CORE IDEA 1: THE CELL AND BIOMOLECULES OF LIFE
TOPIC 1.1: ORGANELLES AND CELLULAR STRUCTURES

Learning Outcomes

You should be able to:

(a) outline the cell theory with the understanding that cells are the smallest unit of life, all cells come from pre-existing cells, and living organisms are composed of cells

(b) interpret and recognise drawings, photomicrographs and electronmicrographs of the following membrane systems and organelles: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus (for practical assessment, candidates may be required to operate a light microscope, mount slides and use an eyepiece graticule and a stage micrometer)

(c) outline the functions of the membrane systems and organelles listed in **(b)**

(d) describe the structure of a typical bacterial cell (small and unicellular, peptidoglycan cell wall, circular DNA, 70S ribosomes and lack of membrane-bound organelles)

Textbooks and References

Campbell, Urry, Cain, Wasserman, Minorsky, Reece (2018) **Biology – A Global Approach (11th Edition)(Global Edition) Chapter 7: Cell Structure & Function pg. 163 – 195** (Pearson Publication) ISBN-10 1-292-17043-3

Note: These textbooks and references are available in our library. You may wish to borrow them to supplement your reading when necessary.

Contents

Introduction

The following questions should help you frame your learning:

1. Why is a cell the basic unit of life and how does it promote continuity of life?

2. How is the basic unit crucial in understanding life?

3. What are the differences between cells of prokaryotes and eukaryotes, between cells of plants and animals, and between cells of unicellular and multicellular organisms?

Sub-cellular structures provide the means to drive cellular processes

Knowing how cellular structures facilitate specific cellular processes is fundamental to explaining how life ‘works’. The cell theory states that the cell is the smallest and most basic unit of life and that cells grow from existing cells. Understanding the role of cellular organelles (such as the nucleus, ribosome, chloroplast and mitochondrion) and cellular structures (for example, the cytoskeleton) will help in understanding the concept of how structure relates to function.

There are significant differences between cells of prokaryotes and eukaryotes. Using bacteria as a model, the nucleoid is not enclosed by any membrane. Plasmids may be present as extra-chromosomal DNA. Membrane-bound organelles, such as mitochondria and endoplasmic reticulum, are absent. Prokaryotic ribosomes are different from eukaryotic ribosomes. Some bacterial cells have cell walls that comprise peptidoglycan rather than cellulose. Within the eukarya domain, the cell model of plants is also different from that of animals.

Eukaryotic cells also contain internal membrane structures that partition the cell into specialised compartments so that cellular processes can occur with optimal activity e.g. chloroplasts and mitochondria. The endomembrane system, consisting of rough and smooth endoplasmic reticulum and Golgi apparatus, is responsible for protein processing and vesicular transport within the cell.

Prokaryotes generally lack such membrane-bound organelles and endomembrane systems; yet they survive and reproduce. In the endosymbiotic theory, organelles like mitochondria and chloroplasts represent formerly free-living prokaryotes that were taken inside another cell, and this could explain the link between the two domains in the tree of life.

A bridge to O Level Biology
(6093 syllabus and 5078 syllabus)

You should have learnt:

A. identify cell structures (including organelles) of typical plant and animal cells from diagrams, photomicrographs and as seen under the light microscope using prepared slides and fresh material treated with an appropriate temporary staining technique:

