

TOPIC 1

CELL BIOLOGY

COMPETENCY: The learner evaluates cells and tissues by analyzing and relating structure to function as a basis of medical research in order to improve health.

Learning outcomes:

- a) Analyze 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)
- b) Operate a light microscope to observe tissues from plants and animals under different magnifications
- c) Analyze the ultrastructure of animal, plant and bacterial cells and the plasma membrane to distinguish prokaryotic and eukaryotic cell characteristics.
- d) Analyze the structures of plant (parenchyma, collenchyma, sclerenchyma, xylem, and phloem) and animal (epithelial, cardiac, areolar, fibrous and skeletal) tissues to assess their roles in physiological processes, disease diagnosis, and levels of organization.

TABLE OF CONTENTS

CHEMICALS OF LIFE.....	2
MICROSCOPY.....	21
CYTOLOGY.....	24
DIVERSITY OF TISSUES.....	38
LEVELS OF ORGANISATION.....	62

Sub-topic 1

CHEMICALS OF LIFE

Living organisms are built and sustained by a wide variety of chemical substances collectively known as chemicals of life. These molecules form the structural framework of cells, provide energy for biological processes and regulate countless reactions that maintain life.

The major groups – carbohydrates, lipids, proteins, nucleic acids and water.

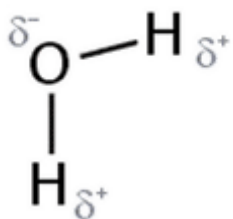
Epistemic cue: Biochemistry

WATER

Water is the most important inorganic molecule in biology. It constitutes about 60% of human body with unique chemical and physical properties to sustain life.

Structure of water molecule

Water is a simple molecule consisting of one oxygen atom bonded to two different hydrogen atoms. Because of the higher **electronegativity** of the oxygen atom, the bonds are polar covalent (**polar bonds**). The oxygen atom attracts the shared electrons of the covalent bonds to a significantly greater extent than the hydrogen atoms. As a result, the oxygen atom acquires a partial negative charge (δ^-), while the hydrogen atoms each acquire a partial positive charge (δ^+) hence a polar molecule. The molecule adopts a bent structure (V-shaped) because of the two lone pairs of electrons on the oxygen atom.



structure of water

Properties of water with their biological significance.

Property	Biological significance
Water is a polar molecule	Water is an excellent solvent for polar substances. These include ionic substances like salts, which contain charged particles (ions), and some non-ionic substances like sugars that contain polar groups (slightly charged) such as the slightly negative hydroxyl group (-OH). This property enables provides a medium for chemical reactions.
High surface tension	Water molecules have a much stronger attraction to other water molecules than to molecules in the air. At an air—water interface (for example, on the surface of a pond), a water molecule on the surface forms hydrogen bonds with other water molecules around and below it, but not with air molecules above it. The unequal distribution of hydrogen bonds produces a force called surface tension . This causes the water surface to contract and form a surprisingly tough film. Surface tension is a measure of how difficult it is to stretch or break a liquid surface: water

	has a greater surface tension than most other liquids. This enables many organisms to settle on water
Water is cohesive and adhesive	The attraction between molecules of different substances is called adhesion . The attraction between molecules of similar substances is called cohesion . Hydrogen bonding gives water considerable cohesive properties. Thus, water molecules stick together and also stick to other surfaces, such as the sides of its container. This attraction between molecules enables water to enter and move along very narrow spaces, a process called capillarity. The high cohesion and adhesion of water molecules is important in cells and in transport of water through xylem in plants
Density of water	The density of water decreases below 4°C and ice therefore tends to float. Since ice floats, it forms at the surface first and the bottom last. Ice insulates the water below it, thus increasing the chances of survival of organisms in the water. This is important in cold climates and cold seasons, and must have been particularly so in the past, such as during Ice Ages. Also, water is denser than air hence supporting large animals like whales.
Viscosity of water	Water has a low viscosity, flows freely, can slide easily over each other, this enables it to flow freely through vessels e.g. blood in blood vessels.
Water is colorless	The colorless nature of water makes it transparent. This enables transmission of sunlight through aquatic environments so that they can photosynthesize and get clear vision
Water is incompressible	This enables water to form an important structural property, where it forms a hydrostatic skeleton e.g. in earthworms and turgor pressure in herbaceous plants.
Water is a liquid at room temperature	This provides a suitable environment for reactions inside a cell and aquatic organisms as a habitat.
Water has high tensile strength	Caused by hydrogen bonds between its molecules. It therefore continuously flows in columns through the xylem up to the top of a tree during transpiration without breaking.

Biological Importances of water

All organisms

- Structure- high water content of cells (70-95%)
- Solvent and medium for diffusion
- Reagent in hydrolysis
- Support for aquatic organisms
- Fertilization by swimming gametes
- Dispersal of seeds, gametes and larval stages of aquatic organisms, and seeds of some terrestrial species e.g. coconut

Plants

- Osmosis and turgidity (important in many ways, such as growth (cell enlargement), support, guard cell mechanism)
- Reagent in photosynthesis
- Transpiration
- Translocation of inorganic ions and organic compounds
- Germination of seeds — swelling and breaking open of the Testa and further development

Animals

- Transport in blood vascular system, lymphatic system, excretory system
- Osmoregulation
- Cooling by evaporation, such as sweating, panting Lubrication, as in joints
- Support — hydrostatic skeleton of e.g. annelid worms
- Protection, for example lachrymal fluid (tears), mucus
- Migration in ocean currents

Test for water

- Water turns **white** anhydrous copper (II) sulphate **blue**
Also
- Water turns **blue** cobalt (II) chloride paper **pink**

LIPIDS

Lipids are a diverse group of water-insoluble organic molecules but soluble in organic solvents like ethanol. They contain carbon, hydrogen and oxygen though the proportion of oxygen is lower than that in carbohydrates.

CONSTITUENTS OF LIPIDS

a) Fatty acids

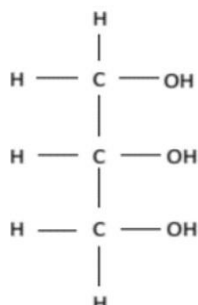
Fatty acids contain the acidic group -COOH (the carboxyl group) and are so named because some of the larger molecules in the series occur in fats. They have the general formula R. COOH where R is hydrogen or a group such as -CH₃, -C₂H₅.

Fatty acids may be **saturated** or **unsaturated**. In a **saturated fatty acid**, each carbon atom in the hydrocarbon chain is linked to a carbon atom on either side and also to two hydrogen atoms. The carbon atoms are bonded to the maximum number of other atoms. Saturated fatty acids have only **single bonds** in the hydrocarbon chain. This makes the chain relatively straight so that triglycerides that contain only saturated fatty acids are able to pack closely together. Thus, triglycerides of saturated fatty acids tend to be **solid ('fats')** at room temperature e.g. butyric (butter fat), stearic (CH₃(CH₂)₁₆COOH) comprised in animal or vegetable oil

In an **unsaturated fatty acid**, such as **oleic acid** (CH₃(CH₂)₇CH=CH(CH₂)₇COOH) a major constituent of olive oil, the carbon atoms in the hydrocarbon chain are not bonded to the maximum number of other atoms. Two or more carbon atoms have **double bonds** between them. Such lipids with unsaturated fatty acids are

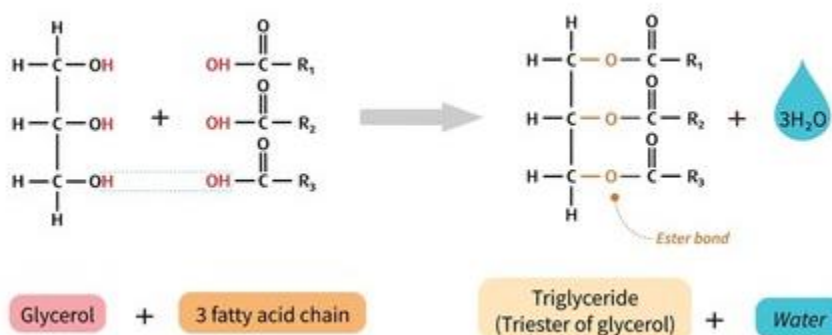
liquids at room temperature i.e. **oils** because the hydrocarbon are loosely packed. This means the attractions between the molecules are very weak, so the substance is a liquid rather than a solid. Many properties of lipids are determined by this tail, including their solubility in water. The tails are said to be hydrophobic, meaning water hating.

b) **Glycerol:** this is an alcohol that contains three carbon atoms each linked to the hydroxyl group



FORMATION OF LIPIDS

Glycerol has 3 hydroxyl (-OH) groups, all of which can condense with a fatty acid. Usually, all three undergo condensation reaction as shown in figure below and lipid formed is called **triglyceride**.



FORMS OF LIPIDS

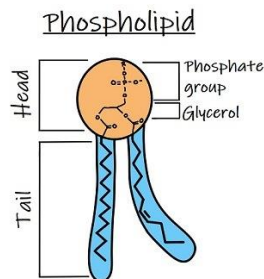
1. Simple lipids: composed of only glycerol and fatty acids only e.g. fats, oils, waxes etc.
2. Conjugated lipids: contain fatty acids and glycerol with other additional components such as phosphate group, sugar or protein. They include;

➤ **Phospholipids**

Forms a major part of cell membranes including the myelin sheath around nerve fibers.

Phospholipids consist of glycerol attached to two (not three) fatty acid chains. The third hydroxyl group of glycerol molecule combines with phosphoric acid to form a polar phosphate group.

It has a polar tadpole structure with the phosphate group forming the head and the fatty acid a double tail. The polar head is strongly attracted by water (**hydrophilic**) and the non-polar tail being made of hydrocarbon chain is oily and therefore, repelled by water (**hydrophobic**) hence said to be **amphiphilic**.



- **Glycolipids**
Are associations of lipids with carbohydrates. The carbohydrate forms the polar head to the molecule and glycolipids like phospholipids, are found in membranes. They are found in cell membrane where they act as recognition sites.
- **Steroids**
These contain four rings of carbon and hydrogen atoms with various side chains. Many animal hormones are steroids, including estrogen and testosterone which are made from cholesterol, a lipid which contains the same four ring structure.
- **Lipoproteins**
These are clusters of proteins and lipids all tangled up together, they act as means of transport of carrying lipids including cholesterol around in blood e.g. some lipoproteins transport dietary lipids from the small intestines to adipocytes and the liver.
- **Waxes**
Are similar to triglycerides but contain fatty acids bonded to long chain alcohols rather than to glycerol. Waxes are usually relatively hard solids at 20°C, providing protection and waterproofing on the surfaces of insects and leaves.
- **Cholesterol**
A waxy, fat-like substance made mostly by your liver but also from animal foods. (plant oils and fats are cholesterol-free). It is a raw material for the manufacture of vitamin D. It is an vital component of mammalian cell membranes, strengthening the membranes at high body temperatures.

Functions of lipids

Physiological

- Rich source of energy, lipids store more energy than similar quantities of carbohydrates due to high hydrogen proportion and many C-H covalent bonds with larger reservoir of energy when oxidized release a lot of energy.
- Solvents for fat soluble vitamins e.g. A, D, E and K
- Source of metabolic water when hydrated in respiration, this is often main source of water to desert animals, young birds.

- Insulation against heat loss since they are poor conductors of heat, hence important in temperature regulation.
- As hormones for chemical coordination e.g. oestrogen and pheromones for animal communication and scent in plants for attracting insect pollinators.

Structural

Epistemic cue: Blubber

- Constituent of adipose tissue/ subcutaneous fat layer.
- Constituent of plasma membrane as phospholipids and glycolipids and contribute to many of its properties.
- They form component of myelin sheath in neurons playing role in transmission of impulses.
- Deposited around delicate mammalian organs such as kidney which are vulnerable to knocks as shock absorbers.
- Oil secretions by terrestrial animals e.g. sebaceous glands and plant leaf surfaces help to conserve water.
- Allows buoyancy in large animals due to its low density than water e.g. whales with fat layer protection called **blubber**.

Why are Lipids better storage substances in organisms?

- Lipids do not dissolve in water because they are non-polar. This means they do not change the osmotic potential inside cells and cannot be easily washed out of cells.
- Lipids are packed tightly and take up very little space. This allows cells to store a lot more lipids than carbohydrates for the same amount of energy.
- Lipids have a high energy (calorific) value because they contain much more hydrogen than carbohydrates. When they are broken down (oxidized), they release more energy.
- When lipids are oxidized, they produce a large amount of metabolic water because of their high hydrogen content.
- Lipids have low density, so some organisms use them for storage to help them float or stay buoyant in water.
- Lipids are poor conductors of heat, which makes them good for keeping the body warm by acting as insulation.

Tests for Lipids: They are tested for using the emulsion test or Sudan III test

Test	Procedure	Observation	Deductions
Sudan III	To 1cc of test solution, add 1cc of Sudan III and shake	A turbid solution turns a red solution	Lipids present
		Turbid or colorless solution remains turbid or colorless solution	Lipids absent
Emulsion (reagents used are ethanol and water)	To 1cc of test solution, add 1cc of ethanol and shake. Then add 5 drops of water and shake.	A turbid solution turns to a cream emulsion	Lipids present
		Turbid solution remains turbid	Lipids absent

PROTEINS

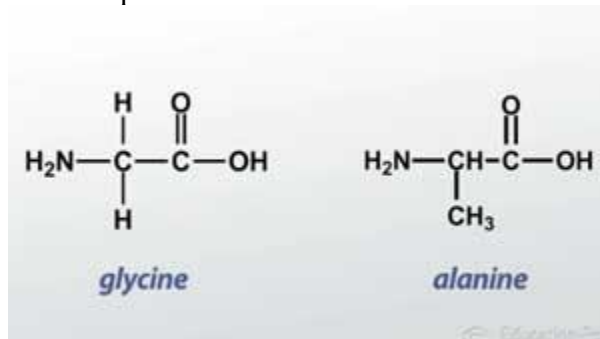
A protein is a complex organic compound composed of chains of amino acids linked by peptide bonds to form a three-dimensional structure of large molecular mass.

Protein consists of elements i.e., carbon, hydrogen, oxygen, nitrogen and sometimes sulphur or phosphorous which play a vital role in formation of body structures. (for example, about 18% of the human body is a protein)

Amino acids

These are basic units from which proteins are made. Amino acids have an **amino group** (-NH₂) and a carboxyl group (-COOH) but only differ in the R-group where R can be hydrogen e.g., in glycine or when R is -CH₃, the amino group is **alanine**.

The R-group gives the amino acid its uniqueness and it is different for all amino acids that naturally occur.



Types of amino acids

- **Essential amino acids:** Are the ones that cannot be synthesized by the body but are obtained from the diet. Proteins with this type of amino acids are largely obtained from animals e.g., lysine, arginine, leucine, histidine.
- **Non-essential amino acids:** can be synthesized by the body through the process of transamination. Mainly got from plant proteins. Their deficiency results in retarded growth e.g. alanine, aspartic acid, glutamic acid.

Amino acids as buffers.

Amino acids are **amphoteric**; that is, they have both acidic and basic properties when they dissociate in water. The acidic properties are derived from the carboxyl group which can donate proton so the molecule becomes negatively charged when in an alkaline solution. The basic properties are derived from the amino group which can take up a proton (hydrogen) so the molecule becomes positively charged in an acidic solution.

At a pH that is quite specific for each amino acid, the molecule ionizes so that different parts of the molecule have positively and negatively charged groups simultaneously. Ions like this with both positive and negative charges are called **zwitterions**.

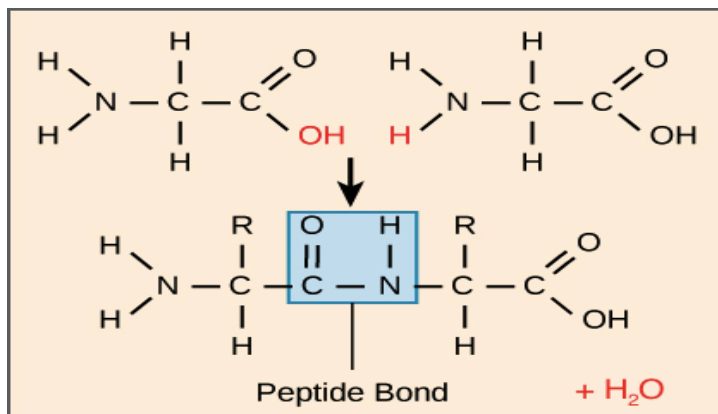
The ability to donate or receive protons causes amino acids solutions to behave as buffers. This plays a role in keeping the pH of blood and other fluids within tolerable levels.

(ref. **Advanced biology by Micheal Kent page 33**)

Building up of polypeptide (protein)

Two amino acids can combine to form a **dipeptide** by a condensation reaction between a carboxyl group of one and the amino group of the other. The resulting bond linking the two amino acids is called a **peptide bond**. Further amino acids can be added to either end of the dipeptide to form a **polypeptide chain**. Proteins consist of one or more polypeptide chains. They are polymers made up of amino acid monomers.

The polypeptide may be folded and cross-linked at intervals forming a **three-dimensional structure**.



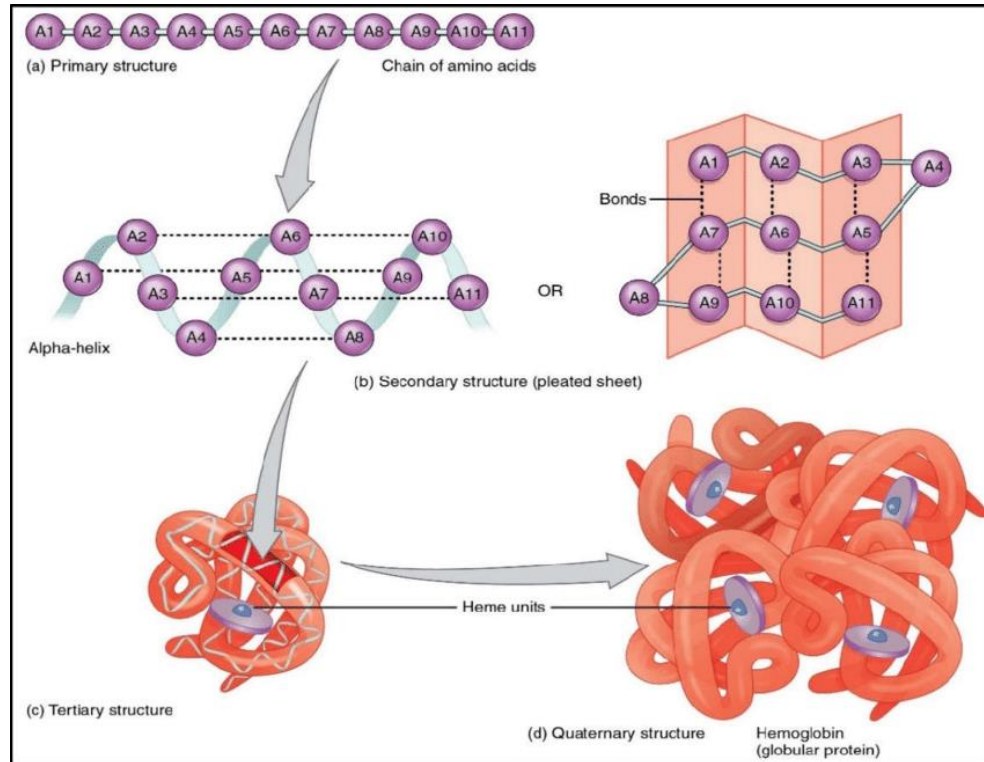
Formation of dipeptide from amino acids, linked by a peptide bond

Protein structure

Proteins consist of one or more chains of amino acids folded into a unique 3-dimensional shape. The shape is determined by up to four levels of structure; **the primary, secondary, tertiary and the quaternary structures**. Each level of structure determines the next.

- **Primary structure:**
This is the sequence of amino acids in the polypeptide chain which is specific for each protein and it is determined by the DNA in the cell from which it is made. The primary structure of a protein determines the biological functions of the protein molecule therefore substitution of a single amino acid causes a major alternation in a protein's function resulting from the formation of a faulty protein as the condition for sickle cell anemia.
- **Secondary structure:**
When amino acids join up in the polypeptide chain, a variety of forces between different parts of the molecule and hydrogen bonding cause the chains or regions of the chain either to coil into an **alpha-helix** or to fold into a **beta-pleated sheet**. Thus, coiling or folding is the protein's secondary structure.
The shape of the helix or sheet is maintained by regularly spaced hydrogen bonds each formed between the -N-H group of one amino acid and the -C=O group of another amino acid in a different part of the polypeptide chain. A single polypeptide chain may have some regions coiled into an **alpha-helix** and others folded into **beta-pleated sheets**. This provides structural roles in maintaining shapes e.g., keratin in hair, horns and myosin in muscles.
- **Tertiary structure (3D shape):**
This refers to the overall three-dimensional shape of a polypeptide chain. It conforms from the further folding and coiling of the polypeptide chains due to interactions between the R groups forming precise, compact and globular shapes.
In tertiary structures, the polypeptide may be folded and cross-linked at intervals, these cross linkages are formed by a number of bonds including hydrogen bonds, ionic bonds and Sulphur bonds.
Proteins are classified into fibrous and globular proteins based on their tertiary structures as we shall discuss later.
- **Quaternary structure:**
This consist of two or more polypeptide chains that form macromolecules/complex protein structure because of this close fitting of the polypeptide chains, hydrogen bonds tend to suffice in maintaining protein structure.

For example; **Hemoglobin** has 4 polypeptide chains of two distinct types and 4-protein haem groups whereas **collagen**, a fibrous protein consists of 3 helical polypeptides that are supercoiled to form a rope-like structure of great strength.



The four levels of protein structure

Classification of proteins

1. Based on tertiary structure

- ✓ **Fibrous proteins:** consist of parallel polypeptide chains cross-linked at intervals to form long fibers or sheets. Fibrous proteins are usually insoluble in water and physically tough, which suits them for their mainly structural functions. They include collagen (found in bones and tendons), keratin, silk (threads of spider web)
- ✓ **Globular proteins:** the polypeptide chains are tightly folded to form spherical shape. Many globular proteins are folded so that their hydrophobic groups are on the inside of the molecule and the hydrophilic groups face outwards, making these proteins soluble in water. They include enzymes, antibodies, hormones.

2. Based on composition (primary structure)

- ✓ **Simple proteins:** These are proteins consisting of only amino acids in structure e.g. albumens, globulins, histones.
- ✓ **Conjugated proteins:** These are globular proteins containing a tightly bound non-protein group called **prosthetic group** which may be inorganic called **activator** or organic called a **co-enzyme**.

