2 BASIC BIOCHEMISTRY

CHAPTER COVERAGE

2.1 INTRODUCTION OF BASIC BIOCHEMISTRY

2.2 CARBOHYDRATES

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2.4 PROTEINS

2.5 ENZYMES

2.6 ATP

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2.1 INTRODUCTION OF BASIC BIOCHEMISTRY

We have looked at the ultrastructure of cells and seen the range of organelles that work together to continue the processes of life. But what is the composition of cytoplasm?

Cytoplasm also consists of important groups of molecules, such molecules are specifically known as **bio – molecules** or simply the **organic compounds**, the organic components of the cell include carbohydrates, lipids, proteins, enzymes, ATP and nucleic acids. Water is the most abundant molecules which constitute large part of the cells, constituting about **70%** of the total mass, It also interact with organic compounds of the cell. The study of these molecules of the cell is called **cell biochemistry.**

WHAT IS CELL BIOCHEMISTRY?

Basic biochemistry is the study of chemical constituents of the cell in a living organism. The same chemicals studied in chemistry make up the molecules, which are found in living organisms and thus the term **chemistry of life.**

What are the applications of basic biochemistry?

The knowledge of basic biochemistry is applied in the following fields:

1. **In agriculture**, for development of pesticides, herbicides, fertilizers and pharmaceutical.

2. **In fermentation industries,** for the production of useful products such as baking products.
3. **In food and nutrition,** for food production and preservation.
4. **In genetic engineering,** for molecular approaches to genetic diseases.
5. **In biotechnology,** for molecular approaches to proteins.

Sample question – 01
Tai question

a. What is the cell biochemistry?
b. Why basic biochemistry is also termed as chemistry of life?
c. Outline the applications of cell biochemistry in our daily basis.

2.2 CARBOHYDRATES

Carbohydrates are organic compounds which contain carbon, hydrogen and oxygen, with hydrogen and oxygen always present in the ratio 2:1.

General formula of carbohydrates:
They can be represented by the general formula of:

$$C_x (H_2O)_y \quad \text{----------} \quad (1)$$

Whereby "x"and "y"are variable numbers

Why are they called carbohydrates?
They are called carbohydrates because carbon is said to be in water or "carbon is hydrated" and thus the biological term **carbohydrates.**

What determine the chemistry of carbohydrates?
The chemistry of carbohydrates is determined by their functional groups which are aldehyde or ketone group. For example: **Aldehyde** is very easily oxidized and hence acts as powerful reducing agent.
For this reason; they can reduce blue colour of copper II ($cu2^{+)}$ of benedict solution into copper I (Cu^{+}) which appears as a brick red ppt which is the best indicator for reducing sugars in food test.

Classification of carbohydrates

Basing on their hydrolysis products, carbohydrates are normally divided into **three (3)** classes:

a. Monosaccharaides (*single sugars*)
b. Disaccharides (*Double sugars*)
c. Polysaccharides (*multi sugars*)

A. **Monosaccharaides (single sugars)**

The word monosaccharide is derived from **two (2)** main Greek words; the first word is *mono* which means "single" and the second word is *saccharide* which means "sugar"; **Monosaccharaides** are generally referred to as simplest carbohydrates having one sugar which cannot be hydrolysed into simple molecules.

Properties of monosaccharaides

Monosaccharaides have the following general properties:

i. They are very sweet sugars.
ii. They have very low molecular weight.
iii. They are highly soluble in water.
iv. They exist in crystalline solid form at room temperature.
v. They are reducing sugars due to the presence of active reducing groups, i.e. **Aldehyde** and **ketone** group. They reducing oxidizing agent such as benedict solution.

Sample question – 02
MOBEP Exam 2021

a. Why monosaccharides are referred to as reducing sugars?
b. How monosaccharides behave? Give five (5) points.
c. With examples from each classify monosaccharides according to the number of carbon atoms.

General formula of monosaccharides:

They can be represented by the general formula of:

$$(CH_2O)_n \quad \text{----------} \quad (2)$$

Whereby letter "n"equals to the number of carbon atoms in the molecule and its value may lay between 3 and 7.

Classification of monosaccharides

Monosaccharaides are classified according to the number of carbon atoms they contain.

Table 2.1 Table showing the common classes of monosaccharides

n	Name	Molecular formula	Example
3	Triose	$C_3H_60_3$	Glyceraldehyde Dihdroxyacetone
4	Tetrose	$C_4H_8O_4$	Erythrose Threose
5	Pentose	$C_5H_{10}O_5$	Ribose Deoxyribose
6	Hexose	$C_6H_{12}O_6$	Glucose Galactose Fructose
7	Heptose	$C_7H_{14}O_7$	Sedoheptulose

*Where by "**n**" is the number of carbon atoms, Six (6) is the most common number, giving six carbon sugars or hexose sugars.*

Remember:

In **monosaccharaides** hexose sugars will be mostly discussed".

Hexose sugars (Hexoses)

Hexoses are the most common type of monosaccharaides with six number of carbon atoms on their molecules.

General formula of hexoses0020:

They can be represented by the general formula of:

$$C_6H_{12}O_6 \quad \text{----------} \quad (3)$$

Examples of hexose sugars

The most common examples of hexose sugars include; glucose, galactose and fructose.

a. **Glucose**

Glucose is the most common hexose sugar which contains aldehyde group at carbon number one.

Natural sources:

The natural sources of glucose are ripening fruits such as grape and mango fruits.

Structure of glucose

Glucose can be written as a straight chain structure, but in fact it is normally exists in a ring or cyclic form. The ring contains five carbon atoms and one oxygen atom – **a pyranose ring**. When in ring form glucose exists in two types, alpha glucose (α – glucose) and beta glucose (β – glucose); in α – glucose the hydroxyl group is below carbon atom 1, whereas it is above it in β – glucose as shown in *Figure 2.1*.

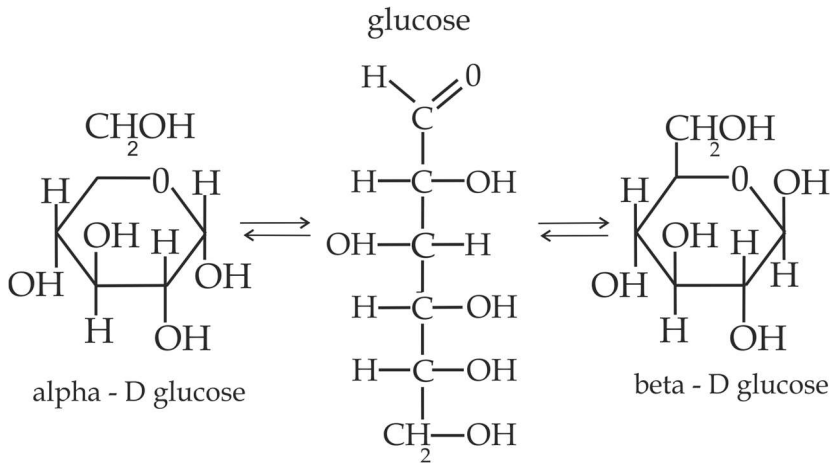


***Fig* 2.1** *Structure of alpha (α) glucose and beta (β) glucose*

Sample question – 03

Lugoba sec school mid – term Exam 2014

- Draw ring form of:
  - i. α – glucose
  - ii. B – glucose
  - iii. Galactose
  - iv. fructose

Did you know?

Our brains need around 130grams of glucose each day to function?

b. **Galactose**

Galactose is the hexose sugar which also contain aldehyde group at carbon number one.

Natural sources:

The natural sources of galactose are milk and yoghurt.

Structure of galactose

Structure of galactose is similar to that of α – glucose except that: The hydroxyl group **(OH)** of α – glucose at carbon number 1 and 4 are projected upward to form galactose as shown in *Figure 2.2*.

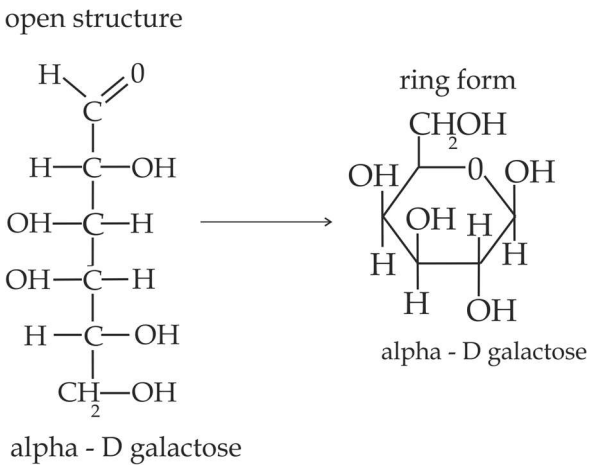


Fig 2.2 *Structure of α – D galactose*

c. **Fructose**

Fructose is the hexose sugar which contains keto group at carbon number two (2).

Natural sources:

The natural sources of fructose are honey and fruits.

Structure of fructose

Structure of fructose is similar to α – glucose except that: The group **"CH_2OH"** is exchanged with**" H"** at carbon number 1 and the **" H"** and **"OH"** at carbon number 2 and 3 are projected upside down to form fructose. In ring form, fructose exist as a **furanose** – the ring contain four carbon atoms and one oxygen atom as shown in *Figure 2.3*.

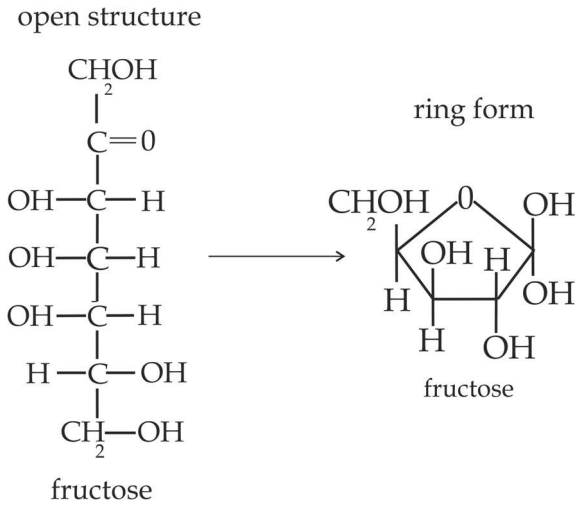


Fig 2.3 *Structure of fructose*

Functions of monosaccharides

The functions of monosaccharides are depending on their classes, which include:

1. **Trioses**
   i. They act as intermediate substrates of glycolysis and photosynthesis in dark reaction such as glyceraldehyde and dihdroxyacetone.
   ii. They can be condensed to form hexose sugars.

2. **Pentoses**
   i. They are used in the synthesis of nucleic acids such as ribose is a constituent of RNA and deoxyribose is a constituent of DNA.
   ii. They are used in the synthesis of ATP, for example ribose.
   iii. They are used in the synthesis of coenzymes such as NAD^{2+} and $NADP^{2+}$ which act as hydrogen carrier.
   iv. They are used in the synthesis of CO_2 acceptor in the photosynthesis such as RUBP.

3. **Hexoses**
   i. They are the source of energy when oxidized, for example glucose.

ii. They are used to synthesize disaccharides and polysaccharides such as lactose, maltose, sucrose, starch, glycogen, chitin, cellulose.

Sample question – 04

Style 1: Necta 2010 / Kilimanjaro Mock 2018

a. Define and classify monosaccharides.
b. Outline the chief functions of monosaccharides.

Style 2: Morogoro Mock 2020

- In three (3) points, state the functions of each of the following carbohydrates:
  i. Hexoses
  ii. Pentoses

B. Disaccharides (double sugars**)**

The word disaccharide is derived from two main Greek words; the first word is *di* which means "double" and the second word is *saccharide* which means "sugar". **Disaccharides** are carbohydrates which yield two monosaccharide molecules when hydrolysed. The molecules of disaccharides are made up of two monosaccharaide units joined together. The monosaccharaides join in a **condensation reaction** to form a disaccharide, and a molecule of water is lost, the bond between the two monosaccharaides which results is known as a **glycosidic link**.

General formula of disaccharides:

They can be represented by the general formula of:

$C_{12}H_{22}O_{11}$ ---------- (4)

Properties of disaccharides

The following are the general properties of disaccharides:

i. They are sweet in taste.
ii. They have low molecular weight.

iii. They are soluble in water.
iv. They exist in a crystalline solid at room temperature.
v. They are reducing sugars except sucrose.

Sample question – 05

MOBEP Exam 2021

a. Fill the following table:

Type	Examples	Sources (two)
Monosaccharides		
Disaccharides		
Polysaccharides		

b. How disaccharides behave? Give five (5) points.
c. Why disaccharides are reducing sugars except sucrose?

Examples of disaccharides sugars
The most common examples of disaccharides include; maltose (malt sugar), lactose (milk sugar) and sucrose (cane sugar).

a. **Maltose** (malt sugar)
Maltose is a disaccharide formed by the condensation reaction between two α - glucose molecules.

$$\text{Glucose} + \text{Glucose} \longrightarrow \text{maltose} + H_20$$

Natural sources:
Maltose is naturally found in germinating cereals, such as maize, sorghum and finger millet.

Structure of maltose (*Fig 2.4***)**
Maltose is formed by the condensation reaction between two α – glucose. This reaction is condensation because water molecule is lost. During this combination **–OH group** at carbon 1 and 4 of the two glucose residues, are involved in formation of oxygen covalent bond called glycosidic bond. Since it is formed between carbon 1 and 4, then it is termed a **1, 4 – glycosidic bond.**

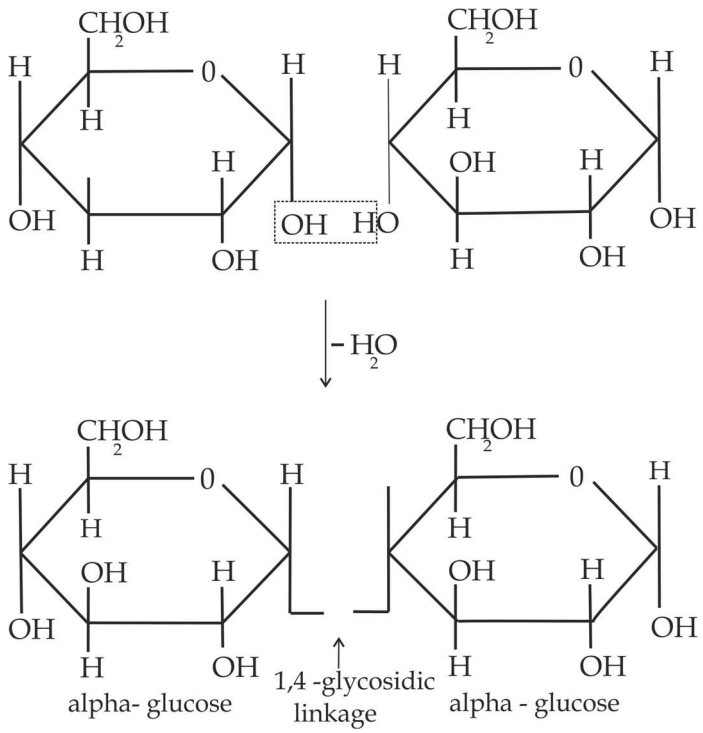


***Fig 2.4** Structure of maltose*

Sample question – 06

Lugoba sec school mid – term 2014

a. What is condensation reaction?
b. By using α – glucose only show how condensation reaction occur and name type of bond formed.

Why maltose is a reducing sugar?

Maltose is a reducing sugar due to the presence of free aldehyde group on its molecule which can reduce **blue Cu^{2+}** into **Cu^{+}** which appears brick red ppt.

$$Cu^{2+} + \bar{e} \longrightarrow Cu^{+}$$

(Blue) (Brick red ppt)

Roles of maltose

1. It is the source of **energy** like all carbohydrates.
2. It forms the basis of **brewery industries**; it is used to produce alcohol in industries.

b. **Lactose (**milk sugar**)**

Lactose is a disaccharide which is formed by condensation of α – glucose and galactose molecules**.**

$$\text{glucose + galactose} \longrightarrow \text{lactose + } H_20$$

Natural sources:

Lactose is naturally found in milk of mammals and in milk products.

Structure of Lactose (*Fig 2.5***)**

Lactose is formed by the condensation reaction between α – glucose molecule and galactose molecule. Also the bond is called **1, 4 – glycosidic bond** because it is normally occurs between the carbon number 1 of α – glucose and carbon number 4 of the galactose residues.

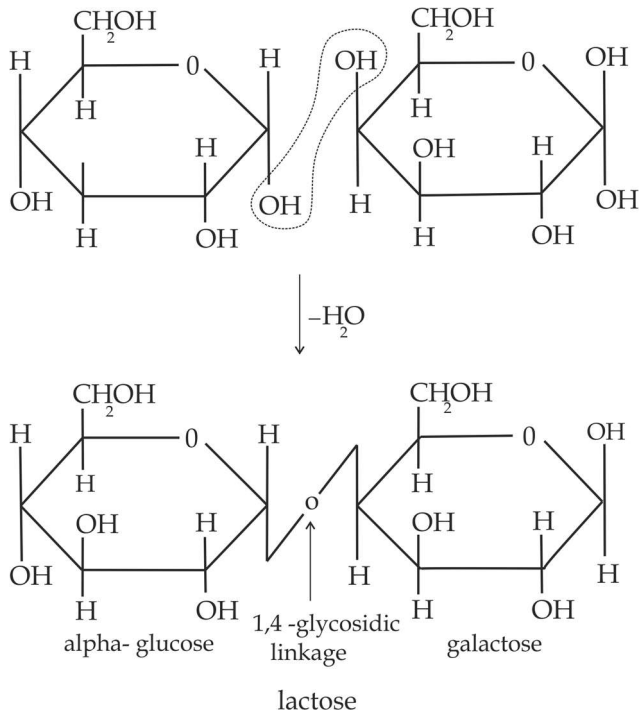


Fig 2.5 *Structure of lactose*

Why Lactose is a reducing sugar?
Like maltose, **lactose** is a reducing sugar due to the presence of a free aldehyde group on its molecule which donates electrons to reduce(Cu^{+2}) copper II sulphate (blue) into(Cu^{+}) copper I which appears as brick red ppt.

Role of lactose
1. Lactose is the main source of energy for young lactating mammals.

Sample question – 07

Tambaza weekly test 2021

a. By using diagram indicates the formation of maltose
b. Suggest the type of bond used in the formation of maltose.
c. What type of reaction involved? Why is it so called?
d. Why lactose is a reducing sugar?
e. By using diagrams only differentiate the following, using ring structures:
   i. α – glucose and β – glucose
   ii. α – glucose and α - galactose

Testing for reducing sugar
Reagent
- Benedict's solution (copper (II) sulphate solution)

Procedure:
- Add 3cc of the reducing sugar solution into a test tube.
- Add an equal volume of benedict solution then boil the mixture gently.

Observation
A series of color is changing from blue to green to orange to yellow and finally to brick red ppt.

Basis for the test
The aldehyde groups of the reducing sugar donate electrons that reduce **Cu^{2+}** of a blue color into **Cu+** which appears brick red ppt.

c. **Sucrose (cane sugar)**

Sucrose is a disaccharide which is formed by condensation of α – glucose and fructose**.**

$$\text{glucose + fructose} \longrightarrow \text{sucrose + } H_20$$

Natural sources:

Sucrose is naturally found in the sugar cane.

