UNVERSITY OF ZAMBIA

SCHOOL OF NATURAL SCIENCES
DEPARTMENT OF BIOLOGICAL SCIENCES

BIO 1401 BIOMOLECULES AND CELLS

LECTURE MODULE

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2019

INTRODUCTION

This is a foundation course in biology which covers the chemistry of living cells. It also compares the structure of prokaryotic and eukaryotics cells. This module is only part of your reading for the course. You are expected to read extensively to deepen and broaden your knwledge of the subject matter. You are encouraged to consult prescribed and recommended readings as wells as references provided in the module as well as to consult the internet.

RATIONALE

In order for you to understand the various functions of living organisms, they need to understand the structure and the physico-chemical properties of atoms and molecules which build the various components of the living cell. They also need to understand the structure and functions of the prokaryotic and eukaryotic cells.

AIMS

This course introduces students to the structure and functions of biomolecules. It also deals with the cellular basis of the life of prokaryotes and eukaryotes.

OBJECTIVES: AT THE END OF THE COURSE A STUDENT SHOULD BE ABLE TO

1. Describe the structure and function of important biological molecules.
2. Identify structures of prokaryotic and eukaryotic cells using the light microscope.
3. Compare and contrast the structure and function of prokaryotic and eukaryotic cells.
4. Interpret electron micrographics of cellar components cellular structures from electron micrographs.

CONTACT TIME : Three 1 hour Lectures per week
One hour tutorial per week
One 3 hour practical session per week

ASSESSMENT: **Continuous Assessment – 50%**
Final Examination – 50%

Task description	**Weighting**
Quizzes and Practical tests	10%
Theory tests	20%
Practical reports	20%
One theory exam paper	50%

PRESCRIBED READINGS

1. Taylor D. J., Green N. P. O. and Stout G.W. (2008). Biological Sciences, (Ed. Soper R.), Third Edition, Cambridge University Press, Cambridge.

RECOMMENDED READINGS

2. Kent, M. 2000. Advanced biology. Oxford University Press, London.
ISBN 0-19-914195-9

3. Campbell N. A, Reece J. B., Taylor M. R. Simon E. J. and Dickey J. L. (2004), Biology; Concepts and Connections. 6th edition, Pearson, Benjamin Cummins and Co. San Francisco, Boston, New York, Cape Town, Hong Kong, London, Madrid, Mexico City, Montreal, Munich, Paris, Singapore, Sydney, Tokyo, Toronto.

4. Stansfield W. D. (2000) Genetics, 3rd edition, Schaum's Outlines, McGraw-Hill Publishers. New Jersey

STUDY SKILLS

As a science student you should make sure your understanding of concepts is based on scientific principles and not on traditional myths. Scientific principles are based on a number of observations which produce results or data which are facts in nature.

In the laboratory, it is necessary to train yourself to make correct observations, remembering that a large number of observations produces facts and that these facts are the foundations of science.

In this course you will be given some of these facts and even though they represent only a fraction of the whole, you might find them too many to absorb. There is no easy way to memorise all these facts but you could try the following suggestions:

1. Take careful notes during lectures. Ask for clarification if you have not understood an important statement.

2. If a detailed explanation is not possible during a lecture, the lecturer will always be willing to help you after the lecture. Alternatively, the question can be asked during a tutorial.

3. Go over your notes soon after the lecture. Fill in any gaps by referring to relevant text reading materials.

4. Write out definitions of terms initially from your lecture notes and then from your memory.

5. Ask yourself questions and answer them from your memory.

6. Compare notes with other students and ask each other question.

7. Keep reading your notes and text books and test yourself in various ways.

8. After doing all the above and you still find a problem, note it down and make it a subject of discussion during the tutorial where either the tutor or classmates will help you to resolve the problem.

UNIT 1: ATOMIC THEORY AND CHEMICAL BONDS

1.1 INTRODUCTION

Atoms are the building blocks of all matter in the Universe. Each atom has three basic parts namely: electrons, protons, and neutrons. Electrons (negatively charged) are the smallest of the three and are found in shells or orbitals. At the centre of the atom is the nucleus that consists of an equal number of protons (positively charged) and neutrons (no charge). The mass of the atom is determined by the number of protons and neutrons i.e. protons + neutrons. The hydrogen atom (whose atomic mass = 1) contains 1 proton and one electron but does not contain any neutrons. The number of protons is equal to the number of electrons for any given atom. Electrons are found in different orbitals around the nucleus. The integrity and functions of biologically important molecules are determined by the structure and behaviour of the constituent atoms.

1.2 OBJECTIVES

At the end of this unit you should be able to:

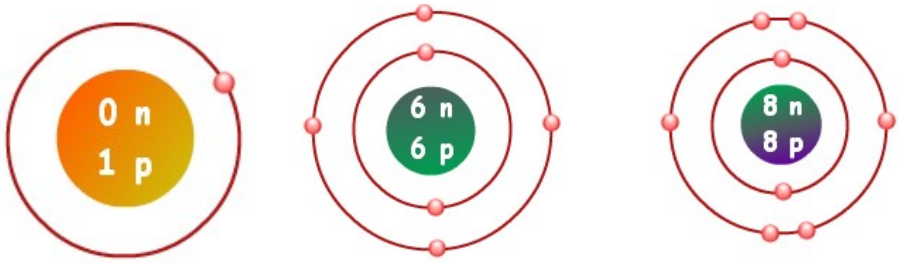
1. Describe the general structure of an atom and the distribution of electrons.
2. Differentiate between an atomic shell and an atomic orbital.
3. Describe the atomic structures of hydrogen, carbon, oxygen, nitrogen, phosphorus, sulphur, sodium and chlorine.
4. Describe the nature of covalent and non-covalent chemical bonds.

1.3 ORBITALS AND SHELLS

An orbital is the physical region or space where an electron is expected to be present. Any orbital can be occupied by a maximum of two electrons. Orbitals exist at different energy levels which the lowest level being the ground state. The orbital with the lowest energy is the s orbital (represented by **sharp** spectroscopic lines). The next orbital is the p (**principle** spectroscopic lines). Orbitals are arranged in form of shells in which the innermost shell has one orbital (1s) which can be occupied by a maximum of two electrons. The second shell has four orbitals (one 2s, and three 2p orbitals). The three 2p orbitals are 2px, 2py and 2pz and each one can be occupied by a maximum of two elctrons. Therefore the second shell can be occupied by a maximum of eight electrons. The third shell has four orbitals (one 3s, and three p orbitals), etc.

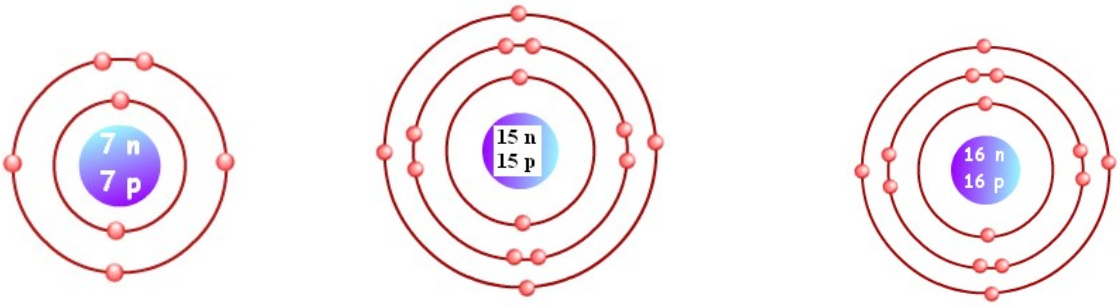
1.4 ATOMIC STRUCTURE AND ELECTRON CONFIGURATION

Figures 1.1 and 1.2 show the atomic structures and electron configurations of some elements which are important constituents of biomolecules.



(a) (b) (c)

Figure 1.1. Atomic structures of the hydrogen (a), carbon (b) and oxygen (c) atoms.



(a) (b) (c)

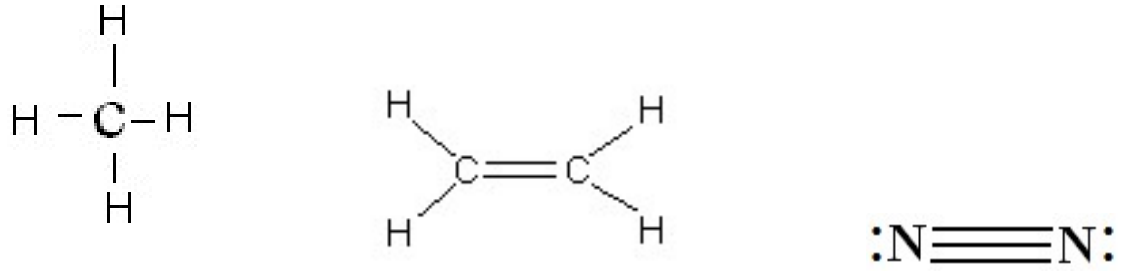
Figure 1.2. Atomic structures of the nitrogen (a), phosphorus (b) and sulphur (c) atoms.

1.5 CHEMICAL BOND

A chemical bond is an attraction between atoms that results into the formation of a chemical compound (molecule) that contains two or more atoms. A chemical bond is caused by the electrostatic force of attraction between opposite charges, either between electrons and protons (in the nucleus), or as the result of a dipole attraction. There are two major classes of chemical bonds i.e. (i) covalent and (ii) non-covalent bonds.

1.5.1. Covalent bond

A covalent chemical bond results from the equal sharing of electrons between two atoms (Fig 1.3). A single covalent bond represents the sharing of two valence electrons, usually from two atoms of different elements. The hydrogen molecule (H_2) has a single covalent bond in which two electrons are shared equally between the two hydrogen atoms (H: H or H-H). In methane (CH_4), each of the four CH bonds is a single covalent bond (C: H or C-H) in which each hydrogen atom shares one pair of electrons with a common carbon atom. Multiple covalent bonds are common for certain atoms. For example ethylene (C_2H_4) has a double covalent bond ($H_2C=CH_2$) which results from the sharing of two pairs of electrons between the two carbon atoms. The nitrogen molecule (N_2) has a triple covalent bond between the two nitrogen atoms. Covalent bonds are very stable because the energies required to break them are much greater than the thermal energy available at room temperature (25 ºC) or human body temperature (37 ºC).



(a) (b) (c)

Figure 1.3. Four single covalent C-H bonds in methane (a), a double C=C bond in ethene (b) and a triple N≡N bond in molecular nitrogen.

In molecular nitrogen, three pairs of electrons are shared by the two nitrogen atoms while the fourth pair of each nitrogen atom is unshared (lone pair: Fig 1.3c).

1.5.2 Noncovalent interactions

The four main types of noncovalent interactions that occur in biological systems are (i) ionic bonds, (ii) hydrogen bonds, (iii) van der Waals interactions and (iv) hydrophobic interactions.

1.5.2.1 Ionic bond

An ionic bond is formed by the attraction of oppositely charged atoms or groups of atoms. When an atom gains or loses one or more electrons, it forms an **ion**. Ions have either a net positive or net negative charge. Positively charged ions are attracted to the negatively charged 'cathode' in an electric field and are called **cations**. **Anions** are negatively charged ions which are attracted to the positively charged 'anode' in an electric field. Every ionic chemical bond is made up of at least one cation and one anion. Sodium (atomic number 11) forms an ionic bond with chlorine (atomic number 17) in sodium chloride (common salt: Fig 1.4).

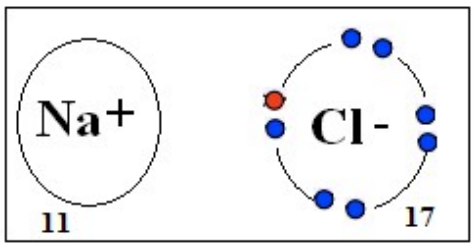
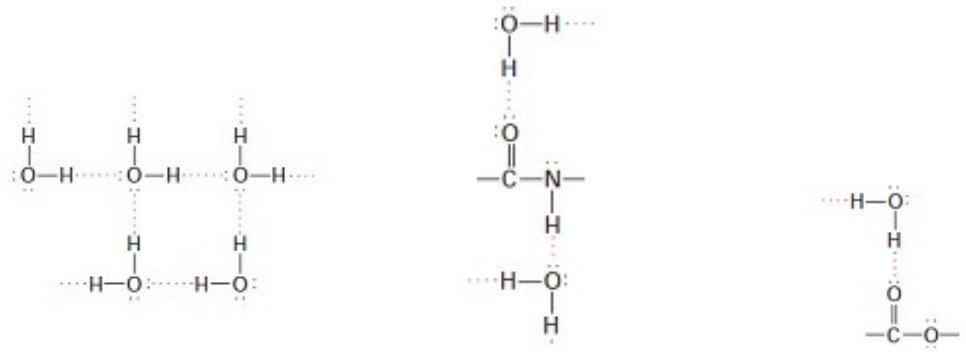


Figure 1.4. An ionic bond formed between a sodium ion (cation) and a chloride ion (anion) in the formation of sodium chloride (common salt).

1.5.2.2 Hydrogen bonds

A **hydrogen bond** is the interaction of a partially positively charged hydrogen atom in a dipolar molecular (e.g., water) with unpaired electrons from another atom, either in the same molecule (intramolecular) or in a different molecule (intermolecular). Normally, a hydrogen atom forms a covalent bond with only one other atom.



(a) (b) (c)

Figure 1.5. Hydrogen bonds between different water molecules (a), between water and a peptide (b) and between water and a carboxyl group (c).

In liquid water, each water molecule apparently forms temporary hydrogen bonds with several others, creating a dynamic network of hydrogen-bonded molecules (Fig 1.5a). Water also can form hydrogen bonds with peptide and carboxyl groups, which explains the high solubility of polypeptide and organic acids (Figs 1.5 b & c). The peptide and ester groups, which are present in many biomolecules, commonly form hydrogen bonds with water.

1.5.2.3 Van der Waals interactions

When any two atoms approach each other closely, they create a weak, nonspecific attractive force called a **van der Waals interaction**. Such nonspecific interactions result from the temporary and random fluctuations in the distribution of the electrons of any atom, which give rises to a temporary unequal distribution of electrons. The van der Waals interactions are responsible for the attraction between molecules of nonpolar liquids and solids, such as long chain biological molecules that cannot form hydrogen bonds or ionic interactions with other molecules.

1.5.2.4 Hydrophobic interactions

Nonpolar molecules or nonpolar portions of molecules tend to aggregate in water due to a phenomenon called the **hydrophobic effect.** In an aqueous environment, nonpolar molecules aggregate with their hydrophobic surfaces facing each other and because of this, less water is needed to completely surround the nonpolar molecules. Therefore water forces the nonpolar molecules to spontaneously form aggregates. In addition, it is observed nonpolar molecules dissolve in nonpolar solvents because of the hydrophobic interactions between the molecules and the nonpolar solvents.

1.5.2.5 Formation of covalent bonds in water and carbon dioxide

Two hydrogen atoms each share their one electron with oxygen to form two covalent bonds and make a water molecule (H_2O: Fig 1.6). Oxygen and hydrogen have two bonds each between their atoms This is called a single bond. The structural formula of a water molecule is written as given below:

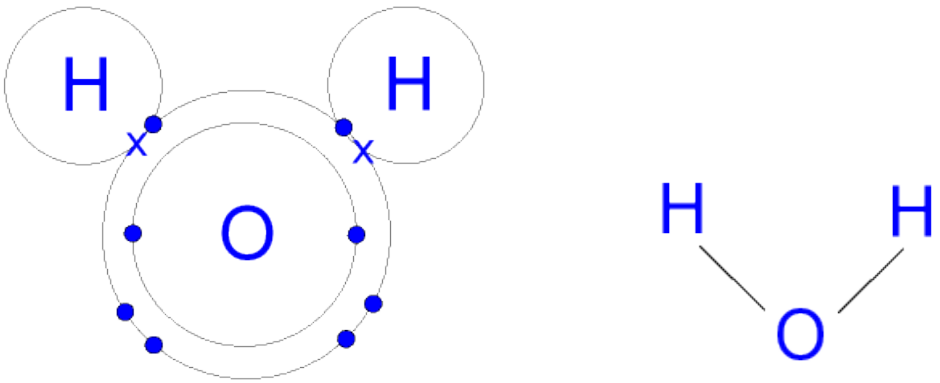


Figure 1.6. Chemical bonds in a water molecule. A single bond forms between an oxygen atom and each of the two hydrogen atoms.

Two oxygen atoms and one carbon atom will each share two electrons to form four covalent bonds and make a carbon dioxide molecule (CO_2: Fig 1.7). Carbon and oxygen have two bonds each between their atoms. This is called a double bond. The structural formula of a carbon dioxide molecule is written as given below:

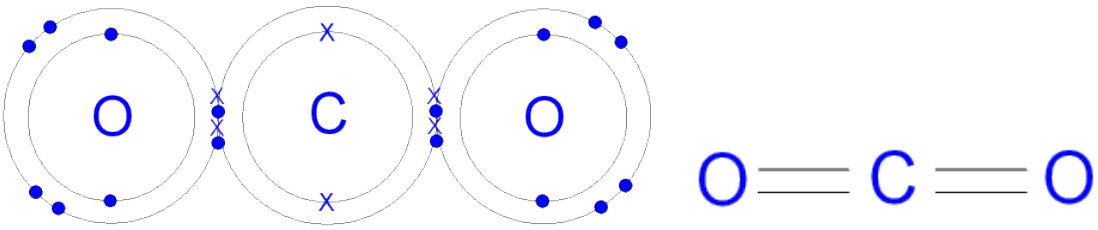


Figure 1.7. Chemical bonds in a water molecule. A double bond forms between a carbon atom and each of the two oxygen atoms.

1.6 REVISION EXERCISE

1. Draw and label the general structure of an atom.
2. Describe the distribution of electrons in atomic orbitals and atomic shells.
2. Differentiate between an atomic shell and an atomic orbital.
3. Draw the atomic structures of hydrogen, carbon, oxygen, nitrogen, phosphorus, sulphur, sodium and chlorine.
4. Describe the nature of covalent and the different types of non-covalent chemical bonds.

1.7 SUMMARY

Each atom has three basic parts namely: electrons, protons, and neutrons. At the centre of the atom is the nucleus that consists of protons (positively charged) and neutrons (no charge). Electrons are negatively charged particles which have no mass. They are the smallest of the three and are found in shells or orbitals around the nucleus. The mass of the atom is determined by the number of protons and neutrons i.e. protons + neutrons. The number of protons is equal to the number of electrons for any given atom. The integrity and functions of biologically important molecules are determined by the structure and behaviour of the constituent atoms. Atoms combine to form different molecules and compounds through covalent and non-covalent bonds.

UNIT 2: BIOMOLECULES

2.1 INTRODUCTION

A biomolecule is any molecule that is synthesised by a living organism. Biomolecules are normally organic compounds which are rich in carbon and hydrogen. They include water, proteins, carbohydrates, lipids, nucleic acids and other molecules.

2.2 OBJECTIVES

At the end of this unit you should be able to:

1. Describe the properties of some important biological molecules
2. Recall, recognise and identify the general formulae and structures of these molecules
3. Understand the roles of these molecules.

2.3 THE ROLE CARBON

All the biological building blocks are organized around the carbon atom, which normally forms four covalent bonds with two to four other atoms. As illustrated by the methane (CH4) molecule, when carbon is bonded to four other atoms, the angle between any two bonds is 109.5º and the positions of bonded atoms define the four points of a tetrahedron (Fig 2.1). This geometry helps define the structures of many biomolecules.

2.4 THE ASYMMETRIC CARBON ATOM

A carbon (or any other) atom bonded to four dissimilar atoms or groups in a non-planar configuration is said to be asymmetric. Many molecules in cells contain at least one asymmetric carbon atom, often called a **chiral carbon** atom.

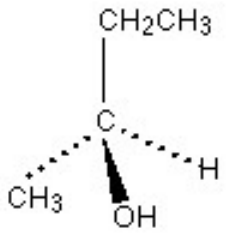


Figure 2.1. The asymmetric carbon atom at the centre of the molecule is bonded to four different groups (–CH_2CH_3, -CH_3, -OH and H).

