Chapter # 10
Bio-Chemistry

INTRODUCTION

"Biochemistry is the branch of science that deals with the chemical processes taking place in the organisms".

It focuses on the study of structure, function and interaction of biological macromolecules such as proteins, carbohydrates and lipids as well as the chemical reactions and pathways that Occur within cells.

CARBOHYDRATES

Carbohydrate is an essential group of foods in human and animal diets. It is more realistic to define a carbohydrate as

"Polyhydroxy aldehydes and ketones or the substances that yield such compounds when they react with water on hydrolysis."

Classification based on structure

"Carbohydrates are classified as monosaccharides, disaccharides, oligosaccharide and polysaccharides".

This classification is based on the number of sugar unit present in carbohydrates.

Monosaccharides contain a single sugar unit for example glucose, fructose, and galactose.

Disaccharides contain two sugar units, examples are sucrose, lactose and maltose.

Oligosaccharide are carbohydrates that are made up of 3 to 10 sugar units, for example ketose (glucose-fructose-fructose) and melezitose (glucose-fructose-glucose).

Polysaccharides Contain more than 10 sugar units, Cellulose, starch and glycogen are examples of polysaccharides.

Monosaccharides are classified on the basis of the number of carbons present in the molecule. In this classification prefix is used to indicate number of carbon atoms in the molecule and the suffix -ose, is used to indicate carbohydrate as a class of biomolecule.

Class of Monosaccharid	**Formula**	**Examples**
Triose	$C_3H_6O_3$	Glyeeraldehyde
Tetrose	$C_4H_8O_4$	Erythrose
Pentose	$C_5H_{10}O_5$	Ribose
Hexose	$C_6H_{12}O_6$	Glucose

Among these monosaccharide, hexose sugar is important since it plays a crucial role in biological system. Hexose sugars are classified into aldohexose and ketohexose. An example of aldohexose is glucose where as ketohexose is fructose.

Glucose and fructose exist in both open chain and close chain form however, the open chain form is relatively unstable. The close chain form of glucose is called pyranose since it resembles with pyran where as the close chain form of fructose is known a furanose since it resembles with furan.

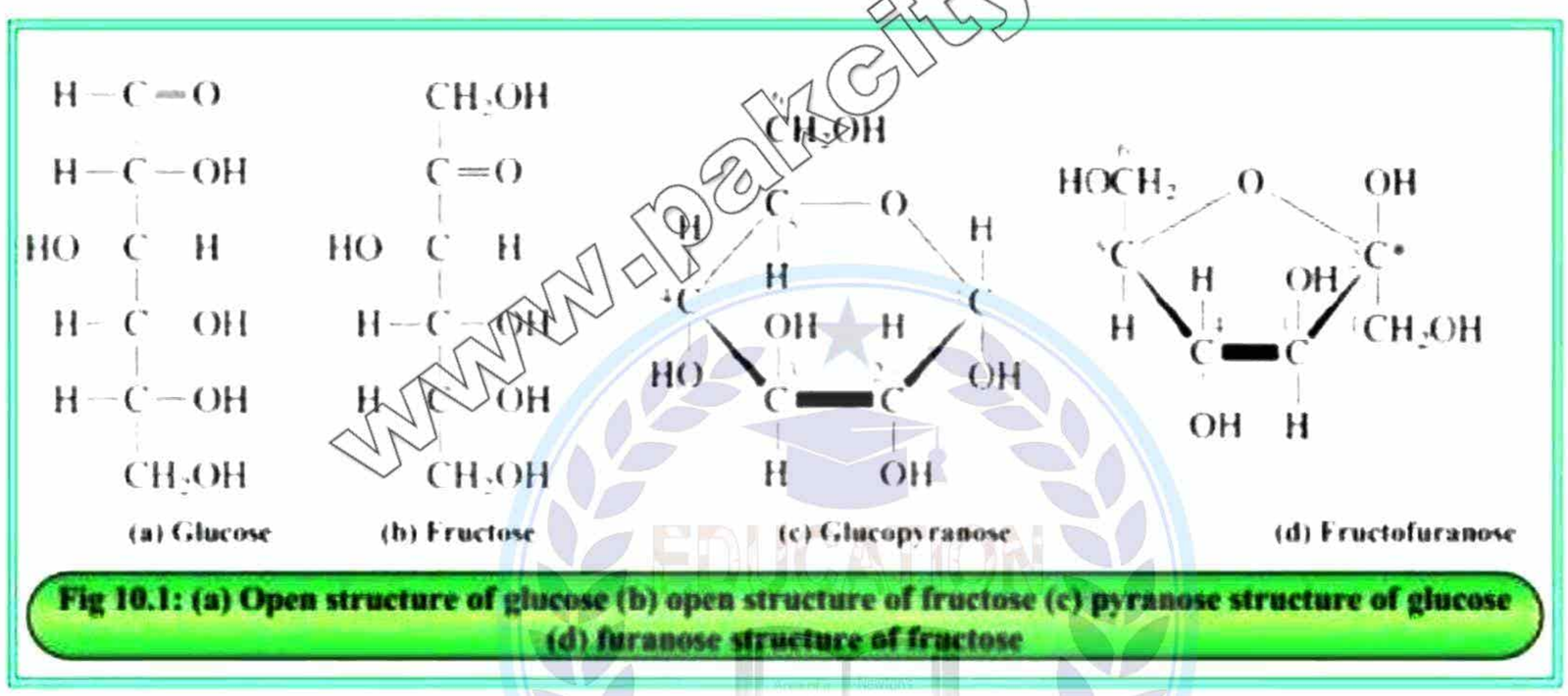


Fig 10.1: (a) Open structure of glucose (b) open structure of fructose (c) pyranose structure of glucose (d) furanose structure of fructose

Disaccharides are carbohydrates consisting of two monosaccharide units join together through glycosidic bond. "A glycosidic bond (0-C-0) is a type of covalent bond that join two monosaccharide units together to form a larger carbohydrate molecule". It is formed through a condensation reaction with the elimination of water molecule (Fig.10.2). Disaccharides are water soluble crystalline solids and represented by molecular formula $C_{12}H_2O_{11}$.