Protein name	Prosthetic group	Location
Hemoglobin	Haem containing iron	blood
Mucin	Carbohydrate	Saliva
lipoproteins	Lipids	Membrane structure

Casein	Phosphoric acid	Milk
--------	-----------------	------

Properties of proteins

- They are neutral in aqueous solutions since they exist as zwitterion ions.
- They are amphoteric with both acidic carboxyl group and basic amino group.
- They are made up of large sized polypeptides.
- They form complexes with heavy metals.
- They are soluble in organic solvents.
- They coagulate when heated.
- They form precipitates and complexes with concentrated acids e.g. conc. Sulphuric acid.
- They are colloidal in nature i.e. their particles remain dispersed in solution rather than dissolving, settling or floating.

Functions of proteins

VITAL ACTIVITY	PROTEIN EXAMPLE	FUNCTION
1. Nutrition	Digestive enzymes e.g. trypsin, amylase, etc. Fibrous proteins in grana lamellae casein	<input type="checkbox"/> Catalyzes hydrolysis of proteins to peptides. <input type="checkbox"/> Helps to arrange chlorophyll molecules to receive unlimited light. <input type="checkbox"/> Assists in transporting of food in filter feeder. <input type="checkbox"/> Storage of proteins in milk.
2. Respiration and transport.	Hemoglobin. Myoglobin Prothrombin/fibrinogen <input type="checkbox"/> Antibodies.	<input type="checkbox"/> Transport of oxygen. <input type="checkbox"/> Stores oxygen in muscles. <input type="checkbox"/> Required for blood clotting. <input type="checkbox"/> Essential for defense.
3. Growth	<input type="checkbox"/> Hormones e.g. thyroxine	<input type="checkbox"/> Controls growth and metabolism.
4. Excretion	<input type="checkbox"/> Enzymes e.g. urease	<input type="checkbox"/> Catalyzes reaction in ornithine cycle and helps in protein break down and urea formation
5. Support and movement	<input type="checkbox"/> Actin/myosin	<input type="checkbox"/> Makes it easy for muscle contraction.
	<input type="checkbox"/> Collagen	<input type="checkbox"/> Gives strength with flexibility in tendons and cartilage.
	<input type="checkbox"/> Keratin	<input type="checkbox"/> Tough for protection e.g. in scale, claws, nails, hooves, etc.

	<input type="checkbox"/> Sclerotin	Provide strength in insect exoskeleton
6. Sensitivity and coordination.	<input type="checkbox"/> Hormones e.g. insulin	Control of blood sugars
	<input type="checkbox"/> Vasopressin	<input type="checkbox"/> Control of blood pressure
	<input type="checkbox"/> Rhodopsin	<input type="checkbox"/> Visual pigments in retina.
7. Reproduction	<input type="checkbox"/> Hormones e.g. prolactin	<input type="checkbox"/> Induces milk production in mammals.
	<input type="checkbox"/> Chromatin	<input type="checkbox"/> Gives structural support to chromosomes.
	<input type="checkbox"/> Chitin	<input type="checkbox"/> Storage of proteins in seeds which nourishes the embryo.
	<input type="checkbox"/> Keratin	<input type="checkbox"/> Forms horns and anthers which are used for sexual display.

Protein denaturation

Denaturation is the loss of the specific three- dimensional shape of a protein molecule. The change may be temporary or permanent, but the amino acid sequence of the protein remains unaffected. If denaturation occurs, the molecule unfolds and can no longer perform its normal biological function. A number of agents may cause denaturation as follows;

- **Heat or radiation:** e.g., infra-red or ultra-violet light. Kinetic energy is supplied to the protein cause its atoms to vibrate violently, so disrupting the weak hydrogen and ionic bonds. Coagulation of the protein then occurs.
- **Strong acids and bases:** ionic bonds are disrupted and the protein is coagulated. Breakage of peptide bond may occur if the protein is allowed to remain mixed with the reagent for a long period of time.
- **Heavy metals:** the positively charged ions of heavy metals form strong bonds with the negatively charged carboxyl groups on the R groups of protein and often disrupt ionic bonds. They also reduce the protein's electrical polarity (its overall charge and thus increase its insolubility). This causes the protein to precipitate out of solution.
- **Organic solvents and detergents:** these reagents disrupt hydrophobic interactions and form bonds with hydrophobic (non-polar) groups. This in turn causes the disruption of hydrogen bonding. When alcohol is used as a disinfectant it functions to denature the protein of any bacteria present.
- **Mechanical/physical force;** physical movement of amino acids break the hydrogen bonds in protein helix e.g. keratin in hair

ENZYMES

Enzymes are biological catalysts, protein in nature that speed up a chemical reaction but remains unchanged itself at the end. They are used to catalyze a vast number of chemical reactions in the body of living organisms.

Enzyme structure.

An enzyme is a globular protein with specific three-dimensional shape which is determined by their sequence of amino-acids.

Despite their large overall size, enzyme molecules only have a small region that is functional known as **active site**. The active site forms a hollow depression within the much large enzyme molecule. The substrate is held within the active site by bonds that temporary form between the R-group of the amino acids of the active site and groups on the substrate molecule. This structure is known as the **enzyme-substrate complex**.

Properties of enzymes

All enzymes are globular proteins

They are biological catalysts

Their presence does not alter the nature or properties of end products of the reaction

A very small amount of enzyme brings about the change of a large amount of substrate hence very efficient

They are highly specific, that is an enzyme will generally catalyze only a single reaction.

The catalyzed reaction is reversible

Their activity is affected by pH, temperature, substrate concentration and enzyme concentration.

Enzymes lower the activation energy of the reactions they catalyze.

Classification of enzymes

Enzyme group	Type of reaction catalyze	Enzyme examples
oxidoreductases	Transfer of O and H atoms between substances i.e. redox reactions	Dehydrogenases Oxidases
Transferases	Transfer of a chemical group from one substance to another	Transaminases Phosphorylases
Hydrolases	Hydrolysis reactions	Peptidases Lipases Phosphatases
lyases	Addition or removal of a chemical group other than by hydrolysis	Decarboxylases
Isomerases	The rearrangement of groups within a molecule	Isomerases Mutases
Ligases	Formation of bonds between two molecules using energy derived from the breakdown of ATP	Synthetases

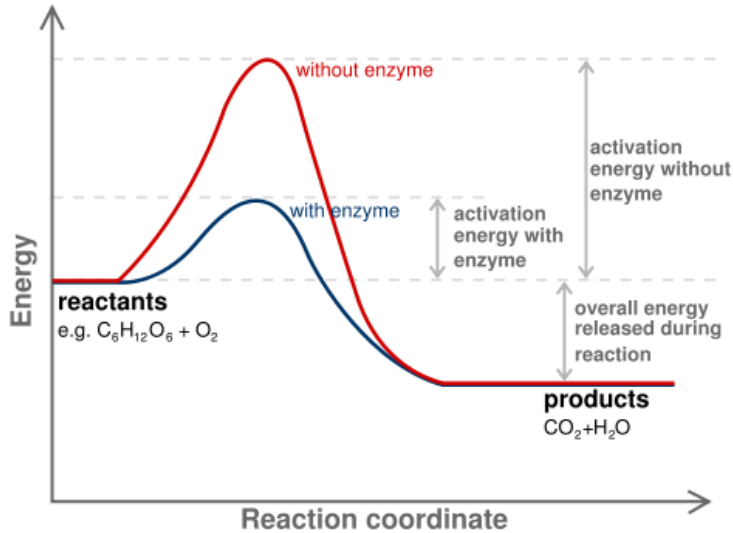
How enzymes work

Every cell carries out many thousands of metabolic reactions. Each reaction starts with reactants and ends with a product or products. Metabolic reactions usually take place in a number of steps, with each intermediate step forming an intermediate molecule on the way to the final product. The intermediate molecules are less stable (of more energy) than either the reactants or the products.

The intermediate molecule containing the most energy is called the **transition state**. Before a reaction can get underway, there must be enough energy available to convert the reactants to the transition state. This energy is called the **activation energy**.

Activation energy.

Enzymes work by reducing this activation energy so as to accelerate reactions. Most enzymes catalyze reactions by combining with the substrate of a reaction to form a series of **enzyme-catalyzed complexes**. The complex in which the substrate binds most tightly to the enzyme corresponds to the transition state. This transition state is more stable (of lower energy) than the activation energy of the reaction it catalyzes.



The lowering of activation energy by an enzyme

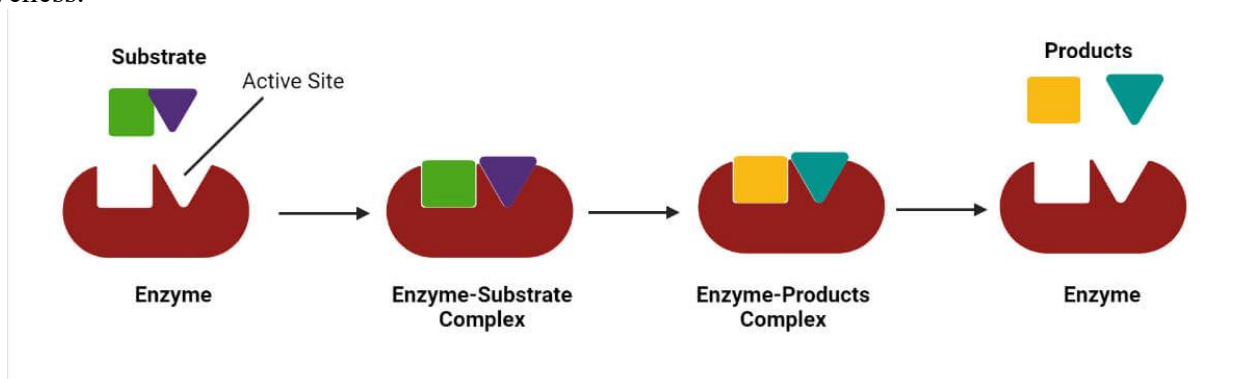
Mechanism of enzyme action

1. The lock and key theory

Most enzymes are huge globular protein molecule with a very precise shape which includes a cleft known as **active site**. In this theory the substrate fits into a rigid active site like a key into a lock.

Various type of a bond including hydrogen bonds and ionic bonds held the substrate in the active site to form an enzyme-substrate complex. Once the complex is formed, the enzyme can change the substrate by either splitting it apart or linking pieces together.

This theory explains why enzymes are specific, and why any change in shape, no matter how small, alters its effectiveness.



2. Induced fit hypothesis

In this model, the active site is able to change its shape to enfold a substrate molecule. The enzyme takes up its most effective catalytic shape after binding with the substrate. The shape of the enzyme is affected by the substrate, just as the shape of a glove is affected by the hand wearing it.

The distorted enzyme molecule in turn distorts the substrate molecule, straining or twisting the bonds. This makes the substrate less stable, reduces its potential energy, and thus lowers the activation energy of the

reaction. The reaction occurs and products are formed which no longer bind to the active site, and so move away. The flexible enzyme then returns to its original shape, ready to bind the next substrate molecule.

Enzyme cofactors

These are the non-protein parts of enzymes that are very important for many enzymes to work properly and efficiently. Without them, the enzymes either wouldn't function at all or would work much more slowly.

They include three main types:

- **Activators** (also called inorganic cofactors or metal ion activators): These are simple inorganic ions (usually metal ions or other small charged particles) that help certain enzymes do their job better. They often attach loosely or temporarily to the enzyme and help change its shape slightly or take part directly in the reaction. Examples include:
 - Calcium ions (Ca^{2+}) — needed for thrombokinase (also known as thrombin or related factors) during blood clotting to help form clots and stop bleeding.
 - Chloride ions (Cl^-) — required by salivary amylase to break down starch into sugars more effectively in the mouth.
- **Coenzymes:** These are non-protein organic molecules that are not permanently attached to the enzyme—they bind loosely and can come off after the reaction. They act like carriers or shuttles, helping to move chemical groups, atoms, or electrons from one enzyme or reaction to another. Many coenzymes come from vitamins in our diet (like vitamin B group). Examples include:
 - NAD (nicotinamide adenine dinucleotide) and FAD (flavin adenine dinucleotide) — these are very important in respiration. They pick up hydrogen atoms (or electrons) from food breakdown reactions and carry them to the electron transport chain (a series of proteins in mitochondria). There, the electrons help create energy (ATP) by passing through cytochromes and other carriers, finally combining with oxygen to form water. Without NAD and FAD, cells couldn't produce much energy from food.
- **Prosthetic groups:** These are non-protein organic molecules that are tightly bound (often permanently attached through strong bonds) to the enzyme, becoming a fixed part of its structure. They stay with the enzyme during its whole working cycle and often help transfer atoms, electrons, or groups in the reaction. Examples include:
 - Haem — this contains an iron atom at its center and is the prosthetic group in enzymes like catalase (which breaks down hydrogen peroxide) and peroxidase (which also deals with peroxides in plants and animals). Haem is also found in cytochrome c oxidase (in the electron transport chain during respiration), where it helps transfer electrons efficiently. The iron in haem can switch between Fe^{2+} and Fe^{3+} states to carry out these transfers.

ENZYME INHIBITION

This is the process by which an enzyme-controlled reaction is slowed down or stopped by a molecule known as **inhibitor**. There are two main groups of inhibitors; i.e. **competitive** and **non-competitive inhibitors**. Inhibitors of either type can be either **reversible** or **irreversible**.

Reversible inhibitors:

The effect of this type of inhibition is temporary and causes no permanent damage to the enzyme because the association of the inhibitor with the enzyme is a loose and it can easily be removed. Removal of the inhibitor restores the activity of the enzyme to normal. The enzyme inhibitor can either be competitive or non-competitive. E.g. malonic acid and cyanide.

Irreversible inhibitor:

These leave the enzyme permanently damaged and so unable to carry out its catalytic function. Heavy metal ions such as mercury (Hg^{2+}) and silver (Ag^+) cause disulphide bonds to break. These bonds help to maintain the

shape of the enzyme molecule. Once broken the enzyme molecule's structure becomes irreversibly altered with permanent loss to its catalytic functions.

Competitive inhibition

In this type, the inhibitor has a shape very similar to the substrate. Because of this similarity, the inhibitor and the substrate compete with each other to bind to the same active site on the enzyme.

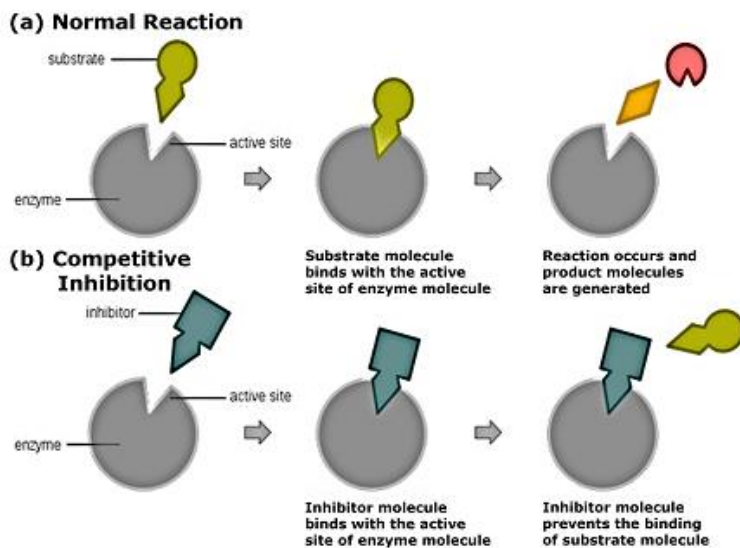
When the inhibitor binds to the active site, it forms an enzyme-inhibitor complex. This complex cannot carry out the reaction, so the substrate is blocked from attaching and the enzyme cannot produce the product. As a result, the rate of the reaction slows down, and it takes longer to form products.

However, if you increase the concentration of the substrate, the reaction rate goes up again. With more substrate molecules around, they have a better chance of finding and binding to the active sites before the inhibitor does. This means fewer active sites are occupied by the inhibitor, and more enzymes can work normally.

Examples:

- Antibiotics like penicillin stop the growth of harmful bacteria by acting as competitive inhibitors. They block enzymes that bacteria need to build their cell walls.
- Malonic acid competes with succinic acid for the active site of the enzyme succinate dehydrogenase. The enzyme-inhibitor complex (with malonic acid) is more stable than the normal enzyme-substrate complex, so it blocks the reaction effectively.

Illustration



Non-competitive inhibition

In this type, the inhibitor is not similar in shape to the substrate. It binds to a different place on the enzyme (outside the active site, often called an allosteric site), forming an enzyme-inhibitor complex.

The inhibitor does not compete with the substrate for the active site. Instead, when it attaches, it changes the overall shape of the enzyme molecule. This change distorts the active site so that the substrate can no longer fit properly or be held in the right position for the reaction. As a result, the enzyme loses its ability to catalyze the reaction.

The amount of inhibition depends only on how much inhibitor is present. Once there is enough inhibitor to bind to all the enzymes (saturation point), the reaction rate drops to zero or a very low level, and adding more substrate cannot overcome the inhibition. The substrate and inhibitor do not fight for the same spot, so extra substrate makes no difference hence the active site remains distorted.

Examples:

- Cyanide attaches to the copper prosthetic group in cytochrome oxidase. This blocks the enzyme's role in aerobic respiration (the final step where oxygen is used to make energy). This type of inhibition is usually reversible.
- Heavy metals such as mercury, silver, and arsenic cause permanent damage. They break the disulfide bonds ($-S-S-$) in the enzyme permanently, which changes the enzyme's overall 3D shape irreversibly and destroys its function.

Allosteric enzymes

Allosteric enzymes are special enzymes that help control metabolic pathways in cells. They have an extra binding site, called the **allosteric site**, which is separate from the active site where the substrate (the molecule the enzyme acts on) normally binds.

When a molecule called an **allosteric effector** binds to this allosteric site, it causes a reversible change in the enzyme's shape. This shape change affects the active site, either making it more suitable for the substrate (activation) or less suitable (inhibition), which adjusts the enzyme's activity.

Allosteric effectors can be:

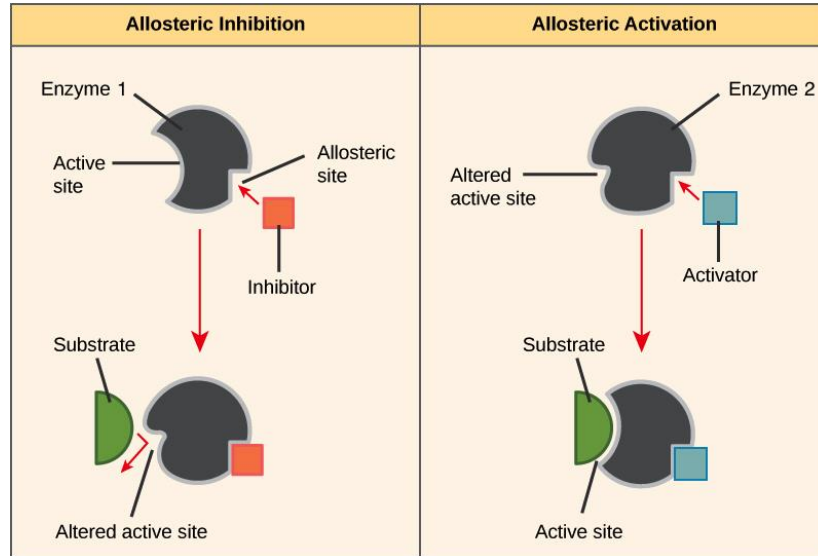
- **Activators** — these increase the enzyme's activity by shifting it toward a more active form (often called the "relaxed" or R state), making the active site better at binding substrate and speeding up the reaction.
- **Inhibitors** — these decrease the enzyme's activity by shifting it toward a less active or inactive form (often called the "tense" or T state), where the active site changes shape so the substrate fits poorly or not at all.

This is different from competitive inhibition, where an inhibitor binds directly to the active site and blocks the substrate from attaching. In allosteric regulation, the effector binds at a distant site, and the effect happens through a shape change transmitted across the enzyme.

Many allosteric enzymes exist in two main conformational (shape) forms: one active (where substrate binds easily) and one inactive or less active (where substrate binding is difficult). The binding of an effector shifts the balance between these forms. This allows fine-tuned control — for example, the end product of a metabolic pathway can act as an allosteric inhibitor to slow down the pathway when there's already enough product (feedback inhibition).

Allosteric enzymes often show a sigmoidal (S-shaped) curve when you plot reaction rate against substrate concentration, rather than the usual hyperbolic curve seen in non-allosteric enzymes. This shape lets them respond more sharply to small changes in conditions.

A classic example is phosphofructokinase in glycolysis, which is activated by AMP (signaling low energy) and inhibited by ATP (signaling high energy). Another well-known case (though not an enzyme) is hemoglobin, where oxygen binding at one site allosterically increases oxygen affinity at other sites.



End product inhibition as a negative feedback

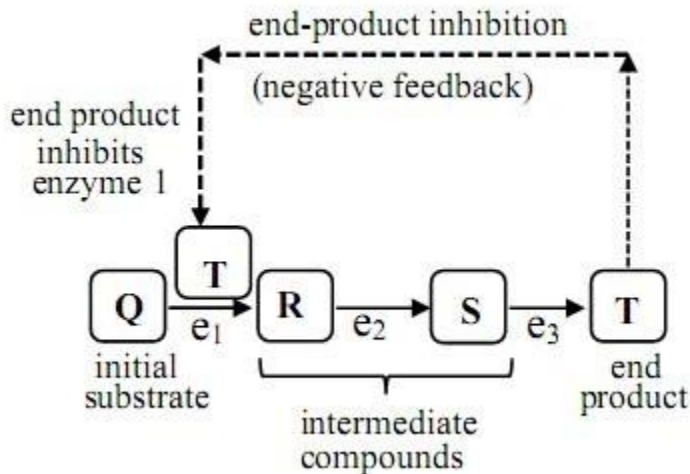
This is a self-regulating mechanism called **feedback inhibition**. In a series of enzyme-controlled reactions (a metabolic pathway), a high level of the final product binds as an **allosteric inhibitor** to the enzyme that controls the very first step of the pathway. This binding changes the enzyme's shape, reducing its activity and temporarily stopping or slowing the production of more end product.

When the concentration of the end product drops (because the cell uses it up), the inhibition eases off. The first enzyme becomes active again, allowing the pathway to restart and produce more of the needed product.

