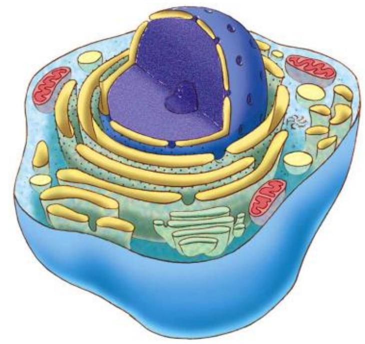
EUKARYOTIC CELLS



- Eukaryotic (Gr., *eu*=good, *karyotic*=nucleated)
- essentially **two envelope systems**
- very much larger than prokaryotic cells.
- Secondary membranes envelop the nucleus and other internal organelles and to a great extent they pervade the cytoplasm as the endoplasmic
- reticulum.
- True cells which occur in the plant (from algae to angiosperms) and the animals (from Protozoa to mammals).
  Though have different shape, size, and physiology; all the cells are typically composed of
- plasma membrane,
- cytoplasm
- and its organelles (mitochondria, endoplasmic reticulum, ribosomes, Golgi apparatus, etc)., and
- a true nucleus.
- Here the nuclear contents, such as DNA, RNA, nucleoproteins and nucleolus remain separated from the cytoplasm by the thin, perforated nuclear membranes.

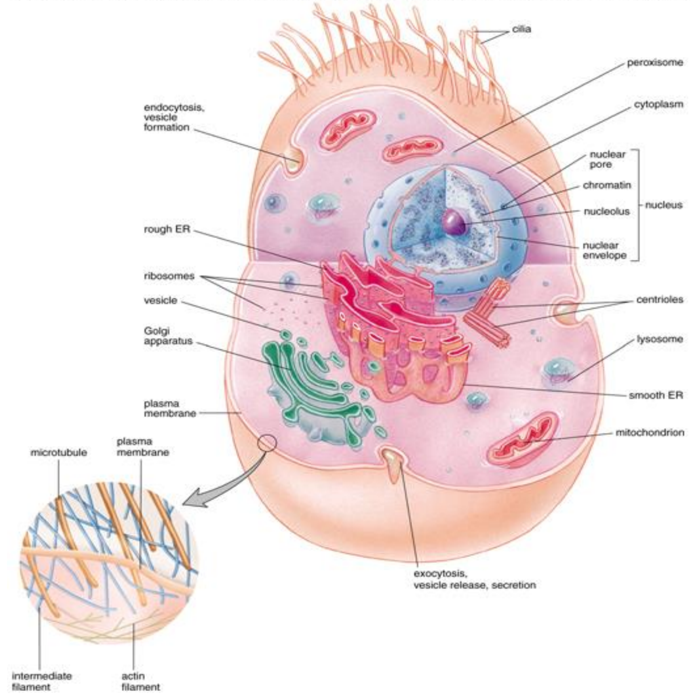
GENERAL FEATURES OF DIFFERENT TYPES OF EUKARYOTIC CELLS

Cell Shape

- The basic shape of the eukaryotic cell is **spherical**,
- however, the shape is ultimately determined by the specific function of the cell.
- Thus, the shape of the cell may be **variable** (*i.e.*, frequently changing the shape) or **fixed**.
- Variable or irregular shape occurs in *Amoeba* and white blood cells or leucocytes
- (In fact, leucocytes are spherical in the circulating blood, but in other conditions they may produce pseudopodia and become irregular in shape).
- Fixed shape of the cell occurs in almost all protists (*e.g.*, *Euglena*, *Paramecium*), plants and animals.
- In unicellular organisms the cell shape is maintained by tough plasma membrane and exoskeleton.
- In a multicellular organism, the shape of the cell depends
  - mainly on its functional adaptations and
  - partly on the surface tension, viscosity of the protoplasm, cytoskeleton of microtubules, microfilaments and intermediate filaments, the mechanical action exerted by adjoining cells and rigidity of the plasma membrane (*i.e.*, presence of rigid cell wall in plant cells).
- Shape may vary from animal to animal and from organ to organ.
- Even the cells of the same organ may display variations in the shape.
- Diverse shapes
- **polyhedral** (with 8, 12 or 14 sides; *e.g.*, squamous epithelium)
- **flattened** (*e.g.*, squamous epithelium, endothelium and the upper layers of the epidermis)
- **cuboidal** (*e.g.*, in thyroid gland follicles)
- **columnar** (*e.g.*, the cells lining the intestine)
- **discoidal** (*e.g.*, red blood cells or erythrocytes)
- **spherical** (*e.g.*, eggs of many animals)
- **spindle shaped** (*e.g.*, smooth-muscle fibres)
- **elongated** (*e.g.*, nerve cells or neurons)
- **branched** (*e.g.*, chromatophores or pigment cells of skin).
- Among plants, the cell shape also depends upon the function of the cell. For example, cells such as
- glandular hairs on a leaf, the guard cells of stomata and root hair cells have their special shape.