"Polysaccharides are macro bio molecules. They are amorphous, water insoluble and made up of more than hexose sugars".

Plant polysaccharide are the reserved carbohydrates of plants. Example of plant polysaccharides are starch and cellulose which are composed of thousands glucose units.

Starch is a main component of our carbohydrate intake. It is found in potato, wheat, burley etc. cellulose is found n the cell wall of plant. It is used in making cotton, cellulose fiber and paper etc.

Importance of Carbohydrates

Carbohydrates are nutritionally significant bio molecules and are essential part of our balanced diet.

Carbohydrates such as starch, sucrose, maltose etc convert into glucose in our digestive system which then absorbed into the bloodstream and transported various cells where is utilized for the biological processes.

$$C_6H_{12}O_{6\ (glucose)} + 6O_2 \longrightarrow 6CO_2 + 6H_20 + \text{Energy}$$

Glucose plays a vital role in energy storage within the body. The extra glucose of the bloodstream is converted into glycogen which serves as a primary form of energy storage in animals including humans. Glycogen is stored in muscles and liver. Another way glucose can be stored by converting it into triglycerides which are then stored as body fat.

Role of Common Carbohydrates in Health and Disease

Glucose: It is a vital component of our blood. Typically, the normal range of glucose in blood ranges between 70 to 110mg per 100 dl. However, if glucose level exceeds this range, it can lead to the Diabetes which can be managed through insulin control.

Fructose:

Fructose is a simple sugar that found in many fruits and honey. It is the sweetest among all other carbohydrates. Its main function is to provide energy during metabolism in the body. However, a high intake of fructose has been associated with weight gain and obesity.

Lactose:

It is a disaccharide. It is found in milk and hence also known as milk sugar. During intake, it is broken down into glucose and galactose in the alimentary canal by the enzymatic activity.

Sucrose:

It is also a disaccharide and made up of a glucose and a fructose sugar. It is known as table sugar or cane sugar. An excess amount of sucrose in our

diet can cause the development of gum disease such as fatness, plaque formation in the teeth, and even tooth decay.

PROTEINS

Proteins are naturally occurring macromolecules made up of long chain of amino acids that fold into precise three dimensional configurations. All living organisms including plants, animals and bacteria contain proteins and their presence is vital for the life.

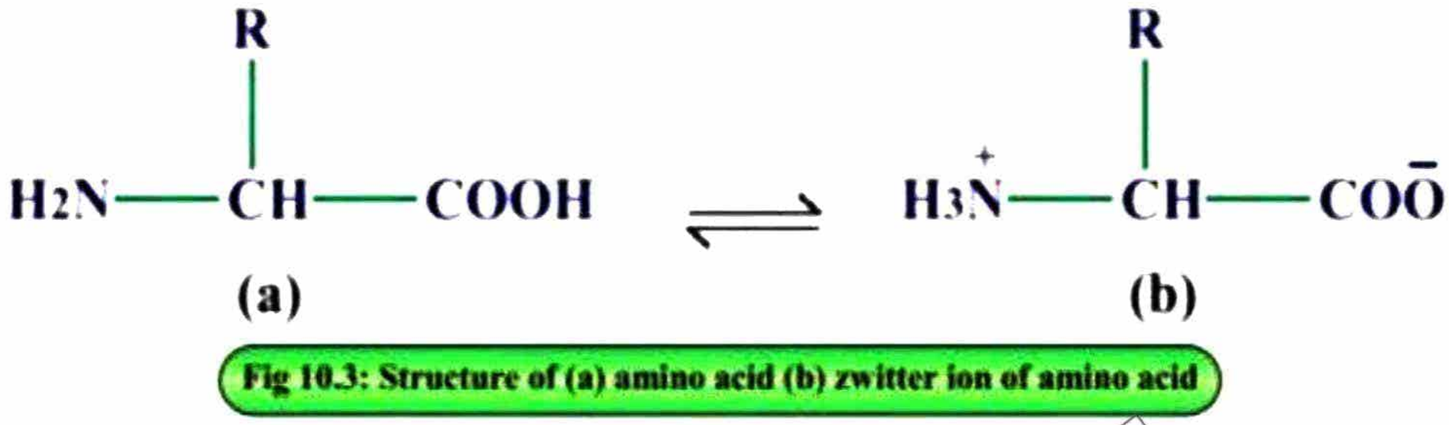


Fig 10.3: Structure of (a) amino acid (b) zwitter ion of amino acid

There are twenty-two (22) different types of alpha amino acids that can be used to build proteins. Each amino acid consists of an amino group as well as a carboxyl group. These amino acids are associated with each other through poly peptide linkage (CONH). The specific arrangement and sequence of these amino acids determine the structure and function of the protein.