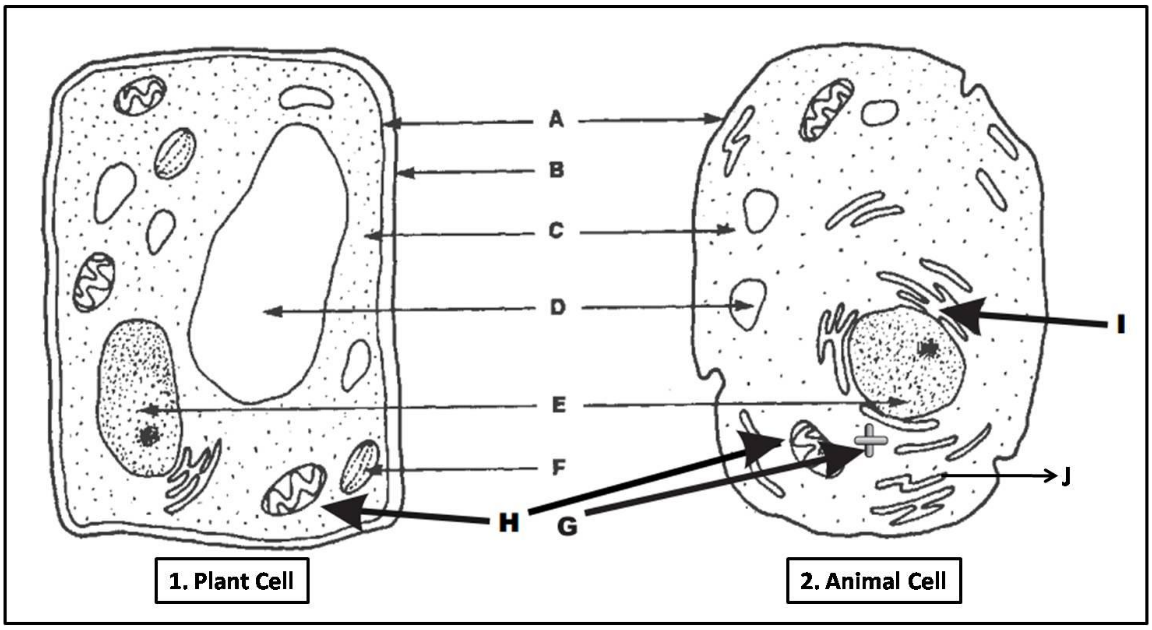
- chloroplasts
- cell surface membrane
- cell wall
- cytoplasm
- cell vacuoles (large, sap-filled in plant cells, small, temporary in animal cells)
- nucleus

B. identify the following membrane systems and organelles from diagrams and electron micrographs:

- endoplasmic reticulum **(6093 only)**
- mitochondria
- Golgi body **(6093 only)**
- ribosomes

Check Your Understanding (1)

Question: The diagram below shows plant and animal cells. Identify structures **A** to **J**. Structure **G** had been identified for you.



A	**F**
B	**G** centrioles
C	**H**
D	**I**
E	**J**

The Cell Theory

Learning Outcome
(a) Outline the cell theory with the understanding that cells are the smallest unit of life, all cells come from pre-existing cells, and living organisms are composed of cells

- Cell theory has a very solid foundation largely because of the use of the microscope.
- Many scientists have contributed to developing the three main principles of this theory.
- These three principles are:

    1. **all organisms are composed of one or more cells**

Practices of Science

- Robert Hooke first described cells in 1665 after looking at cork with a self-built microscope.

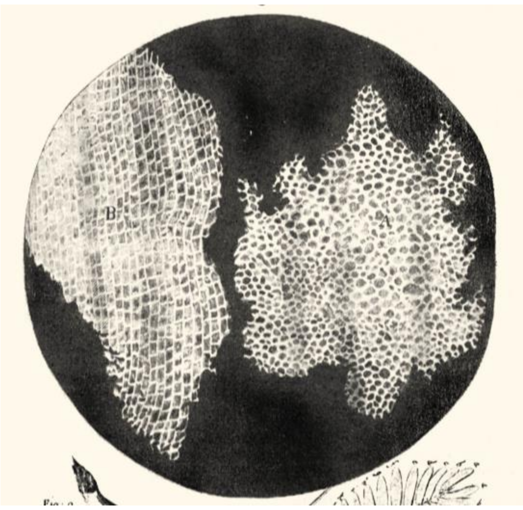


Fig. 1.1 Cork cells seen by Robert Hooke

- A few years later Antonie van Leeuwenhoek observed the first living cells and referred to them as ‘animalcules’, meaning little animals.
- In 1838, the botanist Matthias Schleiden stated that plants are made of ‘independent, separate beings’ called cells.
- One year later, Theodor Schwann made a similar statement about animals.

This shows that scientific knowledge is generated from consensus within the community of scientists through a process of critical debate and peer review.

2. cells are the smallest units of life

- Cells vary considerably in size and shape but they share certain common features:
    - Every living cell is surrounded by a membrane, which separates the cell contents from everything else outside.
    - Cells contain genetic material which stores all of the instructions needed for the cells activities.
    - Many of these activities are chemical reactions, catalysed by enzymes produced inside the cell.
    - Cells have their own energy release system that powers all of the cells activities.
- Therefore, cells can be thought of as the smallest living structures as nothing smaller is considered a living structure.

