *up* in the Haworth projection; for **L-sugars**, it is down.

Anomeric Carbons; Mutarotation

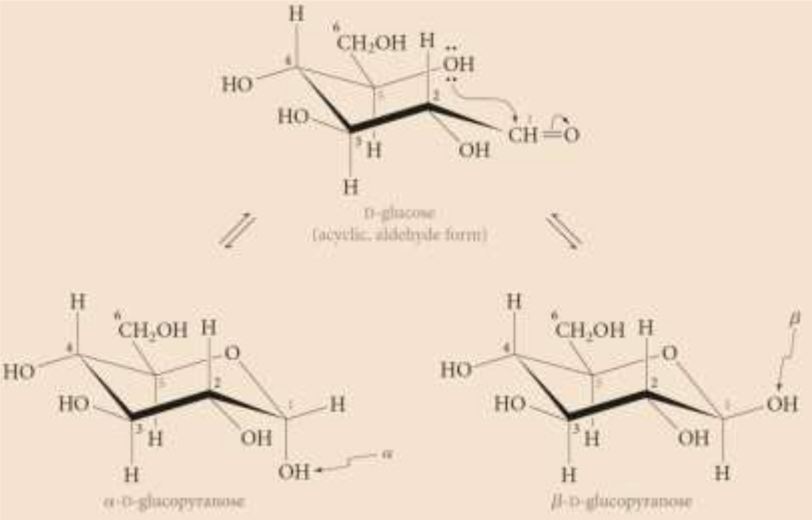
- **Anomeric carbon:** The hemiacetal carbon, the carbon that forms the new stereogenic center.
- **Anomers;** Two monosaccharides that differ only in configuration at the anomeric center are (a special kind of epimers).
- **Anomers** are called α or β, depending on the position of the hydroxyl group.
- **For monosaccharides** in the D-series, the hydroxyl group is “down” in the α anomer and “up” in the β anomer.



If D- glucose is crystallized from methanol, pure α-D-glucose form is obtained, on the other hand crystallization from Acetic acid gives the β- form. The α-D-glucose and β- D-glucose are diastereomers.

Conformations of Pyranoses; Chair Conformation

- **At the anomeric carbon (C-1),** where the hydroxyl group may be axial (in the α anomer) or equatorial (in the β anomer).



Reactions of Monosaccharides

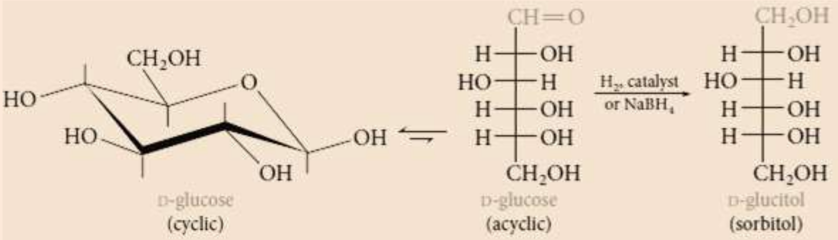
1) Reduction of Monosaccharides

- **The carbonyl group of aldoses and ketoses** can be reduced by various reagents to give polyols, called alditols.

Example:

Catalytic hydrogenation or reduction with sodium borohydride ($NaBH_4$)
converts D-glucose to D-glucitol (sorbitol).

- **Sorbitol** is used commercially as a sweetener and sugar substitute.



2) Oxidation of Monosaccharides

2.1. With Mild Oxidizing Agents

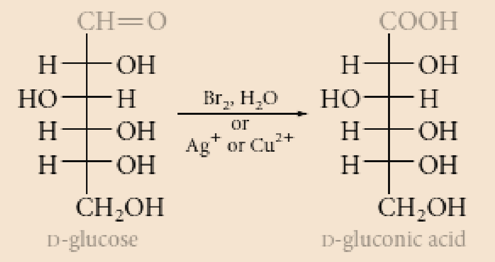
- The oxidation of aldoses is so easy that they react with such mild oxidizing agents as
  - Tollens' reagent (Ag^+ in aqueous ammonia),
  - Fehling's reagent (Cu^{2+} complexed with tartrate ion),
  - Benedict's reagent (Cu^{2+} complexed with citrate ion).

These aldehyde groups can be easily oxidized to acids, which are called aldonic acids.

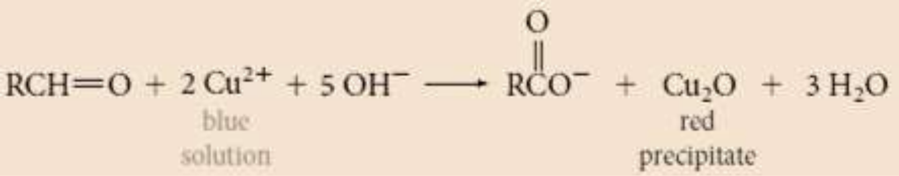
- A carbohydrate that reacts with Ag^+ or Cu^{2+} is called a reducing sugar

Example:

D-glucose is easily oxidized to D-gluconic acid.



- **With the copper reagents, the blue solution gives a red precipitate of cuprous oxide, Cu_2O.**



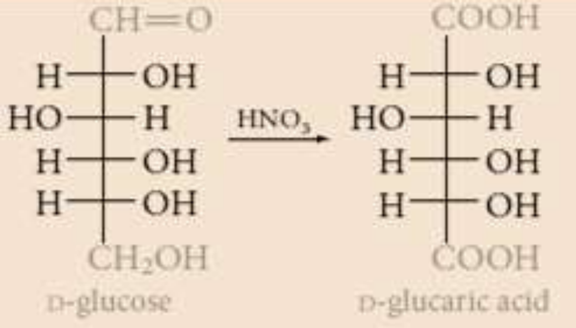
$$RCH{=}O + 2\,Cu^{2+} + 5\,OH^- \longrightarrow R\overset{\overset{O}{\|}}{C}O^- + Cu_2O + 3\,H_2O$$

2.2. With Strong Oxidizing Agents

- **Stronger oxidizing agents, such as aqueous nitric acid.**
- **The aldehyde group and the primary alcohol group can be oxidized, producing dicarboxylic acids called aldaric acids.**
-

Example.

D-glucose gives D-glucaric acid.

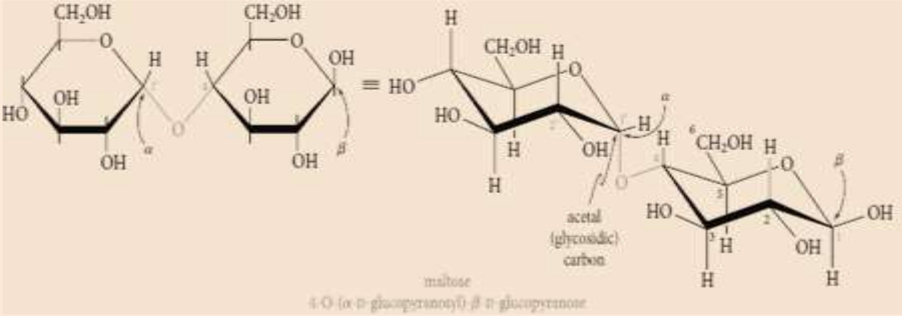


Disaccharides

- The most common oligosaccharides are disaccharides.
- In a disaccharide,

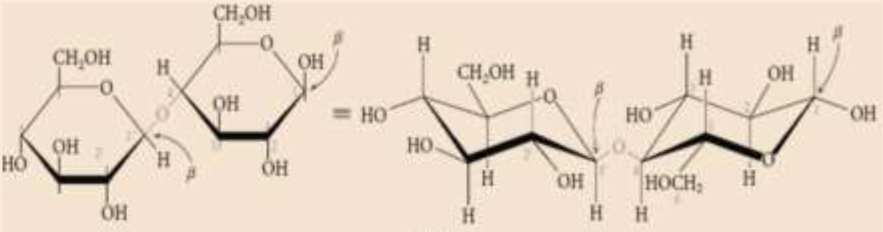
  two monosaccharides are linked by a glycosidic bond between the anomeric carbon of one monosaccharide unit and a hydroxyl group on the other unit.

