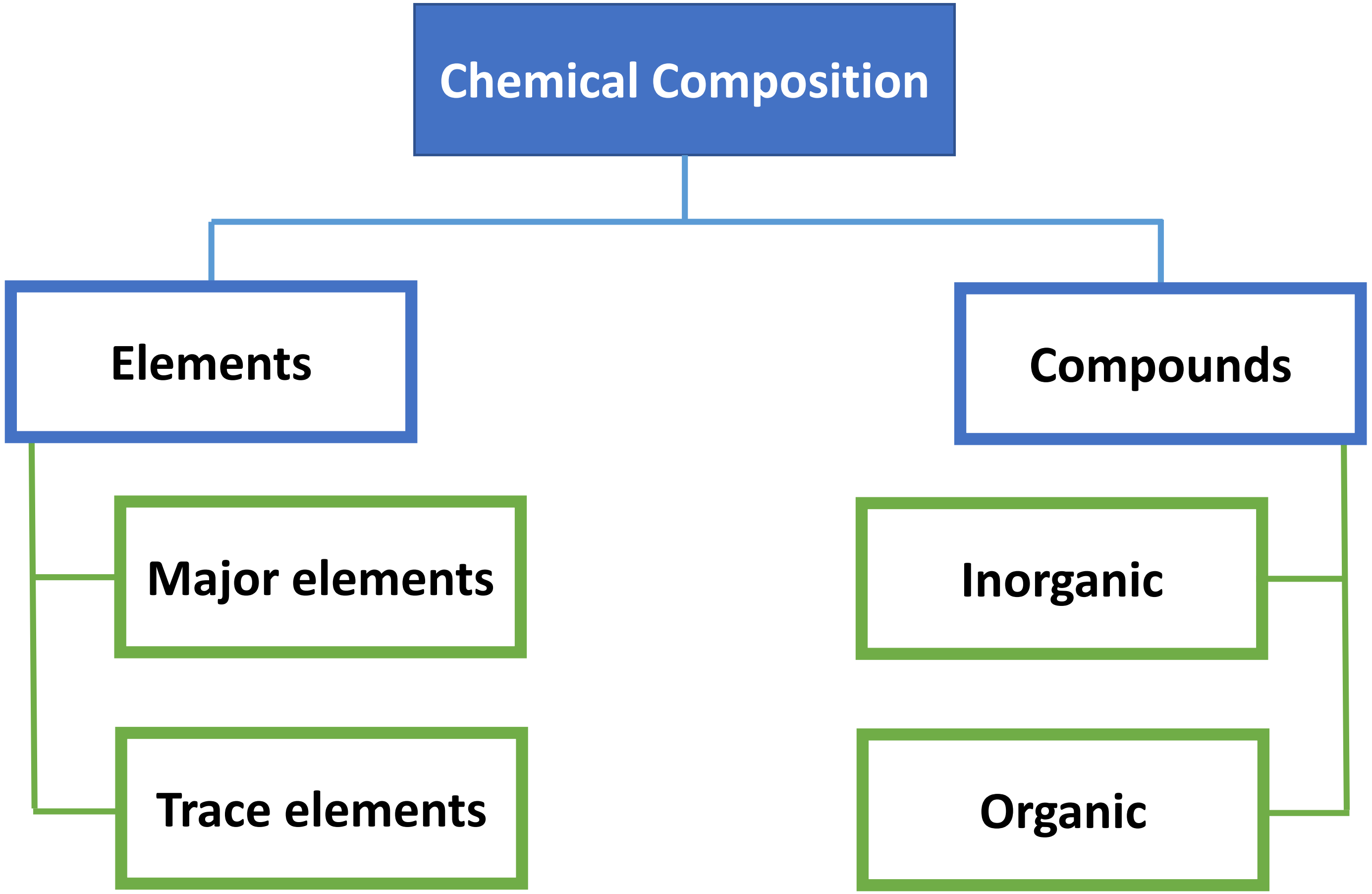
Cell Biology

Chapter 2: Chemical components of the cell

- Elements, H_2O and ions
- Carbohydrates
- Lipids
- Proteins
- Nucleic acids

Chemical composition of the cell

- All cells are composed of chemical components from both inorganic and organic substances that perform the same general functions.



Chemical composition of the cell

I. Elements and ions

- An element is a pure substance which consists of only one kind of atom.
- An ion is an electrically charged atom formed when atoms gain or lose electrons.

a. Major elements and ions

- Carbon (C), oxygen (O), hydrogen (H), nitrogen (N) calcium (Ca) and phosphorus are the most common elements in the cell.

- Carbon, oxygen, hydrogen, nitrogen, phosphorus, and calcium normally make up more than 99% of the mass of living cells.

- They are initially utilized in the synthesis of building units that are used in the construction of inorganic molecules and organic macromolecules.

Chemical composition of the cell

Element/ion	Function
Carbon (C)	Backbone of organic molecules: carbohydrates, proteins, lipids and nucleic acids
Oxygen (O)	- Main component of water (H2O). - Required for cellular respiration. - Required for synthesis of organic molecules: carbohydrates, proteins, lipids and nucleic acids
Hydrogen (H)	- Main component of water (H2O). - Required for synthesis of organic molecules: carbohydrates, proteins, lipids and nucleic acids
Nitrogen (N)	Required for synthesis of organic molecules: proteins, and nucleic acids
Calcium (Ca)	- Required for formation of bones and teeth. - Required for muscle contraction. - Required for blood clotting.
Phosphorus (P)	- Required for synthesis of phospholipids and nucleic acids. - Required for synthesis of ATP.

Chemical composition of the cell

b. Trace elements and ions

Element/ion	Function
Sodium (Na)	- Controls osmotic pressure in the cell. - Controls nerve function. - Controls blood pressure
Potassium (K)	- Required for muscle contractions. - Involves in nerve function. - Required for activation of some enzymes
Sulfur (S)	- Required for synthesis of proteins and vitamins
Iron (Fe)	- Important component of hemoglobin in red blood cells. - Involves in respiration process.

Chemical composition of the cell

II. Compounds

- A compound is a substance which consists of two or more elements combined in a fixed ratio.

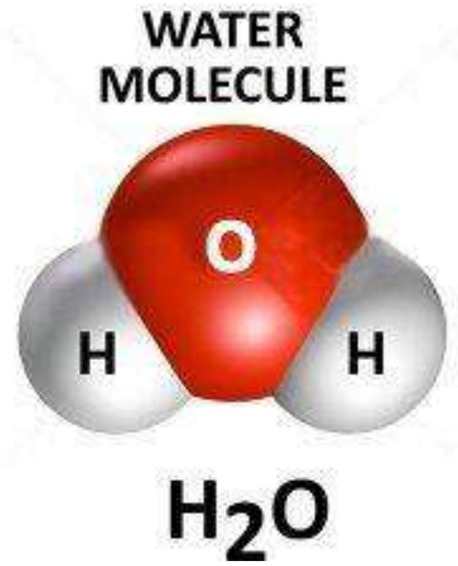
- Elements such as carbon, oxygen, hydrogen, nitrogen, sulfur and phosphorus combined with each other to form various chemical compounds in the cell.

- The chemical compounds can be divided into two types:

  a. Inorganic compounds which do not contain carbon (C): H_2O.

  b. Organic compounds which contain carbon (C): In general, there are four classes of macromolecules within living cells: carbohydrates, lipids, proteins, and nucleic acids.

Chemical composition of the cell



a. **Inorganic compounds:** **Water (H2O)**

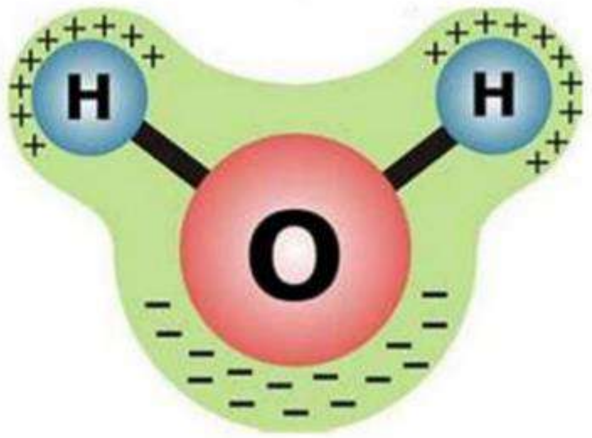
- It is the most abundant substance in the cell.
- It accounts for approximately 70% of the total weight of the cell.

Chemical composition of the cell

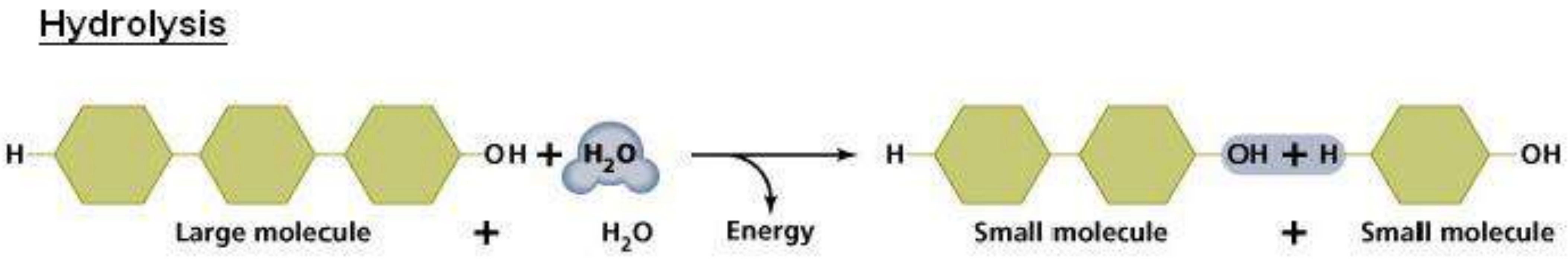
- Due to its chemical and physical properties, water has an important role in the life of organisms.

a. Chemical properties of water

1. Water is an excellent polar substance due to its positive and negative ends
   - Water is the principal solvent for many biological molecules
   - The majority of cell's chemical reactions take place in aqueous solution
   - It acts as a transport medium (blood, lymphatic and excretory systems)



2. Water provides hydrogen (H+) and hydroxyl (OH-) ions so, it is considered as the best reagent for many metabolic cell activities.



Chemical composition of the cell

b. Physical properties of water

1. Water has a high heat capacity

- **Heat capacity is the amount of heat that must be absorbed or lost by 1 gram of a substance to change its temperature 1 degree.**

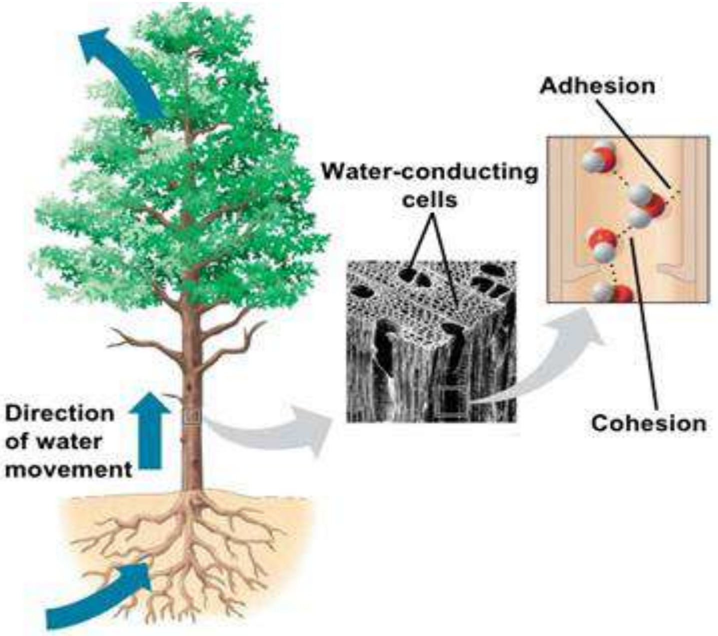
- **Water is considered as a protective agent by maintaining a constant body temperature because it can absorb large amount of heat with only a slight change in its temperature due its ability to form hydrogen bonds.**

2. Water has a high heat of vaporization

- **The amount of heat required to change 1 gram of water (liquid) to vapor (gas).**

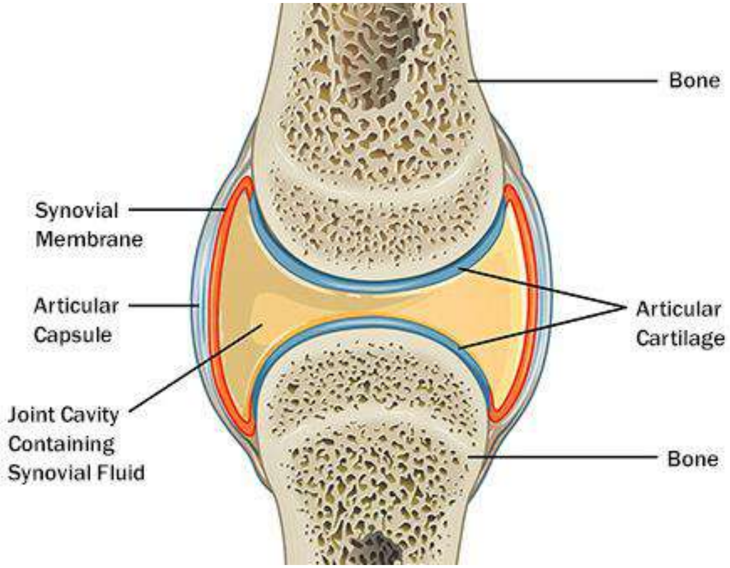
- **Water has a good cooling effect by removing a large amount of heat from many organisms by sweating process.**

Chemical composition of the cell



3. The strong cohesive force between water molecules themselves and the strong adhesion force between water molecules and others help the plants to absorb water from soil and play a very important role in the transport of water.