For example, in cellular respiration (including glycolysis), high levels of **ATP** (the end product) act as an allosteric inhibitor of **phosphofructokinase** (PFK), a key enzyme early in the pathway. This prevents unnecessary glucose breakdown when energy is plentiful. When ATP levels fall (and ADP or AMP rise), the inhibition lifts, the pathway speeds up, and more ATP is generated to meet the cell's energy needs.

This simple feedback system helps cells avoid waste, maintain energy balance, and respond quickly to changing conditions.

Illustration



Commercial application of enzyme inhibition

- ❖ Medical and drug development; antibiotics like penicillin work by irreversibly inhibiting enzymes crucial for bacterial cell wall synthesis, causing the bacteria to burst and die.

- ❖ Agricultural applications; many herbicides and pesticides function by inhibiting critical enzymes in pests or weeds e.g. organophosphate pesticides, irreversibly inhibit acetylcholinesterase, an enzyme essential for nerve function.
- ❖ Food preservation; in the food industry, inhibitors are used to control unwanted enzymatic reactions, such as preventing the browning of fruits or stopping yeast from producing vinegar in wine production, thus enhancing product quality.
- ❖ Detergents; enzymes are common in detergents used in cleansing action of clothes and other materials.
- ❖ Meat tenderizers; proteases are mixed with meat prior to cooking to soften it

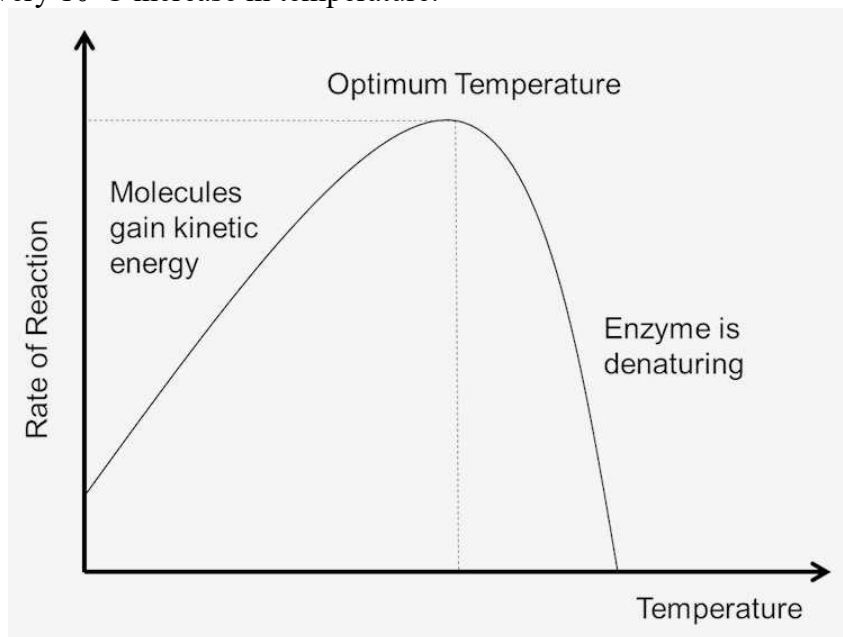
FACTORS AFFECTING ENZYME ACTIVITY

Temperature

Enzymes work faster as temperature rises because the molecules move quicker, collide more often, and react more easily. The reaction rate usually increases up to an **optimum temperature** (around 37–40°C for most human enzymes), where the enzyme is most active.

Beyond this optimum, the rate drops sharply. Very high temperatures break the weak bonds (like hydrogen bonds and ionic bonds) that hold the enzyme's 3D shape together. This causes **denaturation** — the enzyme unfolds and loses its active site shape, so it can no longer work. Very low temperatures slow everything down too much and can make the enzyme inactive, but this is usually reversible.

A useful rule (called the **temperature coefficient**, or Q_{10}) is that, between about 0°C and 40°C, the reaction rate roughly **doubles** for every 10°C increase in temperature.



pH

Each enzyme has its own best **optimum pH** where it works most efficiently. At this pH, the enzyme's shape and active site are ideal for binding the substrate.

If the pH moves too far away from the optimum (either too acidic or too basic), the enzyme's shape changes due to altered charges on amino acids. This leads to **denaturation** or reduced activity, so the reaction rate falls.

Here are some examples of optimum pH for common enzymes:

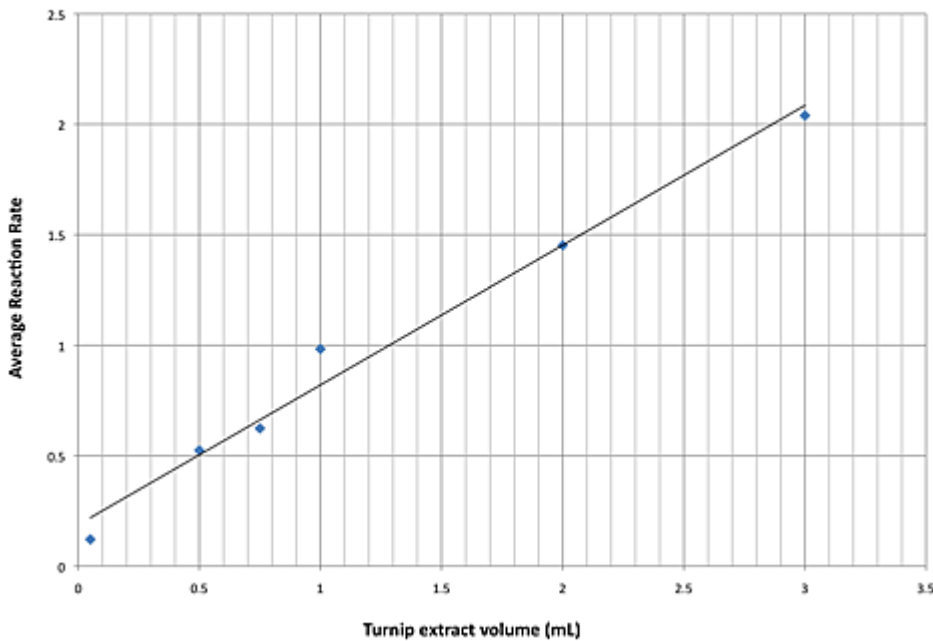
- **Pepsin** (in stomach): 2.0
- **Sucrase** (breaks down sucrose): 4.5
- **Salivary amylase** (in saliva): 4.8
- **Enterokinase**: 5.6
- **Chymotrypsin** (pancreas): 7.0–8.0

- **Catalase** (breaks down hydrogen peroxide): 7.6
- **Pancreatic lipase**: 9.0

Enzyme Concentration

When there is plenty of substrate available, adding more enzyme increases the reaction rate. This happens because there are more active sites for substrate molecules to bind to, so more reactions can occur at once. However, if you keep adding enzyme but the substrate runs out (all substrate molecules are used up), the rate stops increasing and levels off — it becomes limited by the amount of substrate left.

Effect of Peroxidase Concentration on Reaction Rate

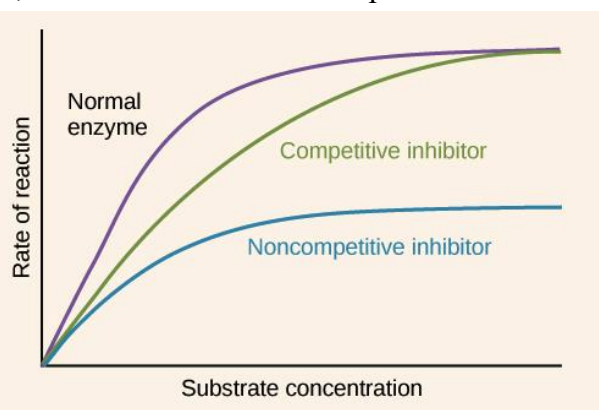
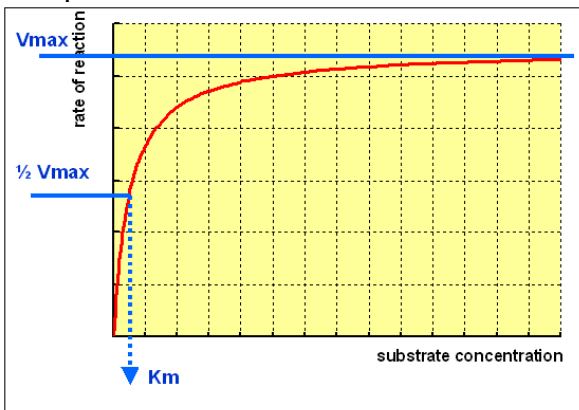


Substrate Concentration

At low substrate levels, the reaction rate increases as you add more substrate so more substrate means more molecules can fit into the enzyme's active sites.

The rate keeps rising until all active sites are filled (saturated). At this point, the enzyme is working at maximum speed (called **V_{max}**), and adding even more substrate makes no difference thus the rate stays constant. To speed it up further, you would need more enzyme molecules.

This pattern follows the **Michaelis-Menten** model, where the curve starts steep and then flattens out.



Sub-topic 2

MICROSCOPY AND CELL STRUCTURE**Microscopy:**

A **microscope** is used to produce a magnified image of an object or specimen. **Anton van Leeuwenhoek** (1632-1732) was the first to invent a microscope powerful enough to explore the world of microbes. Since the 18th century many new types have been invented of which the most commonly used today are the **light microscope** and the **electron microscope**.

Light microscope

A light microscope is a tool that uses light and lenses to make tiny things look much bigger so we can see them clearly.

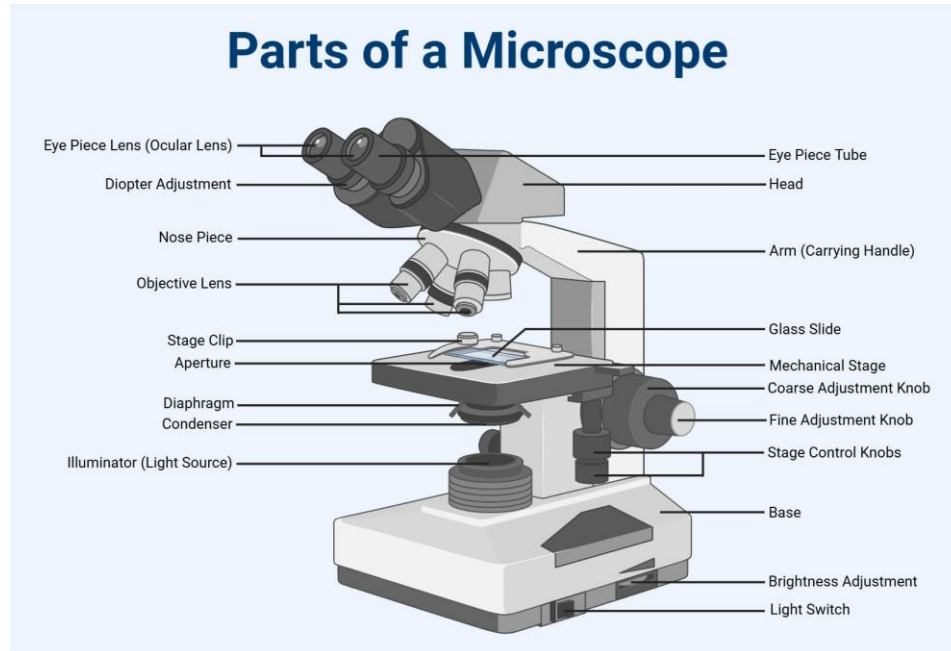
There are two main simple types:

1. **The hand lens** (also called a magnifying glass) — This is the easiest version. It has just one lens and gives low magnification, usually around 5x to 10x. People often use it to look at things like insects, plants, or small details in everyday life.
2. **The compound light microscope** — This is more powerful and commonly used in schools and labs. It has two sets of lenses:
 - The objective lens (near the object/specimen) — There are usually several of these with different powers, like 4x, 10x, 40x, or even 100x.
 - The ocular lens (eyepiece) — This is where you look through, and it usually magnifies 10x.

Light shines through a thin specimen (like cells on a slide), passes through the objective lens first, then the eyepiece lens. These lenses bend (refract) the light to create a bigger, clearer image. You see the image directly with your eye, or sometimes it can be captured on a camera or film.

Magnification vs Resolution — these are not the same thing!

- Magnification is simply how much larger the object appears. In a compound microscope, you calculate the total magnification by multiplying the objective lens power by the eyepiece power. For example:
 - A 40x objective × 10x eyepiece = 400x total magnification.
 - A 100x objective × 10x eyepiece = 1000x total (this is very common for high-power views). In theory, you could make magnification even higher with stronger lenses, but there's a practical limit.
- Resolution (or resolving power) is the microscope's ability to show two very close objects as separate, not blurred together. This is more important than just making things big! If you increase magnification too much without good resolution, the image just looks fuzzy or unclear. Light microscopes are limited by the wavelength of visible light (about 400–700 nm). The best resolution is around 0.2 μm (0.2 micrometers, or 200 nanometers). This means they can't clearly separate details finer than that distance. In practice, good compound light microscopes give clear images up to about 1000x–1500x magnification. Beyond that, the image often becomes too blurry to see extra useful detail.



Magnification = size of the image/size of the object

Advantages of the light microscope

- It is cheaper and easier to operate compared to light microscope.
- It can be used to observe living cells.
- It does not result in destruction of cellular organizations like in electron microscopes;

Disadvantages of light microscope

- It has a low resolving and magnifying power.

Techniques used in preparation of material for light microscopy.

Preparing samples for a light microscope involves several important steps. These steps help turn fresh plant, animal, or other tissue into thin, clear slices that we can see clearly under the microscope.

- **Fixation** This is the first step. It means quickly killing the living tissue and preserving it as close as possible to its natural living state. Small pieces are cut, and special chemicals (called **fixatives**, like formalin or alcohol) are used right away. This stops decay and keeps the structure of cells from changing.
- **Dehydration** After fixation, the tissue still has a lot of water. We slowly remove the water so the specimen can work with other chemicals later. This is done step by step using increasing strengths of alcohol (ethanol), starting from low concentration and ending with 100% (absolute) ethanol. If we skip this slow process, the tissue can shrink or get damaged.
- **Clearing** Next, a special liquid (called a **clearing agent**, like xylene or toluene) is used to make the tissue transparent. This replaces the alcohol and makes the specimen clear so light can pass through easily when we look through the microscope.
- **Embedding** The cleared tissue is placed into a supporting material (called the **embedding medium**) that becomes hard. Common mediums are paraffin wax (for most tissues) or resin/plastic (for very thin sections). This hard block holds the tiny specimen firmly so it can be cut properly.
- **Sectioning** The hard block is cut into very thin slices using a sharp tool called a **microtome** (a machine that cuts super-thin sections, often 5–10 micrometers thick). For simple or thick sections, a sharp razor blade can be used by hand. These thin slices allow light to pass through easily.

- **Staining** Most tissues and cells are almost transparent and hard to see. Stains (colored dyes) are added to make different parts stand out. Common simple stains include:
 - Methylene blue (turns nuclei blue)
 - Iodine solution (stains starch dark blue-black)
 - Phloroglucinol (often used for plant lignin, turns it red) This coloring helps us see cell walls, nuclei, and other structures clearly.
- **Mounting** The thin, stained section is placed carefully onto a clean glass microscope slide. A drop of mounting medium (a clear liquid or resin that dries hard) is added, and then a thin glass **cover slip** is gently placed on top. This protects the specimen, keeps it from drying out, and gives a flat surface for clear viewing under the microscope.

How to operate a compound light microscope (steps that follow after mounting)

- ✓ Plug in the microscope and turn on the light source if it uses electricity or place it near a good lightened area if it is non-electric.
- ✓ Rotate the revolving nosepiece so the lowest power objective lens (usually 4x or 10x) clicks into position over the stage
- ✓ Adjust the diaphragm/iris to a medium setting comfortable brightness
- ✓ Place the slide on the stage, securing it with the stage clips, and center the specimen over the light source
- ✓ Focus under low power; looking from the slide and use the coarse adjustment knob to move the stage up as close to the objective lens as possible without touching it until the specimen comes into broad focus.
- ✓ Then, switch to medium power (usually 40x) by rotating the nosepiece to click the medium power objective lens
- ✓ When finished, return to the lowest power objective, lower the stage completely and remove the slide
- ✓ Turn off the microscope and cover it for storage

The electron microscope: These use a beam of electrons instead of light beam. Electron beam has a much shorter wave length that light waves thus greater resolving power and much greater magnification.

Determining magnification of the object

Total magnification= eye piece magnification x objective magnification

For example, most microscopes have a 10x eyepiece;

- With a low power 10x objective lens, the total magnification is $10x \times 10x = x100$
- With a medium power 40x objective lens, the total magnification is $10x \times 40x = x400$

CYTOLOGY

This is the study of cells. In **1665**, **Robert Hooke**, a scientist discovered cells. He designed one of the earliest microscopes with which he used to examine among many things, the thin section of the cork; he discovered that the cork is made up of many box-like structures which he called cell, from Greek word “**cellulus**” meaning room.

When more material was examined under microscope, in 1839, **Schleiden** and **Theodore** proposed the cell theory.

The cell theory

The concept that cells are basic units of life became embodied in a theory called the cell theory which embraces the following main ideas;

- Cells form the building blocks of living organisms
- Cells are only by the division of existing cells
- Cells contain inherited information which controls their activities
- The cell is the functioning unit of life; metabolism takes place in cels
- Given suitable conditions, cells are capable of independent existence

Epistemic cue:

Any exceptions for the cell theory?

Types of cells

- Prokaryotes
- Eukaryotes

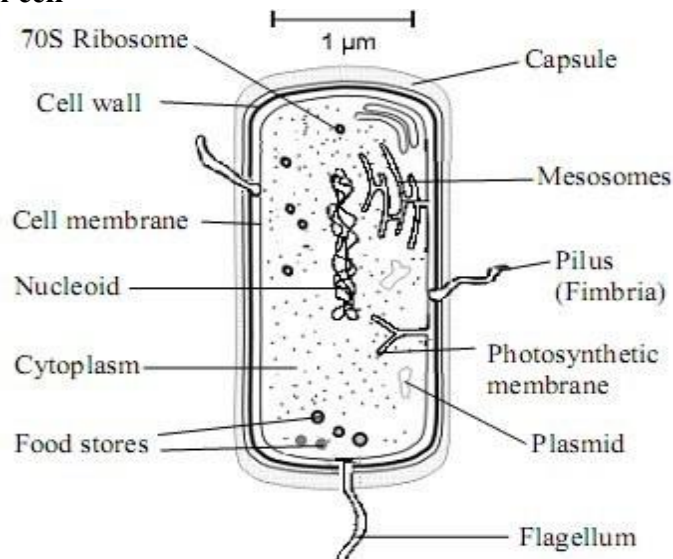
1. Prokaryotes

These belong to the original **kingdom Monera**. These are the bacteria and cyanobacteria; an ancient group of small cellular organisms ranging from 0.1 to 10µm.

The name prokaryote is derived from the Greek **pro**-before, **kaon**-nucleus; signifying the absence of a true nucleus from these cells. The electron microscope has shown that prokaryote cells have the following characteristics;

- ✚ The cell has no distinct nucleus
- ✚ Cell has single circular chromosome as DNA free in cytoplasm
- ✚ Cell lacks membrane-bound organelles (mitochondria, chloroplast and complex structured flagella)
- ✚ Cells are extremely small with cell wall containing murein/peptidoglycan

Ultrastructure of bacterium cell



Functions of the parts of the bacterium cell

- Capsule** - Some species of bacteria have a third protective covering, a capsule made up of polysaccharides (complex carbohydrates). Capsules play a number of roles, but the most important are to keep the bacterium from drying out and to protect it from phagocytosis (engulfing) by larger microorganisms. The capsule is a major virulence factor in the major disease-causing bacteria, such as *Escherichia coli* and *Streptococcus pneumoniae*. Nonencapsulated mutants of these organisms are avirulent, i.e. they don't cause disease.
- Cell Wall** - Each bacterium is enclosed by a rigid cell wall composed of peptidoglycan, a protein-sugar (polysaccharide) molecule. The wall gives the cell its shape and surrounds the cytoplasmic membrane, protecting it from the environment. It also helps to anchor appendages like the pili and flagella, which originate in the cytoplasmic membrane and protrude through the wall to the outside. The strength of the wall is responsible for keeping the cell from bursting when there are large differences in osmotic pressure between the cytoplasm and the environment.

Cell wall composition varies widely amongst bacteria and is one of the most important factors in bacterial species analysis and differentiation. For example, a relatively thick, mesh-like structure that makes it possible to distinguish two basic types of bacteria. A technique devised by Danish physician Hans Christian Gram in 1884, uses a staining and washing technique to differentiate between the two forms. When exposed to a gram stain, gram-positive bacteria retain the purple color of the stain because the structure of their cell walls traps the dye. In gram-negative bacteria, the cell wall is thin and releases the dye readily when washed with an alcohol or acetone solution.
- Cytoplasm** - The cytoplasm, or protoplasm, of bacterial cells is where the functions for cell growth, metabolism, and replication are carried out. It is a gel-like matrix composed of water, enzymes, nutrients, wastes, and gases and contains cell structures such as ribosomes, a chromosome, and plasmids. Unlike the eukaryotic (true) cells, bacteria do not have a membrane enclosed nucleus. The chromosome, a single, continuous strand of DNA, is localized, but not contained, in a region of the cell called the nucleoid. All the other cellular components are scattered throughout the cytoplasm.
- Cytoplasmic Membrane (cell membrane)** - A layer of phospholipids and proteins, called the cytoplasmic membrane, encloses the interior of the bacterium, regulating the flow of materials in and out of the cell. This is a structural trait bacteria share with all other living cells; a barrier that allows them to selectively interact with their environment. Membranes are highly organized and asymmetric having two sides, each side with a different surface and different functions. Membranes are also dynamic, constantly adapting to different conditions.
- Plasmids**-are small, extrachromosomal genetic structures carried by many strains of bacteria. Like the chromosome, plasmids are made of a circular piece of DNA. Unlike the chromosome, they are not involved in reproduction. Only the chromosome has the genetic instructions for initiating and carrying out cell division, or binary fission, the primary means of reproduction in bacteria. Plasmids replicate independently of the chromosome and, while not essential for survival, appear to give bacteria a selective advantage.