2.5 STEREOISOMERS OF CARBON COMPOUNDS

The tetrahedral orientation of bonds formed by an asymmetric (chiral) carbon atom can be arranged in a three-dimensional space in two different ways, producing molecules that are mirror images (stereoisomers) of each other. The different stereoisomers of a molecule usually have completely different biological activities because the arrangement of atoms within their structures differs. This difference gives them their unique properties when they interact and react with other molecules. Glucose has two stereo isomers i.e. D- glucose and L-glucose (Fig 2.2).

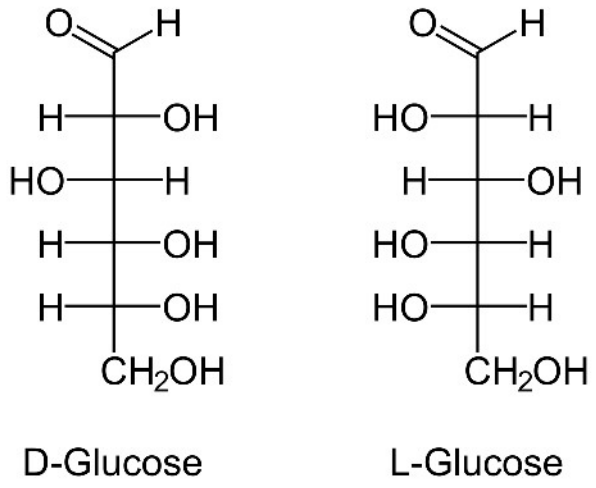


Figure 2.2 D-glucose and L-glucose, the two stereoisomers of glucose

2.6 STRUCTURAL ISOMERS OF CARBON COMPOUNDS

Structural isomerism, is a form of isomerism in which molecules with the same molecular formula have bonded together in different orders.

Structural Isomers are molecules which have the same molecular formula but have different arrangements of atoms. Alkanes can be very simple examples of this. Examples of stereo isomers are (i) glucose and galactose and (ii) glucose and fructose (Fig 2.3).

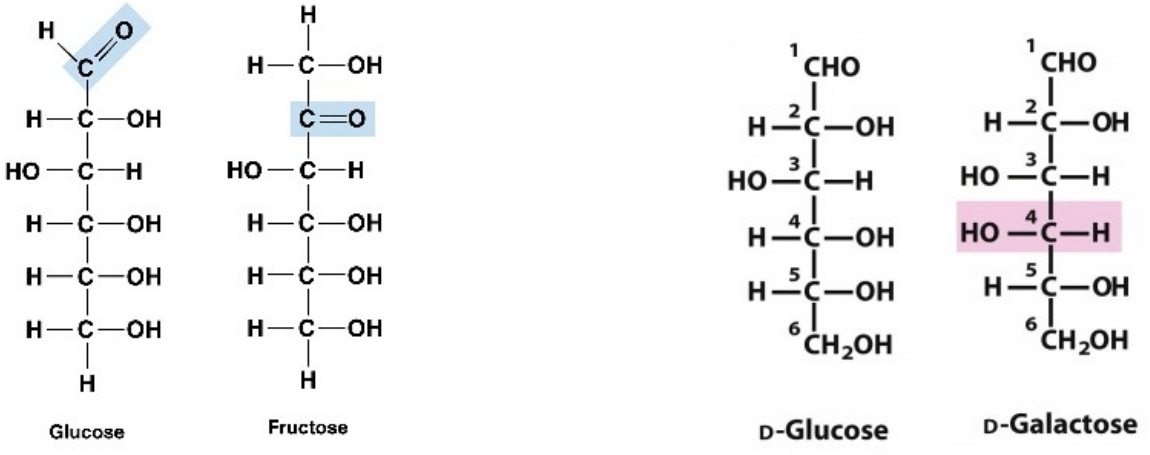


Figure 2.3 Two pairs of structural isomers. Glucose and fructose are on the left side while glucose and galactose are on the right. Source: http://www.namrata.co/isomers-and-epimers.

2.7 CARBON-CARBON DOUBLE BOND

Carbon can also bond to only three other atoms. In this case, the carbon atom forms two typical single bonds with two atoms and a double bond (two shared electron pairs) with the third atom (usually another carbon. The atoms joined by a single bond can rotate freely about the bond axis, while those connected by a double bond cannot. The rigidity imposed by double bonds determines the shapes and flexibility of large biological molecules such as lipids, proteins and nucleic acids.

2.8 OTHER ATOMS FOUND IN BIOMOLECULES

The other atoms that are commonly found in organic compounds, apart from carbon and hydrogen include oxygen, nitrogen, phosphorous and sulphur.

UNIT 3: WATER

3.1 INTRODUCTION

Water is the most abundant compound in living organisms, making up 60-95% fresh mass of all living organisms. Water is important to living organisms because (i) it is an important chemical constituent of living cells and (ii) it provides a habitat for aquatic organisms.

3.2 OBJECTIVES

At the end of this unit you should be able to:

1. Describe the dipolar nature of water
2. Describe the formation of hydrogen bonds by water molecules
3. Explain the role of water as a solvent
4. Explain the roles of water related to its high latent heat of vaporisation, specific heat capacity, density and surface tension.

3.3 DIPOLAR NATURE OF WATER

Water has special physical and chemical properties because of its small size, its polarity and due to hydrogen-bonding between its molecules. Polarity is the unequal charge distribution over a molecule. In water one end of the molecule is slightly positive and the other slightly negative. This is known as dipole. The electronegative oxygen atom (on one water molecule) attracts the electrons of the hydrogen atoms (of surrounding water molecules). Water molecules therefore have an electrostatic attraction for each other. Each oxygen atom has two partial negative charges while each hydrogen atom has one partial positive charge (Fig 3.1). Hydrogen bonds are longer and weaker than covalent O-H bonds.

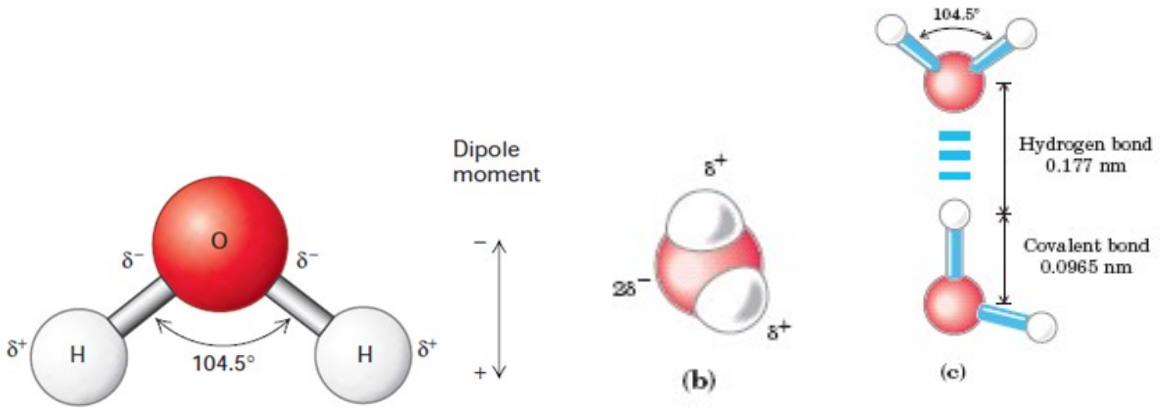


Figure 3.1 The dipolar nature of H_2O molecule is shown by (a) ball-and-stick and (b) space-filling models. In (c) two H_2O molecules are joined by a hydrogen bond between the oxygen atom of the upper molecule and a hydrogen molecule of the lower molecule.

3.4 HYDROGEN BOND FORMATION

The attractions between hydrogen and oxygen atoms of different water molecules are called hydrogen bonds. These weak bonds are also formed between (i) the oxygen atoms of water molecules and hydrogen atoms of different molecules such as acids and (ii) the hydrogen atoms of water and OH groups of other molecules such as alcohols.

3.5 IMPORTANCE OF WATER AS A SOLVENT

Water is a good solvent for ionic substances like sodium chloride (NaCl: Fig 3.2) whose charged particles dissociate into ions in water, and for some non-ionic substances like sugars and simple alcohols which contain charged (polar) groups such as the hydroxyl (-OH) within the molecules. When substances dissolve in water they become more chemically reactive than when they are in the solid form. Therefore, the majority of cellular reactions take place in aqueous solution. The solvent properties of water make it act as a transport medium, in blood, lymphatic system, excretory system and the alimentary canal of animals as well as in xylem and phloem tissues of plants.

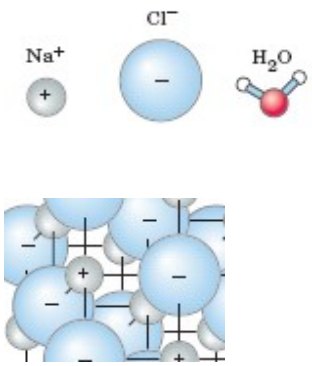
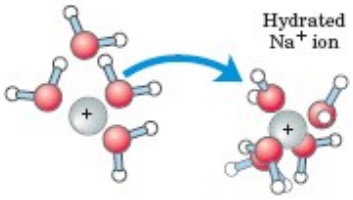
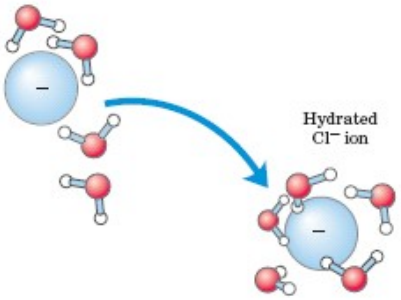
		
Sodium ion, chloride ion , water molecule and sodium chloride crystal	Hydration of the sodium ion by water molecules	Hydration of the chloride ion by water molecules

Figure 3.2 Water as a solvent. Water dissolves crystalline salts such as sodium chloride by hydrating the ions. The NaCl crystal lattice is disrupted as water molecules cluster about the Cl- and Na+ ions. The ionic charges are partially neutralized and the electrostatic attractions needed for crystal formation are weakened.

Non-polar substances such as phospholipids are immiscible with water (insoluble) and are said to be hydrophobic (water-hating). When mixed with water, they either form micelles (Fig 3.3). Hydrophobic interactions are important in maintaining the stability of membranes, many protein molecules, nucleic acids and other sub-cellular structures.

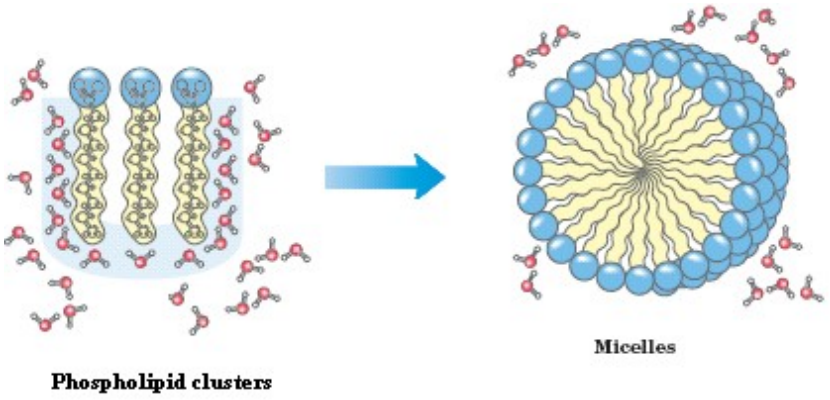


Figure 3.3 The formation of micelles by phospholipid molecules in water

3.6 ROLE RELATED TO WATER'S HIGH SPECIFIC HEAT CAPACITY

The specific heat capacity of water is the amount of heat, in joules, that is required to raise the temperature of 1 kg of water by 1°C.Water has a high heat capacity, meaning that a large increase in heat energy results in a relatively small rise in temperature. This is because much of the energy is used in breaking the hydrogen bonds between the water molecules. This means that temperature fluctuations in water are minimised as a result of its high heat capacity. Biochemical processes in living cells, therefore take place within a narrow temperature range, at constant rates and are usually not affected by changes of temperature of the environment. Water therefore provides a very constant external environment for many cells and organisms.

3.7 ROLE RELATED TO WATER'S HIGH LATENT HEAT OF VAPORIZATION

Latent heat of vaporisation is the amount of the heat energy required to vaporise a liquid. Water has a high latent heat of vaporisation meaning that a large amount of heat can be lost with minimal loss of water from the organism. This heat is used to overcome the cohesive forces (hydrogen bonds) between water molecules so that they can escape as a gas. As a result, water has an unusually high boiling point for such a small molecule. The energy absorbed by water molecules to evaporate results in the loss of energy from their surroundings thus causing a cooling effect in the surroundings. Through sweating and panting mammals cool themselves while leaves are cooled down during transpiration.

3.8 ROLE RELATED TO WATER'S DENSITY

The density of water decreases at temperatures below 4°C and because of this ice tends to float. Each water molecule, in ice, forms the maximum of four hydrogen bonds, creating a regular lattice. The crystal lattice of ice (Fig 3.4) makes it less dense than liquid mater, thus ice floats on liquid water. In liquid water, at room temperature and atmospheric pressure, each water molecule forms an average of 3.4 bonds with other water molecules. Since ice floats, it forms at the surface of water first and at the bottom last. Therefore, ice insulates the water below it, increasing the chances of survival of organisms in the water during the cold season in temperate

climates. The fact that water below 4 °C tends to rise to the surface also helps to maintain circulation in large bodies of water (lakes and oceans). This helps in bringing nutrients from the sediments (floor) of lakes and oceans to the surface (nutrient cycling) and helps organisms (living things) to reach and stay at greater depths.

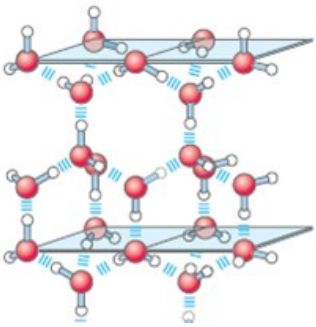


Figure 3.4. Hydrogen bonding in ice.

3.9 ROLE RELATED TO WATER'S COHESION AND SURFACE TENSION

Cohesion is the force which makes similar molecules stick together. At the surface of a liquid, such as water, a force called surface tension exists between the molecules as a result of cohesion. This creates a 'thin skin' over the water surface. Water has a higher surface tension than any other liquid. The high cohesion of water molecules helps in the movement of water in cells especially in the translocation of water through the xylem in plants. In addition, many small aquatic organisms are able to float or skate on water because of its high surface tension.

3.10 ROLE RELATED TO WATER'S ADHESION PROPERTIES

The attraction between water molecules and other different substances is called adhesion. Water, through adhesion, makes things wet by sticking to their surfaces. Adhesion is important in the movement of water along the walls of vascular tissues in plants and along blood vessels in mammals.

3.11 CAPILLARITY IN WATER

This is the ability of water to flow upwards in narrow vessels (Fig 3.5) without the assistance of external forces like gravity or air pressure. Capillarity action of water is due to the action of cohesion and adhesion which together cause water to work against gravity and it occurs when forces of adhesion to the vessel walls are stronger than the forces of adhesion between the liquid molecules. The narrower the tube, the higher the force of capillarity (Fig 3.5).

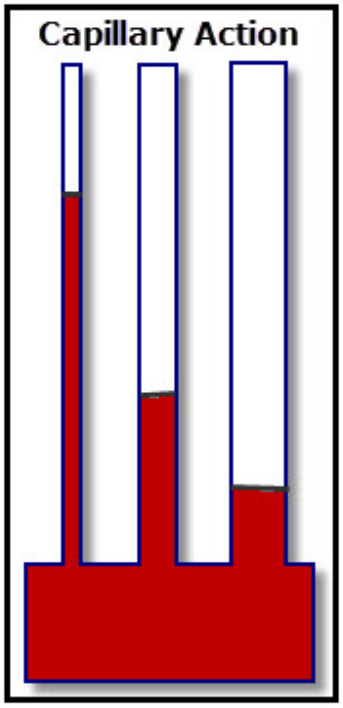


Figure 3.5. Capillarity action of water in tubes of different diameters.

UNIT 4: CARBOHYDRATES

4.1 INTRODUCTION

Carbohydrates (hydrates of carbon) are compounds with the general formula $Cn(H_2O)n$, where *n* is a variable number. The proportions of hydrogen and oxygen are the same as in water. Carbohydrates are either aldehydes or ketones and they all contain several hydroxyl (OH) groups. Aldehyde-carbohydrates are more easily oxidised than ketone-carbohydrates and hence they act as reducing agents. Carbohydrates are divided into three main classes; mono-, di- and polysaccharides. Their names end in a suffix -ose.

4.2 OBJECTIVES

At the end of this topic you should be able to:

1. Recall the structures of trioses, hexoses and pentoses
2. Explain the roles of ribose, deoxyribose, glucose, fructose and galactose
4. Describe the composition of disaccharides and polysaccharides
6. Recall the structures of disaccharides sucrose, maltose and lactose
5. Describe condensation and hydrolysis reactions involved in the synthesis and degradation of disaccharides and polysaccharides.
7. Recall the structures and explain the functions of starch (amylase and amylopectin) cellulose and glycogen.

4.3 MONOSACCHARIDES

Monosaccharides are the simplest form of carbohydrates made up of single sugar units (monomers). They are used by cells as a direct source of energy. Monosaccharides are classified according to the number of carbon atoms they have. Trioses have three carbons (3C), tetroses are 4C, pentoses are 5C, hexoses are 6C and heptoses are 7C. Of these, pentoses and hexoses are the most common. Monosaccharides exist either in open chain forms or in ring forms. The open chain forms can exist as different isomers of a given monosaccharide. The most common isomer is the D-isomer (optical isomer) which rotates polarized light to the right (dextro = D: Fig 4.1). The L-isomer is rare and rotates polarised light to the left (levo = L: Fig 4.1).

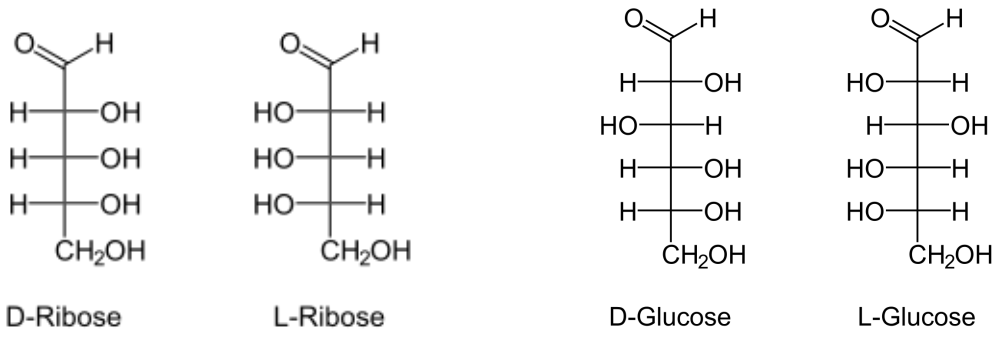


Figure 4.1. Structures of naturally occurring D-ribose (five carbons), D-glucose (six carbons) and their synthetic isomers L-ribose (five-carbons) and L-glucose (six carbons).

4.3.1 TRIOSES

A **triose** is contains three carbon atoms. The three possible trioses are dihydroxyacetone, L-glyceraldehyde and D-glyceraldehyde (Fig 4.2). Trioses are important in cellular respiration. During glycolysis, glucose is broken down into glyceraldehyde and dihydroxyacetone. Lactic acid and pyruvic acid are produced from the metabolism of these trioses.