Cell Size

- larger (mostly ranging between 10 to 100 µm) than the
- prokaryotic cells (mostly ranging between 1 to 10 ⌠m).
- Size of the cells of the unicellular organisms
- is larger than a typical multicellular organism's cells.
- *Amoeba proteus:* biggest among the unicellular organisms; its length being 1 mm (1000 µm).
- *Euglena:* up to 500 ⌠m (0.5 mm) in length.
- *Euplotes* (a freshwater ciliate) is 120 ⌠m in length.
- *Paramecium caudatum* :150 to 300 µm (0.15 to 0.3 mm) in length.
- Diatoms have a length of 200 ⌠m or more.
- The single-celled alga, *Acetabularia* which consists of a stalk and a cap is exceptionally large-sized and measures up to 10 cm in height.
- The size of the cells of multicellular organisms ranges between 20 to 30 µm.



	Cell	Size (Diameter)
Animals	polocytes	4 µm
	human erythrocytes	7 to 8 µm
	egg of ostrich	18 cm (its yolk or deutoplasm is about 5 cm in diameter)
	some nerve cells of humans	a meter long "tails" or axons
Plants	Ovule of Cycas	
	The fibre cells (*i.e.*, sclerenchyma cells) of Manila hemp	100 cm in length.

Cell Volume

- The volume of a cell is fairly constant for a particular cell type and is independent of the size of the organism. (This is called the **law of constant volume**.)
- For example, kidney or liver cells are about the same size in the bull, horse and mouse.
- The difference in the total mass of the organ or organism depends on the number, not on the volume of the cells.
- Thus, the cells of an elephant are not necessarily larger than those of other tiny animals or plants. The large size of the elephant is due to the larger number of cells present in its body.
- If a cell is to be efficient, the ratio of volume to surface should be within a limited range.
- An increase in cell volume is accompanied by a much smaller expansion in the surface area of the cell (In fact, volume increases as cube of radius, while surface area increases as square of radius).
- In other words, a large cell has a proportionately smaller surface and a higher volume : surface ratio than a smaller cell.

- Further, a large cell volume has to accommodate many organelles simultaneously limiting the exchange of information and materials through the surface.
- This problem is partially overcome by developing a cylindrical shape or by forming numerous extensions (*e.g.*, microvilli) of the plasma membrane.
- It is also for this reason that metabolically active cells, tend to be smaller in size.

Cell Number

- varies from a single cell in a **unicellular organism** (Protists such as protozoa and protophyta)
- to many cells in multicellular organisms (Most plants, fungi and animals).
- The number of cells in the multicellular organisms usually remains correlated with size of the organisms and, therefore, small-sized organism has less number of cells in comparison to large sized organisms.
- For example, a human being weighing about 80 kg may contain about 60 thousand billion cells in his body.
- This number would be more in certain other multicellular organisms.
- Further, the number of cells in most multicellular organisms is indefinite, but the number of cells may be fixed in some multicellular organisms.
- For example, in rotifers, number of nuclei in the various organs are found to be constant in any given species.
- This phenomenon of cells or nuclear constancy is called **eutely**.
- In one species of rotifer, **Martini** (1912) always found 183 nuclei in the brain, 39 in
- the stomach, 172 in the cornea epithelium, and so on (see **Hickman**, **Sr**., *et al.* 1979).
- Among plants, colonial green algae exhibit cell constancy.
- For example, the green alga, *Pandorina* has a colony consisting of 8, 16 or 32 cells.
- Likewise, another green alga, *Eudornia,* has 16, 32 or 64 cells in its colony.

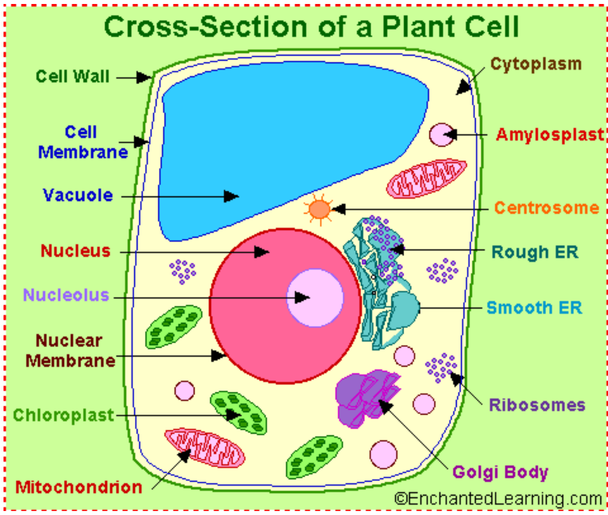
Structure

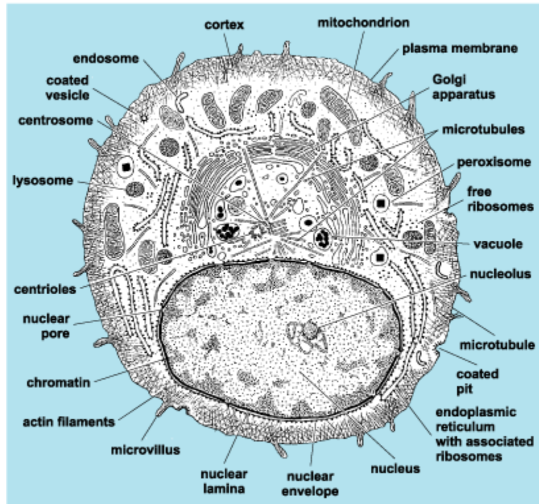
An eukaryotic cell consists of the following components :