Plasmids are passed on to other bacteria through two means. For most plasmid types, copies in the cytoplasm are passed on to daughter cells during binary fission. Other types of plasmids, however, form a tubelike structure at the surface called a **pilus** that passes copies of the plasmid to other bacteria during **conjugation**, a process by which bacteria exchange genetic information. Plasmids have been shown to be instrumental in the transmission of special properties, such as antibiotic drug resistance, resistance to heavy metals, and virulence factors necessary for infection of animal or plant hosts. The ability to insert

specific genes into plasmids have made them extremely useful tools in the fields of molecular biology and genetics, specifically in the area of genetic engineering.

- **Mesosomes**- folded invaginations of the bacterial plasma membrane. They help in the synthesis of the cell wall, replication of DNA and also thought to be sites for respiration.
- **Flagella** - Flagella (singular, flagellum) are hairlike structures that provide a means of locomotion for those bacteria that have them. They can be found at either or both ends of a bacterium or all over its surface. The flagella beat in a propeller-like motion to help the bacterium move toward nutrients; away from toxic chemicals; or, in the case of the photosynthetic cyanobacteria; toward the light.
- **Nucleoid** - The nucleoid is a region of cytoplasm where the chromosomal DNA is located. It is not a membrane bound nucleus, but simply an area of the cytoplasm where the strands of DNA are found. Most bacteria have a single, circular chromosome that is responsible for replication, although a few species do have two or more. Smaller circular auxiliary DNA strands, called plasmids, are also found in the cytoplasm.
- **Pili** - Many species of bacteria have pili (singular, pilus), small hairlike projections emerging from the outside cell surface. These outgrowths assist the bacteria in attaching to other cells and surfaces, such as teeth, intestines, and rocks. Without pili, many disease-causing bacteria lose their ability to infect because they're unable to attach to host tissue. Specialized pili are used for conjugation, during which two bacteria exchange fragments of plasmid DNA.
- **Ribosomes**- are microscopic "factories" found in all cells, including bacteria. They translate the genetic code from the molecular language of nucleic acid to that of amino acids—the building blocks of proteins. Bacterial ribosomes are similar to those of eukaryotes, but are smaller and have a slightly different composition and molecular structure. Bacterial ribosomes are never bound to other organelles as they sometimes are (bound to the endoplasmic reticulum) in eukaryotes, but are free-standing structures distributed throughout the cytoplasm. There are sufficient differences between bacterial ribosomes and eukaryotic ribosomes that some antibiotics will inhibit the functioning of bacterial ribosomes, but not a eukaryote's, thus killing bacteria but not the eukaryotic organisms they are infecting.

However, new discoveries are even making taxonomists question the position of bacteria in kingdom Monera. Further classification of bacteria has been agreed on that there are two very different types of bacteria i.e. the archaeobacteria and the eubacteria.

a) Archaeobacteria (Greek word, archaios=ancient, bakterion=rod)

These bacteria are found thriving in extreme environments where few organisms survive; for example,

- **Methanogenic archaeobacteria** inhabit anaerobic habitats and give off methane as a product of their metabolism. They live in guts of cattle and responsible for the intestinal gases in cattle produce.
- **Thermoacidophilic archaeobacteria** can live in hot acidic springs where temperature may exceed 100°C and pH may be as low as 2.

Because they tolerate extreme conditions similar to those that are thought to have existed at the dawn of life, archaeobacteria are believed to have been the first forms of life on earth. Also, some features of their ultra structure and metabolism suggest that they are the ancestors of both eubacteria and eukaryotes.

b) Eubacteria (Greek word eu-modern or true)

These make up the remaining modern bacteria. They are found in all but the most extreme environments; in soils and sediments, floating free in air and water, both in and on other organisms hence **cosmopolitan**. they occur mainly as single cells, but some bacteria form filaments (rows of cells) or group together in chains or clusters.

Examples are the blue-green algae, cyanobacteria and eubacteria

Comparison between Archaeobacteria and Eubacteria

Character	Archaeobacteria	Eubacteria
Nuclear envelope	Absent	Absent
Peptidoglycan in cell wall	Absent	Present
RNA polymerase	Several kinds	One kind
First amino acid incorporated during translation	Methionine	Formyl-methionine
Membrane enclosed organelles	Absent	Absent
Histones associated with DNA	Present in some species	Absent
Circular DNA	Present	Absent
Growth at temperature $>100^{\circ}\text{C}$	Some species	No
Response to common antibiotics	Very resistant	Sensitive to them

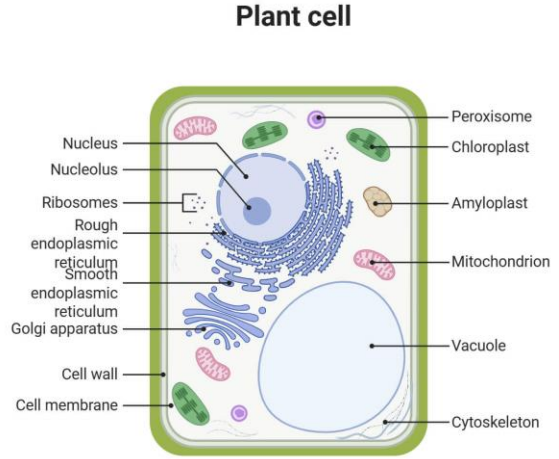
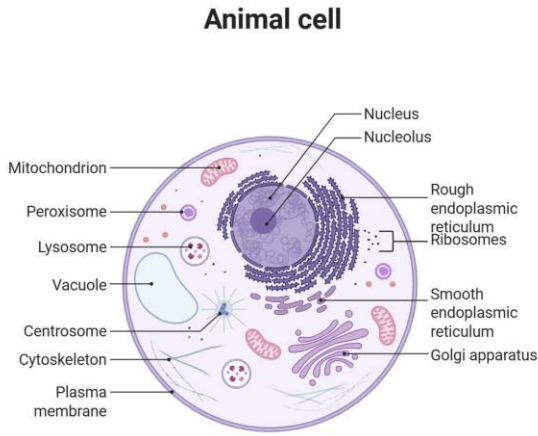
2. Eukaryotes

Eukaryotic cells are a type of cell that have a true nucleus and specialized structures called organelles, all enclosed within a plasma membrane. These cells are found in animals, plants, fungi, and protists. The electron microscope shows that eukaryotic cell has the following characteristics:

- The cell has a nucleus separated from the cytoplasm by its nuclear membrane
- The nucleus contains chromosomes in which DNA occurs, supported by a special protein
- The cytoplasm is compartmentalized by membranes into regions called organelles; these include endoplasmic reticulum, mitochondria and chloroplast
- The cell wall (if present) usually cellulose or chitin
- Cells are large 10-100 μm in diameter

Ultrastructure of plant cell and animal cell

Animal Cell vs. Plant Cell



Comparison between plant cell and animal cell
Similarities

- Both are covered by cell membranes
- Both have distinct nucleus
- Both have membrane bound organelles
- Both have cytoplasm

Differences between plant and animal cells

Feature	Plant Cell	Animal Cell
Cell wall	Present (rigid, made of cellulose)	Absent (only flexible cell membrane)
Chloroplasts / Plastids	Present (for photosynthesis)	Absent
Vacuole	Usually, one large central vacuole	Small vacuoles (if present), scattered
Shape & rigidity	Fixed / rectangular shape (due to cell wall)	Irregular / round shape (flexible)
Energy storage	Starch granules	Glycogen granules
Lysosomes	Rarely present or absent	Present (for digestion of waste)
Centrioles	Absent	Present (help in cell division)
Cilia / Flagella	Usually, absent	Present in some cells (for movement)
Nucleus position	Often pushed to the side (by large vacuole)	Usually, central
Cytoplasm	Thin layer near edge (large vacuole takes space)	Fills most of the cell
Plasmodesmata	Present (channels between cells)	Absent

Differences between eukaryotes and prokaryotes

Feature	Prokaryotic Cells	Eukaryotic Cells
---------	-------------------	------------------

Nucleus	Absent; DNA is in the "nucleoid" region	Present; enclosed by a nuclear membrane
DNA Structure	Single circular chromosome	Multiple linear chromosomes
Organelles	Lacks membrane-bound organelles	Contains membrane-bound organelles (e.g., mitochondria, ER)
Cell Size	Smaller (typically 0.1–5 μm)	Larger (typically 10–100 μm)
Organisms	Always unicellular (Bacteria, Archaea)	Unicellular or multicellular (Animals, Plants, Fungi, Protists)
Reproduction	Asexual only (Binary fission)	Asexual (Mitosis) or sexual (Meiosis)
Ribosomes	Smaller (70S)	Larger (80S)
Cell Wall	Present and chemically complex	Present in plants/fungi; chemically simple
Cytoskeleton	Simple or primitive	Complex (microtubules, microfilaments)

Functions of parts of the Eukaryotic cell

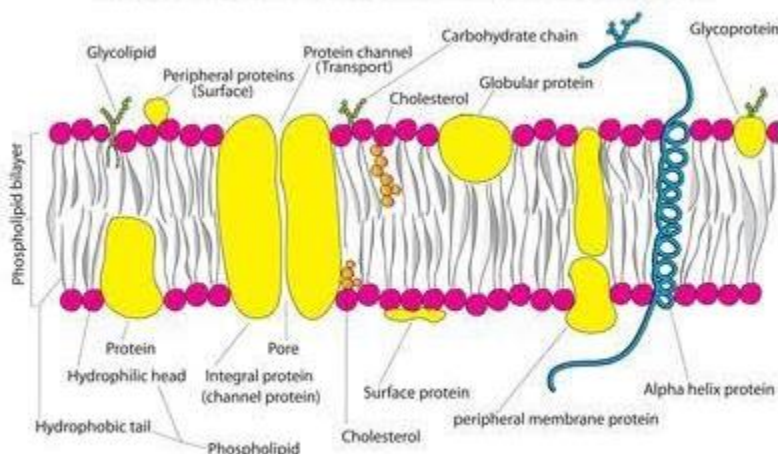
Cell wall

The cell wall is a rigid, non-living protective layer found outside the plasma membrane in many eukaryotic cells, though not all eukaryotes possess one (animal cells and some protists lack it entirely). In plant cells, the cell wall is primarily composed of cellulose (a tough polysaccharide), along with hemicelluloses, pectin, and proteins. It consists of layers: a thin middle lamella (shared between adjacent cells), a flexible primary wall (allowing growth), and often a thicker secondary wall for added strength. This structure provides mechanical support, maintains the cell's fixed shape (often rectangular), protects against physical damage and pathogens, and resists bursting from internal turgor pressure caused by water uptake.

The plasma membrane

Like bacteria and archaea, eukaryotic cells have a *plasma membrane*, a phospholipid bilayer with embedded proteins that separates the internal contents of the cell from its surrounding environment. The plasma membrane controls the passage of organic molecules, ions, water, and oxygen into and out of the cell. Wastes (such as carbon dioxide and ammonia) also leave the cell by passing through the plasma membrane, usually with some help of protein transporters.

Structure of cell membrane according to the fluid mosaic model



The fluid mosaic model, proposed by Singer and Nicolson in 1972, explains the structure of the plasma membrane as a flexible, dynamic arrangement of different molecules. The membrane is about 5–10 nm thick and is described as a “**mosaic**” because it contains various components—phospholipids, proteins, carbohydrates, and cholesterol—embedded within it.

The basic structure of the plasma membrane is a **phospholipid bilayer**. Each phospholipid is amphiphilic, having a hydrophilic (water-loving) phosphate head and hydrophobic (water-repelling) fatty acid tails. In an aqueous environment, phospholipids arrange themselves so that the hydrophilic heads face the inside and outside of the cell, while the hydrophobic tails face inward, forming a barrier that separates the cell’s internal environment from the external environment.

Proteins are the second major component of the membrane. Integral (or transmembrane) proteins are embedded within the phospholipid bilayer and may span the membrane once or multiple times. Their hydrophobic regions interact with the lipid tails, while hydrophilic regions project into the cytoplasm or extracellular fluid. These proteins are involved in transport, cell signaling, enzymatic activity, and structural support.

Carbohydrates are found only on the outer surface of the plasma membrane, attached to proteins (glycoproteins) or lipids (glycolipids). Together, these carbohydrate chains form the glycocalyx, which is important for cell recognition, cell–cell communication, and immune responses. The glycocalyx is highly hydrophilic and helps the cell interact with its watery environment.

Cholesterol is another component of the plasma membrane, especially in animal cells. It is embedded between phospholipid molecules and helps regulate membrane fluidity and stability. Cholesterol prevents the membrane from becoming too fluid at high temperatures and too rigid at low temperatures. It also reduces membrane permeability to small water-soluble molecules, thereby maintaining the integrity and proper functioning of the plasma membrane.

Functions of Components of the Plasma Membrane

1. Phospholipids

- They form the basic structure of the plasma membrane as a double layer.
- They control how **fluid** or **thick (viscous)** the membrane is.
- They determine how easily substances can pass through the membrane.
- Their molecules can move sideways, making the membrane flexible and dynamic.

2. Cholesterol

- It helps control membrane fluidity at different temperatures.
- At high temperatures, it reduces excess movement of phospholipids, making the membrane less fluid.
- At low temperatures, it prevents the membrane from becoming too rigid.
- It increases membrane strength, stability, and flexibility.

3. Proteins

- They support the structure of the membrane by being embedded in the phospholipid layer.
- Some act as **receptors**, receiving signals such as hormones and neurotransmitters.
- Others act as **enzymes**, for example ATP synthase involved in energy production.
- Some proteins function as **transporters**, allowing ions, glucose, and amino acids to cross the membrane.
- Certain membrane proteins act as **electron carriers** in the electron transport chain.
- They provide attachment points for cytoskeleton fibres, helping maintain cell shape.
- They are involved in energy transfer processes in the cell.

4. Glycoproteins

- They help cells recognize chemical messengers like hormones and neurotransmitters.
- They act as **antigens**, helping the immune system identify self and non-self cells.
- They play an important role in cell communication.

5. Glycolipids

- They act as recognition markers on the cell surface.
- They are important in immune responses, organ transplant rejection, and cancer recognition.
- They help strengthen and stabilize the cell membrane.

Various mechanisms by which substances move across the cell membranes

1. OSMOSIS

This is movement of water molecules from their region of higher concentration to a region of lower concentration through a selectively permeable membrane. It involves use of proteins called **aquaporins** embedded on cell membrane.

Plant Cells

In a hypotonic solution (lower solute concentration outside the cell): Water enters the cell by **osmosis** and moves into the vacuole. This causes the cell contents (protoplast) to push against the cell wall, creating **turgor pressure** (an internal pushing force). The rigid cell wall pushes back with **pressure potential** (wall pressure opposing the turgor). Eventually, the cell reaches **full turgidity** — the maximum turgor pressure where the cell wall can stretch no further. At this stage, the cell is **fully turgid**, and turgor pressure equals pressure potential.

In a hypertonic solution (higher solute concentration outside the cell): Water leaves the cell by **osmosis**, so the cell volume shrinks. The protoplast (cell contents) pulls away from the cell wall and membrane. This process is called **plasmolysis**.

- It begins with **incipient plasmolysis** — the point where the protoplast just stops pressing against the cell wall, and the cell membrane starts to lose contact with the wall.
- It reaches **full plasmolysis** when the membrane completely separates from the cell wall. At this stage, the cell is **fully plasmolysed** or **flaccid**.

Animal Cells (e.g., Red Blood Cells)

In a hypotonic solution: The red blood cell takes in water by **osmosis**, causing it to swell and possibly burst. This bursting is called **haemolysis** (or hemolysis). Red blood cells burst easily because they have no rigid cell wall (like the cellulose wall in plant cells) to stop them from expanding too much.

In a hypertonic solution: The red blood cell loses water by **osmosis**, causing it to shrink and look wrinkled or crinkled. This shrinking is called **crenation**.

In an isotonic solution: The cell neither gains nor loses water, so it stays the same size — no shrinking or swelling occurs.

Epistemic cue:

- Water potential
- Solute potential
- Pressure potential
- Osmotic pressure
- osmotic potential

2. SIMPLE DIFFUSION

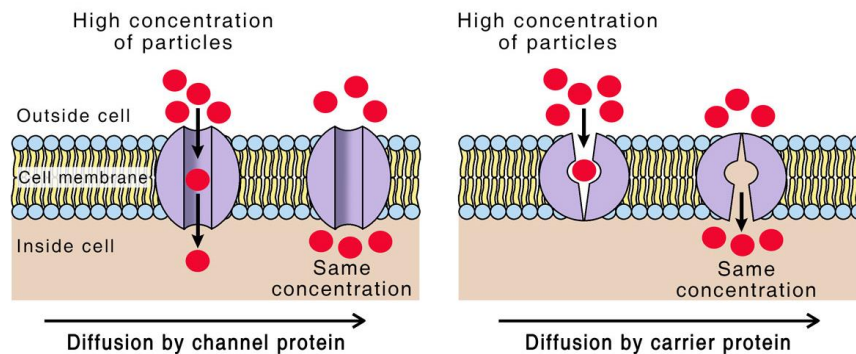
This is molecules pass through the lipid bilayer freely from high concentration into lower concentration. Polar or charged molecules do not pass through interior because they are repelled. No energy expenditure.

3. FACILITATED DIFFUSION

This is passive movement of molecules along a concentration gradient across a cell membrane involving carrier and channel proteins. No use of ATP. For polar molecules that are repelled and charged particles like Na^+ , large molecules like fatty acids that diffuse across slowly. The transport proteins are of two special kinds:

(i) Channel proteins These proteins have water-filled tunnels (called hydrophilic channels or pores) that are shaped to let only specific ions or small polar molecules pass through. Ion channels allow ions to flow in either direction (in or out), but they can open or close — that's why they are called **gated ion channels**.

(ii) Carrier proteins These proteins grab larger polar molecules (like amino acids, sugars, fatty acids, and glycerol) or sometimes ions. After binding the molecule, the protein quickly changes its shape. It has two main shapes, often described as the "ping" state (facing outside the cell) and the "pong" state (facing inside the cell). In this way, it picks up molecules from outside the cell and releases them inside (or vice versa).



4. ACTIVE TRANSPORT

This is movement of molecules/ions from a region of lower concentration to a region of higher concentration using energy from hydrolysis of ATP. Occurs against concentration gradient and involves use of channel proteins and enzymatic pumps.

It occurs in the following ways;

Carrier proteins: These are proteins found in the cell surface membrane. A specific molecule or ion binds to a special recognition site on the carrier protein. This binding triggers the breakdown of ATP, which releases energy. Using this energy, the carrier protein changes its shape (conformational change) and releases the molecule or ion on the other side of the membrane.

The sodium–potassium pump: This is a special carrier protein that actively transports ions. It pumps **three sodium ions (Na^+)** out of the cell while bringing **two potassium ions (K^+)** into the cell at the same time. Both types of ions are moved **against** their concentration gradients (from low to high concentration). This protein is an **ATPase** — it breaks down ATP into ADP and inorganic phosphate, releasing the energy needed for this active transport. The pump creates a difference in electrical charge (and ion concentration) across the membrane. This charge difference is very important for nerve impulses to travel along neurons.

Coupled transport: This is a type of active transport where **two different ions or molecules** are moved across the cell membrane **against** their concentration gradients, using energy. There are two main forms:

(a) **Symport** (also called cotransport) — both substances are transported in the **same direction** across the membrane.

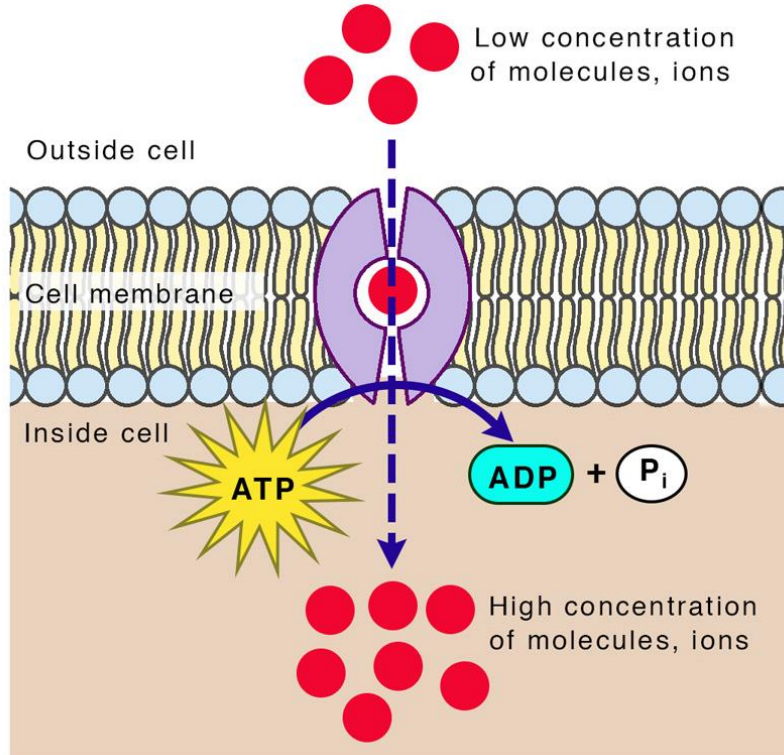
(b) **Antiport** (also called counter transport) — the two substances are transported in **opposite directions** across the membrane.

Examples

(i) Absorption of glucose in the small intestine.

(ii) Reabsorption of glucose in the kidney tubules. In both cases, a carrier protein in the membrane needs **both glucose and sodium ions (Na^+)** to work together.

(iii) Absorption of amino acids in the small intestine, which uses a Na^+ / **amino acid cotransport** carrier protein (sodium and amino acid move together in the same direction).



5. BULK TRANSPORT

Endocytosis and exocytosis are active processes (they require energy) that move large amounts of materials into or out of cells, unlike simple diffusion or carrier-mediated transport. **Endocytosis** brings materials into the cell. **Exocytosis** takes materials out of the cell.

(a) Endocytosis: This happens when the cell surface membrane folds inward or extends outward to enclose the material and form a vesicle (or vacuole) inside the cell. There are two main types:

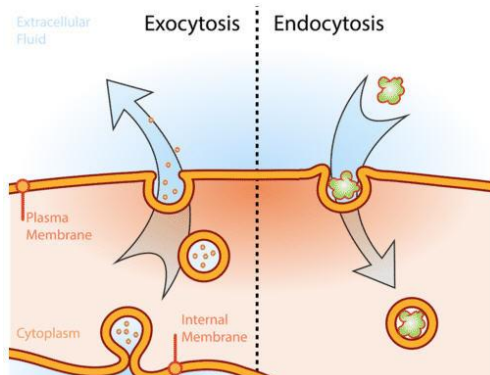
(i) Phagocytosis (“cell eating”) The cell takes in solid particles or objects. This process is carried out by specialized cells called phagocytes. Example: Certain white blood cells (phagocytes) engulf bacteria, forming a phagocytic vacuole (also called a phagosome) around the captured material.