Structure of sucrose (*Figure 2.6)*

Sucrose is formed by the condensation reaction between α – glucose and fructose. During the reaction; the – OH group at carbon 1 of **α -glucose** and that of carbon 2 of **fructose**, contribute to the formation of the **1, 2 – glycosidic bond.** The reaction is also condensation; therefore, a molecule of water is lost.

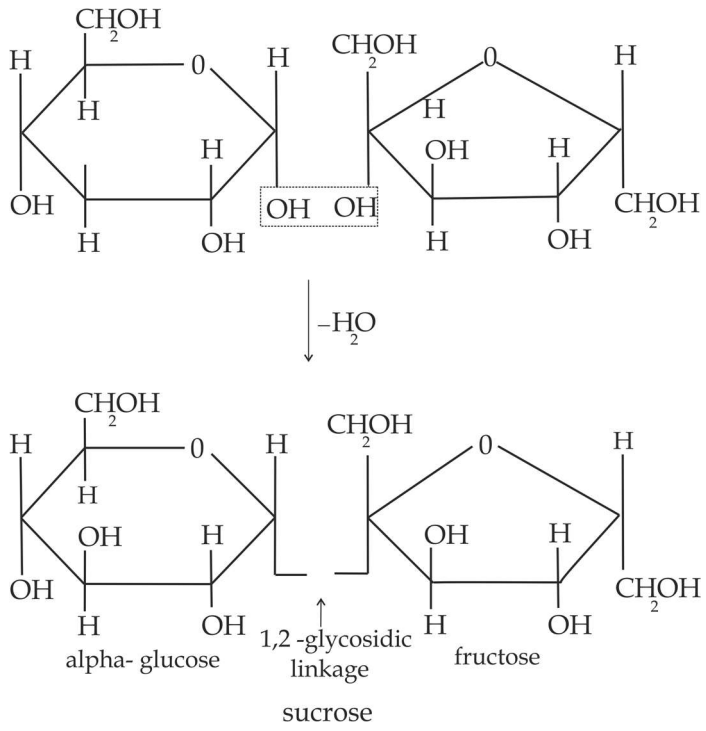


***Fig 2.6** Structure of sucrose*

Why sucrose is the non-reducing sugar?

Sucrose is usually a non-reducing sugar because it lacks any active reducing group. The aldehyde group at carbon 1 of α - glucose and ketone group at

carbon 2 of fructose have their OH contributing to the formation of the glycosidic bond as the result its reducing property disappear.

Sample question – 07

Mtwara and Lindi Mock 2021

- All disaccharides are reducing sugars except sucrose.Jusify.

Testing for reducing sugar

Reagent

- Benedict's solution (copper (II) sulphate solution)
- Dilute Hcl
- Dilute NaOH

Procedure

- Add 3cc of sucrose solution in a test tube.
- Add an equal volume of dilute Hcl and boil for a minute.
- On cooling an equal volume of NaOH solution is added.
- Then **3cc** of benedict solution is added and the mixture is boiled again as per above procedure.

Observation

- A series of color is changing from blue to green to yellow to orange and finally to brick red ppt.

Basis for the test

- Hcl converts non-reducing sugar (sucrose) into reducing sugars.
- NaOH solution is added to neutralize dilute Hcl.
- The aldehyde groups of the reducing sugars donate electrons to reduce a blue Cu^{+2} into brick red Cu^{+}.

Sample question – 08

Tambaza high school 2022

- Outline the procedure for testing non reducing sugars.

C. **Polysaccharides (**multi sugars**)**
The word polysaccharide is derived from **two (2)** main Greek words; the first word is *poly* which means "many "and the second word is *saccharide* which means "sugar". **Polysaccharides** are formed by the condensation reaction between many molecules (residues) of monosaccharaides. So, polysaccharides are polymers of monosaccharaides.

General formula of polysaccharides:
They can be represented by the general formula of:

$$(C_6H_{10}O_5)_n \quad \text{----------} \quad (5)$$

Here "n"may vary from as little as 40 to over 1000

Properties of polysaccharides
The following are the general properties of polysaccharides:

i. They are not sweet, the sweet taste which is characteristics of both mono and disaccharides is lost when many single sugar units are joined to form a polysaccharide.
ii. They have larger molecular weight compared to disaccharides.
iii. They are insoluble in water; they are, therefore, suitable as a storage substance, e.g. Starch in plants and glycogen in animals and fungi.
iv. They cannot be crystallized at room temperature, simply because they are most complex carbohydrates.
v. They are all non-reducing sugars.

Examples of polysaccharides sugars
The examples of polysaccharides include; Starch, Glycogen, cellulose, chitin and inulin.

a. **Starch**
Starch is a polymer of **α – glucose** units; this means; that it is made up of many molecules of α – glucose that are bonded together by **glycosidic bonds.** Starch is the form in which polysaccharide is stored in plants.

Why starch is used as storage molecule in plants?
Starch is a convenient carbohydrate storage in plant due to the following main reasons**:**

i. **Solubility property**:
It is insoluble in water, being insoluble it does not tend to draw water into the cells by osmosis or easily diffuse out of cells.

ii. **Shape property**:
It exist in compact shape, this means that a lot of starch can be stored in a relatively small space.

iii. **Hydrolysis property:**
It is easily broken down into glucose when needed for respiration.

Sample question – 09

Famous question

a. Explain why starch is a convenient storage molecule in living organisms.
b. What is a commercial importance of cellulose?

Structure of starch

Starch exist into two (2) main isomers; amylose and amylopectin. The proportions of which vary with the source of the starch. Usually, however, amylopectin constitutes about **70%** of starch.

- **Amylose** is a linear and unbranched chain of 200 – 1500 glucose residues linked by 1, 4 – glycosidic bonds as shown in *Figure 2.7*.

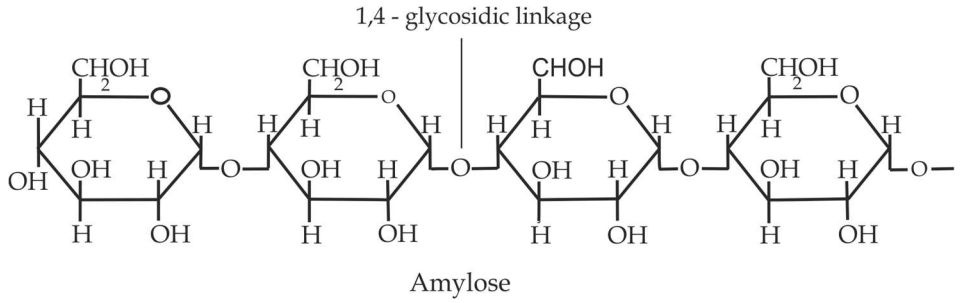


***Fig* 2.7** *Structure of amylose*

- **Amylopectin** is a branched chain of 2000 to 200 000 glucose residues linked by 1, 4 –glycosidic bonds and 1, 6 – glycosidic bonds. Branch points (1, 6 – glycosidic bonds) occur about every 20 residues along the straight chain section as shown in *Figure 2.8*.

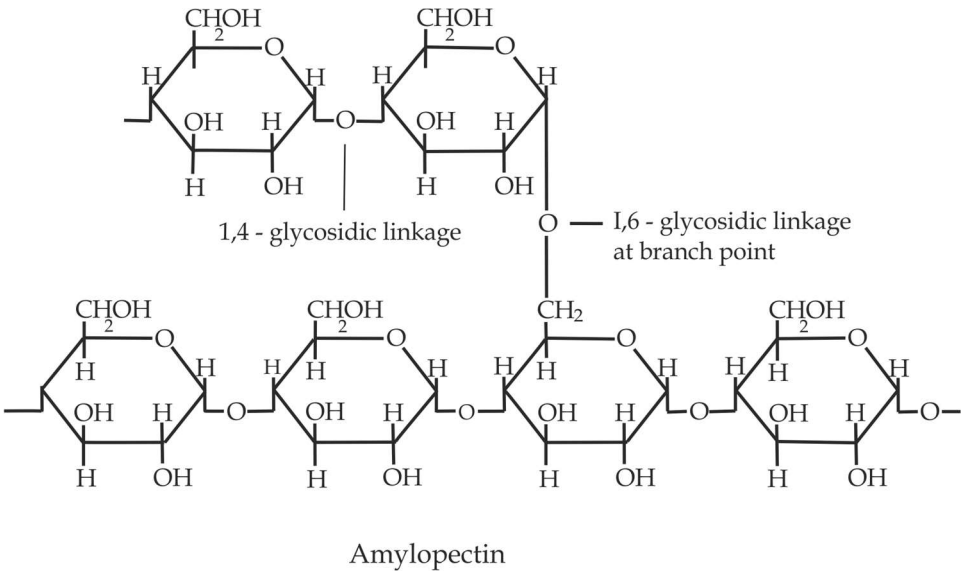


***Fig 2.8** Structure of amylopectin*

Difference between amylose and amylopectin

i. **Amylose** is a linear and unbranched polymer of glucose molecules while **amylopectin** is a branched polymer of glucose molecules.
ii. **Amylose** has few glucose molecules (500 – 1500) while **amylopectin** has many glucose molecules (1500 – 200000).
iii. **Amylose** has only 1, 4 – glycosidic linkages while **amylopectin** has both, I, 4 and 1, 6 – glycosidic linkages.
iv. **Amylose** gives blue black colour with iodine in a solution while **amylopectin** gives red violet colour with iodine solution.
v. **Amylose** is not hydrolysed easily by amylase while **amylopectin** is hydrolysed easily by amylase.

Sample question – 10

Tambaza and Temeke Joint Exam 2021

a. Amylose and amylopectin are two (2) main components of starch. In four points explain how they differ.
b. What is the commercial importance of chitin?
c. Why human being cannot digest cellulose?

Testing for starch
Reagent

- Iodine solution

Procedure

- To a starch solution in a test tube add 3drops of iodine solution then shake the mixture.

Observation
A blue black color is observed.

Basis for the test
A blue black color is the result of the formation of polyiodide starch complex.

Functions of starch

1. They are used as a storage carbohydrate molecule in plants.
2. They act as energy stores; provide large number of glucose molecules for respiration.

b. **Glycogen**

Glycogen is also a branched polymer of α – glucose molecules. Glycogen is the form in which carbohydrate is stored in animals and fungi. It is often called an animal starch, and it is stored mainly in liver and skeletal muscles.

Structure of glycogen
Chemically, glycogen is very similar to amylopectin, although the glycogen is larger in size and much more highly branched than that of amylopectin as shown in *Figure 2.9*.

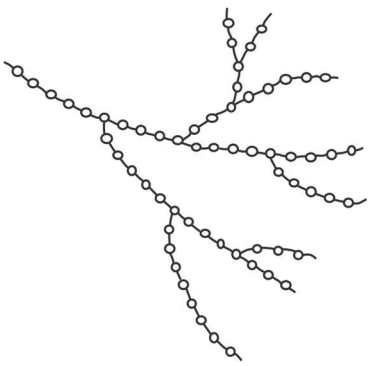


Fig 2.9 *Structure of glycogen, simplified. Each circle represents a α – glucose ring*

Similarities between a glycogen and starch (amylopectin).

i. Both are polymer of α – glucose residues.
ii. Both have 1, 4 and 1, 6 – glycosidic bonds.
iii. Both are the storage form of carbohydrates.

Did you know?

Each of us has approximately 500g of glycogen in our bodies, only enough for about 90 minute of exercise. If we use it all up, we have to rely on our fat reserves.

Functions of glycogen

1. They act as storage carbohydrates in animals and fungi.
2. They are source of energy; provides large number of glucose energy needed for respiration especially during strenuous exercise.

c. Cellulose

Cellulose is a linear and unbranched polymer of β – glucose molecules linked by 1, 4 – glycosidic bonds. Cellulose is by far the most abundant structural polysaccharide in living organisms, although it is found only in plants, where it is the main component of cell walls.

Structure of cellulose

Cellulose is chemically composed of several thousands (10 000) of β – glucose units, joined together by 1, 4 – glycosidic bonds to form long, unbranched chain.

Why cellulose is used as structural molecule in plants?

Cellulose is suitable molecule for supportive and structural formation due to the following reasons:

i. **Solubility property**
It is insoluble in water, to make the molecules impermeable.

ii. **Shape property**
Cross linkages between the chain which make the molecules tough, stiffy and give mechanical strength.

iii. **Strengthening property**
Presence of added chemical to cellulose such as pectin, lignin and hemicellulose which make the molecule more rigid.

Sample question – 11

Style 1: Tahossa Dar 2022

- Give two features which make cellulose suitable for structural formation.

Style 2: Tambaza sec school 2022

- Explain how structure of each of the following carbohydrate is related to its function:
  i. Cellulose
  ii. Starch

Style 3: Necta 2015

- State supporting and storage functions of carbohydrates using one example in each case.

Structure of cellulose

Cellulose is chemically composed of several thousands **(**10 000**)** of β – glucose units, joined together by 1, 4 – glycosidic bonds to form long, unbranched chain as shown in *Figure 2.10*. The way the glucose molecules are oriented means that - **OH** group stick outwards from the chain in opposite directions. These can form hydrogen bonds with neighbouring chains, thereby establishing a kind of lattice called **microfibril**.

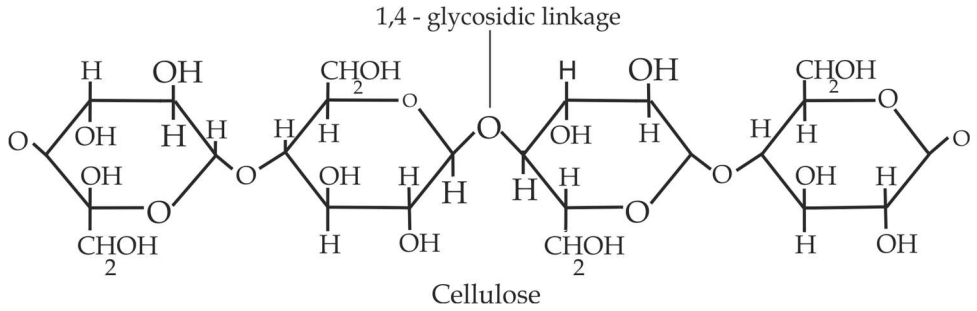


Figure 2.10 *Structure a cellulose molecule*

Commercial applications of cellulose

Cellulose structural strength has made it incredibly more valuable raw materials in manufacturing of various industrial products, which includes:

i. It is used in the manufacturing of papers.

ii. It is used in the manufacturing of furniture.
iii. It is used in the manufacturing of propellant explosives, e.g. Cellulose nitrates.
iv. It is added to ice creams, cosmetics and medicines and gives smooth texture, for example **Carboxylmethy cellulose,**
v. It is used in the manufacturing of propellant explosive, e.g. cellulose nitrate.
vi. It is used in the manufacturing of adhesive tapes.
vii. It is used in the manufacturing of belts.

Sample question – 12

Necta 1998

- What is the commercial importance of cellulose?

Functions of cellulose

1. It is a structural component of all plant cell walls, which provide mechanical strength and support.
2. It is necessary for proper functioning of digestive system.
3. It is a source of food for some animals such as herbivores, bacteria and fungi.

Did you know?

Most animals do not possess the cellulase enzyme needed to break β – 1, 4 – linkages and so they cannot digest cellulose

d. Chitin

Chitin is a polymer of unbranched chain β – glucose molecules linked by 1, 4 – glycosidic bonds. It occurs in the wall of fungal hyphae and in the exoskeleton of arthropods.

Structure of chitin

Chitin is chemically related to cellulose, except that, the hydroxyl group **(-OH)** of chitin at carbon atom number two (2) is replaced by **–**$NH.CO.CH_3$ (*acetyl – amino group*); It is thus a result of glucosamine. These macromolecules

are arranged in long, straight, parallel chains, but are very similar to cellulose in structure as shown in *Figure 2.11*.

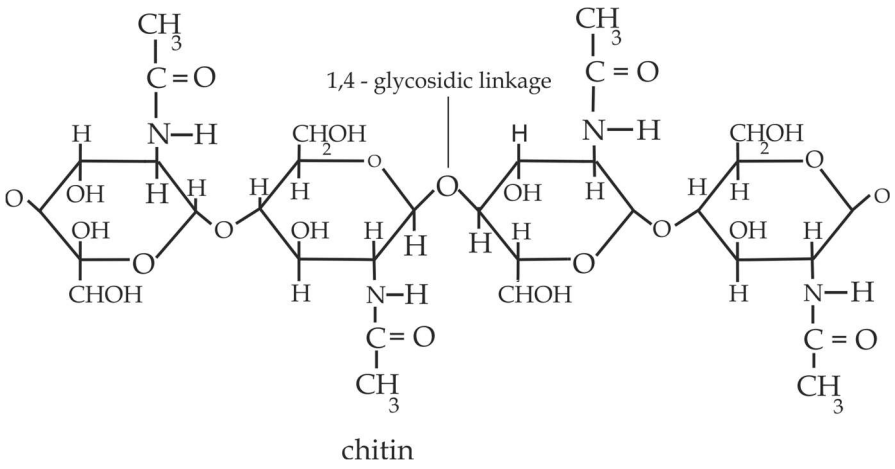


Fig 2.11 *Structure of chitin*

Commercial applications of chitin

i. **DE acetylated chitin** is used in water treatment operations.
ii. It is used as a sizing agent for cotton, wool, and for synthetic fibres.
iii. It shows considerable adhesively to plastics and glass.
iv. It is used as a food supplement.
v. Therapeutically it is used in wound healing preparations.

Function of chitin

1. It is a major structural component of the exoskeleton of arthropods and fungal cell wall.

e. **Inulin**

Inulin is a polymer of unbranched chain fructose molecules linked by 1, 2 – glycosidic bonds.

Function of inulin

1. It is the major carbohydrate storage in some plant roots such as Dahlia root tuber (Jerusalem artichoke).

Remember

Pectin, lignin, murein and agar are the other miscellaneous form of polysaccharides which will not be discussed in this chapter.

Sample question – 13

Kibaha sec school terminal Exam 2008

- Explain briefly the roles of the following:
  i. Chitin
  ii. Inulin
  iii. cellulose

What are the Structural features of carbohydrates account for the fact that varieties of polysaccharides exist?

i. **Presence of α – glucose and β – glucose isomers.**
For example; α – glucose isomer form starch whereas β – glucose isomer form cellulose.

ii. **Presence of aldehyde and keto reducing groups.**
For example; cellulose, starch and glycogen contain aldehyde whereas inulin contains keto group.

iii. **Presence of different types of linkages**.
For example; 1, 4 – glycosidic bond form starch and glycogen whereas 1, 2 – glycosidic bond form inulin.

iv. **Presence of 1, 6 – glycosidic bonds (branching points).**
For example; amylopectin and glycogen are branched [polysaccharides whereas amylose is unbranched polysaccharide.

v. **The extent of branches of the chain of polysaccharides differ greatly.**
For example; amylopectin is less branched than glycogen.

Sample question – 14

Jecas Exam 2011

- What structural features of carbohydrates account for the fact that a wide variety of polysaccharides exist?