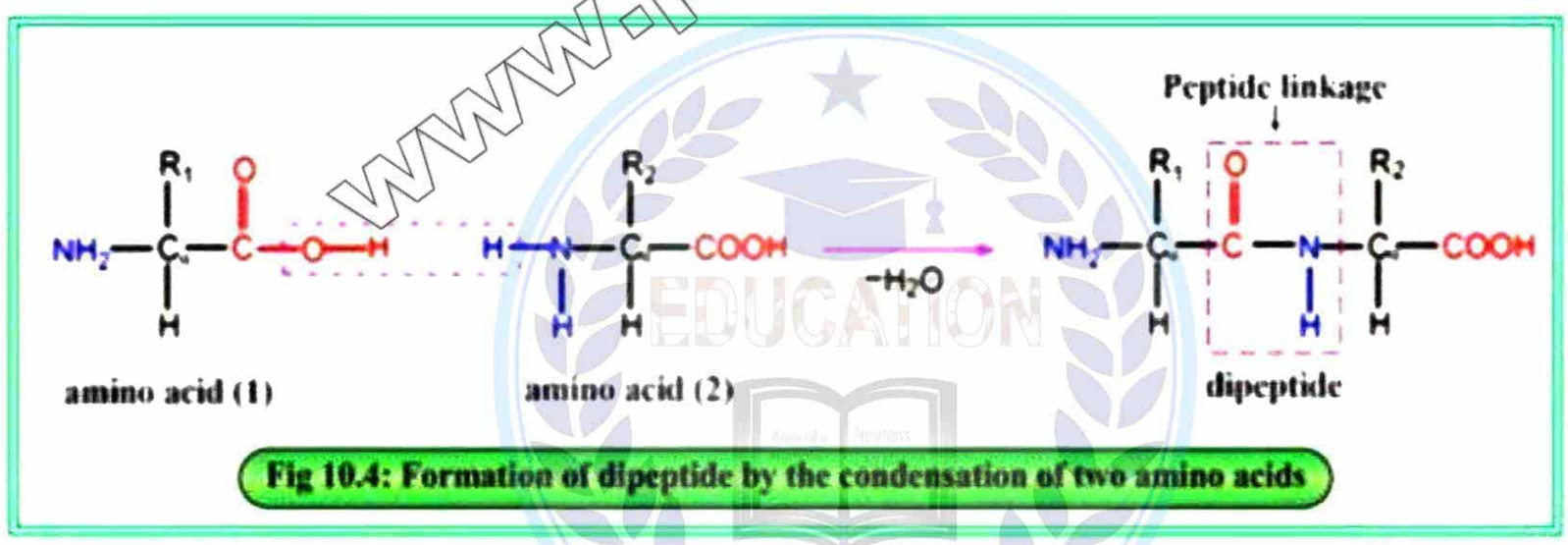


Fig 10.4: Formation of dipeptide by the condensation of two amino acids

Classification of proteins

Proteins may be classified into several groups based on their functions and structures. Based on functions, proteins are classified into following types.

(i) Catalytic proteins (Enzymes):

Enzymes are biological catalysts. They increase the rate of the biological reaction multiple fold as compared to a chemical catalyst. Our bodies contain numerous catalytic proteins which facilitate the chemical reactions inside the body. For example, lipase catalysis the decomposition of lipids into fatty acids in our alimentary canal.

$$\text{Starch} + H_2O \xrightarrow{\text{Amalyase}} \text{Glucose}$$

$$\text{Protein} + H_2O \xrightarrow{\text{Protease}} \text{Amino acid}$$

$$\text{Lipid} + H_2O \xrightarrow{\text{Lipase}} \text{Fatty acid}$$

(ii) Storage proteins:
These proteins store nutrients or metal ions in a particular part of plants or animals. For example, Albumin, Globulin and Casein etc.

(iii) Transport proteins:
These proteins facilitate the movement of molecules, ions and other substances across cellular membranes and in the blood stream. For example, hemoglobin.

(iv) Regulatory or hormonal proteins:
These proteins play a critical role in regulating the function of body by transmitting signals between the cells.

Classification of proteins on the basis of their structure

Proteins are essential macromolecules classified into four main types based on their structure.

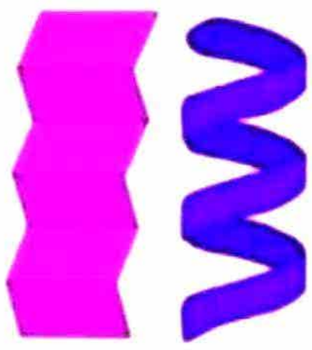
Classification of proteins

Primary

- ✓ It is a linear sequence of amino acids in the protein chain.
- ✓ This sequence plays a crucial role in determining the overall shape and function of the protein.

Secondary

- ✓ It refers to the folding patterns in polypeptide chains due to interactions between nearby amino acids.
- ✓ The two secondary common structures are alpha helix and beta sheets.
- ✓ The Stabilization of secondary structure is due formation of hydrogen bonds between N-H and C-0 groups of amino acids

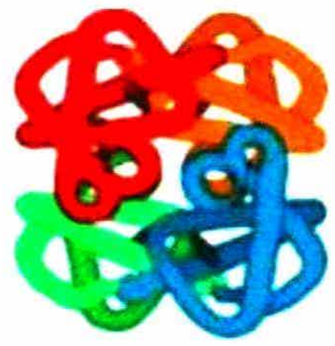


Tertiary

- ✓ It refers to three-dimensional arrangement of a protein molecule having folded and refolded polypeptide chain.
- ✓ The stability of molecule is due to the presence of following types of forces among polypeptide chain:
- ✓ Salt bridge (ionic bond)
- ✓ Disulfide bridge (covalent bond)
- ✓ Van der Waals forces
- ✓ Hydrogen bond
- ✓ Example: Myoglobin exhibits tertiary structure.