4. The high density of water enables ice to float on water, which saves the lives of many aquatic organisms.



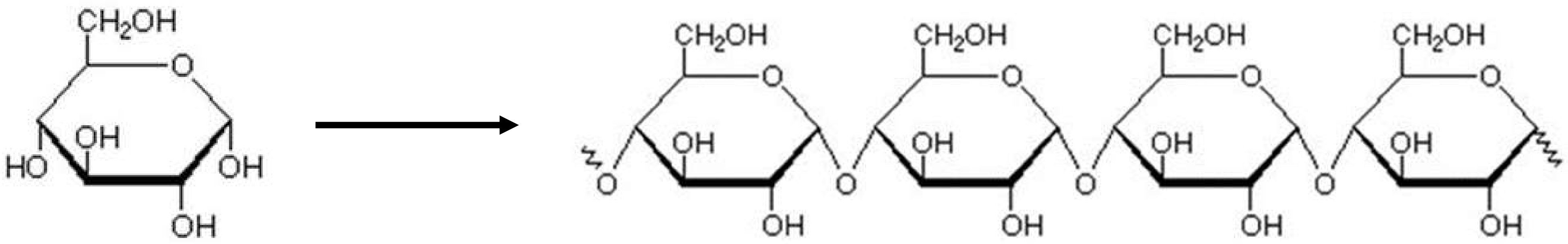
5. The low viscosity of water allows its rapid movement into and throughout cells. Moreover it makes water a useful lubricant to reduce friction in places with constant movement, e.g. synovial fluid.

Chemical composition of the cell

b. Organic compounds

- Most of biological organic compounds in the cell are macromolecules which are classified into four major categories: carbohydrates, proteins, lipids and nucleic acids.

- Macromolecules are polymers consisting of many similar chemical subunits called monomers linked together by covalent bonds.



monomer polymer

- Three of the four biological macromolecules are polymers: carbohydrates, proteins and nucleic acids.

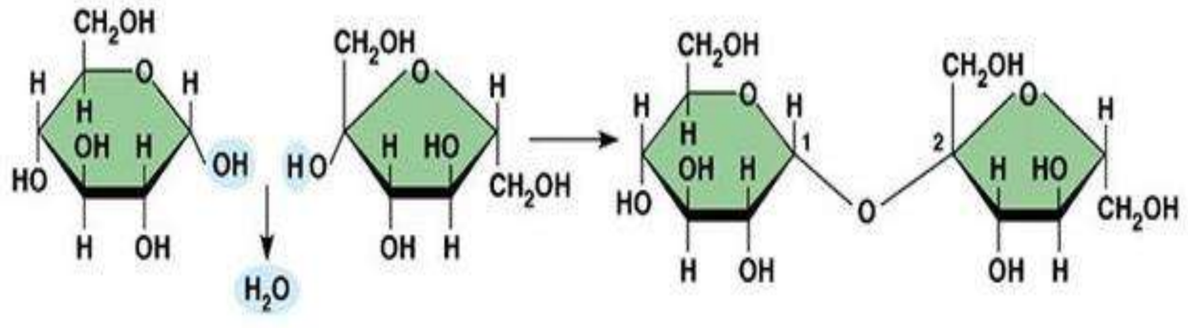
Chemical composition of the cell

- Although the four categories of macromolecules contain different kinds of subunits, they are synthesized in the same way: condensation reaction (dehydration reaction).

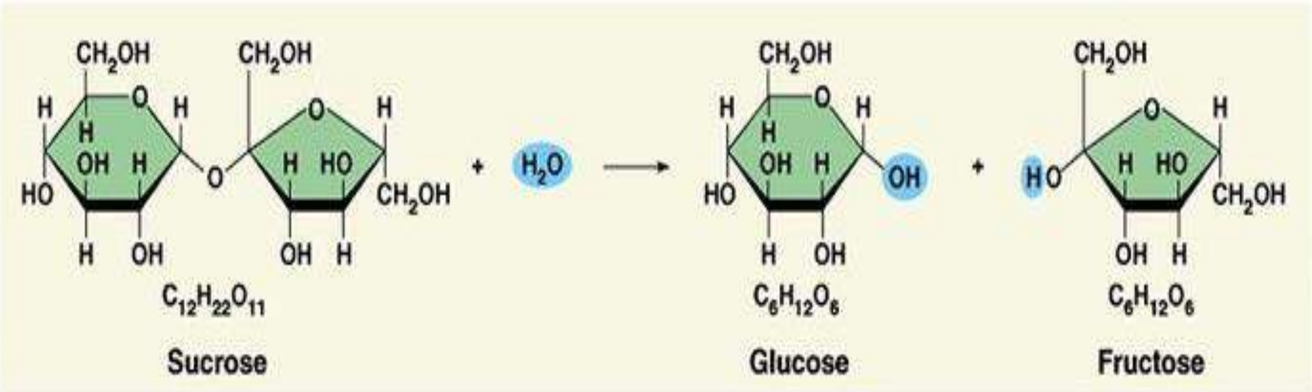
- Dehydration reaction is the releasing of water molecule to form a covalent bond: hydrogen atom from one subunit and hydroxyl ion from the other.

- All macromolecules are broken-down in the same way by hydrolysis reaction: addition of water molecule.

- dehydration synthesis



- hydrolysis



Chemical composition of the cell

1. Carbohydrates

- Carbohydrates are group of organic compounds containing carbon, hydrogen and oxygen. The ratio of H:O atoms is usually 2:1 as in water.
- Its general formula is $C_x(H_2O)_y$.

Role of carbohydrates in the cell

- Main source of energy.
- Act as a storage material: starch and glycogen.
- Act as structural material: cellulose and chitin.

Chemical composition of the cell

Classification of carbohydrates

1. Monosaccharides

- **They are the simplest form of carbohydrates because they cannot be hydrolyzed (broken down) into any simpler carbohydrates.**

- **They contain carbon, hydrogen and oxygen in a ratio 1:2:1, where the general formula is $(CH_2O)n$.**

- **They contain hydroxyl group (OH) at each carbon atom except one which is a carbonyl group.**

- **Monosaccharides are classified by:**

a. Number of carbon atoms

- **When n =5, it is called 5-carbon sugars (pentoses) $(CH_2O)_5$; $C_5H_{10}O_5$; e.g. ribose and ribulose.**

- **When n = 6, 6-carbon sugars (hexoses) $(CH_2O)_6$; $C_6H_{12}O_6$; e.g. glucose, fructose, galactose.**

Chemical composition of the cell

b. Location of carbonyl group

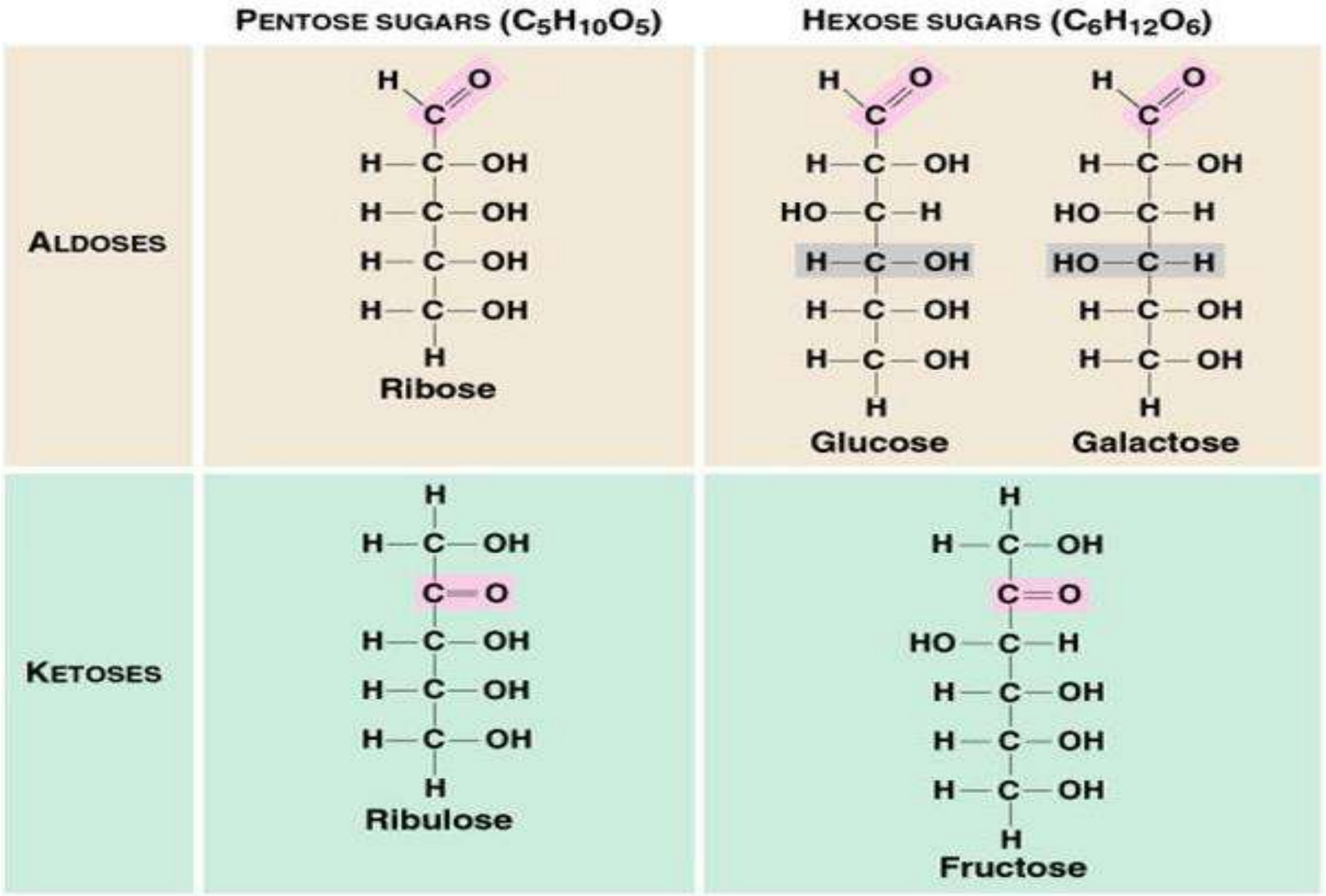
- If the carbonyl group is the first carbon atom, it is aldehyde group and the monosaccharide is called aldose: ribose, glucose and galactose.

- If the carbonyl group is the second carbon atom, it is ketone group and the monosaccharide is called ketose: ribulose and fructose.