Maltose



- Maltose is the disaccharide obtained by the partial hydrolysis of starch.
- Further hydrolysis of maltose gives only D-glucose.
- Maltose must, therefore, consist of two linked glucose units.
- It turns out that the anomeric carbon of the left unit is linked to the C-4 hydroxyl group of the unit at the right as an acetal (glycoside).
- The configuration at the anomeric carbon of the left unit is α.

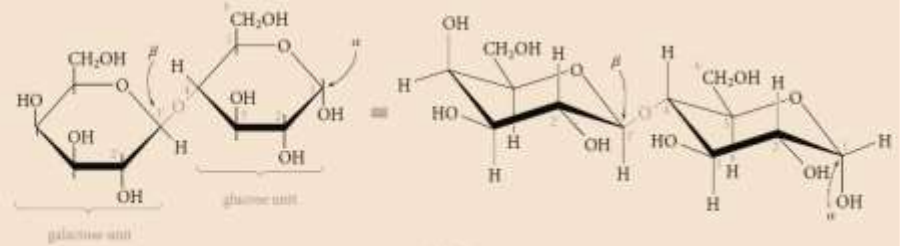
Cellibiose



cellobiose
4-O-(β-D-glucopyranosyl)-β-D-glucopyranose

- Cellobiose is the disaccharide obtained by the partial hydrolysis of cellulose.
- Further hydrolysis of cellobiose gives only D-glucose.
- Cellobiose must therefore be an isomer of maltose.
- In fact, cellobiose *differs from maltose* only *in having the* β *configuration at C-1 of the left glucose unit*

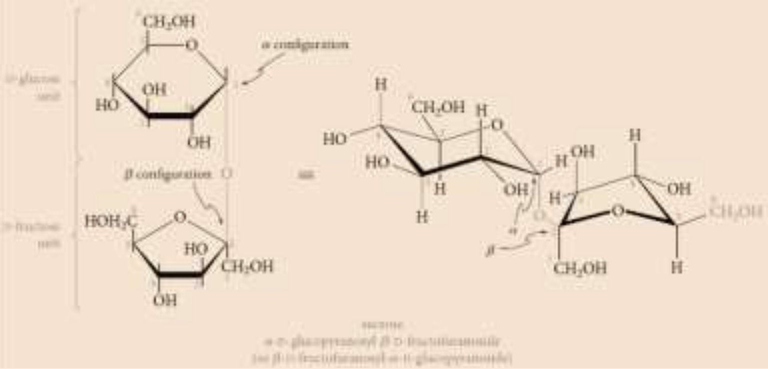
Lactose



lactose
4-O-(β-D-galactopyranosyl)-α-D-glucopyranose

- Lactose is the major sugar in human and cow’s milk (4% to 8% lactose).
- Hydrolysis of lactose gives equimolar amounts of D-galactose and D-glucose.
    - The anomeric carbon of the galactose unit has the β configuration at C-1 and is linked to the hydroxyl group at C-4 of the glucose unit.

Sucrose

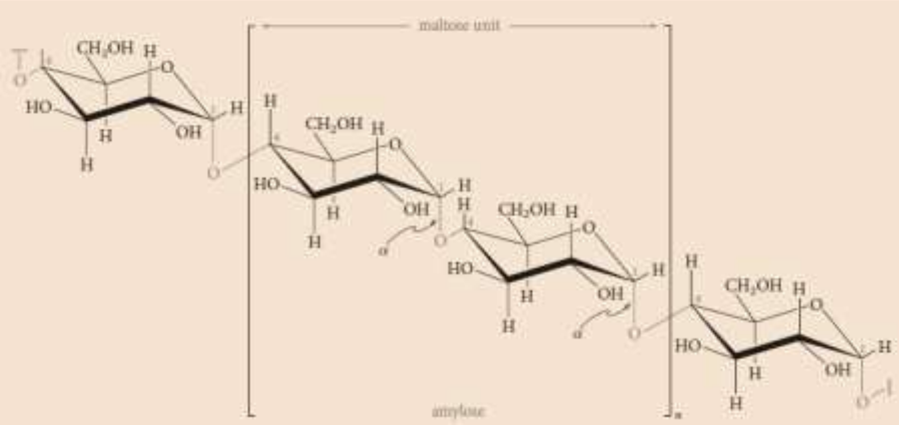


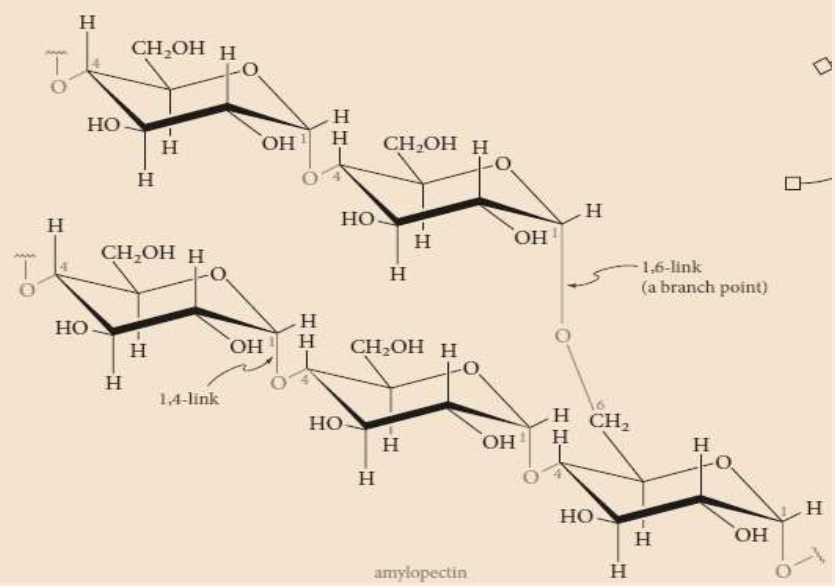
- The most important commercial disaccharide is sucrose, ordinary table sugar.
- Sucrose occurs in all photosynthetic plants, where it functions as an energy source.
- It is obtained commercially from sugar cane and sugar beets, in which it constitutes 14% to 20% of the plant juices.
- Sucrose is very water soluble (2 grams per milliliter at room temperature) because it is polar due to the presence of eight hydroxyl groups on its surface.
- Hydrolysis of sucrose gives equimolar amounts of D-glucose and the ketose D-fructose.

Polysaccharides

- Polysaccharides contain many linked monosaccharides and vary in chain length and molecular weight.
- Most polysaccharides give a single monosaccharide on complete hydrolysis.
- The monosaccharide units may be linked linearly, or the chains may be branched.