A. Cell wall and plasma membrane;

B. Cytoplasm;

C. Nucleus.





Cell Wall and Plasma Membrane

1. **Cell wall.**

- The outermost structure of most plant cells is a dead and rigid layer called **cell wall**.
- It is mainly composed of carbohydrates such as cellulose, pectin, hemicellulose and lignin and certain
- fatty substances like waxes.
- Ultrastructurally cell wall is found to consist of a microfibrillar network lying in a gel-like matrix.
- The microfibrils are mostly made up of cellulose.
- There is a pectin-rich cementing substance between the walls of adjacent cells which is called **middle lamella**.
- The cell wall which is formed immediately after the division of cell, constitutes the **primary cell wall**.
- Many kinds of plant cells have only primary cell wall around them.
- Primary cell wall is composed of pectin, hemicellulose and loose network of cellulose microfibrils. In certain types of cells such as phloem and xylem, an additional layer is added to the inner surface of the primary cell wall at a later stage.
- This layer is called **secondary cell wall** and it consists mainly of cellulose, hemicellulose and lignin.
- In many plant cells, there are tunnels running through the cell wall called **plasmodesmata** which allow communication with the other cells in a tissue.
- The cell wall constitutes a kind of exoskeleton that provides protection and mechanical support to the plant cell.
- It determines the shape of plant cell and prevents it from desiccation.

2. **Plasma membrane.**

- Every kind of animal cell is bounded by a living, extremely thin and
- delicate membrane called **plasmalemma, cell membrane** or **plasma membrane**.
- In plant cells, plasma membrane occurs just inner to cell wall, bounding the cytoplasm. The plasma membrane exhibits a tri-laminar (*i.e.*, three-layered) structure with a translucent layer sandwiched between two dark layers.
- At molecular level, it consists of a continuous bilayer of lipid molecule (*i.e.*, phospholipids and cholesterol) with protein molecules embedded in it or adherent to its both surfaces.
- Some carbohydrate molecules may also be attached to the external surface of the plasma membrane, they remain attached either to protein molecules to form **glycoproteins** or to lipids to form **glycolipids**.
- The plasma membrane is a **selectively permeable membrane**; its main function is to control selectively the entrance and exit of materials.

- This allows the cell to maintain a constant internal environment (**homeostasis**).
- Transport of small molecules such as water, oxygen, carbon dioxide, ethanol, ions, glucose, etc., across the plasma membrane takes place by various means such as osmosis, diffusion and active transport.
- The process of active transport is performed by special type of protein molecules of plasma membrane called **transport proteins** or **pumps**, consuming energy in the form of ATP molecules.
- For bulk transport of large-sized molecules, plasma membrane performs **endocytosis** (*i.e.*, endocytosis, pinocytosis, receptor-mediated endocytosis and phagocytosis) and **exocytosis** both of these processes also utilise energy in the form of ATP molecules.
- Various cell organelles such as chloroplasts, mitochondria, endoplasmic reticulum and lysosomes are also bounded by membranes similar to the plasma membrane.
- All the cellular membranes have a basic trilaminar **unit membrane** construction.
- However, their structure and extent of activity are mainly depended on the relative proportion of their constituent protein and lipid molecules.
- Thus, membranes which are metabolically highly active, *e.g.*, those of mitochondria and chloroplasts have a greater proportion of proteins and more granular appearance than those membranes which are relatively less active, *e.g.*, myelin sheath of certain nerve fibres.
- The plasma membrane is followed by the cytoplasm which is distinguished into following structures :

A. Cytosol.

- The plasma membrane is followed by the colloidal organic fluid called **matrix** or **cytosol**.
- The cytosol is the aqueous portion of the **cytoplasm** (the extranuclear protoplasm) and of the **nucleoplasm** (the nuclear protoplasm).
- It fills all the spaces of the cell and constitutes its true **internal milieu**.
- Cytosol is particularly rich in differentiating cells and many fundamental properties of cell are because of this part of the cytoplasm.
- The cytosol serves to dissolve or suspend the great variety of small molecules concerned with cellular metabolism, *e.g.*, glucose, amino acids, nucleotides, vitamins, minerals, oxygen and ions.
- In all type of cells, cytosol contains the soluble proteins and enzymes which form 20 to 25 per cent of the total protein content of the cell.
- Among the important soluble enzymes present in the matrix are those involved in glycolysis and in the activation of amino acids for the protein synthesis.
- In many types of cells, the cytosol is differentiated into following two parts :
- (i) **Ectoplasm** or **cell cortex** is the peripheral layer of cytosol which is relatively non-granular, viscous, clear and rigid.
- (ii) **Endoplasm** is the inner portion of cytosol which is granular and less viscous.
- **Cytoskeleton and microtrabecular lattice.**
- The cytosol of cells also contains **fibres** that helpto maintain cell shape and mobility and that probably provide anchoring points for the other cellular structures.
- Collectively, these fibres are termed as the **cytoskeleton**.
- At least three general classes of such fibres have been identified.

1. The thickest are the **microtubules** (20 nm in diameter) which consists primarily of the **tubulin** protein.
    - The function of microtubules is the transportation of water, ions or small molecules, cytoplasmic streaming (cyclosis), and the formation of fibres or asters of the mitotic or meitotic spindle during cell division.
    - Moreover, they form the structural units of the centrioles, basal granules, cilia and flagella.