Chemical composition of the cell

Chemical structure of monosaccharides

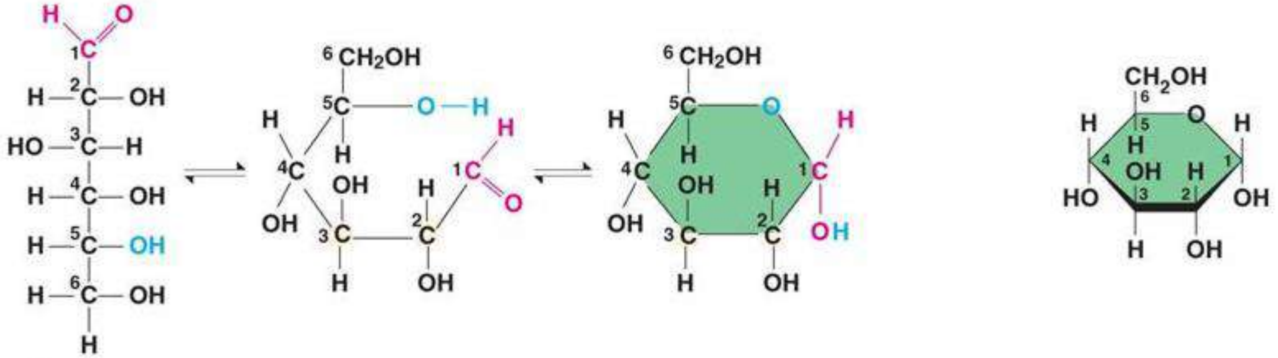
1. Linear form

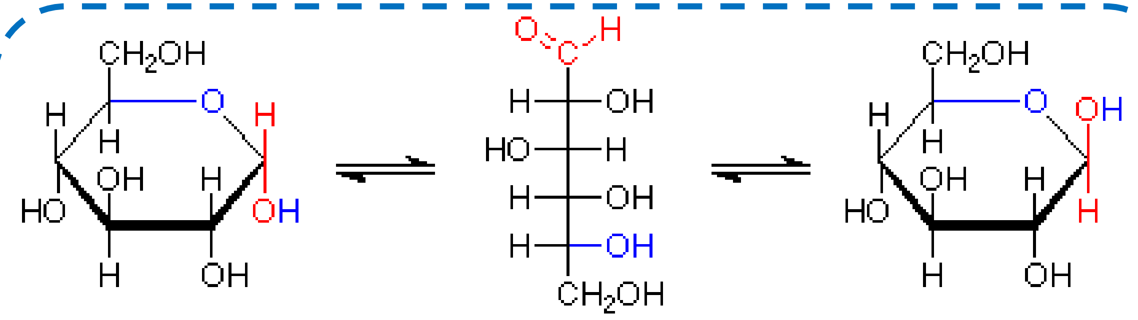


Chemical composition of the cell

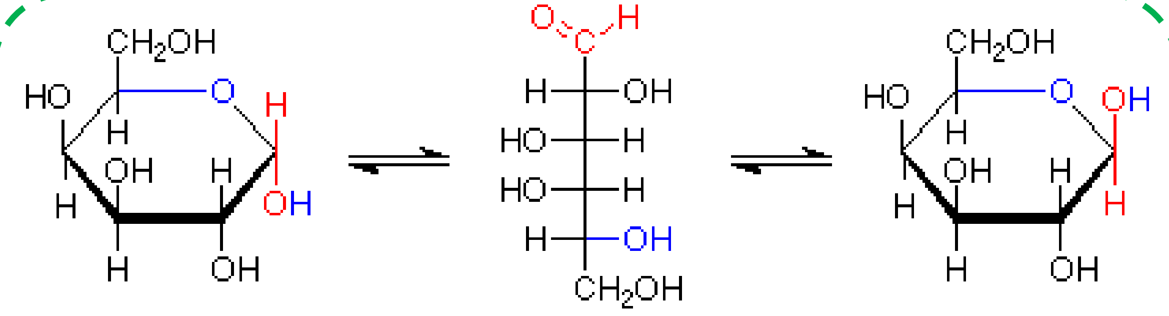
Chemical structure of monosaccharides

2. Ring form

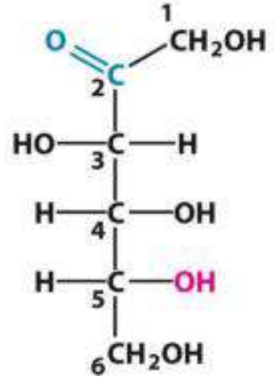




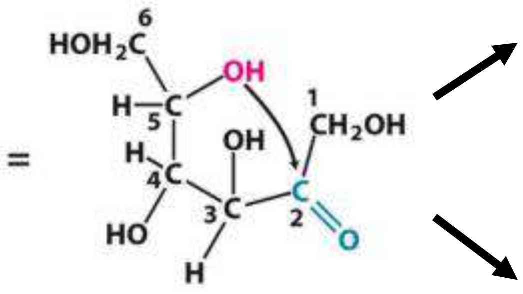
α-glucose **glucose** **β-glucose**

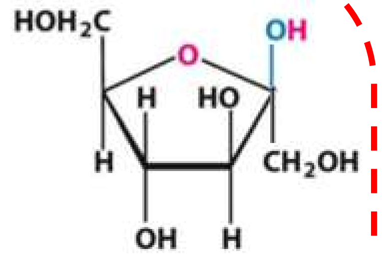


α-galactose **galactose** **β -galactose**

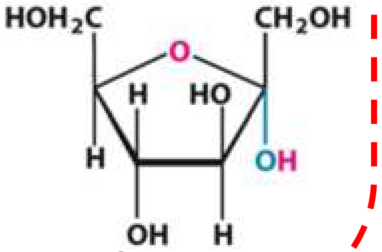


fructose





β -fructose



α-fructose

Chemical composition of the cell

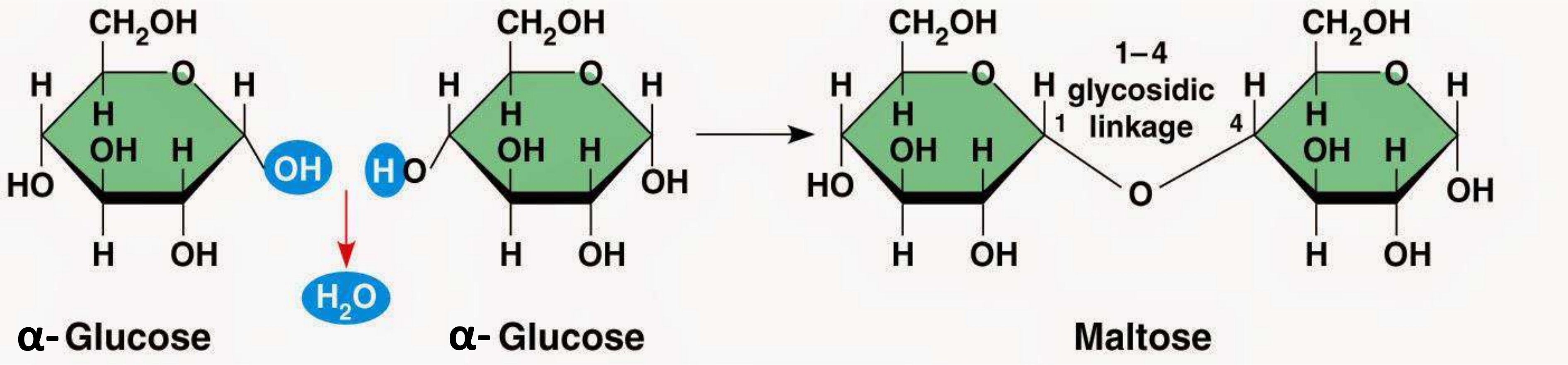
2. Disaccharides

- Disaccharides are formed by two monosaccharide units combining together with the elimination of water molecule (dehydration reaction).

- The two monosaccharides are joined by a covalent bond, called glycosidic bond.

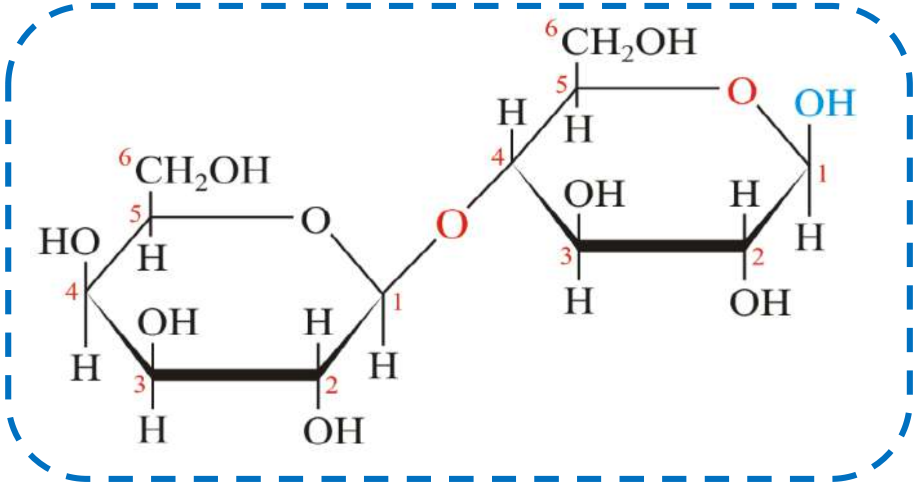
- Examples:

  - Maltose (malt sugar): α-glucose + α-glucose (1-4 glycosidic bond)

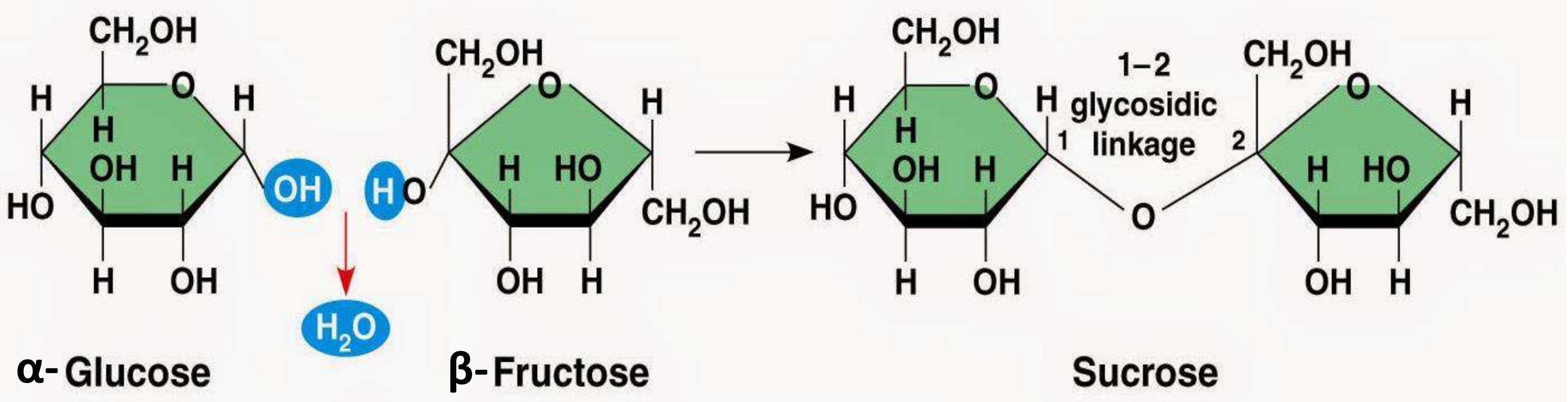


Chemical composition of the cell

- **Examples:**
  - **Lactose (milk sugar): β-glucose + β-galactose (1-4 glycosidic bond)**



  - **Sucrose (table sugar): α-glucose + β-fructose (1-2 glycosidic bond)**



Chemical composition of the cell

2. Polysaccharides

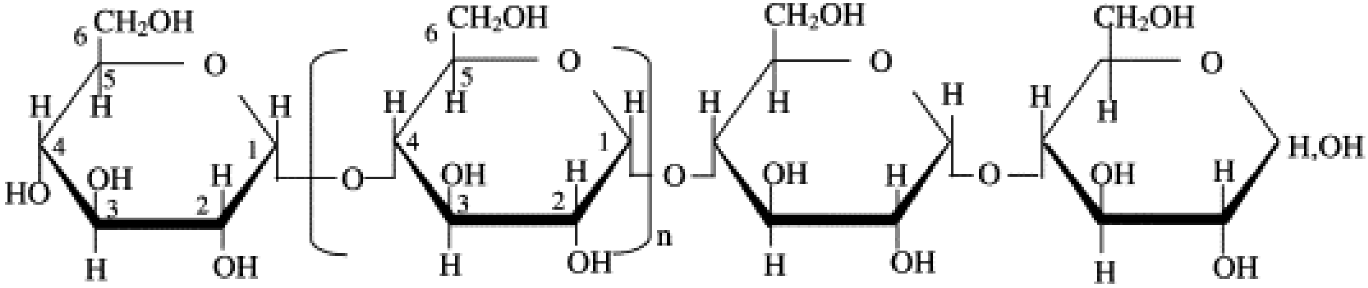
- Polysaccharides are long polymers of monosaccharide units joined by glycosidic bond.
- Examples:

a. Storage polysaccharides: Starch and glycogen

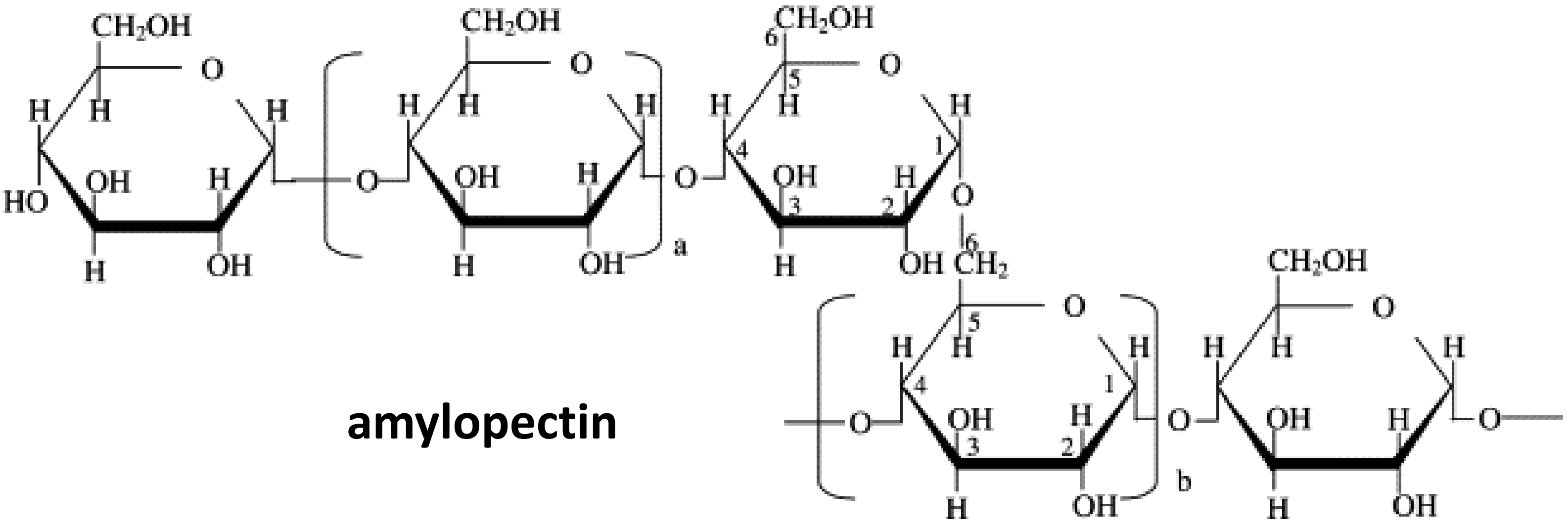
- Starch
    - It is the storage polysaccharide in plant which is stored in plastids.
    - It consists of long chain of α-glucose
    - It consists of 20-30% amylose and 70-80% amylopectin.
    - Amylose is an unbranched chain of α-glucose units linked by α-1,4-glycosidic bonds.
    - Amylopectin is a branched molecule contains α-glucose units with both α-1,4-glycosidic and α-1,6-glycosidic bonds.
    - Enzymes can hydrolyze starch into monosaccharide units (glucose)in hydrolysis reaction and using them as a nutrient for cells.

Chemical composition of the cell

- **Chemical structure of starch**



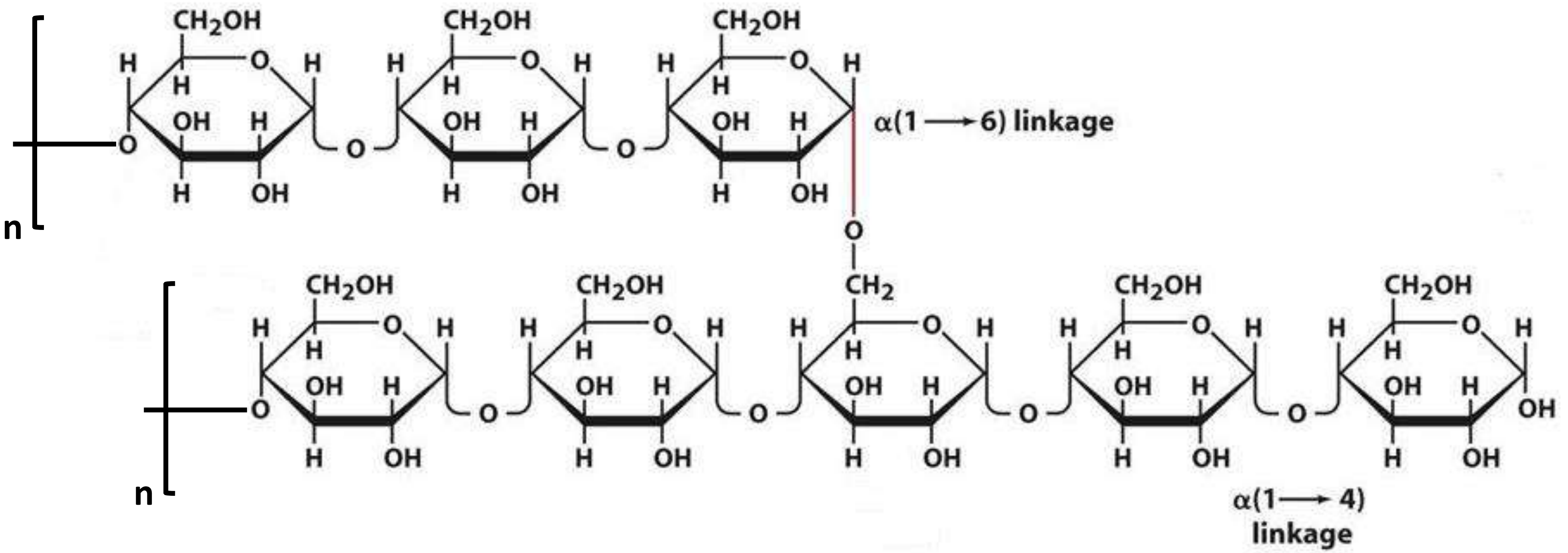
amylose



amylopectin

Chemical composition of the cell

- **Glycogen**
  - It is the storage polysaccharide in humans and animals which is stored in muscles and liver.
  - It is a branched molecule consisting of long chain of α-glucose linked by α-1-4 or 1-6 α-glycosidic bonds. (like amylopectin)

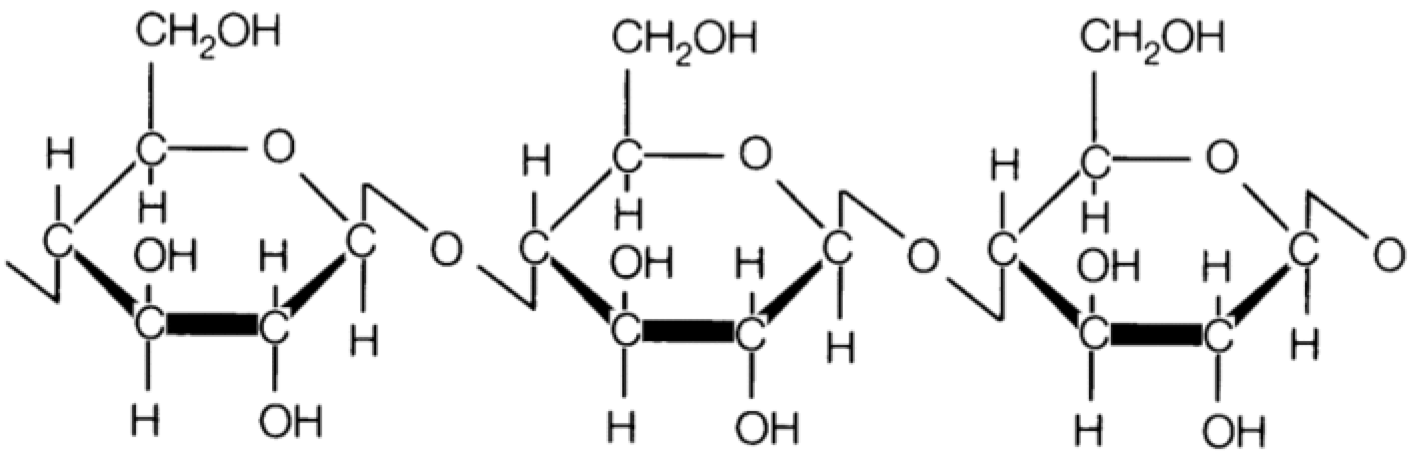


Glycogen

Chemical composition of the cell

b. Structural polysaccharides: Cellulose

- **Cellulose**
  - **It is the main component of plant cell wall.**
  - **It is a polymer of long unbranched chains of β- glucose molecules linked by β-1-4 glycosidic bonds.**
  - **Enzymes that hydrolyze starch are unable to hydrolyze β-1-4 glycosidic bonds into monosaccharide units (glucose).**
  - **Some animals can digest cellulose by specific enzymes secreted from their intestinal bacteria.**



Cellulose

Chemical composition of the cell

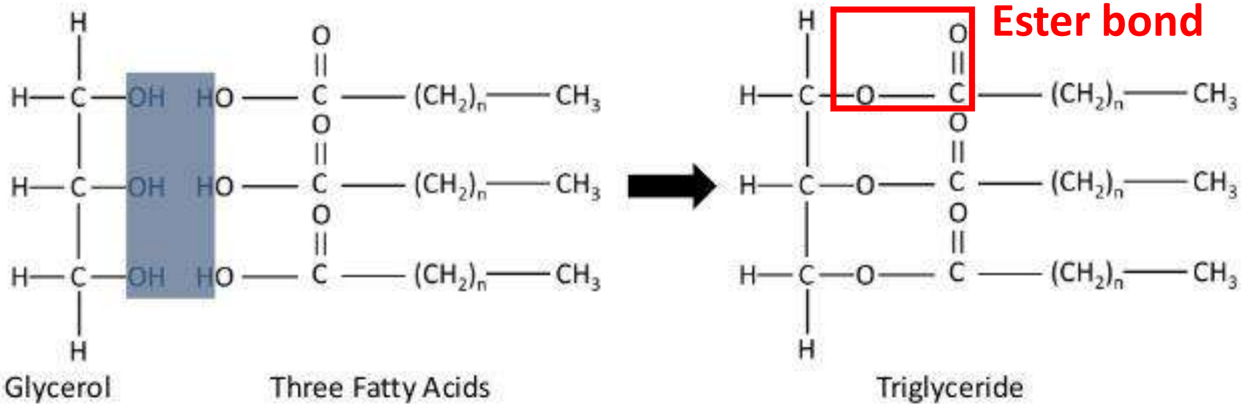
2. Lipids

- Lipids are group of organic compounds containing carbon, hydrogen and oxygen.
- Lipids are esters of fatty acids and an alcohol.

Role of lipids in the cell

- Main component of plasma membrane: phospholipids.
- Source of energy.
- Act as a storage material: triglycerides.
- Required for synthesis of some hormones and vitamins: steroids.
- Act as protective material: wax.

Condensation reaction between glycerol and fatty acids



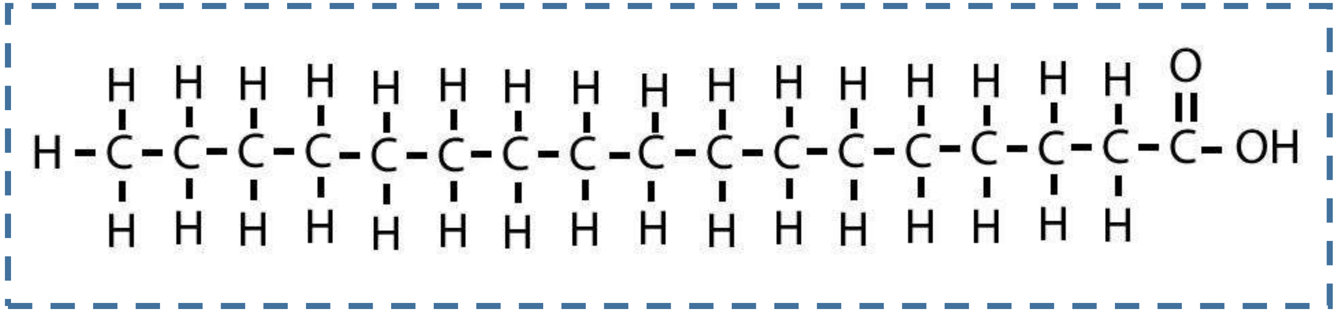
Hydrolysis is the reverse of this process, catalysed by lipase

+ $3H_2O$

Chemical composition of the cell

Fatty acids

- **Fatty acids are hydrocarbon chains with different length containing a carboxyl group (-COOH) at one end.**



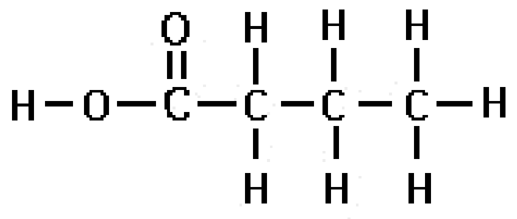
- **Fatty acids can be:**

a. Saturated fatty acids: no double bonds in their hydrocarbon chain. They have higher melting points and are solid at room temperature. Their source is animals.

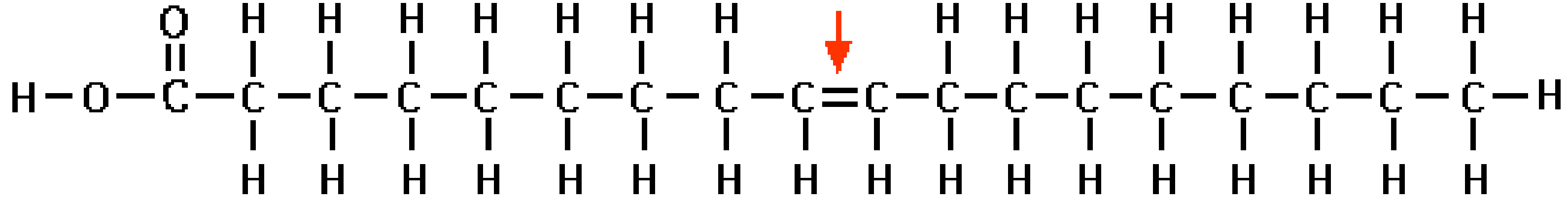
b. Unsaturated fatty acids: they contain one or more double bonds in their hydrocarbon chain. They have low melting point. They are oils or soft fats at room temperature. Their source is plants.