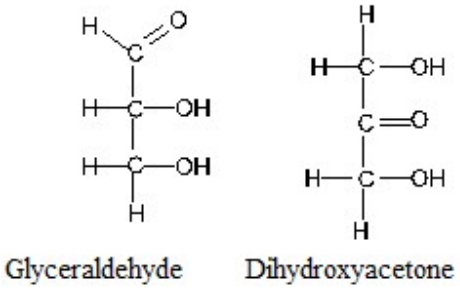


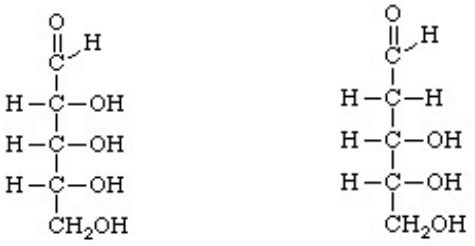
Figure 4.2. Structures of dihydroxyacetone and glyceraldehyde .

4.3.2 PENTOSE SUGARS

Pentoses are 5C sugars with the formula $C_5H_{10}O_5$ e.g. ribulose, ribose, and deoxyribose. Ribulose is an important CO_2 acceptor during photosynthesis while ribose and deoxyribose are important components of nucleic acids.

4.3.2.1 RIBOSE AND DEOXYRIBOSE

These 5C sugars are part of the structure of nucleic acids (RNA and DNA). Ribose is a constituent of RNA while deoxyribose is a constituent of DNA. When carbon 2 has one OH group and one H atom, the result is ribose and when it has two H atoms, the result is deoxyribose (Fig 4.3).

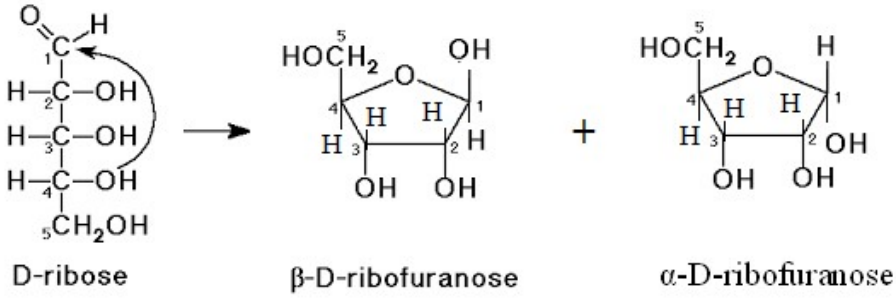


D-ribose open chain (aldose)

D-deoxyribose open chain (aldose)

Figure 4.3. Structures of D-ribose and D-deoxyribose (five-carbon sugars).

Carbon 4 combines with carbon 1 of the open chain of both ribose and deoxyribose resulting in the formation of a five membered furanose ring (Figs 4.4 and 4.5). The oxygen of carbon 4 links with carbon 4 to form a closed ring. The oxygen of the C=O bond on C1 combines with hydrogen of C4 to form an OH group which is above the plane in β ribose and deoxyribose and below the plane in α ribose and deoxyribose. The α and β forms are structural (stereo) isomers and are as a result of the asymmetric (chiral) C1 which is attached to four different groups i.e. OH, H, O and C.



D-ribose β-D-ribofuranose α-D-ribofuranose

Figure 4.4. Formation of a ribose furanose ring. The ring which is at right-angles to the plane of the paper can result into α-D-ribose (with OH group on C1 below the ring) or β-D-ribose (with OH group on C1 above the ring).

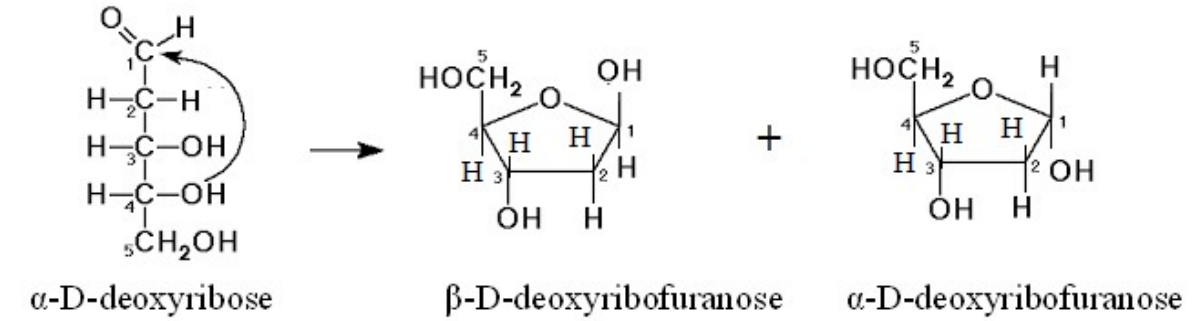


Figure 4.5. Formation of a deoxyribose furanose ring. The ring which is at right-angles to the plane of the paper can result into α-D-deoxyribose (with OH group on C1 below the ring) or β-D-deoxyribose (with OH group on C1 above the ring).

4.3.3 HEXOSE SUGARS

Hexoses are 6C sugars with the formula $C_6H_{12}O_6$. Examples include glucose, fructose and galactose. They are a direct source of energy and are oxidised during cellular respiration. Glucose is the most common respiratory monosaccharide. Hexoses are used in the synthesis of disaccharides (2 monomers), oligosaccharides (2-10 monomers) and polysaccharides (more than 10 monomers).

4.3.3.1 HEXOSE ISOMERS

Isomers are molecules that have the same molecular formula, but have a different arrangement of the atoms in space. Examples of monosaccharide isomers include: (i) optical isomers are molecular which rotate polarised light to the right (D) or left (L) e.g. D-glucose and L-glucose; (ii) stereoisomers isomers have the same molecular formula and structural formula but differ in the spatial arrangement of atoms in the molecule e.g. (a) α-D glucose and β-D glucose and (b) and (b) glucose and galactose; (iii) structural isomers have the same molecular formula but different structural formulae e.g glucose (aldose) and fructose (ketose)

4.3.3.2 GLUCOSE

Glucose (grape sugar) is a simple monosaccharide found in plants. It is an important product of photosynthesis and is a fuel for cellular respiration. Glucose is soluble in water because its hydroxyl groups form hydrogen bonds with water molecules. The open chain form of glucose is an aldehyde (aldose) whose carbon 1 combines with the OH group of carbon 5 of the open chain to give a six-membered pyranose ring (Fig 4.6). The ring structure results in carbon 1 atom becoming asymmetric or chiral (it forms four single bonds with four different atoms and groups). When the OH group on carbon 1 is below the ring the result is the α-isomer of glucose and when the OH group is above the ring the result is the β-isomer. The existence of α- and β-glucose leads to formation of a variety of the dimers and polymers of glucose such as starch and glycogen (from α-glucose) and cellulose (from β -glucose). Glucose is a powerful reducing agent because of the presence of the aldehyde group at carbon 1 in the open chain (aldose). The commonly occurring glucose is the D-isomer while the synthetic L-isomer is commonly used as a low-calorie sweetener and as a laxative. Living organisms cannot use L-glucose as an energy source because they do not have the enzyme to break it down.

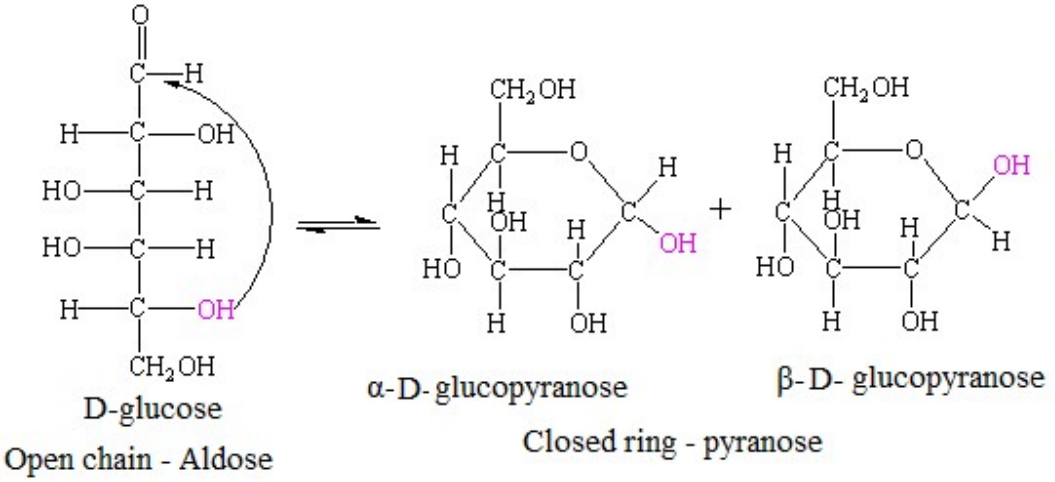


Figure 4.6 Formation of the glucose pyranose ring.

4.3.3.3 GALACTOSE

Galactose is a water soluble monosaccharide (aldose) that is a structural isomer of glucose. It forms a pyranose ring (Fig 4.7) which differs from glucose at C4 where the OH group is above

the plane in galactose and below the plane in glucose. Galactose combines with glucose to form a dimer called lactose (milk sugar) which is present in milk. Galactose is a powerful reducing sugar because its open chain has an aldehyde group.

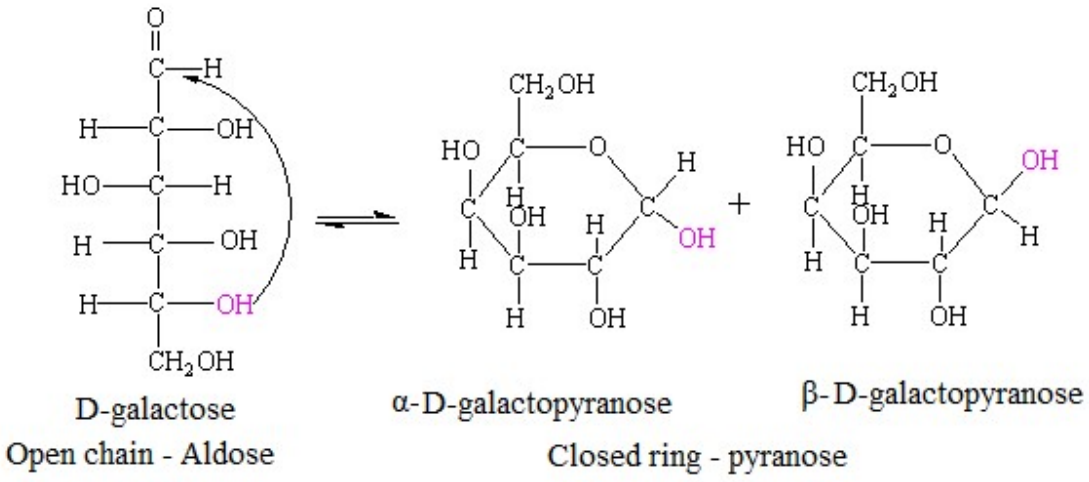


Figure 4.7. Formation of the galactose pyranose ring.

4.3.3.4 FRUCTOSE

Fructose (fruit sugar) is a water soluble monosaccharide found in honey, fruits, flowers, berries, and in root crops. The open chain of fructose is a ketone (ketose) whose carbon 2 combines with the OH group of carbon 5 to form a five-membered furanose ring (Fig 4.8). Like glucose, fructose is used as a source of energy in cellular respiration. Fructose is a weak reducing sugar because its open chain structure is able to isomerise into an aldose (glucose). Carbon 2 of fructose is asymmetric leading to the formation of the α- and β- isomers like in glucose. Fructose is a structural isomer of glucose.

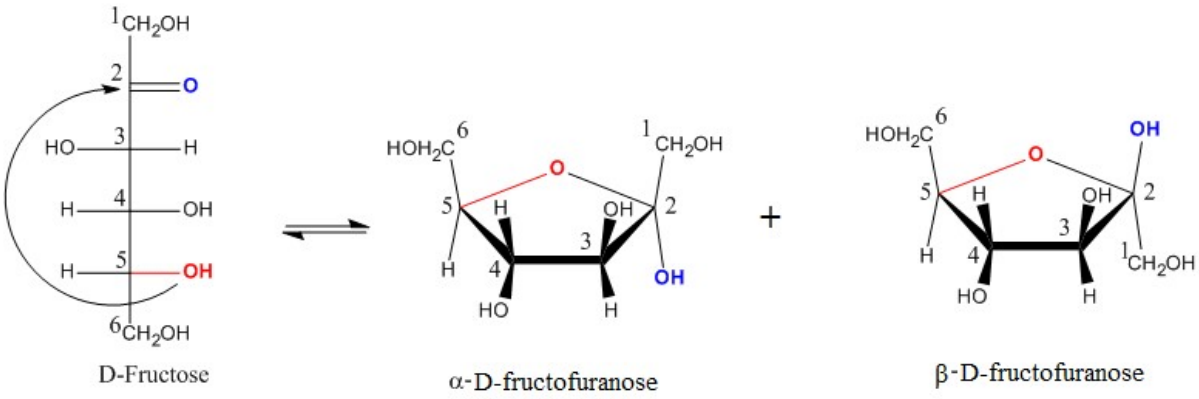


Figure 4.8. Formation of the fructose furanose ring.

4.4 DISACCHARIDES

Disaccharides are made up of two sugar units (dimers). They are crystalline, sweet to taste and readily dissolve in water. Disaccharides are formed by the condensation (dehydration) reaction between two monosaccharides. The bond formed is called a glycosidic bond. The most common disaccharides are sucrose, lactose and maltose. Disaccharides are temporary energy stores which are hydrolysed (broken down) into their different monomers which are then used to produce energy through cellular respiration.

4.4.1 SUCROSE

Sucrose (cane sugar**)** is disaccharide composed of glucose and fructose which are linked through a 1,2 glycosidic bond between C_1 of α-glucose and C_2 of β-fructose (Fig 4.9). It is a temporary energy store which is broken down into glucose and fructose which are then used in cellular respiration. The molecular formula of sucrose is $C_{12}H_{22}O_{11}$. Sucrose is most abundant in plants where it is translocated in large quantities through the phloem tissue**.**

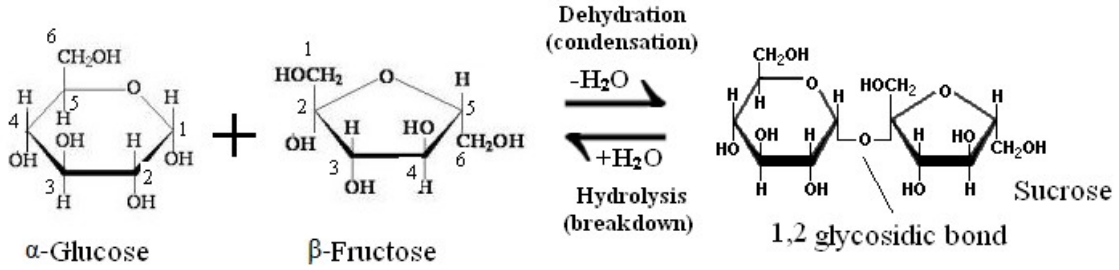


Figure 4.9. Formation and breakdown of sucrose

Sucrose is a non reducing sugar because it is joined through carbon 1 of glucose and carbon 2 of fructose that contain the aldehyde and keto groups which have the reducing properties in the individual open chain structures. Sucrose is broken down into glucose and fructose which are then used to generate energy in tissue respiration. It is used as a sweetener, for baking, confectionery and as a food preservative.

4.4.2 LACTOSE

Lactose (milk sugar) is a disaccharide composed of galactose and glucose which are linked through a β–(1, 4) glycosidic bond between C_1 of β-galactose and C_4 of either α-glucose or β-glucose. It has a formula of $C_{12}H_{22}O_{11}$. Lactose is water soluble and can be extracted from whey (mainly sweet whey). The formation and breakdown of lactose is illustrated in Figure 4.10.

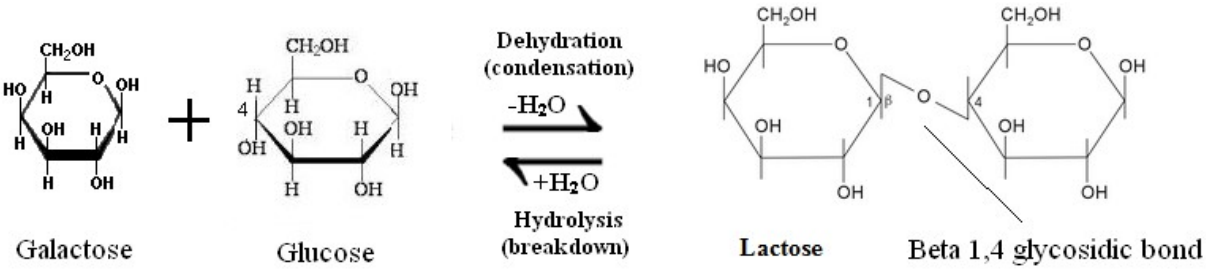


Figure 4.10. Formation and breakdown of lactose

Lactose is a reducing sugar because carbon 1 of its glucose is free and can form an open chain to expose the aldehyde which has the reducing properties. It can be broken down into galactose and glucose which are then used to generate energy in tissue respiration. Lactose is added to pills as filler and to some types of beer (stouts) to reduce the bitter taste.

4.4.3 MALTOSE

Maltose (malt sugar) is a water soluble disaccharide composed of two glucose molecules which are linked through an α 1→4 glycosidic linkage (Fig 4.11). It is a reducing sugar because carbon 1 on one of its glucose monomers is free and can form an open chain to expose the aldehyde which has the reducing properties.

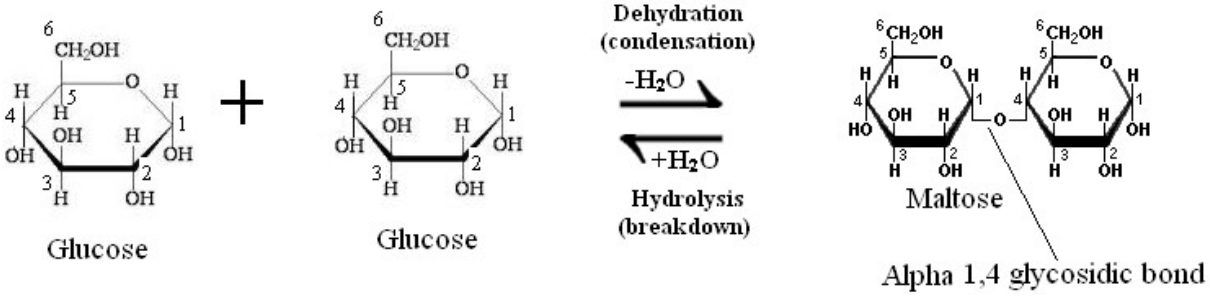


Figure 4.11. Formation and breakdown of maltose

Maltose is normally produced through the breakdown (digestion) starch by the enzyme amylase during animal digestion and in germinating seeds. Maltose is then broken down into glucose units by the enzyme maltase. It is an important intermediate during the production of beer from cereals such as barley, millet, maize and rice.

4.5 POLYSACCHARIDES

Polysaccharides are non-sweet, non-crystalline macromolecules which are insoluble or slightly soluble in water. They are formed by the condensation (dehydration) reactions between many monosaccharides. Polysaccharides are used either as food and energy stores (e.g. starch and glycogen) or as structural materials (e.g. cellulose and chitin).

Starch and glycogen are suitable as energy storage molecules because they (i) are insoluble in water, (ii) don't affect the osmotic potential of the cell, (iii) fold into compact shapes within limited space (iv) are easily converted to disaccharides and monosaccharides by hydrolysis (digestion). Cellulose and chitin are suitable as structural materials because they (i) are insoluble in water (ii) are made of long thread (fibres) (iii) have very high tensile strength.

4.5.1 STARCH

This is a polymer of α-glucose monomers which first join to form maltose. It is insoluble in cold water because it is a very long molecule with many glycosidic bonds between glucose monomers and its tightly packed structure. It has two components: (i) Amylose which has a straight chain structure, consisting of thousands of α-glucose molecules linked through 1,4 glycosidic bonds and coils into a helix forming a compact shape. A suspension of amylose in water gives a blue-black colour with iodine solution because the iodide complex slips into the α-helix coil. It constitutes 20-30% of starch. (ii) Amylopectin which has a similar structure to amylose but has branches, formed by 1, 6 glycosidic bonds and its chains are shorter. A suspension of amylopectin in water gives a red-violet colour with iodine solution because there is little interaction between the iodide complex and the amylopectin. It constitutes 70-80% of starch.