3. **all cells come from pre-existing cells.**

    - Cells do not formed spontaneously from its component
    - They divide from pre-existing cells via mitosis, meiosis and binary fission

Practices of Science (POS)

- Louis Pasteur sterilized chicken broth by boiling it.
- He showed that living organisms would not ‘spontaneously’ reappear.
- Only after exposure to pre-existing cells was life able to re-establish itself in the sterilized chicken broth.

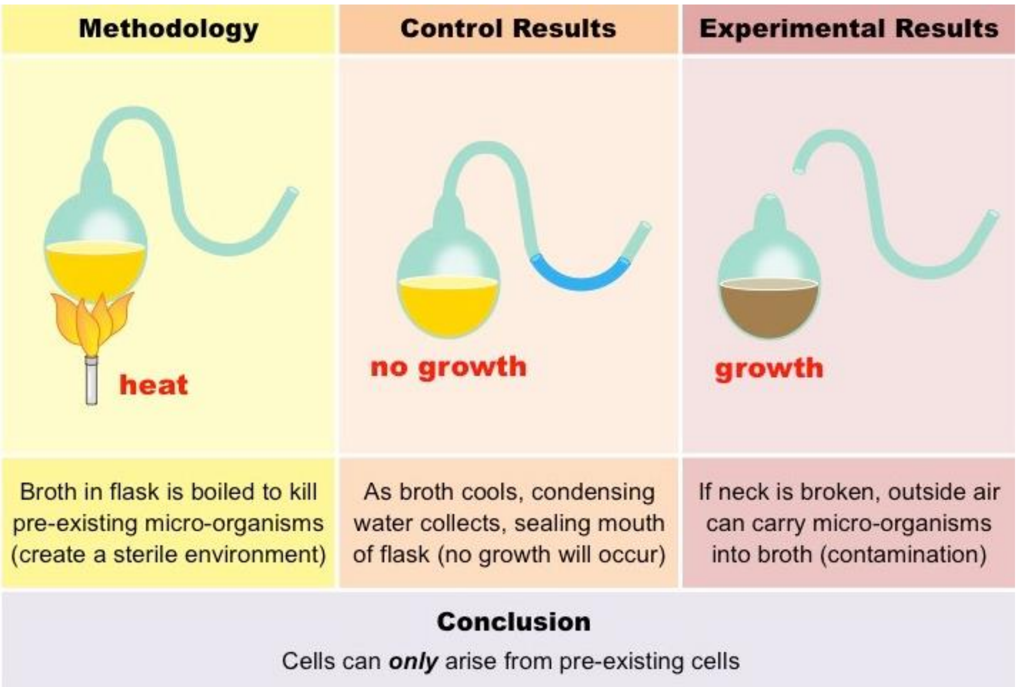


Fig. 1.2 Experiment to show that cells only arise from pre-existing cells

This shows that science is an evidence-based, model-building enterprise concerned with the natural world.

Cell Types

- Living organisms can be distinguished by two structural organisations:

    1. Eukaryote (which means ‘true nucleus’)

        - includes all plants, animals, fungi and protists.
        - possesses a true nucleus containing genetic materials enclosed within the nuclear envelope.
        - has membrane bound organelles.

    2. Prokaryote (which means ‘before the nucleus’)

        - includes bacteria.
        - lacks a true nucleus. The genetic material is a circular DNA molecule, which is not enclosed within membranes but lies freely in the cytoplasm in a region called the nucleoid.
        - does not have membrane-bound organelles

Cell Size

- Cells are extremely small and ranges from 5-500 μm. Most bacteria (prokaryotic cells) are 1-10 μm in diameter and most eukaryotic cells are between 10-100 μm.