Chemical composition of the cell

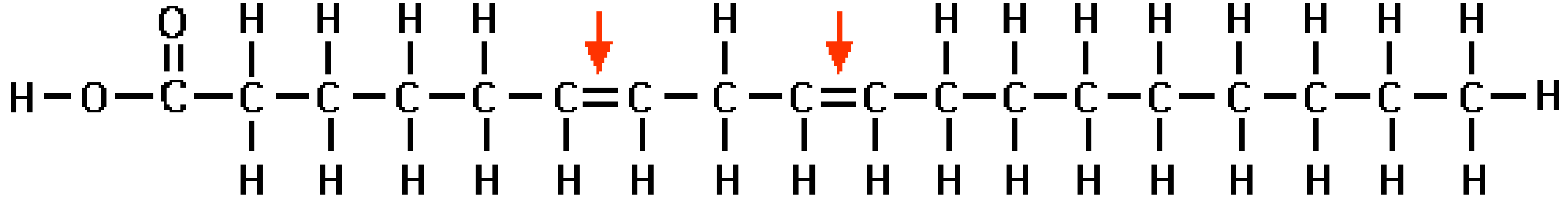
Examples of saturated and unsaturated fatty acids



Butyric Acid- Saturated Fatty Acid



Oleic Acid- Monounsaturated Fatty Acid



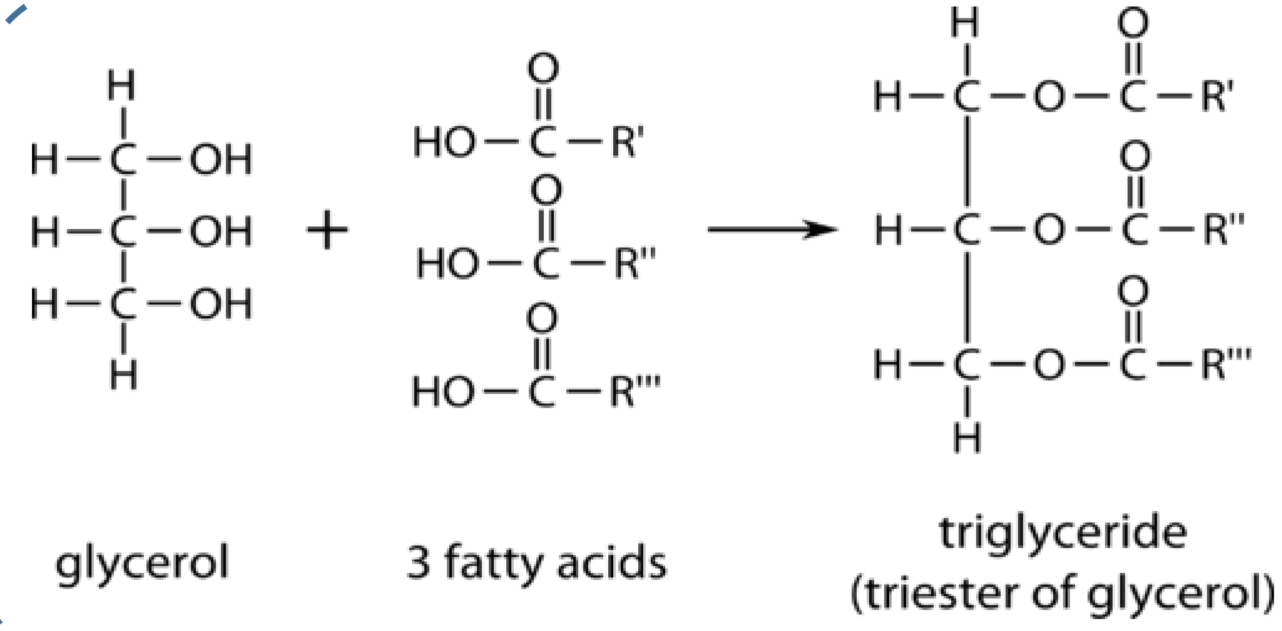
Linoleic Acid- Polyunsaturated Fatty Acid

Chemical composition of the cell

<u>Types of lipids</u>

1. Triglycerides

- **They are a simple form of lipids which are formed of one glycerol molecule and three fatty acids.**
- **They act as both energy source and energy store in animals.**

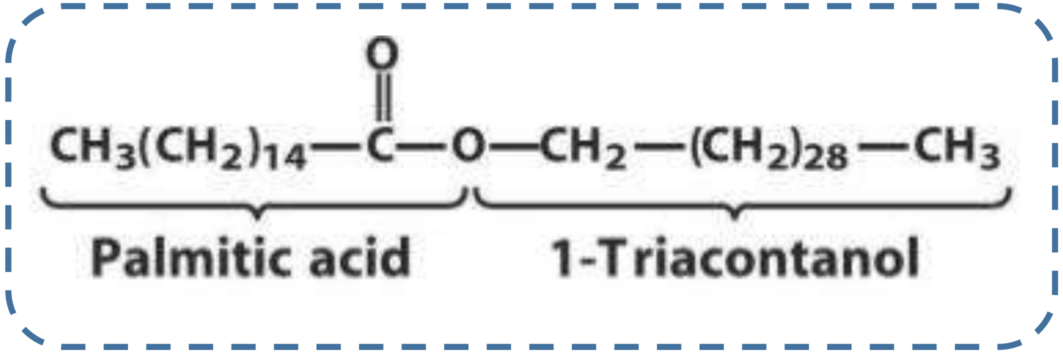


Chemical composition of the cell

<u>Types of lipids</u>

2. Waxes

- **They are a simple form of lipids which are formed of long chain monoalcohol and one long chain saturated fatty acids.**
- **They act as a protective layer in plants and animals.**



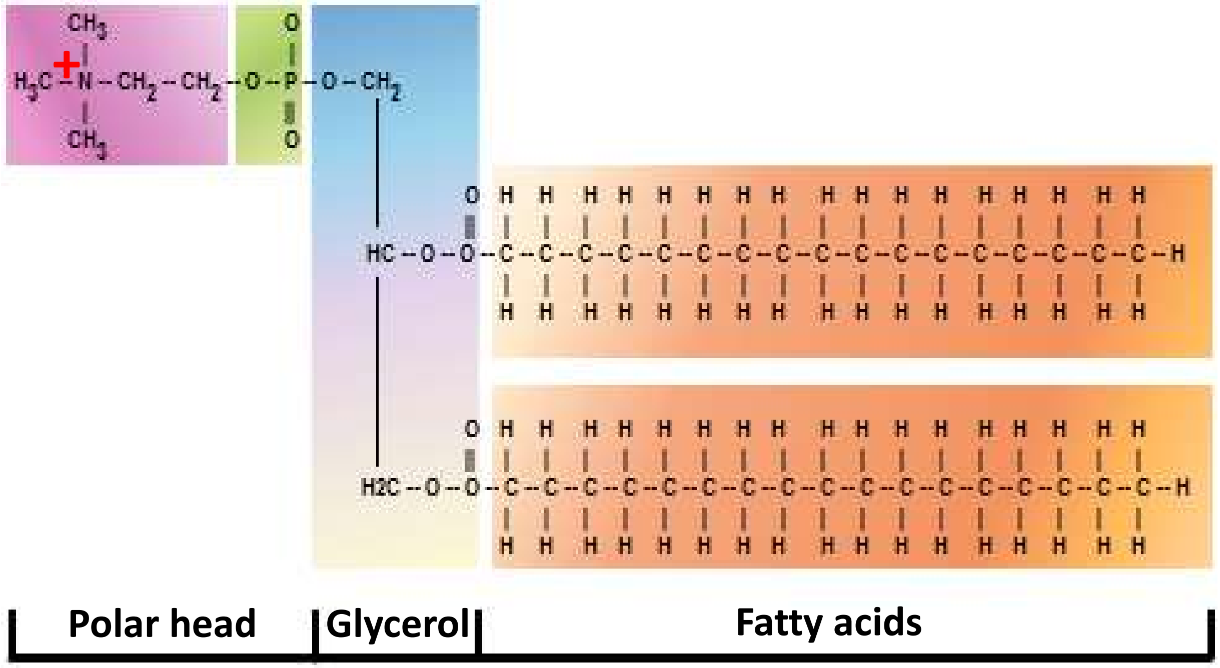
beeswax

Chemical composition of the cell

<u>Types of lipids</u>

3. Phospholipids

- They are a complex form of lipids.
- They are the main component of cell membranes.
- Their general structure is made of three subunits:
  a. Glycerol: hydrocarbon alcohol having 3 hydroxyl groups.
  b. Two fatty acids which are attached to two hydroxyl groups of glycerol.
  c. Phosphate group which is attached to one end of the glycerol. Usually a polar organic molecule binds with phosphate group to form a polar end.



(Hydrophilic head)

Non-polar head (Hydrophobic head)

Chemical composition of the cell

3. Proteins

- **Proteins are the most important macromolecules in the cell.**
- **Proteins are polymers of large number of smaller units called amino acids linked together with covalent bond called peptide bond.**

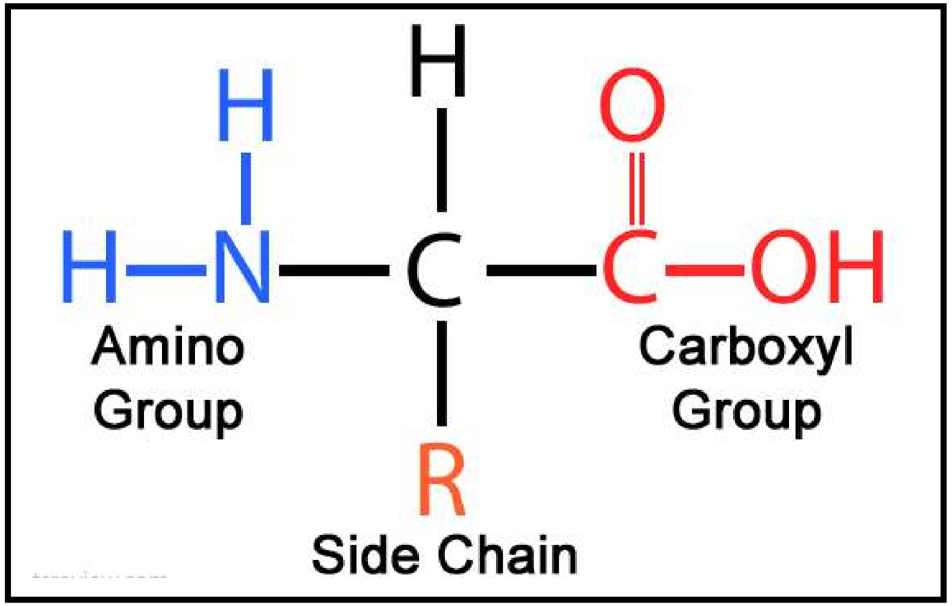
Role of proteins in the cell

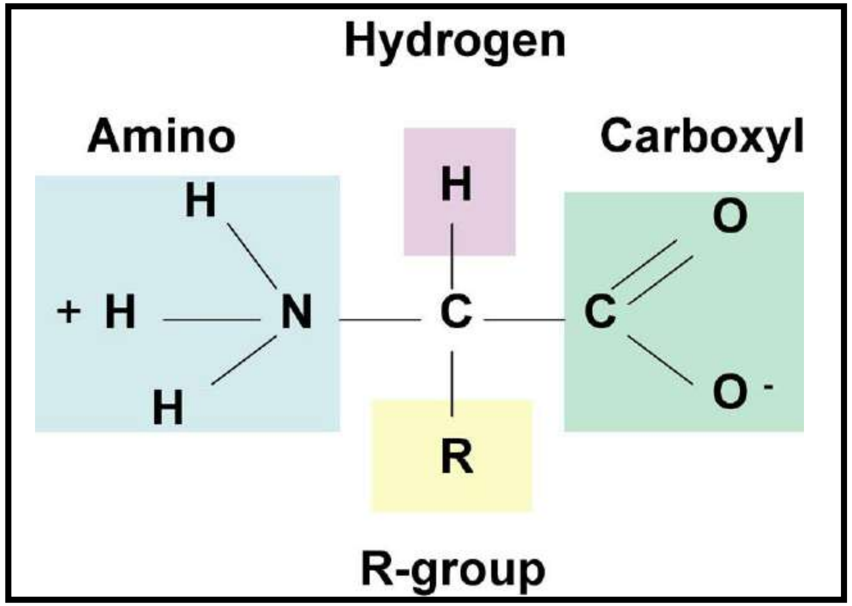
- **Structural components: collagen in cartilage, keratin in hair, actin in cytoskeleton**
- **Hormones: insulin, glucagon (regulation of glucose metabolism)**
- **Enzymes: most enzymes are proteins e.g. digestive enzymes**
- **Signaling: receptors and ligands**
- **Transport: cell membrane protein, haemoglobin**
- **Protection: antibodies involved in immune system**
- **Movement: actin, myosin (muscle contraction)**