Starch



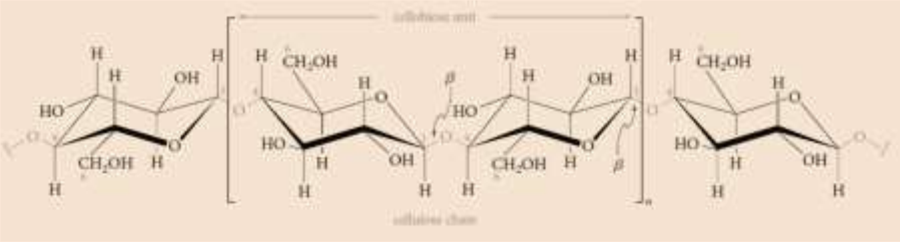


- **Starch** is the energy-storing carbohydrate of plants.
- It is a major component of cereals, potatoes, corn, and rice.
- Starch is made up of glucose units joined mainly by 1,4-α-glycosidic bonds, although the chains may have a number of branches attached through 1,6- α -glycosidic bonds.
- Partial hydrolysis of starch gives maltose, and complete hydrolysis gives only D-glucose.
- Starch can be separated by various techniques into two fractions: amylose and amylopectin.
- In amylose, which constitutes about 20% of starch, the glucose units (50 to 300) are in a continuous chain, with 1,4 linkages.
- Amylopectin is highly branched. Although each molecule may contain 300 to 5000 glucose units, chains with consecutive 1,4 links average only 25 to 30 units in length.
- These chains are connected at branch points by 1,6 linkages.

Glycogen

- Glycogen is the energy-storing carbohydrate of animals.
- Like starch, it is made of 1,4- and 1,6-linked glucose units.
- Glycogen has a higher molecular weight than starch (perhaps 100,000 glucose units), and its structure is even more branched than that of amylopectin, with a branch every 8 to 12 glucose units.
- Glycogen is produced from glucose that is absorbed from the intestines into the blood; transported to the liver, muscles, and elsewhere; and then polymerized enzymatically.
- Glycogen helps maintain the glucose balance in the body by removing and storing excess glucose from ingested food and later supplying it to the blood when various cells need it for energy.

Cellulose



- Cellulose is an *unbranched* polymer of glucose joined by 1,4-β-glycosidic bonds.
- It consists of linear chains of cellobiose units.
- These linear molecules, containing an average of 5000 glucose units, aggregate to give fibrils bound together by hydrogen bonds between hydroxyls on adjacent chains.
- Cellulose fibers having considerable physical strength are built up from these fibrils, wound spirally in opposite directions around a central axis.
- Wood, cotton, hemp, linen, straw, and corncobs are mainly cellulose.

Chapter 2

AMINO ACIDS,
PEPTIDES AND PROTEINS

❖ Definition of Amino acids

Amino acids are organic molecules that serve as the building blocks for proteins. They consist of a basic amino group, an acidic carboxyl group, and a unique organic side chain.

❖ Sources of Amino acids

Proteins as sources of Amino acids are (naturally occurring) polymers composed of amino acid units joined one to another by amide (or peptide) bonds.

Example,

animal hair and muscle, egg whites, and hemoglobin are all proteins.

❖ Peptides:

Peptides are oligomers of amino acids that play important roles in many biological processes.

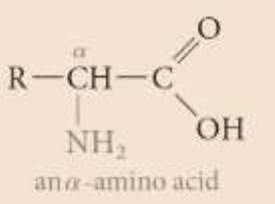
Example,

the peptide hormone insulin controls our blood sugar levels.

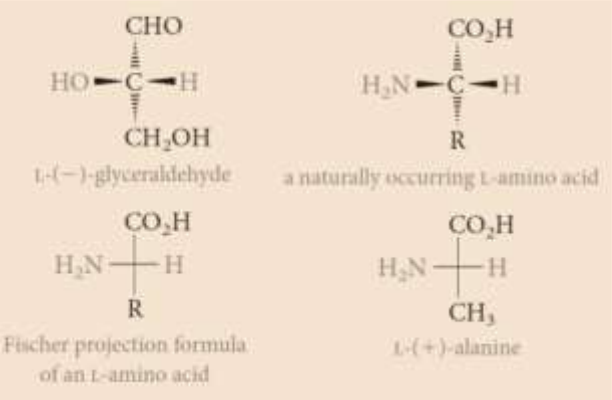
❖ Structure of Amino Acids

Proteins, peptides, and amino acids are essential to the structure, function, and reproduction of living matter.

- The amino acids obtained from protein hydrolysis are α-amino acids.
- The amino group is on the α -carbon atom, the one adjacent to the carboxyl group.



- With the exception of glycine, where R = H, a-amino acids have a stereogenic center at the α -carbon.
- All except glycine are therefore optically active.
- They have the L-configuration relative to glyceraldehyde.
- Note that the Fischer convention, used with carbohydrates, is also applied to amino acids.

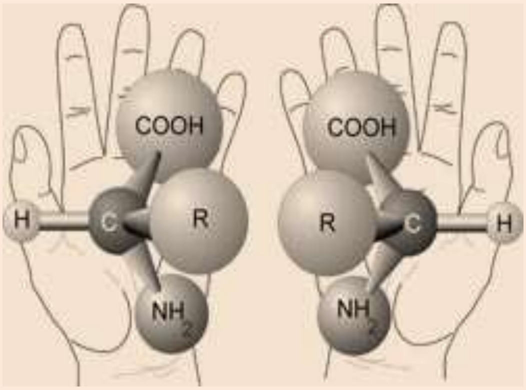


L-(−)-glyceraldehyde

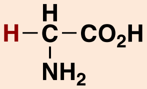
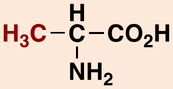
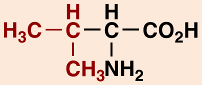
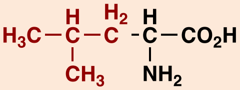
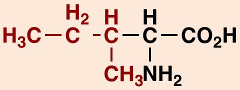
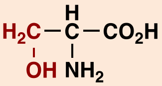
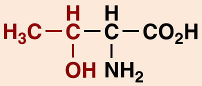
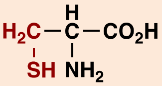
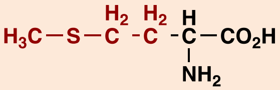
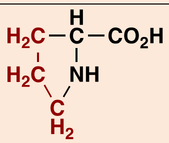
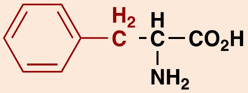
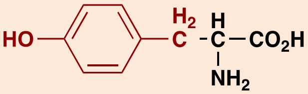
a naturally occurring L-amino acid

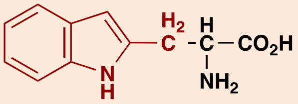
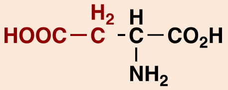
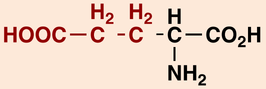
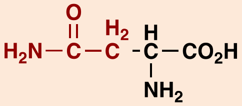
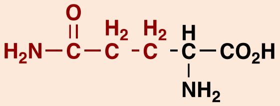
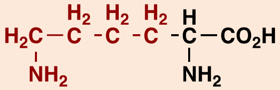
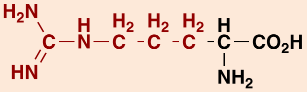
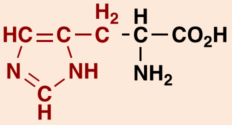
Fischer projection formula of an L-amino acid

L-(+)-alanine



List of the 20 α-amino acids commonly found in proteins.

