THE NEW ADVANCED SECONDARY CURRICULUM

CLASS: S.5

TOPIC: CELL BIOLOGY

SUB TOPIC 1: CHEMICALS OF LIFE

Competency: The learner evaluates cells and tissues, by analysing and relating their structure

to function, as a basis for medical research in order to improve health.

LEARNING OUTCOMES

The learner should be able to:

Analyse the properties and functions of chemical compounds (water, lipids, proteins including enzymes from mammals) in a cell, focusing on their roles in maintaining cellular structure and metabolic processes in living organisms. (Thermal properties of water not required.)

CHEMICALS OF LIFE

These are compounds needed to maintain life of living organisms. They are divided into two groups, i.e.

i) Inorganic compounds e.g. water, vitamins, salts, acids and roughages.
ii) Organic compounds e.g. carbohydrates, lipids, proteins and nucleic acids.

WATER

It is the most important inorganic compound in life and most abundant within living organism.

A human cell contains about 80% water and the whole body has over 60% water.

Water is formed when two hydrogen atoms combine with an oxygen atom by sharing electrons. The shape of a water molecule is triangular and the angle between the nuclei of atoms is approximately 105 DEGREES

Water molecules form weak hydrogen bonds with other water molecules nearby and its bonds give it the unique properties.

Properties of water

i) It is liquid at room temperature.
ii) It has a high heat capacity therefore much energy is used to raise its temperature because it is used to break the hydrogen bonds which restrict the mobility of the molecules. As a result water is relatively slow to heat up or to cool down thus a high heat capacity.
iii) Water expands as it freezes unlike other liquids which contract on cooling.
iv) Water reaches its maximum density above its freezing point at 4 oC hence when water freezes, the ice formed is less dense than the water and hence floats on top of the surface. In this way, ice insulates water below making it less dense and able to float hence the water will be warmer than the air above.
v) Water has a high surface tension. Surface tension is the force that causes the surface of a liquid to contract so that it occupies the least area. It is high due to the fact that molecules are oriented so that most hydrogen bonds point inwards towards other water molecules.
vi) It has a high latent heat of fusion i.e. much heat must be removed before freezing occurs.
vii) It has high adhesive and cohesive properties preventing it from breaking under tension.

viii) It is colourless and transparent.
ix) It has a low viscosity i.e. water molecules slide over each other very easily.
x) It dissolves more substances than any other liquid i.e. it is a universal solvent.

Functions of water

- It is a component of cells
- It is a solvent and a medium of transport
- It is a reagent in hydrolysis
- It enables fertilization by swimming gametes
- It enables dispersal of seeds, fruits, gametes and larvae stages in aquatic organisms.
- It is important in transpiration in plants.
- It is important in translocation in plants.
- It enables germination to proceed by activating enzymes, transporting hydrolyzed stored food, swelling and breaking open the testa.
- It is involved in Osmo-regulation in animals
- It enables cooling by evaporation as a result of sweating and panting.
- It is a component of lubricants at joints e.g. the synovial fluid.
- It offers support in hydrostatic skeleton.
- It offers protection as a component of mucus and tears.
- It enables migration to occur as a result of river flow or ocean currents.

QUESTION: ***HOW DO THE PROPERTIES OF WATER RELATE TO ITS BIOLOGICAL ROLE?***

1) Water is transparent and this allows light penetration in aquatic habitats to enable photosynthesis of aquatic autotrophs and visibility of aquatic animals.
2) Water has a low viscosity and this allows for smooth flow of water and other dissolved substances in an aquatic medium for easy transport.
3) It has a high surface tension providing support to aquatic organisms and allowing movement of living organisms on water surface.
4) Has a high latent heat of vaporization hence a cooling effect on the body surface since evaporation of water from the body of an organism draws out excess heat.
5) It has a high boiling point thus provides a stable habitat and medium since a lot of heat which is not normally provided in the natural environment is needed to boil the water.
6) It has a high latent heat of fusion and hence a low freezing point thus providing a wide range of temperature for survival of aquatic organisms since it prevents freezing of cells and cellular components.
7) It has a high specific heat capacity which minimizes drastic temperature changes in biological systems and provides a constant external environment for many plant cells and aquatic organisms.
8) It has a maximum density at 4o C hence ice floats on top of water insulating the water below hence increasing the chances of survival of aquatic organisms below the ice.
9) Water is liquid at room temperature providing a liquid medium for living organisms and metabolic reactions and a medium of transport.
10) It has high adhesive and cohesive forces creating enough capillarity forces for transport in narrow tubes of biological systems.
11) It is a universal solvent hence providing a medium for biochemical reactions.
12) Water is a polar molecule allowing solubility of polar substances, ionization or dissociation of biochemical substances.
13) Water is incompressible thus providing support in hydrostatic skeleton and herbaceous stems.
14) Water is neutral hence does not alter the pH of cellular components on their environment.

15) A water molecule is relatively small for easy and fast transport across a membrane.

QUESTION: *OUTLINE THE ROLE OF MINERALS AND IONS IN BIOLOGICAL SYSTEMS.*

1) They are components of smaller molecules e.g. phosphorus is contained in ATP and iodine is contained in thyroxin, etc.

2) They are constituents of large molecules e.g. proteins contain nitrogen and sulphur, phospholipids contain phosphorus, nucleic acids contain nitrogen and phosphorus, etc.

3) They are components of pigments e.g. haemoglobin and cytochromes which contain ion, chlorophyll contain magnesium, etc.

4) They are metabolic activators e.g. activates glucose before it is broken down in cell respiration, calcium ions activate ATPase enzyme during muscle contraction.

5) They determine the anion, cation balance e.g. Na+ , K+ and Ca+ are important in transmission of impulses and muscle contraction.

6) They determine the osmotic pressure and water potential so that it does not fluctuate beyond narrow limits e.g. Na+ , K+ and Cl- are involved in water balance in the kidneys.

7) They are constituents of structures in cell membranes, cell walls, bones, enamel and shells.

INTERACTION OF WATER WITH POLAR AND NON-POLAR SUBSTANCES.

The interaction of water with polar and non-polar substances is a fundamental concept in chemistry, primarily influenced by water's molecular structure and the nature of the substances it interacts with. Water is a highly polar molecule, meaning it has a partial positive charge on the hydrogen atoms and a partial negative charge on the oxygen atom due to its bent shape and the difference in electronegativity between oxygen and hydrogen.

1. Interaction of Water with Polar Substances

Polar substances are molecules that have an uneven distribution of charge, resulting in a dipole moment. These substances can interact with water through hydrogen bonding or dipole-dipole interactions.

- Hydrogen Bonding: This occurs when the partial positive charge of hydrogen in water interacts with the partial negative charge of an electronegative atom (like oxygen or nitrogen) in the polar substance. This is the main interaction that allows water to dissolve many polar substances, like salts (NaCl), alcohols, and sugars. For example, in water, the hydrogen of one water molecule can form a hydrogen bond with the oxygen atom of another molecule.

- Solubility of Polar Substances: Because of these interactions, water is often referred to as the "universal solvent" for polar compounds. Polar substances are generally soluble in water because their positive and negative poles interact with the positive and negative parts of the water molecules. For example, NaCl (sodium chloride) dissolves in water because the positively charged sodium ions (Na^+) are attracted to the oxygen (partially negative) of water, while the negatively charged chloride ions (Cl^-) are attracted to the hydrogen (partially positive) atoms of water.

Water interacts strongly with **polar substances** due to its own highly polar nature. Water molecules have a bent shape with a partial positive charge on the hydrogen atoms and a partial negative charge on the oxygen atom. This polarity allows water to form interactions like **hydrogen bonding** with other polar molecules, enabling it to dissolve or interact in a variety of ways with different polar substances.

Key Mechanisms of Interaction Between Water and Polar Substances:

1. Hydrogen Bonding

Hydrogen bonding is the primary force through which water interacts with polar substances. A hydrogen bond is an attractive interaction between a hydrogen atom, which is covalently bonded to an electronegative atom (like oxygen or nitrogen), and another electronegative atom with a lone pair of electrons. Since water has an oxygen atom with lone pairs of electrons, it can form hydrogen bonds with polar molecules that contain electronegative atoms (such as oxygen or nitrogen).

- Example: Water and Alcohols: Alcohols, such as ethanol (C_2H_5OH), are polar because they have a hydroxyl group (-OH). The oxygen in the hydroxyl group can form hydrogen bonds with the hydrogen atoms of water molecules. This is why ethanol is miscible (able to mix in all proportions) with water.

- Example: Water and Acids/Bases: Many acids and bases are polar and can dissolve in water because of their ability to form hydrogen bonds. For instance, hydrochloric acid (HCl) dissociates in water to form H^+ and Cl^- ions, and water molecules surround and stabilize these ions through hydrogen bonding.

2. Dipole-Dipole Interactions

Besides hydrogen bonding, water can also interact with other polar molecules through dipole-dipole interactions. These interactions occur between the positive end of one molecule and the negative end of another molecule.

- Example: Water and Acetone (C_3H_6O): Acetone, a polar solvent, contains a carbonyl group (C=O), which has a partial negative charge on the oxygen atom and a partial positive charge on the carbon atom. Water molecules can align their positive hydrogen atoms with the negative oxygen of acetone, forming dipole-dipole interactions. This is why acetone is miscible with water.

3. Ion-Dipole Interactions

When polar substances dissolve in water, they can dissociate into ions (charged particles). Water can interact with these ions through ion-dipole interactions, which occur between the charged ions and the partial charges on the water molecules.

- Example: Water and Sodium Chloride (NaCl): Sodium chloride is an ionic compound that dissociates into Na^+ and Cl^- ions when it dissolves in water. The partially negative oxygen atoms of water molecules surround the positively charged sodium ions (Na^+), and the partially positive hydrogen atoms surround the negatively charged chloride ions (Cl^-). These ion-dipole interactions help dissolve the salt in water, making it a common example of water's ability to dissolve polar and ionic substances.

4. Solubility of Polar Substances in Water

Water is often called the "universal solvent" because it is excellent at dissolving many polar substances. This solubility is driven by the fact that water molecules can surround polar solutes and form favorable interactions through hydrogen bonds, dipole-dipole, and ion-dipole interactions.