General functions of carbohydrates

Carbohydrates perform the following functions in living organisms:

1. **Energy source**
Monosaccharaides such as hexoses are the chief energy sources in the living organisms because they are oxidized to give energy.

2. **Water source**
   Monosaccharaides are oxidized to release metabolic water for various physiological processes in the cells.

3. **Structural body parts**
   Polysaccharides form structural body parts. For example cellulose make cell wall in plants and chitin makes cell wall in fungi and exoskeleton of arthropods.

4. **Chemical constituents**
   Pentose such as ribose and deoxyribose form various chemical constituents of the cell. Ribose sugar is used in the synthesis of **Ribonucleic acid (RNA), ATP, NADP** and **RUBP** whereas deoxyribose is used in the synthesis of **deoxyribonucleic acid (DNA).**

5. **Storage molecules**
   Polysaccharides such as starch and glycogen are used as storage molecules, For example starch act as storage carbohydrates in plants and glycogen acts as storage carbohydrates in animals and fungi.

6. **Intermediate products**
   Triose sugars such as glyceraldehyde and dihdroxyacetone are used as intermediate products in respiration process during glycolysis and in photosynthesis during dark reaction.

7. **Flower nectar**
   Flower nectar contains sugar, which is important in the attraction of insects during pollination.

Sample question – 15

Style 1: Tahossa Kinondoni May 2014

- Explain the roles played by carbohydrates in living organism.

Style 2: Work out Biology Macmillan

- Outline the role of carbohydrates in the life of a plant.
  Hints: Explain the roles of carbohydrates in plants only.

2. **LIPIDS**

Lipids are organic compounds which contain carbon, hydrogen and oxygen but the proportion of oxygen is smaller compared to that of carbohydrates of the same size. Lipids are important constituents of the diet, because they are the source of high energy calorific value of all the biological respiratory substrates due to the presence of larger number of hydrogen atoms on its chain, for this reason, most animals store lipids rather than carbohydrates.

Similarities between carbohydrates and lipids:

i. Both contain carbon, hydrogen and oxygen element.
ii. Both are respiratory substrates.
iii. Both can be stored in bodies of organisms.
iv. Both occur in plants and animals.

Table 2.2 Differences between carbohydrates and lipids:

Carbohydrates	Lipids
Contain large quantity of oxygen.	Contain small quantity of oxygen
Yield less energy	Yield much energy
Yield less metabolic water	Yield much metabolic water
Are aldehyde or ketone	Are esters
Form long chain polymers	Do not form long chain polymers

Sample question – 16

Marian Girls 2004

a. Explain briefly, in what ways do lipids differs from carbohydrates?
b. Using examples to illustrate your answers, describe the functions of lipids in organisms.
c. Why do many organisms store lipids than carbohydrates?
d. Describe the following functions of lipid in living organisms:
   i. Source of energy
   ii. Insulation
   iii. Protection
   iv. Buoyancy

In this part, the following aspects should be discussed:
2.3.1: General properties of lipids
2.3.2: Classification of lipids
2.3.3: Test for lipids
2.3.4: Functions of lipids

2.3.1: General properties of lipids

The properties of lipids include the following:

i. **State of matter**
They are either liquid or solids at room temperature (20℃), e.g. fat is solid at room temperature whereas oil is liquid at room temperature.

ii. **Physical state**
They are colourless, odourless and tasteless in a pure form.

iii. **Density**
They are less dense than water, this is why they float on water.

iv. **Solubility**
They are insoluble in water but soluble in organic solvents such as benzene and alcohol.

v. **Hydrolysis**
They are hydrolysed by alkaline compounds such as *NaOH* to form ester by the process known as saponification.

vi. **Conduction**
They are poor heat and electrical conductors .For this reason, they are functional parts of nerve cells and skin sub – cutaneous layer.

vii. **Energy value**
They have a high calorific value due to the presence of large number of hydrogen atoms.

vii. **Saponification**
They form emulsion mixture when agitated with water in the presence of soap or other emulsifier.

2.3.2: Classification of lipids

Lipids are derived into three classes, based on the chemical composition which includes:

A. Simple lipids or homolipids
Example; Fats and oils (triglycerides) or waxes

B. Compound lipids or heterolipids
Example; phospholipid, glycolipid, sphingolipid.

C. Derived lipids or lipoids
Example; steroids and terpenes.

Sample question – 17

Tahossa Ilala region 2020

a. Analyse the chemical composition of lipids.
b. Using one example in each, classify lipids basing on their chemical composition.
c. Describe chemical tests of various types of carbohydrates in a given solution.

Hints:

a. Lipids are composed of C, H and O.
b. i. Simple lipids, i.e. waxes
   ii. Compound lipid, i.e. phospholipid
   iii. Derived lipid, i.e. steroid
c. Explain the procedure for testing:
   - Reducing sugar
   - Non reducing sugar
   - Starch

A. Simple lipids or homolipids

These are esters of fatty acids and various alcohols. Such lipids include fats and oils (whose alcohol is glycerol) and waxes which contain alcohol higher than glycerol.

a. Fats and oils

Fats and oils are lipids which are made by the condensation of glycerol and three fatty acids. For this season, they are known as **triglycerides.**

Structure of Fats and oils

Fats and oils are of the same basic chemical structure, both fats and oils consist of one glycerol molecule and three fatty acids.

i. **Glycerol** is a type of alcohol contains three hydroxyl groups. Its chemical structure, which may react with the carboxyl groups of three fatty acid molecules, eliminating three molecules of water as shown in *Figure 2.12* The product is a molecule of triglyceride.

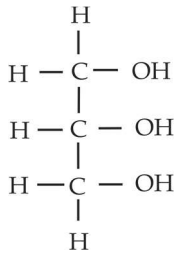


***Fig 2.12** Glycerol*

ii. **Fatty acids**

These are organic acids consist of a long unbranched hydrocarbon chain, CH_3 $(CH_2)_n$ – ending with a carboxylic acid (COOH) group. The hydrocarbon chain is non polar, but the terminal carboxyl group is partially ionised and can form the ionic bonds. The carboxyl group is therefore polar. The length of the carbon chain can differ, although in living organism is frequently between 14 and 16 carbon atoms long.There is a wide range of fatty acids, over 70 different ones have been extracted from living tissues. More importantly, the fatty acid may be **saturated** or **unsaturated**.

- **Saturated fatty acids (***Figure 2.13***)**

These are fatty acids whose hydrocarbon chain has single bonds between the carbon atoms. They are naturally found in animal fats, for example; stearic acid [C_{18}] in a red meat.

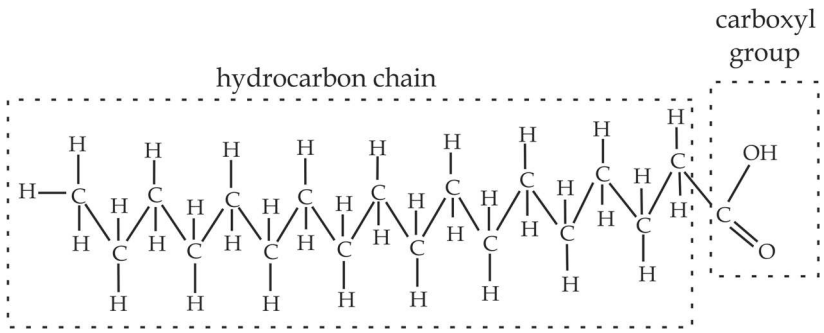


Fig 2.13 *Saturated fatty acid*, e.g. stearic acid, CH_3 $(CH_2)_{16}COOH$

Properties of saturated fatty acids

i. They have long hydrocarbon chain
ii. They are solid at room temperature(for example butter), the presence of single bonds attracts the carbon atoms in the hydrocarbon chain to lie close together and makes the lipid more solid.
iii. They have high melting point.
iv. They may lead to fat deposits in the arteries and block the blood arteries by a process called **atherosclerosis** which may result into arterial diseases such as stroke, high blood pressure and heart diseases, for this reason; it is not advisable to use fat diet on regular basis.

- **Unsaturated fatty acids** *(Figure 2.14***)**

These are fatty acids whose hydrocarbon chain has one or more double bonds between the carbon atoms. They are naturally found

in plant oils, for example; oleic acid [C_{18}] or omega 9 in sunflower, almond and olive oil.

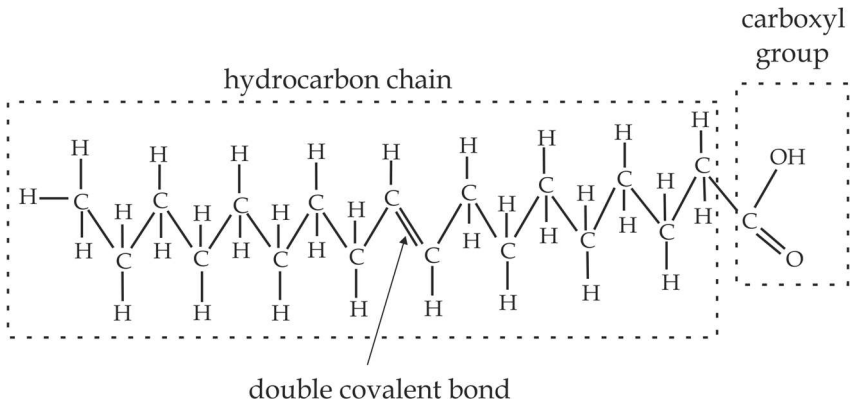


Fig 2.14 *Unsaturated fatty acid, e.g.* oleic acid, $CH_{17}H_{33}COOH$

Properties of unsaturated fatty acids

i. They have short hydrocarbon chain
ii. They are liquid at room temperature(for example margarine), The presence of double bonds stop the hydrocarbon chains of neighbouring triglycerides lying too close together and makes the lipid more fluid
iii. They have low melting point.
iv. They may not lead to fat deposits in the arteries; thus not result into arterial diseases, for this reason; it is advisable to use fat diet on regular basis.

Table 2.3 Differences between fats and oils

Fats	oils
saturated fatty acids present	Unsaturated fatty acids absent
solid at room temperature	Liquid at room temperature
High melting point	Low melting point
Originated from animals	Originated from plants
May result into arterial diseases	May Not result into arterial diseases

Sample question – 18

Dar Mock 2016

a. Tabulate three differences between fats and oils.
b. Why it is not advisable to use a diet contains fats on a regular basis.

Formation of fats and oils
(Chemistry triglyceride) *(Figure 2.15)*
Fats or oils are formed by the condensation reaction between one glycerol molecule and three fatty acids. Each hydrogen atom of the hydroxyl group of the glycerol molecule reacts with each of the hydroxyl (-OH) group of the carboxylic acid group of the three fatty acids to form triglyceride. The bonds formed between glycerol and fatty acids known as ester bonds

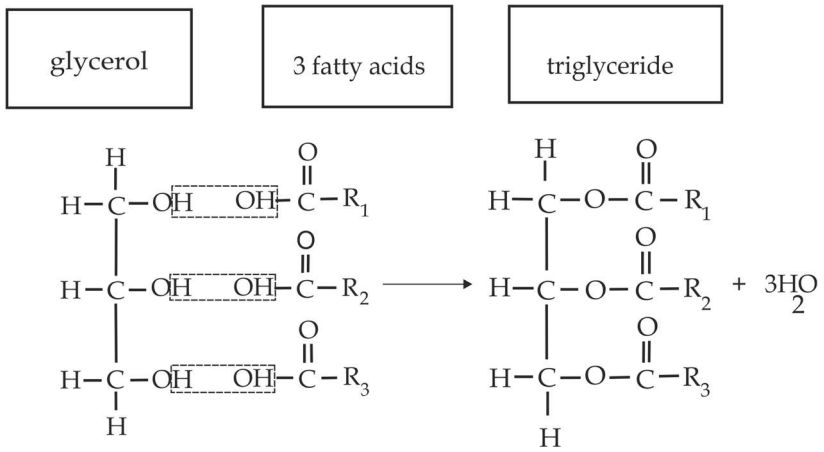


Fig 2.15 *Formation of triglyceride*

Sample question – 19

Pre – Necta Dar 2017
a. Briefly explain the chemistry of triglyceride.
b. Differentiate between saturation and unsaturation when referring to oils and fats.

Functions of fats and oil (triglycerides) in living organisms
1. Triglycerides act as long term energy store, yielding much more energy than an equivalent amount of carbohydrates. While carbohydrates are the most direct source of energy in living organisms because they can be **mobilised** directly, and used under aerobic or anaerobic conditions. The energy in fats cannot be released in the absence of oxygen.

2. Triglycerides are source of metabolic water when oxidized. Metabolic water is very useful to some desert animals such ads kangaroo, rat and camels.
3. Triglycerides are also stored under the skin surface of mammals as subcutaneous fat where they act as a heat insulator.
4. Triglycerides are source of metabolic water when oxidized. Metabolic water is very useful to some desert animals such ads kangaroo, rat and camels.
5. Triglyceride play a major role in the structure of cell membrane, here they are combined with phosphoric acid to form phospholipids. In the formation of a phospholipid the phosphoric acid reacts with one of the three hydroxyl groups of glycerol. The other two hydroxyl groups of glycerol react with fatty acid chains in the usual way.
6. Triglycerides aid buoyance in aquatic animals such as whale and dolphin.

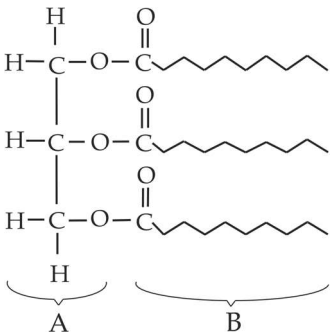
Sample question – 20

Style 1: St. Joseph's cathedral and Tambaza joint

- Give an account on occurrence and functions of triglycerides in living organisms.

Style 2: Tahossa Temeke 2017

a. The diagram below shows the structure of a certain organic compound in cells.



i. Identify the structure above.
ii. Name the parts labelled A and B.
iii. Name the chemical reaction used to form the bond between A and B, and define it.
iv. State one function of the above structure.

b. **Waxes**

Waxes are esters of fatty acids and long chain alcohol higher than glycerol. Unlike fats and oils waxes are complex chemical structure. In animals waxes are found in arthropods cuticle, vertebrae skin, bird feathers, honey combs and mammalian fur; in plants waxes are found on the leaves cuticles.

Commercial Application of waxes

i. They are used to make cosmetics, e.g. Facial makeup.
ii. They are used to make polishes and vanish.
iii. They are used to make dissecting dishes.
iv. They are used to make shoe soles.
v. They are used to make candles

Functions of waxes

The functions of waxes are depending on the possessed organisms which include:

1. **Animal waxes**
   - Animal waxes found on skin and hair help to make them soft and pliable.
   - Human ear waxes containing cerumin which prevent the entry of pathogens to the eardrum.
2. **Bee waxes**
   - Bee waxes produced by honey bees is used to make honey comb which store honey.

3. **Plant waxes**
   - Plant waxes form a cuticle over the leaves surfaces which prevent transpiration.

B. **Compound lipids or heterolipids**

These are lipids in which a fatty acid or glycerol molecule in a simple lipid is replaced by another group. Such lipids include; Phospholipids, glycolipid, lipoprotein and sphingolipid.

a. **Phospholipids** are compound lipids in which one fatty acid in a simple lipid is replaced by a phosphate group **(PO_4^{3-}).**The phosphate group is electrically charged (or polar) and dissolves in water – it is **hydrophilic** or water loving, the hydrocarbon tails are non – polar and do not dissolve in water – they are **hydrophobic** or water hating. The polar phosphate heads would be on the outside of the layer because they can interact with water and the non-polar fatty acid tails which will be away from the water

on the inside of bilayer; Such a molecule is described as **amphipathic,** this property of phospholipids is important in determine the structure of the cell surface membrane as shown in *Figure 2.16*.

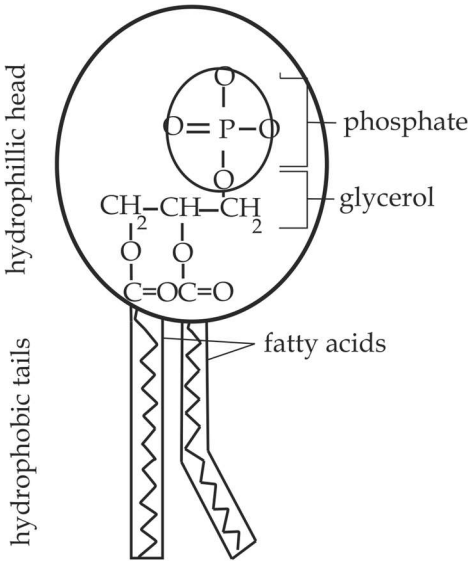


***Fig 2.16** Structure of phospholipid*

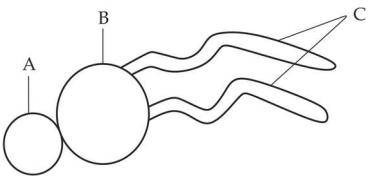
Functions of phospholipids

1. They form structural framework of the cell membrane.
2. They facilitate the passage of non – polar and lipid soluble molecules across the membrane.
3. They give the fluidity and flexibility of the membrane.

Sample question – 21

Advanced Biology Study aids

- The diagram represents a phospholipid molecule.



a. Name the parts of the molecule A, B and C.
b. Explain how phospholipid molecule form a double layer in a cell.

b. **Glycolipids**

Glycolipids are compound lipids in which one fatty acid is replaced by a carbohydrates particulary glucose or galactose.They are often called **cerebrosides** because of their abundance in brain tissues as shown in *Figure 2.17.*

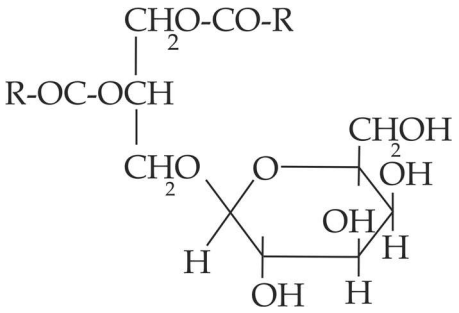


Fig 2.17 *Structure of glycolipid*

Functions of glycolipid

- They act as cell recognition sites . , this recognition function is very important to cells, as it allows the immune system to differentiate between body cells (called self ") and foreign cells (called non self").
- They act as receptors for hormones and neurotransmitters.

c. **Lipoproteins**

Lipoproteins are compound lipids in which one fatty acid in a simple lipid is replaced with an amino acid. Examples of such lipids include fibrinogen, prothrombin and albumin.

Functions of lipoproteins:

- They aid in blood clotting, e.g. fibrinogen and prothrombin.
- They regulate osmotic pressure of the blood, e.g. albumin.

d. **Sphingolipids**

Sphingolipids are lipids comparable to phospholipids except the sphingosine is present instead of glycerol, Sphingosine occur mostly in the cells of the brain.The most common type of sphingolipid is sphingomyelin which have phosphate and choline(phosphocholine) as addition groups.It is found in myelin sheath of nerve cells.

Function of sphingolipids

- They are structural components of myelin sheath which aid in nerve conduction because they normally increase the transmittion speed of the nerve impulde during nerve conduction.