2. The thinnest are the microfilaments (7 nm in diameter) which are solid and are principally formed of **actin** protein.

- They maintain the shape of cell and form contractile component of cells, mainly of the muscle cells.

3. The fibres of middle order are called the **intermediate filaments** (**IFs**) having a diameter of 10 nm.

- They having been classified according to their constituent protein such as **desmin filaments**, **keratin filaments**, **neurofilaments**, **vimentin** and **glial filaments**.
- Recently, cytoplasm has been found to be filled with a three-dimensional network of interlinked filaments of cytoskeletal fibres, called **microtra-becular lattice** (**Porter** and **Tucker**, 1981).
- Various cellular organelles such as ribosomes, lysosomes, etc., are found anchored to this lattice.
- The microtrabecular lattice being flexible, changes its shape and results in the change of cell shape during cell movement.

B. Cytoplasmic structures.

- In the cytoplasmic matrix certain non-living and living structures remain suspended.
- The non-living structures are called **paraplasm** or **inclusions**,
- while the living structures are membrane bounded and are called **organoids** or **organelles**.
- Both kinds of cytoplasmic structures can be studied under the following headings :

(a) Cytoplasmic inclusions.

- The stored food and secretory substances of the cell remain suspended in the cytoplasmic matirx in the form of refractile granules forming the cytoplasmic inclusions.
- The cytoplasmic inclusions include oil drops, triacylglycerols (*e.g.,* fat cells of adipose tissue), yolk granules (or **deutoplasm**, *e.g.*, egg cells), secretory granules, glycogen granules (*e.g.*,muscle cells and hepatocytes of liver) and starch grains (in plant cells).

(b) Cytoplasmic organelles.

- Besides the separate fibrous systems, cytoplasm is coursed by a multitude of internal membranous structures, the organelles (literally the word organelle means a tiny organ).
- Membranes close off at specific regions of the eukaryotic cells performing specialized tasks :
- oxidative phosphorylation and generation of energy in the form of ATP molecules in mitochondria
- formation and storage of carbohydrates in plastids;
- protein synthesis in rough endoplasmic reticulum;
- lipid (and hormone) synthesis in smooth endoplasmic reticulum;
- secretion by Golgi apparatus;
- degradation of macromolecules in the lysosomes;
- regulation of all cellular activities by nucleus;
- organization of spindle apparatus by centrosomes and so forth.
- Membrane-bound enzymes catalyze reactions that would have occurred with difficulty in an aqueous environment.
- The structure and function of some important organelles are as follows:

1. Endoplasmic reticulum (ER).

- Within the cytoplasm of most animal cells is an extensive network (reticulum) of membrane-limited channels, collectively called **endoplasmic reticulum** (or ER).
- Some portion of ER membranes remains continuous with the plasma membrane and the nuclear envelope.
- The outer surface of **rough ER** has attached ribosomes, whereas **smooth ER** do not have attached ribosomes.
- Functions of smooth ER include **lipid metabolism** (both catabolism and anabolism; they synthesize a variety of phospholipids, cholesterol and steroids);
- **Glycogenolysis** (degradation of glycogen; glycogen being polymerized in the cytosol) and **drug detoxification** (by the help of the **cytochrome**
- On their membranes, rough ER (RER) contain certain ribosomespecific, transmembrane glycoproteins, called **ribophorins I** and **II**, to which are attached the ribosomes while engaged in polypeptide synthesis.
- As a growing secretory polypeptide emerges from ribosome, it passes through the RER membrane and gets accumulated in the lumen of RER.

- Here, these polypeptide chains undergo tailoring, maturation, and molecular folding to form functional secondary or tertiary protein molecules. RER pinches off certain tiny proteinfilled
- vesicles which ultimately get fused to cis Golgi. RER also synthesize membrane proteins and
- glycoproteins which are cotranslationally inserted into the rough ER membranes. Thus, endoplasmic
- reticulum is the site of biogenesis of cellular membranes.

2. **Golgi apparatus.**
    - It is a cup-shaped organelle which is located near the nucleus in many types of cells.
    - Golgi apparatus consists of a set of smooth **cisternae** (*i.e.*, closed fluid-filled flattened membranous sacs or vesicles) which often are stacked together in parallel rows.

- It is surrounded by spherical membrane bound **vesicles** which appear to transport proteins to and from it.
- Golgi apparatus consists of at least three distinct classes of cisternae : **cis Golgi, median Golgi** and **trans Golgi**, each of which has distinct enzymatic activities.
- Synthesized proteins appear to move in the following direction : rough ER →cis Golgi → median Golgi →trans Golgi→secretory vesicles/ cortical granules of egg/ lysosomes or peroxisomes.
- Thus, the size and number of Golgi apparatus in a cell indicate the active metabolic, mainly synthetic, state of that cell.
- Plant cells contain many freely distributed sub-units of Golgi apparatus, called **dictyosomes**, secreting cellulose and pectin for cell wall formation during the cell division.
- Generally, Golgi apparatus performs the following important functions :
  1. The packaging of secretory materials (*e.g.*, enzymes, mucin, lactoprotein of milk, melanin pigment, etc.) that are to be discharged from the cell.
  2. The **processing** of proteins, *i.e.*, glycosylation, phosphorylationsulphation and selective proteolysis.
  3. The synthesis of certain polysaccharides and glycolipids.
  4. The sorting of proteins destined for various locations (*e.g.*, lysosomes, peroxisomes, etc.) in the cell.
  5. The proliferation of membranous element for the plasma membrane.
  6. Formation of the acrosome of the spermatozoa.