- Example: Sugar (Sucrose): Sucrose, a polar molecule, dissolves in water because the hydroxyl groups (-OH) in sucrose can form hydrogen bonds with the water molecules. This interaction helps break the sugar's intermolecular forces, allowing it to dissolve in water and form a homogeneous solution.

5. Formation of Hydration Shells

When a polar substance dissolves in water, the water molecules arrange themselves around the solute molecules to maximize the interactions between the solute and the solvent. This arrangement of water molecules around the solute is called a hydration shell.

- Example: Dissolving Ionic Compounds: When salts like NaCl dissolve in water, the water molecules surround each ion in a hydration shell. The oxygen atoms (with their partial negative charge) surround the cations (Na^+), and the hydrogen atoms (with their partial positive charge) surround the anions (Cl^-), stabilizing the ions in solution and preventing them from recombining into solid salt.

Examples of Polar Substances That Interact Well with Water:

1. Salts: Ionic compounds like sodium chloride (NaCl), potassium chloride (KCl), and magnesium sulfate ($MgSO_4$) are polar and dissociate into ions when mixed with water, interacting through ion-dipole forces.

2. Alcohols: Organic compounds like ethanol (C_2H_5OH) and methanol (CH_3OH) are polar due to their hydroxyl (-OH) groups, and they can form hydrogen bonds with water molecules, making them soluble in water.

3. Sugars: Carbohydrates, such as glucose ($C_6H_{12}O_6$), are polar due to their multiple hydroxyl groups. These molecules can form hydrogen bonds with water, making them highly soluble in water.

4. Acids and Bases: Many acids, like hydrochloric acid (HCl), and bases, like sodium hydroxide (NaOH), are polar and dissociate into ions when dissolved in water, leading to strong interactions with water molecules.

Conclusion:

Water's polarity is key to its interactions with other polar substances. The formation of hydrogen bonds, dipole-dipole interactions, and ion-dipole interactions allows water to dissolve and interact with a wide range of polar molecules. This ability to form favorable interactions with other polar molecules underpins water's status as the "universal solvent," making it essential for countless biological and chemical processes. Whether it's dissolving salts, alcohols, or sugars, water's unique structure allows it to engage in a variety of interactions that support life and facilitate chemical reactions.

2. Interaction of Water with Non-Polar Substances

Non-polar substances, on the other hand, lack a significant charge difference within the molecule, meaning they don't have positive or negative poles. This leads to very different interactions with water.

- Lack of Hydrogen Bonding: Non-polar substances do not form hydrogen bonds with water because they don't have the necessary dipole character. Water molecules, being highly polar, prefer to interact with other polar molecules or ions, rather than with non-polar molecules.

- Formation of Hydrophobic Interactions: When non-polar substances are introduced into water, they tend to cluster together rather than dissolve. This behavior is referred to as "hydrophobic" (water-fearing) interaction. The non-polar molecules are unable to form favorable interactions with the polar water molecules, so the water molecules tend to reorganize around the non-polar molecules to minimize their exposure to the non-polar substance. This leads to the non-polar molecules aggregating together, forming structures like oil droplets in water.

- Solubility of Non-Polar Substances: Non-polar substances, such as oils, fats, and hydrocarbons, generally do not dissolve in water. Since there is no attraction between the non-polar molecules and the water molecules, the non-polar molecules remain separated. For example, when oil is added to water, the oil forms a separate layer instead of dissolving because the water molecules prefer to bond with each other rather than interact with the oil molecules.

The interaction of water with non-polar substances is an interesting and important concept in chemistry, particularly when discussing solubility, molecular interactions, and behavior in various environments.

1. Polarity of Water

Water (H_2O) is a highly polar molecule. The oxygen atom in a water molecule has a partial negative charge, and the hydrogen atoms have partial positive charges. This polarity gives water several unique properties, including the ability to form hydrogen bonds and interact with other polar substances.

2. Non-Polar Substances

Non-polar substances are molecules where the charge distribution is symmetrical, meaning there is no significant difference in electronegativity between the atoms in the molecule, resulting in no dipole moment. Examples of non-polar substances include oils, fats, and hydrocarbons (e.g., methane, benzene, and hydrocarbons like hexane).

3. Why Non-Polar Substances Don't Mix Well with Water

Since water is polar and non-polar substances lack significant charges or dipoles, there is minimal interaction between water molecules and non-polar molecules. Water molecules prefer to interact with other polar molecules, forming hydrogen bonds and maintaining their own hydrogen-bonding network. When water encounters a non-polar substance, the interactions between water and the non-polar molecules are weak and don't disrupt the water's hydrogen-bonded structure effectively.

Because of this, non-polar substances are generally **insoluble** in water. For example, if you try to mix oil and water, the water molecules will form hydrogen bonds with each other, and the oil molecules will stick together. The two will separate, with the non-polar oil forming its own distinct phase.

4. "Like Dissolves Like"

This principle is central in chemistry, especially when considering solubility. Since water is polar, it tends to dissolve other polar or ionic substances (like salts or sugars), whereas non-polar solvents tend to dissolve other non-polar substances. This is why oil (non-polar) and water (polar) do not mix.

5. Hydrophobic Effect

This term describes the tendency of non-polar substances to cluster together in water rather than interact with the water molecules. This behavior is primarily driven by entropy. When non-polar substances are in water, the water molecules around them become more ordered (because they form a "cage-like" structure around the non-polar substance), which is thermodynamically unfavorable. The non-polar molecules "hide" from the water molecules to minimize this ordering, resulting in the formation of distinct non-polar phases.

This effect plays a crucial role in biological systems, such as the formation of cell membranes, where hydrophobic molecules like lipids form bilayers to shield their hydrophobic tails from water.

6. Interaction on Molecular Level

At the molecular level, when water encounters non-polar substances, the interactions that occur are mainly **van der Waals forces** (specifically dispersion forces), which are much weaker than the hydrogen bonds that water forms with itself or with polar molecules. These weak interactions don't provide the necessary energy to dissolve non-polar substances in water.

7. Surfactants as Intermediaries

In practical situations, surfactants (molecules with both polar and non-polar regions) can help to mix water with non-polar substances. Surfactants have a hydrophilic (water-loving) head and a hydrophobic (water-fearing) tail, allowing them to interact with both water and non-polar substances. This is why detergents can emulsify oils (non-polar) in water.

8. Applications

- **Oil Spills**: The difficulty in mixing non-polar substances like oils with water is a challenge in cleaning up oil spills. Specialized surfactants are used to break up the oil and help it disperse.
- **Biological Systems**: The hydrophobic effect is fundamental to the structure and function of proteins and cellular membranes. For example, the hydrophobic amino acids in a protein will typically fold inward, away from the surrounding water.
- **Emulsification**: In food chemistry, non-polar substances like oils are mixed with water to create emulsions (e.g., mayonnaise). This process relies on surfactants or emulsifiers to keep the oil droplets suspended in the water phase.

Conclusion

The interaction between water and non-polar substances is minimal due to the fundamental difference in polarity. This results in poor solubility of non-polar substances in water, leading to phenomena like phase separation and the hydrophobic effect. However, surfactants and other agents can be used to overcome this, allowing for the mixing of water with non-polar substances in specific applications.

3. Key Differences in Water's Interaction with Polar and Non-Polar Substances

The interaction of water with **polar** and **non-polar** substances is governed by the fundamental differences in molecular structure and the nature of intermolecular forces. Let's explore the key differences in how water interacts with these two types of substances:

1. Polarity of the Substances

- **Polar Substances**: Polar molecules, like water itself, have an uneven distribution of electrical charge, with one part of the molecule being slightly negative (typically the oxygen atom) and another part being slightly positive (typically the hydrogen atoms). This creates a **dipole moment**, meaning that one end of the molecule has a partial positive charge and the other has a partial negative charge.
- **Non-Polar Substances**: Non-polar molecules do not have an uneven charge distribution. The electrons are more symmetrically shared, resulting in no significant positive or negative ends (dipoles). Non-polar molecules may be homonuclear (e.g., O_2, N_2) or heteronuclear (e.g., hydrocarbons like methane or oil), but they lack a dipole moment.

2. Intermolecular Forces

- **With Polar Substances**: Water molecules can interact strongly with polar molecules because of **hydrogen bonding**. The partial positive charge of hydrogen in water can interact with the partial negative charge of electronegative atoms (like oxygen or nitrogen) in polar molecules. This allows water to dissolve many polar substances (like salts and sugars) through the formation of hydrogen bonds.
- **With Non-Polar Substances**: Water's interaction with non-polar molecules is much weaker, primarily relying on **van der Waals forces** (specifically dispersion forces). These forces are much weaker than hydrogen bonds, and as a result, non-polar substances tend to be poorly soluble in water.

3. Solubility

- **Polar Substances in Water**: Water is an excellent solvent for polar substances due to the **"like dissolves like"** principle. Since water is polar, it tends to dissolve other polar substances or ionic compounds (like salts) because of the strong interactions between water molecules and the polar solutes. For instance, water can dissolve sodium chloride (NaCl) because the positively charged sodium ions (Na^+) and negatively charged chloride ions (Cl^-) interact favorably with the polar water molecules.
- **Non-Polar Substances in Water**: Non-polar substances do not dissolve well in water. Since water molecules prefer to interact with other polar molecules, non-polar substances like oil, fats, and hydrocarbons do not dissolve in water. Instead, they tend to form separate phases, like when oil forms droplets or a layer on top of water.

4. Hydrophobic vs. Hydrophilic Effects

- **Hydrophilic (Water-Loving) Substances**: Polar molecules and ions that can form hydrogen bonds with water are considered hydrophilic. They interact favorably with water, forming strong connections that result in high solubility in water. Examples include salts, alcohols, and sugars.
- **Hydrophobic (Water-Fearing) Substances**: Non-polar molecules tend to be hydrophobic because they do not form strong interactions with water. In fact, water molecules surrounding non-polar substances tend to form an ordered structure (which is entropically unfavorable), so these substances tend to aggregate or separate from water. This is known as the **hydrophobic effect** and is a driving force in the behavior of biological molecules like proteins and lipids.

5. Structure and Behavior in Water

- **Polar Molecules in Water**: When polar molecules are mixed with water, they typically dissolve and distribute evenly in the solution. Water molecules surround and stabilize the solute through hydrogen bonds. For example, when salt (NaCl) is added to water, water molecules surround and separate the Na^+ and Cl^- ions, dissolving them.
- **Non-Polar Molecules in Water**: Non-polar molecules tend to form distinct separate phases or aggregates in water. For example, when oil is added to water, it forms separate droplets or layers because the water molecules prefer to interact with each other rather than with the oil molecules. The non-polar molecules aggregate together to minimize the disruption of the water's hydrogen-bonding network.