C. Derived lipids

Derived lipids are molecules derived from the hdrolysis of simple and compound lipids.The properties of these molecules have little in common with lipids so far described, except for being insoluble in water but soluble in organic solvents.The most common derived lipids are **steroids.**

Structure of steroids

Unlike true lipids, steroids consist of seventeen carbon atoms, arranged in **four(4)** fused rings**, 3 rings** are of cyclohexane and **1 ring** of cyclopentane as shown in *Figure 2.18* . These four rings have solubility to lipids, and this is a reason why steroids are classified as lipids.Steroids occur in both plants and animals.In mammals, one of the most widespread steroids in the tissues is **cholesterol**.

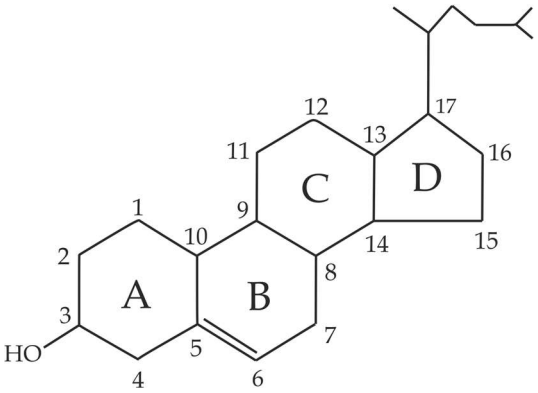


Fig 2.18 *A steroid*

Effects of excess cholesterol

- **Cholesterol** can be precipitated into the gallbladder leading to gallstone.
- **Cholesterol** in the blood vessels can reduce the diameter of blood vessels, this may lead to high blood pressure, stroke and heart diseases.

Functions of cholesterol

The following are the advantages of cholesterol in living organisms:

1. It usually regulate the fluidity and flexibility of the cell membrane.
2. It is used to make steroid hormones in the testes and ovaries such as oestrogen and progesterone.
3. It is used by the liver to make bile acid which form bile salts such as cholic acid.
4. It is used to make vitamin D.
5. It is used to make neurotransimitter substance called acetylcholine.

Sample question – 22

Advanced biology principles and Application

- What might be the advantages and disadvantages of trying to drastically lower the level of cholesterol in the body?

Did you know?

Terpenes are another derived lipids in plants found particularly in conifers, citrus trees and some insects, they are responsible for formation of aroma in medicine, such as aromatherapy, perfumes and food additives.

2.3.3: Testing for fats or oils

Requirements

- Sudan III solution

Procedure

- To a 3cc fat solution in a test tube an equal volume of water is added.
- Then 3drops of Sudan III solution and the mixture is shaken and settle.

Observation

A red stained oil layer separates on the surface of water.

Basis for the test

The fat or oil globules are stained red (by Sudan iii solution) float on water because they are less dense.

General functions of lipids

Lipids have the following functions in a living organisms:

1. **Energy sources**
   They are oxidized to release energy as second respiratory substrates; therefore, they are used when all carbohdrates are exhausted.Fats release roughly twice as much energy per gram as do carbohydrates. The energy in fat cannot be released in the absence of oxygen.

2. **Water source**
   They are oxidized to yield metabolic water.This is important source of water for animals found in arid and semi – arid areas such as camels.

3. **Structural components**
   They are used to form the structural components of the cell membrane such as phospholipids, glycolipid and cholestrol which are important for proper function of membrane.

4. **Insulation**
   They insulate the body against heat loss.For example, fats found in the sub – cutaneous layer of the skin.

5. **Protection**
   They protect and hold internal vital organs such as heart and kidneys in the proper position and against mechanical injury.

6. **Waterproofing**
   They form protective layers against water loss for example waxes in plants and sebum on animal skin.

7. **Bouyance**
   Being less denser than water, lipids aid bouyancy in the aquatic animals such as whales, sharks and dolphin.

8. **Precursors of substances**
   They are precursors of important body requirements such as vitamin D and sex hormones.

Sample question – 23

Famous Mock question

- Describe the following functions of lipid in living organisms
  i. Sources of energy
  ii. Insulation
  iii. Protection
  iv. Buoyancy
  v. Waterproofing materials
  vi. Structural components

5. **PROTEINS**

Proteins are organic compounds which contain carbon, hydrogen, oxygen and nitrogen, in some cases also contain sulphur and phosphorous. About **two – thirds** of the total dry mass of a cell is composed of protein. They are made up of long chains of α – amino acids linked by peptide bonds. The smallest protein molecule contains at least 50 amino acids and the largest over a thousand.

In this part, the following aspects should be discussed:
2.4.1: amino acids
2.4.2: Bonds used in protein structure
2.4.5: Classification of proteins
2.5.6: Denaturation of proteins
2.5.6: Test for proteins
2.5.7: General functions of proteins

2.4.1: AMINO ACIDS

Structure of amino acids

Amino acids are the basic structural and functional unit of proteins; this means, they are the monomers of proteins, there are **20** different types of amino acids that occur naturally, but all amino acids have the same basic structure. That is, each amino acid contain a central carbon atom known as **α – carbon** which is attached by acidic carboxyl group **(-COOH),** a basic amino group **($-NH_2$),** a hydrogen atom **(-H)** and alkyl group **(-R).**The R – group is called a side chain which gives each amino acid its uniqueness or determine the name of the amino acid as shown in *Figure 2.19*.
For example; R = H (*glycine*), R = CH_3 (*alanine*). R = C_2H_5 (*valine*).

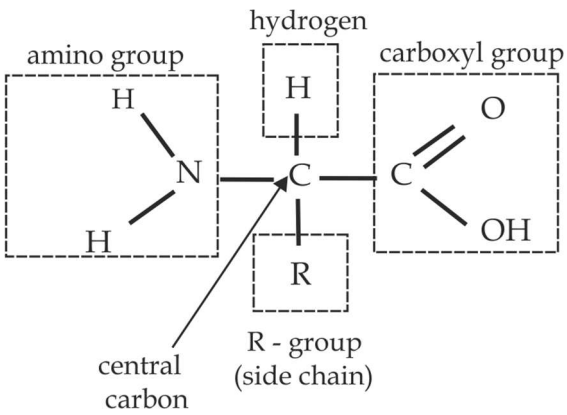
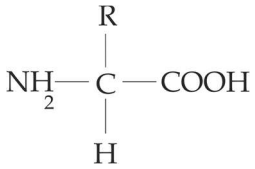


Fig 2.19 *The general structure of amino acid*

Sample question – 24

Necta 2006

- Study the molecular formula below and answer questions that follow:



a. What is the general name given to the molecular formula above?
b. What is the simplest form of R?
c. State six (6) properties of enzymes.

Properties of amino acids

i. They are **colourless** and **crystalline solids**.
ii. They are **soluble in water** but insoluble in organic solvents such as ether, chloroform and acetone.
iii. They have **high melting point**, often above 200℃.
iv. They exist as **dipolar ions** in aqueous neutral solution medium known as **Zwitterions** as shown in *Figure 2.20***.** That is; the acidic carboxyl group (-COOH) has a tendency of donating hydrogen proton (H+) and become negatively charged (- COO^-) whereas, the basic amino group (-NH2) has a tendency of accepting hydrogen proton (H+) and become positively charged ($NH3^+$).

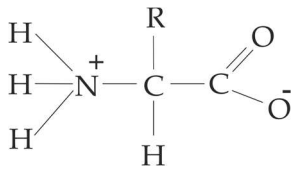


Fig 2.20 *Structure of zwitterion*

Note:
Isoelectric point (IEP) is the pH of amino acid in neutral aqueous solution.

v. They are **amphoteric in nature**, this is due to the presence of acidic property of the carboxyl group (-COOH) and basic property of amino group (- NH2) as shown in *Figure 2.21*.

Biological significance of being amphoteric in nature

- They stabilizing pH in the body by resisting pH changes when small amount of acid or alkali is added.

  For example
  - In acidic medium (when the pH of IEP is lowered), the carboxyl group (COO^-) accepts hydrogen ions and the structures become positively charged.
  - In alkaline medium (when the pH of IEP is increased, the amino group ($NH3^+$) donates hydrogen ion and the structure become negatively charged.

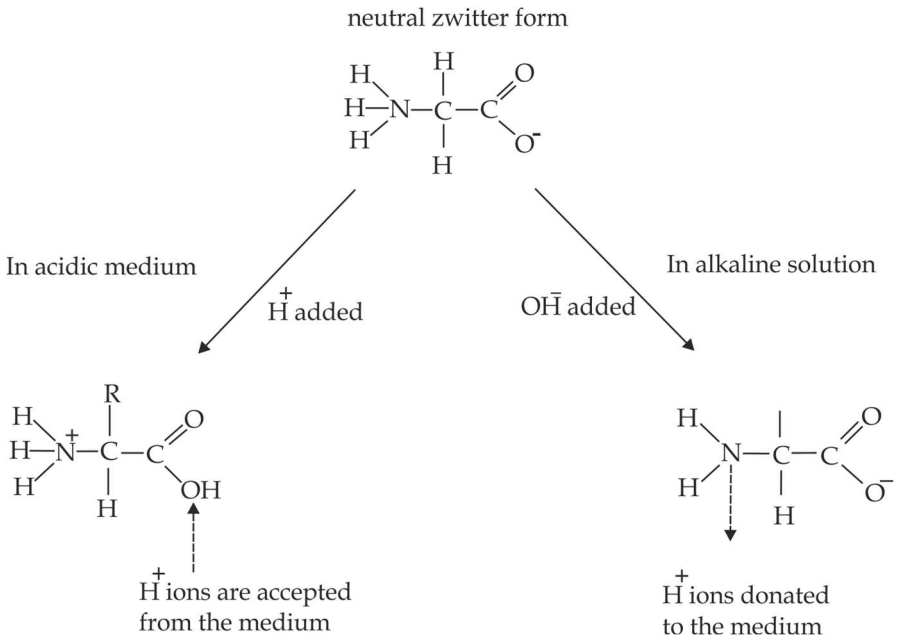


Fig 2.21 *Amino acids are amphoteric*

Sample question – 25

Dar Mock 2021

a. Explain why molecules of amino acids are described as dipolar or "zwitterions"?
b. Why are proteins said to be amphoteric?
c. What is the biological significance of this property?

Types of amino acid

Generally, there are **20** common types of amino acids found naturally in living organisms. The **20** amino acids are further categorized into two (2) types; **essential amino acids** and **non-essential amino acids.**

Essential amino acids

These are amino acids which cannot be synthesized by the body.i.e; they can be supplied only from the diet ,Proteins which are rich in essential amino acids are called **first class proteins** such as animal proteins, For example milk, eggs, Meat and fish.

Non-essential amino acids

These are amino acids which can be synthesized by the body. Proteins which are rich in non – essential amino acids are called **second class proteins** such as plant proteins, For example, beans, peas and lentils.

Table 2.4 Names of twenty amino acids

Essential	Non – essential
These – Threonine	**A**lmost – Alanine
Ten - Tryptophan	**A**ll – Asparagine
Valuable – Valine	**G**irls – Glutamate
Amino – Arginine*	**G**o – Glutamine
Have – Histidine*	**C**razy – Cysteine
Long – Lysine	**A**fter – Aspartate
Preserved - Phenylanine	**G**etting – Glycine
Life - Lysine	**T**aken – Tyrosine
In – Isoleucine	**F**rom – (f = p) Proline
Men – Methionine	**S**hopping = Serine

* *Essential in children (Arginine and histidine), both required for growth and development; but are non-essential in adults.*

Sample question – 26

Possible question at any time

- Differentiate between essential and non-essential amino acids, giving two (2) examples in each case.

2.4.2: **BONDS USED IN PROTEIN STRUCTURE**

Basically, there are **five (5)** main types of bonds which involve in the formation of protein structure; which includes:

A. Peptide bond

Peptide bond is a bond between carboxyl group **(- COOH)** and amino group **(NH_2)** of adjacent amino acids. Peptide bonds hold together the amino acids in the linear polypeptide chain. The first step in this process involves the union of two amino acids. A reaction occurs between the amino group of one amino acid and the carboxyl group of another amino acid, a molecule of water is removed in a condensation reaction ant the two amino acids become joined together by a **dipeptide**. Continued condensation reactions lead to addition of further amino acids, resulting in the formation of a long chain called **polypeptide** as shown in *Figure2.22***;** Polypeptide may be composed of up to around **400** amino acids.

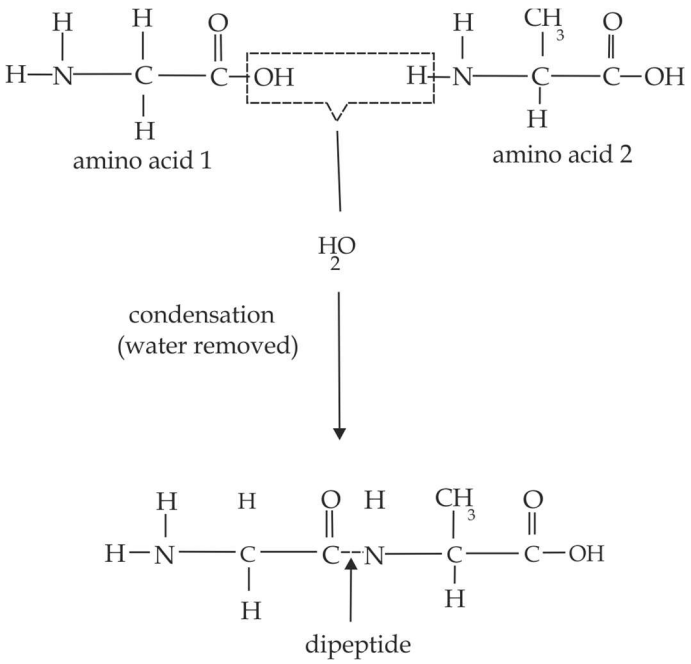


***Fig* 2.22** *Formation of peptide bond*

A. Hydrogen bond

Hydrogen bond is the bond between a more electronegative atom, such as nitrogen **(N)** or oxygen **(O)** and more electropositive hydrogen atom. Although hydrogen bonds are very weak, the absolute number of bonds

plays a considerable role in shape and stability of the polypeptide chain. The hydrogen bond also can be formed in a folded polypeptide chain provided that hydrogen atom (H) and the oxygen atom of carboxyl or nitrogen atom of the amino group face each other and attract as shown in *Figure 2.23*.

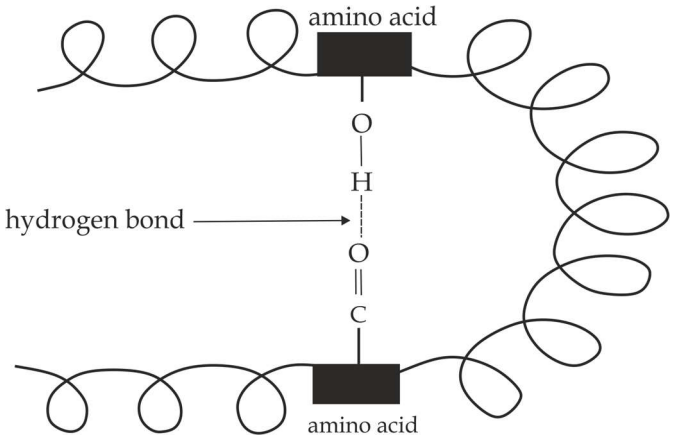


Fig 2.23 *Formation of hydrogen bond*

C. Ionic bond

This is a bond between the positively charge basic R group (NH_3^+) and negatively charged acidic R – group (- COO^-) of amino acids as shown in *Figure 2.24*. Ionic bonds are weak, can be broken by changing the pH of a medium, The ionic bond also can be formed in a folded polypeptide chain such as secondary and tertiary structure protein.

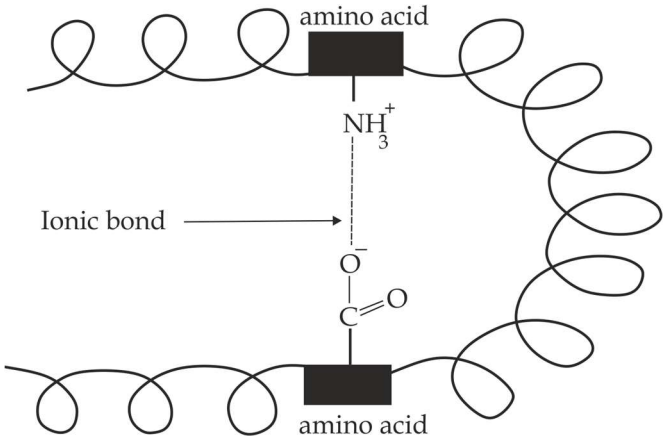


Fig 2.24 *Formation of ionic bond*

D. Disulphide bond

This is a strong covalent bond between two (2) oxidized sulfhydryl (-SH) group of cysteine amino acids as shown in *Figure 2.25*; Disulphide bond stabilizes the tertiary structure of a protein into compact globular shape.

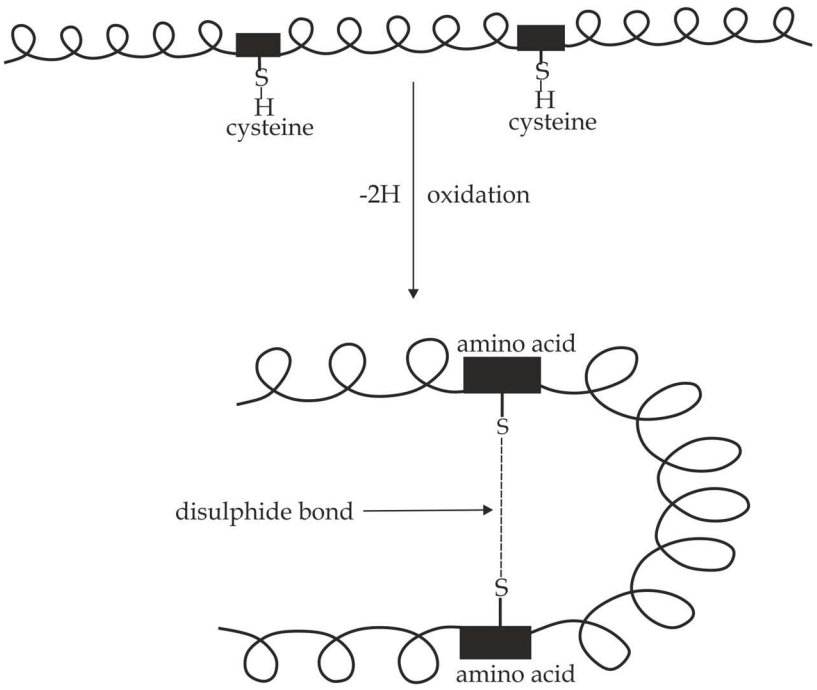


Fig 2.25 *Formation of disulphide bond*

E. **Hydrophobic interaction**

This is the attraction forces between non – polar R groups (hydrophobic) of a polypeptide chain in aqueous solution. The R groups (hydrophobic) tend to point inwards towards the centre and exclude water (clustering) as shown in *Figure 2.26*, although hydrophobic interaction is not a true bond, but the clustering effect influence the shape of proteins.