3. **Lysosomes.** The cytoplasm of animal cells contains many tiny, spheroid or irregular-shaped, membrane-bounded vesicles known as **lysosomes**.

- The lysosomes are originated from Golgi apparatus and contain numerous (about 50) hydrolytic enzymes (*e.g.*, **acid phosphatase** that is cytochemically identified) for intracellular and extracellular digestion.
- They digest the material taken in by endocytosis (such as phagocytosis, endocytosis and pinocytosis), parts of the cell (by autophagy) and extracellular substances.
- Lysosomes have a high acidic medium (pH 5) and this acidification depends on ATP- dependent **proton pumps** which are present in the membrane of lysosomes and which accumulate protons (H+) inside the lysosomes.
- Lysosomes exhibit great **polymorphism**, *i.e.*, there are following four types of lysosomes :
    - ➢ primary lysosomes (storage granules),
    - ➢ secondary lysosomes (digestive vacuoles),
    - ➢ residual bodies and autophagic vacuoles.
- The lysosomes of plant cells are membrane-bounded storage granules containing hydrolytic digestive enzymes, *e.g.*, large **vacuoles** of parenchymatous cells of corn seedlings, **protein** or **aleurone bodies** and **starch granules** of cereal and other seeds.

3. **Cytoplasmic vacuoles.**

- The cytoplasm of many plant and some animal cells (*i.e.*, ciliate protozoans) contains numerous small or large-sized, hollow, liquid-filled structures, the **vacuoles**.
- These vacuoles are supposed to be greatly expanded endoplasmic reticulum or Golgi apparatus.
- The **vacuoles** of animal cells are bounded by a lipoproteinous membrane and their function is the storage, transmission of the materials and the maintenance of internal pressure of the cell.
- The vacuoles of the plant cells are bounded by a single, semipermeable membrane known as **tonoplast**.

- These vacuoles contain water, phenol, flavonols, anthocyanins (blue and red pigment), alkaloids and storage products, such as sugars and proteins.

4. **Peroxisomes.**
    - These are tiny circular membrane- bound organelles containing a crystal-core of
- enzymes (such as urate oxidase, peroxidase, D-amino oxidase and catalase, *e.g.*, liver cells and kidney
- cells).
- These enzymes are required by peroxisomes in **detoxification** activity, *i.e.*, in the metabolism or production and decomposition, of hydrogen peroxide or H2O2 molecules which are produced during neutralization of certain superoxides—the end products of mitochondrial or cytosolic reactions.
- Peroxisomes are also related with ®-oxidation of fatty acids and thermogenesis like the mitochondria and also in degradation of the amino acids. In green leaves of plants, peroxisomes carry out the process of **photorespiration**.

5. **Glyoxysomes.**

- These organelles develop in a germinating plant seed (*e.g.*, castor bean or *Ricinus*) to utilize stored fat of the seed (*i.e.*, to metabolise the triglycerides).
- Glyoxysomes consist of an amorphous protein matrix surrounded by a limiting membrane. The membrane of glyoxysomes originates from the ER and their enzymes are synthesized in the free ribosomes in the cytosol. Enzymes of glyoxysomes are used to transform the fat stores of the seed into carbohydrates by way of **glyoxylate cycle**.

6. **Mitochondria.**

- Mitochondria are oxygen-consuming ribbon-shaped cellular organelles of immense importance.
- Each mitochondrion is bounded by two unit membranes.
- The outer mitochondrial membrane resembles more with the plasma membrane in structure and chemical composition.
- It contains **porins**, proteins that render the membrane permeable to molecules having molecular weight as high as 10,000. Inner mitochondrial membrane is rich in many enzymes, coenzymes and other components of electron transport chain.
- It also contains **proton pumps** and many **permease** proteins for the transport of various molecules such as citrates, ADP, phosphate and ATP.
- Inner mitochondrial membrane gives out finger-like outgrowths (**cristae**) towards the lumen of mitochondrion and contains tennis-racket shaped **F1 particles** which contain ATP-ase enzyme for ATP synthesis.
- Mitochondrial matrix which is the liquid (colloidal) area encircled by the inner membrane, contains the soluble enzymes of Krebs cycle which completely oxidize the **acetyl-CoA** (an end product of cytosolic glycolysis and mitochondrial oxidative decarboxylation) to produce CO2, H2O and hydrogen ions.
- Hydrogen ions reduce the molecules of NAD and FAD, both of which pass on hydrogen ions to respiratory or electron transport chain where oxidative phosphorylation takes place to generate energy-rich ATP molecules.
- Since mitochondria act as the 'power-houses' of cells, they are abundantly found on those sites where energy is earnestly required such as sperm tail, muscle cell, liver cell (up to 1600 mitochondria), microvilli, oocyte (more than 300,000 mitochondria), etc.
- Mitochondria also contain in their matrix single or double circular and double stranded DNA molecules, called **mt DNA** and also the 55S ribosomes, called **mitoribosomes**.
- Since mitochondria can synthesize 10 per cent of their proteins in their own protein-synthetic machinery, they are considered as **semi-autonomous organelles**. Mitochondria may also produce heat (brown fat), and accumulate iron-containing pigments (Heme ferritin), ions of Ca2+ and HPO 2-- (or phosphate; *e.g.,* osteoblasts of bones or yolk proteins).