Chemical composition of the cell

Amino acid

- **It is the building unit of proteins (monomer).**
- **It has a structural formula: NH_2-R-CH-COOH containing four basic structure bound to a central carbon atom:**
  - **Amine group (NH_2)**
  - **Carboxyl group (COOH)**
  - **Hydrogen atom**
  - **Side chain group (R group) specific to each amino acid**





Chemical composition of the cell

Classification of amino acids

- **There are about 20 different amino acids, and the body needs all of these amino acids, in varying degrees, to be healthy and fully functional.**
- **Amino acids (20) can be classified according to:**

1. Their synthesis by the cell

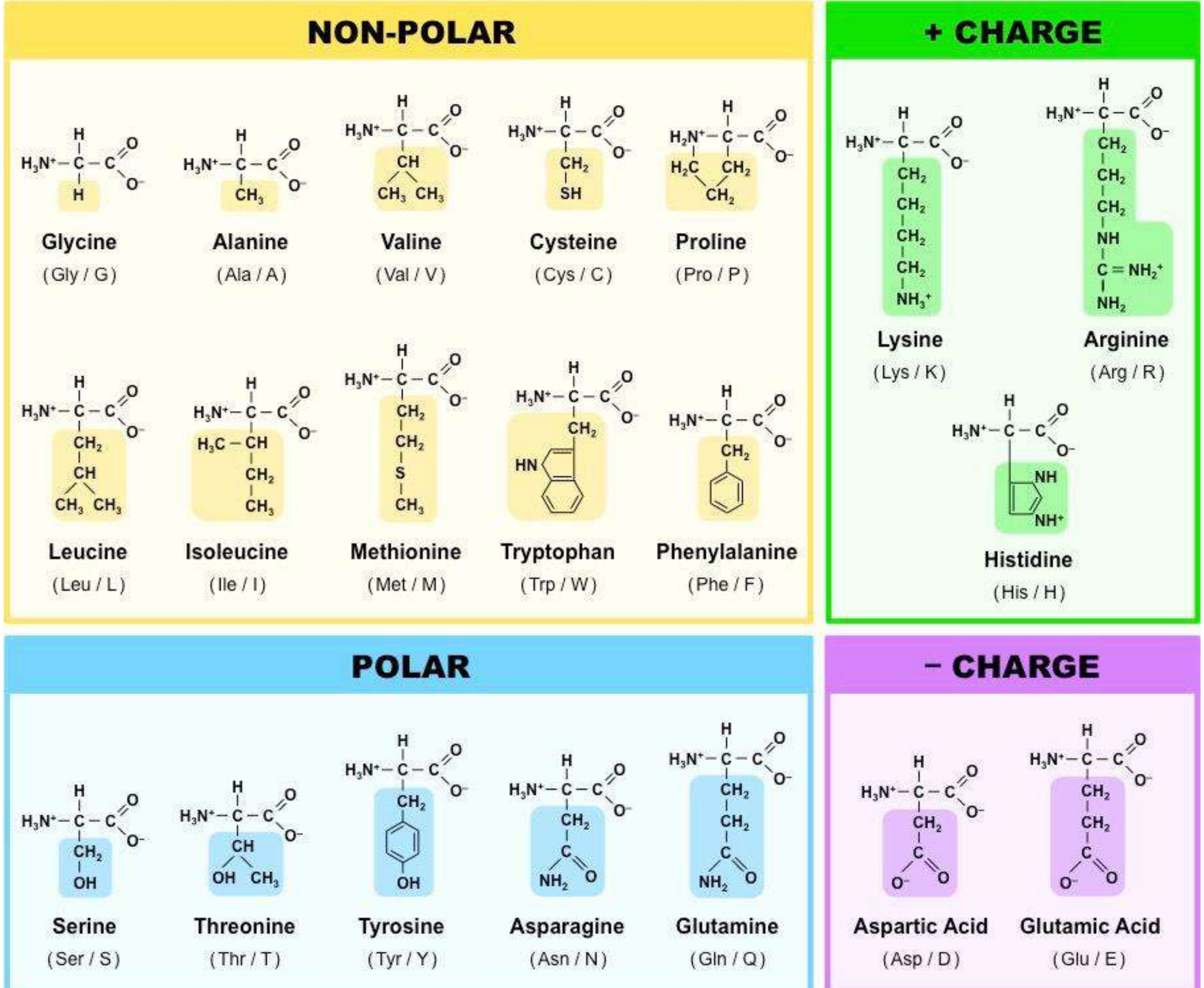
a. Essential amino acids

- **Amino acids which can’t be synthesized in the body, and they are (9) amino acids.**
- **So, they must be obtained from the food.**
- **lysine, methionine, valine, tryptophan, isoleucine, leucine, threonine, histidine and phenylalanine.**

b. Non-essential amino acids

- **Amino acids which can be synthesized in the body, and they are (11) amino acids.**
- **alanine, glycine, tyrosine, arginine, asparagine, aspartate, glutamine, glutamate, proline, serine, and cysteine.**

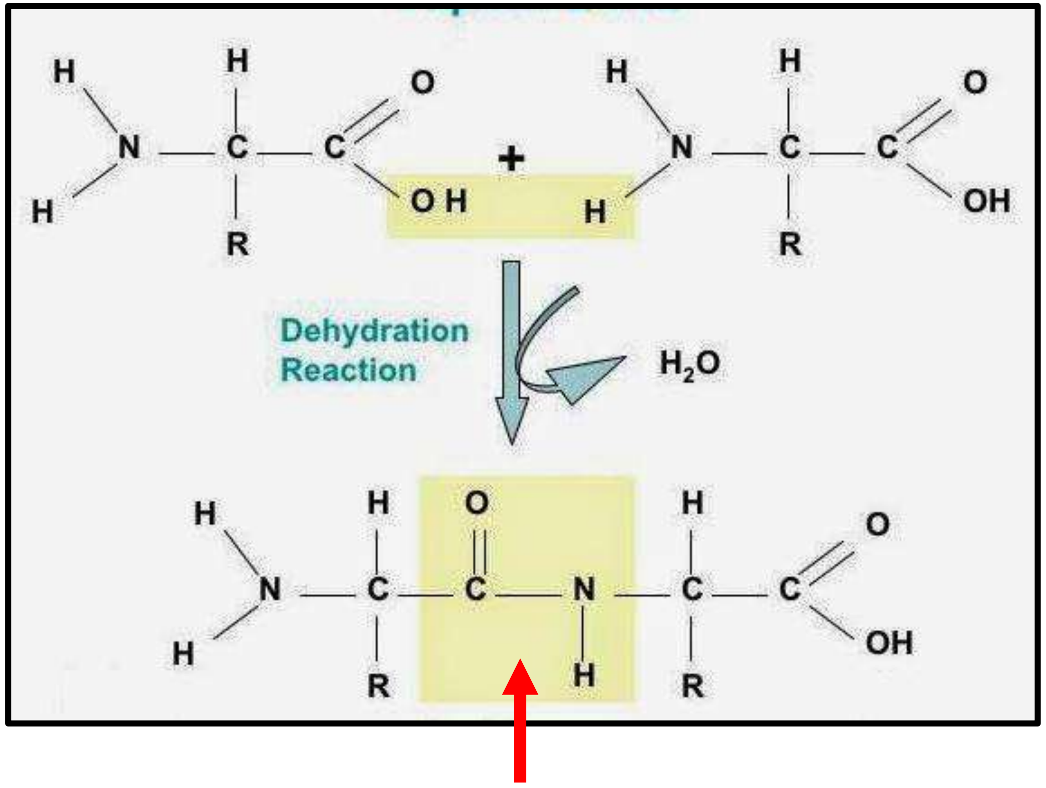
2. The chemical properties of side chain R group.



Chemical composition of the cell

Peptide bond

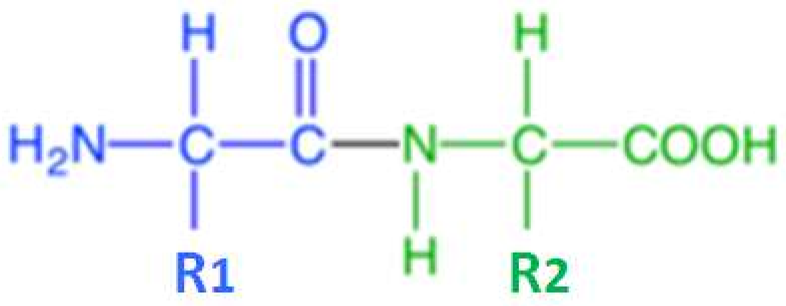
- Peptide bond is a covalent bond linking two amino acids from the carboxyl group of one amino acid with the amine group of the other amino acid, causing the release of a molecule of water (H_2O).



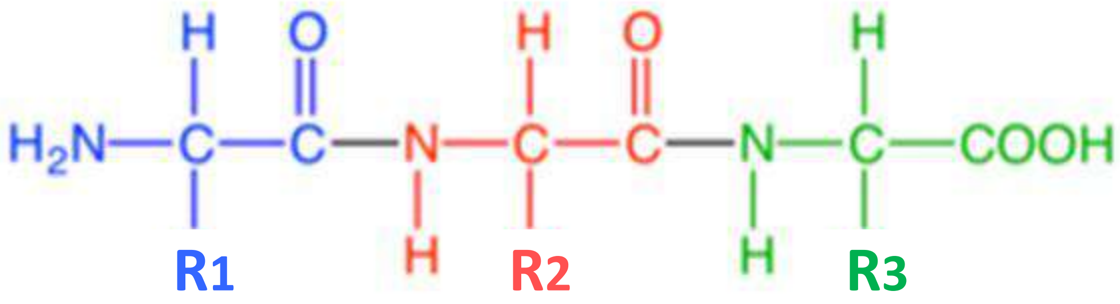
Chemical composition of the cell

- When two amino acids bind together by a peptide bond, the resulted molecule is called dipeptide.
- Tripeptide (three amino acids, two peptide bonds), tetrapeptide (four amino acids, three peptide bonds).
- So the protein is called polypeptide.

Dipeptide



Tripeptide



Chemical composition of the cell

Structural organization of proteins

- **Proteins differ from each other in the type, numbers and order of their constituent amino acids.**
- **Individual protein is determined by the sequence of amino acids including in its polypeptide chain, together with the shape of folding and cross-linkage.**

1. Primary structure

- **The primary structure of a protein is the linear sequence of amino acids in its molecule.**

2. Secondary structure

- **It is folding and twisting of the polypeptide chain to form a helix (α-helix) or sheets (β-sheets).**
- **It is due the interaction between the peptide bonds in the same protein by hydrogen bonds.**