Starch which is a major energy store in plants and is the most common carbohydrate in human staple foods such as rice, wheat, maize, cassava and potatoes. Starch is easily broken down into maltose (disaccharide) and glucose (monosaccharide) by hydrolysis (digestion) (Figs 4.12 and 4.13). In industry, starch is used as a thickening agent, stabilizer or as a prebiotic.

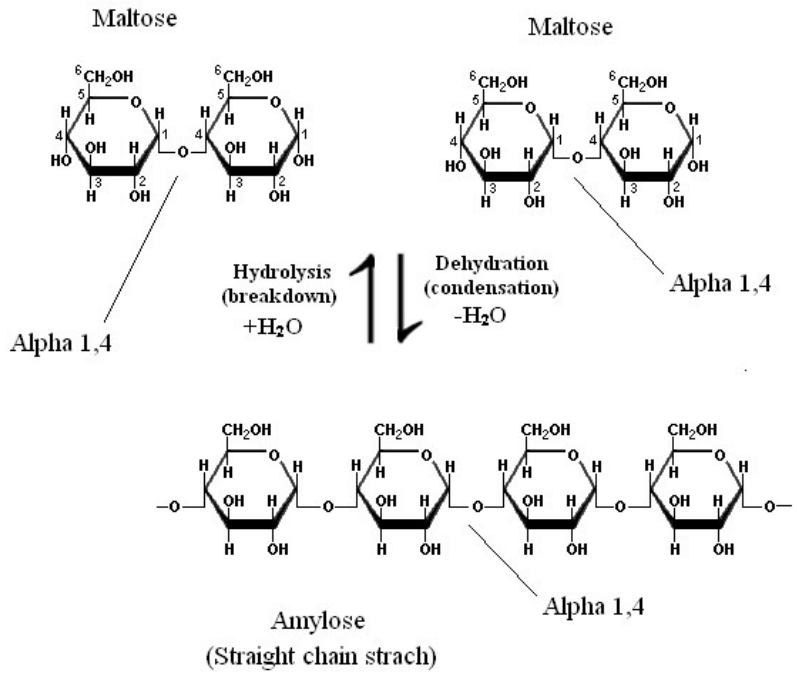


Figure 4.12. Synthesis and breakdown of amylose (straight chain starch)

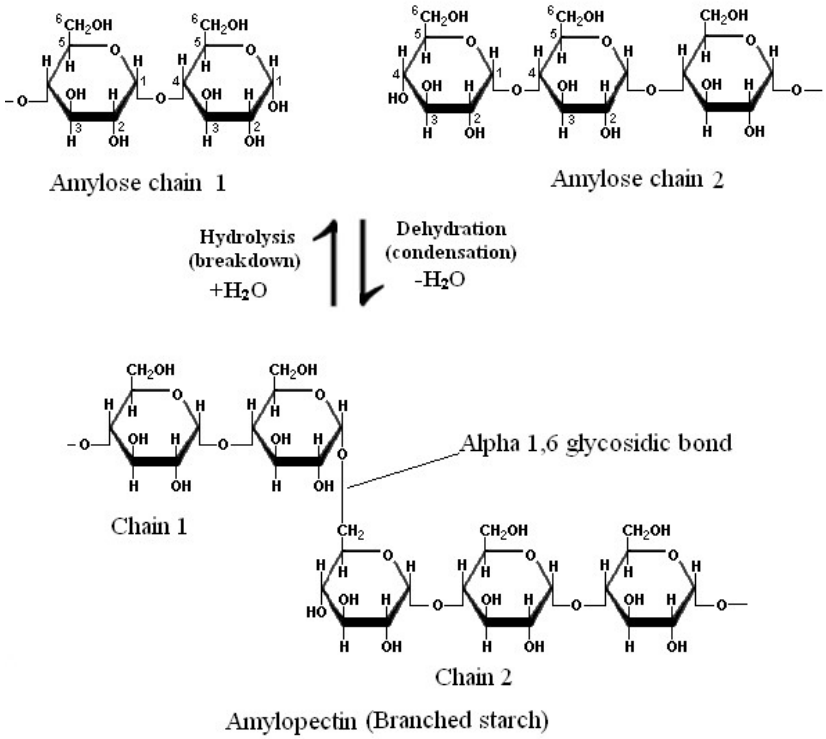


Figure 4.13. Synthesis and breakdown of amylopectin (branched starch)

4.5.2 GLYCOGEN

Glycogen is the animal equivalent of starch (amylopectin) and is made from α-glucose. It is water insoluble because of the numerous α(1-4) and α(1-6) bonds between its glucose monomers and its compact structure. It exists in form of granules (Figure 4.14). in the cytoplasm of many types of cells but is stored mainly in the liver and muscle cells of vertebrates. Glycogen is hydrolysed into glucose for use in respiration when need arises. Although it is similar to amylopectin, its branches are shorter and more frequent. The glucose chains of glycogen are organized in branches of a tree originating from a protein molecule at the centre of the structure.

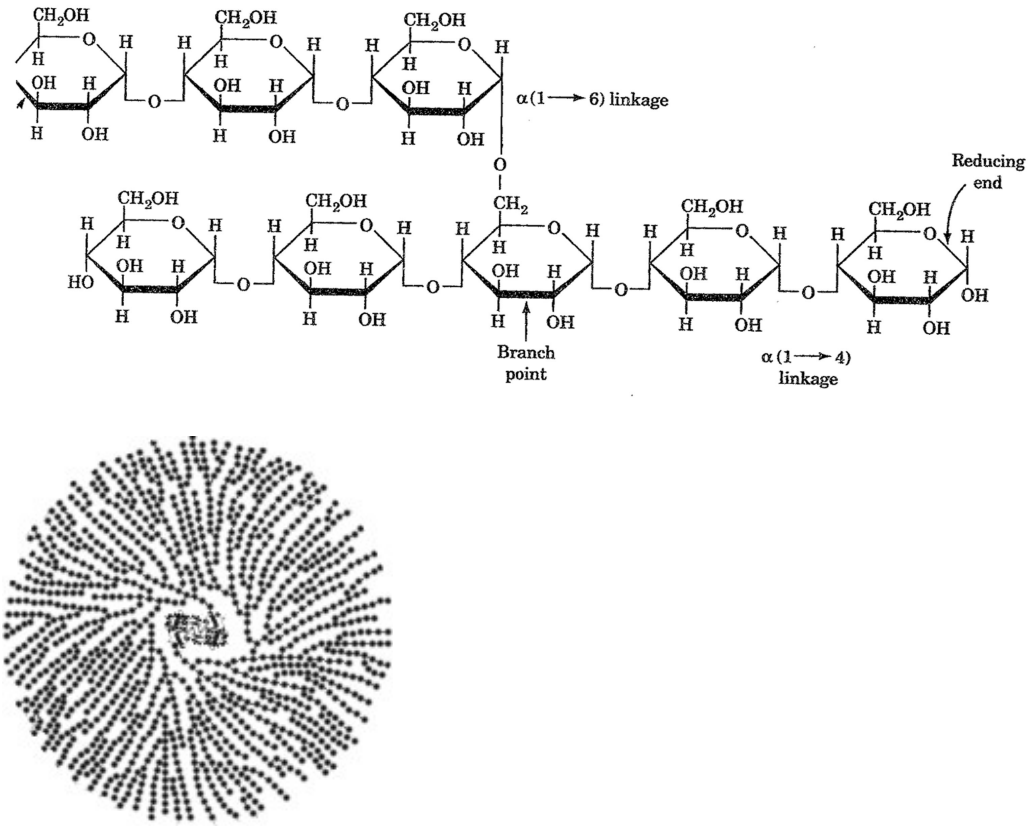
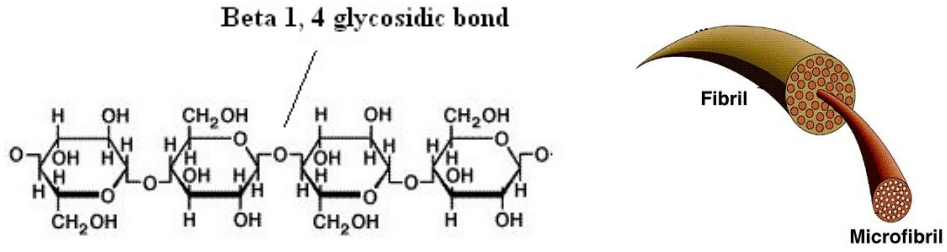


Figure 4.14. Structure of glycogen

4.5.3 CELLULOSE

Cellulose is a water insoluble polymer of β-glucose with -CH_2OH groups alternating above and below the plane of the long unbranched cellulose molecule (Figure 4.15). The hydroxyl (OH) groups which project outwards from each chain form hydrogen bonds with neighbouring chains. Neighbouring cellulose molecules lie close together in layers and form rigid structures called microfibrils, which are arranged in larger bundles called macrofibrils. These bundles are arranged in layers and have tremendous tensile strength. The cellulose layers are fully permeable to water and solutes which are important in the functioning of plant cells. Cellulose is the most abundant organic compound on earth and is the major structural material of plant cell walls.



(a) (b)

Figure 4.15. Structures of cellulose (a), a fibril and a microfibril (b)

Cattle, horses and other ruminant mammals as wells as termites have bacteria living in their digestive systems that are able to digest cellulose into soluble sugars which are then used by both the bacteria and their hosts (a relationship called symbiosis).

Cellulose is important in human diets as dietary fibre. In industry, cellulose is used to produce paper and cotton thread. There is some research aimed at converting cellulose into biofuels.

4.5.4 CHITIN

Chitin is an unbranched polymer of N-acetyl-D-glucosamine. It is found in cell walls of fungi and in exoskeletons of insects, crabs, and shrimps. It is similar to cellulose, but the hydroxyl group of carbon 2 of each glucose unit has been replaced with an acetamido ($NH(C=O)CH_3$) group (Figure 4.16).

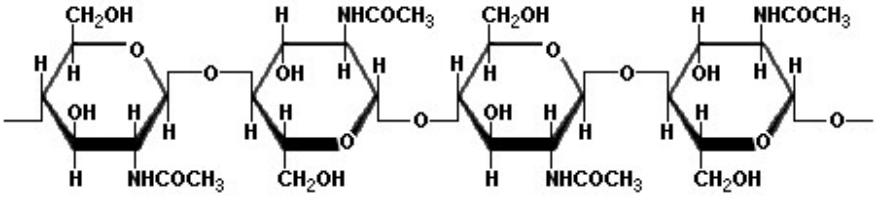


Figure 4.16. Structure of chitin

4.6 METABOLISM OF CARBOHYDRATES

The different carbohydrates are metabolised to release energy as summarised in Table 4.1.

Table 4.1 The breakdown of various carbohydrates

#	**Carbohydrate**	**Enzyme (s)**	**Products**
1	Starch	Amylase	Maltose
2.	Maltose	Maltase	Glucose
2.	Sucrose	Sucrase/Invertase	Glucose + Fructose
3.	Lactose	Lactase	Galactose + Glucose
4.	Glycogen	Glycogen phosphorylase	Glucose
5.	Glucose	Various glycolytic enzymes	$CO_2 + H_2O$ + Energy
6.	Fructose	Various glycolytic enzymes	$CO_2 + H_2O$ + Energy
7.	Galactose	Various glycolytic enzymes	$CO_2 + H_2O$ + Energy

UNIT: 5 LIPIDS

5.1 INTRODUCTION

Lipids are a group of naturally occurring esters of fatty acids and alcohols. They include fats, waxes, fat-soluble vitamins (such as vitamins A, D, E, and K), glycerides, phospholipids, and steroids (special type of lipids with a ring structure). They are water-insoluble and can be extracted from cells using organic solvents such as ether, chloroform and benzene. The main biological functions of lipids include (i) energy storage (ii) cell signalling (iii) structural support of cell membranes (iv) heat and electrical insulation (v) buoyancy (vi) water proofing (vii) production of metabolic water and (viii) protection of internal organs.

5.2 OBJECTIVES

At the end of this topic you should be able to:

1. Classify lipids as fats, oils and waxes
2. Recall the structure of a triglyceride synthesised from glycerol and fatty acids
3. Describe the formation of ester bonds
4. Describe the nature of saturated and unsaturated fatty acids
5. Describe the roles of lipids as stores, and, in protection, waterproofing, insulation and Buoyancy
6. Describe the structure and explain the properties of phospholipids and their role in the cell membranes.
7. Recall the structure and role of steroids

5.3 FATTY ACIDS

A fatty acid is made of a hydrocarbon chain ($R = CH_3(CH_2)_x$ -) that terminates with a carboxylic acid group (COOH-). This makes the fatty acid molecule amphipathic meaning that it has a polar, (hydrophilic) head and a nonpolar (hydrophobic) tail.

5.3.1 Saturated fatty acids

Fatty acids without any carbon-carbon double bonds are said to be saturated meaning each carbon atom has the required number of hydrogen atoms. They have only single carbon-carbon bonds (C-C). The absence of double bonds makes saturated fatty acids rigid (not flexible). Saturated fatty acids are found in butter, cheese, coconut oil, meat, margarine and fried foods. An example of a saturated fatty acid is stearic acid which has 18 carbons, with a chemical formula $CH_3(CH_2)_{16}COOH$ (Fig 5.1). Stearic acid is a waxy solid at room temperature. It is mainly used in the production of detergents, soaps, and cosmetics such as shampoos and shaving cream products.

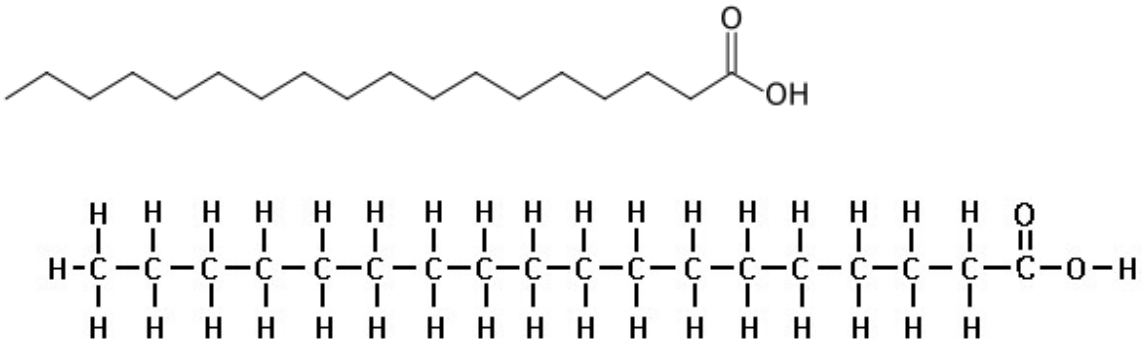


Figure 5.1. The structure of stearic acid an unsaturated fatty acid

5.3.2 Unsaturated fatty acids

Fatty acids with one or more carbon-carbon double bonds (C=C) are said to be unsaturated meaning that some carbon atoms have less than the required number of hydrogens. Monounsaturated fatty acids have one double bond while polyunsaturated fatty acids have two or more. The presence of double bonds makes unsaturated fatty acids flexible (fluid) and this is why they melt at much lower temperature than saturated fatty acids. An example of an unsaturated fatty acid is oleic acid, a mono unsaturated 18 carbon molecule with a chemical formula $CH_3(CH_2)_7CH=CH(CH_2)_7COOH$ (Fig 5.2). It is an oily liquid at room temperature. Oleic acid is found in olive oil, avocado, soya bean oil, canola oil, sunflower oil and walnuts.

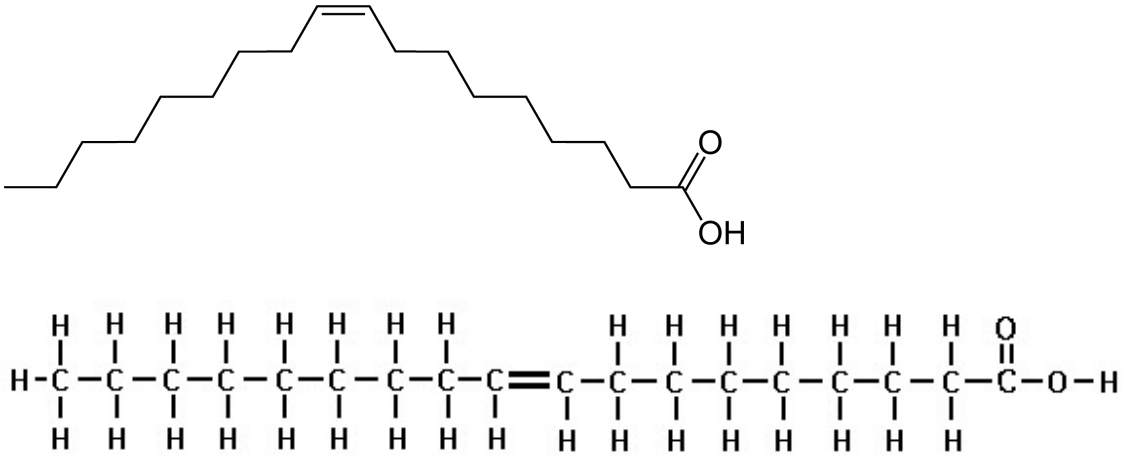


Figure 5.2. Structure of oleic acid a saturated fatty acid

5.3.2.1 Cis and trans unsaturated fatty acids

Cis unsaturated fatty acids have hydrogen bonds on the same side of the double bond making them relatively more flexible than trans unsaturated fatty acids which have hydrogen atoms on opposite sides of the double bond (Fig 5.3).

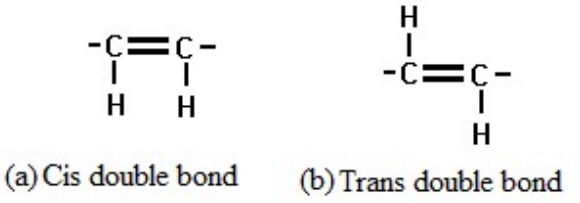


Figure 5.3. Structure a cis and a trans carbon-carbon double bond

5.4 GLYCEROL

Glycerol (or glycerine) is a simple sugar poly alcohol which combines with fatty acids in the synthesis of lipids known as glycerides. It is colourless, odourless, viscous and sweet-tasting. It has three hydroxyl groups (Fig 5.4**)** which make it soluble in water and make it able to absorb water. Its chemical formula is $C_3H_8O_3$.

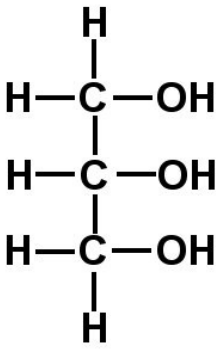


Figure 5.4. Structure of glycerol (propane 1,2,3 triol or 1,2,3 propanetriol).

It is an important component of natural lipids called glycerides which are esters of fatty acids and the OH group (s) of gelycerol. It is produced from the lipids through saponification and used in the food industry a solvent, sweetner or preservative and in the pharmaceutical and cosmetic industry as an additive in cough mixtures, skin care products, etc.

5.5 GLYCERIDES

Glycerides are ester compounds of glycerol and fatty acids. Glycerol has three hydroxyl (OH) groups each of which can condense with a carboxyl group (COOH) of a fatty acid to form an ester (-COO-) bond (Fig 5.5).

This is a condensation reaction and water is released in the process. Monoglycerides have a single fatty acid chain; diglycerides have two fatty acid chains while triglycerides have three fatty acid chains.