Name	Abbreviation by one and three letters	Formulas	R
Amino acid with one amino group and one carboxy group			
1. Glycine	G- Gly-	 $H-\overset{H}{\underset{NH_2}{C}}-CO_2H$	R- is hydrogen or an alkyl group
2. Alanine	A- Ala-	 $H_3C-\overset{H}{\underset{NH_2}{C}}-CO_2H$	
3. Valine	V- Val-	 $H_3C-\underset{CH_3}{\overset{H}{C}}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
4. Leucine	L- Leu-	 $H_3C-\underset{CH_3}{\overset{H}{C}}-\overset{H_2}{C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
5. Isoleucine	I- Ile-	 $H_3C-\overset{H_2}{C}-\underset{CH_3}{\overset{H}{C}}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
6. Serine	S- Ser-	 $\underset{OH}{H_2C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	R- contains alcohol function group
7. Threonine	T- Thr-	 $H_3C-\underset{OH}{\overset{H}{C}}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
8. Cysteine	C- Cys-	 $\underset{SH}{H_2C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	R- contains sulfur
9. Methionine	M- Met-	 $H_3C-S-\overset{H_2}{C}-\overset{H_2}{C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
10. Proline	P- Pro-		Amico group is secondary and a part of the ring
11. Phenylalanine	F- Phe-		
12. Tyrosine	Y- Tyr-		

13. Tryptophane	W- Trp-		
One amino group and two carboxyl groups			
14. Aspartic acid	D- Asp-	 $HOOC-\overset{H_2}{C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
15. Glutamic acid	E- Glu-	 $HOOC-\overset{H_2}{C}-\overset{H_2}{C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
16. Asparagine	N- Asn-	 $H_2N-\overset{O}{\overset{\|}{C}}-\overset{H_2}{C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
17. Glutamine	Q- Gln-	 $H_2N-\overset{O}{\overset{\|}{C}}-\overset{H_2}{C}-\overset{H_2}{C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	
One carboxyl group and two basic groups			
18. Lysine	K- Lys-	 $H_2\underset{NH_2}{C}-\overset{H_2}{C}-\overset{H_2}{C}-\overset{H_2}{C}-\underset{NH_2}{\overset{H}{C}}-CO_2H$	The second basic group is a primary amine, a guanidine or an imidazole
19. Arginine	R- Arg		
20. Histidine	H- His-		

❖ Nomenclature

- **The amino acids** are known by common names.

- Each also has a **three-letter abbreviation** based on this name, which is used when writing the formulas of peptides, and a one-letter abbreviation used to describe the amino acid sequence in a protein.

❖ Classification

- The amino acids are classified into:

- Essential amino acids

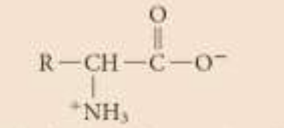
Eight amino cannot be synthesized by adult humans and therefore must be included in the diet in the form of proteins.
e.g., Valine, Leucine, Isoleucine, Threonine, Methionine, Phenylalanine, Tryptophan, and Lysine.

- Non-essential amino acids

Twelve amino acids can be synthesized in the body from other foods.
***e.g.,* Glycine, Alanine, Serine, Cysteine, Proline, Tyrosine, Aspartic acid, Glutamic acid, Asparagine, Glutamine, Arginine, and Histidine.**

❖ The Acid–Base Properties of Amino Acids

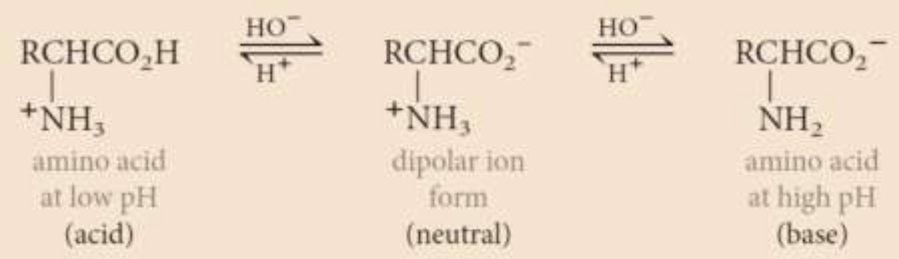
- The carboxylic acid and amine functional groups are *simultaneously* present in amino acids, and we might ask whether they are mutually compatible since one group is acidic and the other is basic.
- Amino acids with one amino group and one carboxyl group are better represented by a dipolar ion structure.



$$R-\underset{^{+}NH_3}{\underset{|}{CH}}-\overset{O}{\overset{\|}{C}}-O^-$$

dipolar structure of an α-amino acid

- The **o group** is protonated and present as an ammonium ion, whereas the carboxyl group has lost its proton and is present as a carboxylate anion.
- This **dipolar structure** is consistent with the salt-like properties of amino acids, which have rather high melting points and relatively low solubility in organic solvents.
- **Amino acids are *amphoteric*.**
  They can behave as acids and donate a proton to a strong base, or they can behave as bases and accept a proton from a strong acid.

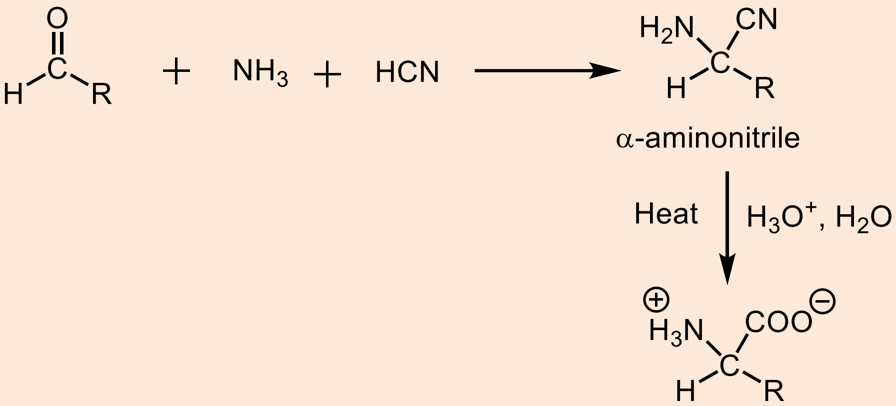


$$\underset{^{+}NH_3}{RCHCO_2H} \underset{H^+}{\overset{HO^-}{\rightleftharpoons}} \underset{^{+}NH_3}{RCHCO_2^-} \underset{H^+}{\overset{HO^-}{\rightleftharpoons}} \underset{NH_2}{RCHCO_2^-}$$

- The **isoelectric point (pI),** the amino acid will be dipolar and have a net charge of zero.

❖ Synthesis of Amino Acids

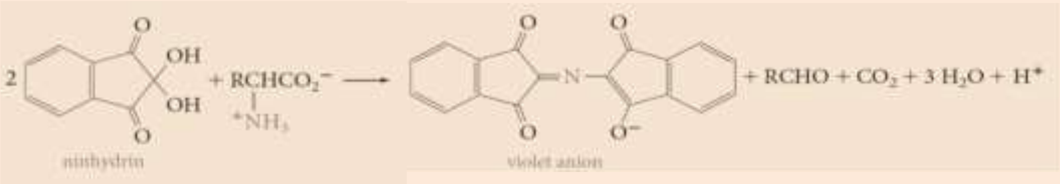
Strecker Synthesis: Recall reductive amination and Cyanohydrin formation.



❖ Reactions of Amino Acids

1- **The Ninhydrin Reaction**

- Ninhydrin is a useful reagent for detecting amino acids and determining the concentrations of their solutions.
- *Ninhydrin is the hydrate of a cyclic triketone, and when it reacts with an amino acid, a violet dye is produced.*

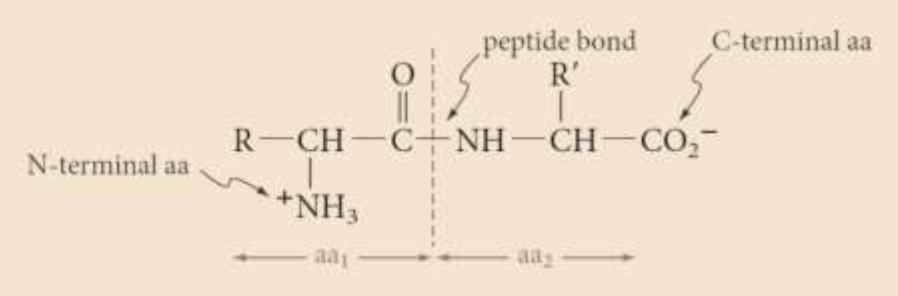


- Only the nitrogen atom of the violet dye comes from the amino acid (primary amino group); the rest of the amino acid is converted to an aldehyde and carbon dioxide.