Real situation

Mfano mzuri unapotoka kuoga bafuni, nywele zinakunja kwasababu makundi mengine ya amino acids kwenye protein ya nywele (α – helix keratin) yanakimbia maji

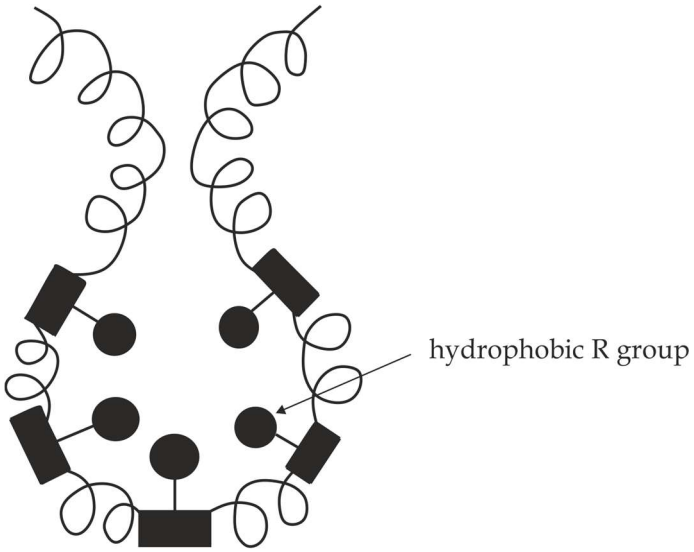


***Fig 2.26** Hydrophobic interaction*

Sample question – 28

Tambaza and Temeke Joint Exam 2021

- Describe five types of bonds formed in proteins.

2.4.3: CLASSIFICATION OF PROTEINS

Due to their complexity, it is difficult to classify protein molecules into a single, well defined category. They can be classified according to the level of organization, structure, composition and functions.

A. Classification of proteins based on their level of organization.

Knowing the sequence of amino acids in a protein is important because this sequence determine practical all the properties of the protein. There are four types of proteins based on the level of structural organization, namely; primary, secondary, tertiary and quaternary structures of proteins.

a. Primary structure of protein

The primary structure of protein is a linear sequence of amino acids that make up the polypeptide chain as shown in *Figure 2.27*. This structure is due to peptide bonds. Examples of proteins with the

primary structure include insulin hormones. In the living cell the sequence of amino acids in a polypeptide chain is specified by the DNA.

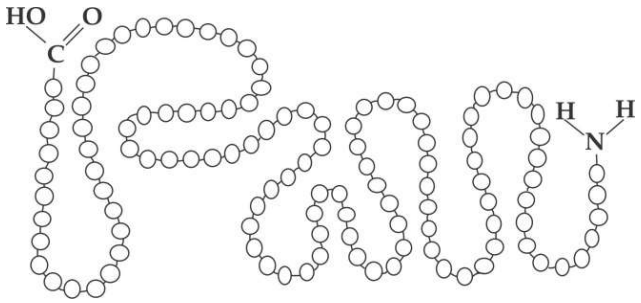


Fig 2.27 *Primary structure protein*

B. Secondary structure of protein

The secondary structure of protein is a twisted or folded polypeptide chain by hydrogen bonds. The most common types of secondary structure are **alpha helix** (α – helix) and **beta – sheets** (β –sheets) as shown in *Figure 2.28(a), (b)*.

i. **α – helix** - Is an extended spiral spring chain whose structure is held in place by hydrogen bonds between adjacent **CO** and **NH** group
Examples of **α – helix** protein are **keratin proteins:**
- hair,
- horns
- nails,
- wool
- beaks
- feathers

Collagen proteins such as found in mammalian connective tissues including tendons, bones and cartilages.

ii. **β- Sheets** – Formed when two or more polypeptide chains line side by side are held by hydrogen bonds between CO and NH group. The surface of β – sheets appear " pleated" and these structures are, therefore, often called " β – pleated sheets". An example is the protein fibroin in silk, which consists almost entirely of the β – sheet form.
For example,
- Spider secretes spider webs from the last abdominal segment which appears as β – sheet pleated.

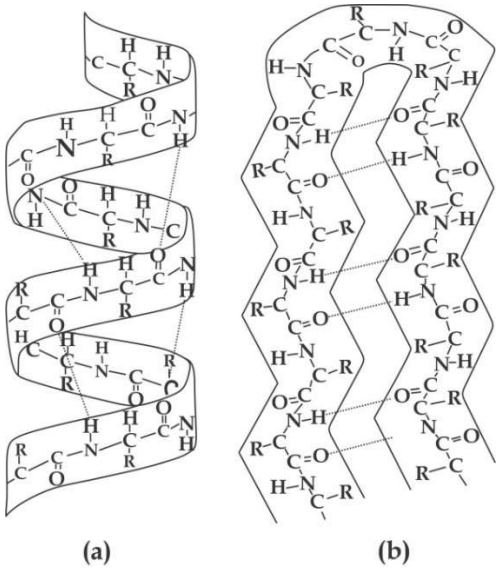


Fig 2.28 *The secondary structure of proteins (a) alpha helix and (b) beta plate*

c. Tertiary structure of protein

Tertiary structure of protein is highly coiled polypeptide chain into a compact globular shape as shown in *Figure 2.29*. The shape is maintained by the hydrophobic interactions, ionic, hydrogen and disulphide bonds. Proteins with a globular shape generally possess specific metabolic activity. Examples of tertiary structure proteins:

- Enzymes
- Antibodies.

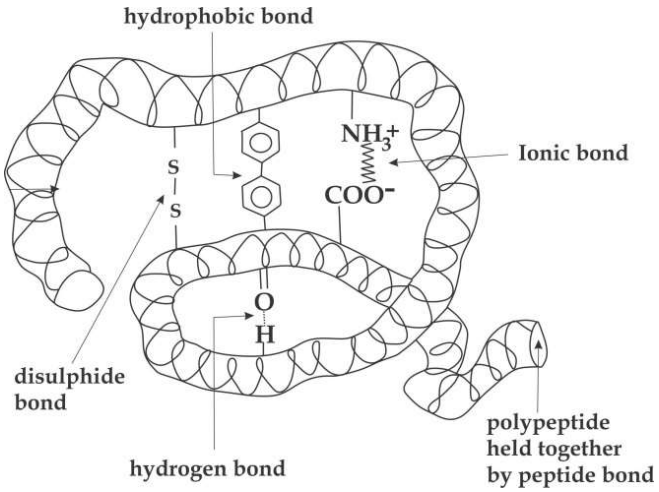


Fig 2.29 *Tertiary structure of protein*

d. **Quaternary structure of protein**

Quaternary structure of protein consists of two or more polypeptide chains held together by hydrogen bond, ionic bond and hydrophobic interactions as shown in *Figure 2.30*. Example is haemoglobin, which consists of four main polypeptide chains (two **α** and two β – globulins) each of which is combined with an iron – containing haem groups (prosthetic groups) for transportation of oxygen and carbon dioxide gas.

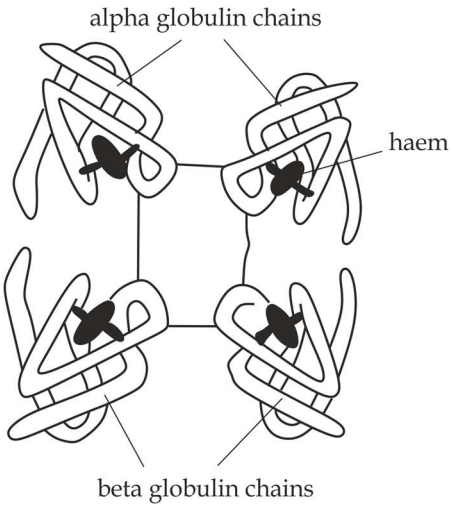


Fig 2.30 *Quaternary structure of protein*

Sample question – 29

Style 1: Necta 2015

- Outline the four (4) types of bonds which will contribute to the formation of tertiary structure of protein.

Style 2: Feza Boys 2008

a. Explain on primary, secondary, tertiary and quaternary structure of protein.
b. State six (6) properties of enzymes.
c. i. What are chemical composition of proteins?
   ii. What does amphoteric protein means?
   iii. What is the role of amphoteric property in a biological system?

B. Classification of proteins based on their structure

Based on their structure, proteins are categorized as fibrous, globular and intermediate proteins:

a. Fibrous proteins

Fibrous proteins are proteins that have secondary structures.

Nature of fibrous proteins:

Fibrous proteins have the following properties:

i. Fibrous proteins are insoluble in water.
ii. They are more stable. For the above reasons, fibrous are used to form structural body parts.

Role of fibrous proteins:

- They have structural and supportive role, i.e. keratin which form hair, skin, horns and collagen which form bones, cartilage and muscles.

b. Globular proteins

Globular proteins are proteins that have tertiary structure.

Nature of globular proteins:

Globular proteins have the following properties:

i. They are soluble in water.
ii. They are less stable.

Role of globular proteins:

- They have metabolic functions, i.e. enzymes and antibodies.

c. Intermediate proteins

These are fibrous proteins but soluble in water.

Role of intermediate proteins:

- They aid in blood clotting, i.e. fibrinogen.

Table 2.5 Differences between structural and functional proteins.

Structural protein	Functional protein
It is secondary in structure.	It is tertiary in structure.
It is insoluble in water.	It is soluble in water.
It is more stable	It is less stable
Length of chains may vary in two examples of the same protein.	Length of chains is always identical in two examples of the same protein.
It has a structural role.	It has a metabolic role.
Examples: keratin and collagen proteins.	Examples; enzymes and antibodies.

Sample question – 30

Style 1: Feza Boys 2011

a. Briefly describe the chemical composition of protein.
b. Describe the classes of proteins according to structure.

Style 2: Necta 2001

Distinguish between structural and functional protein.

Hints:

Structural (fibrous) and functional (globular).

C. Classification of proteins based on their composition.

Based on their composition, proteins can be classified as simple and conjugated proteins.

a. Simple proteins

These are proteins made up of only amino acids sequence. The common examples of simple proteins are albumin and globulins.

b. Conjugated proteins

These are proteins containing the amino acids and also non-protein substances known as **prosthetic groups**. Examples of conjugated proteins and their prosthetic groups.

Table 2.6 Examples of conjugated proteins and their prosthetic groups are shown in the table below:

Name	Prosthetic group	Location
Hemoglobin	Haem	blood
Glycoprotein	carbohydrate	Cell membrane
Flvoprotein	$FAD2^{+}$	Krebs cycle and ETC
Cytochrome	Copper	ETC
Chromoprotein	pigment	chlorophyll
lipoprotein	lipid	Cell membrane

D. Classification of proteins based on their functions.

The functions of proteins depend upon the nature and arrangement of the constituent amino acids. Twenty different amino acids commonly occur in proteins. They are organized into many different sequences which in turn give rise to an almost infinite variety of proteins with diverse structural and metabolic functions; which include:

a. **Structural proteins**
These are proteins which normally form structural body parts in organisms. For example: keratin and collagen proteins.

b. **Contractile proteins**
These are proteins which aid movement of the body parts: For example actin and myosin proteins in the muscles.

c. **Enzyme proteins**
These are proteins which catalyse the biochemical reactions in the living cells: For example: amylase which catalyses the hydrolysis of starch into maltose.

d. **Hormone proteins**
These are proteins which regulate the body: For example; Insulin hormones which regulate the level of sugar in the blood plasma.

e. Transport protein
These are proteins which transport materials around the body; for example haemoglobin transport oxygen and carbondioxide gas.

f. Defense proteins
These are proteins which fight against infections and mechanical injury: For example; Antibodies which fight against viruses and bacteria while fibrinogen and thrombin fight against blood clotting caused by the mechanical injury such as cut injury which may lead to bleeding.

g. Storage proteins
These are proteins which are involved in the storage of some substances: For example casein in milk, aleurine protein in seeds and albumin in eggs.

h. Toxin proteins
These are proteins which form poisons such as snake venoms.

Sample question – 31

Style 1: Necta 2016

a. Name the chemical composition of protein.
b. Explain six (6) categories protein based on their functions.

Style 2: Dar Mock 2017

- Copy and complete the table below giving a named example of a protein having the function indicated:

Function	Example of protein
Contractile	
Enzyme	
Transport	
Structural	
Hormone	
Protection	

E. Protein denaturation

Protein denaturation is the loss of the three dimensional structure of a protein molecule. This alters the bonds that maintain the secondary and tertiary structure of the protein, even though the sequences of amino acids remain unchanged. The protein molecule may begin to unfold, and the properties of the protein that depend upon shape are then lost as shown in *Figure 2.31*.

Protein renaturation is the process by which a protein refolds into its original structure after denaturation provided that conditions are stable.

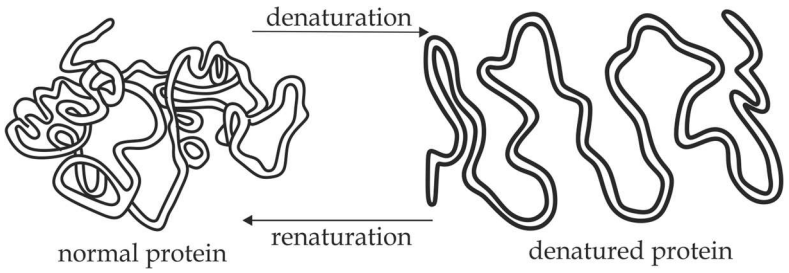


Fig 2.31 *Illustration of protein denaturation and renaturation*

Causes of protein denaturation

The causes of protein denaturation include heat, organic solvents and detergents, strong acids and alkali, inorganic chemicals, urea solution and mechanical forces.

a. Heat

Heat and radiations provide high kinetic energy which causes strong vibrations of protein molecules as the result into breaking of ionic and hydrogen bonds, Example: The protein albumin in egg white denatures and coagulates during cooking.

b. Organic solvents and detergents

Organic solvents such as (spirit) methyl ethanol, chloroform, benzene, toluene and detergents disrupt hydrophobic interactions and hydrogen bonds in a protein. Example; Methyl alcohol (spirit), which is used as disinfectant to clean the skin before injection, denatures proteins in bacterial cell walls. This is what makes methyl alcohol useful for sterilization.

c. Strong acids and alkali

Strong acids and alkali disrupt ionic bonds and result to unfolding of protein globular shape. The **strong acids** release high concentration of $\mathbf{H^+}$ ions which combine with carboxylate ion ($-COO^-$) of the amino acids to form the carboxylic group (COOH).This causes the ionic bonds to break. On the other hand, **alkalis** release high concentration of OH^- which causes NH_3^+ group to loose $\mathbf{H^+}$ and form NH_2, thus breaking ionic bond. Example; the souring of milk by the lactic acid is applied in fermentation industries to denature the casein milk and making it insoluble and form curds.

d. Inorganic chemicals

Inorganic chemicals normally include heavy metals and non-metals elements Heavy metals such as mercury (Hg^{+2}), silver (Ag^+) and lead (Pb^{2+}) are highly electropositive, they combine with carboxylate group ($-COO^-$) and disrupt ionic bond, on the other hand, high electronegative non-metals such as cyanide (CN^-) combine with NH_3 group and disrupt ionic bond, Example: **Cyanide** inhibits cytochrome oxidase in the electron transport chain.

e. Urea solution and alkaloids

Urea and alkaloids tend to disrupt hydrogen bonds. Being amide - like, they form hydrogen bonds of its own via distorting the unique

configuration of the protein molecule. Example; Alkaloids solutions are applied on burnt areas to destroy the protein and lead to the formation of fibrous mesh which prevents entry of germs into the body.

f. Mechanical forces

Physical movement of proteins may break hydrogen bonds. For example, Stretching of hair breaks the hydrogen bonds in the keratin helix. The helix is extended and the hair stretches, if released , the hair return to its normal length, if however, it is wetted and dried under tension, it keeps its new length the basis of hair styling.

Sample question – 32

Style1: Necta 2017

- Explain how each of the following factors cause protein denaturation:
  i. Heat
  ii. Acid
  iii. Alkali
  iv. Mechanical force

Style 2: MOBEP 2021

a. Give short notes on the term protein denaturation and protein renaturation.
b. What causes protein to lose its natural three dimension conformation? Give five points.

Style3: Mbeya Region Mock Exam 2021

- Explain any five (5) factors that may cause protein denaturation.

Medical application of protein denaturation:

1. In sterilization process

The effect of detergents such as alcohols denature the proteins of the microorganism causing diseases and stops spreading of the infection.

2. In preventing poisons

Fresh milk (undenatured protein) is taken by a person who accidentally swallow heavy metal poisons, the milk offers its charged protein which react with the heavy metals and form non-toxic substances.

Sample question – 33

TAI question

- Explain the medical importance of protein denaturation

2.4.5: Testing for protein (Biuret test)

Reagent:

- Copper II sulphate
- Sodium hydroxide (NaOH)

Procedure

- Add 3cc protein sample solution in a test tube followed by 3cc of NaOH solution.
- Then add 3drops of $CuSO_4$ and mix the mixture.

Observation

Purple color is observed.

Basis for the test

In the presence of dilute $CuSO_4$ solution in alkaline medium, Nitrogen atoms in the peptide chain form purple complex copper II ions ($Cu2^+$).

Sample question – 34

Necta 2017

a. Briefly explain how to test for the protein in a given solution using biuret test.
b. What is the basis of protein test?

General functions of proteins

Proteins have structural and metabolic functions in living organisms which include the following:

A. In structures

1. Proteins form structural components of the body parts. For instance, **keratin** is a structural protein of hair, horns, and hooves and nails whereas **collagen** is a structural protein of connective tissues such as muscles, tendons, ligaments and bones.

B. **In metabolism**

1. **Energy source**
   Proteins are alternatively respiratory substrates when both lipids and carbohydrates are completely depleted such as in case of starvation.
2. **Movement**
   Proteins such as actin and myosin aid in the movement of the body; therefore, they interact to bring about contraction and relaxation of muscles, hence, the movement of body.
3. **Enzymes**
   Proteins such as enzymes are involved in various body metabolism.
4. **Hormones**
   Proteins such as hormones regulate the body metabolites and act as chemical messengers, Example of such proteins are insulin and glucagon, which usually regulate the level of blood sugars in mammals.
5. **Defense and protection**
   Proteins such as antibodies protect the body against infections.
6. **Haemoglobin**
   Proteins such as haemoglobin transport oxygen and carbon dioxide around the body of a living organism.
7. **Storage**
   Proteins such as casein in milk and Ovalbumin of egg white are storage in function, for example albumin supplies food to a developing embryo.
8. **Poisons**
   Proteins such as snake venoms and spider venoms are important in the formation of toxic substances.
9. **Buffer**
   Proteins act as a buffer in the body fluid such as blood plasma, i.e. they resist pH changes in acidic or basic medium.
10. **Absorption**
    Proteins play a vital role in the absorption of excess fluid in the body. This explains why a kwashiorkor victim has swollen limbs and stomach. This is due to accumulation of excess fluid in the body tissues, a condition called oedema.

Sample question – 35

Necta 2000

a. What are proteins?
b. Discuss the importance of proteins in the structure and metabolism of organism.

2.5: ENZYMES

The word enzyme came from the Greek word which literally means "Yeast" and it was coined for the active ingredient in yeast cells that causes fermentation. It is now used as the collective name of the thousands of organic compound that have be extracted from cells and found to speed up the chemical reactions which occur in organisms.

WHAT ARE ENZYMES?