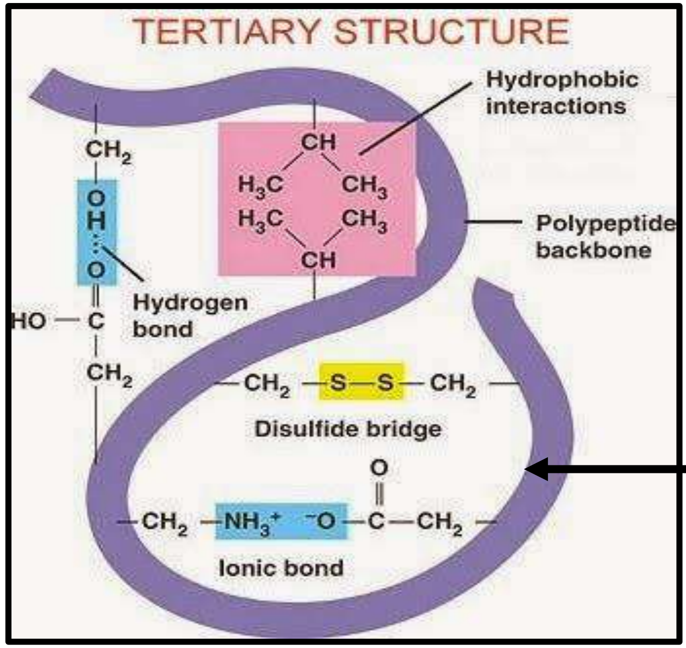
Chemical composition of the cell

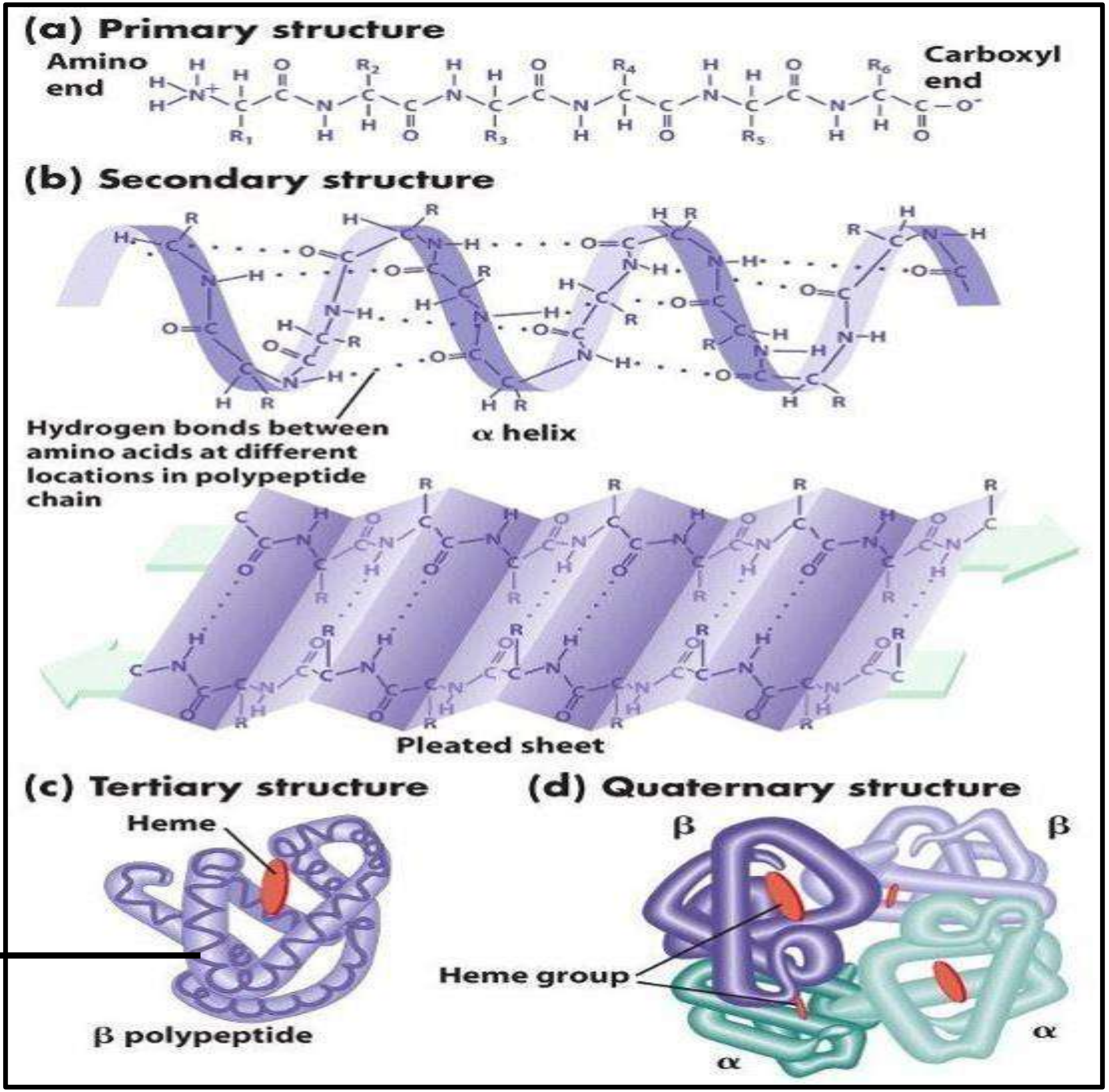
3. Tertiary structure

- **It is twisting of the polypeptide α-helix or β-sheets into a more complex structure.**
- **It is due the interaction between (R) side groups through different types of bonding (disulfide bond, ionic bond, hydrogen bond and hydrophobic interaction).**

4. Quaternary structure

- **It forms when two or more complex proteins (tertiary structure) associate together by the various forms of bonding to form a functional protein.**
- **An example is haemoglobin, which consists of four polypeptide chains – two α-chains and two β-chains**


TERTIARY STRUCTURE
Hydrophobic interactions
Polypeptide backbone
Hydrogen bond
Disulfide bridge
Ionic bond


(a) Primary structure
Amino end
Carboxyl end
(b) Secondary structure
Hydrogen bonds between amino acids at different locations in polypeptide chain
α helix
Pleated sheet
(c) Tertiary structure
Heme
β polypeptide
(d) Quaternary structure
β
β
Heme group
α
α

Chemical composition of the cell

Denaturation of protein

- **Both secondary and tertiary structure of proteins determine and maintain their shape.**

- **Protein shape can be changed based on the physical and chemical properties of the surrounding environment: PH, temperature, radiation and salt concentration**

- **The change in protein shape due to PH, temperature, radiation or salt concentration is called protein denaturation and leads to inactive protein.**

- **In protein denaturation, the amino acid sequence remains unaffected.**

Chemical composition of the cell

4. Nucleic acids

- **Nucleic acids are long macromolecules (polymers) built up of nucleotides (monomers) linked together by phosphodiester bond.**

- **Nucleic acids are also called polynucleotide molecules.**

- **Two types of nucleic acid are found in living cells:**
  a. Deoxyribonucleic acid (DNA)

  - **Present in the nucleus which contains the genetic information used in the development and functioning of all known living organisms.**
  - **The DNA segments carrying this genetic information are called genes.**

  b. Ribonucleic acid (RNA)

  - **Some of RNA is present in the nucleus, but the majority in cytoplasm.**

  - **RNA functions in converting genetic information from genes into the amino acid sequences of proteins.**

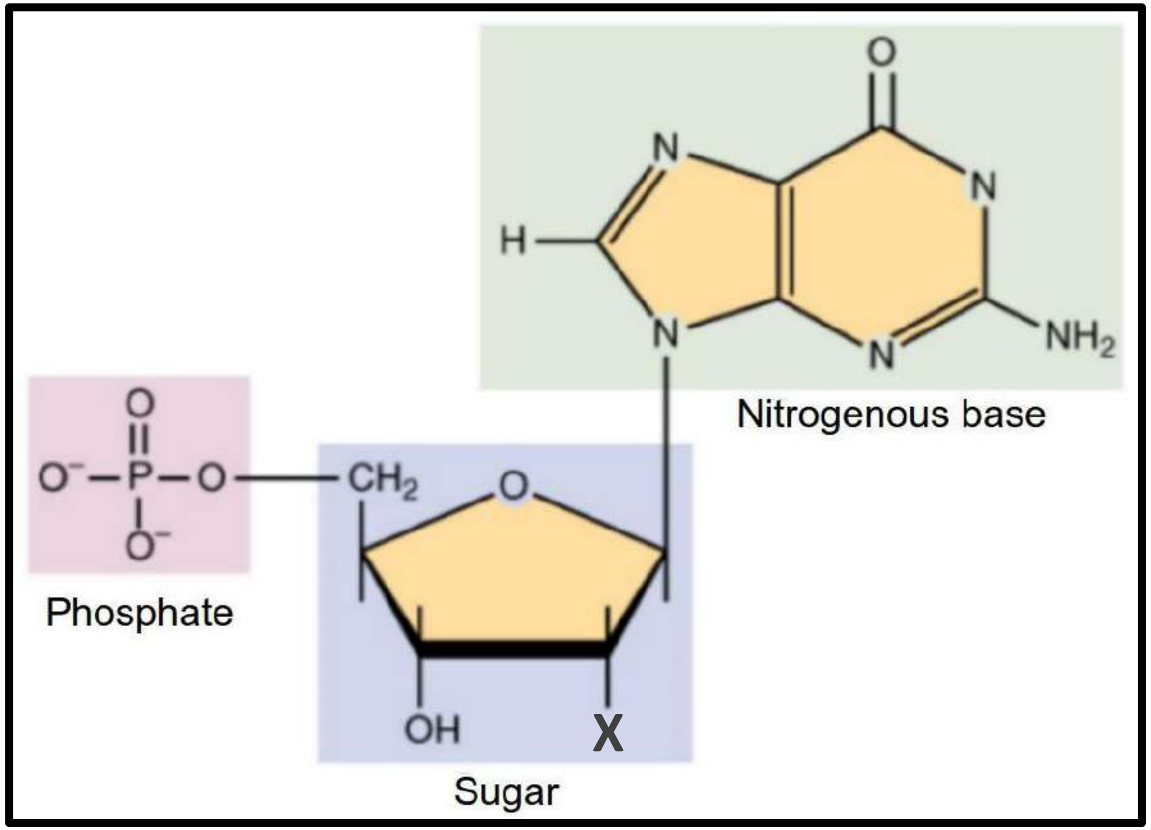
Chemical composition of the cell

Nucleotides

- **Nucleotides are the building blocks of nucleic acids.**
- **Each nucleotide consists of three parts:**

1. **Five-carbon sugar (pentose): ribose or deoxyribose**
2. **Nitrogen-base attached to C1 of the pentose sugar: purine or pyrimidine type**
3. **Phosphate group attached to C5 of the pentose sugar**

Nucleotide Structure



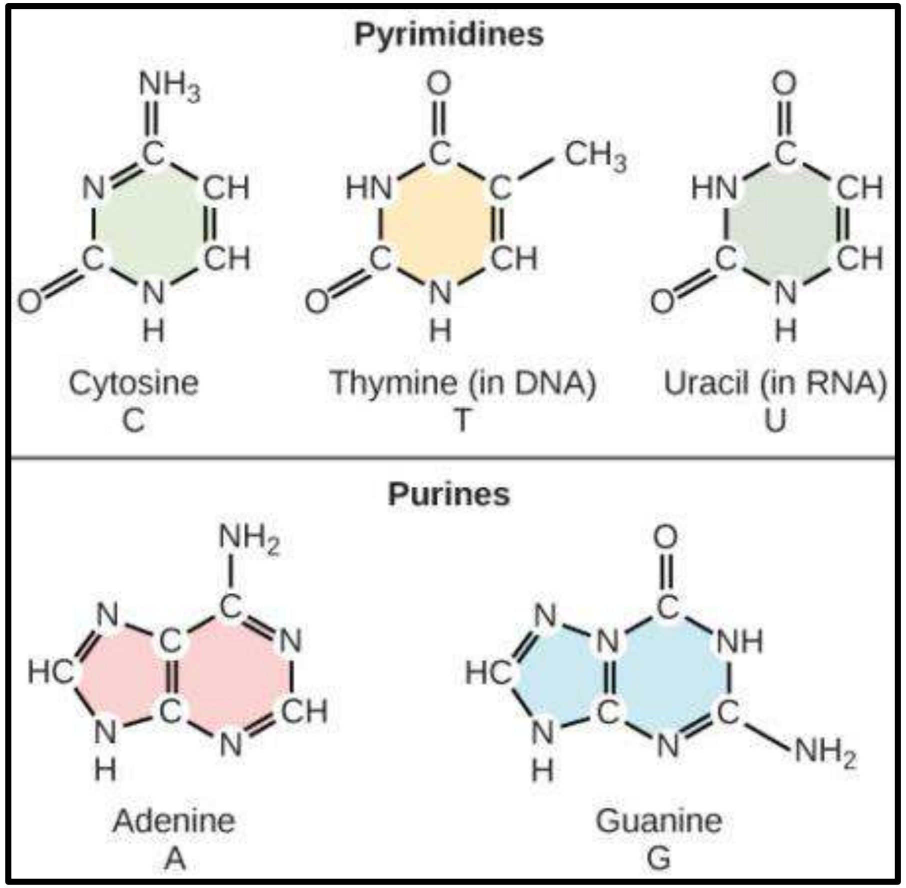
X: H, deoxy ribose as in DNA

X: OH, ribose as in RNA

Chemical composition of the cell

Nitrogen-base

- **Each nucleic acid (DNA, RNA) contains 4 different bases, 2 derived from purine and 2 from pyrimidine.**
- **Purine base has 2 rings (hexa-member ring) and (one penta-member ring) consisting of adenine (A) and guanine (G).**
- **Pyrimidine base has one ring (hexa-member ring) consisting of cytosine (C) and thymine (T) in DNA or uracil (U) in RNA.**
- **The bases are commonly represented by their initial letters A, G, C, T in DNA and A, G, C, U in RNA.**