- Only proline, which has a secondary amino group, reacts differently to give a yellow dye, but this, too, can be used for analysis.

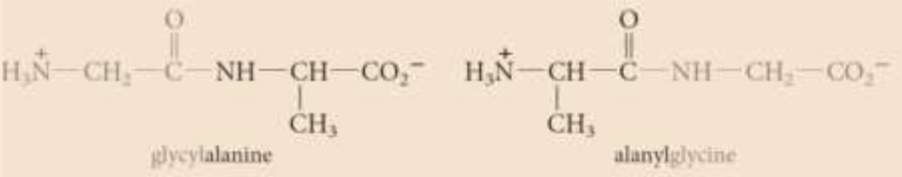
2- Formation of an amide linkage (The peptide bond: Proteins)

- Amino acids are linked in peptides and proteins by an amide bond (*peptide bond*) between the carboxyl group of one amino acid and the α-amino group of another amino acid.
- A molecule containing only *two* amino acids (the shorthand aa is used for amino acid) joined in this way is a dipeptide:



- By convention, the peptide bond is written with the amino acid having a free $^+NH_3$ group at the left and the amino acid with a free CO_2^- group at the right.
- These amino acids are called, respectively, the N-terminal amino acid and the C-terminal amino acid.
- We often write the formulas for peptides in a kind of shorthand by simply linking the three-letter abbreviations for each amino acid, *starting with the N-terminal one at the left.*

- For example, glycylalanine is Gly—Ala, and alanylglycine is Ala—Gly.



Structure of Proteins

- Proteins are biopolymers composed of many amino acids connected to one another through amide (peptide) bonds.
- Some proteins are major components of structural tissue (muscle, skin, nails, and hair).
- Others transport molecules from one part of a living system to another.
- The main features of peptide and protein structure.

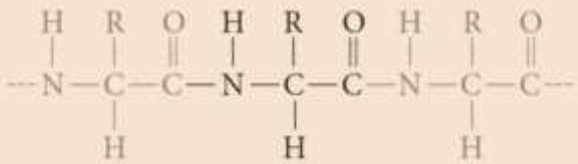
- *Primary structure;*

  How many amino acids are present and what their sequence is in the peptide or protein chain.
- *Secondary*, *tertiary*, and *quaternary structures;*

- *Three-dimensional aspects of peptide and protein structure, usually referred to as their.*

The Primary Structure of Proteins

- **The backbone of proteins is a repeating sequence of one nitrogen and two carbon atoms.**



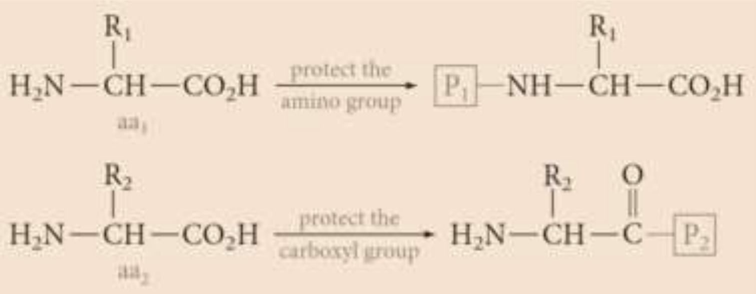
protein chain, showing amino acids linked by amide bonds

- **Peptides and proteins can be hydrolyzed to their amino acid components by heating with 6 M HCl.**
- **An instrument called an amino acid analyzer is used to determine the amino acids mixture.**

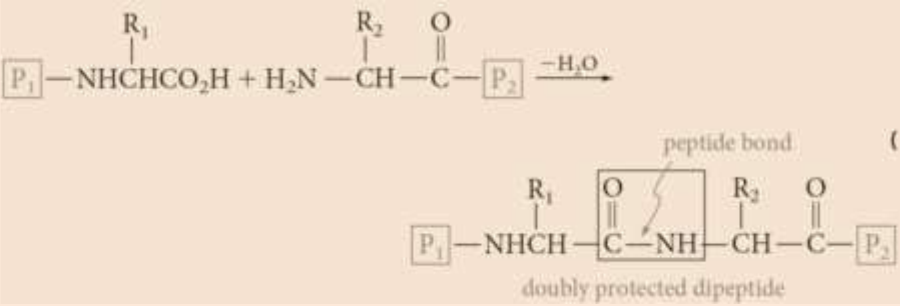
Peptide Synthesis

- Many methods have been developed to link amino acids in a controlled manner.

  To link the carboxyl group of one amino acid to the amino group of a second amino acid, we must first prepare each compound by protecting the amino group of the first and the carboxyl group of the second.



- In this way, we can control the linking of the two amino acids so that the carboxyl group of aa_1 combines with the amino group of aa_2.

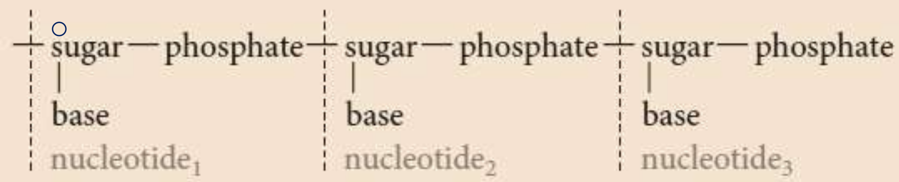


Chapter 3

NUCLEIC ACIDS

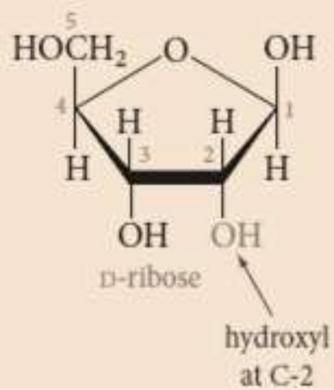
The General Structure of Nucleic Acids

- The overall structure of the nucleic acid itself is a macromolecule with a backbone of sugar molecules connected by phosphate links and with a base attached to each sugar unit.

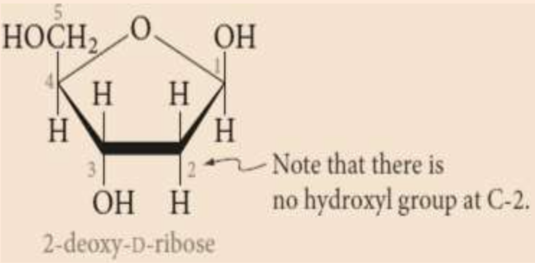


schematic structure of a nucleic acid

- **Definition of Nucleic acids:**
  Nucleic acids are high polymers consisting of a *pentose sugar containing a heterocyclic base and a phosphate moiety*.
- **Pentose Sugar**
  Ribonucleic acid (RNA) contains the pentose ribose.



- Deoxyribonucleic acid (DNA) contains the pentose deoxyribose.

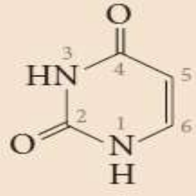


Note that there is no hydroxyl group at C-2.