Quaternary

- ✓ It is a large complex protein molecule and formed by the interaction of multiple protein subunits.
- ✓ Example: Hemoglobin, which consists of four subunits and illustrates the quaternary structure.



Properties of proteins

(i) Proteins are water soluble due to the di polar terminal of amino acids in the polypeptide chain.

(ii) Proteins are amphoteric in nature because of the presence of COOH as well as NH_2 group in their structure of amino acid sequences.

(ii) Proteins exhibit flexibility due to the ability of amino acid chain rotation.

(iv) Certain proteins exist in various colours i.e. hemoglobin.

(v) Proteins are thermally stable, however the structure of proteins are disrupted by heating, at elevated temperature or by a sharp change in the pH.

Importance of proteins

(i) Proteins provide energy for the body and in a rough estimation, 1g of protein provides four calories.

(i) Hemoglobin is a protein, it transports oxygen from the lungs to every tissue of the body.

(ii) Harmons are proteins which regulate various physiological functions in the body.

(iv) Antibodies are proteins which play a very important role in the immune system of the body.

LIPIDS

"Lipids are naturally occurring heterogeneous organic compounds that are insoluble in water but soluble in Bloor's Bloor's reagent".

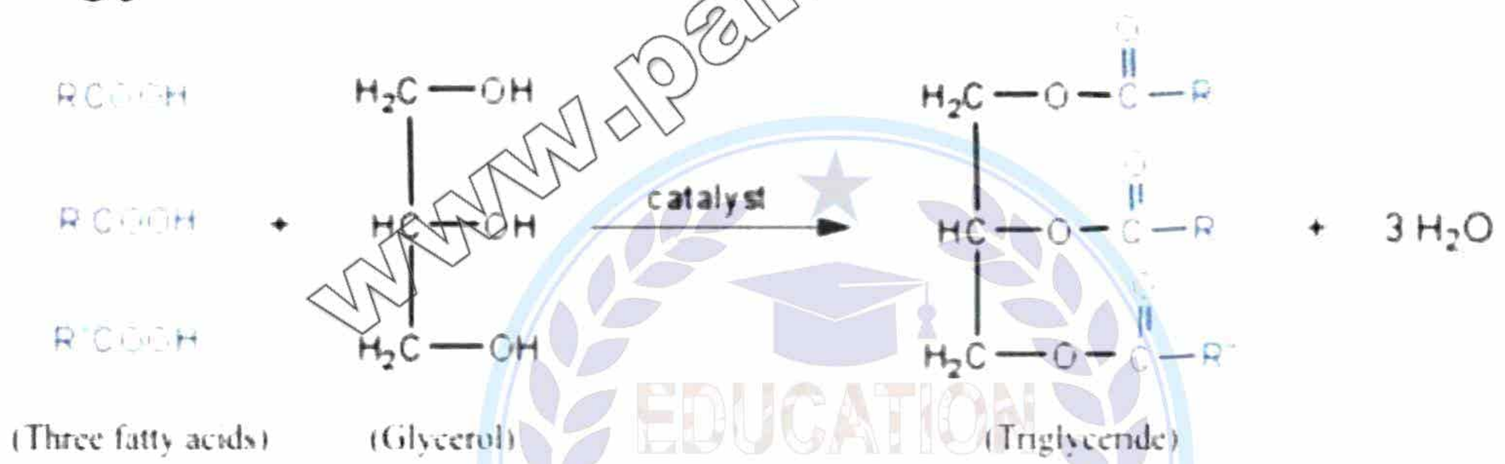
The term "lipid" originates from the Greek word "Lipos"" meaning "fat like" due to their greasy or oily texture when touched.
Lipids are vital components of our diet and can be obtained from various sources such as animal fat (e.g. butter, ghee) vegetable oil etc.

Classification of lipids
On the basis of chemical composition lipids are classified into three main groups, named as simple lipids, compound lipids and steroids.

Simple Lipids
These lipids are chemically esters, made up of fatty acids and alcohols, mainly serve as energy source to the body.

Simple lipids are further classified into fat, oil and waxes.

Fats and Oils
"These lipids are abundantly found in nature and chemically known as triglycerides or triesters", They are formed by the condensation of three fatty acid and a glycerol molecule.



The fatty acid chains in the molecules of fat and oil consists of C_{12} to C_{24} carbon atoms which may be saturated or unsaturated. Vegetable oil contains unsaturated fatty acids and are liquid at room temperature. Animals fats are composed of saturated fatty acids and usually solids at room temperature.

Types of fatty acids
Saturated Fatty Acid
Contains only single bonds between carbon atoms
Example: Stearic Acid, Palmitic Acid

Unsaturated Fatty Acid
Contains at least one double bond between carbon atoms
Example: Oleic Acid, Linoleic Acid.

Waxes

"Waxes are the naturally occurring esters of long-chain fatty acids and long chain alcohols".