(ii) Pinocytosis (“cell drinking”) The cell takes in liquids or dissolved substances. The vesicles formed are usually very tiny, so this is often called micropinocytosis (and the vesicles are micropinocytotic vesicles).

Example: Human egg cells (oocytes) take up nutrients from the surrounding follicle cells using pinocytosis.

(b) Exocytosis: A vesicle inside the cell moves to the cell surface, fuses with the cell membrane, and releases its contents to the outside. It is used for two main purposes:

- Removing waste products (excretion), such as undigested solid remains left in phagocytic vesicles.
- Secreting useful materials, such as hormones, enzymes, or other substances. Example: The pancreas secretes digestive enzymes into the small intestine by exocytosis.



The cytoplasm

The cytoplasm refers to the entire region of a cell between the plasma membrane and the nuclear envelope. It is composed of organelles suspended in the gel-like **cytosol**, the cytoskeleton, and various chemicals. Even though the cytoplasm consists of 70 to 80 percent water, it nevertheless has a semisolid consistency. It is crowded in there. Proteins, simple sugars, polysaccharides, amino acids, nucleic acids, fatty acids, ions and many other water-soluble molecules are all competing for space and water.

The Nucleus

The nucleus controls the activities of the cell and stores the hereditary information of the organism. The nucleus is surrounded by a double membrane called the **nuclear membrane or nuclear envelope**. This membrane has many large pores known as **nuclear pores**, which allow the movement of large molecules such as RNA and proteins between the nucleus and the cytoplasm.

Inside the nucleus is a jelly-like substance called the **nucleoplasm**. The nucleoplasm contains chromatin, which is made up of DNA and proteins (mainly histones). During normal cell activities, chromatin remains loosely arranged, but during cell division, it becomes tightly packed to form chromosomes.

Within the nucleus, there are usually one or two small, round structures called **nucleoli** (singular: **nucleolus**).

The nucleolus is responsible for the production of ribosomal RNA (rRNA) and the assembly of ribosomes, which later move to the cytoplasm for protein synthesis.

The nucleus is present in eukaryotic cells but absent in prokaryotic cells such as bacteria. (Details shall be discussed in topic of Inheritance and Evolution)

Functions of the Nucleus

- It stores the genetic material (DNA) in the form of chromosomes.
- It acts as the control center of the cell by regulating chemical reactions and activities.
- It contains DNA which provides instructions for protein synthesis.
- It is involved in the production of RNA and ribosomes.
- It plays a key role in cell division and inheritance of traits.

Mitochondria

Mitochondria are essentially universal in the eukaryotes, and with their own DNA somewhat resemble prokaryotic cells.

Mitochondria are organelles in eukaryotic cells. The mitochondrion is commonly called “**the powerhouse of the cell**” for its function providing energy by oxidizing sugars or fats to produce the energy-storing molecule ATP. Mitochondria have two surrounding membranes, each a phospholipid bilayer, the inner of which is folded into invaginations called **cristae** where aerobic respiration takes place.

Mitochondria contain their own DNA, which has close structural similarities to bacterial DNA, from which it originated, and which encodes rRNA and tRNA genes that produce RNA which is closer in structure to bacterial RNA than to eukaryote RNA. (Details shall be discussed in the topic of Respiration)

Epistemic cue:
Endosymbiotic
theory

Chloroplasts

Chloroplasts are plant cell organelles that carry out photosynthesis. Like the mitochondria, chloroplasts have their own DNA and ribosomes, but chloroplasts have an entirely different function.

Like mitochondria, chloroplasts have outer and inner membranes, but within the space enclosed by a chloroplast's inner membrane is a set of interconnected and stacked fluid-filled membrane sacs called **thylakoids**. Each stack of thylakoids is called a granum (plural = grana). The fluid enclosed by the inner membrane that surrounds the grana is called the stroma. The chloroplasts contain a green pigment called **chlorophyll**, which captures the light energy that drives the reactions of photosynthesis. Like plant cells, photosynthetic protists also have chloroplasts. Some bacteria perform photosynthesis, but their chlorophyll is not relegated to an organelle.

The central vacuole

The central vacuole is a large and very important structure found in most plant cells. It often occupies up to 70–90% of the cell's volume, making it the most prominent feature in mature plant cells.

The central vacuole is surrounded by a membrane called the **tonoplast**. This membrane controls the movement of substances into and out of the vacuole. Inside the vacuole is a watery solution known as **cell sap**, which contains water, dissolved salts, sugars, amino acids, pigments, organic acids, enzymes, and waste products. The central vacuole helps maintain turgor pressure, which keeps plant cells firm and supports the plant structure. When the vacuole is full of water, the cell becomes turgid; when it loses water, the cell becomes flaccid, leading to wilting.

The vacuole also acts as a storage organ for useful substances such as food reserves and pigments, as well as harmful or waste materials. In some plants, pigments stored in the vacuole contribute to the color of flowers and fruits, helping in pollination and seed dispersal.

In young plant cells, vacuoles are small and numerous, but as the cell matures, they fuse to form a single large central vacuole.

Functions of the Plant Central Vacuole

- Maintains turgor pressure for support and rigidity of plant cells
- Stores water, nutrients, ions, pigments, and waste products
- Helps regulate osmotic balance and pH within the cell
- Plays a role in cell growth and elongation
- Isolates toxic substances, protecting the cytoplasm
- Contributes to the coloration of plant parts such as petals and fruits

Lysosomes

Animal cells have another set of organelles not found in plant cells: lysosomes. Colloquially, the **lysosomes** are sometimes called the cell's "garbage disposal". Enzymes within the lysosomes aid the breakdown of proteins, polysaccharides, lipids, nucleic acids, and even "worn-out" organelles. These enzymes are active at a much lower pH than that of the cytoplasm. Therefore, the pH within lysosomes is more acidic than the pH of the cytoplasm. In plant cells, many of the same digestive processes take place in vacuoles.

Ribosomes

Ribosomes are the cellular structures responsible for protein synthesis. When viewed through an electron microscope, ribosomes appear either as clusters (polyribosomes) or single, tiny dots that float freely in the cytoplasm. They may be attached to the cytoplasmic side of the plasma membrane or the cytoplasmic side of the endoplasmic reticulum and the outer membrane of the nuclear envelope.

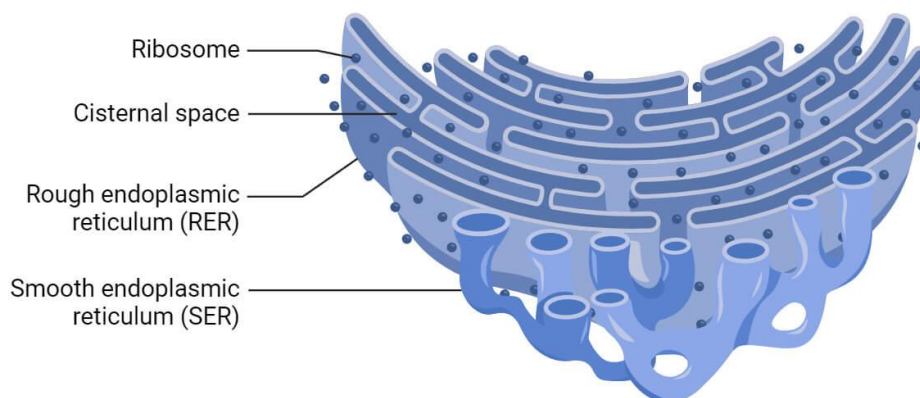
Ribosomes receive their "instructions" for protein synthesis from the nucleus, where the DNA is transcribed into messenger RNA (mRNA). The mRNA travels to the ribosomes, which translate the code provided by the sequence of the nitrogenous bases in the mRNA into a specific order of amino acids in a protein. (This is covered in greater detail in the topic of inheritance covering the process of translation)

Endoplasmic Reticulum

The endoplasmic reticulum (ER) is a network of membrane-bound sacs and tubes called **cisternae** found inside eukaryotic cells. It is usually connected to the outer nuclear membrane (except in red blood cells).

The ER provides a large surface for chemical reactions and helps in transporting materials within the cell.

Endoplasmic Reticulum (ER) Structure



There are two types of endoplasmic reticulum:

(i) **Rough Endoplasmic Reticulum (RER)**

The rough ER is made of flattened sacs whose outer surface has many ribosomes attached. These ribosomes give it a rough appearance.

Functions of RER

- Makes proteins using ribosomes
- Transports newly made proteins to other parts of the cell
- Provides a large surface for protein synthesis
- Helps support the internal structure of the cell
- Assists in forming the nuclear membrane during cell division

(ii) **Smooth Endoplasmic Reticulum (SER)**

The **smooth ER** has no ribosomes on its surface and is made of smooth tubules with a fluid-filled space inside called the **lumen**. It is common in liver cells, muscle cells, and hormone-producing glands.

Functions of SER

- Produces and transports **lipids (fats)**
- Makes steroid hormones and cholesterol
- Detoxifies harmful substances like drugs and alcohol
- In muscle cells, it forms the sarcoplasmic reticulum, which controls calcium and helps in muscle contraction

- Helps maintain cell shape together with RER

Golgi Apparatus (Dictyosomes)

The **Golgi apparatus** is a stack of **flattened membrane sacs** with small vesicles around it. Animal cells usually have one Golgi body, while plant cells have many, called **dictyosomes**. It is well developed in cells that secrete substances and works as the cell's **post office**.

Functions of the Golgi Apparatus

- Modifies proteins into **glycoproteins**
- Packages proteins and enzymes for secretion
- Produces some **carbohydrates**, including those for plant cell walls
- Transports and stores lipids
- Forms **lysosomes**

Peroxisomes

Peroxisomes are small, round organelles surrounded by a single membrane. They carry out chemical reactions that break down **fatty acids and toxic substances**. These reactions produce **hydrogen peroxide (H₂O₂)**, which is quickly broken down into water and oxygen by enzymes inside the peroxisome.

In plants, special peroxisomes called **Glyoxysomes** convert stored fats into sugars during seed germination.

Functions of Peroxisomes

- Break down fatty acids and amino acids
- Detoxify harmful substances (e.g. alcohol in liver cells)
- Protect the cell from damage by hydrogen peroxide

Cytoskeleton

The cytoskeleton is a network of protein fibers that gives the cell shape, strength, and movement, and helps transport materials inside the cell.

It has **three main parts**:

1. Microtubules

- Long, hollow tubes made of tubulin
- Help move organelles and form spindle fibers during cell division

2. Microfilaments (Actin)

- Thin and flexible fibers
- Help in cell movement and support the cell membrane

3. Intermediate Filaments

- Strong fibers
- Provide mechanical strength and hold organelles in place

Centrosome and Centrioles

The centrosome is the main area where microtubules are organized. In animal cells, it contains **two centrioles**. Centrioles help form **spindle fibers** during cell division.

Cilia and Flagella

Cilia and flagella are hair-like structures on the surface of some cells. They have a **9+2** arrangement of microtubules and are anchored by basal bodies.

- Cilia move substances across the cell surface
- Flagella help the whole cell move (e.g. sperm cell)

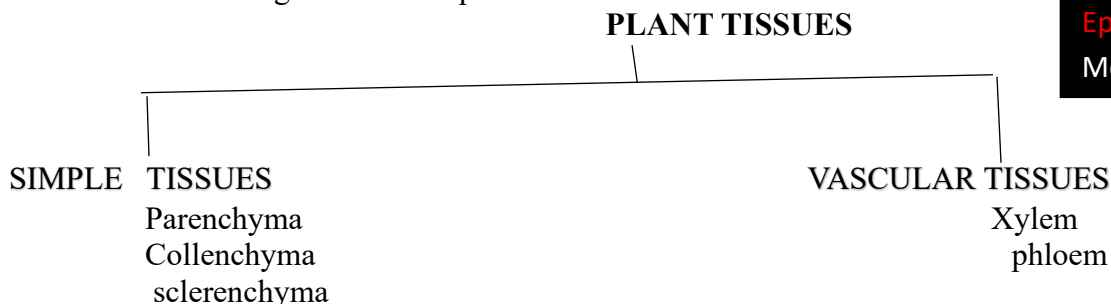
Sub-topic 3 DIVERSITY OF TISSUES (HISTOLOGY)

In most multicellular organisms, groups of cells of the same type associate together to form tissues. The cells in a tissue act together to perform a common function. Working as a group of cells is often more efficient than working individually.

Therefore, a **tissue** is a group of physically linked cells and associated intercellular substances that is specialized for a particular function and share a similar origin in the embryo.

Plant tissues

Plant tissues are categorized as simple and vascular

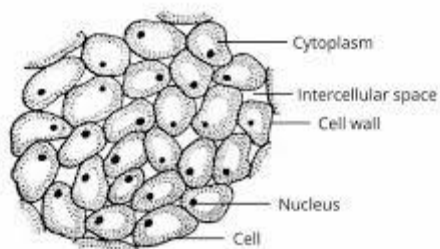


Simple plant tissues

These consist only one type of cell each. They are normally grouped according to the degree of thickening present in the cell wall.

Parenchyma tissue

Parenchyma tissues is a simple permanent plant tissue composed of living, thin-walled cells that are typically spherical in shape though may vary depending on location to be oval or polygonal. These cells possess a large central vacuole and thin primary walls made of cellulose and hemicellulose, a structure that allows for flexibility and metabolic activity.



Structure of parenchyma tissue cells

Functions.

- Forms a packing tissue between more specialized tissues like filling the extensive gaps in vascular bundles such as the xylem.
- It serves as a primary site for photosynthesis as chlorenchyma in the mesophyll layer of leaves
- It stores food and water in leaves, roots and tubers
- They play a defensive role in wound healing due to ability to divide at maturity
- Specialized forms like Aerochyma which provides buoyancy and facilitates gas exchange in aquatic plants
- They offer support when they become fully turgid as a result of osmotic uptake of water especially in herbaceous plants.

Adaptations of parenchyma tissue

- ❖ The cells are unspecialized able to divide and differentiate into different structure hence performing a variety of functions.
- ❖ Many intercellular spaces to allow diffusion and exchange of gases.
- ❖ Thin cellulose cell walls to allow passage of materials for transport.
- ❖ Transparent cell walls to allow light penetration for photosynthesis.
- ❖ The cells are large and contain large vacuoles with a thin layer of cytoplasm to provide storage space for materials of the plant.
- ❖ Have isodiametric, roughly spherical or elongated cells to serve as a packing material between specialized cells.
- ❖ Cells have permeable walls to allow entry of light for photosynthesis.
- ❖ Cells have leucoplasts such as amyloplasts to store food such as starch.
- ❖ Cells have chloroplasts to allow photosynthesis.

Modifications of parenchyma tissue, structure, function and their distribution

Modification	Structure	Function	Distribution
Epidermis	Elongated and flattened	Protection from desiccation and infection. Hairs and glands may have additional functions.	Single layer of cells covering entire primary plant body
Mesophyll	Roughly spherical, irregular or column shaped depending on location	Photosynthesis Storage of starch	Between the upper and lower epidermis of leaves
endodermis	Elongated and flattened	Selective barrier to movement of water and mineral salts in roots. Starch sheath with possible role in gravity in response in stems	Around vascular tissue (innermost layer of cortex)
Pericycle	Roughly spherical to elongated	In roots it retains meristematic activity producing lateral roots and contributing to secondary growth if this occurs	In roots between central vascular tissue and endodermis
Companion cells	Contains numerous mitochondria	Generate energy to loading of sugars in the sieve tubes with metabolic activity	In phloem tissues

Collenchyma tissue

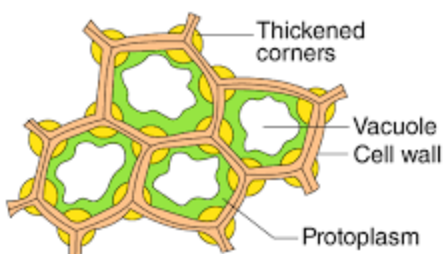
Collenchyma is a supportive simple permanent tissue composed of elongated, living cells characterized by unevenly thickened primary cell walls primarily made of cellulose and pectin.

These thickenings often occur at the cell corners, providing high mechanical strength and structural rigidity to withstand stress from wind or gravity while maintain the flexibility necessary for growth. Unlike more rigid tissues, collenchyma cells can extend and adjust as plant organs elongate because they lack a lignified secondary wall.

It is recognized as a vital component for protecting young plants from mechanical injury. It is typically located beneath the epidermis in the stems and leaf stalks of dicotyledonous plants.

Location:

- In the cortex of the stems and roots.
- In the petiole and midribs of leaves.



Structure of collenchyma tissue

Adaptations of collenchyma tissue

- ✓ The cells are closely packed with no intercellular spaces to offer great strength
- ✓ The cells have extra deposition of cellulose in the corners of the cell to offer great mechanical strength.
- ✓ The cellulose is flexible, stretchable allowing growth and bending to occur in young plants.
- ✓ Some cells may have chloroplasts to carryout photosynthesis

Sclerenchyma tissue

Sclerenchyma is a simple permanent tissue composed of cells with highly thickened, lignified secondary walls that are typically dead at maturity, providing essential mechanical strength and structural support to the plant. Its structure consists of two primary types i.e. fibers and sclereids.

Fibers are elongated cells pointed (tapering) at both ends. They are packed in bundles as strands or sheets.

Sclereids are spherical, with very heavy deposition occurs in some cells leaving behind small lumen which are closely packed without intercellular spaces.

FIBERS	SCLEREIDS
Thick, elongated, spindle shaped cells with pointed tips	Sclerenchyma cells with highly-thickened lignified cell walls having a narrow lumen
Elongated cells	Broad cells with irregular shape
Tapering end walls	Blunt end walls
Unbranched	Branched or unbranched
Originate from meristematic cells	Originate from secondary wall thickening of parenchyma cells
Generally, occur in bundles	Singly or loose groups

Found in cortex, pericycle, xylem, and phloem	Found in cortex, pith, pulp of fruits, and fruit walls
Provides mechanical strength	Provides stiffness

Adaptations of sclerenchyma tissue to its functions.

- ✓ Cells have highly lignified thick walls to provide enough resistance to forces of the environment.
- ✓ Cells are dead and therefore take no extra metabolic demand on the plant.
- ✓ Fibers are elongated and arranged in sheets/strands to increase strength.
- ✓ Fibers are interlocked to enhance their combined strength.

Vascular plant tissues

These are tissues responsible for transport and translocation of materials from one part of the plant to another. They consist of the **xylem** and **phloem** tissues.

Xylem tissue

Xylem is a complex vascular tissue responsible for the unidirectional transport of water and minerals from roots to leaves and providing mechanical support. It is composed of a mixture of living and dead cells that work together to provide both conduction and mechanical support.

Most functional xylem cells are dead at maturity, appearing as hollow tubes with lignified walls to withstand high negative pressure.

Xylem consists of four main cell types i.e. tracheid, vessel elements, xylem fibers and xylem parenchyma.

○ Tracheids

These are long, narrow, single cells with tapering ends. They have thick, lignified secondary walls for strength but lack perforations plates, meaning their end walls remain intact.

Functionally, they conduct water vertically through pits (small pores in the cell walls). Their narrow diameter and high surface-area-to-volume ratio help support the water column against gravity and prevent air bubbles.

They are found in all vascular plants (ferns, gymnosperms, angiosperms)

○ Vessel elements

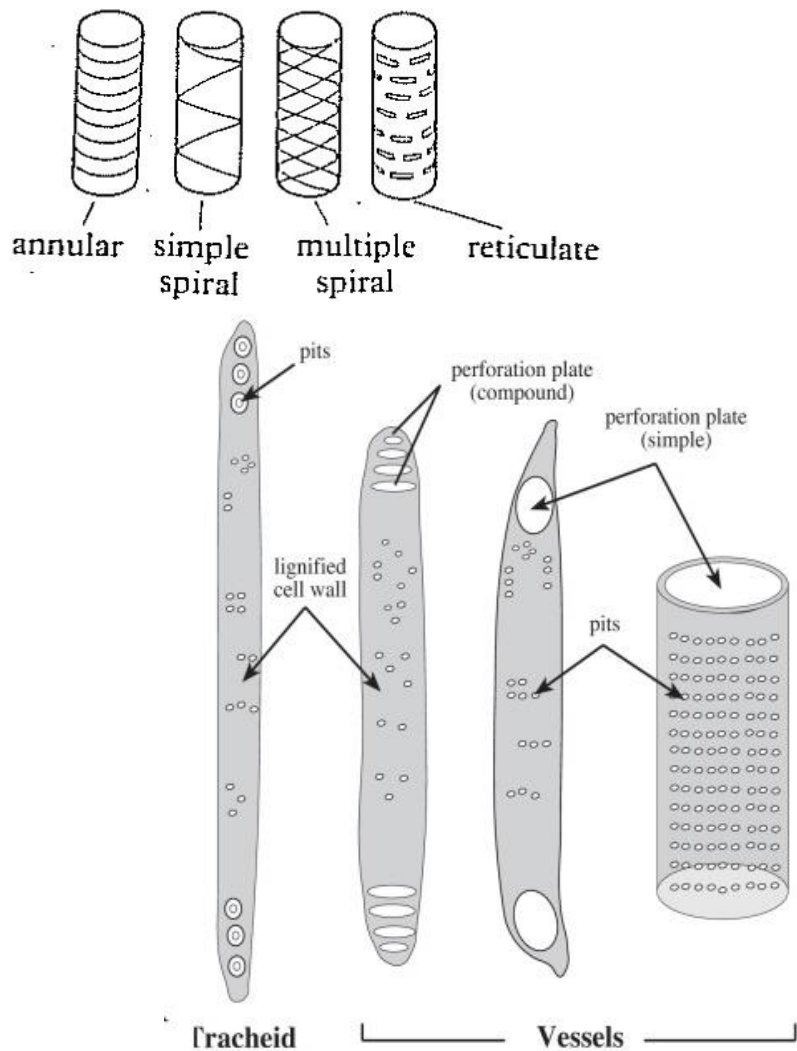
Shorter and wider cells than tracheids, arranged end-to-end to form a continuous, pipe-like tubes. Unlike tracheids, their end walls are perforated.

Functionally, provide highly efficient, low-resistance water transport. Their wide lumen allows for a much greater volume of water flow compared to tracheids.

The thickenings on the vessels could be **annular, spiral, scalariform, reticulate or pitted forms**.

Thickening/lignification gives the vessels additional strength and prevents the walls from curving in.