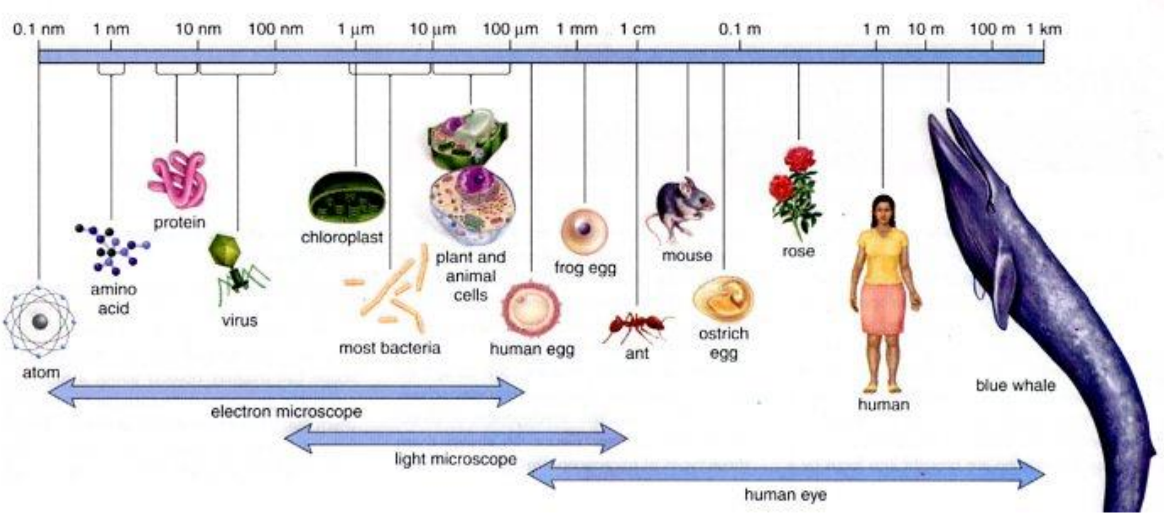


Fig. 1.3 Relative sizes of cells and cell components.
Starting with 10m, each unit of measurement marks a tenfold decrease in size.

SI unit of length is metre (m) and other SI-derived units include:

1 metre(m)	=	100 centimetres(cm)
1 cm	=	10 millimeters (mm)
1 mm	=	10^3 micrometers (μm)
1 μm	=	10^3 nanometers(nm)
1 nm	=	10^3 picometers (pm)

- Cells are very small, no matter how big an organism is.
- Cells do not and cannot grow to be very large.
- Cell size is restricted by the surface area to volume ratio:
  - The volume determines the level of metabolic activity that takes place within it.
  - The surface area determines the rate of exchange of materials with the extracellular environment.
  - As a cell grows larger, its surface area to volume ratio decreased. Therefore, it has less surface area to obtain the materials it needs and to dispose its waste.
  - The rate of exchange of materials across the outer membrane becomes limiting and cannot keep up with the cell’s requirement.

Organisation of cells within the body of multicellular organisms

- A unicellular organism consists of only one cell. It is able to manufacture all the necessary chemicals and perform all the functions for the maintenance of life, within one cell. Examples include amoeba and bacteria

- A multicellular organism is made up of millions of cells. It would be inefficient for each cell to perform every function for the maintenance of life. Instead the cells are organised into different levels as illustrated below:

UNSPECIALISED CELLS
Unspecialised cells (e.g. cambium cells in vascular bundle of plants) differentiate to become specialized cells (e.g. xylem and phloem cells)
↓
SPECIALISED CELL
↓
TISSUE
A tissue is a collection of similar specialized cells organized to perform one or more particular functions. Some tissues are made up of one type of cells
↓
ORGAN
An organ is a group of tissues performing one or more specific functions
(e.g. the smooth muscle, nerve tissue and connective tissue are tissues of the organ stomach)
↓
SYSTEMS
A system is a group of organs which carry out one function.
(e.g. the heart and blood vessels are organs of the circulatory system)

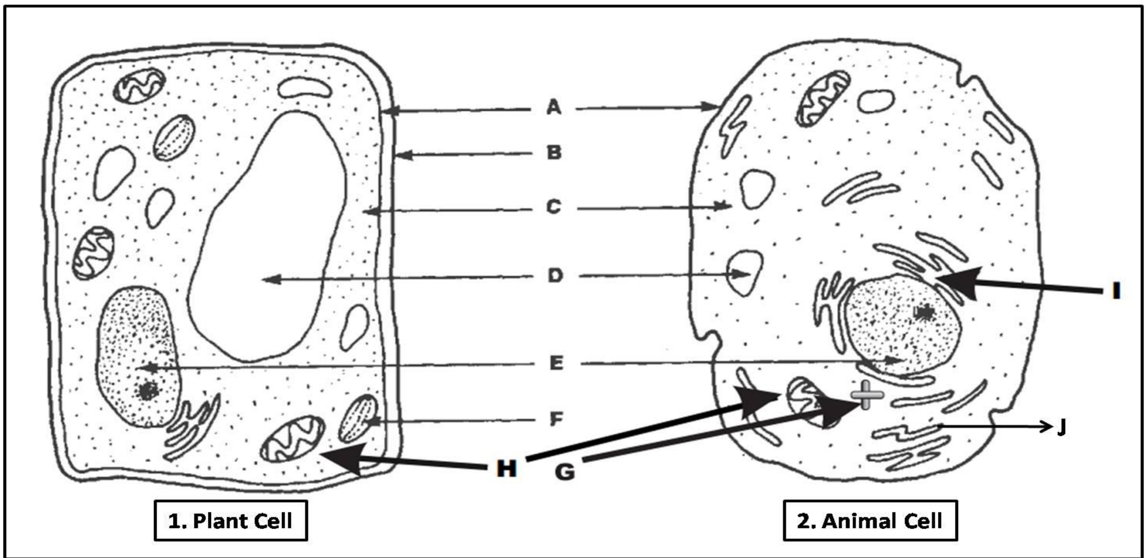
A bridge to O Level Biology
(6093 syllabus and 5078 syllabus)