6. Effects on Biological Systems

- **Polar Interactions in Biology**: Polar molecules are crucial in biological processes. Water's ability to dissolve ions and polar molecules is essential for cellular functions, like nutrient transport, enzyme activity, and signal transduction. Hydrophilic interactions also play a significant role in the formation of **hydrophilic channels** in cell membranes and the folding of proteins.
- **Non-Polar Interactions in Biology**: Non-polar molecules are equally important in biological systems. For example, the **hydrophobic effect** drives the formation of lipid bilayers in cell membranes, where the hydrophobic tails of lipids aggregate together, away from the water, while the hydrophilic heads face outward, interacting with the water. Additionally, the folding of proteins into their native structures often involves the burial of hydrophobic regions in the interior of the protein to avoid interaction with water.

7. Examples of Polar vs. Non-Polar Interactions with Water

- **Polar**: When sugar (sucrose) is dissolved in water, the hydroxyl (-OH) groups of sugar form hydrogen bonds with water molecules. This is why sugar dissolves easily in water.
- **Non-Polar**: When hexane (a non-polar hydrocarbon) is added to water, the molecules do not interact significantly with the water molecules. Instead, the hexane forms a separate phase, as water molecules prefer to interact with each other rather than with the non-polar hexane molecules.

8. Energy Considerations (Enthalpy and Entropy)

- **Polar Molecules**: The interactions between polar substances and water are typically **exothermic**, meaning they release energy as they form hydrogen bonds. This makes these interactions favorable in terms of both enthalpy and entropy, and thus, polar molecules tend to dissolve well in water.
- **Non-Polar Molecules**: The lack of strong interactions between water and non-polar molecules leads to unfavorable enthalpy changes. Furthermore, when non-polar substances are added to water, water molecules become more ordered around the non-polar substance, leading to a decrease in entropy. This makes the interaction energetically unfavorable, which is why non-polar substances don't dissolve in water.

Summary of Key Differences:

Property	Polar Substances	Non-Polar Substances
Polarity	Uneven charge distribution (dipole moment).	Symmetrical charge distribution, no dipole.
Intermolecular Forces	Hydrogen bonds (strong) and dipole-dipole.	Van der Waals forces (weak).
Solubility in Water	High solubility (dissolve in water).	Low solubility (form separate phases).
Effect on Water	Water surrounds and dissolves polar solutes.	Water forms separate phases with non-polar solutes.
Biological Role	Involved in hydration, nutrient transport, and enzyme interactions.	Drives the formation of cell membranes, protein folding.
Example	Salt (NaCl), alcohol, sugar.	Oil, waxes, methane.

In essence, **polar substances** readily dissolve in water due to the strong attractive forces between water molecules and the solute, while **non-polar substances** have limited interaction with water and generally remain separate.

LIPIDS

These are large group of organic compounds. Like carbohydrates, they contain carbon, hydrogen and oxygen but the proportion of oxygen is smaller than in carbohydrates hence they are more reduced than the carbohydrates.
Lipids are insoluble in water.
They are of two types i.e. fats and oils. Fats are solid at room temperature while oils are liquids at room temperature.

Properties of lipids

- They are insoluble in water but soluble in non-polar solvents like benzene, chloroform, diethyl ether, etc. The low solubility is due to the low oxygen content which results into a small number of polar hydroxyl groups in lipids hence very few hydrogen bonds.
- They have a high proportion of hydrogen in their molecules.
- They are non-polar compounds.
- They are less dense than water.
- They can be solids or liquids at room temperature.
- Their melting point increases with increase in saturation.
- They undergo high oxidation in respiration to yield large amounts of energy.

- They are poor conductors of heat.

SIMPLE LIPIDS

Simple lipids are a category of lipids that consist of fatty acids and alcohol, without any additional functional groups like phosphate or carbohydrates. They are the most basic form of lipids, and they can be further categorized based on the types of alcohols involved (usually glycerol or long-chain alcohols). Simple lipids play vital roles in energy storage, insulation, protection, and structure within biological systems.

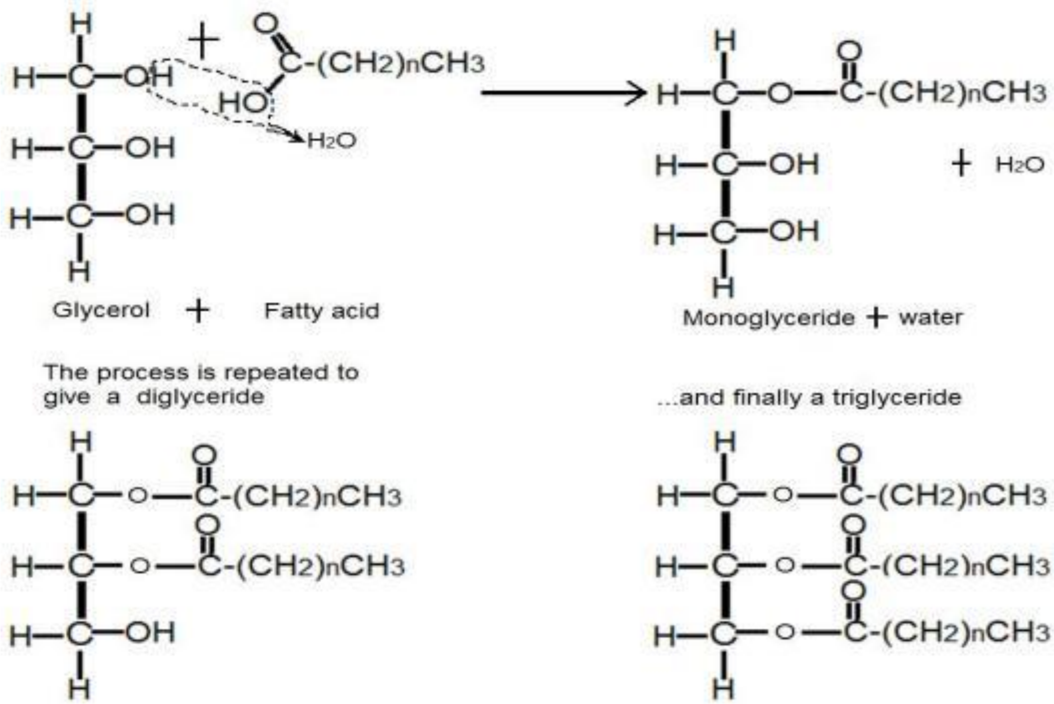
Types of Simple Lipids

1. **Triglycerides (Triacylglycerols)**:
   - **Structure**: Composed of one molecule of **glycerol** (a three-carbon alcohol) and three fatty acid molecules. The fatty acids are connected to the glycerol backbone via ester bonds.

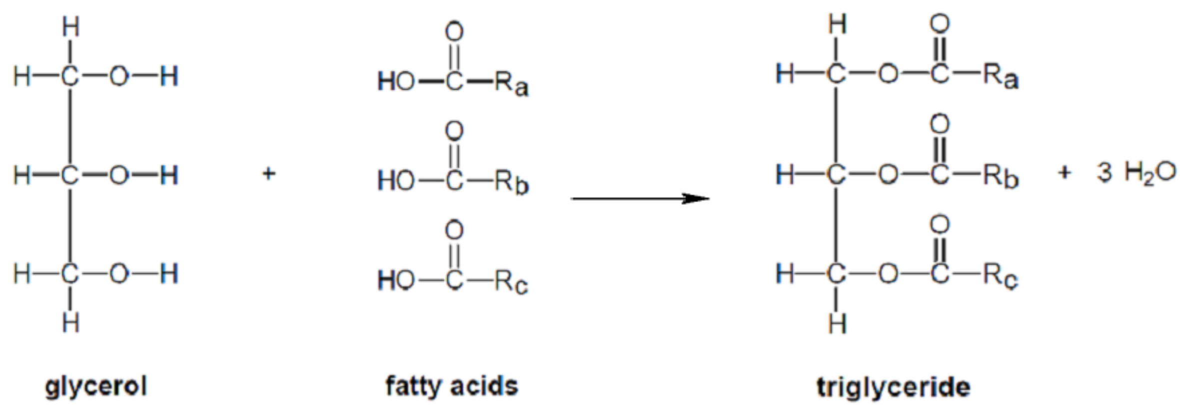
Formation of triglycerides

Lipids are made of fatty acids and glycerol. Glycerol has 3 OH groups and each combines with a separate fatty acid to form a lipid chemically known as a triglyceride. This is a condensation reaction that leads to liberation of 3 water molecules.

Metabolic water is formed and an ester bond is formed between the glycerol and fatty acid. Since the glycerol possesses 3 hydroxyl groups to which 3 fatty acids attach themselves, 3 water molecules are formed. In this reaction, the fatty acids may all be the same or different, saturated or unsaturated.



For example



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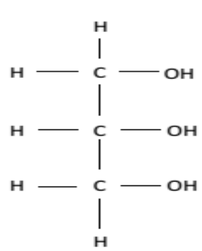
Using the structural formular below For glycerol, and molecular formula $CH_3(CH_2)nCOOH$ for a fatty acid, show the formation of a triglyceride from fatty acids and glycerol.



- **Properties**:
  - They are typically **hydrophobic** (water-insoluble).
  - The physical state (solid or liquid) depends on the **fatty acid composition**. If they contain **saturated fatty acids**, they tend to be solid at room temperature (e.g., butter, lard). If they contain **unsaturated fatty acids**, they tend to be liquid (e.g., olive oil, canola oil).
  - They are **non-polar** molecules, meaning they do not dissolve in water but are soluble in organic solvents like ether and chloroform.
- **Functions**:
  - **Energy Storage**: Triglycerides are the main form of **energy storage** in the body, stored in **adipose tissue**. They provide a dense source of energy, as they contain more energy per gram than carbohydrates or proteins.
  - **Insulation and Protection**: Stored triglycerides in adipose tissue act as **thermal insulation** to help regulate body temperature and provide **mechanical protection** for internal organs.
  - **Energy Source**: When energy is needed, triglycerides are broken down into fatty acids and glycerol through a process called **lipolysis** and can be metabolized for ATP production.