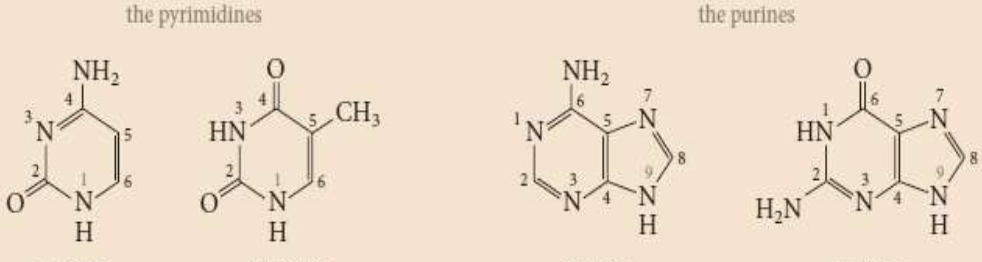
2-deoxy-D-ribose

Heterocyclic Base

- The sugars also contain a **pyrimidine or purine base** present on the 1-carbon replacing the hydroxyl group with a base.



uracil



the pyrimidines

the purines

cytosine (C)

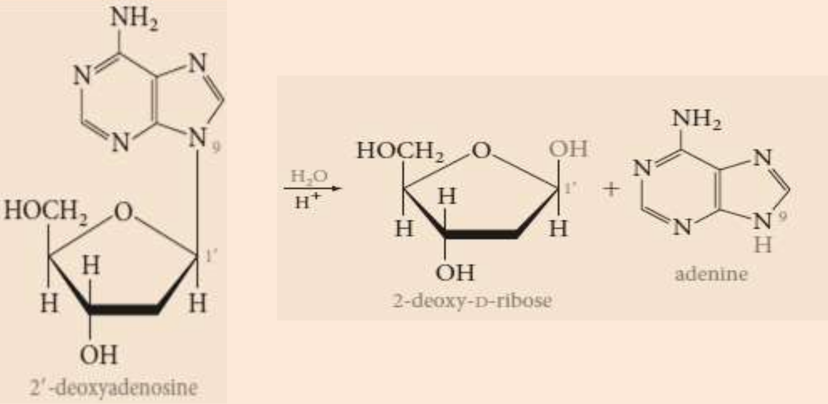
thymine (T)

adenine (A)

guanine (G)

- Both DNA and RNA contain adenine and guanine.
- Uracil is found only in RNA.
- Thymine or methyluracil is found only in DNA.

- The combination of the pentose sugar and a purine or pyrimidine base is called a nucleoside.

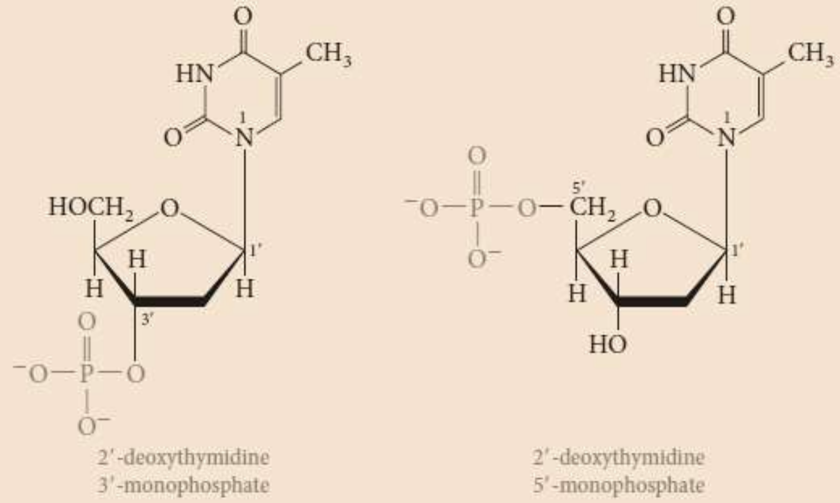


- **Nucleotide:**

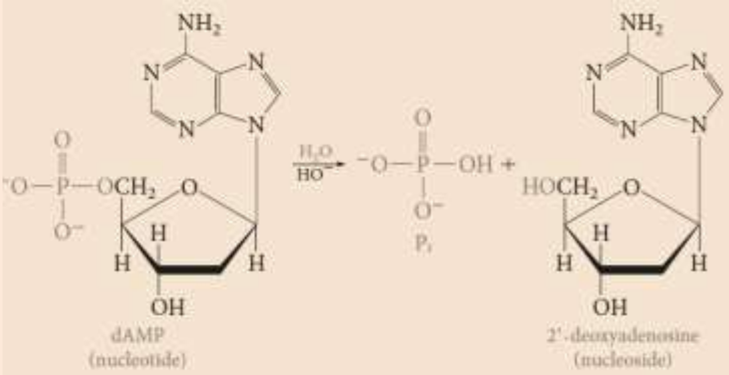
  Nucleotides are phosphate esters of nucleosides.

  A hydroxyl group in the sugar part of a nucleoside is esterified with phosphoric acid.

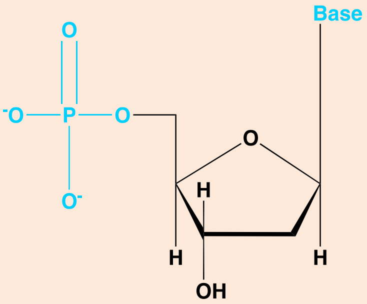
  In DNA nucleotides, either the 5’ or the 3’ hydroxyl group of 2-deoxy-d-ribose is esterified.



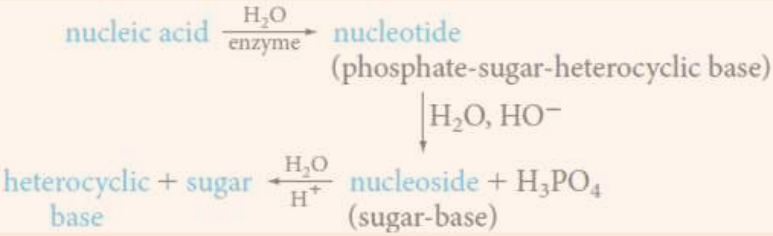
- Nucleotides can be hydrolyzed by aqueous base (or by enzymes) to nucleosides and phosphoric acid.
- Nucleotides are named as the 3’- or 5’-monophosphate esters of a nucleoside.



- In these abbreviations, letter d stands for 2-deoxy-d-ribose, the next letter refers to the heterocyclic base, and MP stands for monophosphate.

<table>
<tr><th colspan="3">The common 2-Deoxyribonucleotides</th></tr>
<tr><td colspan="3">
</td></tr>
<tr><td>Base</td><td>Monophaosphate name</td><td>Abbreviation</td></tr>
<tr><td>Cytosine (C)</td><td>2’-deoxycytidine 5’-monophosphate</td><td>dCMP</td></tr>
<tr><td>Thymine (T)</td><td>2’-deoxythymidine 5’-monophosphate</td><td>dTMP</td></tr>
<tr><td>Adenine (A)</td><td>2’-deoxyadenosine 5’-monophosphate</td><td>dAMP</td></tr>
<tr><td>Guanine (G)</td><td>2’-deoxyguanosine 5’-monophosphate</td><td>dGMP</td></tr>
</table>

- Hydrolysis of nucleic acids gives nucleotides, which are the building blocks of nucleic acids, just as amino acids are the building blocks of proteins.



- Nucleic acids are polynucleotides attached by the phosphate moieties through the 3′ and 5′ sites on the pentose.
- The name nucleic acid is derived from the fact that they are acidic, containing a phosphoric acid moiety, and are found in the nuclei of cells.

- Nucleoproteins, which are conjugated proteins, may be separated into nucleic acids and proteins in aqueous sodium chloride.
- The name “nuclein” which was coined by Miescher in 1869 to describe products isolated from nuclei in pus, was later changed to nucleic acid.
- Pure nucleic acid was isolated by Levene in the early 1900s.
- He showed that either D-ribose or D-deoxyribose was present in what are now known as ribonucleic acid (RNA) and deoxyribonucleic acid (DNA).