Waxes are solids with water repellent nature. In plants they form coating on the surface of leaves, fruits and other parts helping to prevent water loss and protect against environment. Honey bees produce wax to build honey combs for the protection of hives.

$$C_{15}H_{31} - COO - C_{16}H_{33}$$

(Bees wax)

Compound lipids

These are esters of glycerol with two fatty acids and some other compounds such as carbohydrates, amino acids, phosphoric acid etc".

These are classified into phospho lipids, glyco lipids and lipo proteins on the basis of introduction of dditional groups like phosphoric acid, glycogen and protein etc.

Example: LDL (low-density lipoprotein).

Steroids

These are derived lipids that are composed of specific structure of four interconnected carbon rings (Cyclopentanophenanthrene nucleus).

Examples of steroids are cholesterol and cholic acid.

The structure of lipids varies depending on their classification. However the basic structure consists of a hydrophilic head and a hydrophobic carbon tail.

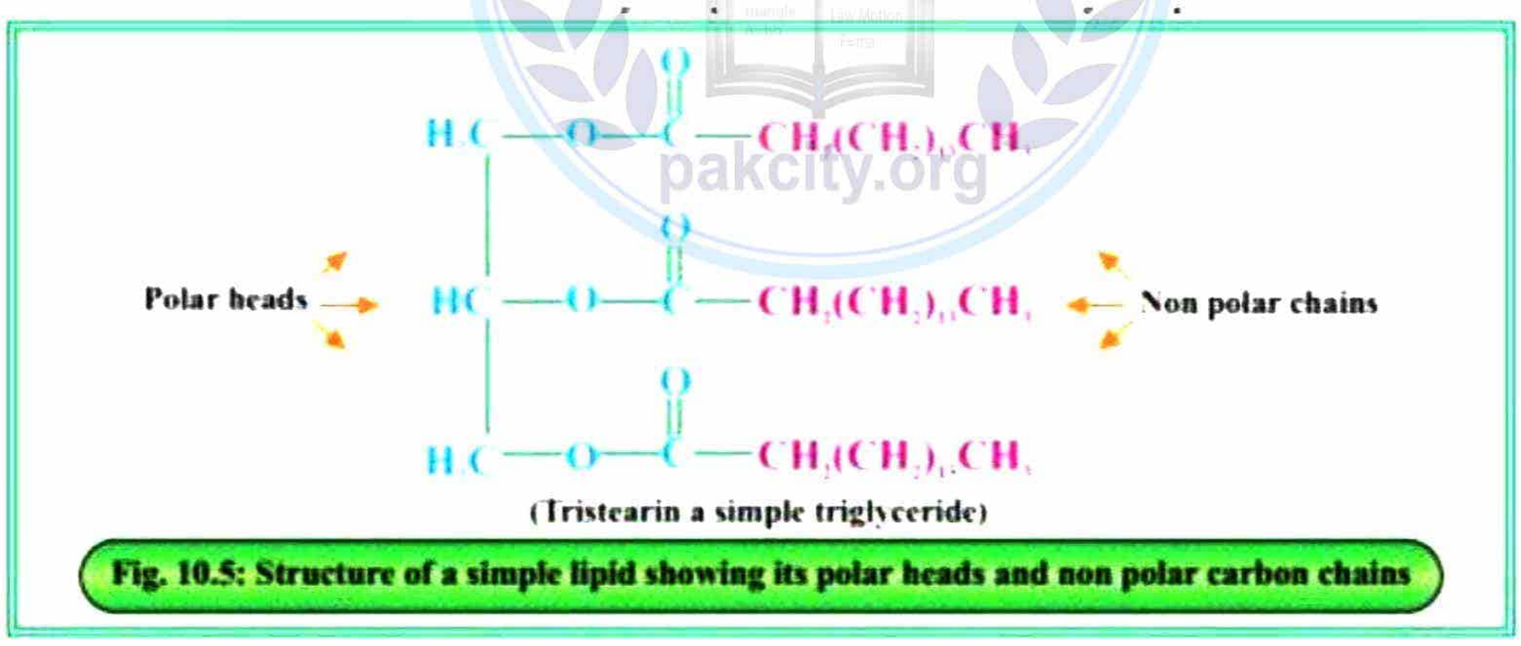


Fig. 10.5: Structure of a simple lipid showing its polar heads and non polar carbon chains

Properties of lipids

Physical Properties

- ✓ Lipids exist in different physical states depending upon their chemical nature and temperature.

- ✓ For example, fat exists in solid state, wax is semisolid state and oil in liquid state at room temperature.
- ✓ Lipids are translucent or opaque in nature.
- ✓ Lipids are insoluble in water and soluble in the organic solvents; like Bloor's reagent.
- ✓ Lipids have low density which enables them to float on water.
- ✓ Melting point of saturated lipids is higher than unsaturated lipids.
- ✓ Lipids are poor conductors of heat and electricity therefore serve as insulators for the animal body.