2. **Waxes**:
   - **Structure**: Waxes are esters of long-chain **fatty acids** and **long-chain alcohols**. They differ from triglycerides by having a single fatty acid chain esterified to an alcohol (instead of three fatty acids).
   - **Properties**:
     - Waxes are **hydrophobic** and **solid** at room temperature due to their long fatty acid chains.
     - They have a **high melting point**, which makes them useful as protective barriers.
   - **Functions**:
     - **Waterproofing**: Waxes act as **water repellents** and are used by many organisms for protection against water loss. For example, the **cuticle** of plant leaves is coated with wax to prevent water evaporation.
     - **Protection**: Waxes form protective coatings in various organisms, such as the **beeswax** in bee hives, **earwax** (cerumen) in humans, and the wax coating on the feathers of birds.
     - **Structural**: Waxes contribute to the **structural integrity** of certain plant and animal organs by creating a hard outer layer.

3. **FATTY ACIDS**

All occurring lipids have glycerol and therefore it is the nature of the fatty acids which determines the characteristics of any particular lipid. All fatty acids have a carboxyl group (COOH), the reminder of the molecule being a hydro carbon chain of varying length.

These chains may possess one or more double bond in which case it is said to be unsaturated. If it possesses no double bonds, it is said to be saturated.

Nature of fatty acid	General formula	Saturated/unsaturated	Occurrence
1. Butyric acid	C_3H_7COOH	Saturated	Butter fat
2. Linoleic acid	$C_{17}H_{31}COOH$	Unsaturated	Seed oil
3. Oleic acid	$C_{17}H_{33}COOH$	Unsaturated	All fats
4. Palmitic acid	$C_{15}H_{31}COOH$	Saturated	Animal & veg fat
5. Selotic acid	$C_{25}H_{51}COOH$	Saturated	Wood oil
6. Arachidic acid	$C_{19}H_{39}COOH$	Saturated	P.nut oil

From the table, it is seen that the hydrocarbon chains may be very long forming long tails which extend from the glycerol molecules. These trails are hydrophobic (water repelling) which makes the lipids insoluble in water.

Saturated and unsaturated fatty acids

In saturated fatty acids all the available bonds in carbon atoms are used and there are a maximum possible number of hydrogen atoms. Saturated fatty acids lack double bonds in the hydrocarbon tail.
Unsaturated fatty acids do not contain the maximum number of hydrogen atoms, they have one or more double bonds between some of the carbon atoms in the hydrocarbon chain.
Saturated fatty acids have high melting points and are therefore found in fats while in unsaturated fatty acids, the presence of the double bonds lowers the melting point and are therefore found in oils.
Since there are many types of fatty acids but one type of glycerol, lipids (fats and oils) vary due to the fatty acids.

Essential fatty acids

These are fatty acids which cannot be synthesized by the body and must be supplied in the diet.

Common sources of essential fatty acids are; vegetables and seed oils. A deficiency of these fatty acids results in retarded growth, reproductive disorders and kidney failure.

Non-essential fatty acids

These are fatty acids that can be synthesized by the body from metabolism of other compounds like proteins and carbohydrates.

How cholesterol causes arthesclerosis

Cholesterol is produced by the liver and is used as the starting point for the synthesis of other steroid molecules. The major source of cholesterol is diet and many dairy products are rich in cholesterol or fatty acids from which cholesterol can be synthesized. Thyroxin stimulates cholesterol production in the liver and also increases the rate of excretion of bile. Excessive amounts of cholesterol in blood can be harmful. It can be deposited in walls of arteries leading to arthesclerosis and increased risk of formation of a blood clot which may block blood vessels, a condition known as thrombosis. This is often fatal if it occurs in the coronary artery in the wall of the heart (coronary thrombosis or heart attack) or brain (cerebral thrombosis). Although cholesterol is harmful in excess, it is essential to have some in the diet for reasons stated.

Question: ***explain why lipids are insoluble in water?***

Lipids are **insoluble in water** primarily because of their **hydrophobic nature**. This characteristic arises from the **structure** of lipids, which are predominantly composed of long, non-polar hydrocarbon chains (fatty acids) or rings (as in steroids). Let's break down the reasons why lipids are insoluble in water:

1. Non-Polar Nature of Lipids:

- The key feature of lipids, such as **fatty acids** and **triglycerides**, is the long **hydrocarbon chains** (chains of carbon atoms bonded to hydrogen atoms). These hydrocarbon chains are **non-polar**, meaning they do not have a charge or dipole.
- Water, on the other hand, is a **polar** molecule, with a partial negative charge on the oxygen atom and partial positive charges on the hydrogen atoms. Polar molecules tend to interact with other polar molecules through **hydrogen bonding** or dipole-dipole interactions.

2. Lack of Hydrogen Bonding with Water:

- Water molecules are highly attracted to other polar molecules because they can form hydrogen bonds, which are a type of attractive force between the hydrogen atom of one molecule and the electronegative atom (like oxygen) of another molecule.
- **Lipids**, being non-polar, cannot form hydrogen bonds with water molecules, which limits their ability to dissolve in water.

3. Hydrophobic Effect:

- When lipids are placed in water, the **hydrophobic effect** occurs. The non-polar hydrocarbon chains of lipids tend to **avoid** interacting with the water molecules. Instead of dissolving, the lipid molecules aggregate together to minimize their exposure to water.
- For example, in the case of **phospholipids**, the non-polar tails (fatty acid chains) will face inward, away from water, while the polar heads (phosphate groups) face outward, interacting with water. This forms **lipid bilayers** in biological membranes, where the hydrophobic tails are shielded from the water.

4. Energy Considerations:

- When water molecules surround a lipid molecule, they form a structured "clathrate" or cage-like structure around the lipid. This structure is **energetically unfavorable** because it requires the water molecules to organize themselves in a way that reduces entropy (disorder).
- Lipids do not readily interact with water to "disrupt" this ordered structure, and instead, they **aggregate** to minimize the disruption of water's hydrogen-bonding network.

5. Difference in Solubility:

- Solubility in a solvent depends on the ability of molecules to interact with each other. Since water molecules are polar and lipids are non-polar, they don't mix well. Lipids are soluble in **non-polar solvents** (like chloroform or ether) because these solvents do not require the disruption of water's hydrogen bonds and have similar non-polar characteristics as the lipid molecules.

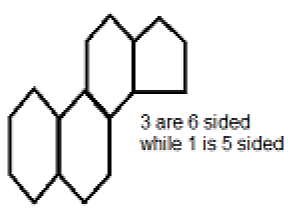
Summary:

- **Lipids are insoluble in water** because their long, non-polar hydrocarbon chains (or rings) cannot interact with water molecules, which are polar. The **hydrophobic nature** of lipids leads to their aggregation in water rather than dissolving, and the **hydrophobic effect** minimizes the exposure of their non-polar parts to water.

4. **STEROIDS**

These are biologically important substances in both plants and animals. The skeleton of a steroid molecule consists of four complex rings of carbon atoms. Three of these are six sided while one is 5 sided.

The various steroids differ in the side groups attached to the carbon atoms of the skeleton. Like lipids, they contain hydrogen atoms and oxygen atoms but do not contain any fatty acid. They have a general skeleton shown below.



Examples of steroids include;

- Cholesterol which is a component of the plasma membrane and a raw material for many other steroids like bile acids.
- Bile acids e.g glycolic acid and taurochloric acid used in the emulsification of fats during digestion.
- Vitamin D (calciferol) which promotes phosphorous and calcium absorption and metabolism.
- Sex hormones e.g testosterone and oestrogen. Hormones from adrenal cortex i.e are referred to as corticosteroids.

General Properties of Simple Lipids:

1. **Hydrophobic Nature**:
   - Simple lipids, including triglycerides and waxes, are **hydrophobic**, meaning they repel water. This is due to the long hydrophobic hydrocarbon chains in their structure.
2. **Energy-Dense**:
   - They are **highly energy-dense** molecules. Triglycerides, in particular, provide about **9 kcal/g**, which is more than twice the energy content of carbohydrates or proteins (which provide 4 kcal/g). This makes them the most efficient storage form of energy.
3. **Solubility**:
   - Simple lipids are not soluble in water because they lack polar groups that can interact with water molecules. They are, however, soluble in organic solvents like **ether**, **chloroform**, and **benzene**.
4. **Storage**:
   - Simple lipids are stored in specialized cells called **adipocytes** (fat cells) in the body. Triglycerides are stored in **adipose tissue**, where they serve as long-term energy reserves.
5. **Inert and Stable**:
   - Waxes, in particular, are **chemically inert** and resistant to degradation, which is why they are used as protective coatings by various organisms.

Functions of Simple Lipids:

1. **Energy Storage**:
   - The primary function of **triglycerides** is **energy storage**. When energy is needed, triglycerides are broken down to release fatty acids and glycerol, which can be metabolized to produce ATP.
2. **Insulation**:
   - In animals, particularly mammals, stored triglycerides in **adipose tissue** act as **insulation** to conserve heat and maintain body temperature. In cold environments, fat stores help protect the body from heat loss.
3. **Protection of Organs**:
   - Fat tissue (mainly triglycerides) provides **cushioning** around vital organs, such as the kidneys, heart, and liver, protecting them from physical shock and injury.
4. **Waterproofing and Protection**:
   - **Waxes** are used by plants and animals to **prevent water loss**. For example, plant leaves have a waxy coating that prevents excessive water evaporation, and animals like birds have waxy coatings on their feathers to keep them dry and buoyant.
5. **Structural Components**:
   - In addition to energy storage, simple lipids (especially phospholipids and triglycerides) are integral parts of **cell membranes** and provide structural support. The hydrophobic properties of lipids help form bilayers in membranes, creating barriers that separate the cell's internal environment from the external surroundings.
6. **Chemical Signaling**:
   - Although this is more relevant to other types of lipids like **steroids**, the breakdown products of triglycerides, such as **eicosanoids** (derived from polyunsaturated fatty acids), also play a role in **cell signaling** and inflammation.