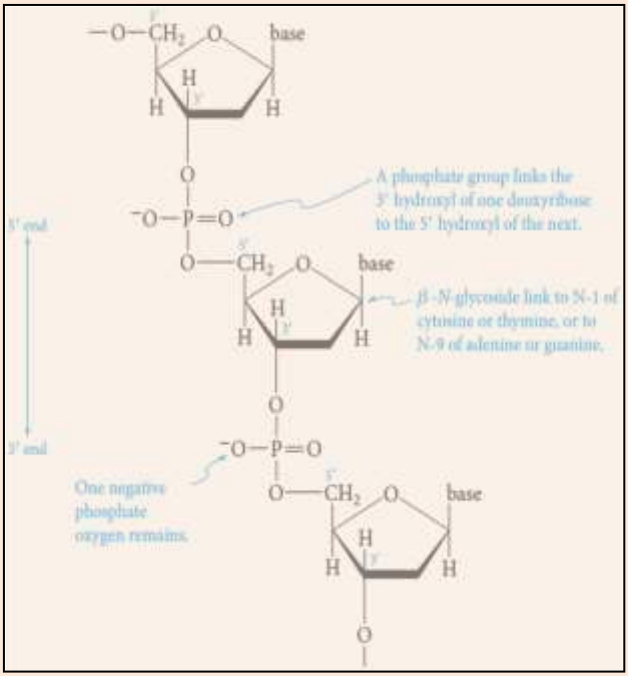
Types of nucleic acids

There are two major types of nucleic acids:

- Deoxyribonucleic acid (DNA) and
- Ribonucleic acid (RNA).

❖ Deoxyribonucleic acid (DNA) and

1- The Primary Structure of Deoxyribonucleic Acid (DNA)

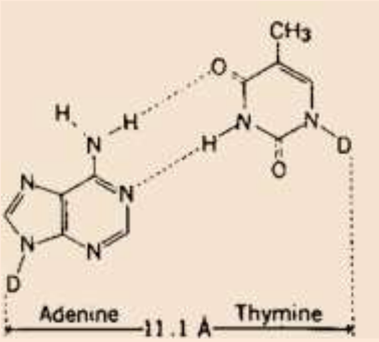
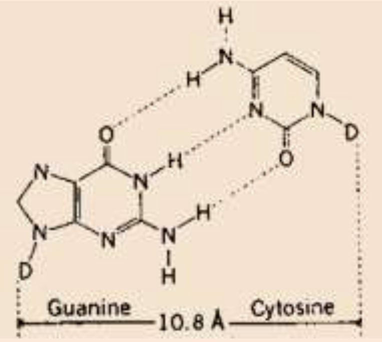


A segment of a DNA chain

- In deoxyribonucleic acid (DNA), 2-deoxy-d-ribose and phosphate units alternate in the backbone.
- The 3’ hydroxyl of one ribose unit is linked to the 5’ hydroxyl of the next ribose unit by a phosphodiester bond.
- The heterocyclic base is connected to the anomeric carbon of each deoxyribose unit by a *β*-*N*-glycosidic bond.
- In DNA, there are no remaining hydroxyl groups on any deoxyribose unit.

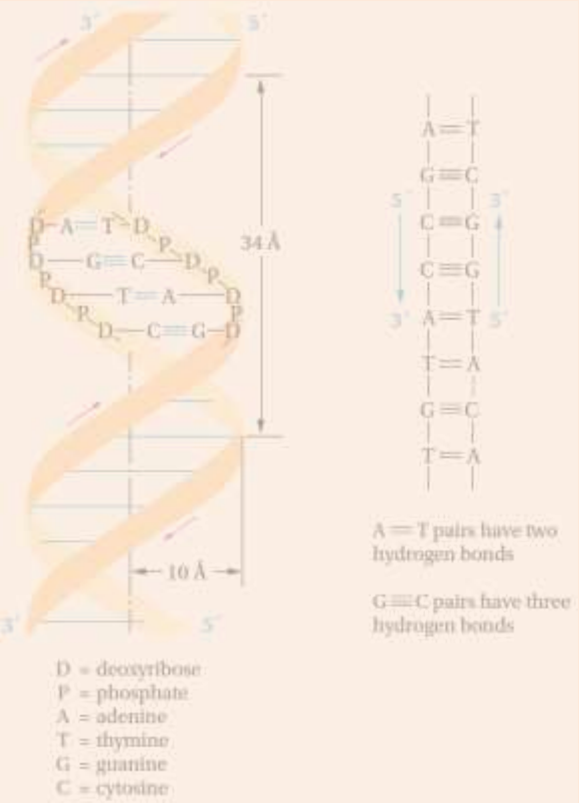
- Each phosphate, however, still has one acidic proton that is usually ionized at pH 7, leaving a negatively charged oxygen.
- If this proton were present, the substance would be an acid; hence the name nucleic acid.
- A complete description of any particular DNA molecule, which may contain thousands or even millions of nucleotide units, would have to include the exact sequence of heterocyclic bases (A, C, G, and T) along the chain.

2- Secondary DNA Structure; the Double Helix

	
Two hydrogen bonds	**Three hydrogen bonds**

Model and schematic representations of the DNA double helix.

The space-filling model at the left shows the base pairs in the helix interior, in planes perpendicular to the main helical axis. The center drawing shows the structure more schematically, including the dimensions of the double helix. At the far right is a schematic method for showing base pairing in the two strands.



- ○ In 1953, when Watson and Crick, working together in Cambridge, England, proposed the double helix model for DNA.
- ○ They received simultaneous supporting x-ray data for their proposal from Rosalind Franklin and Maurice Wilkins in London.

The important features of their model follow:

1. DNA consists of two helical polynucleotide chains coiled around a common axis.

2. The helices are right-handed, and the two strands run in opposite directions with regard to their 3’ and 5’ ends.

3. The purine and pyrimidine bases lie *inside* the helix, in planes perpendicular to the helical axis; the deoxyribose and phosphate groups form the outside of the helix.

4. The two chains are held together by;

- ***Purine–pyrimidine base pairs* connected by hydrogen bonds.**
- ***Adenine is always paired with thymine, and***
- ***Guanine is always paired with cytosine.***

5. The diameter of the helix is 20 A.

Adjacent base pairs are separated by 3.4 A and oriented through a helical rotation of 36°.

There are therefore 10 base pairs for every turn of the helix (360°), and the structure repeats every 34 A.

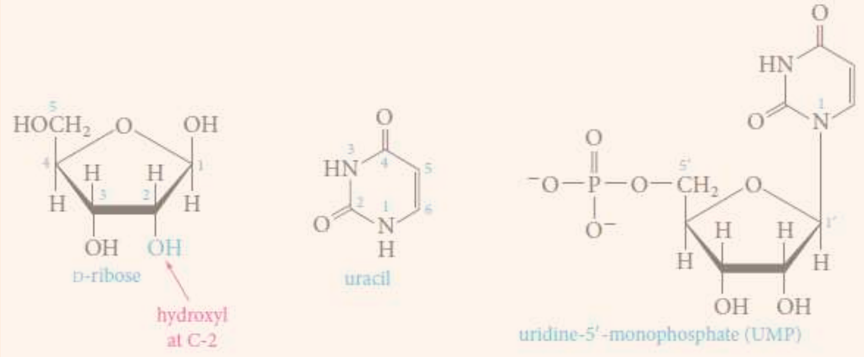
6. There is no restriction on the sequence of bases along a polynucleotide chain. The exact sequence carries the genetic information.