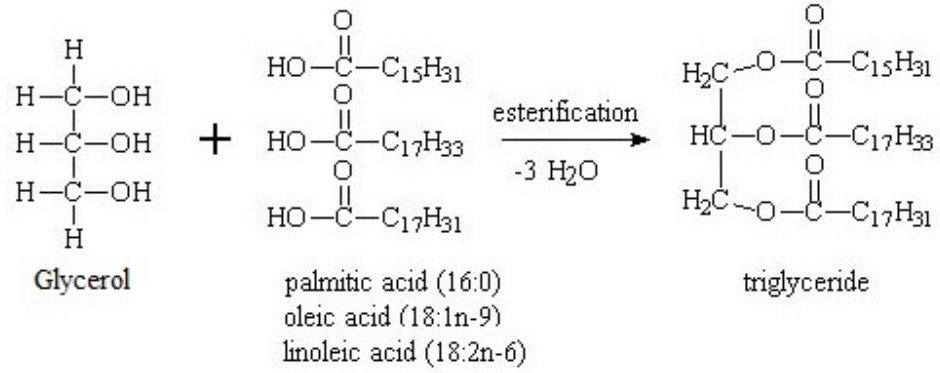


Figure 5.5. Formation of a triglyceride (lipid) from three fatty acids and glycerol by a condensation reaction

The long hydrocarbon chains of the fatty acids form hydrophobic tails which make lipids insoluble in water. Triglycerides are the commonest lipids in nature and are classified as fats (if they are solid at 20°C) and as oils (if they are liquid at 20°C).

5.6 PHOSPHOLIPIDS

A phospholipids is a triglyceride derivative in which one fatty acid has been replaced by a phosphate group and a nitrogen-containing molecule. One of the two fatty acid chains of a phospholipid is saturated while the other chain is unsaturated (has a bend or kink: Fig 5.6).

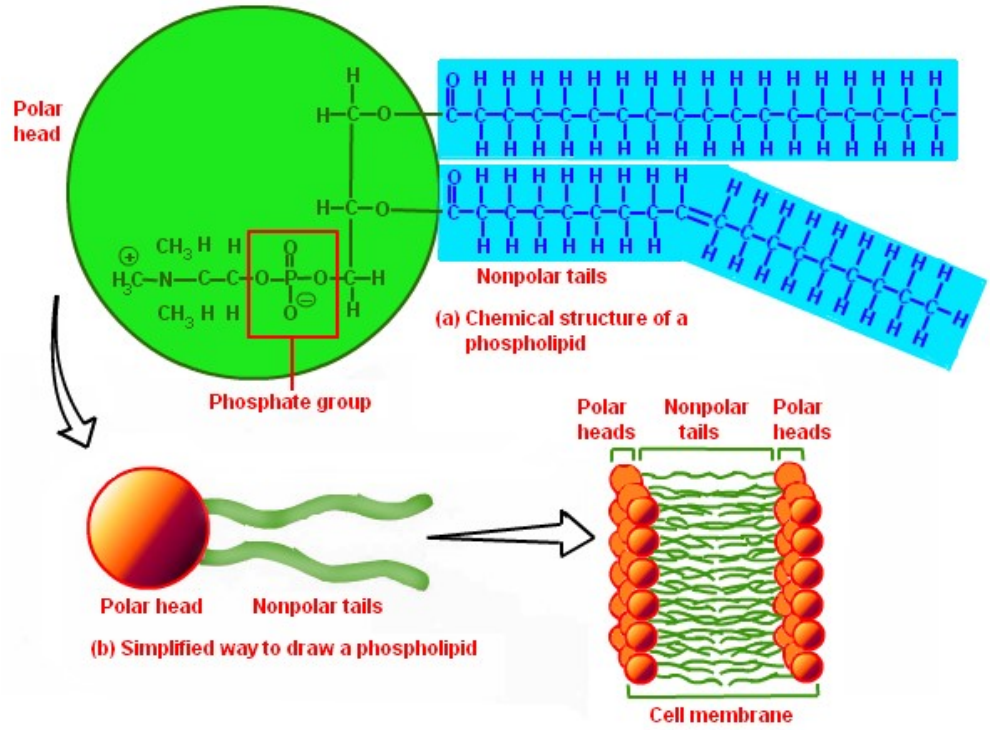
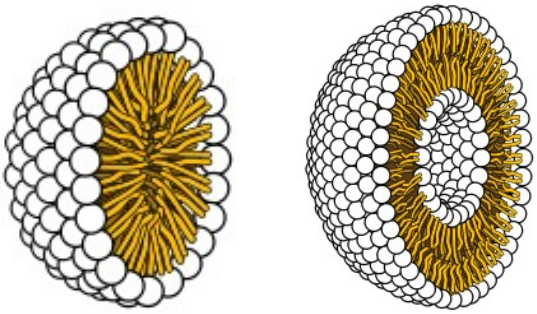


Figure 5.6. Structure of a phospholipid and the cell membrane bilayer

Phospholipids form micelles or liposomes (ball-shapes) in water because of the hydrophobic interactions between the fatty acid chains which tend to cluster inwards away from water while the phosphate groups (heads) stick out into the surrounding water (Fig 2.7).



(a) (b)

Figure 5.7. Formation of a micelle (a) and a liposome (b) in water by phospholipids

Phospholipids are found in the cell membrane where they form a phospholipid bilayer which is important for the function of the cell membrane.

5.7 WAXES

Waxes are mainly esters of fatty acids with long-chain alcohols **(Fig 5.8).** They are used as waterproofing material by plants and animals. In plants they form an additional protective layer on the cuticle of the epidermis of leaves, fruits and seeds. In vertebrate animals they are found in skin, fur and feathers while in insects they are part of the exoskeleton (chitin).

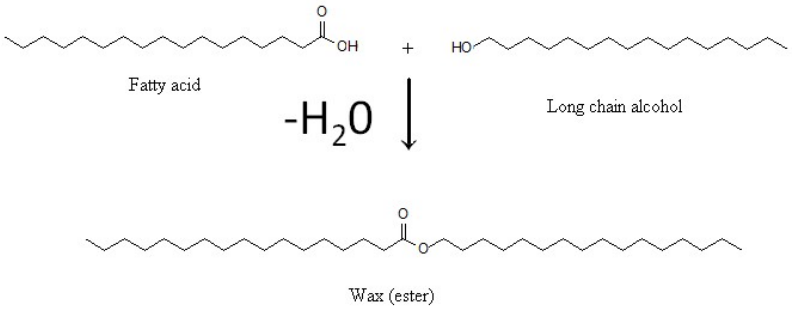


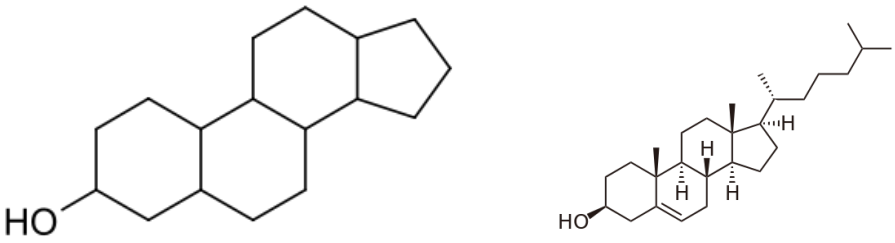
Figure 5.8. Formation of a wax ester from a fatty acid and an alcohol.

Beeswax is a special type of wax found in the honeycombs. The bees use it to store honey and to protect the larvae and pupae. Humans use it in the food industry as a glazing agent (for fruits), a coating agent (in cheese), in chewing gum, etc; in cosmetic as lip ice, lip stick, moisturisers, hair products, etc

Carnauba wax also called Brazil wax or palm wax is a wax of the leaves of the palm tree. It is used in automobile waxes, shoe polishes, instrument polishes, floor and furniture waxes and polishes, dental floss and in food products such as sweets.

5.8 STEROIDS

These are special lipid compounds with four rings (**Fig 5.9)** which are found in plants, animals and fungi.



Steroid **Cholesterol**

Figure 5.9. Chemical structure of a steroid and of cholesterol

The large number of CH groups makes steroids non-polar. The most common type of animal steroid is cholesterol which is an important part of the animal cell membrane structure and function **(Fig 5.10).** Cholesterol is also a precursor to fat-soluble vitamins and steroid hormones (e.g. sex hormones).

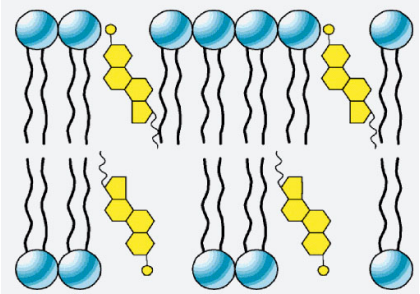


Figure 5.10. The interaction between cholesterol and phospholipids in cell membrane

5.9 FUNCTIONS OF LIPIDS

The functions of lipids include energy storage, protection, waterproofing, insulation, buoyancy, cell signalling, formation of cell membranes, and production of metabolic water.

5.9.1 Energy storage

The major function of lipids is to act as energy stores. They have a higher calorific value than carbohydrates. This is because lipids have a higher proportion of hydrogen and very low proportion of oxygen compared to carbohydrates. Animals store extra fat under the skin when hibernating. Migratory birds which must fly long distances without eating use stored energy in form of triglycerides enable them to fly. Plant seeds, fruits and chloroplasts are usually rich in oils which they use as energy stores.

5.9.2 Protection

Lipids provide structural support so as to prevent injury to vital organs like the liver, kidney and spleen. Lipids also act as a cushion to internal body organs by reducing the effect of shock or trauma. This protects the organs against mechanical damage.

5.9.3 Waterproofing

The plasma membrane which is rich in lipids makes the skin of vertebrates water proof. The skin also secretes oils which form a layer on the surface to prevent loss of water from the body. Water from outside is also prevented from entering the body directly through the skin. In birds such as ducks, oil found on their feathers helps in insulation. In insects, a waxy layer is deposited on the outside of their cuticle. In plants, leaves are covered by waxy cuticles, which prevent excess water loss or entry.

5.9.4 Insulation

Lipids which are stored under the skin of vertebrate animals including humans provide insulation against temperature changes. Since lipids are poor conductors of heat, they help the animals keep of the core (centre) of the body warm during the cold season. Some temperate mammals such as seals and polar bears need a very thick layer of lipid (blubber) in order to survive the harsh winter. The myelin sheath around axons of nerve cells is rich in lipidsand this provides electrical insulation of the nerve cells. They also insulate the body from extreme temperature changes and heat loss.

5.9.5 Buoyancy

In aquatic animals living in cold climates, such as whales, the fat deposit in form of blubber is also used for buoyancy.

5.9.6 Cell signalling

Glycolipids are made up of carbohydrates and lipids. The carbohydrate component allows substances such as antibodies and hormones to recognise it. Steroid hormones which are lipid-derived are use in transmitting signals to activate certain cellular activities. Plant growth hormones are also lipid –derived signal molecules.

5.9.7 Cell membrane lipids

Membranes contain phospholipids, lipoproteins and glycolipids. The phospholipids and lipoproteins form the bulk of the cell membranes

5.9.8 Production of metabolic water

When fats are oxidised metabolic water is the product. This metabolic water can be very useful to some desert animals, such as the kangaroo rat, which stores fat for the purpose of generating water. A camel stores fat in the hump primarily as a water source rather than as an energy source.

UNIT 6 PROTEINS

6.1 INTRODUCTION

Proteins are complex organic compounds which always contain carbon, hydrogen, oxygen and nitrogen and in some cases sulphur. They made up of chains of monomers called amino acids. Proteins are the most diverse organic molecules found in living cells and make up over 50% of the total dry cellular mass. The functions of proteins include (i) structure provision (e.g. collagen of the skin), (ii) transport (e.g. haemoglobin of red blood cells) (iii) enzymatic activity (e.g. sucrase) (iv) hormonal activity (e.g. insulin), (v) protective (e.g. antibodies).

6.2 OBJECTIVES

At the end of this topic you should be able to:
At the end of this topic you should be able to:
1. Explain the nature of amino acids as monomers of polypeptides and proteins
2. Recall the general formula and general structure of amino acids
3. Describe formation and break down of peptide bonds in polypeptides.
4. Classify proteins into primary, secondary, tertiary and quaternary structures.
6. Explain the roles of ionic, hydrogen and disulphide bonds in the structure of proteins as illustrated by insulin and collagen
7. Explain the structure and functions of enzymes and their co-factors.
8. Explain the effects of different factors on enzyme activity.
9. Explain the nature and roles of fibrous and globular proteins as illustrated by insulin and collagen.

6.3 AMINO ACIDS

There are 20 amino acids found in naturally occurring proteins. Plants are able to make all the 20 amino acids from simpler substances. Animals are unable to synthesis all the 20 amino acids so they must obtain some of them 'ready-made' directly from their diet. The amino acids which animals are unable to synthesise are called essential amino acids. Most amino acids are alpha (α) amino acids, in which the amino ($-NH_2$) group is attached to the α carbon of the carboxylic (-COOH) group (Fig 6.1). Only proline is an alpha imino acid. The general formula of an amino

acid is given in Figure 6.1.

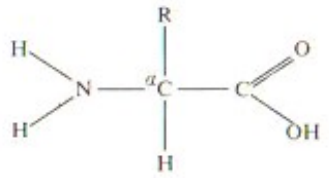


Figure 6.1. General formula of an amino acid showing the amino (NH_2) and carboxylic (COOH) groups attached to the α-carbon.

The alpha carbon of an amino acid has four groups attached i.e. an amino group, a carboxylic group, an alkyl group and a hydrogen atom. The majority of amino acid possess one carboxylic group and one amino group and are said to be neutral. In some cases there may be two or more amino groups present giving rise to a basic amino acid. When two or more carboxylic groups are present, the result is an acidic amino acid. The composition of the alkyl (residue/R/functional) group differs from one amino acid to another and is responsible for the unique properties which each amino acid displays.

The simplest amino acid is glycine which is formed when the R group is represented by H. Since four different R groups attach to the α carbon, this carbon is therefore asymmetrical. This means that the amino acid will possess two optically active isomers. All amino acids except glycine are optically active and may exist in either the D or L forms. In nature amino acids are generally found in the L form. The names of the twenty common amino acids, their abbreviations and properties are shown in the Table 6.1.while the side chains (R groups) are shown in Table 6.2.

Table 6.1. Naturally occurring amino acids

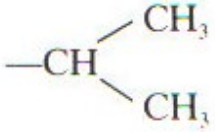
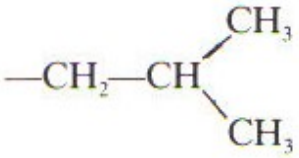
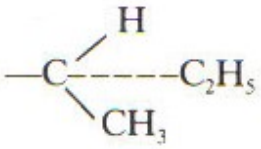
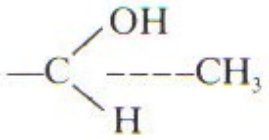
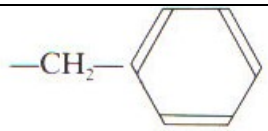
#	Amino acid	Three letter	One letter	Comment	Type
1	Glycine	Gly	G	Smallest aa	
2	Alanine	Ala	A		
3	Valine	Val	V	Essential	Non-polar,
4	Leucine	Leu	L	Essential	Aliphatic

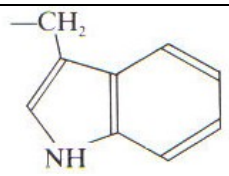
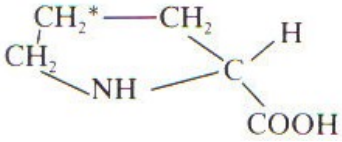
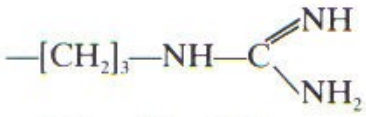
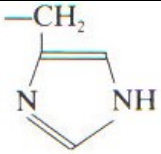
5	Isoleucine	Ile	I	Essential	
6	Serine	Ser	S		
7	Threonine	Thr	T	Essential	
8	Asparagine	Apn	N		
9	Glutamine	Gln	Q		Polar, aliphatic
10	Phenylalanine	Phe	F	Essential	
11	Tyrosine	Tyr	Y		
12	Tryptophan	Trp	W	Essential	Aromatic
13	Cystein	Cys	C		Sulphur-
14	Methionine	Met	M	Essential	containing
15	Proline	Pro	P		Imino acid
16	Aspartic acid/Aspartate	Asp	D		
17	Glutamic acid/Glutamate	Glu	E		Acidic
18	Lysine	Lys	K	Essential	
19	Arginine	Arg	R		
20	Histidine	His	H		Basic

6.3.1 Amino acid side chains

The side chains (R groups) of the natural amino acids are shown in Table 6.2.

Table 6.2. Amino acid side chains

#		Amino acid	Side chain (R group)
1		Glycine	—H
2		Alanine	—CH_3
3		Valine	
4		Leucine	
5		Isoleucine	
6		Serine	—CH_2—OH
7		Threonine	
8		Asparagine	—CH_2—CO—NH_2
9		Glutamine	—$[CH_2]_2$—CO—NH_2
10		Phenylalanine	
11		Tyrosine	

12		Tryptophan	
13		Cystein	$—CH_2—SH$
14		Methionine	$—[CH_2]_2—S—CH_3$
15		Proline	 Whole molecule
16		Aspartic acid	$—CH_2—COOH$
17		Glutamic acid	$—[CH_2]_2—COOH$
18		Lysine	$—[CH_2]_4—NH_2$
19		Arginine	
20		Histidine	

6.3.2 Properties of amino acids

Amino acids are colourless, crystalline solids. They are generally soluble in water, but insoluble in organic solvents. In neutral aqueous solutions they exist as dipolar ions (amphoteric zwitterions) possessing both basic and acidic properties (Fig 6.2).

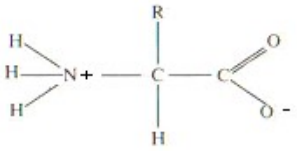


Figure 6.2. Zwitterionic nature of amino acids

Amino acids act as buffers in solutions, meaning that they keep the pH of their environment constant because they can either donate or accept hydrogen ions. The Amino group can accept hydrogen ions while the carboxylic group can donate hydrogen ions.

6.3.3 Classification of amino acids

Amino acids can be classified into non-polar, aliphatic (glycine, alanine, valine, leucine and isoleucine); polar, aliphatic (serine, threonine, asparagine, and glutamine); aromatic (phenylalanine, tryptophan and tyrosine); sulphur-containing (cysteine and methionine); imino acid (proline); acidic (aspartic and glutamic acids); and basic (lysine, histidine and arginine).

6.4. FORMATION AND BREAKDOWN OF PEPTIDES AND PROTEINS

Amino acids form peptide bonds with each other resulting in the polymers called peptides which can be oligopeptides (2-20 aa), polypeptides (more than 20 aa) and proteins (functional molecules). A peptide bond is formed between a carboxylic group of one amino acid and an amino group of the next amino acid. Water is eliminated in the process (condensation) as shown in Fig 1.4b. The product of two amino acids is called a dipeptide which possesses a free amino group at one end and a free carboxylic group at the other. This enables further joining of other amino acids to the free amino or carboxylic group. Three amino acids form a tripeptide and so on. When water is added to the peptide bond, it breaks (hydrolyses) to release the two amino acids (Fig 6.3).

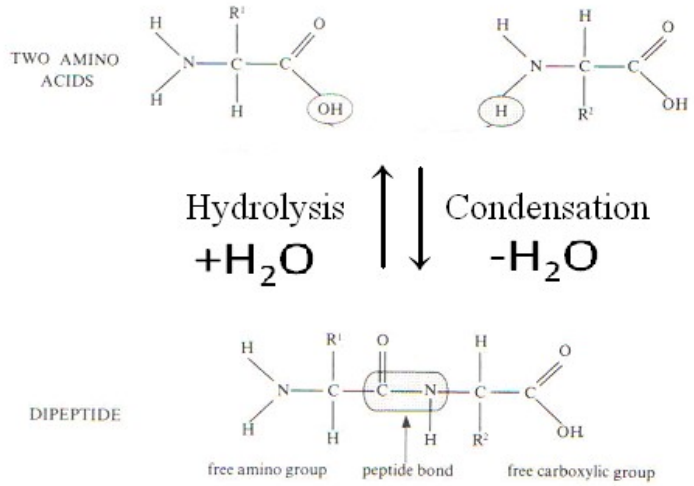


Figure 6.3. Formation and breaking of a dipeptide bond between two amino acids .