Summary of Simple Lipids:

Type of Simple Lipid	Structure	Properties	Functions	Examples
Triglycerides	Glycerol + 3 fatty acids	Hydrophobic, energy-dense, water-insoluble, storage form of fat	Energy storage, insulation, organ protection	Butter, olive oil, animal fats (lard, tallow)
Waxes	Long-chain fatty acids + long-chain alcohols	Hydrophobic, solid at room temperature, high melting point	Waterproofing, protection, structural integrity in plants/animals	Beeswax, plant cuticle wax, earwax, candle wax

In conclusion, **simple lipids** (triglycerides and waxes) are crucial for energy storage, insulation, and protection. They serve as an energy reserve in animals and humans and help organisms maintain their structure, protect their bodies, and avoid dehydration or water loss.

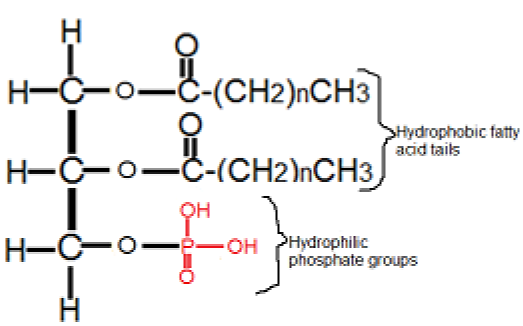
CONJUGATED LIPIDS

Conjugated lipids are a class of lipids that consist of fatty acids combined with other molecules, such as proteins, carbohydrates, or phosphates, in addition to the usual components like glycerol or sphingosine. Unlike simple lipids, which are composed only of fatty acids and alcohol, conjugated lipids have more complex structures due to the presence of additional functional groups. These lipids play important roles in cell signaling, membrane structure, and various metabolic processes.

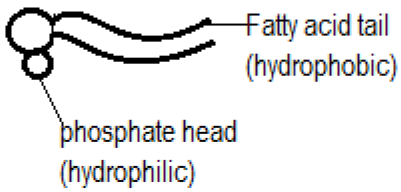
Types of Conjugated Lipids

1. **Phospholipids**
   - **Structure**: Phospholipids consist of a glycerol backbone, two fatty acid chains, a phosphate group, and sometimes an additional polar group (e.g., choline, ethanolamine, or serine).
   - **Properties**:
     - Amphipathic: Phospholipids have both a **hydrophobic** tail (the fatty acid chains) and a **hydrophilic** head (the phosphate group and polar group).
     - They are essential for **membrane formation**, as they form lipid bilayers in cell membranes.

STRUCTURE OF A PHOSPHOLIPID



A phospholipid can be simply represented as:



- **Functions**:
  - **Cell Membrane Structure**: Phospholipids are the major components of biological membranes, forming bilayers that act as selective barriers, controlling the movement of substances into and out of cells.
  - **Signal Transduction**: Phospholipids are involved in cell signaling, particularly through molecules like **phosphatidylinositol** derivatives (e.g., inositol trisphosphate).
  - **Lipid Rafts**: Phospholipids help organize **lipid rafts**, which are microdomains in the cell membrane that cluster proteins involved in signaling and trafficking.

2. **Glycolipids**
   - **Structure**: Glycolipids consist of a **glycerol or sphingosine backbone**, two fatty acids, and a **carbohydrate group** (such as glucose or galactose).
   - **Properties**:
     - Amphipathic: Like phospholipids, glycolipids have a **hydrophobic** tail (fatty acids) and a **hydrophilic** head (carbohydrate group).
     - These lipids are often found in the **outer leaflet** of the plasma membrane.
   - **Functions**:
     - **Cell Recognition**: Glycolipids play a critical role in **cell-cell recognition** and **communication**. The carbohydrate moiety is involved in interactions between cells and their environment, such as in the immune response.
     - **Blood Type Determination**: The **ABO blood group** antigens are glycolipids found on the surface of red blood cells, which are crucial for blood type compatibility.
     - **Membrane Stability**: Glycolipids help stabilize the structure of the cell membrane and influence its fluidity.
     - **Neuroprotection**: In the nervous system, glycolipids like **gangliosides** are involved in neuronal protection and signaling.
3. **Lipoproteins**
   - **Structure**: Lipoproteins consist of **lipids (such as phospholipids, cholesterol, and triglycerides)** combined with **proteins**. These proteins are called **apolipoproteins**, and they help transport lipids through the bloodstream.
   - **Properties**:
     - Amphipathic: The lipid portion is hydrophobic, while the apolipoproteins are hydrophilic, allowing the complex to be soluble in blood plasma.
   - **Functions**:

        - **Lipid Transport**: Lipoproteins transport **lipids** (triglycerides, cholesterol) through the bloodstream to various tissues.
        - **Types of Lipoproteins**:
            - **Chylomicrons**: Transport dietary lipids from the intestines to other parts of the body.
            - **VLDL (Very Low-Density Lipoproteins)**: Carry triglycerides from the liver to peripheral tissues.
            - **LDL (Low-Density Lipoproteins)**: Deliver cholesterol to cells for membrane synthesis and hormone production.
            - **HDL (High-Density Lipoproteins)**: Transport cholesterol from tissues back to the liver for excretion or recycling.

4. **Sphingolipids**
    - **Structure**: Sphingolipids are based on the **sphingosine** backbone rather than glycerol. They contain one fatty acid, sphingosine, and sometimes additional functional groups, such as a **phosphate** or **carbohydrate** group.
    - **Properties**:
        - Amphipathic: The **hydrophobic** fatty acid tail and the **hydrophilic** head (carbohydrate or phosphate) give sphingolipids the ability to interact with both water and lipid environments.
    - **Functions**:
        - **Membrane Structure**: Sphingolipids are important components of **cell membranes**, particularly in the nervous system. They help maintain membrane stability and are involved in signaling.
        - **Signal Transduction**: Sphingolipids, such as **sphingosine-1-phosphate**, act as signaling molecules in processes like cell proliferation, survival, and migration.
        - **Neuroprotective Role**: Sphingolipids such as **cerebrosides** and **gangliosides** are involved in the **myelin sheath** structure around neurons, essential for efficient nerve signal transmission.

General Properties of Conjugated Lipids

- **Amphipathic Nature**: Most conjugated lipids, such as phospholipids and glycolipids, are amphipathic (they have both hydrophobic and hydrophilic regions), which makes them ideal for forming the bilayers of biological membranes. This characteristic allows them to interact with both water-soluble and lipid-soluble substances.
- **Functional Diversity**: Conjugated lipids play roles beyond just structural components; they are involved in **cell signaling**, **membrane fluidity**, **transport**, **cell recognition**, and **immunological responses**.
- **Membrane Structure**: Conjugated lipids are crucial for maintaining the structural integrity and functionality of biological membranes. They can influence membrane properties like **fluidity**, **flexibility**, and the **organization of membrane proteins**.

Functions of Conjugated Lipids

1. **Cell Membrane Structure**:
    - Phospholipids, glycolipids, and sphingolipids are integral components of **cell membranes**, forming **lipid bilayers** that provide a semi-permeable barrier to separate the internal environment of the cell from the external environment.

- The **hydrophobic tails** of these lipids face inward, while the **hydrophilic heads** face outward, interacting with the aqueous environment inside and outside the cell.

2. **Signal Transduction**:
    - Phosphoinositides (derived from phospholipids) play a major role in **cell signaling** pathways, including activation of kinases and regulation of cellular processes like **growth**, **differentiation**, and **metabolism**.
    - Sphingolipids, such as **sphingosine-1-phosphate**, serve as second messengers in signaling pathways involved in **cell growth**, **survival**, and **apoptosis**.
3. **Lipid Transport**:
    - **Lipoproteins** facilitate the transport of lipids through the bloodstream, ensuring that essential lipids (such as cholesterol and triglycerides) are delivered to cells and tissues that need them.
4. **Cell Recognition and Immunity**:
    - **Glycolipids** on the surface of cells are important for **cell recognition**, allowing cells to identify and communicate with each other. They play critical roles in immune responses, including the recognition of pathogens.
    - Glycolipids are also involved in **blood type determination** (e.g., ABO blood group).
5. **Neuroprotection**:
    - **Sphingolipids** are especially important in the **nervous system**, where they form the myelin sheath around nerve fibres, ensuring proper nerve conduction and protecting neurons.

Summary of Conjugated Lipids

Type of Conjugated Lipid	Structure	Properties	Functions	Examples
Phospholipids	Glycerol backbone, two fatty acids, phosphate group	Amphipathic, form lipid bilayers, essential for membranes	Membrane structure, signaling, cell recognition	Phosphatidylcholine, phosphatidylserine, sphingomyelin
Glycolipids	Glycerol or sphingosine backbone, fatty acids, carbohydrate	Amphipathic, involved in cell signaling	Cell recognition, blood type, neuroprotection	Cerebrosides, gangliosides
Lipoproteins	Lipids (phospholipids, cholesterol, triglycerides) + proteins	Amphipathic, transport lipids in the bloodstream	Lipid transport, cholesterol homeostasis	LDL, HDL, VLDL, chylomicrons
Sphingolipids	Sphingosine backbone, fatty acid, phosphate/carbohydrate	Amphipathic, involved in membrane structure	Membrane structure, signaling, neuroprotection	Sphingomyelin, cerebrosides, gangliosides

In summary, conjugated lipids, including **phospholipids**, **glycolipids**, **lipoproteins**, and **sphingolipids**, are integral to a wide variety of biological functions, such as cell membrane structure, signaling, lipid transport, and cellular communication. These lipids are essential for the proper functioning of cells and tissues in all living organisms.

GENERAL FUNCTIONS OF LIPIDS

Structural:

i) They are components of the plasma/cell membrane.

ii) They form subcutaneous fat in the dermis of the skin hence insulating the body since they are poor conductors of heat.

iii) They are components of the waxy cuticle in plants and insects there by preventing water loss (desiccation).

iv) They form a component of the myelin sheath of nerves hence playing a role in the transmission of impulses.

v) They protect delicate organs e.g. the heart and kidney from injury.

vi) They coat on fur of animals enabling it to repel water which would otherwise wet the organism.

vii) They are component of adipose tissue.

Physiological:

i) They provide energy through oxidation.

ii) They are solvents for fat soluble vitamins (ADEK).

iii) They are a good source of metabolic water to desert animals, young birds and reptiles while still in their shells.

iv) They are a constituent of the brown adipose tissue which provides heat for temperature regulation (thermogenesis).

Other functions:

i) Some lipids provide a scent in plants which attracts insects for pollination.

ii) Wax is used by bees to construct honey combs.

iii) Wax from bees is used in the manufacture of candles.