7. **Plastids.**

    Plastids occur only in the plant cells.

    They contain pigments and may synthesize an accumulate various substances. Plastids are of the following types:

1. Leucoplasts are colourlessplastids of embryonic and germ cells lacking thylakoids and ribosomes.
2. Amyloplasts produce starch.
3. **Proteinoplasts** accumulate protein.
4. **Oleosomes** or **elaioplasts** store fats and essential oils.
5. **Chromoplasts** contain pigment molecules and are coloured organelles.

- Chromoplasts impart variety of colours to plant cells, such as red colour in tomatoes, red chillies and carrots, various colours to petals of flowers and green colour to many plant cells.
- The green coloured chromoplasts are called **chloroplasts**.
- They have chlorophyll pigment and are involved in the photosynthesis of food and so act like the kitchens of the cell.
- Chloroplasts have diverse shapes in green algae but are round, oval or discoid in shape in higher
- plants.
- Like mitochondria, each chloroplast is bounded by two membranous envelopes, both of which have no chlorophyll pigment.
- However, unlike mitochondria there occurs third system of membranes within the boundary of inner membrane, called **grana**.
- The grana form the main functional units of chloroplast and are bathed in the homogeneous matrix,
- called the **stroma**.
- Stroma contains a variety of photosynthetic enzymes and starch grains. Grana are stacks of membrane-bounded,
- flattened discoid sacs, arranged like neat piles of coins.
- A chloroplast contains many such interconnected grana on which are located various photosynthetic enzymes and the molecules of green pigment chlorophyll and other photosynthetic pigments to trap the light energy. They contain DNA, ribosomes and complete protein synthetic machinery.

8. **Ribosomes.**

- Ribosomes are tiny spheroidal dense particles (of 150 to 200 A0 diameter) that contain approximately equal amounts of RNA and proteins.
- They are primarily found in all cells and serve as a scaffold for the ordered interaction of the numerous molecules involved in protein synthesis.
- Ribosome granules may exist either in the **free state** in the cytosol (*e.g.*, basal epidermal cells) or
- **attached** to RER (*e.g.*, pancreatic acinar cells, plasma cells or antibodies-secreting lymphocytes,
- osteoblasts, etc.).
- Ribosomes have a sedimentation coefficient of about **80S** and are composed of two subunits namely **40S** and **60S**.
- The smaller 40S ribosomal subunit is prolate ellipsoid in shape and consists of one molecule of 18S ribosomal RNA (or rRNA) and 30 proteins (named as S1, S2, S3, and so on).
- The larger 60S ribosomal subunit is round in shape and contains a **channel** through which growing polypeptide chain makes its exit.
- It consists of three types of rRNA molecules, *i.e.*, 28S rRNA, 5.8 rRNA and 5S rRNA, and 40 proteins (named as L1, L2, L3 and so on).

9. **Microtubules and microtubular organelles.**
    - With rare exceptions, such as human erythrocyte, microtubules are found in the cytoplasm of all types of eukaryotic cells.
    - They are long fibres (of indefinite length) about 24 nm in diameter. In cross section each microtubule appears to have a dense wall of 6 nm thickness and a light or hollow centre.
    - In cross section, the wall of a microtubule is made up of 13 globular subunits, called **protofilaments**, about 4 to 5 nm in diameter.

- Chemically, microtubules are composed of two kinds of protein subunits : 〈**-tubulin (tubulin A)** and **tubulin** (**tubulin B**), each of M.W. 55,000 daltons.

The following cell organelles are derived from special assemblies of microtubules :

(1) Cilia and flagella.

- Ciliary and flagellar cell motility is adapted to liquid media and is
- executed by minute, specially differentiated appendices, called **cilia** and **flagella**.
- Both of these organelles have very similar structure; they differ mainly in size and number (*i.e.*, flagella are longer and fewer in number, while cilia are short and numerous).
- Cilia are used for locomotion in isolated cells, such as certain protozoans (*e.g., Paramecium*). or to move particles in the medium, as in air passages and oviduct.
- Flagella are generally used for locomotion of cells, such as the spermatozoon and *Euglena* (protozoan).
- All cilia and flagella are built on a common fundamental plan : a bundle of microtubules called the **axoneme**
- (1 to 2 nm in length and 0.2 μm in diameter) is surrounded by a membrane that is part of the plasma membrane. The axoneme is connected with the basal body which is an intracellular granule lying in the cell cortex and which originates from the centrioles.
- Each axoneme is filled with **ciliary matrix**, in which are embedded two central **singlet** microtubules, each with the 13 protofilaments and nine outer pairs of microtubules, called **doublets**.
- This recurring motif is known as the 9 + 2 array. Each doublet contains one complete microtubule, called the **A subfibre,** containing all the 13 protofilaments. Attached to each A subfibre is a **B subfibre** with 10 protofilaments.
- Subfibre A has two **dynein arms** which are oriented in a clockwise direction. Doublets are linked
- together by **nexin links**.
- Each subfibre A is also connected to the central microtubules by **radial spokes** terminating in fork-like structures, called **spoke knobs** or **heads**.
- Propulsion by both cilia and flagella is caused by bending at their base.
- Cilia move by a whiplike **power stroke** fueled by hydrolysis of ATP, followed by a **recovery stroke.** Flagellar movement
- is also powered by ATP hydrolysis. In contrast to cilia, they generally move by waves that emanate
- from the base and spread outward toward the tip.