Enzymes are biological catalysts which speed up the chemical reactions in living organism. Enzymes are biological catalysts because they are proteins made by living cells.

The study of enzyme is called enzymology; in enzymology, the following aspects should be discussed:

2.5.1: Properties of enzymes
2.5.2: Enzyme specificity
2.5.3: Modes of enzyme action
2.5.4: Factors affecting the rate of enzyme activity
2.5.5: Allosteric enzymes
2.5.6: Enzyme inhibitors
2.5.7: Enzyme regulation in metabolic pathways
2.5.8: Enzyme cofactors
2.5.9: Nomenclature of enzymes

2.5.1: properties of enzymes

The properties of enzymes in the living cells include the following:

i. **They are proteins in nature**
   All enzymes are globular protein in nature, being proteins can be coded by the DNA.
ii. **They are biological catalyst**.
   Being catalyst enzyme lower the activation energy of the reaction by combining with substrate to form enzyme – substrate complex which increase the chances of the reaction to occur.

ii. **They are highly specific**
All enzymes catalyse only on a specific substrate. Just as a key has a specific shape and therefore fits only complementary lock, so only a specific substrate fits the active site of enzyme. Example, the enzyme **catalase** will only break down the hydrogen peroxide and not any other compounds.

iii. **They are highly efficient**
That means, a very small amount of enzyme brings about a change to a large amount of substrate. Example, the enzyme carbonic anhydrase, found in red blood cells (RBC'S), can catalyse the conversion of **3.6×10^7** molecules of carbondioxide to hydrogen carbonate per minute per mole of enzyme.

iv. **Reversibility**
Enzyme – catalysed reactions are reversible that is enzyme catalyses the forward and reverse reaction equally. They do not therefore alter the equilibrium itself, only the speed at which it is reached. The enzyme carbonic anhydrase, For example, accelerates the conversion of carbondioxide and water to carbonic acid in respiring tissues and the reverse reaction in the lungs of mammals.

v. Their activity is usually affected by pH, temperature, and substrate and enzyme concentration. (**This will be discussed in the factors affecting the rate of enzyme activity**).

vi. They possess active site where the reaction takes place; the active sites have specific shapes. (***An active site*** *is a region of an enzyme molecule where the substrate binds).*

Sample question – 36

Mock Coast Region Exam 2004

a. Discuss the general properties of enzymes.
b. By using three (3) points, show how enzymes differ from a catalyst.
c. Explain three (3) classes of cofactors.
d. What do you understand by the Lock and Key of enzyme action?
By using diagram describe the concept (15 marks)

Table 2.6 Differences between enzymes and inorganic catalyst

Enzyme	Inorganic catalyst
They are protein in nature	They are mineral ions
They are catalase only specific reaction	They are catalyst different reactions
They are more efficient	They are less efficient
They have active site which the substrate can bind	They have no active site
They are more sensitive to pH and temperature	They are less sensitive to pH and temperature changes
They control reactions in living cells	They control reactions outside the living cells

Sample question – 37

Tahossa Dar 2022

a. By using three (3) points, show how enzymes differ from a catalyst.
b. Explain three (3) classes of cofactors.

2.5.2: Enzyme specificity

Enzyme specificity is an ability of an enzyme to bind one substrate for catalytic reaction. Enzyme specificity ensures that; each reaction is catalysed by a specific enzyme within the cell to avoid interruption or interference of metabolism from surrounding reactions. For example; in human, there over 1000 different reactions take place in an individual cell.

Basis of enzyme specifity:

According to lock and key hypothesis; specifity of different enzymes is determined by the shapes of their active sites. The active sites possess specific rigid geometric shape that fit with specific substrates.

Sample question – 38

Tabora Boys/ Pre – syndicate Exam 2021

- Describe the specificity of the enzyme based on the key and lock model.

Types of enzyme specifity
There are **four (4)** types of enzyme specifity; which include the following:

a. Absolute specificity
This is an enzyme specifity in which the enzyme catalyses only one kind of substrate or reactions. Example; lipase catalyse only lipid into fatty acid and glycerol.

b. Group specificity
This is an enzyme specificity in which enzyme catalyses only on molecule that have specific functional group (amino, phosphate or methyl group).Example; hexokinase catalyses the molecule with phosphate group on hexose sugar.

c. Stereo chemical specifity
This is an enzyme specifity in which the enzyme catalyses in only one kind of organism. Example; The enzyme catalyses lactate in mammals cannot catalyse lactate in bacteria.

d. Linkage specifity
This is enzyme specifity in which the enzyme catalyses on a particular type of chemical bond regardless of the molecular structure. Example; α – amylase is specific to α – 1, 4 – glycosidic bond.

Disadvantages of enzyme specifity
i. It consumes a lot of energy to synthesize different enzymes for different metabolic reactions, since each enzyme acts on the specific substrate or reaction.
ii. It may result into absence of some reactions due to absence of a specific enzyme.
iii. It may result into incomplete of some reactions due to absence of a single enzyme in a metabolic pathway which require more than two different enzymes for complete reaction. Example; the hydrolysis of starch into glucose requires two enzymes, amylase and maltose.

Sample question – 39

Kilimanjaro Mock 2018
- One of the properties of enzymes is their specifity to reactions they promote. What are the disadvantages of such specifity?

2.5.3: Modes of enzyme action
(How enzymes Work)

There are two (2) main hypotheses that explain the mechanism of enzyme controlled reaction in living cells; which include:

a. Key and Lock hypothesis
b. Induced fit hypothesis

A. Key and Lock hypothesis

This hypothesis was suggested by a scientist called " Emil Fischer" in **1890.** According to this hypothesis, it states that:

" *Substrate fits accurately into the rigid specific active site of the enzyme molecule in the same way that a key fits in one lock, the two molecules form the enzyme – substrate complex which later dissociates into products and enzyme*" .

The weakness of this hypothesis is that; any structural modification of either substrate or enzyme leads no catalysis because no binding of substrate to the enzyme will take place and thus no enzyme – substrate complex formation. Due to this weakness, this theory was discouraged and it was considered as the old hypothesis of the mechanism of enzyme action.

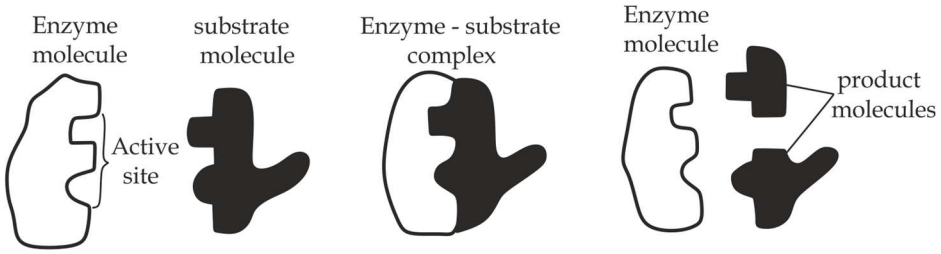


Fig 2.32 Key and lock model of Emil Fischer

Sample question – 40

Tahossa Ilala Region 2015

a. What do you understand by the "Lock and Key model "of enzyme action?
   By using diagram describe the concept.
b. What is the weakness of the lock and key model of enzyme action?

B. Induced fit hypothesis (*Figure 2.33***)**

This hypothesis was put forward by Daniel Koshland in **1959** to modify the key and lock model. So it is currently accepted hypothesis. According to this hypothesis, *it states* that:

" the active site of the enzyme is not rigid but could be modified as the substrate interacts with the enzyme to form enzyme – substrate complex which later dissociates into products and enzyme".

Unlike in the key and lock hypothesis, the induced fit hypothesis describe the enzyme active site as **dynamic** in nature. When a substrate combines with an enzyme, it induces slightly changes in the enzyme shape. The amino acids which make up the active site are mounded into a precise form, which enables the enzyme to perform its catalytic function effectively.

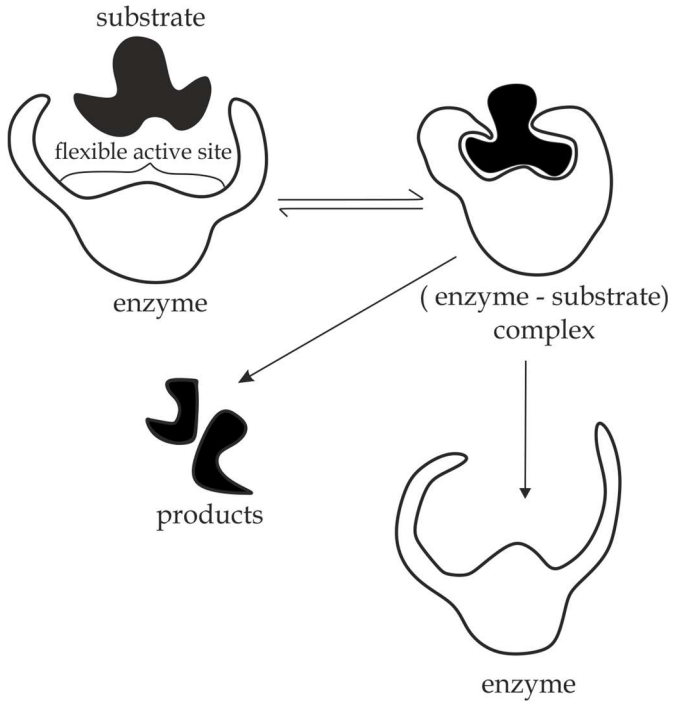


***Fig* 2.33** *Induced fit hypothesis by Daniel Koshland*

Sample question – 41

Marian Girls 2003

- How the mechanism of enzyme activity is explained by scientist like you?

Table 2.7 Differences between key and lock and induced fit hypothesis:

Key and lock hypothesis	Induced fit hypothesis
Enzyme has a rigid active site	Enzyme has a flexible active site
Enzyme does not change in shape	Enzyme undergo conformation change in shape
Substrates are complementary to the active site	Substrates are non-complementary to the active site
It catalyses a single substrate	It catalses different substrates

Sample question – 42

Possible at any time

- Explain the differences between the "lock and key "and "induced fit "hypothesis of enzyme action.

2.5.4: Factors affecting enzyme activity

Basically, there are **five (5)** factors affecting the rate of enzyme activity, which includes;

a. substrate concentration
b. enzyme concentration
c. temperature
d. PH level.

Remember

There is another factor which can affect the rate of enzyme activity known as inhibitor, but will be discussed in the part of enzyme inhibitor (2.5.6)

a. Substrate concentration (*Figure 2.34***)**

As the substrate concentration increases, the rate of enzyme controlled reaction also increases until it reaches the **saturation point;** above this point any increase in substrate concentration has no effect in the rate of enzyme reaction because all the active sites of the enzyme become fully saturated, thus, extra substrates have to wait for the enzyme to release the product and become free to accommodate other substrate.

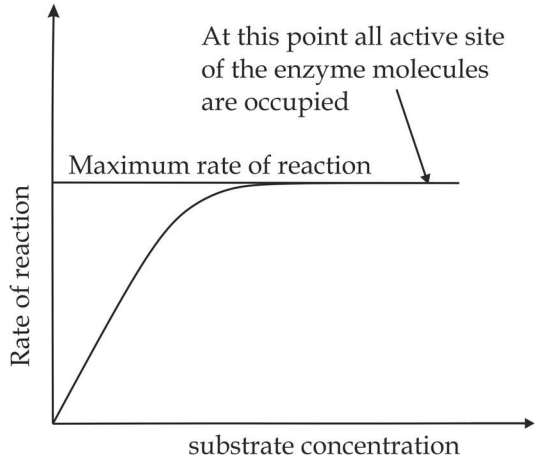


Fig 2.34 *The effect of substrate concentration on the rate of reaction*

b. Enzyme concentration (*Figure 2.35***)**

The rate of an enzyme controlled reaction is directly proportional to the enzyme concentration, provided that substrate concentration is kept at a higher level, when the substrate is in short supply an increase in enzyme concentration has no effect

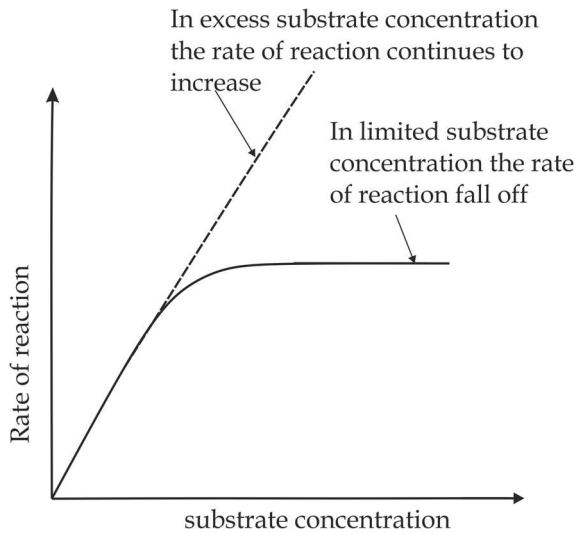


Fig 2.35 *the effect of enzyme concentration on the rate of reaction*

c. **The effect of temperature (***Figure 2.36***)**

The rate of an enzyme controlled reaction on temperature is explained by the temperature coefficient factor Q_{10}.

According to the Q_{10} rule, it states that:

" Rate of enzyme controlled reaction is doubled for every 10℃ rise in temperature until the optimum temperature is attained (0℃ - 40℃)"

Key concept:

- If the temperature is increased above the optimum value, denaturation of enzyme occurs then the rate of reaction declines.
- If the temperature is near to or below freezing point enzymes are inactive, this explains why it is not advisable to drink cold water soon after a meal.

A mathematical expression of Q_{10} is represented below:

$$Q_{10} = \frac{\text{rate of reaction at } (X + 10)\ ℃}{\text{Rate of reaction at } X℃}$$

*Where: **X** is the initial temperature*

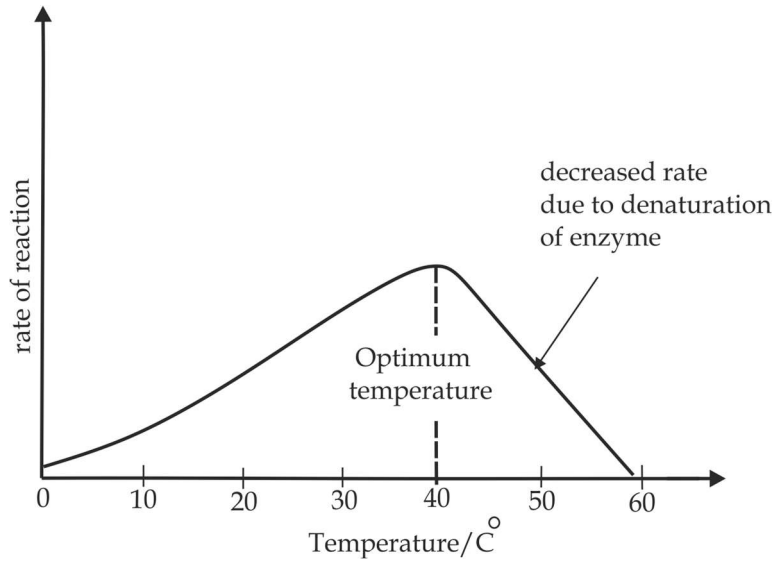


***Fig* 2.36** *The effect of temperature on the rate of reaction*

d. The effect of pH *(Figure 2.37)*

The rate of enzyme controlled reaction is maximum at the optimum pH. When the pH is altered above or below the optimum value, the rate of enzyme reaction declines, this is because a change of pH alters the ionic bond of acidic and basic groups, and causes the shape to change and destroy the active sites hence protein denaturation. Unlike the effect of heat on enzymes, however the effect of pH is normally reversible.

Restoring the pH to the optimum level usually restore the rate of reaction. Thus each enzyme works best at its optimum pH

Table 2.8 Enzymes versus optimum pH

Enzyme	Optimum pH
Pepsin	2.00
Sucrase	4.05
Salivary amylase	7.00
Ariginase	10.00

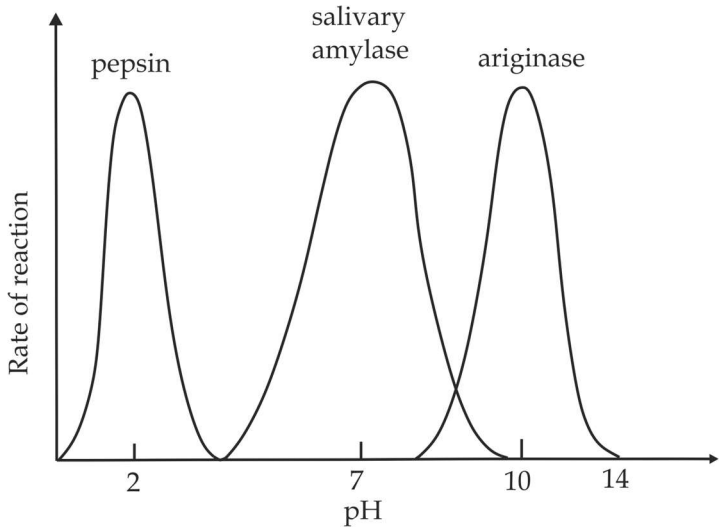


Fig 2.37 *the effects of pH on the rates of enzyme - catalysed reactions*

Sample question – 43

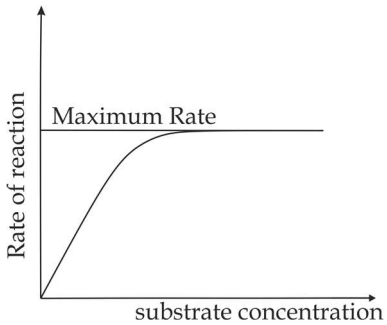
❖ **Question of substrate and enzyme concentration**

Style 1: Mock Coast Region 2021

a. Explain the way substrate concentration affect the speed of enzyme reaction.
b. When all active sites of enzymes are occupied, how does increasing the substrate concentration affect the rate of enzyme controlled reaction?

Style2: Necta 1998

The graph below show the effect of substrate concentration on the rate of enzyme controlled reaction.



a. Give a reasoned interpretation of the graph.
b. How can the rate of the reaction be increased?

Style 3: Necta 2007

a. State the properties of enzymes.
b. Sketch graph to show the type of curves that would be obtained when investigating enzyme activity under constant condition when:
   i. A fixed quantity of enzyme is used.
   ii. Excess substrate is used.

Sample question – 44

❖ **Questions of temperature**

Style 1: Bwiru Boys 2018

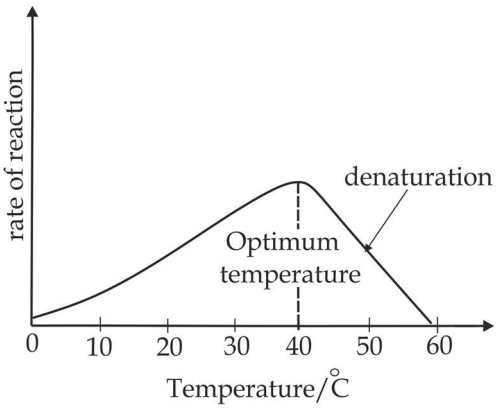
- Discuss the effect of temperature on the rate of enzyme controlled reaction.