QUESTION: ***WHAT PROPERTIES DO LIPIDS POSSES AS STORAGE COMPOUNDS?***

i) They are compact taking up little space.

ii) They are insoluble in water hence cannot be lost in solution.
iii) They are light to keep the weight to a minimum and allow buoyancy.
iv) They have a high calorific energy value.
v) They have a high hydrogen-oxygen content hence can yield a lot of water on oxidation.

PROTEINS

These are organic compounds of large molecular mass and insoluble in water. In addition to C, H and O, they always contain N, usually S and sometimes P.

Whereas there are few carbohydrates and fats, the number of proteins is limitless e.g. a single bacterium may have around 800 types of proteins while man has 10,000 types. This is because there are several amino acids which may join in different patterns hence forming the various types of proteins.

Proteins are specific to each species hence determine the character of the species.

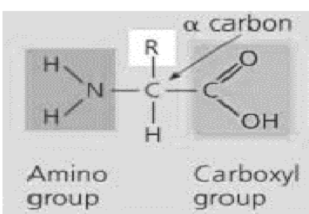
Proteins are not stored in the organism except in eggs and seeds where they are used to form new tissues. Proteins form the structural basis of all living cells.

Their building blocks are the amino acids.

AMINO ACIDS

These are groups of many chemicals of which around 20 occur in proteins. They contain an amino group (NH2) and a carboxyl group (COOH). Most amino acids have one of each and are therefore neutral but a few have more amino groups than carboxyl making them alkaline or may have more carboxyl than amino groups making them acidic.

Structure of amino acids

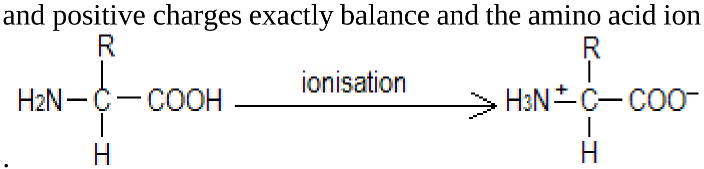


Where R is a variable

Amino acids are soluble in water and ionize to form ions.

The carboxyl end of the amino acid is acidic in nature. It will ionize in water to give H^+. This will make the COOH group negatively charged.

The amino end (NH2) is basic in nature. It attracts the H^+ in solution making it positively charged. The ion is now dipolar i.e. having a negative and a positive pole. Such ions are called zwitter ions i.e. the negative and positive charges exactly balance and the amino acid ion has no overall charge i.e



. Zwitter ion (no overall charge)

Therefore in acidic solutions, an amino acid acts like a base and in alkaline solutions, it acts as an acid. In neutral conditions found in the cytoplasm of most living organisms, the amino acid acts as both.

Amino acids therefore show both acidic and basic properties i.e. they are amphoteric. The overall charge of the amino acid depends on the pH of the solution.

At some characteristic pH, the amino acid has no overall electric charge i.e. it exists as a zwitter ion. This

pH is called the isoelectric point of an amino acid.
If the pH falls below the iso-electric point i.e. the solution becomes more acidic, H+ are taken up by the carboxyl ion. This reduces the concentration of the H+ in solution making the solution less acidic and the amino acid gains an overall positive charge.
If the pH rises above the iso-electric point i.e. it becomes less acidic or more alkaline, hydrogen ions are lost by the amino group. This increases the concentration of free H+ in the solution making it more acidic and the amino acid gains an overall negative charge. Therefore being amphoteric, amino acids are buffers.
NOTE: a buffer solution is one which resists the tendency to alter its pH even when small amounts of acid or base are added to it.

Questions: how do amino acids act as buffer solutions?

Amino acids make the proteins serve as buffers. The amphoteric nature of amino acids is useful biologically as it means that they serve as buffers in solution resisting changes in PH. The buffer action depends on concentration of hydrogen ions. When an acid is i.e more hydrogen ions(H+), the hydrogen ions(H+) are accepted by the amino acids making them positively charged hence reducing the H+ concentration of the solution. When a base is added, or a decrease in H+ concentration of the solution, the amino acid releases H+ to the solution.

Types of amino acids **1. Essential Amino acids**	**2. Non-Essential amino acids**
These are amino acids that cannot be synthesized by the body and therefore got from the diet that the organism feeds on. They include: • Histidine • Isoleucine • Leucine	These are amino acids that are synthesized by the body through a process called transamination. They include: • Tyrosine • Alanine • Glycine • Serine
• Proline • Phenylalanine • Valine • Arginine • lysine • Methionine • Tryptophan	• Theonine • Cystine • Cystein • Aspartic acid • Glutamic acid • Asparagine
Proteins can be classified into: **first class proteins** which contain all the essential amino acids e.g. from beans and **second-class proteins** which are deficient of one or more essential amino acid.	

Protein structures

There are 3 main protein structures i.e. primary structure, secondary structure and tertiary structure.

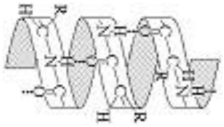
1. Primary structure:

It is a sequence of amino acids in a polypeptide chain. It is made up of 2 polypeptide chains held together by di- sulphide bridges. The sequences of amino acids of a protein dictate its biological functions. Examples of primary structures are insulin and lysosomes.

2. Secondary structure:

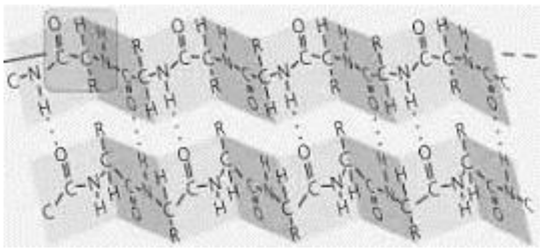
This involves folding or twisting of the polypeptide chains into a spiral shape or beta-pleated shape. It is maintained by many ionic bonds which are formed between neighbouring COO^- and $NH3^+$ groups.

(i) **Spiral shape**; proteins in this shape take the form of an alpha helix. They are hard but stretchable. The helical structure is maintained by hydrogen bonds. Examples of such proteins include; keratin, collagen, etc. keratin is found in hair, beaks, nails, feathers, claws, horns, etc.



(ii) **Beta pleated sheets:**

These result from the folding of two or more adjacently joined parallel polypeptide chains which are stabilized by hydrogen bonds. They then get arranged into sheets. Proteins with this structure are very stable and rigid (unstretchable) e.g fibroin protein found in silk. Beta pleated sheets have a flat zig zag structure. They commonly occur in insoluble structural proteins but also in parts of some soluble proteins.



Tertiary structures

The polypeptide chain coils extensively forming a compact globular shape. This structure is maintained by interaction of the four types of bonds i.e. ionic, hydrogen, di sulphide bonds and hydrophobic interactions.

The hydrophobic interactions are quantitatively the most important and occur when a protein folds to shield the hydrophobic side groups from the aqueous surrounding and at the same time exposing hydrophobic side chains.

Quaternary structure

It is a combination of several polypeptide chains clumped together and associate with non-protein parts to form complex proteins e.g. in haemoglobin.

Types of proteins

1. **Fibrous proteins (**plays structural roles**)**

These form long chains which may run parallel to one another being linked by cross bridges. They are very stable molecules and have structural roles within the organism e.g. collagen in made of such proteins.

It has a primary structure which is a repeat of tri peptide sequence (glycine, proline and alanine) and forms a long unbranched chain.

2. **Globular proteins (**plays metabolic roles**)**

They have a highly irregular sequence of amino acids in their polypeptide chains. Their shape is compact and globular. All enzymes are globular proteins. Others include hormones and haemoglobin.

3. **Conjugated proteins**

These are proteins which incorporate other chemicals within their structure. The non-protein part is the prosthetic group and plays a virtual role in the functioning of the proteins e.g.

Name of protein	Where it is found	Prosthetic group
Haemoglobin	Blood	Haem (iron)
Mucin	Saliva	Carbohydrate
Casein	Milk	Phosphoric acid
Cytochrome oxidase	Electron carrier path way	Copper
Nucleoplasm	Ribosomes	Nucleic acid

QUESTION: *HOW DOES THE MOLECULAR STRUCTURE OF PROTEINS RELATE TO THEIR ROLES?*

i) Some proteins have a structural function, these are fibrous proteins with a secondary structure insoluble in water and physically tough e.g. collagen in connective tissues, bone, tendons and cartilage. Other structural proteins include keratin in feathers, nails, hair, horns, beaks and skin.

ii) Some proteins function as enzymes. These have a globular structure and are soluble in water e.g. digestive enzymes like pepsin, respiratory and photosynthetic enzymes.

iii) Some proteins function as hormones regulating metabolic processes. These are globular and soluble in water e.g. insulin which regulates metabolic activity.

iv) Some proteins functions as respiratory pigment. These are globular proteins with a quaternary structure that increases their surface area for transport or storage of respiratory gases e.g. haemoglobin which transports oxygen in blood and myoglobin that stores oxygen in muscles.

v) Some proteins are involved in transport and are globular with primary or tertiary structures e.g. serum albumen that transports fatty acids and lipids in blood.

vi) Some proteins are involved in immunological responses hence protecting the body. These are globular e.g. antibodies, fibrinogen and thrombin.

vii) Some proteins are contractile e.g. they are fibrous with a secondary structure e.g. myosin and actin filaments in muscles.

viii) Storage proteins are toxins and soluble and water with a globular structure e.g. snake venom, bacteria toxins, etc.

ix) Some proteins are insoluble in water e.g. ovalbumin that occurs in egg white, casein in milk, etc.

x) Globular proteins form colloidal suspensions that hold molecules in position within cells e.g. proteins in the cytoplasm of most cells where they are soluble in water and have a large surface area.

xi) Globular proteins in blood are buffers since they are soluble in water.

Differences between globular and fibrous proteins

Globular	Fibrous
• Soluble in water • Easily denatured by very high temperature • Functional in nature • Tertiary proteins • Non identical polypeptide chain length • Consist of compact and spherical molecules.	• Insoluble in water • Not easily denatured by high temperature • Structural in nature • Secondary proteins • Identical polypeptide chain length • Consist of long fibrous molecules.

Denaturation of proteins

The dimensional structure of the protein is due to weak ionic and hydrogen bonds. Any agent which breaks these bonds causes the three dimensional shape to be changed to a more fibrous form. This process is known as denaturation.