When many amino acids are joined together, a polypeptide is formed (Fig 6.4). When the polypeptide is hydrolysed, it is broken down into its constituent amino acid as is the case during digestion in the mammalian intestine.

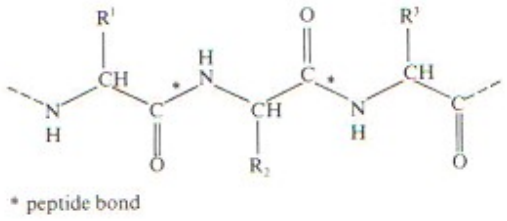


Figure 6.4. Part of a polypeptide showing the joining of three amino acids with side chains R_1, R_2 and R_3.

6.5 LEVELS OF PROTEIN STRUCTURE

The structure of proteins is at four levels namely; primary, secondary, tertiary and quaternary.

6.5.1 Primary structure

The primary structure is the number and sequence of amino acids held together by peptide bonds in a polypeptide chain (Fig 6.5). Each protein has a unique sequence of amino acids. The first protein to have its amino acid sequence elucidated (determined) was insulin, a peptide hormone. Insulin has two peptide chains in which chain A has 20 amino acids and chain B has 31 amino acids.

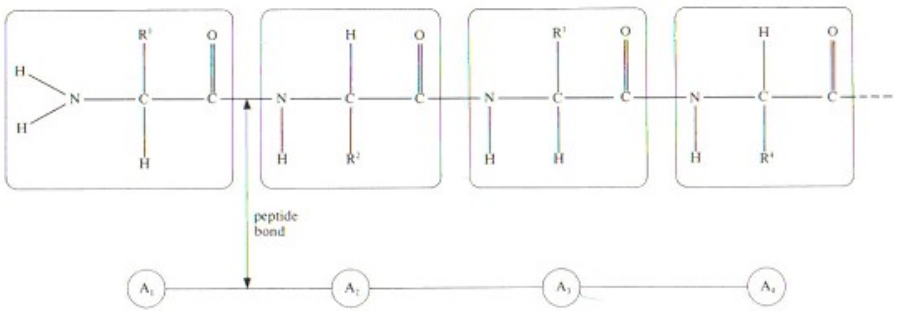


Figure 6.5. Part of a polypeptide chain primary structure. A_1, A_2, A_3 and A_4 are amino acids.

6.5.2 Secondary structure

The secondary structure of a protein is the arrangement of the amino acids within the chain. The two types of secondary structures are the α-helix (most common) and the β-pleated sheet (less common). See Figure 6.6.

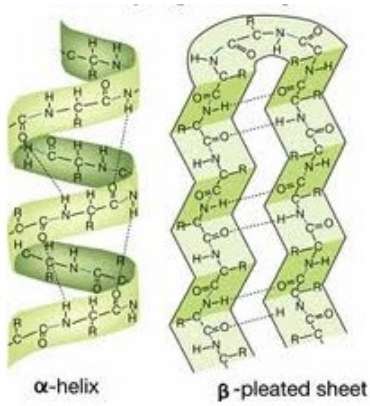


Figure 6.6. The alpha helix and beta-pleated sheet

The alpha helix is a right-handed coiled or spiral structure. This structure is maintained by many hydrogen bonds which are formed between adjacent CO and NH groups. The NH group of one amino acid is hydrogen-bonded to the CO group three amino acids away. X-ray diffraction analysis shows that the α-helix makes one complete turn for every 3.6 amino acids (Figure 1.4g). Keratin is an example of a fibrous protein which is entirely α-helical. It is the structural protein found in hair, wool, nails, claws, beaks, feathers, horns and skin of vertebrates.

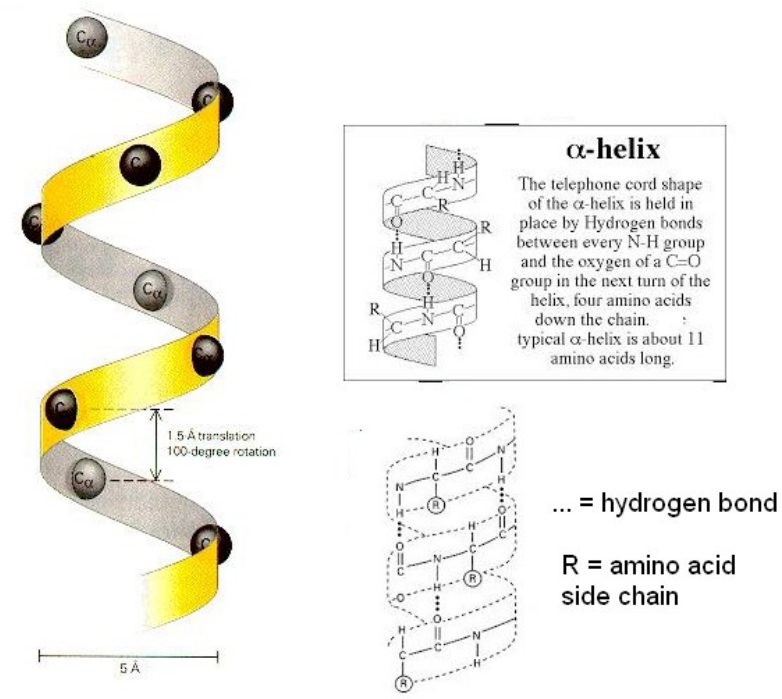


Figure 6.7. Structure of the α-helix of a peptide chain

The β-pleated sheets are extended forms of polypeptide chains (Fig 6.7). They are formed in some proteins due to (i) interference in hydrogen bonding by certain R groups, (ii) the occurrence of disulphide bonds (bridges) between different parts of the same chain and (iii) the inability of the amino acid proline to make intrachain hydrogen bonds. The β-pleated sheet is best represented by silk fibroin, the protein produced by silkworms which they use to spin their cocoon. This protein contains a number of adjacent polypeptide chains which are more extended than α-helices. They are normally arranged in an anti-parallel fashion, running in opposite direction to each other. They are brought together by interchain hydrogen bonds formed between C=O and NH groups of one chain and the NH and C=O groups of adjacent chains (Fig 6.8). This hydrogen bonding makes the β-pleated structure very stable.

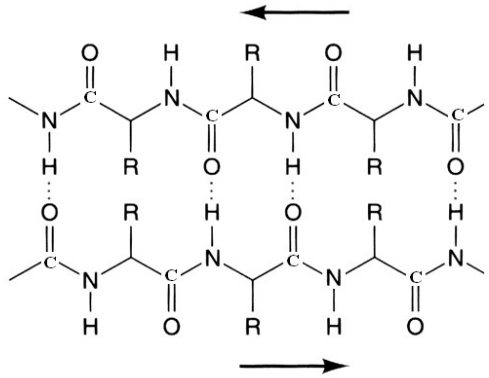


Figure 6.8. Two anti-parallel polypeptide chains forming a beta sheet

6.5.3 Tertiary structure

The tertiary structure of a protein is the bending and folding of the protein forming a precise globular shape. Most proteins are only active when they form this shape. When a globular protein loses its shape, it is said to be 'denatured' and usually it will also lose its biological function. The tertiary conformation is maintained by ionic, hydrogen and disulphide bonds as well as hydrophobic interactions and van der Waals forces (Fig 6.9).

6.5.3.1 Hydrogen bonds (2-10 kcal/mol; 5-30 kJ/mol)

These result because the electropositive hydrogen atoms of the OH or NH groups share the electrons of a neighbouring electronegative oxygen atom of the CO group. Hydrogen bonds can form between (i) atoms on two different amino acid side chains (ii) atoms on amino acid side chains and water molecules (iii) atoms on amino acid side chains and protein backbone atoms (iv) backbone atoms and water molecules at the protein surface (v) backbone atoms on two different amino acids. Although an individual hydrogen bond is weak, there are a lot of them within a polypeptide and their total effect is enough to provide stability as observed in the structure of silk.

6.5.3.2 Ionic bonds (20kJ/mol)

At a suitable pH an interaction may occur between ionised amino and carboxylic side chains (R groups). The result is the formation of an ionic bond. In solution the ionic bond is much weaker than a covalent bond and can be broken by changing the pH of the medium.

6.5.3.3 Disulphide bonds (60kcal/mol; 251 kJ/mol)

When two neighbouring molecules of the amino acid cysteine combine, their sulphhydryl (-SH) groups form a disulphide bond which is a covalent bond. Interchain or intrachain disulphide bonds may be formed. Disulphide bonds are the strongest in the tertiary structure of proteins.

6.5.3.4 Hydrophobic interactions (<40kJ/mol)

These are interactions in which nonpolar side chains of proteins aggregate in aqueous solution and exclude water molecules. They are important in the proper folding of a protein. Hydrophobic interactions usually form in the interior (hydrophobic core) of the protein where hydrophobic side chains are closely associated and are shielded from water.

6.5.3.5 Van der Waals forces (0.4-4.0kJ/mol)

These are weak electrical attractions which exist between different atoms which are very near to each other. They are produced by constantly fluctuating charges (dipoles) produced within individual atoms. Van der Waals forces are attractive within a certain distance between atoms. If the atoms are too close a repulsive force is produced. If the atoms are too far from each other, there is no effect of the van der Waals forces.

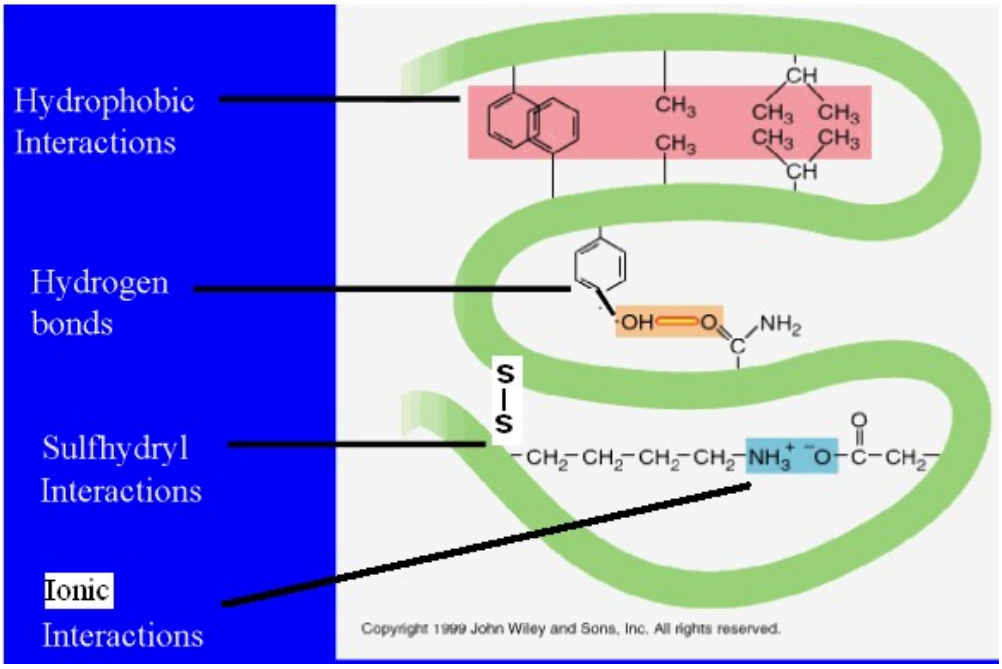


Figure 6.9. Bonds stabilizing the tertiary structure of proteins which include hydrogen bonds, disulphide (sulphhydryl) bonds, ionic bonds and hydrophobic (van der Waals) bonds.

In the case of insulin, the three-dimensional structure is further stabilised by disulphide bridges on cysteine residues. There are 6 cysteines, so 3 disulphide bridges are formed (Fig 6.10). In addition, the are many ionic interactions (salt bridges) as well as van der Waal's forces.

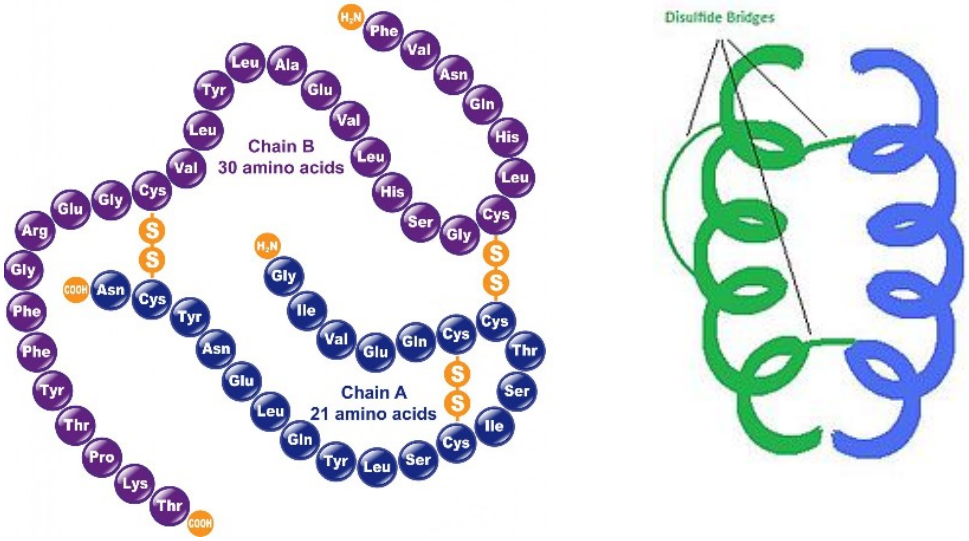


Figure 6.10. Disulphide bonds stabilizing the tertiary structure of insulin.

Another example of a globular protein is myoglobin (Fig 6.11), an oxygen-binding protein with 153 or 154 amino acids arranged in eight alpha helices.

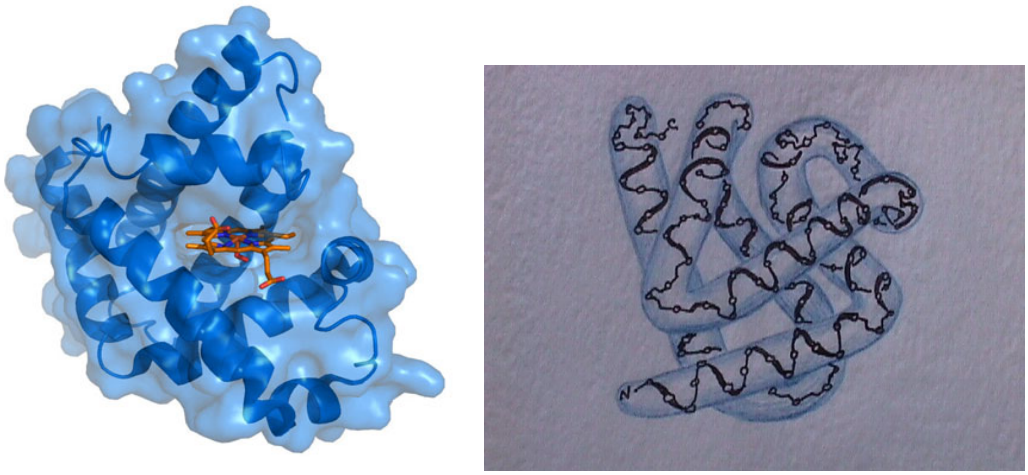


Figure 6.11. The tertiary structure of myoglobin, an oxygen-binding protein

6.5.4 Quaternary structure

The quaternary structure is the aggregation (coming together) of different polypeptide chains (subunits) held together by hydrophobic interactions, hydrogen bonds and ionic bonds. A lot of proteins have such a structure.

Haemoglobin is an example of a protein with quaternary structure (Fig 6.12). It consists of four globular chains i.e. two α-chains (containing 141 amino acids each) and two β-chains (containing 146 amino acids each). It is a transport protein molecule which can only function if it attains the quaternary structure. Each chain is called a subunit.

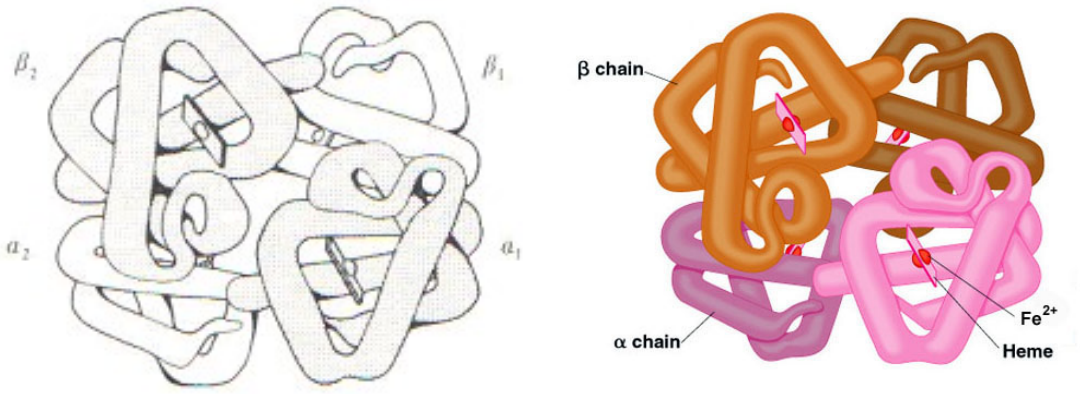


Figure 6.12. The quaternary structure of haemoglobin showing four chains α_1, α_2, β_1 and β_2.

6.5.4.1 Insulin

Insulin is a peptide hormone whose major function is to regulate the amount of glucose in the blood. When there is too much glucose in the blood, insulin promotes the synthesis of glycogen which is the stored in the liver and muscles. When the level of glucose become very low, insulin promotes the breakdown of glycogen to release glucose. Insulin is active when it is in single chain form (monomer: Fig 6.13). It is converted into dimers (two polypeptides) and then into hexamers (six polypetide granules) grouped around 2 zinc ions due to interactions between hydrophobic surfaces. The hexamer is the form in which insulin is stored in the beta cells of the pancreas and in which it is secreted into the blood stream.

Insulin monomer - The A chain is shown in blue and the B chain in red

Insulin dimer

Insulin hexamer

Figure 6.13. Insulin monomer, dimer and hexamer (with 3 dimers clustered around 2 zinc ions).

6.5.4.2 Collagen

Collagen is a fibrous protein which has three polypeptide chains wound around each other to form a triple helix (Fig 6.14). The secondary structure is the most important. It is in the form of elongated fibrils which form fibrous tissues. Collagen cannot be stretched and this is important for its connective function in tendons, cartilage, bone, skin, blood vessels, digestive tract and other tissues.

Figure 6.14. Collagen triple helix structure

UNIT 7: ENZYMES

7.1 INTRODUCTION

Enzymes are biological catalysts which speed up the rate of cellular reactions without themselves being used up. They are globular proteins produced by living cells. A very small amount of enzyme catalyses the reaction of a very large amount of substrate. Enzyme catalysed reactions are reversible and specific. The rate of enzyme catalysed reactions varies with pH, temperature, substrate concentration and enzyme concentration. Enzyme reactions can either be anabolic (involved in synthesis) or catabolic (involved in breakdown).

7.2 OBJECTIVES

At the end of this topic you should be able to:

1. Explain the concept of active site and enzyme specificity
2. Explain the Lock and Key and Induced fit mechanisms of enzyme activity
3. Explain the role of enzymes as biological catalysts;
4. Explain role of coenzymes
5. Predict enzyme activity in relation to pH, temperature, substrate and enzyme concentration
6. Distinguish between competitive and non-competitive enzyme inhibition
7. Explain the commercial uses of pectinases and proteases.

7.3 THE CONCEPT OF THE ACTIVE SITE AND SPECIFICITY

Enzymes are large globular molecules. The globular shape of enzymes is needed for the formation of a small and special portion called the active (binding) site (Fig 7.1). This is the only portion of the enzyme that reacts with the substrate. The remaining part of the protein is used to maintain the correct globular shape of the molecule which helps the active site to function at the maximum rate.