2. Basal bodies and centrioles.

  - Basal bodies and centrioles are similar in structure and function; both act as nucleating centres from which microtubules grow.

- **Centrioles** are cylinders that measure 0.2 μmx 0.5 μm.
- This cylinder is open on both ends, unless it carries a cilium or flagellum (then it is called **basal body** or **kinetosome**).
- The wall of a centriole has nine groups of microtubules arranged in a circle.
- Each group, called **blade** is a **triplet** formed of three tubules — A, B, and C that are skewed toward the centre.
- Tubule A has 13 protofilaments, while tubules B and C have only 10 protofilaments each.
- There are no central microtubules in the centrioles and no dynein arms like the cilia; however, triplets are linked by connectives.
- The **procentriole** (or daughter centriole) is formed at right angles to the centriole and is located near the proximal end of the centriole.
- Both centrioles are found in a specially differentiated region the **centrosome, cell centre** or **centrosphere**. The centrosome is juxtanuclear (L., juxta = near) and firmly attached to the nuclear envelope.
- At the time of cell division two pairs of centrioles are formed and form the spindle of microtubules which help in the separation and movement of chromosomes during concluding stages of cell divisions.

C. Nucleus

The nucleus is centrally located and spherical cellular component which controls all the vital activities of the cytoplasm and carries the hereditary material the DNA in it. The nucleus consists of the following three structures :

1. **Chromatin.** Nucleus being the heart of every type of eukaryotic cell, contains the **genes**, the hereditary units. Genes are located on the **chromosomes** which exist as **chromatin network** in the non- dividing cell, *i.e.*, during interphase.

The chromatin has two forms :

1. Euchromatin is the well-dispersed form of chromatin which takes lighter DNA-stain and is genetically active, *i.e.*, it is involved in gene duplication, gene transcription (DNA- dependent RNA synthesis) and **phenogenesis** or phenotypic expression of a gene through some type of protein synthesis.

2. **Heterochromatin** is the highly condensed form of chromatin which takes dark DNA-stain and is genetically inert.

- Such type of chromatin exists both in the region of centromere (called **constitutive heterochromatin**) and in the sex chromatin (called **facultative heterochromatin**) and is latereplicating
- one.
- Chemically, the chromatin contains a single DNA molecule, equal amount of five basic types of histone proteins, some RNA molecules and variable amount of different types of acidic proteins.
- In fact, the chromatin has its unit structures in the form of **nucleosomes**.
- The chromatin binds strongly to the inner part of nuclear lamina, a 50 to 80 nm thick fibrous lamina lining the inner side of the nuclear envelope.
- Nuclear lamina is made up of three types of proteins, namely **lamin A**, **B** and **C**.
- Lamin proteins are homologous in structure to IF proteins and serve the following functions :

1. They anchor parts of interphase chromatin to the nuclear membrane.
   They tend to interfere with chromatin condensation during interphase of cell cycle.
   2. Lamins may play a crucial role in the assembly of interphase nuclei after each mitosis.

3. **Nuclear envelope and nucleoplasm.**
   Nuclear envelope comprises two nuclear membranes—

- **inner nuclear membrane**
- **outer nuclear membrane**
- At certain points the nuclear envelope is interrupted by structures called **pores** or **nucleopores.** Nuclear pores contain octagonal **pore complexes** which regulate exchange between the nucleus and cytoplasm.
  3. **Nucleolus.**

- Nucleus contains in its nucleoplasm a conspicuous, darkly stained, circular suborganelle, called **nucleolus**.
- Nucleolus lacks any limiting membrane and is formed during interphase by the ribosomal DNA (rDNA) of **nucleolar organizer** (**NO**).
- Nucleolus is the site where ribosomes are manufactured.
- It is here where ribosomal DNA transcribes most of rRNA molecules and these molecules undergo processing before their step-wise addition to 70 types of ribosomal proteins to form the ribosomal sub-units.