In case the actual sequence of the amino acid is not altered but only the overall shape of the molecule is changed.

Factors causing protein denaturation

Factor	Explanation	Example
1. Heat	Causes the atoms of the protein to vibrate more thus breaking the hydrogen and ionic bond.	Coagulation of albumen (egg white becomes more fibrous).
2. pH	When the pH is adjusted to the normal isoelectric point for protein, its net charge will be zero (zwitterion). If the pH is lowered far below the isoelectric point, the protein will lose its negative charge and contain only positive charges. The like charges will repel each other and prevent the protein from aggregating as readily, preventing formation of amine bonds.	
3. Acids	Addition of hydrogen ions in acids combine with COO^- of amino acids and form COOH ionic bonds are hence broken.	Souring of milk by acid and lowering pH of casein making it insoluble.
4. Alkalis	Reduced number of H^+ cause NH^+ group to loose H^+ to form NH_2 therefore ionic bonds broken.	Souring of milk by alkalis.
5. Inorganic chemicals	Ions of heavy metals e.g. mercury and silver combine with COO^- groups destructing the ionic bonds.	Enzymes are inhibited by being destructed in presence of ions e.g. cytochrome oxidase.
6. Organic chemicals	Organic solvents alter hydrogen bonding with a protein.	Alcohol denatures certain bacterial proteins. This is what makes it useful for sterilization.

7. Mechanical force	Physical movement can break hydrogen bonds.	On stretching a hair, the hydrogen bonds in the keratin helix is extended and hair stretches.

FUNCTIONS OF PROTEINS

VITAL ACTIVITY	PROTEIN EXAMPLE	FUNCTION
1. Nutrition	• Digestive enzymes e.g. trypsin, amylase, etc. • Fibrous proteins in grana lamellae • casein	• catalyses, hydrolysis of proteins to peptides. • Helps to arrange chlorophyll molecules to receive unlimited light. • Assists in transporting of food in filter feeder. • Storage of proteins in milk.
2. Respiration and transport.	• Haemoglobin. • Myoglobin • Prothrombin/fibrinogen • Antibodies.	• Transport of oxygen. • Stores oxygen in muscles. • Required for blood clotting. • Essential for defense.
3. Growth	Hormones e.g. thyroxine	Controls growth and metabolism.
4. Excretion	Enzymes e.g. urease	Catalyzes reaction in ornithine cycle and helps in protein break down and urea formation
5. Support and movement	Actin/myosin	Makes it easy for muscle contraction.
	Collagen	Gives strength with flexibility in tendons and cartilage.
	Keratin	Tough for protection e.g. in scales, claws, nails, hooves, etc.
	Sceleratin	Provide strength in insect exo-skeleton
6. Sensitivity and co-ordination.	Hormones e.g. insulin	Control of blood sugars
	Vasopressin	Control of blood pressure
	Rhodopsin	Visual pigments in retina.
8. Reproduction	Hormones e.g. prolactin	Induces milk production in mammals.
	Chromatin	Gives structural support to chromosomes.
	Chitin	Storage of proteins in seeds which nourishes the embryo.
	Keratin	Forms horns and anthers which are used for sexual display.

ENZYMES

Enzymes are biochemical catalysts made up of globular proteins. An enzyme is always associated with a non-protein component known as co-factor which is tightly bonded to the enzyme.

Enzymes are organic compounds protein in nature that speed up the rate of biochemical reactions in the body of an organism and remains unchanged at the end of the reaction.

Importance of enzymes

The rate at which some reactions occur in the body without enzymes is too slow to sustain life. Enzymes therefore ***speed up the rate of the reaction without changing the product formed and the nature of reaction*** i.e. an enzyme cannot make a reaction that would not occur to take place and it cannot make an endothermic reaction exothermic but only ensures that products are formed in the shortest time possible.

They also control metabolic processes hence promoting normal body functions.

Mechanism of enzyme action

Each enzyme has a unique surface structure which provides a precise position known as active site, at which the substrate can join the enzyme molecules to form an enzyme substrate complex.

This infinite contact is maintained until the reaction is complete. The precise and specific fit between enzyme and substrate is sometimes compared with the lock and key mechanisms. There are two theories put forward to describe the mechanism of enzyme action i.e.

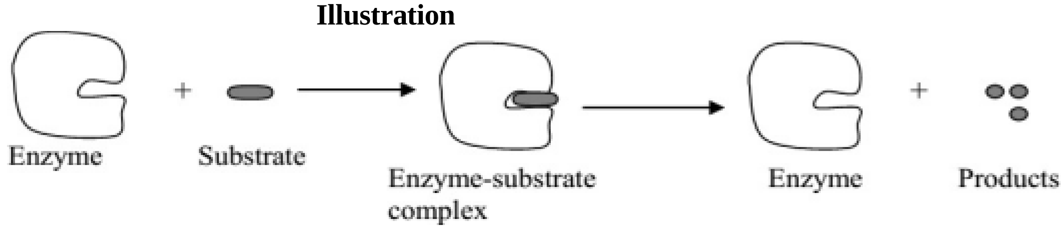
(i) Lock and key hypothesis
(ii) Induced fit hypothesis

The lock and key mechanism

The widely accepted mechanism by which enzymes are known to work is the "**key and lock" theory**.

The theory suggests that the enzyme has a specific region known as the active site where the substrate fits like a key fits in a lock. The substrate must have a complementary shape to the active site of the enzyme. In this theory the key is analogous to the substrate and the lock to the enzyme. When the substrate combines with the enzyme, an enzyme- substrate complex is formed. This breaks down to release the products and the enzyme, which can pick other substrates.

Illustration



Advantages of the lock and key hypothesis

1. It explains why enzymes are specific in action i.e. only substrates with complementary shapes to the active site fit into the active sites and are converted to products.
2. It explains why the rate of enzyme controlled reaction is affected by substrate concentration. If all the active sites are in use, no more substrates a can fit or occupy the active site hence the rate is constant.
3. It explains why and enzymes can be inhibited.
4. It explains why enzymes are able to lower the activation energy in a chemical reaction.

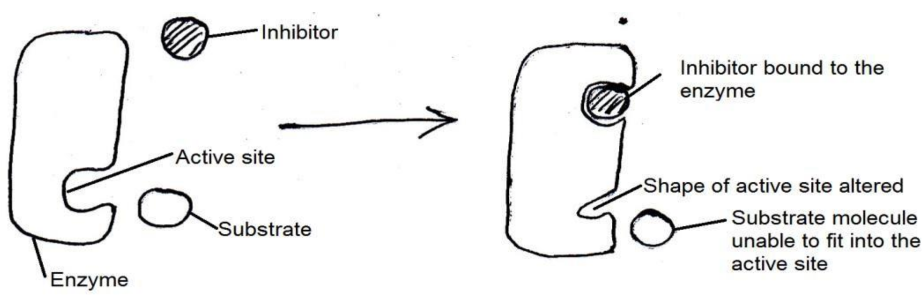
The induced fit theory

The bonds between the amino acids of the active site of the enzyme are relatively flexible. When the substrate combines with an enzyme, the active site may mould into the shape of the substrate. The theory says that when the substrate molecule enters the active site, it causes the enzyme to change its shape so that the two molecules fit together more tightly. The induced fit hypothesis is believed to make the substrate molecules more active because as the active site changes shape, it presses on the substrate molecule exposing the weak bonds.

Enzyme inhibitors

Enzymes may be inactivated by substrates called inhibitors which interfere with catalytic processes. This effect may be produced in several ways.

1. Active sites at the enzyme may be blocked by the formation of the enzyme inhibitor complex. This is known as ***competitive inhibition*** and occurs when inhibitor molecule is structurally similar to the usual substrate of the enzyme. The reaction can be reversed if the substrate concentration is increased.
2. The inhibitor may react irreversibly with the enzyme to form an inactive non-enzymatic end product. A small concentration of heavy metal ions combine permanently with the enzyme and completely inhibit it.
3. The inhibitor may alter the shape of the enzyme at its point of activity so that the enzyme substrate complexes cannot form. This is known as **non-competitive enzyme inhibition**. These attach themselves not to the active site of the enzyme but elsewhere on the enzyme molecule. These cause breakage of some bonds in the enzyme molecule leading to alteration of the 3 dimensional structure and hence the shape of the enzyme molecule.
   Change in the shape of the enzyme molecule leads to change of the shape of the active site. Therefore the substrate can no longer fit in the active site.



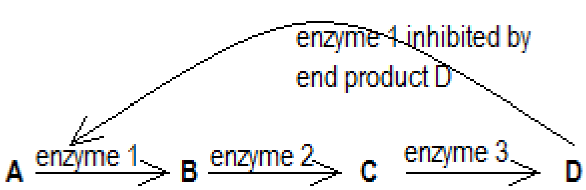
An increase in the substrate concentration does not change the rate of reaction. This is because the inhibitor alters/changes the shape of the enzyme and that of the active site permanently whenever it comes into contact with the enzyme hence it leaves the active site non complementary. Non competitive inhibitors are mostly non reversible inhibitors. Non competitive inhibitors include; heavy metals (mercury, lead, silver, etc), cyanide, nerve gas, insecticides, herbicides, etc.

Importance of inhibitors

(i) They can be used in medicine and agriculture
(ii) They control metabolic pathways by regulating the different stages in them
(iii) They provide important information about the shapes and properties of enzymes.

2. End product inhibition

This takes place in some metabolic pathways when the end product combines with the first enzyme controlling the first step of the pathway for its production so that further formation of the end product is slowed or stopped. This is an example of negative feedback which is important in regulation of body processes. The end product acts as an allosteric inhibitor.



These are enzymes that occur in two forms, i.e. active and inactive.

The inactive form is shaped in such a way that the substrate will not fit into its active sites. Therefore for such enzymes to work, it must be transformed into the active form.
Allosteric enzymes can be inhibited by molecules which do not combine with the active site but with the other parts of the enzyme. In this case, the inhibitor prevents the enzymes from changing into the active form, and substrates which bring about this are known as allosteric inhibitors.

Co-factors

Co-factors are non-protein components required by enzymes for their efficient functioning.
In some instances an enzyme must be associated with smaller molecule in order to function properly. There are three types of co-factors:

i) **Inorganic ions**; e.g salivary amylase activity is increased by the presence of chloride ions.
ii) **Prosthetic groups**; these are non-protein organic molecules tightly bound to the active site e.g. FAD, haem, etc.