You should have learnt:

C. state the functions of the membrane systems and organelles (identified above) ***ref to LO A and B on pg. 4***

Check Your Understanding (2)

Question: Complete the table below by using the diagram below. Function of structure **G** had been completed for you.



Structure	Function
A	
B	
C	
D	
E	
F	
G	Function as microtubule organising centre in nuclear division
H	
I	
J	

Functions of membrane systems and organelles in cells

Learning outcomes

(b) Interpret and recognise drawings, photomicrographs and electron micrographs of the following membrane systems and organelles: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus (for practical assessment, candidates may be required to operate a light microscope, mount slides and use an eyepiece graticule and a stage micrometer)

(c) Outline the functions of the membrane systems and organelles listed in **(b)**

- Eukaryotic cells are compartmentalized by single or double membranes.

- The compartments in the cytoplasm are known as organelles. Each organelle in a eukaryotic cell has a distinctive structure and function.

- There are several advantages in being compartmentalized:

  - Increased Efficiency:
    - Membrane-bound compartments create **specialized environments** for various cellular processes, increasing the efficiency of these processes by isolating them and minimizing conflicting interactions.

  - Localized Conditions:
    - Different compartments can maintain **unique chemical or pH environments** suited for specific reactions, such as acidic conditions in lysosomes for degradation or high calcium concentrations in the endoplasmic reticulum for protein folding.

  - Damage Containment:
    - Compartmentalization helps to **contain damage** from harmful substances or processes. For example, enzymes that generate reactive oxygen species are sequestered in mitochondria to prevent oxidative damage to other cellular components.

  - Concentration of Substrates:
    - Compartmentalization allows cells to **concentrate substrates and enzymes**, increasing the rate of biochemical reactions. For example, the Krebs cycle enzymes are concentrated within the mitochondrial matrix.

  - Regulation of Metabolic Pathways
    - Having **distinct compartments** enables precise regulation of metabolic pathways. For example, the separation of catabolic and anabolic pathways prevents futile cycles (where opposing pathways undo each other's work).