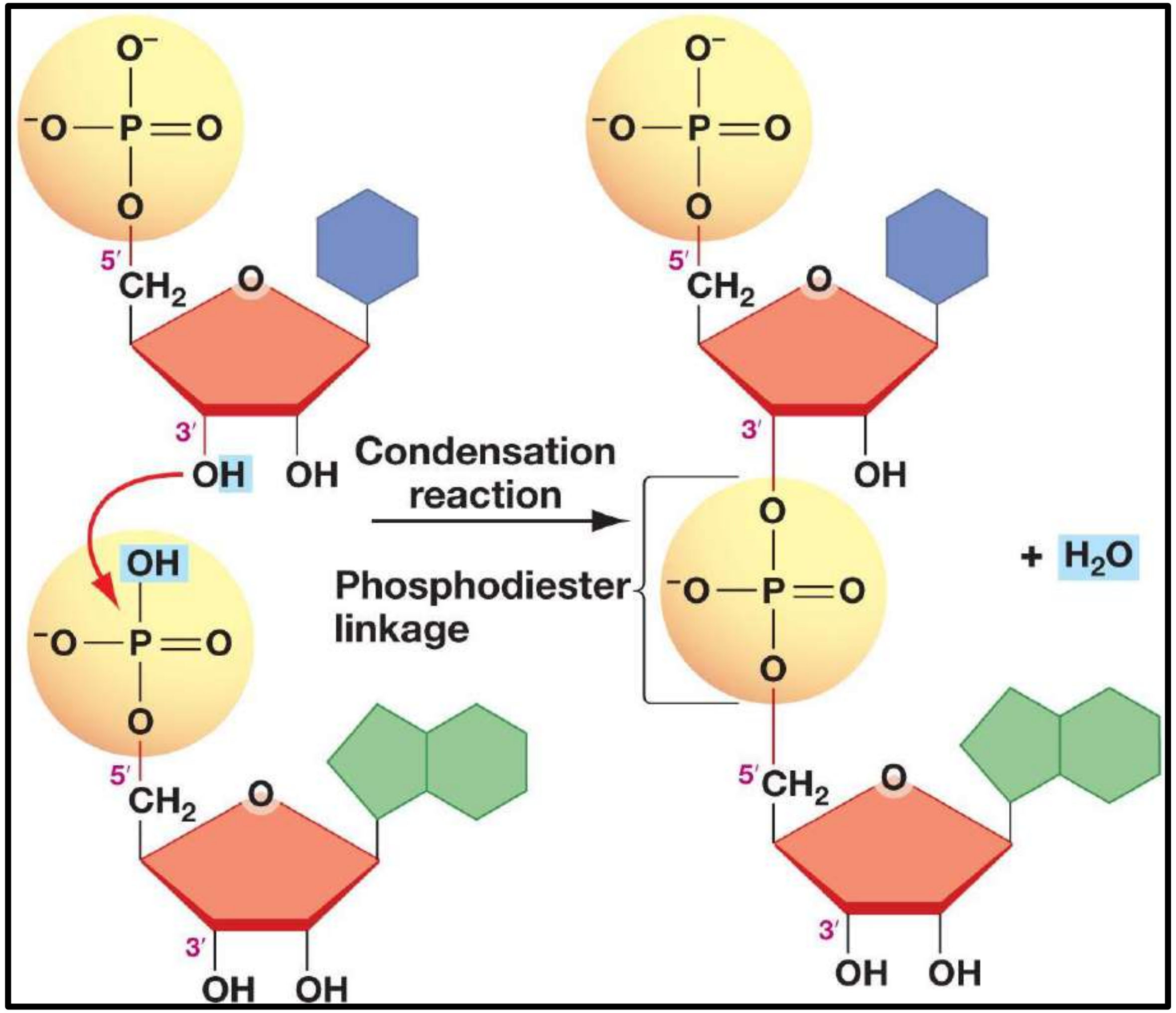


Chemical composition of the cell

Formation of polynucleotide

- **2 nucleotides join to form a dinucleotide by condensation reaction between the phosphate group of one nucleotide (at C5) with the pentose sugar of the other nucleotide (at C3) to form a phosphodiester bridge.**

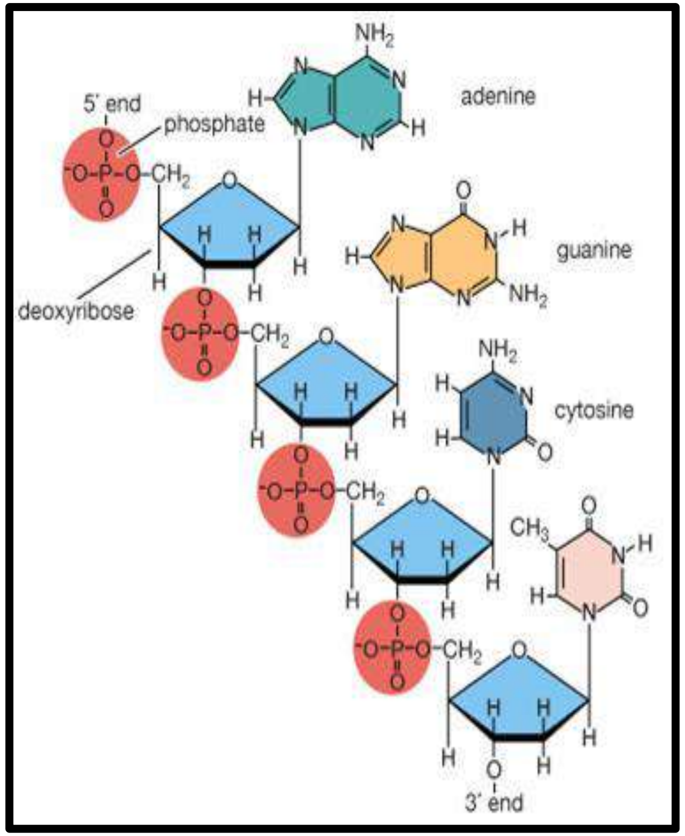
- **The process is repeated up to several million times to make an unbranched sugar-phosphate backbone between the 3’ and 5’ carbon atoms of the sugars to form the polynucleotide chain.**

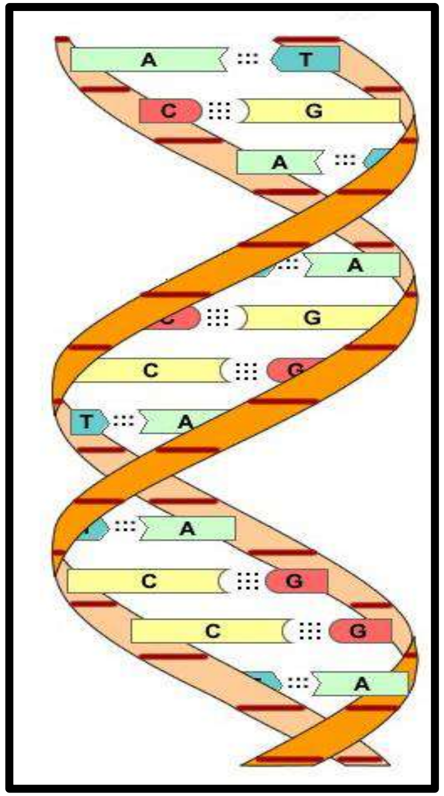


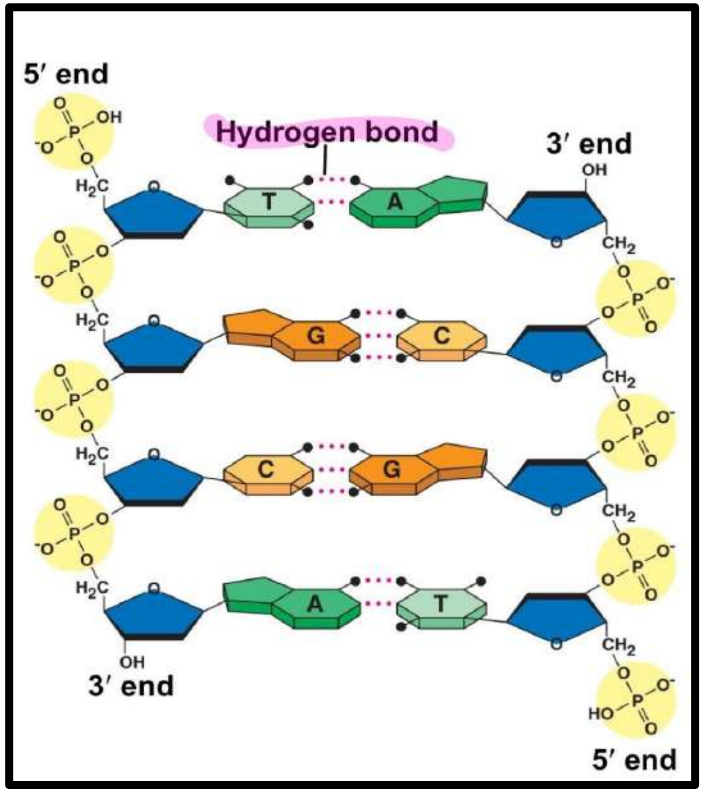
Chemical composition of the cell

DNA

- **DNA is a polymer of four nucleotides containing A, C, G, and T nitrogen bases.**
- **DNA molecule is made of 2 parallel polynucleotide chains (strands) coil around each other to form a double helix form.**
- **Each polynucleotide chain has a sugar-phosphate backbone which binds by Hydrogen bond with the bases of opposite chain as the following: A=T, C≡G.**



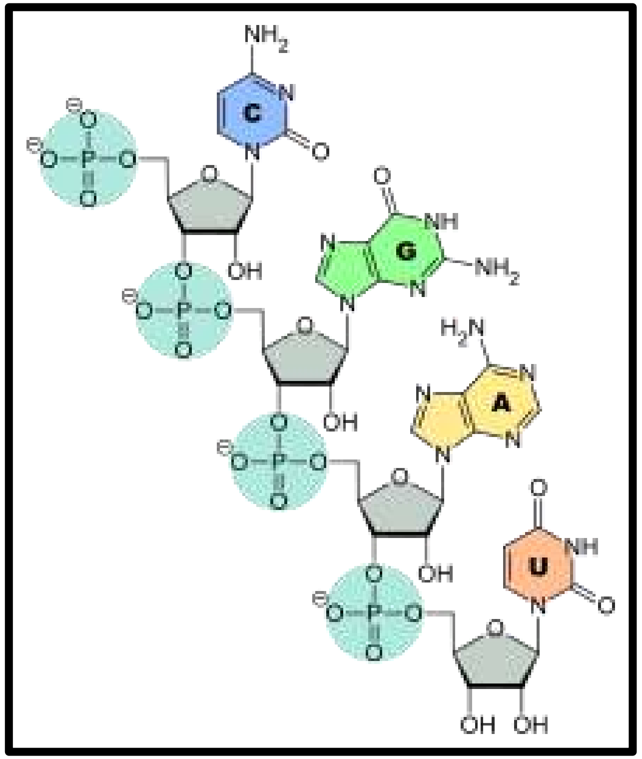




- **The 2 chains are complementary, the sequence in one chain determines the other (base pairing).**
- **For example:**

AACGTAATCCG is complementary to TTGCATTAGGC

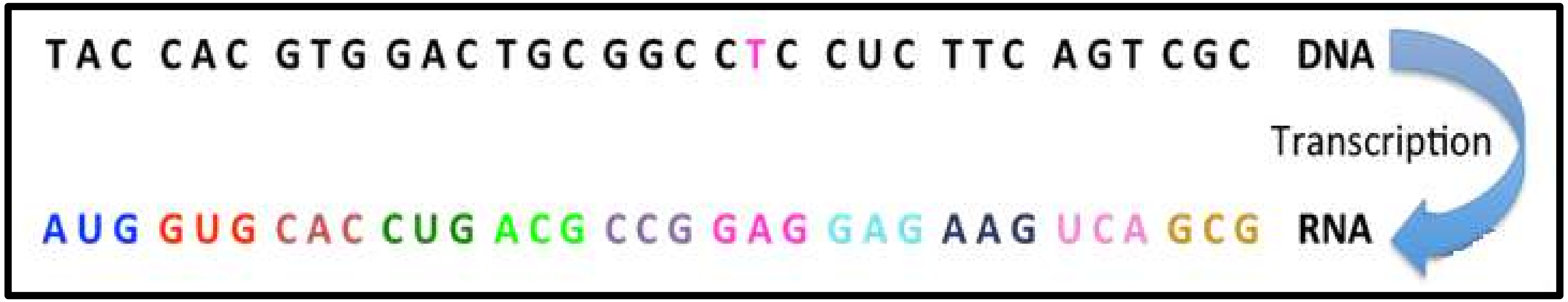
Chemical composition of the cell



RNA

- **RNA is a single-stranded nucleic acid polymer of four nucleotides A, C, G, and U joined through a backbone of alternating phosphate and ribose sugar residues.**

- **RNA is a complementary sequence of a section of double-stranded DNA, called a gene which is made by a process called transcription**



Chemical composition of the cell

Comparison between RNA and DNA

	RNA	DNA
Sugar	Ribose	Deoxyribose
Nitrogen bases	Adenine, Guanine, Cytosine and Uracil	Adenine, Guanine, Cytosine and Thymine
Strands	Single	Double
Function	Protein synthesis	Stores genetic information