❖ Ribonucleic Acid (RNA)

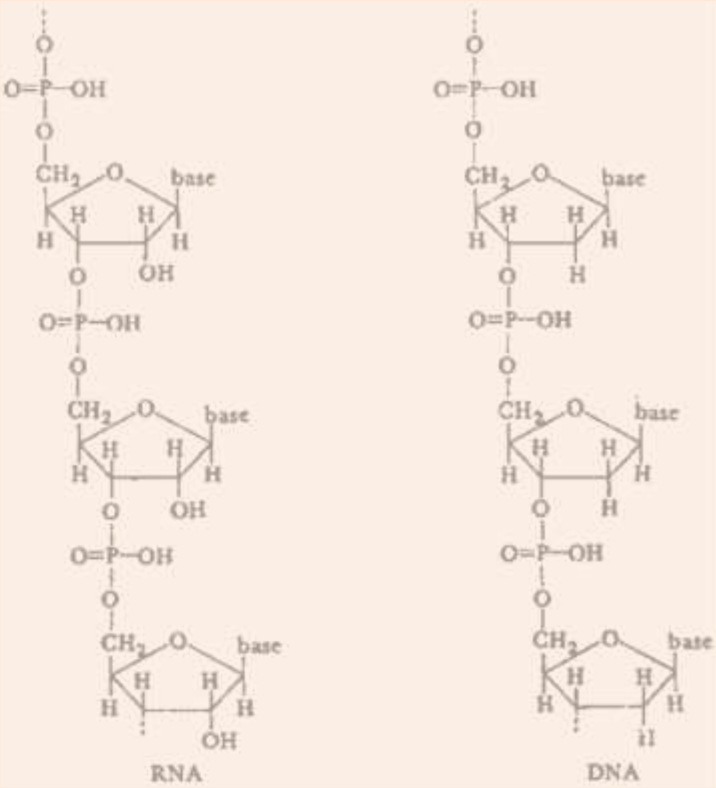
(1) The sugar is D-ribose;

(2) Uracil replaces thymine as one of the four heterocyclic bases; and

(3) Most RNA molecules are single stranded, although helical regions may be present by looping of the chain back on itself.



- The transcription product of DNA is always single-stranded RNA.



- The single strand generally assumes a right-handed helical conformation mainly caused by base-stacking interactions also present in the DNA.

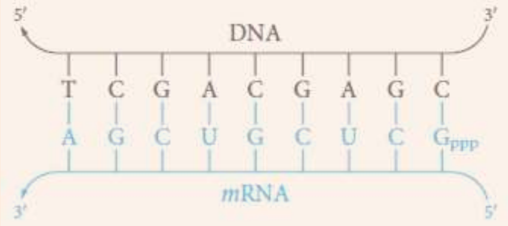
- The order of interaction is purine-purine >> purine-pyrimidine > pyrimidine-pyrimidine.
- The purine–purine interaction is so strong that a pyrimidine separating two purines is often displaced from the stacking order to allow the interaction between the two purines to occur.
- Base paring is similar to that of the DNA except that uracil generally replaces thymine.
- For coupled RNA the two strands are antiparallel as in DNA.
- Where complementary sequences are present, the predominant double-stranded structure is an A form right-handed double helix.
- Many RNAs are combinations of complementary two-stranded helices, single-stranded segments, as well as other complex structures.

Major types of RNA

Cells contain three major types of RNA.

1) Messenger RNA (mRNA)

- mRNA varies greatly in size from about 75 units to over 3000 nucleotide units giving a molecular weight of 25,000 to one million.
- It is present at a percentage of about 5% of the total RNA in a cell.
- mRNA is involved in transcription of the genetic code and is the template for protein synthesis.
- There is a specific mRNA for every protein synthesized by the cell.
- The base sequence of mRNA is complementary to the base sequence in a single strand of DNA, with U replacing T as the
- complement of A.



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2) Transfer RNA (tRNA)

- tRNA has about 73–94 nucleotides with a corresponding molecular weight range of 23,000–30,000.
- It is present in the cell at a level of about 15%.
- tRNA carries amino acids in an activated form to the ribosome for peptide bond formation, in a sequence determined by the mRNA template.
- Each tRNA has a three-base sequence, C-C-A, at the 3' hydroxyl end, where the amino acid is attached as an ester.

3) Ribosomal RNA (rRNA)

- It comprises about 80% of the total cellular RNA (tRNA = 15%, mRNA = 5%) and is the main component of the ribosomes.
- Its molecular weight is large, and each molecule may contain several thousand nucleotide units.
- rRNA is a part of the protein synthesizing machinery of cells, ribosomes.

Questions

1- What is the difference between proteins and peptides in terms of chemical structure and biological function

2- Mention one method for preparing phenylalanine:

3- Define carbohydrates and state their appropriate classes

4- What is the difference between the following sugars in terms of its chemical structure:

glucose, fructose, maltose, sucrose, and lactose

5- Explain the following items.

.A) The cyclic structure of glucose

.b) Oxidation of monosaccharides

C) Stereoform of monosaccharide carbohydrates

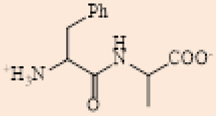
6- How do you prove that hexose has a ring structure

7- Choose the correct answer for each of the following Questions.

1. Which of the following sugars consist of the *a*-glycosidic bond?
   A) Maltose B) Cellulose C) Lactose D) Cellobiose

2. The monomeric unit of nucleic acid is called ....
   A) Nucleotides B) Nucleosides C) Pyrimidines D) Purines

3. The following peptide structure



   is consisted of ......
   A) Phe–Gly B) Phe-Phe C) Phe-Ala D) Ala-Ala

4. A nucleotide consists of ....
   A) sugar, base and phosphate B) sugar and phosphate
   C) sugar and base D) sugar, base and sulfate

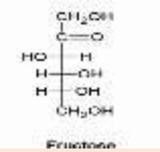
5. Which of the following sugars contain *a*--linkage:
   a) Maltose b) Cellulose c) Lactose d) Cellobiose

6. The relationship between α–D-glucose and its β-isomer is......
   A) Enantiomeric B) Epimeric C) Geometric D) Anomeric

7. The reaction of *D*-glucose with $NaBH_4$ will result in forming of…

A) *D*-Mannitol B) *D*-Glucitol C) *D*-Gluconic acid D) *D*-Glucaric acid

8. The number of optical isomers that would be obtained from *D*-Fructose is…



Fructose

A) 3 B) 6 **C)** 8 D) 16

9. The name of sugar that would obtain D- galactose and D-glucose upon hydrolysis is..

A) *D*-Sucrose B*)* *D*-Maltose C) Amylose D) *D*-Lactose

10. The simplest amino acid among the following is…...

A) Glycine B) Alanine C) Asparagine D) Tyrosine

11. The naturally occurring proteins consist of….

D-amino acids B) *L*-amino acids D) both A and B D) Amylose

12. monosaccharide obtained by the complete hydrolysis of starch.

A) Maltose B) D-glucose C) Cellobiose D) D-galactose

13. Which of the following sugars consist of the *a*-glycosidic bond?

A) Lactose B) Cellulose C) Starch D) Cellobiose

14. Nucleotides can be hydrolyzed to nucleosides and phosphoric acid by:-

A) nitration B) oxidation C) reduction D) aqueous base

17. Equimolar amounts of D-galactose and D-glucose would be obtained from hydrolysis of:-

A) *D*-Sucrose B*)* *D*-Maltose C) Amylose D) *D*-Lactose

18. The following compound is classified as…

A) lactone B) ester C) acid anhydride D) carboxylic acid

REFRENCES

1- The main reference is the lectures related to the health sciences course in the Chemistry Department king Saud University.
2- Basics Of Organic Chemistry by Altheyab Salem (in Arabic) Ch.13 & ch.14