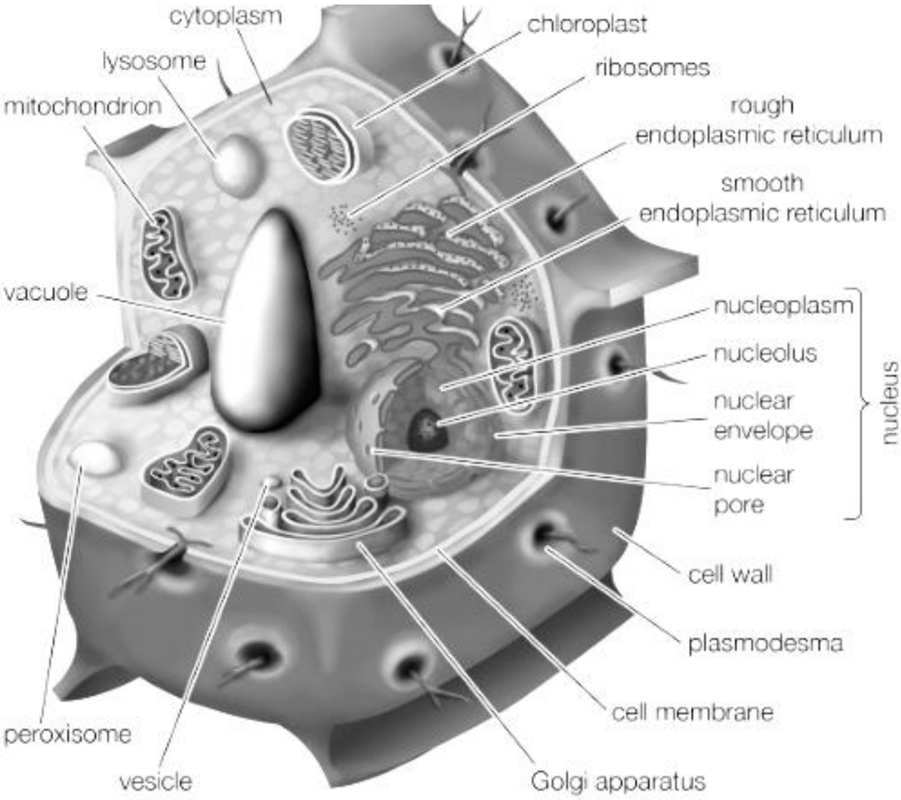


Fig. 1.6 Plant cell ultrastructure

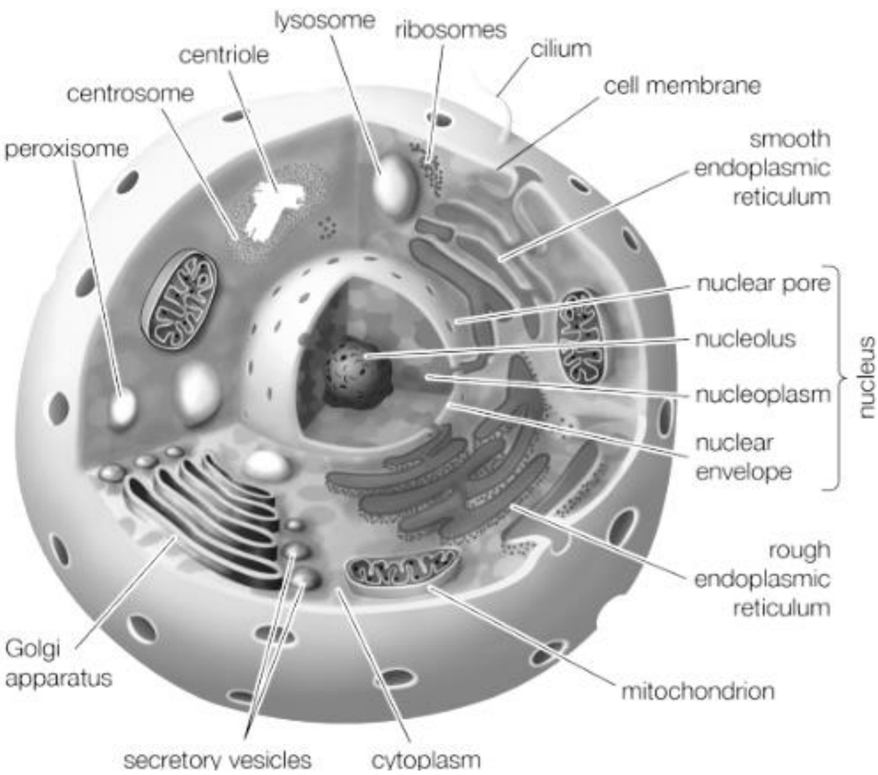


Fig. 1.7 Animal cell ultrastructure