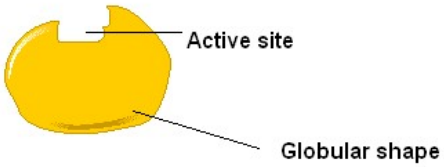


Figure 7.1 The structure of an enzyme showing the globular shape and the active site

7.4 THE KEY AND LOCK (FISCHER) MODEL OF ENZYME ACTIVITY

This model was developed by Fischer (1890) who suggested that each enzyme has a particular shape into which the specific substrate fits exactly. This model is the basis of the 'lock and key' hypothesis, where the substrate is the key whose shape is complimentary to the enzyme, which is the lock. The substrate binds at the active site to form an enzyme/ substrate (ES) complex. When the ES complex is formed it is 'activated' into forming the products of the reaction. Once the products are formed, they no longer fit into the active site and escape into the surrounding medium, leaving the active site free to receive new substrate molecules (Fig 7.2).

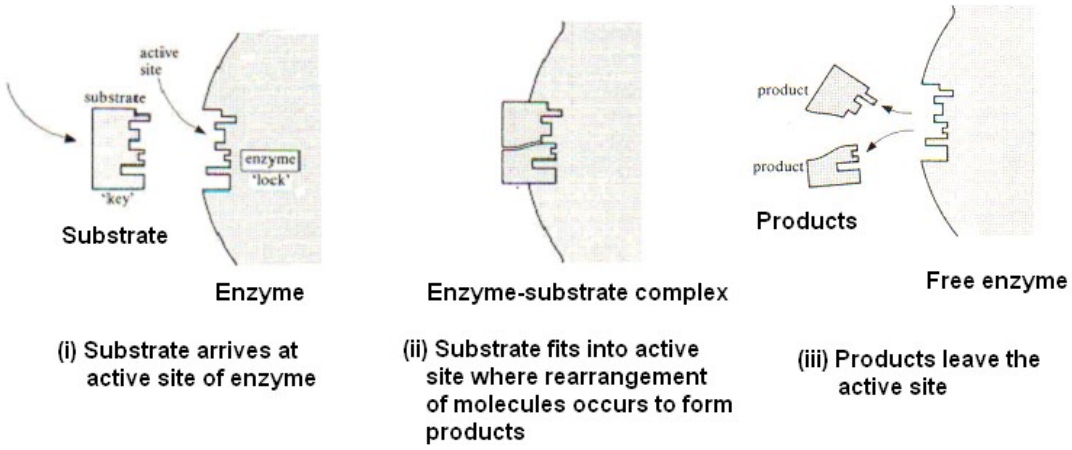


Figure 7.2 (i) Fischer's lock and key model of an enzyme and its substrate. (ii) The substrate fits into active site to form an enzyme substrate complex. (iii) Products leave the active site leaving the enzyme free and unchanged.

7.5 THE INDUCED – FIT (KOSHLAND) MODEL OF ENZYME ACTIVITY

Koshland (1958) proposed that the shape of an enzyme changes slightly when it binds its substrate (Fig 7.3). The change in shape of the enzyme results into an enzyme-substrate (ES) complex in which the enzyme and substrate fit exactly. This model is the basis of the 'induced-

fit' hypothesis. When the ES forms the products, the enzyme changes back to its original shape and the products no longer fit into the active site and escape into the surrounding medium, leaving the active site free to receive new substrate molecules (Fig 7.3).

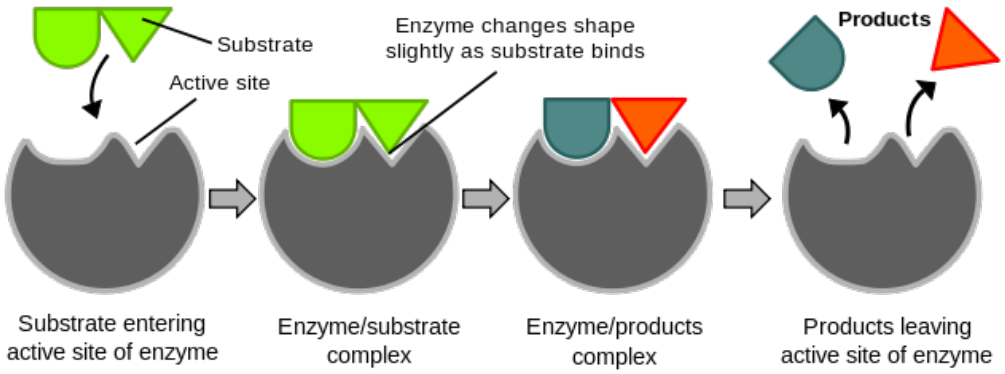


Figure 7. 3 Koshlands's induced-fit model of an enzyme and its substrate, the ES complex and formation of products and recycling of the enzyme.

7.6 ENZYMES AS BIOLOGICAL CATALYSTS

Enzymes catalyse (speed up) the rate of thermodynamically feasible biological reactions by reducing the activation energy (E_a) needed by the substrates for them to change into products. By reducing the E_a, enzymes speed up the rate of reaction without the need to raise the temperature at which the reaction takes place (Fig 7.4). The enzyme combines with its substrate to form a short-lived enzyme/substrate (ES) complex (Fig 7.3). The ES complex then breaks up into the free enzyme and products. The enzyme remains unchanged at the end of reaction and is free to interact again with more substrate

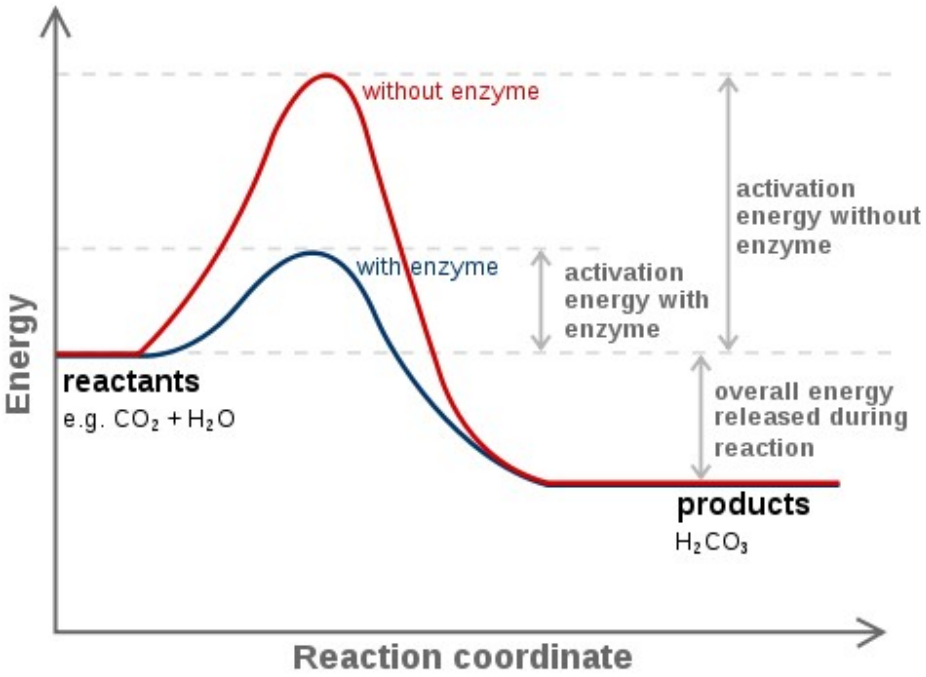


Figure 7.4 Energy diagram of an enzyme catalysed and a non-catalysed reaction. https://en.wikibooks.org/wiki/Structural_Biochemistry/Enzyme/Activation_energy#/media/File:Carbonic_anhydrase_reaction_in_tissue.svg

7.7 COFACTORS AND COENZYMES

7.7.1 Cofactors

Some enzymes require non-protein molecules called cofactors to be bound for them to become active. Cofactors can be either inorganic (e.g. metal ions such as iron, magnesium, manganese, cobalt, zinc, copper, etc) or organic (also called coenzymes). When an enzyme that requires a cofactor is not bound to its cofactor, it is called an *apoenzyme* and this is the inactive form of the enzyme. When the apoenzyme is bound to its cofactor, it is called a *holoenzyme* and this is the active form. Most cofactors are not covalently attached to an enzyme, although they are very tightly bound.

7.7.2 Coenzymes

Coenzymes are small organic molecules cofactors that can be loosely or tightly bound to an enzyme. Tightly bound coenzymes are also called prosthetic groups. Coenzymes transport chemical groups such as hydrogens, phosphates and alkyl groups from one enzyme to another.

Co-enzymes include a number of vitamins such as riboflavin, thiamine and folic acid and other prosthetic groups such as NAD, NADPH, ATP and coenzyme A.
Coenzymes are usually continuously regenerated and their concentrations are maintained at a steady level inside the cell.

7.8 RATE OF ENZYME ACTIVITY

The rate of an enzyme reaction also called the velocity (V) is measured as the amount of substrate disappearing or amount of product appearing per unit time (Fig 7.5). It can be expressed as the reciprocal of time (1/Time).

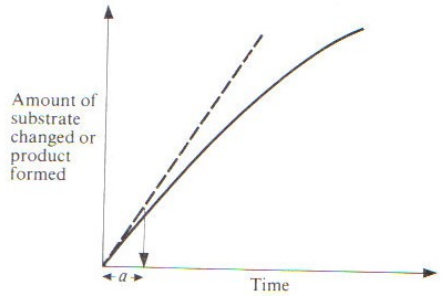


Figure 7.5 Rate of an enzyme controlled reaction

The rate is affected by factors such as temperature, pH, and substrate and enzyme concentrations. When investigating the effect of one factor on the rate of an enzyme-controlled reaction, all the other factors must be kept constant and at optimum levels wherever possible.

7.8.1 Effects of temperature on rate of enzyme activity

The rate of an enzyme catalysed reaction increases with temperature because heat increases the kinetic energy of the molecules of both the substrate and enzyme and this increases the probability of the substrate and enzyme coming into contact. The temperature at which the enzyme activity is at maximum rate is the optimum temperature for that enzyme. If the temperature is increased above the optimum level, there is a decrease in the rate of reaction (Fig 7.5) because the enzyme is denatured (the secondary and tertiary structures of the enzyme

protein are disrupted;). If the temperature is reduced to around the freezing point, enzymes are only inactivated and not denatured. Inactivated enzymes will regain their catalytic ability when the temperature increases.

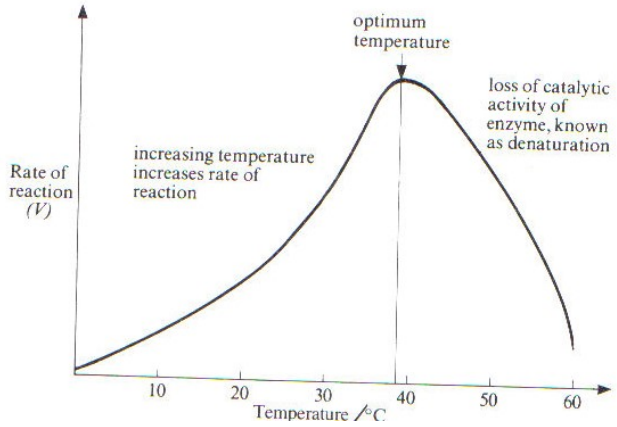


Figure 7.5 The effect of temperature on the rate of an enzyme-controlled reaction. The rate is highest at the optimum temperature.

The optimum temperature of an enzyme depends on the organism. Human enzymes have their optimum temperature around 37°C while enzymes of bacteria living in hot water spring have their optimum temperature around 100°C.

7.8.2 Effects of pH on rate of enzyme activity

Every enzyme functions most efficiently over a narrow pH range. The pH at which the maximum rate of an enzyme catalysed reaction occurs is the optimum pH for that enzyme (Fig 7.6).

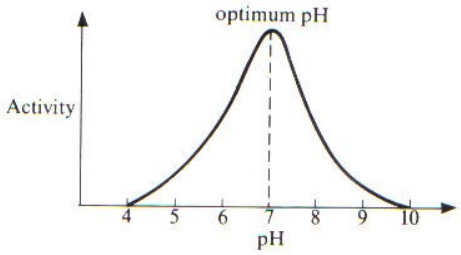


Figure 7.6. The effect of pH on the rate of an enzyme-controlled reaction. The optimum pH is around the value of 7.

When the pH is changed below or above this value, the enzyme will become denatured and the rate of its activity is reduced. Changes in pH lead to changes in the ionic charge of the acidic and basic R groups that are important in the maintenance of the shape of the enzyme. These lead to changes in the globular shape of the enzyme and disrupt the active site. Table 7.1 shows the optimum values of some enzymes.

Table 7.1 Optimum pH values for some enzymes

Enzyme	*Optimum pH*
Pepsin	2.00
Sucrase	4.50
Enterokinase	5.50
Salivary amylase	6.80
Catalase	7.60
Chymotrypsin	7.00–8.00
Pancreatic lipase	9.00
Arginase	9.70

7.8.3 Effects of substrate concentration on enzyme activity

The rate of an enzymatic reaction increases with increasing substrate concentration. A point is reached (maximum velocity = Vmax) when any further increase in substrate concentration produces no significant change in reaction rate. This is because at high substrate concentrations the active sites of the enzyme molecule at any given moment are saturated with substrate. Thus any extra substrate has to wait until a substrate/enzyme complex has dissociated into products and free enzyme before it may itself bind with the free enzyme (Fig 7.7).

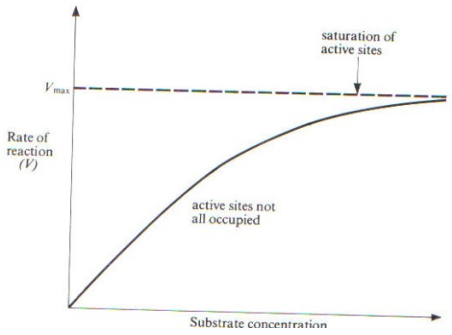


Figure 7.7 Effect of substrate concentration on the rate of an enzyme controlled-reaction. The maximum rate (V_{max}) is reached when all active sites are occupied.

7.8.4 Effects of enzyme concentration on enzyme activity

The rate of reaction is proportional to enzyme concentration, provided that the substrate concentration is maintained at a high level and other conditions such as pH and temperature are kept constant. Therefore, as the enzyme concentration is increase, the rate of the enzymatic reaction will also increase (Fig 7.8). Under normal circumstances reactions are catalysed by enzyme concentrations which are much lower than substrate concentrations.

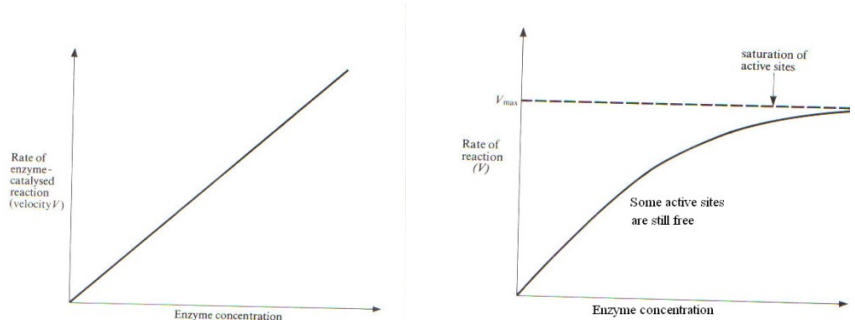


Figure 7.8 Effect of enzyme activity (a) In the presence of excess substrate (b) in the presence of limited substrate.

7.9 Inhibition of enzyme action

A number of substances can reduce the rate of an enzyme-catalysed reaction. These substances are called enzyme inhibitors. Enzyme inhibition can be reversible or irreversible. Reversible inhibitors can be easily removed from the enzyme under certain conditions and their inhibition may be competitive or non-competitive.

7.9.1 Competitive reversible inhibition

In this case a substance with a structure which is similar to that of the normal substrate binds to the active site of the enzyme but is unable to form any product(s). While at the active site, the inhibitor prevents the normal substrate from binding. Since the inhibitor and substrate compete for the active site, this kind of inhibition is said to be active site directed (competitive inhibition) (Fig 7.10). This inhibition can be reversed when the concentration of the normal substrate is increased in relation to the concentration of the inhibitor.

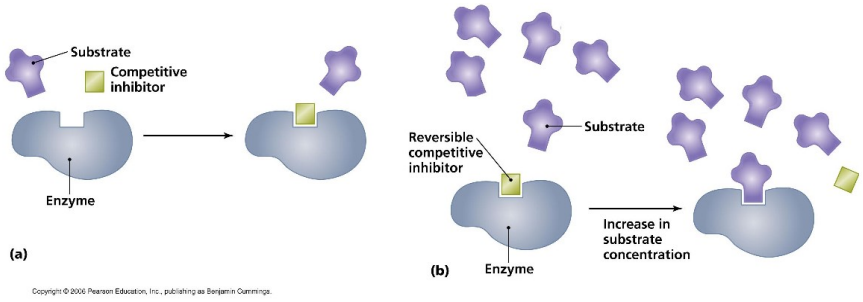


Figure 7.10 (a) Active site of enzyme bound by a competitive inhibitor.
When the concentration of inhibitor is higher than that of enzyme (b) Active site is bound by the normal substrate when the concentration of substrate is higher than that of inhibitor.

7.9.2 Non-competitive reversible inhibition

Non-competitive inhibition is also called non-active site directed inhibition. The structure of a non-competitive inhibitor is different from that of the substrate. When such an inhibitor is not attached to the enzyme, the enzyme is able to carry out its normal function (Fig 7.11).

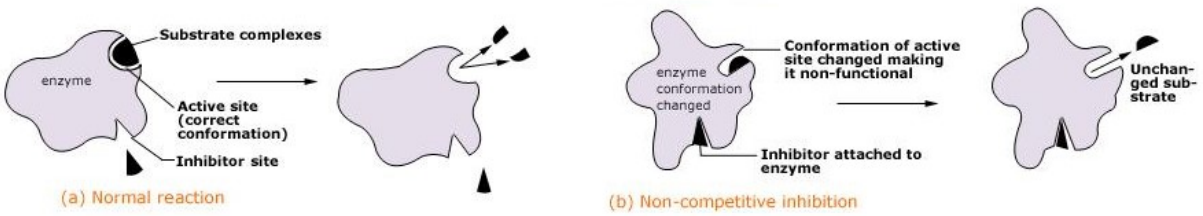


Figure 7.11 Enzyme showing its active site as well as its inhibitor site. (a) When the inhibitor is not attached to the enzyme, the enzyme is able to carry out its normal function. (b) When the inhibitor is attached to the enzyme the active site is changed and hence the enzyme is unable to carry out its normal function.

But when the inhibitor binds to enzyme, an enzyme/inhibitor complex is formed and this changes both the normal globular structure of the enzyme and the structure of the active site. Even if the normal substrate binds to the modified active site of the enzyme, catalysis does not take place and the substrate is not converted into products (Fig 7.11). When the concentration of the substrate is increased in relation to the inhibitor the inhibition can be reversed.

7.10 COMMERCIAL USES OF ENZYMES

There are a number of enzymes which have commercial use. These include enzymes used in the brewing industry, food industry, pharmaceuticals etc. Commercially important enzymes are usually extracted from microorganisms and they are purified before use. Examples of commercially important enzymes are pectinases and proteases.

7.10.1 Pectinases

Pectinases are enzymes that break down pectin, a polysaccharide found in plant cell walls. Pectin is the jelly-like substance of the cell wall in which the other components, such as cellulose fibrils, are embedded. Pectinases can be extracted from fungi such as *Aspergillus niger*. The fungus uses these pectinases to digest plant cell walls so that it can extract nutrients from the plant tissues. Pectinases are used in the breakdown of plant materials for various purposes such as:

(i) In fruit juice production: Pectinases speed up the extraction of fruit juice from fruit pulp e.g. apple marsh

(ii) In jam production: Pectinases are used to form the jelly during jam-making

(iii) In brewing: They are use to extract flavours from the mash

(iv) In wine making: They are used to make wine clear.