Chemical Properties

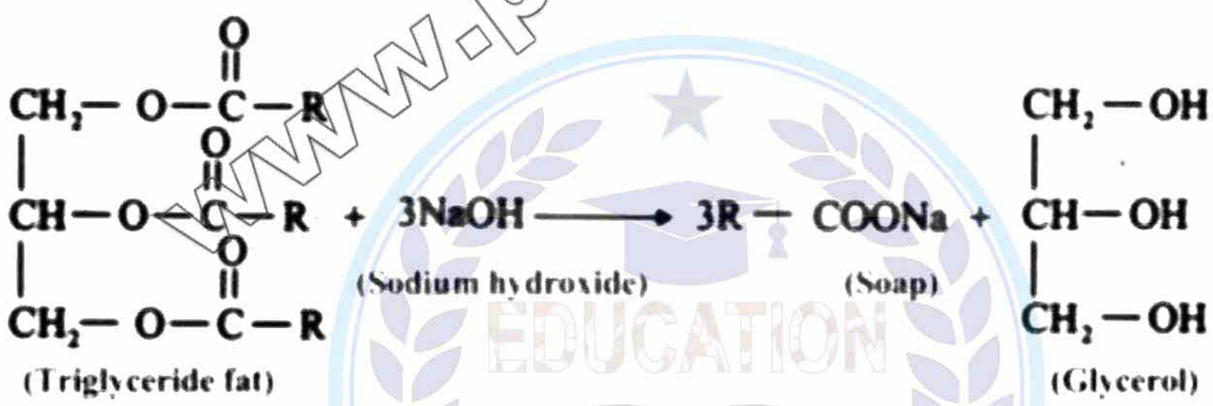
Addition reactions

Oils undergo addition reactions with hydrogen in the presence of nickel (catalyst) to produce fats. In this chemical reaction, unsaturated fatty acids of oil convert into saturated fatty acids.

$$R\text{-}CH\text{-}CH\text{-}COOH + H_2 \longrightarrow R\text{-}CH_2\text{-}CH_2\text{-}COOH$$

Saponification

Fat and oil are hydrolyzed when heated with an alkali to produce soap and glycerol, this process is known as saponification.



Rancidity

When animal fats are exposed to moist air, they undergo oxidation and hydrolysis reactions simultaneously leading to the development of an unpleasant taste and Odour. This process is commonly referred to as rancidity.

Importance of lipids

Lipids play important role in human body.

(iv) They store chemical energy in the form of triglycerides in adipose tissues. They store more than twice energy as compared to carbohydrates and proteins. This stored energy is used during fasting.

(ii) They are fundamental building blocks of cell membranes. Due to their water insolubility, they protect the cell by forming a phospholipid layer which allows the movement of substances in and out of the cell.

(iii) Lipids in adipose tissues help maintaining the body temperature and serve as insulation of the body.
(iv) They help in the absorption and utilization of fat soluble vitamins such as vitamin A, D, E and K.

MINERALS OF BIOLOGICAL SIGNIFICANCE

"Minerals are inorganic substances that are required to maintain physical health and prevent us from certain diseases".

Sources of important minerals

Minerals are generally found in fruits, vegetables, whole grains, dairy products, meats, sea food and water etc.

Sources of some minerals are listed

Minerals	Sources
Calcium	Milk, Cheese, Yogurt, Leafy greens
Iron	Red meat, Poultry, Sea Food, Bean, Lentils
Zinc	Beef, Chicken, Sea Food, Beans
Phosphorous	Meat, fish, dairy products, nuts, seeds, and whole grains.

Short Questions

1. Mention the three main functions of lipids.

Notes

2. Comparing with other nutrients, why lipids are better source of energy?

Energy Density:

- **Lipids:** One gram of fat provides about 9 calories of energy, while carbohydrates and proteins only offer around 4 calories per gram. This means lipids pack more energy per unit weight.

Storage:

- **Lipids:** Our bodies can store excess energy in the form of triglycerides (fats) in adipose tissue. These fat deposits act as a reserve fuel source, especially during times of limited food intake or high energy expenditure.
- **Carbohydrates:** The primary storage form of carbohydrates is glycogen, mainly stored in the liver and muscles. However, glycogen storage capacity is limited compared to fat storage.
- **Proteins:** Proteins are primarily used for building and repairing tissues and are not a preferred source of energy. While the body can break down proteins for energy in extreme situations, this process is less efficient and can have negative consequences like muscle breakdown.

Slow and Sustained Energy Release:

- **Lipids:** The breakdown of fats for energy is a slower process compared to carbohydrates. This slower release of energy provides a more sustained source of fuel, helping to regulate blood sugar levels and prevent energy crashes.

Essential Fatty Acids:

- **Lipids:** Some essential fatty acids cannot be synthesized by the body and must be obtained from the diet. These fats play crucial roles in various bodily functions, including hormone production and cell membrane structure.

However, it's important to note:

- Not all fats are created equal. Saturated and trans fats can contribute to health problems like heart disease. Unsaturated fats, particularly polyunsaturated and monounsaturated fats, are considered healthier options.
- A balanced diet needs all three macronutrients (carbohydrates, proteins, and lipids) for optimal health. Carbohydrates provide readily available energy for the brain and other organs, while proteins are essential for building and maintaining tissues.

In summary:

Lipids offer a concentrated source of energy, efficient storage capacity, and sustained energy release. However, it's crucial to consume healthy fats in moderation as part of a balanced diet.

3. Carbohydrates are necessary component of our diet. Give two dietary importance of carbohydrates.

Here are two key dietary importances of carbohydrates:

1. **Primary Source of Energy:** Carbohydrates are the body's preferred source of readily available energy. They are broken down into glucose (blood sugar) through digestion and absorption. Glucose enters the bloodstream and is transported to cells throughout the body, where it fuels various cellular processes.