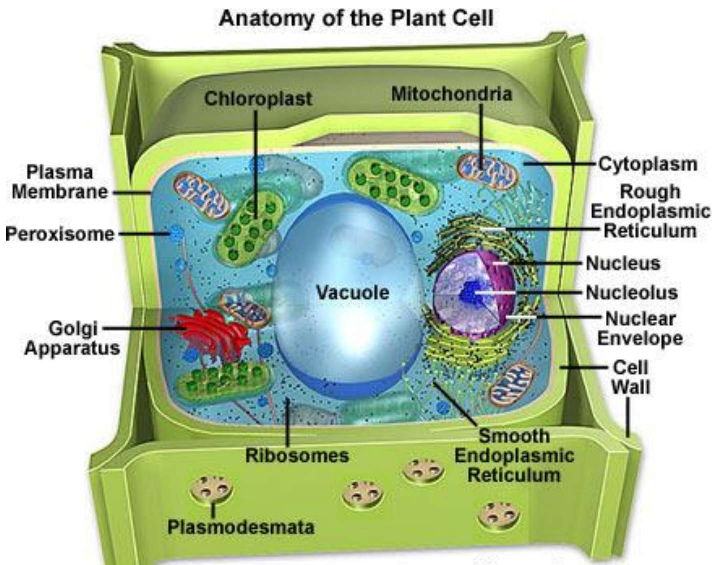
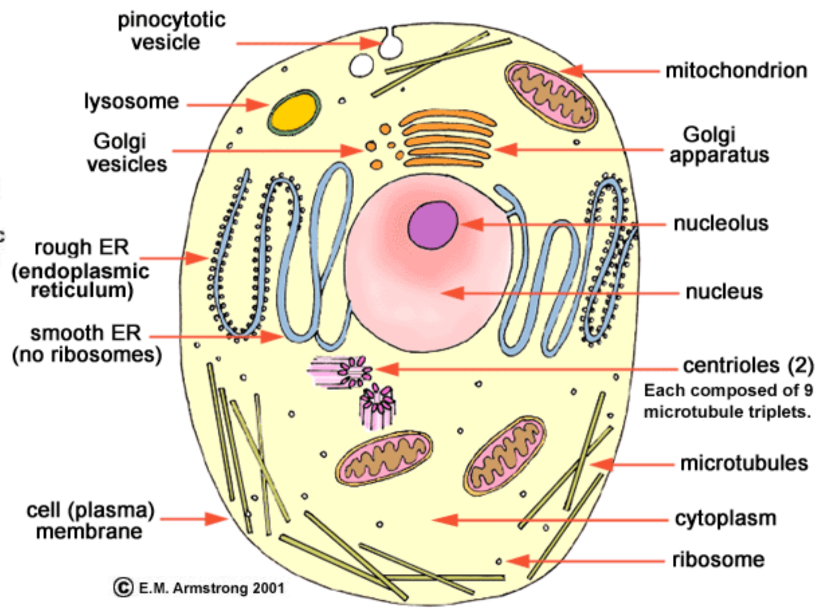


Figure 1



Differences between prokaryotic and eukaryotic cells (Source : Maclean and Hall, 1987).

	Feature	**Prokaryotic cell**	**Eukaryotic cell**
1	Size	Mostly 1-10 μm	Mostly 10-100 μm
2	Multicellular forms	Rare	Common, with extensive tissue formation
	Cell wal	Present in most but not in all	Present in plant and fungal cells only
4	Plasma membrane	Present	Present
5	Nucleus	Absent	Present
6	Nuclear membranes	Absent	Present
7	Chromatin with histone	Absent	Present
8	Genetic material	Circular or linear, double-stranded DNA : genes are not frequently interrupted by	Linear double-stranded DNA : genes interrupted by intron * sequences, especially in higher eukaryotes

		intron	
9	Nucleoli and mitotic apparatus	Absent	Present
10	Plasmids	Commonly present	Rare
i	Cellular organelles : Mitochondria	Absent	Present
Ii	Endoplasmic reticulum	Absent	Present
iii	Vacuoles	Absent	Present
iv	Lysosomes	Absent	Present
v	Chloroplasts	Absent	Present (only in plants)
vi	Centrioles	Absent	Present(absent in higher plants)
vi i	Ribosomes	Present(70S)	Present(80S)
vi ii	Microtubules	Absent	Present
ix	Flagellae	Simple structure composed of the protein flagellin	Complex 9 + 2 structure of tubulin and other protein
12	Respiration	Many strict anaerobes (oxygen fatal)	All aerobic, but some facultative anaerobes by secondary modifications
13	Metabolic patterns	Great variations	All share cytochrome electron transport chains, Krebs cycle oxidation, Embden-Meyerhof glucose metabolism or glysolysis
14	Photosynthetic Enzymes	Bound to plasma membrane as composite chromatophores	enzymes packaged in plastids bound by membrane
15	Sexual system	Rare : if present one way (and usually partial) ; transfer of DNA from donor to recipient cell occurs	Both sexes involved in sexual participation and entire genomes transferred; alternation of haploid and diploid generations is also evident

The cells of animals and plants have the following differences :

	Animal cell	**Plant cell**
1.	Animal cells are generally small in size	.Plant cells are larger than animal cells
2.	Cell wall is absent	The plasma membrane of plant cells is surrounded by a rigid cell wall of cellulose.
3.	. Except the protozoan *Euglena* no animal cell possesses plastids.	Plastids are present
4.	Vacuoles in animal cells are many and small	Most mature plant cells have a large central sap vacuole.
5.	Animal cells have a single highly complex and prominent Golgi	Plant cells have many simpler units of Golgi apparatus, called dictyosomes

	apparatus	
6.	Animal cells have centrosome and centrioles	Plant cells lack centrosome and centrioles.