Style 2: Mock Coast 2021

a. Explain why at temperature above 40^{o} C mammalian enzymes normally do not function efficiently?
b. Why is not appropriate to drink cold water soon after taking a meal?

Style 3: Famous question

a. **Figure 1** below is a graph showing the effect of temperature on the activity of an enzyme.



i. Interprets the graph
ii. Predict the effect on enzyme activity after lowering the temperature to below 0 °C.

b. Draw simple graph which illustrate below the of typical – enzyme controlled reaction varies with:
i. Substrate concentration
ii. Enzyme concentration
iii. PH. level
iv. Competitive inhibitor

In each case, explain as fully as you can, the reasons.

Sample question – 45

❖ **Questions of PH**

Style 1: Kibaha sec school 2006

- What is the effect of PH in functioning of the enzyme?

Style 2: Feza Boys sec school

Study Figure 1 below, then answer the questions that follow:

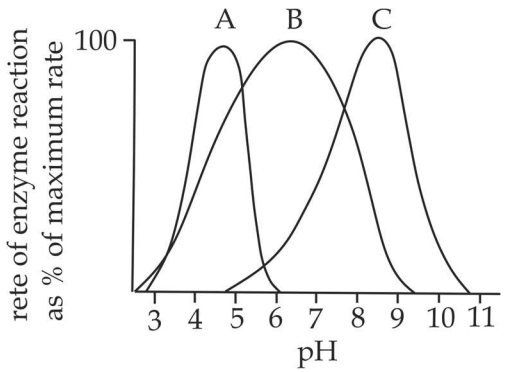


Figure 1

a. What is the optimum pH for the activity of enzyme B?
b. Give an example which could be represented by:
   i. Activity curve A
   ii. Activity curve B
c. Why the enzyme activity of C does decreases at PH values of between 8 and 9.
d. Why PH regulation is important in cells?

2.5.5: Allosteric enzymes

Allosteric enzymes are enzymes which contain active site and allosteric site**.**

Active site: Is a region of an enzyme molecule whereby the substrate bind and reaction takes place.

Allosteric site: Is a region of an enzyme molecule whereby the allosteric effector (modulator) bind and cause a reversible change in the enzyme active site. The allosteric effectors are of two groups; **Allosteric activators** which reversibly bind to the enzyme allosteric site and speed up catalysis; and **allosteric inhibitors** which reversibly bind to the enzyme allosteric site and slow down the reaction as shown in *Figure 2.38*.

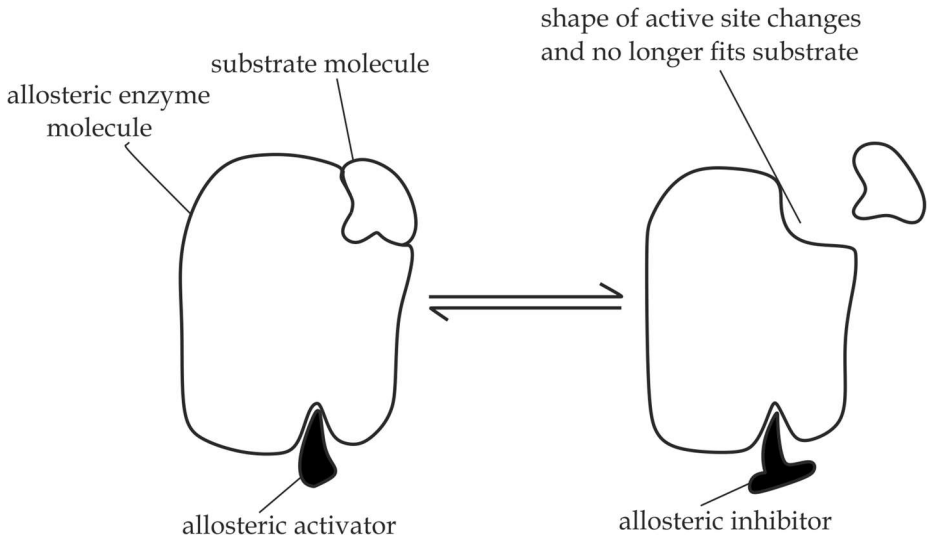


Fig 2.38 *Allosteric enzyme showing allosteric activator and inhibitor*

2.5.6: Enzyme inhibitors

Enzymes inhibitors are small molecules which can reduce the rate of enzymes controlled reaction. Many drugs and poisons act as inhibitors. Inhibitors fall into two categories:

a. Competitive inhibitors
b. Non-competitive inhibitors.

a. Competitive inhibitors

These are inhibitors which compete with the substrate molecules for the active of an enzyme.

Structure:

The competitive inhibitors have structure similar to the substrates, i.e. the inhibitors are complementary to the substrates.

Mechanism of action:

The competitive inhibitors prevent substrate molecules from binding with the enzyme active site as the result reduces the rate of enzyme controlled reaction as shown in *Figure 2.39*.

Example:

Malonic acid is a competitive inhibitor; it competes with succinic acid for the active site of succinic acid dehydrogenase, an important enzyme in Krebs cycle.

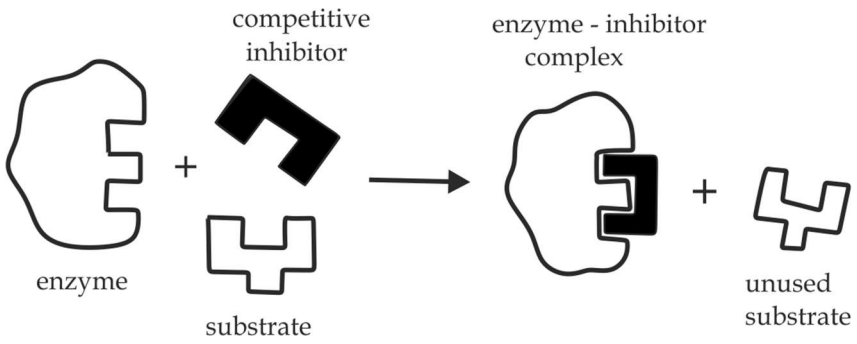


Fig 2.39 *Competitive inhibition*

Effect:
The overall effect of competitive inhibition can be reduced by increasing the substrate concentration as shown in *Figure 2.40*.

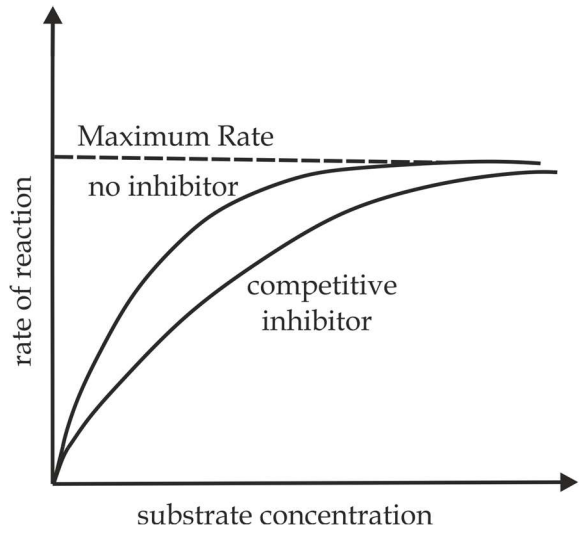


Fig 2.40 *The graph showing the effect of competitive inhibitor on the rate of enzyme controlled reaction*

Interpretation of the graph:

- At low substrate concentrations, the rate of enzyme controlled reaction in the absence of a competitive inhibitor is higher as the result the graph is displaced to the left side than that in its presence.

- At high substrate concentration, the rate of enzyme reaction in the two graphs are almost equal, this is due to the fact that, the rate of

enzyme reaction under competitive increase with the increase in substrate concentration.

Sample question – 46

Samwasses 2020

a. How competitive inhibitor of an enzyme does takes place.
b. Why are enzymes inhibitors important in biochemical processes (pathways) of the cell?

Applications of competitive inhibitor

The knowledge of competitive inhibitor can be applied in **pharmaceutical**, **medical** and **agriculture field**.

a. In the manufacturing of antibiotics

In the manufacturing of antibiotics some drugs have structure similar to those of bacterial components, when such drug is introduced to the body of an infected organism; they bind on the enzyme active sites and prevent the bacteria from combining to the enzyme's active site by competitive inhibition, so they slow down the multiplication of the bacteria, thereby controlling the disease. For example**,** sulphonamide drugs such as prontosil to combat the bacterial infection, Prontosil is similar in molecular structure to p – amino benzoic acid**(PABA)** which bacteria use to synthesize folic acid, when unable to make folic acid, they cannot grow and multiply in the human body.

b. In HIV control

Some HIV/ AIDS drugs **(ARV'S)** have structure similar to those of HIV RNA. When drug is introduced to the body of infected organism, they bind on the reverse transcriptase enzyme, so they slowdown the multiplication of the HIV thereby slowing down the HIV/AIDS progression.

c. In agriculture

Pesticides or **herbicides** have structure similar to those of herbs/pests. When such drug is introduced to the infected plant, they bind on the enzyme, so they inhibit the growth and multiplication of the pests and herbs.Organophosphorous insecticides such as Malathion are good examples of competitive inhibitors.

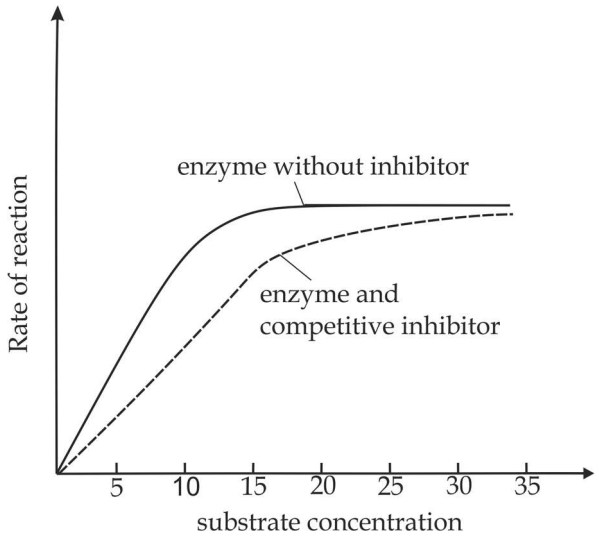
Sample question – 47

Style 1: Necta 2021

a. Explain the properties of enzymes.
b. In what way is the knowledge of competitive inhibitor important?
c. Suggest why substrate concentration has no effect on non – competitive inhibition.

Style 2: **Possible at any time**

The graph shows the results of an investigating into the effect of a competitive inhibitor on an enzyme controlled reaction over a range of substrate concentrations.



a. Give one factor which would need to be kept constant.
b. Explain the difference in the rate of chemical reaction at the substrate concentration of 10 $\mu molcm^{-3}$.
c. Explain why the rates of reaction are similar at the substrate concentration of 30 µmolcm-3.

b. Non-competitive inhibitors

These are inhibitors which combine with the enzyme at a point other than its active site; they are also known as **allosteric inhibitors.**

Structure:

The non-competitive types of inhibitors do not have structure similar to the substrates, i.e. they are not complementary to the substrates.

Mechanism:

The non-competitive types of inhibitors alter the shape of the active site of enzyme in such a way that enzymes can no longer accommodate the substrates. But the effect could be either **reversible** or **non-reversible** depending on the type of non-competitive inhibitor shown in *Figure 2.41*.

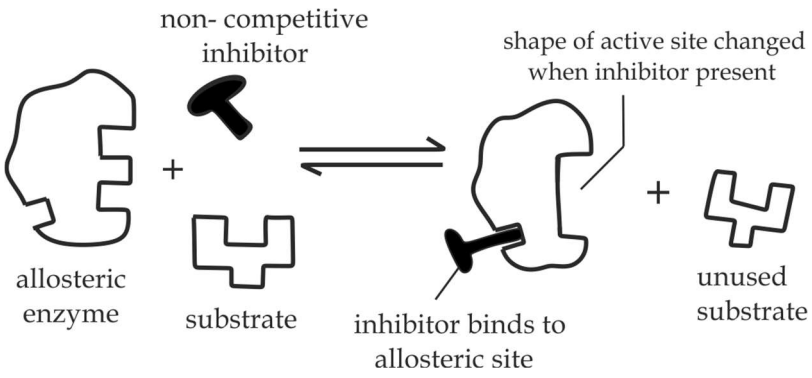


Fig 2.41 *Non-competitive inhibition*

Types of non – competitive inhibitors:

Non - competitive inhibitors are further divided into two (2) main types, which are **reversible** and **irreversible non - competitive inhibitors.**

i. Reversible non - competitive inhibitors

These are non-competitive inhibitors which bind to the enzyme at a position other than active site and cause temporary changes in the active site. When such inhibitor is removed from the enzyme, the active site regains its specific shape for catalysis. Example of such inhibitor is cyanide; the cyanide ion is a non-competitive inhibitor of cytochrome oxidase, an enzyme involved in terminal oxidation in the hydrogen transport system of aerobic respiration. More important these are important substances that regulate enzyme metabolic pathways by combining reversibly with the

enzyme such mechanism is called allosteric inhibition (*discussed in the next sub – section*).

ii. Irreversible inhibitors

These are non-competitive inhibitors which bind to the enzyme at a position other than active and cause permanently changes in the active site. They may combine covalently with sulfhydryl **(-SH)** groups in the enzyme molecule, thereby breaking the sulphur bridges that hold the protein molecule. Example of inhibitors are heavy metals such as mercury (Hg^{+}), lead (Pb^{+2}) and gold (Au+).

Effects:

The effect of non-competitive inhibitor is not reduced by increasing the substrates concentration because inhibitors and substrate molecules do not compete for the same active site as shown in *Figure 2.42*.

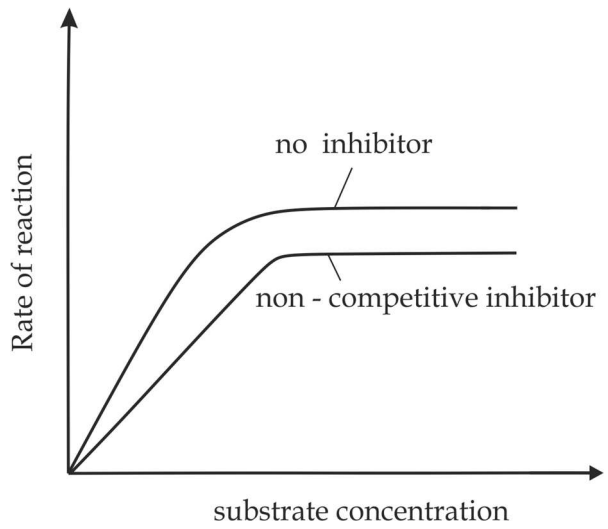


Fig 2.42 *Graph showing the effect of a non – competitive inhibitor on the rate of enzyme controlled reaction*

Interpretation of the graph:

- At low substrate concentrations, the rate of enzyme controlled reaction in the absence of a non - competitive inhibitor is higher as the result the graph is displaced to the left side than that in its presence.

- At high substrate concentration, the rate of enzyme reaction in the absence of a non-competitive inhibitor is still higher than in its presence, this is due to the fact that, the effect of non – competitive inhibitor is not reduced by increasing the substrate concentration.

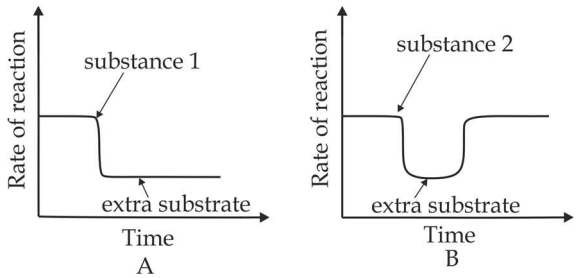
Sample question – 48

Style 1: Dar Mock 2018

a. With the help of a diagram briefly explain the non – competitive inhibitor of enzyme activity.
b. Suggest why substrate concentration has no effect on non – competitive inhibition.

Style 2: Alpha high school 2015

a. Define enzyme
b. In an experiment, substance 1 and 2 were added to an enzyme working on a specific substrate. Additional substrate was also added later and the rate of enzyme reaction measured. The following graphs were obtained.



- Explain what is happening in graph A and B.

2.5.7: Enzyme regulation in metabolic pathways

A metabolic pathway is a series of reactions in which each step is catalysed by an enzyme, such as in glycolysis or Krebs cycle during the respiration process. Enzyme reactions are important to be regulated in order to prevent the accumulation of excess products. These excess products usual lead to imbalance of metabolic pathways.

Ways through which enzymatic activities are regulated:
The regulation of these enzymatic activities includes:

a. End product inhibition control
b. Pro – enzyme control (Zymogen)
c. Genetic control

a. End product inhibition control

Inhibition of enzyme function can be lethal, but in many situations inhibition is essential. For example, suppose a metabolic pathway becomes overactive and too much end product is produced. In these circumstances the metabolic reaction must be very finely controlled and balanced, in so doing the end product inhibits one of the enzymes that catalyses an early step in the metabolic pathway, so less product is formed. This is called **end product inhibition**, it is also known as **negative feedback of inhibition**, because the information from the end of the pathway which is feedback to the start has a negative effect. Enzymes that are inhibited often exist in two different forms, one inactive form *(allosteric site)* and the other active form *(active site)* and the enzymes known as **allosteric enzymes**.

What is the end product inhibition?

End product inhibition is the process whereby the enzyme catalysing the first step in the reaction sequence is inhibited by the end product.

What is the main importance of the end product inhibition?

It acts as a self – regulatory system of the metabolic pathways in the living organisms, such as respiration, growth and homeostasis.

Mechanism of end product inhibition

The excess accumulated end products act as allosteric inhibitors which bind to the allosteric site of the first enzyme in the reaction sequence as the result changes the active site shape in such a way that enzyme is no longer accommodate the substrate ,thus slow down or stop its catalytic function. For this reason; it is also referred to as **Allosteric inhibition.**

For example;

Case 1:

Product "**Y**"acts as an inhibitor to enzyme "$\mathbf{E_1}$". If the level of product **Y** rises above normal, inhibition of $\mathbf{E_1}$ increases; therefore, the level of **Y** is reduced.

Case 2:

If the level of product **Y** falls, the inhibition is reduced, in this way the homoeostatic of **Y** is achieved as shown in *Figure 2.43*.

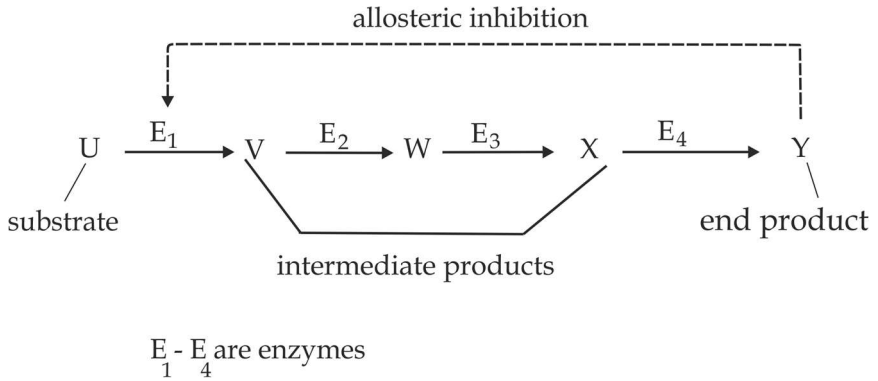


Fig 2.43 *Allosteric inhibition of a rate – limiting enzyme by the end product*

b. Pro enzyme control (Zymogens)

In this way, enzymes are synthesized in inactive forms and they are only activated when they are needed to work and at the right time. Activation of such enzymes, known as zymogens or pro enzymes, require a chemical reaction that either adds or splits off part of the molecule. Example; Some enzymes that digest proteins in the stomach, i.e. pepsinogen and prorenin.

c. Genetic control

This is the regulation of enzymatic activity by genes which codes for the type of enzyme to be synthesized, i.e. Genes carry the codes for making enzymes which accelerate or decelerate enzyme synthesis.