They are almost exclusively found in angiosperms.



Differences between tracheids and vessel elements

Tracheids	Vessel elements
These are single elongated cells	Formed of several cells with dissolution of the end walls
Shorter	Longer
They have tapering ends	They are more like pipes with rounded end
The end walls are perforated and the water moves through bordered pits on the end walls	The end walls may have one or several openings of perforations
They have narrow lumen	They have wider lumen

- **Xylem fibers**
Long, dead cells with heavily lignified walls that provide primary mechanical support.
- **Xylem parenchyma**
The only living cells in mature xylem; they store nutrients (starch, fats) and assist in the lateral conduction of water.

Adaptations of xylem tissue

- Xylem vessels and tracheids are long cells joined end to end, forming continuous tubes that allow water to move from the roots to the leaves.
- In xylem vessels, the end walls are completely broken down, forming a hollow tube that allows free and uninterrupted flow of water.
- Tracheids have end walls with small openings, which reduce resistance to water movement from one cell to another.
- The walls of vessels and tracheids are thickened with lignin, making them strong and rigid so they do not collapse under the strong pulling force caused by transpiration.
- Lignin is deposited in different patterns such as spiral and ring-like (annular) thickening. These patterns strengthen the walls and also help water to move upward by capillary action.
- The lumen of vessels and tracheids is narrow, which increases capillary force and supports upward movement of water.
- Pits in the lignified walls allow sideways movement of water, enabling water to pass between neighboring xylem cells.
- In some plants, bordered pits have a torus, which acts like a valve to control water movement and prevent air bubbles from spreading.

PHLOEM TISSUE

Phloem is a complex living tissue responsible for translocation, the bi-directional transport of organic nutrients-primarily sucrose and amino acids-from “sources” (e.g., leaves) to “sinks” tissues (like roots or fruits). Unlike xylem, phloem consists of living cells and facilitates bidirectional transport.

Phloem consists of four main cell types; sieve tubes, companion cells, phloem parenchyma and phloem fibers.

- **Sieve tubes Elements:**

Elongated cells arranged end-to-end to form continuous tubes for nutrient flow. Comprised of **sieve plates** which have perforated end walls allowing the cytoplasm of adjacent cells to connect, facilitating the continuous flow of materials.

At maturity, they lack a nucleus, ribosomes, and vacuoles to minimize resistance and maximizes space for solute movement. They have thick, rigid cellulose walls to withstand high hydrostatic pressure

Functionally, they act as the primary channel for the mass flow of sap.

- **Companion cells**

Highly metabolically active specialized parenchyma cells found adjacent to sieve tube elements. In its plasmodesmata are numerous microscopic channels connecting the cytoplasm of companion cells to sieve tube elements for the exchange of signaling molecules and metabolites. They contain a large nucleus, dense cytoplasm, and numerous mitochondria to produce energy for active transport.

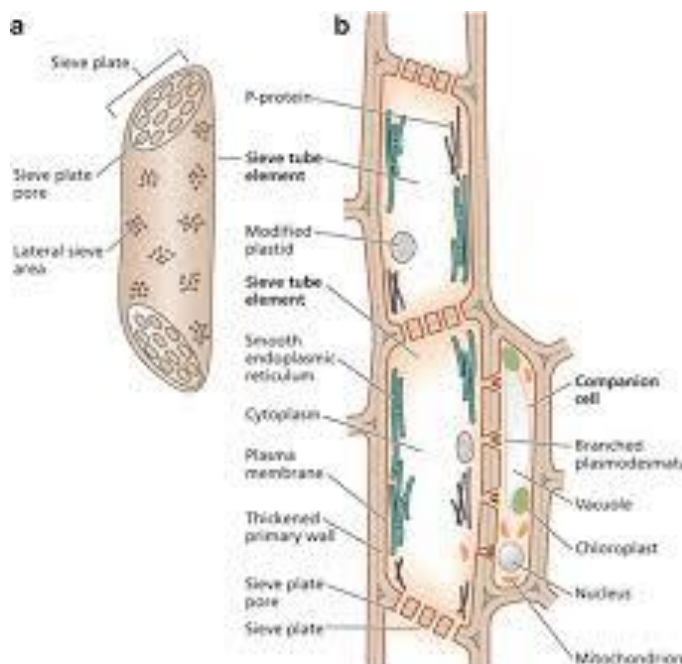
Functionally, they provide metabolic support crucial in active loading and unloading of sugars into the sieve tubes.

- **Phloem parenchyma**

These are thin walled, living parenchymatous cells with elongated, tapering cylindrical cells that have dense cytoplasm and nucleus. Cells that store starch, lipids, and resins and assist in radial conduction.

- **Phloem fibers**

Long, non-living sclerenchyma cells with very thick cell walls that provide structural support and tensile strength to the tissue.



a) Sieve element b) sieve tube consisting of sieve elements

Adaptations of phloem tissues to their functions

- ❖ Sieve tube elements are arranged end to end, forming long tubes that transport manufactured food (mainly sugars) throughout the plant.
- ❖ End walls of sieve tube elements form sieve plates which have many small holes (sieve pores). These pores allow food to pass easily from one cell to the next.
- ❖ Sieve tube elements lack a nucleus and have very little cytoplasm pushed to the sides. This reduces blockage and allows food to flow smoothly.
- ❖ Companion cells are closely associated with sieve tube elements and are connected to them by plasmodesmata. This allows exchange of materials and communication between the cells.
- ❖ Companion cells are metabolically active and contain many mitochondria which produce ATP needed for active transport during food loading and unloading.
- ❖ Transfer cells (a type of companion cell) have folded cell membranes that increase surface area. This helps in faster absorption and loading of sugars into sieve tubes.
- ❖ Phloem transport is bidirectional, meaning food can move both up and down the plant depending on where it is needed (from source to sink).

ANIMAL TISSUES

These tissues are the building blocks of organs and organ systems. From the protective barrier of epithelial tissue to the contractile properties of cardiac muscle, each type of tissue has unique characteristics and functions that enable animals to move, grow and respond to their environment.

There are different types of animal tissues i.e. epithelial, connective, muscle, nervous etc. but here we shall focus on epithelial, connective and cardiac (as type of muscle tissue)

EPITHELIAL TISSUES.

Epithelial tissue is a group of closely packed cells that form continuous sheets covering body surfaces, lining cavities and tubes, and forming glands.

Characteristics of epithelial tissues

- ✚ Cells are tightly joined with little or no intercellular space forming effective protective barriers and controls movement of substances.
- ✚ A thin non-cellular basement membrane/layer supporting the epithelium and allows regeneration.
- ✚ Cells have an apical/free surface and a basal surface
- ✚ The tissues are vascular (no supplied with blood) but supplied with nerves; relies on diffusion
- ✚ Cells divide very rapidly by mitotic for regeneration to repair damage due to wear or tear.

Types of epithelial tissues

Simple epithelial tissues; these consist of one layer of cells and they include;

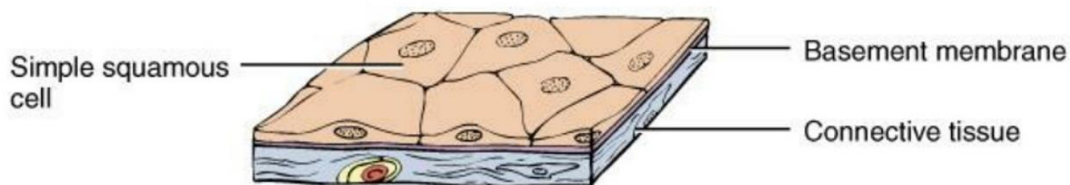
1. Simple squamous epithelium

This is specialized tissue consisting of a single layer of thin, flattened cells like pavements, wider than they are tall with centrally placed single nucleus. The cells are tightly packed together and rest on a basement membrane which anchors the tissue to underlying connective structures.

Functions

The extreme thinness minimizes the distance molecules must travel thus ideal for rapid diffusion

The tightly packed cells form a smooth surface which reduces friction allowing organs to slide past one another without damage.



Located: Alveoli, Endothelium of capillaries, Bowman's capsule

2. Simple cuboidal epithelium

Simple cuboidal epithelium consists of a single layer of cub-shaped cells with approximately equal height and width. Each cell typically contains a large, spherical, centrally located nucleus.

Functions

The increases thickness and volume of the cytoplasm allow numerous organelles like mitochondria and endoplasmic reticulum that facilitates active transport processes for secretion and absorption.

Some have microvilli on the free surface as in the kidney tubules which increase surface area for reabsorption of substances.



Location: kidney tubules (PCT and collecting ducts), glans, ovaries and bronchioles

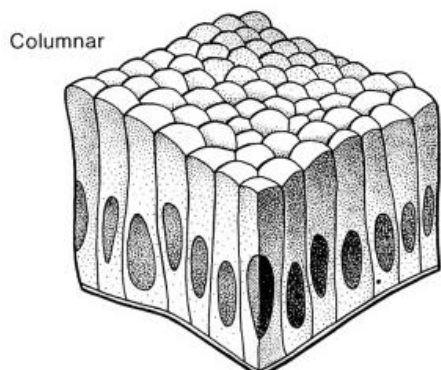
3. Simple columnar epithelium

Simple columnar epithelium consists of a single layer of tall, narrow cells that resemble rectangular columns. The cells are taller than wide, with an oval shaped nucleus situated in the basal region/bottom of the cells. Adjacent cells are tightly bound by junctional barriers which create a selectively permeable barrier to prevent leaking between cells.

Functions

- Some have microvilli on the surface ton increase surface area for absorption.

- Some contain **goblet cells** which are specialized unicellular glands to secrete protective mucus.
- Some possess cilia to trap or move fluids or particles across surfaces.



Location: fallopian tubes, respiratory tract, intestines, stomach

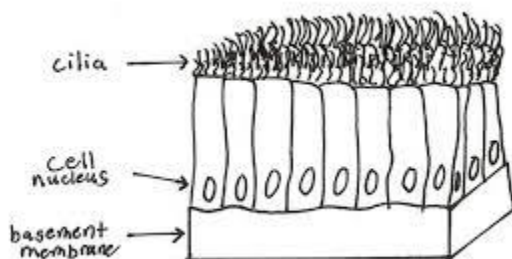
4. Simple ciliated epithelium

Simple ciliated epithelium consists of a single row of tall, rectangular cells (columnar) all of which are in direct contact with the underlying basement having an oval-shaped nucleus located near the base. The top surface of each cell features a motile, hair-like projection called **cilia**. These are composed of a “9 +2” arrangement of microtubule that allow for active bending.

Functions

In the respiratory tract, the rhythmic beating of cilia traps and moves trapped dust and pathogens within a layer of mucus toward the throat to be expelled.

It acts as a transport system for large cells or particles that cannot move independently like ovum along fallopian tubes.



Location: fallopian tubes, bronchioles

5. Simple pseudostratified epithelium

Pseudostratified epithelium is a specialized type of simple epithelium consisting of a single layer of columnar cells in direct contact with the basement membrane that varies in height, giving a false (pseudo) appearance of multiple layers. Cells differ in size; some are short and do not reach the apical surface, while others are tall and columnar making their nuclei positioned at various levels.

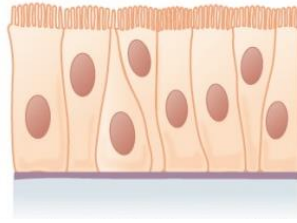
Functions

Some consist of goblet cells that produce mucus to lubricate surfaces and trap foreign particles

Acts as barrier against pathogens in areas where they have cilia and mucus like airways

Non-ciliated areas increase surface area for absorbing excess fluid

Ciliated surfaces facilitate the movement of mucus or cells e.g. sperms, oocytes in a specific direction.



Compound epithelial tissues these consist of many layers of cells but only the lower layer rests on a basement membrane. They include;

1. STRATIFIED EPITHELIUM

Stratified epithelium is made up of many layers of cells. Only the bottom layer rests on the basement membrane.

The cells in the bottom layer divide continuously by mitosis, pushing older cells toward the surface.

This type of epithelium is mainly found in places where protection is needed.

a) Stratified Squamous Epithelium

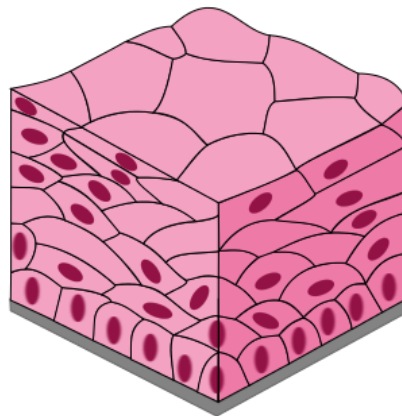
- The cells formed on the basement membrane are cuboidal, but as they move toward the surface, they flatten and become squamous.
- It is the thickest type of epithelium and is mainly involved in protection against wear and tear.
- The surface cells may:
 - **Contain keratin (keratinized)**
 - **Lack keratin (non-keratinized)**

Keratin is a tough protein that:

- Prevents loss of water
- Protects against friction
- Helps keep out bacteria

Locations

- **Non-keratinized stratified squamous epithelium** lines moist surfaces exposed to abrasion, such as:
 - Mouth
 - Oesophagus
 - Vagina
 - Part of the epiglottis
- **Keratinized stratified squamous epithelium** forms the **epidermis of the skin**.



b) Stratified Cuboidal Epithelium

- This epithelium has **several layers of cells**, with the **outermost layer made of cuboidal cells**.
- It is mainly involved in **protection and strengthening of ducts**.

Locations

- Large ducts of:
 - Sweat glands
 - Mammary glands
 - Salivary glands
- Parts of the male urethra

c) Stratified Columnar Epithelium

- This epithelium also has **many layers**, but the **surface layer is made of columnar cells**.
- It is **rare** in the body.
- Its main functions are **protection and absorption**.

Locations

- Parts of the urethra
- Large ducts of some glands
- Part of the conjunctiva of the eye

2. TRANSITIONAL EPITHELIUM

The tissue typically consists of 3-6 layers of large, dome-shaped cells. These cells often contain multiple nuclei and have specialized thickened plasma membranes called **uroplakin plaques**, which provide water proof. The basal cells are either cuboidal or columnar serving as source for cell regeneration.

Functions

Dome-shaped cells flatten and the intermediate layers reorganize into fewer, thinner layers allowing the tissue to stretch without tearing once an organ fills with fluid.

The tight junctions between cells and the uroplakin plates create a resistant osmotic barrier hence prevents leaking of materials from urine.

Location: urinary bladder, ureters, prostate gland

GLANDULAR EPITHELIUM

This is a specialized type of epithelial tissue organized into structures called **glands**, primarily dedicated to **the synthesis and secretion of macromolecules like hormones, enzymes**, and mucus. Its structure varies based on the number of cells and delivery method.

Categorized by how they release their secretions;

- Exocrine glands; these secrete their materials like sweat, saliva enzymes directly to a target surface or organ through a specialized duct system.
- Endocrine glands; these secrete their materials mainly hormones into the bloodstream which transports them to target organs thus ductless.

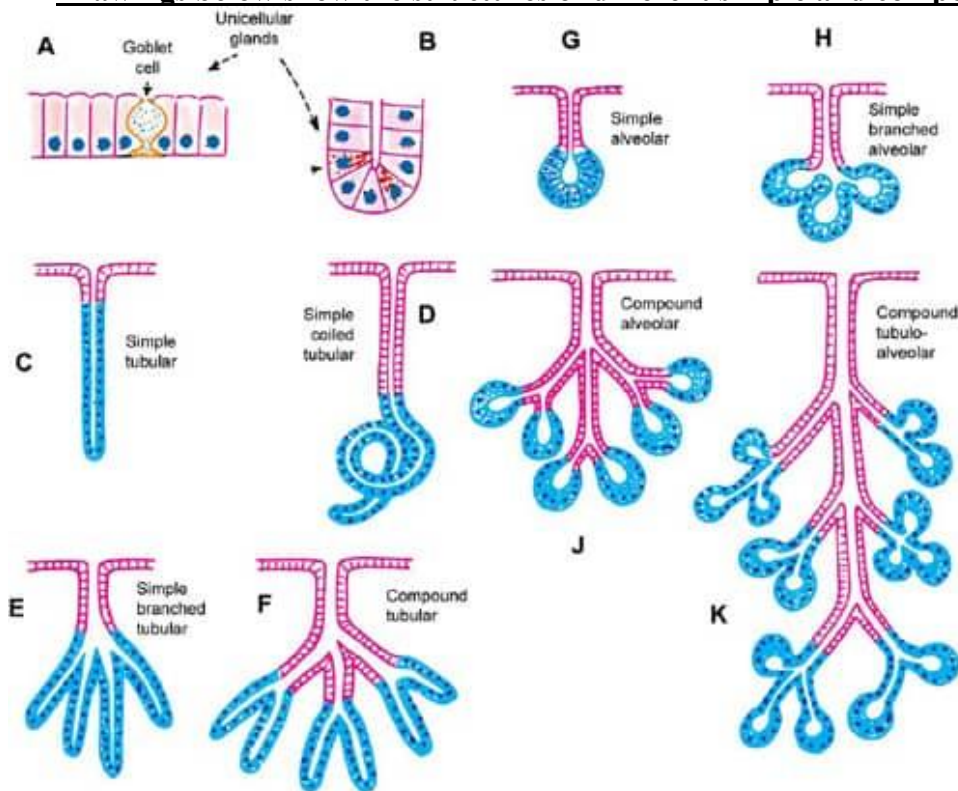
Categorized by the modes of secretion;

- Merocrine glands:** the secretions produced within the cell are discharged on its cell surface without losing any of its cytoplasm. E.g. goblet cells, pancreatic glands and sweat glands.
- Apocrine glands:** in these glands, the cell loses a part of its cytoplasm while releasing its secretions. The secretions are stored in the apical part of the cell which bursts open to release the contents e.g. mammary glands.
- Holocrine glands:** the entire cell breaks down in order to release its secretions which extrude from the epithelial surface e.g. sebaceous glands.

Categorized based on shape and complexity

- i) **Simple glands:** these are exocrine glands characterized by a single, unbranched duct leading from their secretory portion. Various forms of simple glands are given below;
- simple tubular e.g., crypts of leiburkhun in intestines
 - simple coiled tubular e.g., sweat glands
 - simple alveolar e.g., mucus secreting glands
 - simple branched alveolar e.g., sebaceous glands
 - simple branched tubular e.g., gastric glands
- ii) **Compound glands:** these are complex glands with a branched duct system that leads to numerous secretory units. Various forms of compound glands are given below;
- ✓ Compound alveolar e.g., mammary glands and pancreatic glands
 - ✓ Compound tubular e.g., salivary glands
 - ✓ Compound tubule-alveolar e.g., salivary and mammary glands

Drawings below show the structures of different simple and compound glands



General adaptations of epithelial tissues to their functions.

- Epithelial cells are tightly packed and joined by tight junctions, forming a strong, waterproof barrier that protects the body, especially the skin.
- Stratified epithelium is thick and often keratinized, as seen in the skin. This protects the body from physical damage, drying out, and entry of disease-causing organisms.
- Squamous epithelium is made of thin, flat cells, which reduce the distance for diffusion, allowing fast exchange of gases and other materials.
- Cuboidal and columnar epithelia may have microvilli on their free surface. These finger-like projections increase surface area and improve absorption.

- Some cuboidal and columnar epithelia have cilia on their surface. Cilia help move substances such as mucus, dust, and germs out of the respiratory tract and help move the zygote toward the uterus.
- Transitional epithelium has surface cells that can change shape, allowing organs like the urinary bladder to stretch and expand without damage.
- Glandular epithelium is highly folded, increasing surface area for efficient secretion of substances such as enzymes, hormones, and mucus.
- Specialized epithelial cells in the ear (organ of Corti and cupula) act as mechanoreceptors. They detect movement of fluid in the inner ear, making hearing and balance more sensitive.
- Germinal epithelium in the gonads can divide actively, producing reproductive cells such as sperm and ova.
- Pigment-producing cells (melanocytes) in the skin release melanin, which gives skin its color and protects it from harmful ultraviolet radiation.
- In some areas, epithelium is modified to form structures such as hair, nails, claws, and horns, which provide protection and support.

CONNECTIVE TISSUES.

Connective tissues are the most abundant and diverse types in the human body. They originate from embryonic mesoderm and are characterized by having cells spaced far apart with an extensive extracellular matrix.

They are classified into the following groups;

1. AREOLAR TISSUE

This is the most abundant type of connective tissue found all over the body beneath the skin, connecting organs together and filling spaces between adjacent tissues.

Areolar connective tissue consists of a gelatinous matrix or ground substance made of water, glycoproteins and proteoglycans containing two types of protein fibers and four types of cells. The protein fibers include;

I) Collagen fibers

Contain mainly densely packed collagen fibers; it is flexible but relatively unstretchable/inelastic and has great tensile strength, found in tendons attaching muscles to bones for providing strength and support.

II) Elastic fibers

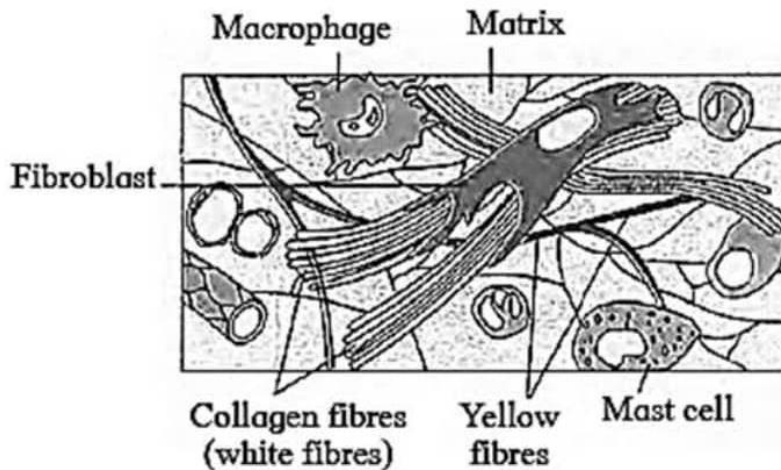
They are thin yellow fibers which are highly branched forming a network in the matrix. They are flexible and elastic. The main function of fibers is to give the areolar tissue its strength and toughness. It also allows the tissue to be flexible and elastic.