Coenzymes; non-protein organic groups loosely associated with the enzyme, NAD and ATP. Prosthetic groups and coenzymes act as carriers of groups of atoms.

Classification of enzymes

Each enzyme is given two names; a synthetic name based on the six classification groups. The trivial names are derived by the following;

(i) Start with the name of the substrate on which the enzyme acts e.g. Succinate.
(ii) Add the name of the type of reaction which is catalysed e.g. dehydrogenation.
(iii) Convert the end of the last word to an …"ase" suffix e.g. Succinate Dehydrogenase.

Enzyme group	Type of reaction catalysed	Examples of enzymes
1. Oxidoreductases	Oxidation and reduction reaction	Dehydrogenase and oxidase
2. Transferases	Transfer of chemical groups	Transaminase and phosphorylase
3. Hydrolases	Hydrolysis reactions	Maltase, amylases, lipase, peptidase
4. Lyases	Addition or removal of a chemical group by hydrolysis	decarboxylase
5. Isomerases	Arrangement of groups within the molecule	Isomerases, mutases
6. Ligases	Formation of bonds between two molecules using energy derived from the breakdown of ATP	synthetases

Enzymes are classified depending on the type of reaction they catalyze. The following are some of the classes of enzymes.

1) **Isomerase;** these catalyze reactions involving isomerism
2) **Phosphorylases**; these catalyze reactions involving addition of a phosphate
3) **Hydrogenases;** these catalyze reactions involving addition of hydrogen.
4) **Dehydrogenase;** these catalyze reactions involving removal of hydrogen.

5) **Kinases;** these catalyze reactions involving movement of molecules from one area to another.
6) **Carboxylases;** these catalyze reactions involving addition of Carbon dioxide.

Nomenclature of enzymes

Enzymes are named by adding a suffix “ase” to their substrates. A substrate is a substance, which the enzyme acts upon, or simply it is the raw material for the enzyme.

Examples of enzymes and their substrates

Enzyme	**Substrate**
Peptidase	Peptides
Lipase	Lipids
Maltase	Maltose
Sucrase	Sucrose
Lactase	Lactose
Cellulase	Cellulose

Some enzymes however retained their names they had before this convention. Such enzymes include pepsin and trypsin.

Sometimes the enzymes digesting carbohydrates are generally called carbohydrases and those digesting proteins as proteases.

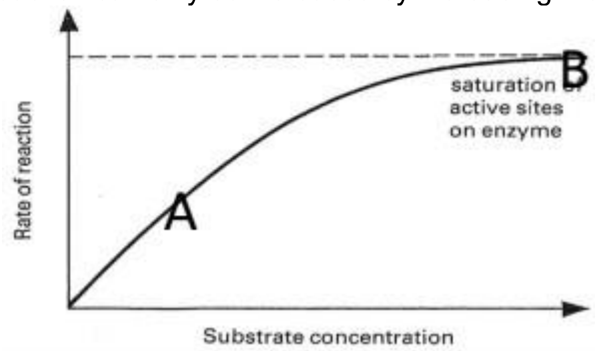
PROPERTIES OF ENZYMES

1) They are all protein in nature.
2) They are specific in their action i.e. they catalyze specific food i.e. Maltase on Maltose.
3) They speed up the rate of chemical reactions (they are catalysts).
4) They are effective even in small amounts.
5) They remain unchanged at the end of the reaction.
6) They are denatured by high temperatures since they are protein in nature and are inactivated by low temperatures.
7) They are inactivated by inhibitor chemicals (poisons e.g. cyanide).
8) They work at a specific PH. (either acidic or alkaline).
9) Their reactions are reversible.
10) Their activity can be enhanced by enzyme activators e.g. chloride ions activate amylase.

FACTORS AFFECTING THE RATE OF ENZYME CONTROLLED REACTIONS

1. Substrate concentration;

The rate of enzyme controlled reaction increases with increase in substrate concentration until all the active sites of the enzyme are occupied by the substrate molecule. At this point the rate of reaction can only be increased by increasing the enzyme concentration.



A: The rate of reaction increases with enzyme concentration because there are free active sites into which more substrates fit increasing the rate of product formation

B: The rate of reaction is constant because all the enzyme active sites are occupied by substrates. Any more substrate molecules added will have no active sites to be occupied hence constant rate of reaction. The limiting factor at this point is the low enzyme concentration.

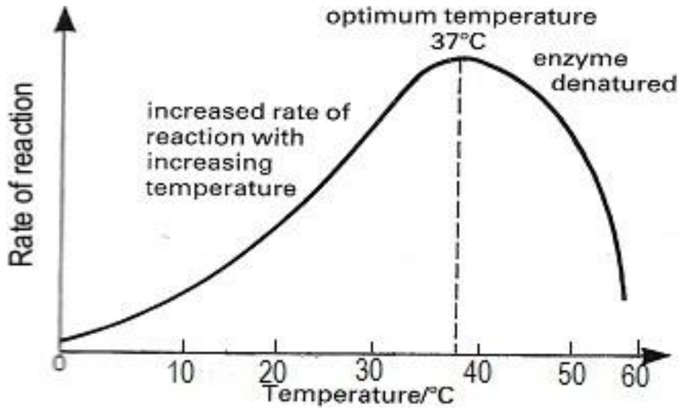
2. Temperature;

Within the physiological range (4^0c-40^0c) the rate of the enzyme controlled reaction increases with increase in temperature. This is because temperature increases the kinetic energy of reacting molecules leading to more collisions between the enzyme and substrate molecules.

Beyond 40^0c, the rate of the reaction decreases with increase in temperature due to Denaturation of the enzyme molecules.

Very high temperatures lead to breakage of some bonds that maintain the enzyme structure. As a result, the 3 dimensional structure of the enzyme is altered leading to a change in the shape of the active site.

The shape of the active site at this point can no longer fit in it hence no enzyme reaction.



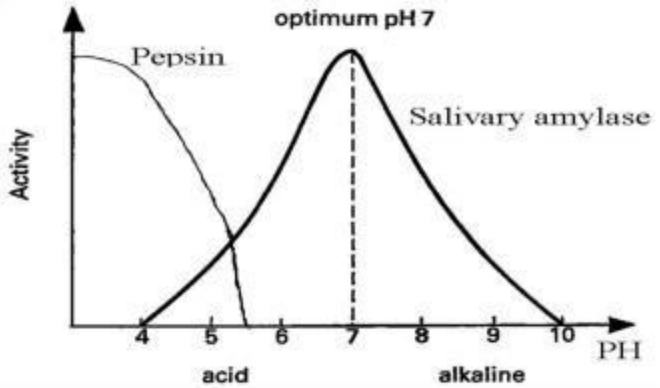
3. **Enzyme concentration;**

Provided there is an excess of substrate molecules, the rate of an enzyme controlled reaction increases with increase in enzyme concentration. This is because the number of active sites increases which leads to increase in number of substrate molecules that fit into and occupy the active sites hence increase in the rate of product formation.

4. **PH of the medium;**

All enzymes work efficiently within a particular PH range. However there is an optimum PH for each enzyme. Any deviation from the optimum PH results in Denaturation of the enzyme hence decrease in the rate of reaction.

Enzyme	**Optimum PH**
Pepsin	2.00
Sucrase	4.50
Enterokinase	5.59
Salivary amylase	4.80
Catalase	7.60
Chymotrypsin	7.00-8.00
Pancreatic lipase	9.00



1. **Enzyme inhibitors;**

These lower the rate of enzyme controlled reactions or they may stop enzyme action altogether.

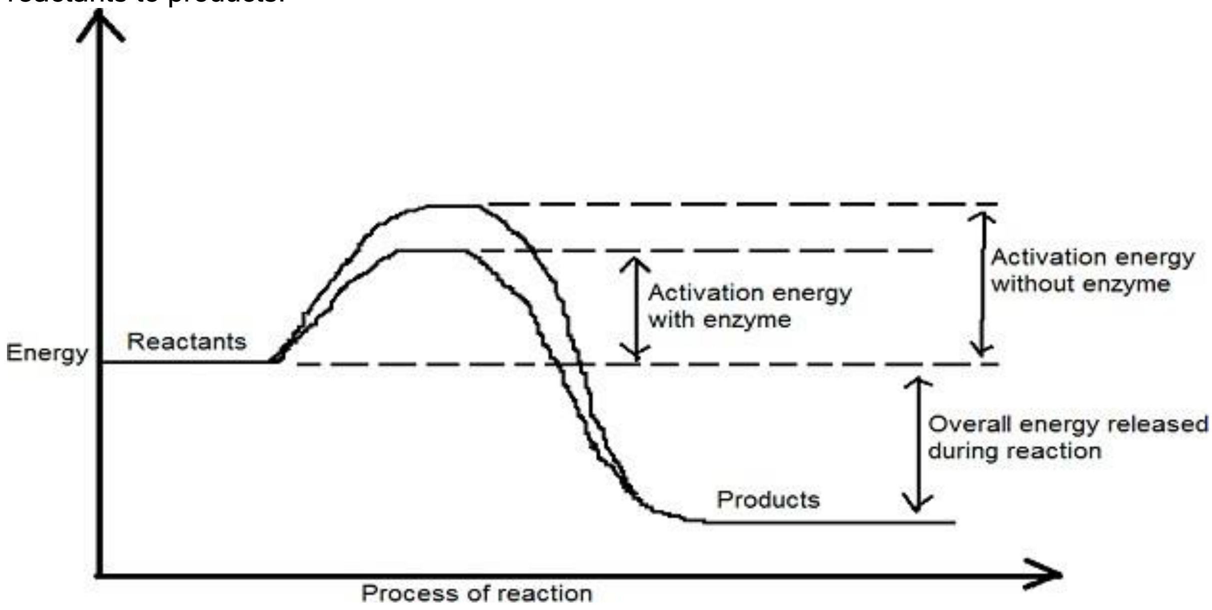
2. **Presence of cofactors;**

For some enzymes, the rate of enzyme controlled reaction depends on cofactors.

How enzymes work

Enzymes work by lowering the activation energy to allow the reaction to take place. Activation energy is the energy barrier that has to be overcome before a reaction takes place. Since heat is usually the source of energy, enzymes make it possible for reactions to take place at low temperature.

For enzymes to work, they lower the activation energy so that there is easy conversion of reactants to products.



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