7.10.2 Proteases

Proteases are enzymes that are able to break down proteins and polypeptides into short peptides or into amino acids. Some uses of proteases:

(i) In detergent production: When added to detergents, proteases remove protein stains such as grass, blood, egg and human sweat from laundry. As a result of the combined effect of detergent and enzymes, stubborn stains can be removed from the laundry.

(ii) In treatment of stroke: A special protease called tissue plasminogen activator (TPA) is used to treat patients with ischemic stroke. It helps in the breakdown of fibrin, a protein which is found in blood clots.

(iii) In wound debridement: Proteases such as papain, bromelain, collagenase and trypsin are used in wound debridement. This involves the removal of dead or damaged tissue from wounds in order to assist healing.

(iv) In production of meat tenderizers: Proteases such as papain from paw paw and bromelain from pine apple are used as meat tenderizers to make beef and other steaks soft before they are cooked.

UNIT 8: CELL STRUCTURE AND FUNCTION

8.1 INTRODUCTION

The cell ("small room") is the basic structural, functional, and biological unit of all living organisms. They are often called the "building blocks of life". Cells consist of a protoplasm surrounded by a membrane. Within the protoplasm is the nucleus and the cytoplasm. Living organisms are either unicellular (single cell, e.g. bacteria) or multicellular (e.g. plants and animals). The cell can be prokaryotic (without a true nucleus or any membrane-bound organelles) or eukaryotic (containing a true nucleus and membrane-bound organelles).

8.2 OBECTIVES

At the end of this topic you should be able to:

1. Explain that the basic unit of living organisms is the cell
2. Distinguish between a eukaryotic and prokaryotic cell
3. Describe the structure of a bacterial cell and its inclusions as illustrated by *Escherichia coli*
4. Explain the roles of the cell wall, cell surface (plasma) membrane and its invaginations
5. Explain the roles of the flagella, bacterial chromosomes, plasmids, glycogen granules and lipid droplets
6. Recognise and identify structures in electron micrographs of bacterial cells.
7. Describe the organisation of eukaryotic cells as illustrated by a leaf palisade cell and a liver cell
8. Recognise and identify the structure of eukaryotic cells as revealed by light and electron microscopy
9. Predict the magnification and resolution that can be achieved using light and electron microscopy;
10. Interpret electron micrographs and identify the organelles
11. Describe the structure and understand the roles of the nucleus, nucleolus, rough and smooth endoplasmic reticulum, Golgi apparatus, lysosomes, chloroplasts, mitochondria, ribosomes, centrioles, microtubules and the cellulose cell wall
12. Describe the structure and understand the properties and roles of the cell surface (plasma) membrane.

8.3 PROKARYOTIC CELLS

Such cells do not possess a true nucleus and their genetic material (DNA) is not enclosed by a nuclear membrane but lies free in the cytoplasm. The best example of prokaryotes is that of bacteria. A schematic diagram of a bacterial cell (*E. coli*) is shown in Figure 8.1.

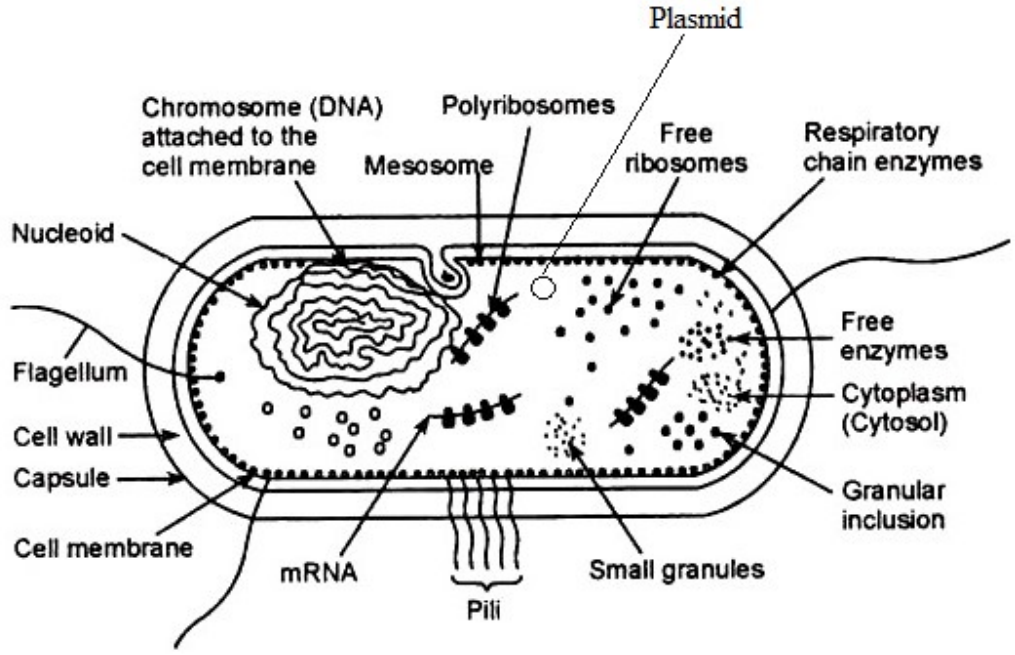


Figure 8.1 Diagramatic representation of an *E.coli* cell

The bacterial cell has the following parts:

8.3.1 Cell wall

The cell wall gives rigidity and shape to the bacterium. It prevents the cell from swelling and bursting as a result of osmosis when the cell is in a medium of high water potential. Water, various ions and small molecules can pass freely through the tiny pores in the wall, but larger molecules like proteins and nucleic acids are excluded. The cell wall has a substance called murein consisting of polysaccharide chains cross-linked by short peptide chains. Gram positive (+) bacteria e.g. *Lactobacillus* can be stained by the Gram stain while Gram negative (-) bacteria e.g. *E. coli* cannot be stained by the Gram stain.

8.3.2 Cell (plasma) membrane

The bacterial cell is surrounded by a partially permeable cell membrane. The bacterial cell membrane is also used as the site of respiratory enzymes. In some bacteria the cell membrane is used for photosynthesis. The cell membrane is mainly composed of a lipid bi-layer but also contains protein and carbohydrate molecules (Fig 8.2).

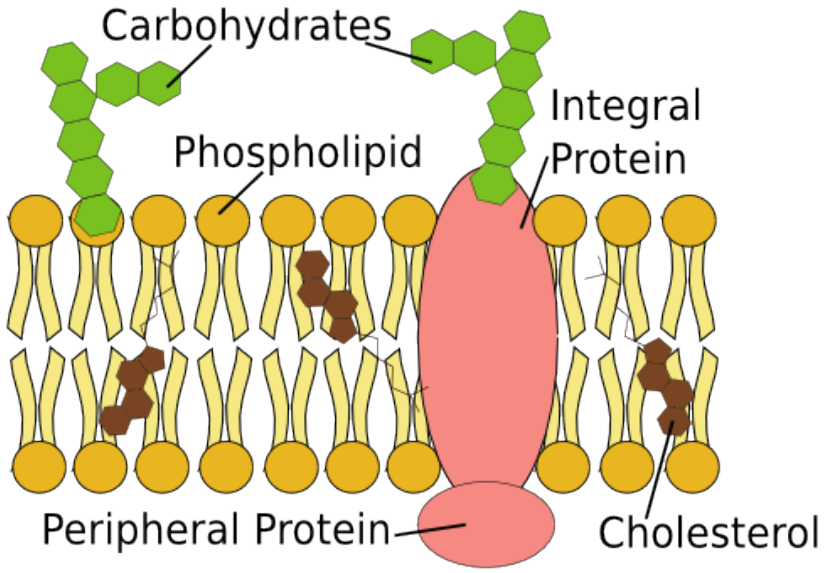


Figure 8.2 Cell membrane. Source: http://study.com/academy/lesson/cell-membrane-functions-role-structure.html.

8.3.3 Pili (pilus)

These are hairlike protein structures found on the surface of bacterial cells. They help differnt bacterial cells to stick to each other for the purpose of exchange of genetic material during reproduction.

8.3.4 Flagellum (flagella)

This is a complex whip-like structure made of a protein called flagellin. It helps bacteria move around by the use of a motor protein that spins the flagellum like a propeller. The base of the flagellum rotates on ring-shaped bearings so that the flagellum performs rotational motion to push the cell forwards.

8.3.5 Cytoplasm

This is the fliud contained is the bactrial cell enclosed by the cell membrane. It coontains ribsomes, DNA, enzymes, lipid droplets and carbohydrate granules.

8.3.6 Nucleoid

This is the region of the cytoplasm which contains circular double-stranded DNA (bacterial chromosome) which stores the hereditary material (genetic information) that controls the cell and will be passed on to daughter cells. Bacteria chromosome is not enclosed in any membrane but exists as a naked DNA freely bathing in the cytoplasm

8.3.7 Plasmids

These are small pieces of DNA which are separate from the chromosomal DNA. They usually replicate at the same time as bacterial DNA but are not essential for the survival of the bacterial cell.

8.3.8 Ribosomes

These are the site of protein synthesis. Bacterail ribosomes are 70S consistiing of two subunits (the 50S and 30S). They help in protein synthesis by bringing together messenger RNA and transfer RNA.

8.3.9 Glycogen granules and lipid droplets

Glycogen granules and lipid droplets appear as inclusions in the bacteria cell. They are used as energy stores which become useful when the bacterium is experiencing starvation.

8.4 EUKARYOTIC CELLS

Eukaryotic cells are complex have a true nucleus in which the genetic material is enclosed by the nuclear membrane. They also have membrane-bound organelles found in the cytoplasm. Examples include the plant leaf palisade cell and the animal liver cell (Figs 8.3 and 8.4).

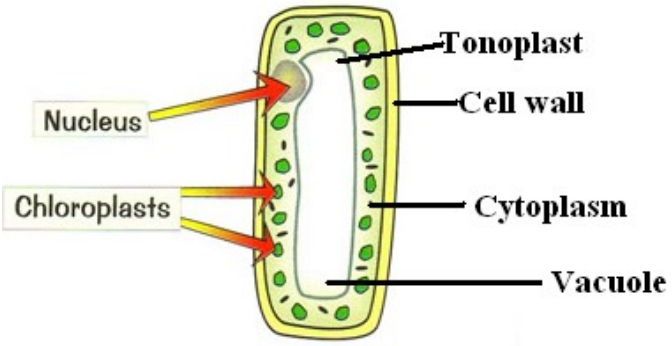


Figure 8.3 The Plant palisade cell

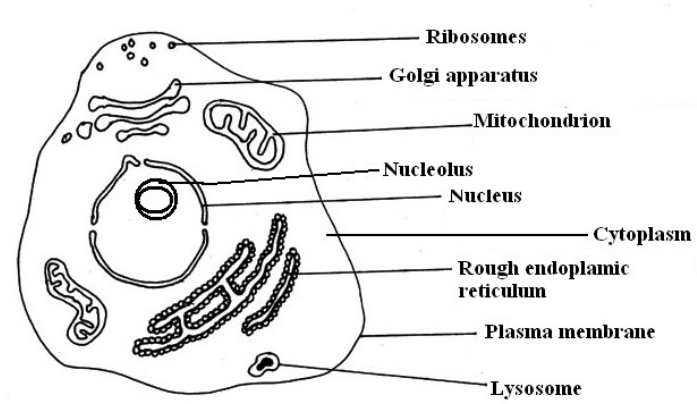


Figure 8.4 The animal liver cell

Eukaryotic cells can be represented by the plant palisade cell and the animal liver cell.

The plant palisade cell is rich in chloroplasts which contain the green photosynthetic pigment called chlorophyll. These cells give the green colour to leaves. These cells are positioned near the top surfaces of the leaves, underneath the epidermis. Making them efficient at converting light energy into the chemical energy of carbohydrates.

The animal liver is rich in mitochondria which contain the enzymes used in tissue respiration leading to the production of energy. The high concentration of the mitochondria gives the liver its brownish colour.

The eukaryotic cell has the following parts:

8.4.1 Cell wall

This is a protective layer found in plant cells. It consists of cellulose and complex polysaccharides. The major functions of the cell wall include (1) mechanical strength, (2) resistance to expansion preventing the cell from bursting when exposed to dilute solutions, (3) limiting and controlling cell growth and shape, (4) providing intercellular connections through pores (5) reducing water loss and risk of infection, (6) long distance translocation of materials through the xylem and phloem tissues.

8.4.2 Plasma membrane

Similar to the prokaryotic cell membrane (Fig 8.2). It consists of 40% proteins and 60% phospholipids. The functions of the plasma membrane include (i) Selective permeability (ii) Control of information flow between cells and their environment through specific receptors (iii) Production of energy as ATP during photosynthesis and oxidative respiration (iv) support (anchor) for enzymes involved in photosynthesis and respiration

8.4.3 Nucleus

This is the largest organelle that is found in almost all eukaryote cells. It contains the genetic material (DNA) which is used to control all the cellular metabolic activities and for the replication of the cell. The nucleus is surrounded by a nuclear membrane which contains a nucleolus and nucleoplasm. The function of the nucleolus is to manufacture ribosomal RNA (rRNA). The nuclear membrane has nuclear pores which allow exchange of substances between the nucleus and the cytoplasm. The nucleoplasm is fluid containing enzymes, genetic material and other substances such as ions.

8.4.4 Vacuole

This is an organelle present in all plant cells and some animal cells. Its membrane, called the tonoplast is filled with water containing inorganic and organic molecules including enzymes. It is involved in controlling tugor pressure, maintaining pH, removing harmful waste substances and storage of important proteins. The vacuole shape or size varies depending on the cell type and function.

8.4.5 Rough and smooth endoplasmic reticulum

The endoplasmic reticulum (ER) is an extensive complex system of membranes running through the cytoplasm of all eukaryotic cells. When the ER is covered by ribosomes, it is called a rough

endoplasmic reticulum (rough ER) while the smooth ER is not covered by ribosomes. The rough ER is concerned with the transport of proteins the smooth ER is mainly involved in lipid synthesis. In the liver cell both smooth and rough ER are involved in removal of toxic wastes.

8.4.6 Golgi apparatus

This organelle is found in all eukaryotic cells and consists of a pile of sacs called cisternae and smaller Golgi vesicles (Fig 8.5). The function of the Golgi apparatus is to modify and transport materials proteins and materials particularly in secretory cells such as in the cells of the pancreas. It is also involved in the lipid transport from the smooth ER to the lymphatic system. The Golgi is also involved in the synthesis of lysosomes.

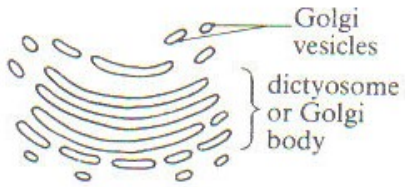


Figure 8.5 General structure of the Golgi body

8.4.7 Lysosomes

Lysosomes are most abundant in animal cells involved in phagocytic activity. They are simple sacs (Fig 8.6) that contain hydrolytic (acidic) enzymes such as proteases, nucleases, lipases and phosphatases. These enzymes which are synthesised on rough ER and transported to the Golgi apparatus have to be kept away from the cell to avoid self-destruction of the cell. Golgi vesicles containing the processed enzymes later bud off and are called primary lysosomes which have a number of functions, mostly involving digestive processes within the cell.

Figure 8.6 General structure of a lysosome

8.4.8 Chloroplasts

These are organelles that contain photosynthetic pigments mainly chlorophyll and carotenoids. They are mainly found in palisade layer of green leaves. They are surrounded by two membranes which contain chlorophyll and photosynthetic enzymes. The membrane consists of many sacs called thylakoids which form stacks called grana, interconnected by lamella (Fig 8.7).

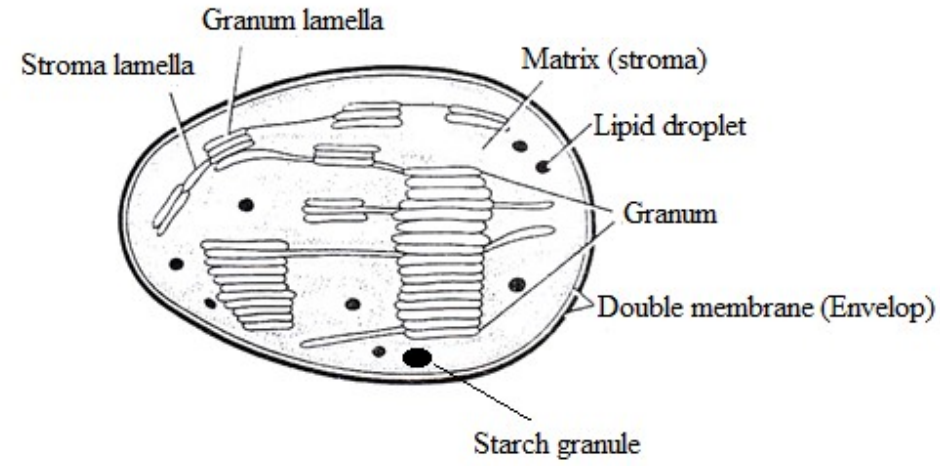


Figure 8.7 General structure of a chloroplast

8.4.9 Mitochondria (Sing-mitochondrion)

These organelles are present in all eukaryotic cells and are the major site of aerobic (oxidative) respiration within cells. Liver and muscle cells have large numbers of mitochondria. Each mitochondrion is bounded by two membranes with the inner one being separated from the outer one. The inner membrane is semi-permeable and touches the cytoplasm fluid where it is folded inwards into cristae (Fig 8.8). The cristae increase the inner membrane's surface area for increased enzyme activity. The outer membrane is permeable to many molecules including large ones. Although mitochondria have their own DNA, they cannot reproduce themselves independently and need nuclear DNA for their reproduction.

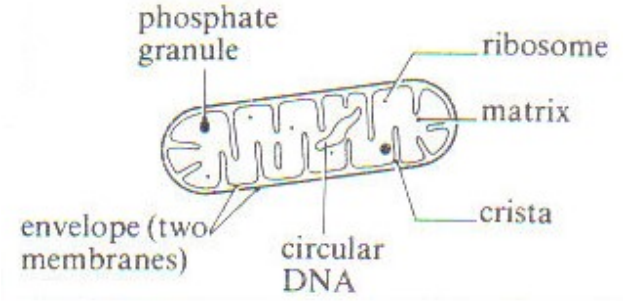


Figure 8.8 General structure of a mitochondrion

8.4.10 Ribosomes

These are small organelles found in large numbers throughout the cytoplasm of plant and animal cells. They are the sites of protein synthesis. The eukaryotic (80S) ribosome consists of one large (60S) and one small (40S) subunit (Fig 8.9). Chloroplasts and mitochondria contain the 70S ribosomes. During protein synthesis, amino acids are joined together by mRNA and tRNA using

the ribosome as the binding site for this process. Free ribosomes float freely in the cytoplasm while and bound ribosomes are stuck to the ER.

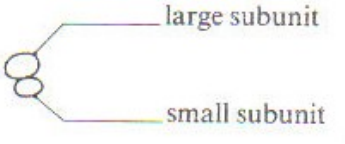


Figure 8.9 General structure of a ribosome

8.4.11 Microtubules

These are cylindrical organelles called microtubules made up of a protein called tubulin. Microtubules are involved in a number of cellular processes such as (1) formation of centrioles (2) intracellular transport, (3) cytoskeleton and (4) spindle fibres.

8.4.12 Centrioles

These are small hollow cylinders that occur in pairs called a centrosome (Fig 8.10) in most animal and lower plant cells. At the beginning of nuclear division, the centrioles replicate themselves and the two new pairs migrate to opposite poles of the spindle fibres on which the chromosomes become aligned.

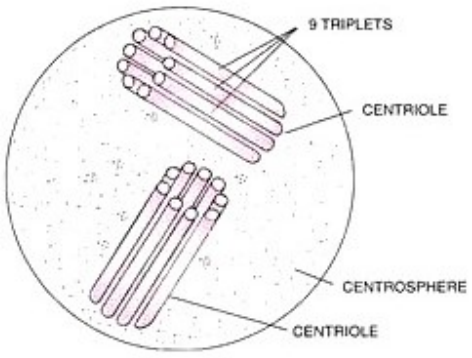


Figure 8.10 Structure of a centrosome with two centrioles

END