- **Brain Function:** The brain relies heavily on a constant supply of glucose for proper functioning. Carbohydrates provide the necessary fuel for cognitive activities, memory, concentration, and mood regulation.
- **Muscular Activity:** During physical activity, especially moderate to high-intensity exercise, glucose is the primary source of energy for muscles. Carbohydrates ensure sustained energy levels for workouts and daily activities.

2. **Fiber for Digestive Health and Satiety:** Not all carbohydrates are created equal. Complex carbohydrates, particularly those rich in fiber, play a vital role in digestive health and promoting a feeling of fullness.

- **Fiber:** Dietary fiber, a type of complex carbohydrate, helps regulate digestion by adding bulk to stool and promoting smooth passage through the digestive tract. It also aids in the growth of beneficial gut bacteria, contributing to overall gut health.
- **Satiety:** Complex carbohydrates, especially those with high fiber content, take longer to digest and absorb compared to simple carbohydrates. This slower digestion process helps you feel fuller for longer, promoting satiety and potentially aiding in weight management.

4. What is meant by saponification? Give the reaction.

Saponification

Saponification refers to the chemical reaction between a **triglyceride (fat or oil)** and an **alkali (base)**, typically sodium hydroxide (NaOH) or potassium hydroxide (KOH), to produce **soap (a fatty acid salt)** and **glycerol**.

Here's the general reaction for saponification:
Triglyceride + 3 NaOH → 3 Soap + Glycerol
(fat/oil) (or 3 KOH) (fatty acid salt)

5. What is rancidity which chemical reaction involves in this process?
Rancidity refers to the spoilage of fats and oils that leads to unpleasant odors and flavors. It's caused by a group of chemical reactions that break down the fats and oils, primarily involving:

1. Oxidation:
This is the main culprit behind rancidity. Oxygen in the air reacts with the unsaturated fatty acids (fats with double bonds between carbon atoms) present in the fats and oils. This reaction is similar to how iron rusts in the presence of oxygen.

- **Free Radicals:** The oxidation process often starts with the formation of free radicals. These are highly reactive molecules with an unpaired electron, making them unstable and prone to further reactions.
- **Chain Reaction:** Free radicals can steal hydrogen atoms from unsaturated fatty acids, creating new free radicals and propagating the oxidation chain reaction. This chain reaction leads to the breakdown of the fatty acid molecules.

2. Hydrolysis:
While less prominent than oxidation, hydrolysis can also contribute to rancidity. This reaction involves the breakdown of fats and oils by water molecules. Enzymes naturally present in some foods or introduced by microorganisms (bacteria or mold) can accelerate hydrolysis.

Products of these reactions:

- The breakdown of fats and oils through oxidation and hydrolysis produces various volatile compounds with unpleasant odors and flavors. These can include aldehydes, ketones, and short-chain fatty acids.
- Additionally, the breakdown products can be irritating to the digestive system.

Factors affecting rancidity:

- **Unsaturation:** Fats and oils with a higher degree of unsaturation (more double bonds) are generally more prone to rancidity due to their increased reactivity with oxygen.
- **Light, Heat, and Air:** Exposure to light, heat, and air can accelerate the oxidation process, leading to faster rancidity.

- **Storage:** Proper storage methods like refrigeration or using airtight containers can help minimize exposure to these factors and slow down rancidity.

6. Write three essential functions of protein in the body.

Here are three essential functions of protein in the body:

1. **Building and Repairing Tissues:** Proteins are the building blocks of our body's tissues. They are crucial for:

- **Growth and Development:** During childhood and adolescence, protein is essential for building new tissues like muscles, bones, skin, hair, and organs.
- **Maintenance and Repair:** Throughout life, our bodies constantly repair and replace damaged tissues. Protein provides the necessary amino acids to rebuild and maintain these tissues.
- **Cell Structure:** Proteins are major components of cell membranes and other cellular structures, providing support and shape.

2. **Enzymes:** Enzymes are biological catalysts that regulate and accelerate countless biochemical reactions within the body. Most enzymes are proteins with specific shapes that allow them to bind to particular molecules (substrates) and speed up their conversion into products. Without enzymes, these reactions would occur very slowly or not at all, hindering vital cellular processes. Examples include enzymes involved in digestion, energy production, and waste removal.
3. **Transportation and Storage:** Proteins play a vital role in transporting various molecules throughout the body. For instance:

- **Hemoglobin:** This protein in red blood cells carries oxygen from the lungs to tissues throughout the body.
- **Lipoproteins:** These transport molecules carry lipids (fats) like cholesterol in the bloodstream.
- **Plasma Proteins:** Proteins present in blood plasma can also bind and transport various substances like hormones, vitamins, and metal ions. Proteins can also serve as storage molecules for essential amino acids. When dietary protein intake is insufficient, the body can break down stored proteins to access amino acids for building other proteins or generating energy.

7. Write down the sources from which we intake fructose and lactose.

Fructose Sources:

- **Fruits:**

A wide variety of fruits naturally contain fructose, including:

Apples, berries, grapes, citrus fruits (oranges, grapefruits), pears, mangoes, dates, etc.

- **Honey:**

This natural sweetener from bees is a mixture of fructose and glucose.

Lactose Sources:

- **Milk:**

Lactose, or milk sugar, is naturally found in milk from mammals like:

  - Cows, goats, sheep

- **Milk Products:**

Lactose is present in various dairy products derived from milk, such as:

  - Cheese (amounts vary depending on the type)
  - Yogurt
  - Ice cream

- **Fortified Foods:**

Some processed foods may be fortified with lactose or milk solids, adding it as an ingredient.