The cells within the matrix include;

- Fibroblasts
 - These are flattened and spindle like shaped cells containing an oval nucleus. They are generally closely applied to fibers but migrate to the wounded tissue to secrete more fibers in that region that effectively seal off the injured area. The function of fibroblasts is to secrete fibers.
- Macrophages
 - They are large cells capable of amoeboid movement for which reason; they are referred to as amoeboid cells. Their function is to engulf/ingest bacteria and other foreign particles. They are generally mobile but at times, they wonder to areas of bacterial invasion. Therefore, they serve to defend the body against diseases.
- Mast cells
 - These are amoeboid in shape or oval shaped and contain granular cytoplasm. They secrete fats filled cells and an anticoagulant or ground matrix or substance and macrophages.
- Fat cells

- They are mainly filled by lipid droplets. The cytoplasm and nucleus of a fat cell are confined to the margins of the periphery.

structure of areolar connective tissue



2. FIBROUS TISSUE

This is also referred to as dense connective tissue with high concentration of protein fibers and relatively small amount of ground matrix and cells. The fibers are mainly **collagen (white fibrous)** which are tough, rope-like proteins providing high tensile strength. found in tendons attaching muscles to bones for providing strength and support.

It may also contain **elastic (yellow)** fibers for flexibility. Found in ligaments binding bones together across joints and walls of bladder allowing it to stretch as it fills with urine. The primary cell type is **fibroblast** which synthesizes the fiber and matrix.

The tissue is arranged in two ways;

- ⑩ Dense regular; Fibers are packed into tidy, parallel bundles providing extreme unidirectional strength that resists pulling forces along a single axis e.g., in tendons
- ⑩ Dense irregular; Fibers are arranged in a random, interwoven, mesh-like network providing multidirectional strength; resists tearing and tension from various directions e.g., dermis of the skin, joint capsules

3. SKELETAL TISSUE

Skeletal connective tissue consists of specialized forms of connective tissue- cartilage and bone that provide the body's primary structural support, protection, and framework for movement.

□ Cartilage

Cartilage is a specialized connective tissue that provides flexible support, cushioning, and smooth surfaces for movement in the body. It consists of **chondrocytes** (mature cells) embedded in an abundant extracellular matrix rich in proteoglycans, glycosaminoglycans, and collagen fibers. This matrix gives cartilage its resilience and ability to withstand compression while remaining pliable.

Chondroblasts actively secrete the matrix during growth; once surrounded by it, they mature into chondrocytes within spaces called **lacunae**. Most cartilage is covered by a fibrous **perichondrium**, which contains progenitor cells for growth and repair. Cartilage is avascular (no blood vessels), so nutrients and waste exchange occur via diffusion, making healing slow. It also lacks nerves, so injuries are often painless initially.

Cartilage excels at resisting compressive forces and providing low-friction surfaces (e.g., in joints as articular cartilage). It acts as a shock absorber, maintains shape in flexible structures, and supports airways. In adults, cartilage appears in specific sites: joint surfaces, nose, ears, respiratory tract, and intervertebral discs.

Types of Cartilage

There are three main types, distinguished by matrix composition:

- **Hyaline Cartilage:** The most common type, with a glassy, translucent matrix dominated by type II collagen and proteoglycans (e.g., aggrecan) for hydration and resilience. Chondrocytes are scattered in lacunae, often in clusters. It offers support with some flexibility and low friction.

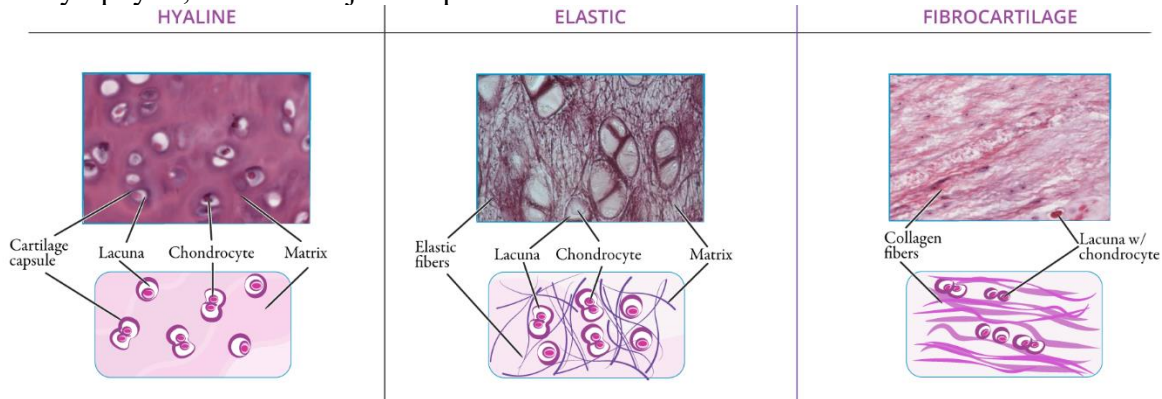
Location includes articular surfaces of joints, nasal septum, costal cartilages (ribs to sternum), and walls of trachea and bronchi. It forms the fetal skeleton template before bone replacement.

- **Elastic Cartilage:** Similar to hyaline but with abundant elastic fibers in the matrix, providing superior flexibility and rapid shape recovery after bending.

Location includes the external ear (pinna), epiglottis, auditory (Eustachian) tubes, and some laryngeal cartilages.

- **Fibrocartilage (White Fibrous Cartilage):** The toughest type, combining hyaline-like matrix with dense bundles of type I collagen fibers for high tensile strength. It often lacks a perichondrium and transitions into tendons or ligaments.

Location includes intervertebral discs (cushioning and flexibility), knee menisci (shock absorption), pubic symphysis, and certain joint capsules or tendon insertions.



□ Bone

Bone is a hard, dynamic connective tissue that forms the rigid skeleton. Its matrix (**ossein**) combines organic collagen fibers (for flexibility and tensile strength) with inorganic hydroxyapatite crystals (calcium phosphate for rigidity and compressive strength). Key cells include:

- Osteoblasts (build bone by secreting matrix)
- Osteocytes (mature cells in lacunae that maintain it)
- Osteoclasts (break down bone for remodeling)

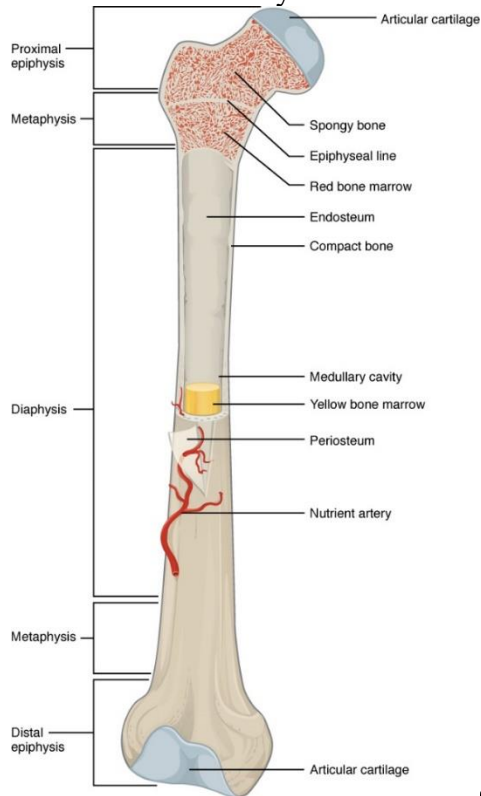
Bone is highly vascularized and innervated, allowing rapid nutrient supply, waste removal, and lifelong remodeling in response to mechanical stress or metabolic needs.

Bone structure features **osteons** (Haversian systems) in compact areas: concentric lamellae around central canals containing blood vessels and nerves. Fine **canaliculi** connect **lacunae** for cell communication and nutrient diffusion. The outer **periosteum** (fibrous layer) contains blood vessels and cells for growth/remodeling.

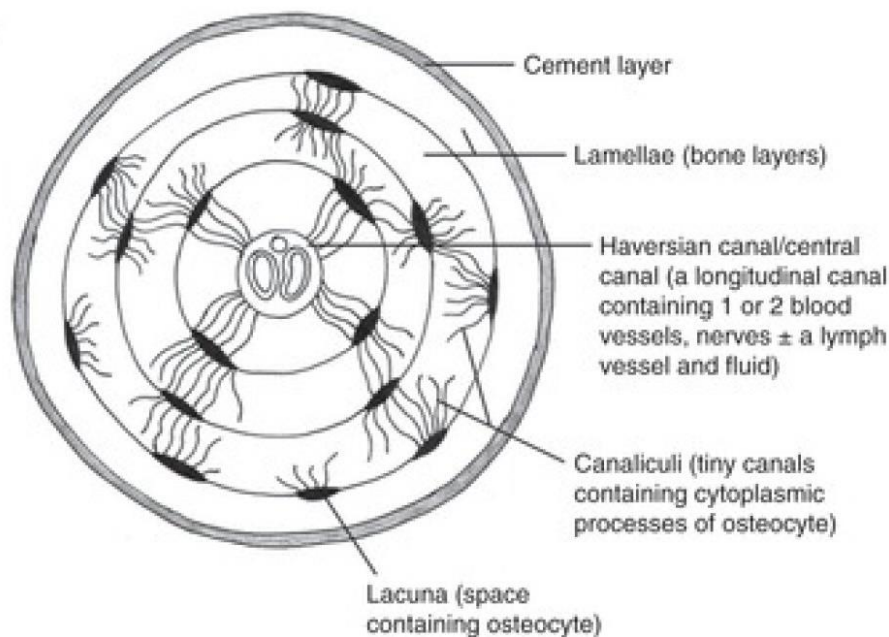
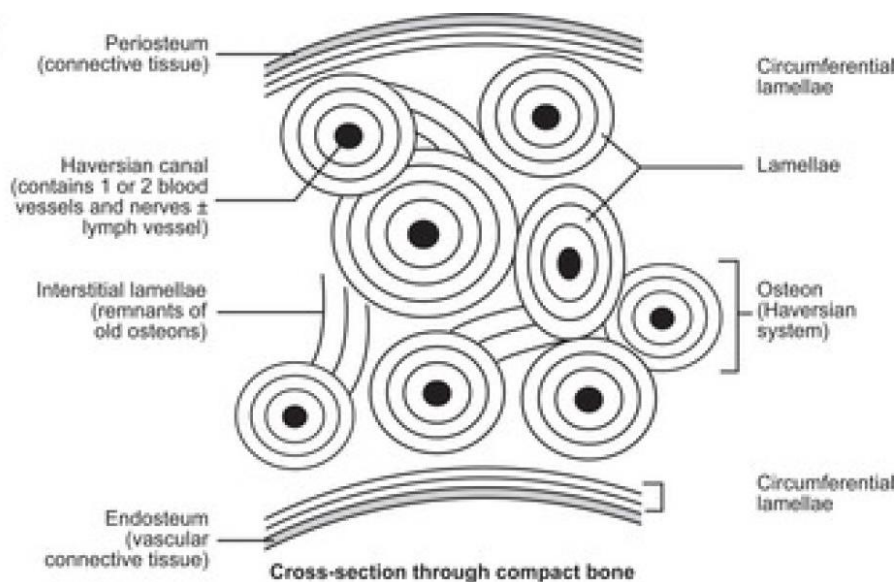
Types of Bone Tissue

- **Compact (Cortical) Bone:** Dense and solid, forming the outer layer of all bones and shafts of long bones. It consists of several Haversian systems arranged concentrically and covered by a solid connective tissue called **periosteum**, once imprisoned in the lacunae, osteoblasts stop secreting matrix material and become known as **osteocytes**, found in shafts of limb bones e.g. femur. It provides strength and protection, with osteons aligned for load-bearing.
- **Spongy (Cancellous or Trabecular) Bone:** Porous with interconnecting trabeculae, found inside bones (e.g., epiphyses of long bones, vertebrae). It reduces weight, houses marrow (red for blood production, yellow for fat storage), and aligns along stress lines for efficient force distribution.

- ❖ Long bones show both: compact in the shaft (diaphysis) and spongy at ends (epiphyses), with a central marrow cavity.



Structure of a long bone



Differences between compact bones and spongy bones

Spongy bones	Compact bones
Arranged in osteons	Arranged in trabeculae
Found in outer layer of bones	Found in interior of bones
Solid and dense	Honey-comb like
Provides strength and support	Supports metabolic needs and bone marrow production

Bone Development (Ossification)

Ossification is the process of formation and development of bone. Bone forms via two processes:

- **Intramembranous Ossification:**

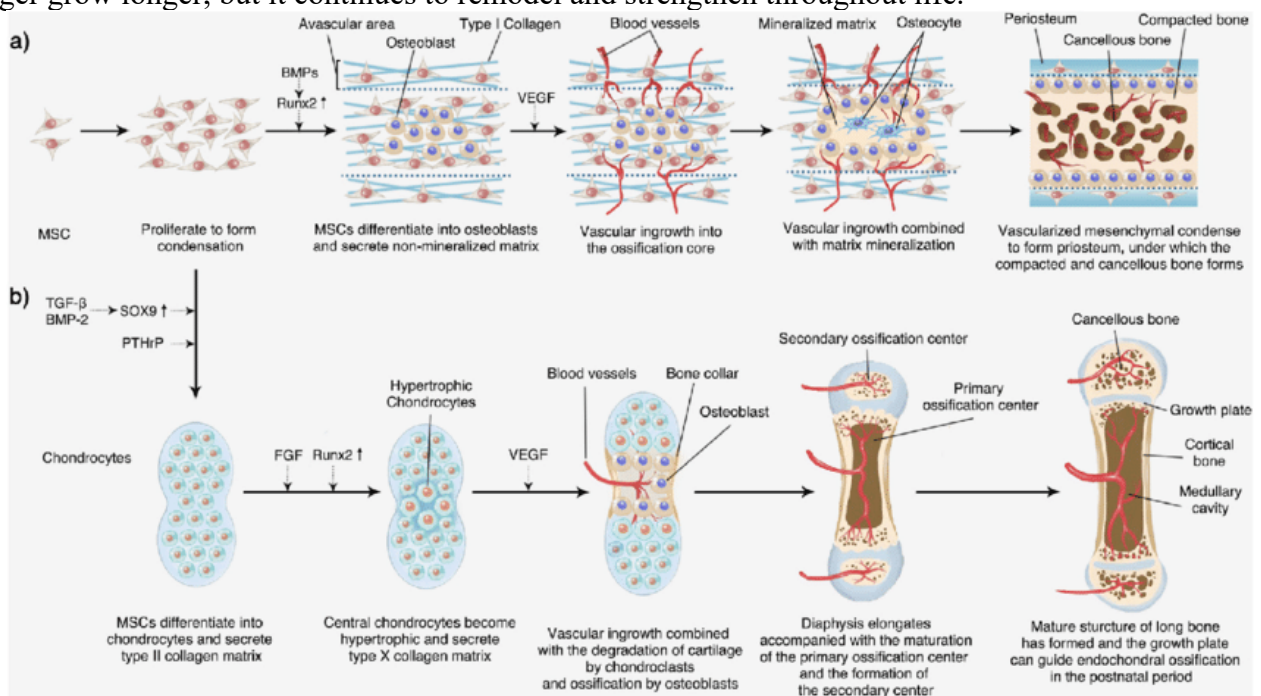
- Intramembranous ossification is the process by which certain flat bones, such as those in the skull, clavicles, and parts of the face, form directly from mesenchymal tissue without first turning into cartilage. It begins during early embryonic development, usually around the 6th to 8th week of pregnancy, and continues after birth as the bones grow and mature.
- First, loose mesenchymal cells, which are a type of primitive connective tissue cell, gather together in specific areas to form dense clusters called ossification centers. These clusters become highly supplied with blood vessels. Within each center, some mesenchymal cells change into osteoblasts, the cells that build bone.
- The osteoblasts then start producing osteoid, which is the soft, organic part of bone matrix made mostly of collagen. As more osteoid is laid down, some osteoblasts get trapped inside it. These trapped cells mature into osteocytes, which are the main cells that maintain bone tissue. Very quickly after the osteoid is secreted, calcium and phosphate minerals are deposited into it, turning the soft osteoid into hard bone. This creates small, irregular spikes or rods of bone called spicules or trabeculae.
- These early bone spicules grow and connect with one another, forming a loose network that looks like spongy bone. The spaces between the trabeculae are filled with blood vessels and remaining mesenchymal tissue, which will later become bone marrow spaces. At the same time, the mesenchymal tissue on the outer surface condenses to form the periosteum, a tough covering layer that contains cells ready to make more bone when needed.
- As development continues, the initial woven, immature bone is gradually reshaped. Osteoclasts break down excess or unnecessary bone, while osteoblasts add new layers in a more organized way. This remodeling turns the outer parts of the spongy bone into dense compact bone and helps the bone take on its final shape and thickness. In the skull, multiple ossification centers spread outward and eventually meet, leaving soft fibrous joints called sutures that allow the head to pass through the birth canal and the brain to grow during infancy.
- By the end of the process, the bone has a strong outer layer of compact bone and an inner layer of spongy bone, perfectly suited for protection and muscle attachment while remaining relatively lightweight. This direct formation from membrane makes intramembranous ossification faster and simpler than the cartilage-replacement method used for most other bones in the body.

- **Endochondral Ossification:**

- Endochondral ossification is the process by which most bones in the body, especially long bones like those in the arms and legs, form by gradually replacing a hyaline cartilage model with real bone. It begins in the fetus and allows bones to grow longer throughout childhood and adolescence until the growth plates close in early adulthood.
- First, a small cartilage model shaped like the future bone is formed early in development. Mesenchymal cells turn into chondroblasts, which produce hyaline cartilage surrounded by a membrane called the perichondrium. This cartilage model grows rapidly both by cells dividing inside it and by new layers being added on the surface.
- In the middle of the shaft, called the diaphysis, the cartilage cells in the center start to enlarge and mature. They release substances that cause the surrounding matrix to calcify, and then these enlarged cells die, leaving empty spaces. At the same time, blood vessels from the perichondrium grow into this area, bringing in cells that will form bone. The perichondrium changes into the periosteum, and osteoblasts begin making a thin collar of true bone around the outside of the shaft.
- Inside the shaft, the calcified cartilage is broken down by osteoclasts, creating a large hollow space that will become the marrow cavity. Osteoblasts follow and lay down bone along the remaining cartilage

fragments, forming the first true spongy bone in what is called the primary ossification center. This spreads toward both ends of the bone.

- While the shaft is turning into bone, cartilage continues to grow quickly at both ends of the model, in the regions called the epiphyses. This growth allows the bone to get longer. Later, usually around the time of birth or shortly after, similar changes happen in each epiphysis, creating secondary ossification centers. Cartilage cells enlarge, the matrix calcifies, blood vessels enter, and bone replaces most of the cartilage there too.
- A thin layer of cartilage, known as the epiphyseal plate or growth plate, remains between the shaft and each epiphysis. As long as this plate is active, the bone can keep growing in length. The plate has organized zones where cartilage cells divide, enlarge, and eventually get replaced by bone on the shaft side. This pushes the epiphysis farther away, lengthening the bone.
- The bone also grows thicker by osteoblasts in the periosteum adding new layers on the outside while osteoclasts remove bone on the inner surface to enlarge the marrow cavity. Over time, the initial spongy bone in the shaft is remodeled into compact bone, and the epiphyses fill with spongy bone.
- When a person reaches full adult height, usually in late teens or early twenties, hormones signal the growth plates to stop producing new cartilage. The plates gradually thin out, become fully ossified, and fuse the epiphyses to the shaft, leaving a faint line called the epiphyseal line. After this, the bone can no longer grow longer, but it continues to remodel and strengthen throughout life.



b) Intermembranous ossification b) Endochondral ossification

Adaptations of Bone to its functions

- ❖ Bone is covered by a tough fibrous layer called the periosteum, which protects the bone and the cells inside it.
- ❖ Strong collagen fibers from the periosteum enter the bone, firmly attaching the periosteum to the bone and providing a strong surface for tendon attachment, which helps in movement and locomotion.
- ❖ Bone cells are embedded in a hard matrix, made strong by calcium salts and other mineral ions. This gives bones their hardness and strength.
- ❖ Compact bone is made of concentric layers (lamellae) arranged around central channels called Haversian canals, giving the bone uniform strength.

- ❖ Osteoblasts are bone-forming cells that produce and secrete the bone matrix and are found in spaces called lacunae within the lamellae.
- ❖ Some osteoblasts become less active and are called osteocytes. These cells maintain the bone and can become active again when bone repair or growth is needed.
- ❖ Osteoclasts are bone-resorbing cells that break down bone tissue, allowing reshaping and remodeling of bones during growth and repair.
- ❖ Each lacuna is connected to others by tiny channels called canaliculi, which allow nutrients, gases, and messages to pass between bone cells and the central canal.
- ❖ Haversian canals contain blood vessels and lymph vessels, which supply nutrients and oxygen and remove waste products from bone cells.
- ❖ Nerve fibers in the Haversian canals help coordinate bone growth and remodeling, allowing bones to adjust to changes in mechanical stress during development.
- ❖ Spongy bone has many spaces between supporting structures called trabeculae, making bones lighter and allowing easier movement.
- ❖ Bones act as mineral reservoirs, releasing calcium and phosphate into the blood when needed, under the control of hormones such as parathormone and calcitonin.

Key Differences Between Cartilage and Bone

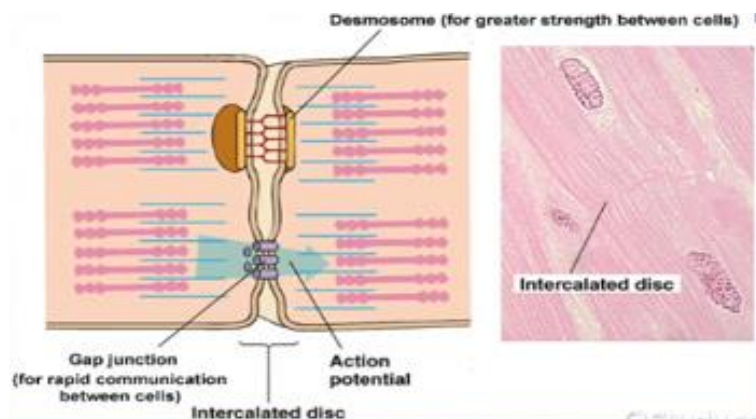
Feature	Cartilage	Bone
Rigidity	Flexible, elastic/compressible	Rigid, hard
Vascularity	Avascular (diffusion for nutrients)	Highly vascular
Matrix Composition	Proteoglycans, type II collagen (varies by type); no mineralization	Collagen + hydroxyapatite (mineralized)
Cells	Chondroblasts → Chondrocytes	Osteoblasts → Osteocytes; Osteoclasts
Growth/Repair	Slow (appositional from perichondrium; limited interstitial)	Rapid remodeling throughout life
Structure	Lacunae only; no canals	Lacunae + canaliculi + Haversian systems
Strength	Resists compression; some tensile (fibrocartilage)	High compressive and tensile strength

CARDIAC MUSCLE TISSUE

Cardiac muscle tissue, also known as myocardium, forms the thick middle layer of the heart wall. It consists of specialized muscle cells called **cardiomyocytes**. These cells are shorter and thicker than skeletal muscle fibers, and they often branch, connecting to form a complex network.