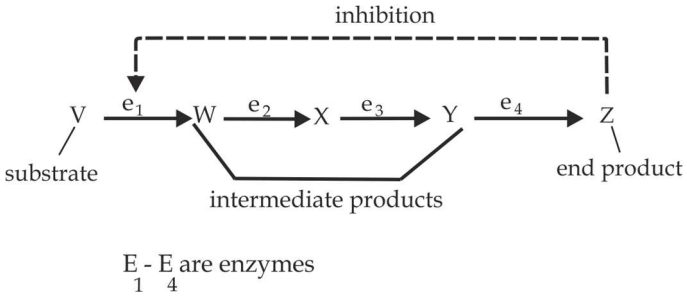
Sample question – 49

Style 1: Mtwara and Lindi Mock 2021
(Be carefully with this question)

a. Explain three (3) common ways through which enzyme activities are regulated.
b. Why are enzyme inhibitors important in biochemical pathways of the cell?
c. Explain how allosteric inhibitors differ from other non – competitive inhibitors.
d. List four (4) common heavy metals that are toxic to humans
   ii. Explain in general terms why these heavy metals are toxic to life.

Style 2: Famous BS question

The diagram below represents metabolic pathway controlled by enzymes.



E - E are enzymes
1 4

a. Name the type of control mechanism which regulates the production of compound **Z**.
b. Explain precisely how an excess of compound **Z** will inhibit its further production.

2.5.8: Enzyme cofactors

Some enzymes only work in the presence of another chemical which serve as a *" helper"* such chemicals are called **cofactors.**

What are the enzyme cofactors?

These are non-protein substances or molecules which increase the efficient of enzyme functioning.

- An enzyme – cofactor complex is called a **halloenzyme.**
- An enzyme without its cofactor is called an **apoenzyme.**

Types of enzyme cofactors

There are **three (3)** types of enzyme cofactors, which include:

a. Inorganic ions
b. Prosthetic groups
c. Coenzymes

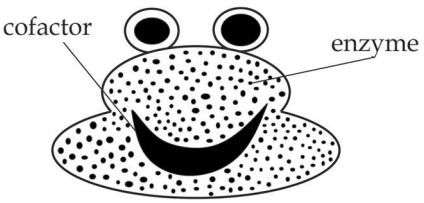


Fig 2.44 Simple illustration as A, B, C

a. Inorganic ions

These are non-organic molecules which assist in forming the enzyme – substrate complex easily by moulding the enzyme into a suitable shape. For this reason may serve as the catalytic centre of the enzyme; thus termed as the **enzyme activators.** For example, the activity of salivary amylase is increased by the **chloride ions** (Cl^-).

b. Prosthetic groups

These are usually tightly bounded organic molecules which increase the catalytic function of the enzyme, for example, **catalase**; the enzyme which speed the decomposition of hydrogen peroxide, has an iron – containing **haem** prosthetic group. Prosthetic groups are not confined to enzymes only; they are essential components of certain other proteins as well (conjugated proteins). For example, **haemoglobin** and other blood pigments contain prosthetic group (the haem part of the molecule) whose role is similar to that of enzyme prosthetic groups, namely to carry atoms or chemical groups from one place to another, In the case of blood pigments it is oxygen that is carried.

c. Coenzymes

These are usually loosely bound organic molecules which transfer atoms from one molecule to another in the chemical reactions. For example, Nicotinamide adenine dinucleotide (NAD), an important coenzyme in respiration, is made from nicotinamide, one of the B – group vitamins which carrier's hydrogen atoms in the **dehydrogenase enzymes.**

Sample question – 50

Kilimanjaro Mock 2020

a. Sometimes biological catalyst need some kind of booster in their activity.
b. Give the proper biological name of the booster used.
c. Explain three types of named booster in a (i) that assist the catalyst in its efficient activity and give example in each.
d. Describe the key and lock model for the enzyme controlled activity.
(Diagram is necessary)

2.5.9: Nomenclature of enzymes

To avoid the continued haphazard naming of enzymes, in 1961 the international union of biochemistry (IUB) introduced a system of classifying enzymes based on the type of reactions they catalyse. This system recognized **six (6)** major functional classes of enzymes:

The mnemonics for the classification of enzymes is the word "**OTHLIL**".

mnemonics

O - **O**xidoreductase
T – **T**ransfarase
H – **H**ydrolase
L – **L**yase
I – **I**somerase
L - **L**igase

a. Oxidoreductases

They catalyse biological oxidation and reduction by the transfer of hydrogen atoms, oxygen or electrons from one molecule to another; e.g. Dehydrogenase enzymes.

$$\text{Ethanal} + NADH_2 \xrightarrow{\text{Alcoholic dehydrogenase}} NAD^+ + \text{Ethanol}$$

b. Transfarases

They catalyse the transfer of a chemical group from one molecule to another, i.e. Hexokinase enzyme.

$$\text{Glucose} + ATP \xrightarrow{\text{Hexokinase}} \text{Glucose – 6 – phosphate} + ADP^+$$

c. Hydrolases

They catalyse the splitting of a large molecule into two simplier products in the presence of water (hydrolytic reaction); e.g. digestive enzymes.

$$\text{Lactose} + \text{water} \xrightarrow{\text{Lactase}} \text{Glucose} + \text{galactose}$$

d. Lyase

They catalyse non – hydrolytic (without water) removal of a chemical group on a molecule; i.e. decarboxylase.

$$\text{Pyruvate (3C)} \xrightarrow{\text{Pyruvate decarboxylase}} \text{Acetyl (2C)} + CO_2$$

e. Isomerases

They catalyse rearrangement of atoms in a molecule; i.e. converting one isomer into another; i.e. hexoisomerase.

$$\text{Glucose – 6 – phosphate} \xrightarrow{\text{Phosphoisomerase}} \text{fructose – 6 - phosphate}$$

f. Ligases

They catalyse the joining together of two molecules by forming a chemical bond under the presence of energy derived from the breaking down of ATP; i.e. amino – acyl tRNA synthetase.

$$\text{Amino acid + tRNA + ATP} \xrightarrow[\text{Synthetase}]{\text{Amino – acyl tRNA}} \underset{\text{Complex}}{\text{aminoacid – tRNA + ADP}^{+}}$$

Sample question – 51

Dar Mock 2017

- Categories enzymes into **six (6)** groups according to the type of reactions they catalyse and give an example in each group.

2.6: ATP (ADENOSINE TRIPHOSPHATE)

Many of the reactions occurring in cells are endergonic, for example the synthesis of enzymes, the transport of sodium ions across the cell surface membrane and the movement of endocytic vacuoles through the cytoplasm. To ensure these endergonic reactions occur, cells need a source of energy in a form that can be released instantaneously in amounts which are small enough for the cell to use/. The most important source of energy in all cells is **adenosine triphosphate**.

WHAT IS ATP?

ATP is a principle molecule for storing and transferring energy in all living organisms. It is often referred to as the **energy currency** of the cell and can be compared to storing money in the bank.

WHO DISCOVERED ATP?

ATP was first isolated in the early 1930s, having been extracted from muscle tissues. Its function in muscles was subsequently demonstrated in America by ***Albert Szent – Gyorgyi*** *in Fig 2.45.* He showed that isolated muscle fibres contract when ATP is placed on them but not when glucose is placed on them. This suggested that ATP rather than glucose is the immediate source of energy for muscle contraction.

Since then ATP has been shown to be the immediate source of energy for many other biological processes including movement, active transport, nerve transmission, biosynthesis and secretion of cell products.

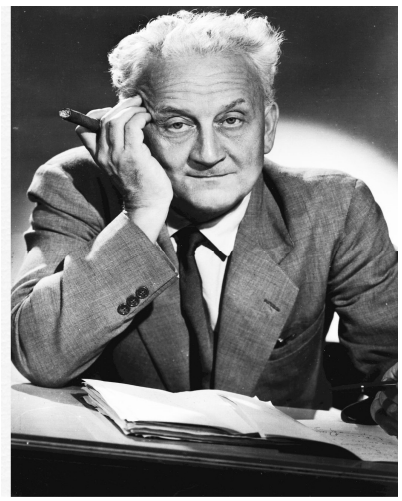


Fig 2.45 *Albert Szent –Gyorgyi, who discovered the energetic role of ATP in muscle. Genius, Szent – Gyorgyi used to say. " is seeing what everyone else has seen, and thinking what no one else has thought"*

In this part, the following aspects should be discussed:
2.6.1: Properties of ATP
2.6.2: Chemical structure of ATP
2.6.3: Formation (synthesis) of ATP
2.6.4: Hydrolysis of ATP
2.6.5 Uses of ATP

2.6.1: **Properties of ATP**

ATP molecule has the following major properties for proper functioning in the cell:

a. ATP – As universal currency

It provides quick energy when required to all metabolic reactions within the living cells. For this reason, it can be compared as storing money in the bank.

b. ATP – as Universal carrier
It is transported more easily within the cells by facilitated diffusion.

Sample question – 52

Possible at any time
- State **two (2)** advantages of storing energy in form of ATP.

2.6.2: Chemical structure of ATP (*Figure 2.46***)**
ATP contains three (3) chemical components:
a. Adenine (organic base)
b. Pentose (ribose)
c. 3 – phosphate molecules (triphosphate)

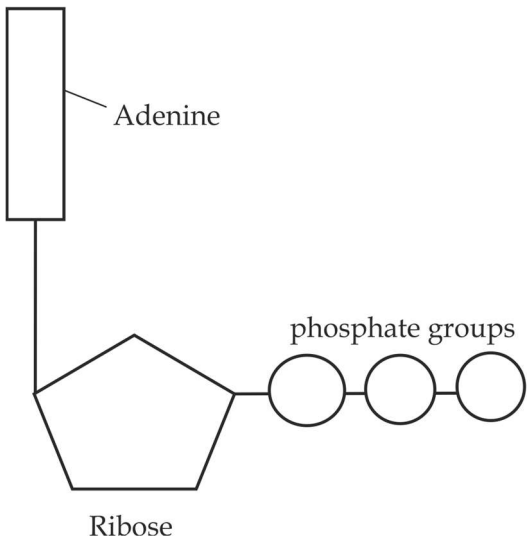


Fig 2.46 *the chemical structure of ATP*

Sample question – 53

Style 1: Necta 2016
- Draw the structure of ATP molecule and explain how it is formed?

Style 2: Dar Mock 2019
- Identify the chemical composition of ATP.

2.6.3: Formation (synthesis) of ATP

All the time a significant number of ATP molecules are constantly being spent by a cell for various physiological and metabolic processes and therefore, they must be continuously replaced.

ATP is usually formed when **inorganic phosphate** (Pi), is energetically bonded to **adenosine diphosphate** (ADP^+). The amount of energy normally required in this process is **30.66 $KJmol^-$.**

The process that a yield ATP is therefore referred to as **phosphorylation,** they are of two types;

a. Photosynthetic phosphorylation

It is a process of making **ATP** by adding a phosphate group (Pi) to ADP^+ under the presence of energy derived from the **sunlight**. It occurs in all photosynthetic organisms such as plants.

b. Respiratory phosphorylation

It is a process of making **ATP** by adding a phosphate group (Pi) to ADP^+ under the presence of energy derived from the **oxidation of glucose.** For this reason, it is also called oxidative phosphorylation. It occurs in all plants and animals during cellular respiration.

Sample question – 54

Tai question

- Briefly explain the process of ATP formation.

Similarities between photosynthetic and oxidative phosphorylation

- Both produce ATP energy.
- Both take place in living organisms.
- Both occur in specialized organelles.
- Both are controlled by the enzymes.
- Both involve electron transfer.

T 2.9 Differences between oxidative and photosynthetic phosphorylation:

Oxidative phosphorylation	Photosynthetic phosphorylation
Oxygen is used	Oxygen is not used
Take place in mitochondrion	Take place in chloroplast
It decreases dry mass	It increases dry mass
Occur all the time	Occur during the day
It occurs in plants and animals	It occurs in plants only

Sample question – 55

Necta 1999

- Compare photosynthetic phosphorylation and oxidative phosphorylation

2.6.4: Hydrolysis of ATP

Hydrolysis of ATP is the breaking down of ATP into ADP^+ and Pi by hydrolytic reaction to release energy necessary for various uses in a living organism.

- Hydrolysis of ATP into ADP^+ and Pi releases 30.66 KJ of energy.

$$ATP + H_2O \longrightarrow ADP^+ + Pi\ (30.66\ KJ)$$

- Hydrolysis of ADP^+ into AMP^+ and Pi releases a similar amount of energy , but this reaction is rarely to occur due to high energy bond in the ADP^+.

$$ADP^+ + H_2O \longrightarrow AMP^+ + Pi\ (30.66\ KJ)$$

- Hydrolysis of AMP+ into Adenosine and Pi is almost negligible, but theoretically, it releases 14.2 KJ of energy.

$$AMP^+ + H_2O \longrightarrow Adenosine + Pi\ (14.2\ KJ)$$

Did you know?

Typically, ATP molecules give up energy within sixty seconds of their formation and it is estimated that a resting human uses about 40 kg of ATP in 24 hours.

2.6.5: Uses of ATP

In a metabolically active cell, up to 2 million molecules of ATP are required every second, This ATP is used for variety of processes include;

a. Anabolic process

ATP provides the energy necessary to build up macromolecules from their components, such proteins biosynthesis from amino acids.

b. Active transport

ATP provides energy needed for the transportation of materials against a concentration gradient, e.g. by the use of ion pump.

c. Secretion

ATP provides energy for the secretion of cell products.

d. Movement

ATP provides energy necessary for many forms of cellular movement, such as cilliary action in trachea and fallopian tubes, spindle fibres during cell division and muscle contraction.

e. Activation of chemicals

ATP provides energy necessary to make chemicals more reactive, e.g. phosphorylation of glucose at the beginning of glycolysis.

Sample question – 56

Jecas 2011

- Write short notes on ATP.
- Summarizes the uses of ATP.

2.7: WATER

Water is a polar molecule composed of one atom of oxygen and two atoms of hydrogen combine by sharing electrons (covalent bonding). Without water, life would not exist on this planet. It is very important for **two (2)** reasons; **firstly**, it is the most abundant molecule in a cell, constituting about **70%** to **80%** of the mass of the cell. **Secondly**, it provides an environment for those organisms that live in water. Three – quarter of the planet is covered in water.

Properties of water in relation to their importance in organisms:

Although it is a simple molecule, water has some surprising properties which biological are significant for the survival of living organisms, generally, the cells and body of an organism at large use the properties of water to meet their maximum functioning, which include:

1. Water as a universal solvent

It is readily dissolves many substances than any other liquid.

Biological significances of water being universal solvent:
The importance of this property is that, it acts as a transport medium:

a. **In animals**, it acts as a transport medium in blood system, digestive system, lymph and excretory system which transport substances such as ions, glucose, wastes, etc.
b. **In plants,** it acts as a transport medium in xylem and phloem which transport dissolved minerals and sugar solution.

2. Water as a reagent

It is used as a raw material for various forms of metabolic reactions in living organisms.

Biological significances of water being a reagent:
The importance of this property is that, it involves in metabolic reactions, this is also referred to as **metabolic role**:

a. **In animals,** It participates in the following metabolism:
   i. It is used in hydrolysis reaction such as digestion.
   ii. It is used in respiration process.
   iii. It is used in condensation reaction such as urea formation.
b. **In plants**, It participates in the following metabolism:
   i. It is used in hydrolysis of many substances such as proteins into amino acids, fats into fatty acids and glycerol.
   ii. It is used as a source of hydrogen atoms during light dependent stage of photosynthesis.
   iii. It is used in the condensation of many reaction such as synthesis of disaccharides and polysaccharides.
   iv. It is used as a raw material necessary for seed germination, because it activates enzymes.

3. Water has low viscosity

It has high tendency of its molecules to slide easily through the surface.
Biological significance of water due to its low viscosity:
The importance of this property is that, it acts as a lubricant, this is also referred to have **lubricant role:**

a. It acts as a synovial fluid which normally lubricate the movement of vertebrates joint.
b. It acts as a pleural fluid which lubricates the movement of lungs.
c. It acts as a pericardial fluid which lubricates the movement of heart.

4. Water has high surface tension

It has high attraction forces between its molecules (cohesive force) due to strong hydrogen bonding.

Biological significance of water due to its high surface tension:
The importance of this property is that, it acts as a supportive medium, this is referred to as a **supportive role**:

a. In some organisms such as **millipede**; it is used as hydrostatic skeleton which allow support and locomotion.
b. It is used as a supportive medium in small organisms such as **pond skater** which can settle or skater over water surface.
c. **In plants**, it provides turgor pressure which support primary growth in woody plants.

5. Water has high heat capacity

It requires large amount of heat energy to raise its temperature. This means that; water can absorb a lot of energy for only small rise in body temperature.

Biological significance of water due to its high heat capacity:
The importance of this property is that, it normally maintain stable body temperature especially in endotherms.

6. Water has high heat of vaporization

It requires large amount of heat energy to vaporize water, as a result more heat is lost as a vapour. That is why, water remains liquid throught the time unless body cooling is taking place

Biological significance of water due to high heat of vaporization:
The importance of this property is that, it is used as a coolant:

a. **In animals**, evaporation of water during sweating.
b. **In plants,** evaporation of water during transpiration.

7. Water has high latent heat of fusion

It requires large amount of heat energy to melt from ice, conversely water must loose large amount of energy to freeze. This means, significant amount of heat energy is required before water can change its state.

Biological significance of water due to high latent heat of fusion:
The importance of this property is that, living organisms and aquatic environment are slow to freeze in cold condition.

8. Density and freezing property

Water is less dense when exist as a solid than as a liquid, below 4 ^{o}C the density of water starts to decrease, ice therefore floats on liquid water and insulate the water under it.

Biological significance of water due to its low density and freezing
The survival of aquatic organisms such as fish in ice – covered lakes without any effect is due to this property.

Sample question – 57

Style 1: Tahossa Ilala Region 2013

- Discuss the biological significances of the properties of water to living organisms (10 marks).

Style 2: St, Joseph cathedral and Tambaza Joint 2000

- State the property of water that allow each of the following to take place and, in each case, explain its importance
  i. The cooling of skin during sweating
  ii. The survival of fish in ice – covered lakes.
  iii. The ability of insects such as pond skaters, to walk on water.
  iv. The transport of glucose and ions in a mammal.

Style 3: Tai question

- Explain the supporting and metabolic role of water to plants and animals

Style 4: Wazo Hill high school 2020

- How is water and life inter – related?