Descriptive Questions

1. What are Carbohydrates? Give their classification on the basis of structure.

Notes

2. Explain the role of glucose, fructose, sucrose and lactose in the health of human being.

Glucose:

- **Essential Energy Source:** Glucose is the primary source of energy for most cells in the body. It plays a crucial role in fueling various bodily functions, including:
  - Brain function
  - Muscle activity
  - Organ function
  - Cellular processes
- **Blood Sugar Regulation:** The body tightly regulates blood sugar (glucose) levels for optimal functioning. Hormones like insulin and glucagon work together to maintain blood sugar balance.
- **Excessive Intake Concerns:** While essential, chronically high blood sugar due to excessive intake of carbohydrates or impaired regulation can contribute to health problems like diabetes and metabolic syndrome.

Fructose:

- **Natural Sweetener:** Found in fruits and honey, fructose provides sweetness and contributes to the overall taste of these foods.
- **Moderate Intake:** In moderation, fructose from natural sources can be part of a healthy diet. However, excessive consumption, particularly from added sugars like high-fructose corn syrup (HFCS), has been linked to various health concerns, including:
  - Increased risk of obesity
  - Non-alcoholic fatty liver disease
  - Insulin resistance
  - Increased triglycerides (blood fats)

Sucrose (Table Sugar):

- **Common Sweetener:** Sucrose is a disaccharide composed of glucose and fructose. It's the most common table sugar and widely used as a sweetener in processed foods and beverages.
- **Health Effects:** Consuming large amounts of added sucrose can have similar health consequences as excessive fructose intake, including obesity, metabolic syndrome, and increased risk of chronic diseases.

Lactose:

- **Milk Sugar:** Lactose is a natural sugar found in milk from mammals. It provides some energy and nutrients like calcium.
- **Lactose Intolerance:** Some individuals lack sufficient lactase, the enzyme needed to break down lactose in the small intestine. This can lead to digestive discomfort like bloating, gas, and diarrhea after consuming milk or dairy products.

Overall:

- Moderate intake of natural sugars like fructose and lactose from whole fruits and dairy (for those without lactose intolerance) can be part of a healthy diet.
- Excessive consumption of added sugars, particularly from processed foods and beverages, can negatively impact health.
- Glucose is essential for energy but maintaining healthy blood sugar levels is crucial.

3. What are Proteins? Classify various types of proteins on the basis of their function.

Notes

4. What are Lipids? Give their classification, properties and biological significance.

Notes

5. How can you explain primary, secondary and tertiary structure of proteins?

Notes

6. Describe physical properties of proteins.

Notes

7. Why minerals are essential for our health? Give the biological significance of Calcium, Iron, Zinc, and phosphorus.

Minerals are essential for our health because they play a multitude of vital roles in various bodily functions. They cannot be produced by the body and must be obtained from our diet. Here's a breakdown of the biological significance of Calcium, Iron, Zinc, and Phosphorus:

Calcium (Ca):

- **Bone Health:** Calcium is the most abundant mineral in the body, constituting a major component of bones and teeth. It provides structural strength and rigidity to these skeletal structures.
- **Muscle Function:** Calcium is crucial for proper muscle contraction and relaxation, including both skeletal muscles for movement and smooth muscles for organ function.
- **Nerve Impulse Transmission:** Calcium ions play a vital role in transmitting nerve impulses throughout the nervous system.
- **Blood Clotting:** Calcium is necessary for blood clotting, helping to prevent excessive bleeding from injuries.
- **Enzyme Regulation:** Calcium acts as a cofactor for various enzymes, influencing essential biochemical reactions in the body.

Iron (Fe):

- **Hemoglobin Production:** Iron is a central component of hemoglobin, the protein in red blood cells responsible for transporting oxygen throughout the body. Deficiency can lead to anemia, characterized by fatigue, weakness, and shortness of breath.
- **Myoglobin Formation:** Iron is also involved in myoglobin, a protein in muscle cells that stores oxygen for energy production during physical activity.
- **Enzyme Function:** Iron is a cofactor for several enzymes essential for energy production, DNA synthesis, and cellular processes.

Zinc (Zn):

- **Immune Function:** Zinc plays a crucial role in supporting a healthy immune system. It helps with the development and function of immune cells that fight off infections.
- **Wound Healing:** Zinc is necessary for proper wound healing and tissue repair.

- **Enzyme Activity:** Zinc acts as a cofactor for over 300 enzymes involved in various bodily functions like metabolism, protein synthesis, and DNA replication.
- **Sense of Taste and Smell:** Zinc is essential for the proper functioning of taste and smell receptors.

Phosphorus (P):

- **ATP (Energy):** Phosphorus is a key component of adenosine triphosphate (ATP), the primary energy molecule in cells. ATP fuels all cellular processes, making phosphorus crucial for energy production and utilization throughout the body.
- **Bone Health:** Phosphorus, along with calcium, is a major building block of bones and teeth, providing strength and structure.
- **Nucleic Acids (DNA and RNA):** Phosphorus is a vital component of the backbone structure of DNA and RNA, the genetic material that carries instructions for protein synthesis and cellular function.
- **Cell Membranes:** Phospholipids, containing phosphorus, are essential components of cell membranes, maintaining their structure and function.