Under a microscope, cardiac muscle shows clear **striations**—alternating light and dark bands—just like skeletal muscle. These bands come from the organized arrangement of actin and myosin filaments that slide past each other during contraction. Each cardiomyocyte usually has one centrally located nucleus (sometimes two), and the cells are packed with numerous **mitochondria**, which provide the massive energy needed for nonstop beating.

Another key feature of cardiac muscle is the presence of **intercalated discs**. These are special junctions where adjacent cells connect end-to-end. Intercalated discs contain two main structures: **desmosomes**, which act like strong spots of glue to hold cells together during forceful contractions, and gap junctions, which allow electrical impulses to pass quickly from cell to cell.



Cardiac muscle is involuntary, meaning we do not consciously control it, and it has built-in rhythmicity—it can generate its own electrical impulses without needing signals from nerves (though nerves modulate the rate). The tissue is highly resistant to fatigue because of its abundant mitochondria and good blood supply, allowing the heart to contract rhythmically about 100,000 times a day without tiring.

Adaptations of cardiac tissue to its functions

- ✚ Presence of intercalated discs to spread impulses/waves of excitations through all the muscle fibers
- ✚ The branched muscle fibers allow spread of waves of excitations
- ✚ Numerous mitochondria in the muscle fibers to generate more energy required for muscle contractions
- ✚ The muscle fibers are richly supplied with blood to supply enough oxygen and nutrients and remove waste products
- ✚ High concentration of myoglobin to store large amounts of oxygen
- ✚ The cardiac muscle is myogenic making it able to contract without fatigue

Disease diagnosis of some mammalian tissues

This is the process of identifying an illness by analyzing its signs and symptoms often using physical exams and lab/imaginary tests to pinpoint the cause and guide treatment.

Tissues of different organs are commonly destroyed by physical particles or disease-causing germs affecting both their structure and functioning of the organ.

Diseases tissues samples are always affected and examined under microscope to spot cellular changes.

Epistemic cue: Histopathology

Comparisons of micrographs of healthy and diseases tissues of some body organs

1. Liver tissues

Healthy tissue	Diseased tissue e.g., hepatitis, cirrhosis
Smooth, reddish brown, uniform texture	Nodular, enlarged or shrunken
No fat accumulation	Pale/yellow
No scar tissue	Fat accumulation
No inflammation	Fibrous (scar tissues)
❖ This structure allows the liver to detoxify blood and carry out metabolism efficiently	❖ Reduced ability to detoxify blood and portal hypertension

Possible causes: excessive alcohol consumption causing chronic liver injury, viral hepatitis B, auto-immune conditions

Possible control and treatment measures: limit alcohol intake, vaccine against hepatitis B, excessive to prevent obesity, liver transplant in end-stage cases.

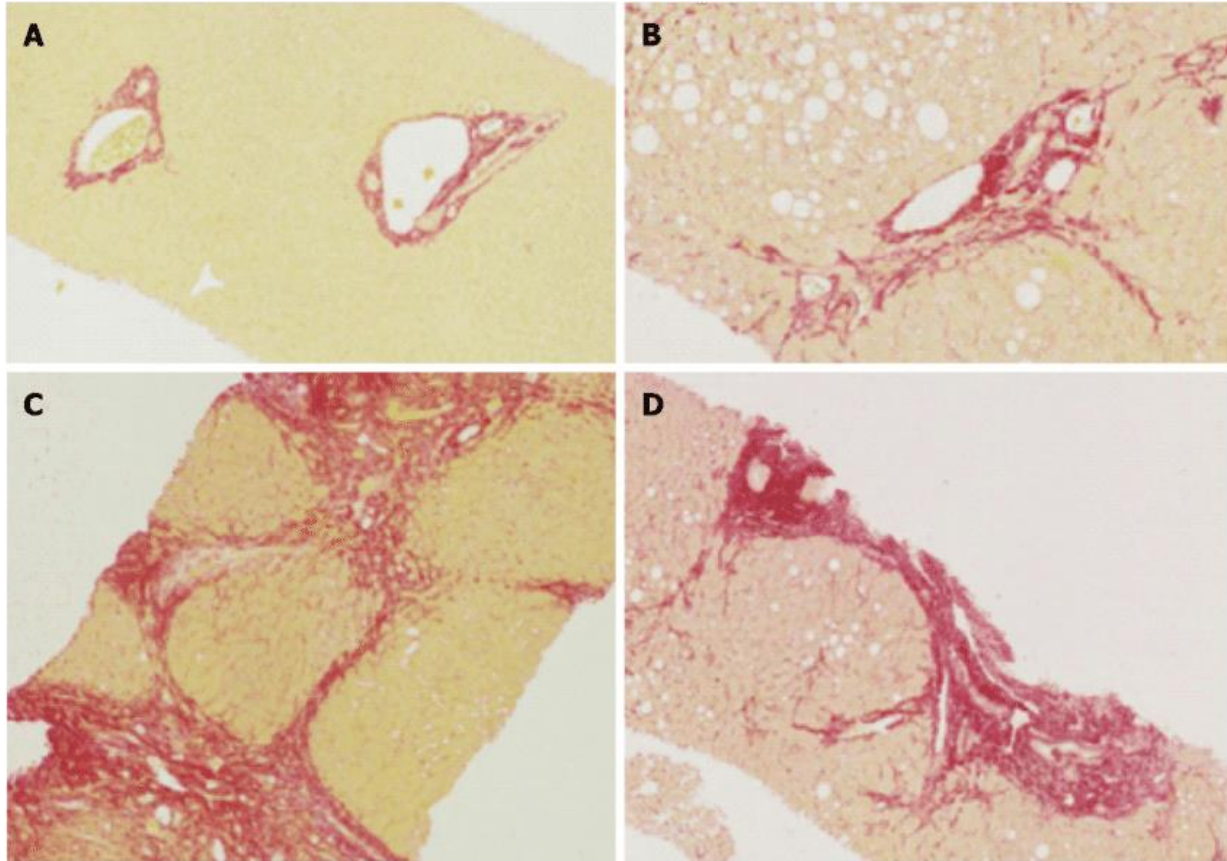


Figure shows (A) Normal liver (B) mild to moderate fibrosis with portal expansion (C) moderate bridging fibrosis (D) Cirrhosis

N.B Fibrosis means scarring of liver tissue due to chronic injury that potentially leads to cirrhosis (permanent scarring), liver failure, or liver cancer.

2. Lung tissues

Healthy tissue	Diseased tissue e.g., emphysema, pneumonia
Thin air sacs on alveoli No fluid in the airspaces No inflammation	Thickened alveolar walls Air spaces filled with fluid or pus Inflammation in response to injury
⑩ Healthy lungs have high S.A for efficient gas exchange	⑩ Such reduce elasticity, S.A and ability to expand and contract hence shortness of breath and reduced O ₂ uptake.

Possible causes: long term smoking, air pollution exposure,

Possible control and treatment measures: withdraw from smoking, use of protective gears in polluted environment, use of antibiotics and anti-inflammatory drugs, supplemented oxygen in severe cases.

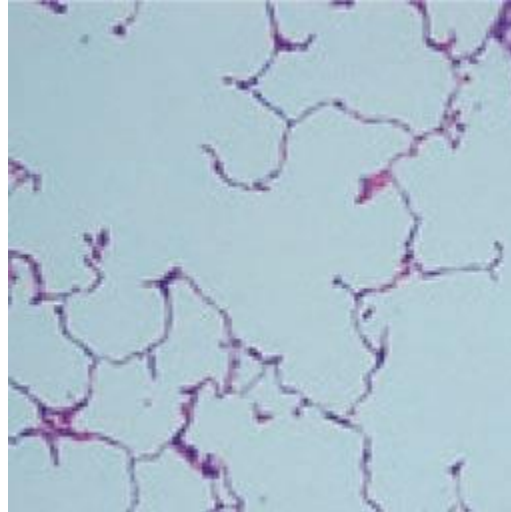


Figure above shows emphysematous lung with distended alveolar ducts associated with rupture of alveolar septa

3. Heart tissues (cardiac muscle)

Healthy tissue	Diseased tissue e.g., heart attack
Branched muscle fibers Normal amount of collagen in the spaces between muscle cells Normal size of muscle cells Thin endocardium	Muscle fibers disorganized in arrangement Increased collagen deposition in spaces between muscle cells leading to scarring Muscle cells may appear elongated and thin in appearance Thickened endocardium due to scarring
✓ Ensures strong and coordinated heart contractions	✓ Weak pumping of blood due to weak contractions

Possible causes: hypertension, smoking, diabetes, sedimentary lifestyle

Possible control and treatment strategies: low fat diet, regular physical exercises, withdraw from smoking, use of lipid-lowering drugs

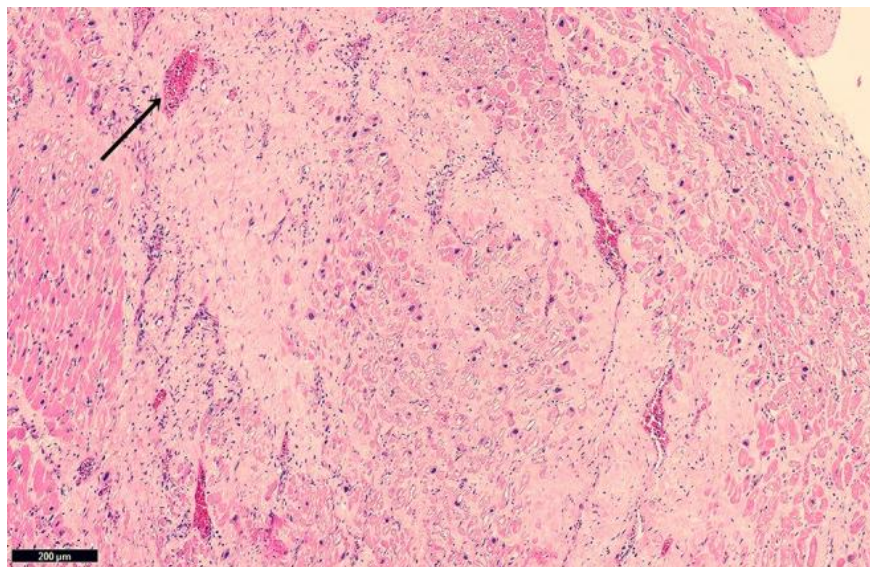


Figure shows well-formed granulation tissue with collagen deposition (scars) and new abnormal blood vessels (black arrow)

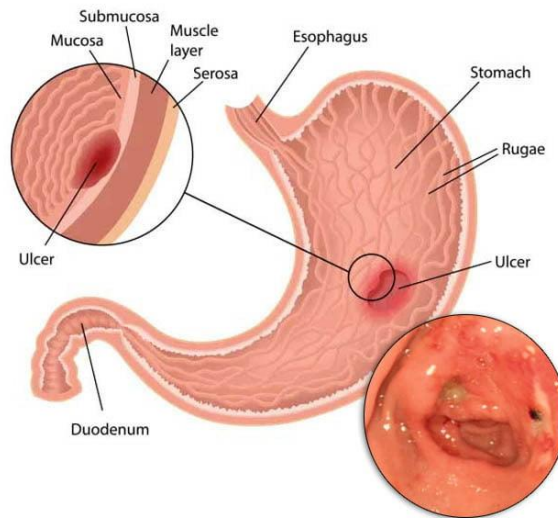
4. Intestinal tissue

Healthy tissue	Diseased tissue e.g., ulcers, infection
Well-developed crypts of lieberkuhn and no inflammation Presence of villi with normal thickness of the wall Normal number of goblet cells Well-developed mucosa layer	Inflammation and destruction of crypts. Erosion, ulcers affecting the entire thickness of the intestinal wall Loss of villi Decrease in number of goblet cell and loss of mucosa layer
<ul style="list-style-type: none"> Villi increase S.A for absorption of nutrients 	<ul style="list-style-type: none"> Inflammation and structural damage lead to malabsorption and pain

Possible causes: smoking, processed food with high acid content e.g., soda

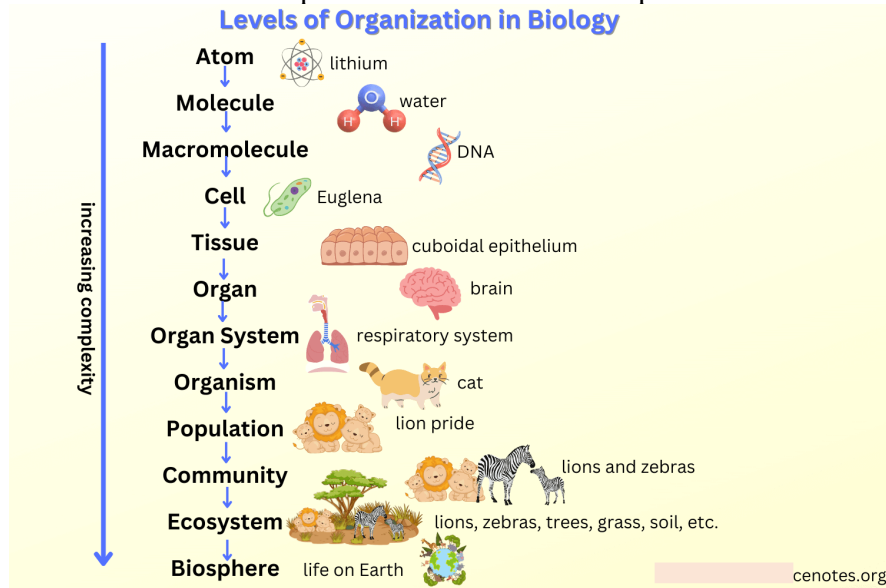
Possible control and treatment measures: Anti-inflammatory diets e.g., low fiber, low processed foods, early screening and anti-acid drugs

STOMACH ULCER



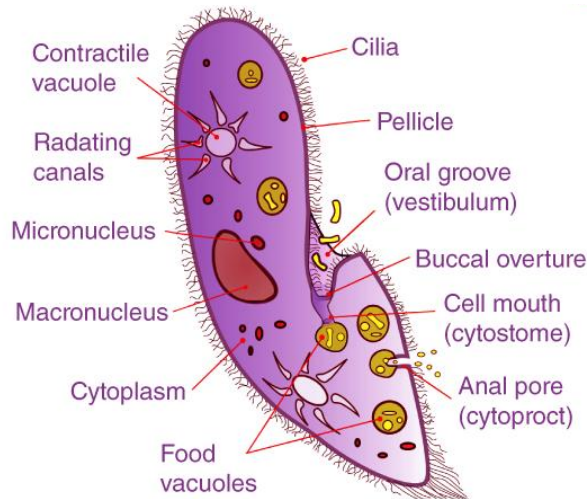
LEVELS OF ORGANISATION

The levels of organization in biology represent a hierarchical structure that illustrates how life is built from simple components into increasingly complex systems. Starting from subatomic particles and atoms, progressing through **molecules, cells, tissues, organs, organ systems, and whole organisms**, the hierarchy extends to ecological levels including populations, communities, ecosystems, and ultimately the biosphere—the global sum of all ecosystems on Earth. This framework highlights emergent properties at each level, where higher organizations exhibit characteristics not present in their individual parts.



Unicellular level of organization

The unicellular level of organization is characterized by a single cell carrying out all essential life processes through its specialized organelles. This level is exemplified by protozoans like Paramecium, which are free-living single-celled eukaryotes, Amoeba, plasmodium etc.



paramecium structure

Paramecium features several key structures with specific roles:

- **Macronucleus:** Regulates non-reproductive activities such as metabolism and growth.
- **Micronucleus:** Plays a key role in genetic exchange during conjugation for reproduction.
- **Cilia:** Enable movement and generate water currents to direct food toward the oral groove.

- Contractile vacuoles (one anterior and one posterior): Maintain water balance by expelling excess fluid from the cytoplasm.
- Food vacuoles: Enclose ingested particles where enzymatic digestion occurs near the cytopharynx.
- Cytoproct: Serves as the anal pore for releasing indigestible waste materials outside the cell.
-

Benefits of unicellular organization

1. Minimal distance between the cell surface and interior facilitates rapid diffusion of nutrients, gases, and wastes.
2. High surface area to volume ratio enhances efficient material exchange across the membrane.
3. Simple asexual reproduction via binary fission allows quick population increase.

Drawbacks of unicellular organization

1. Absence of division of labor leads to reduced efficiency in performing multiple functions simultaneously.
2. Limited potential for significant body size increases due to diffusion constraints.

Benefits of small body size

1. Supports rapid and agile movement in aquatic environments.
2. Greater surface area relative to volume promotes quicker gas and nutrient absorption.
3. Enables passage through narrow crevices and pores.
4. Permits colonization of diverse microhabitats.
5. Favors high reproduction rates with better offspring survival odds.
6. Reduces visibility to potential predators.

Drawbacks of small body size

1. Rapid heat loss occurs due to elevated surface area to volume ratio.
2. Elevated metabolic demands require frequent feeding.
3. Inability to deter or frighten larger predators.
4. Vulnerability to being swallowed entirely by enemies.

Benefits of large body size

1. Lower metabolic rate per unit mass reduces overall food requirements.
2. Reduced surface area to volume ratio minimizes heat loss.
3. Greater ability to intimidate or repel predators through sheer size.
4. Predators can typically consume only portions rather than the whole organism.

Drawbacks of large body size

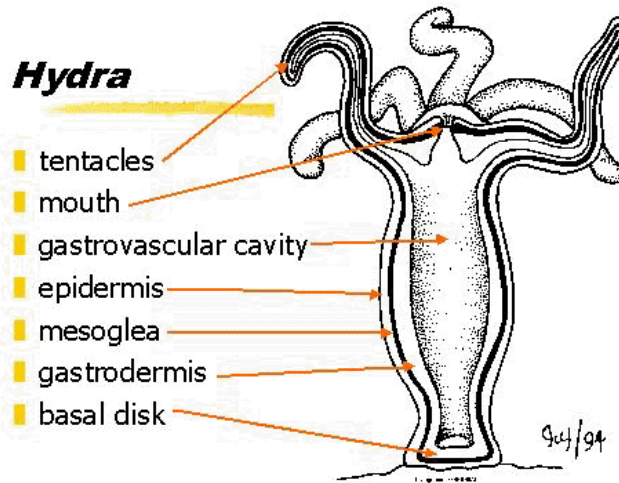
1. Movement tends to be slower and less efficient.
2. Smaller surface area slows material exchange with the environment.
3. Difficulty navigating confined spaces restricts habitat options.
4. Generally lower reproduction rates with reduced survival probabilities for young.
5. Increased detectability makes them more conspicuous to predators.

Tissue level of organization

The **tissue level** of organization represents an intermediate stage in the biological hierarchy where similar cells group together to form **tissues** that perform specific functions. This level emerges after the cellular level and precedes the organ level. Organisms at this stage exhibit **true tissues** with some division of labor, but lack complex organs or organ systems.

Key Characteristics

- Cells differentiate into distinct types and aggregate into layers or sheets.
- Basic tissues include epithelial (covering/protection), muscular (movement), connective (support), and nervous (coordination) in more advanced cases, though simpler organisms have fewer types.
- Physiological processes distribute among specialized cell groups rather than relying on a single cell.
- This level appears primarily in members of the phylum **Cnidaria** (e.g., Hydra, jellyfish, sea anemones, corals) and, to a limited extent, in **Porifera** (sponges), though sponges show loose tissue organization without true tissue layers in some classifications.



Advantages of the Tissue Level

Compared to the cellular level, it introduces division of labor among tissues, enhancing efficiency in functions like protection, digestion, and sensation.

It permits larger body sizes than single cells, supports basic coordination via nerve nets, enables high regeneration potential, and provides structural support for aquatic lifestyles.

Colonial level of organization

The colonial level involves aggregates of independent unicellular or simple multicellular individuals that live together in a group, often connected physically but with limited functional integration. Each unit (zooid or cell) can survive separately, and there is partial division of labor, such as reproductive and somatic roles. Classic examples are **Volvox** (a spherical colony of flagellated cells with daughter colonies) and some Portuguese man-of-war variants, though true colonies are common in algae and certain protozoans.

Advantages of the Colonial Level

It combines benefits of unicellular independence with multicellular cooperation, allowing larger colony sizes for better predator deterrence, coordinated movement (e.g., rolling in *Volvox*), specialized reproduction in certain cells,

Increased survival through collective nutrient sharing while retaining individual viability if separated.

Organ level of organization

The organ level features integration of different tissue types into discrete organs, each performing complex functions. Organisms are usually triploblastic (with mesoderm), enabling bilateral symmetry and cephalization. This level first appears in flatworms (Platyhelminthes) like planarians, which have organs such as eyespots, pharynx, and gastrovascular cavity, and extends to higher animals with organ systems.

Specific Advantages of organ level Over Tissue and cellular levels

Permits emergence of organ systems for coordinated physiology.

Dramatic increase in size and complexity with extensive division of labor eliminating overload on single cells e.g., muscles for locomotion.

Enhanced coordination and response to environment

Potential for terrestrial adaptation through specialized respiratory and supportive organs for example lungs that aids gaseous exchange in air as a medium.

Sample activity of integration

You are part of a research team at a gastroenterology innovation lab investigating why the intestinal epithelial lining fails in patients with **chronic inflammatory bowel diseases (IBD)**. Patients experience recurrent inflammation, abdominal pain, diarrhoea, and increased risk of complications like ulcers.

Clinical data from patients include;

- Biopsies and imaging show disrupted epithelial barrier function in intestines without primary genetic mutation in structural proteins.
- Increased intestinal permeability
- Electron micrographs show disorganized apical actin cytoskeleton in enterocytes (absorptive cells in intestinal mucosa)
- Reduced number and irregular arrangements of microvilli on the epithelial surface.

Write a report to explain the patients' conditions and recommend control and treatment measures

“Biology gives you a brain. Life turns it into a mind”-JEFFREY EUGENIDES

Thank you for studying these notes. They are open for review incase of any suggestion. For any assistance contact on mahesironald@gmail.com or 0764671959/0743639548