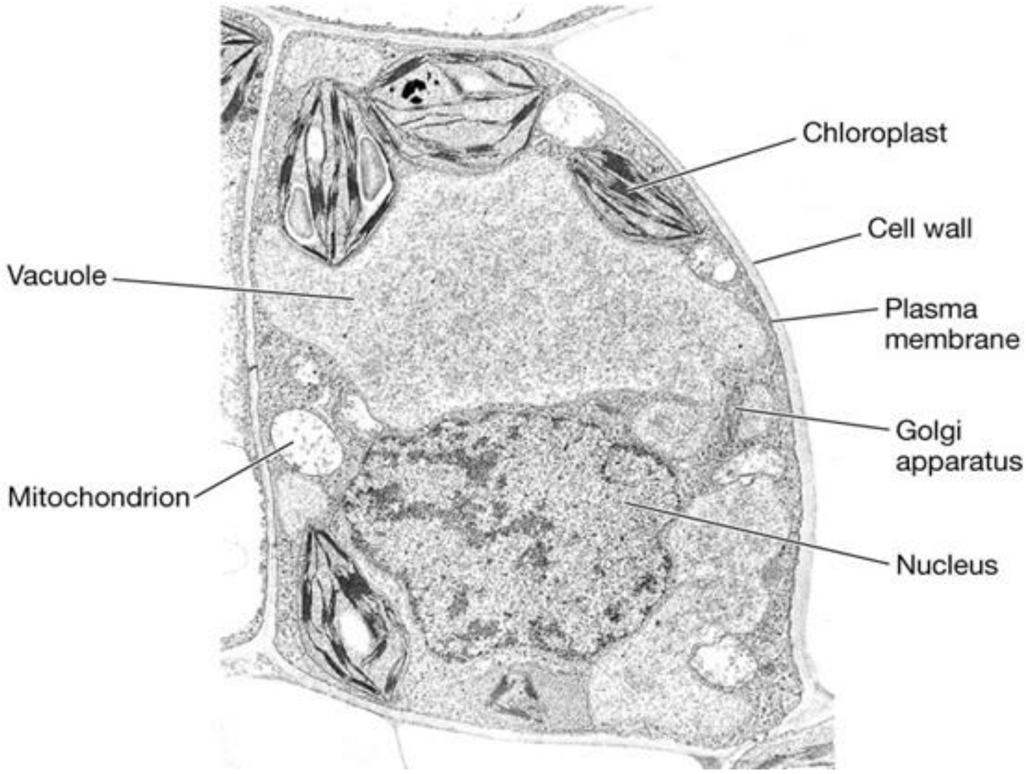


Fig. 1.8 Plant cell electron micrograph

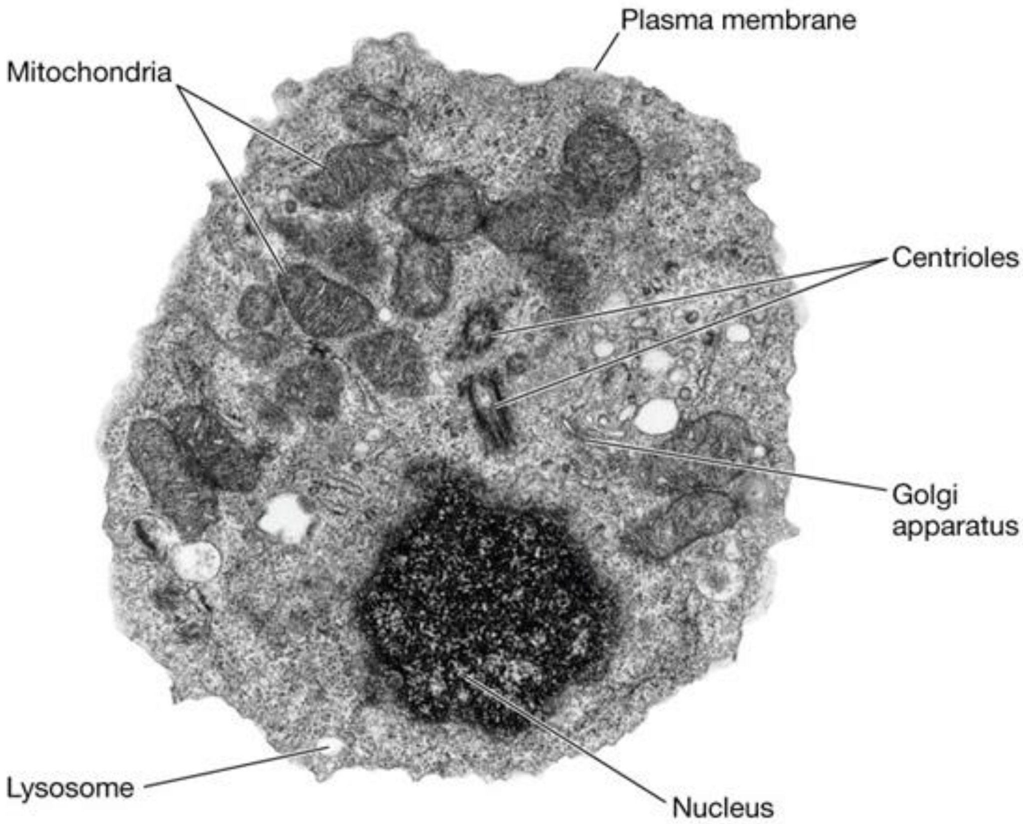


Fig. 1.9 Animal cell electron micrograph

Cell Surface Membrane

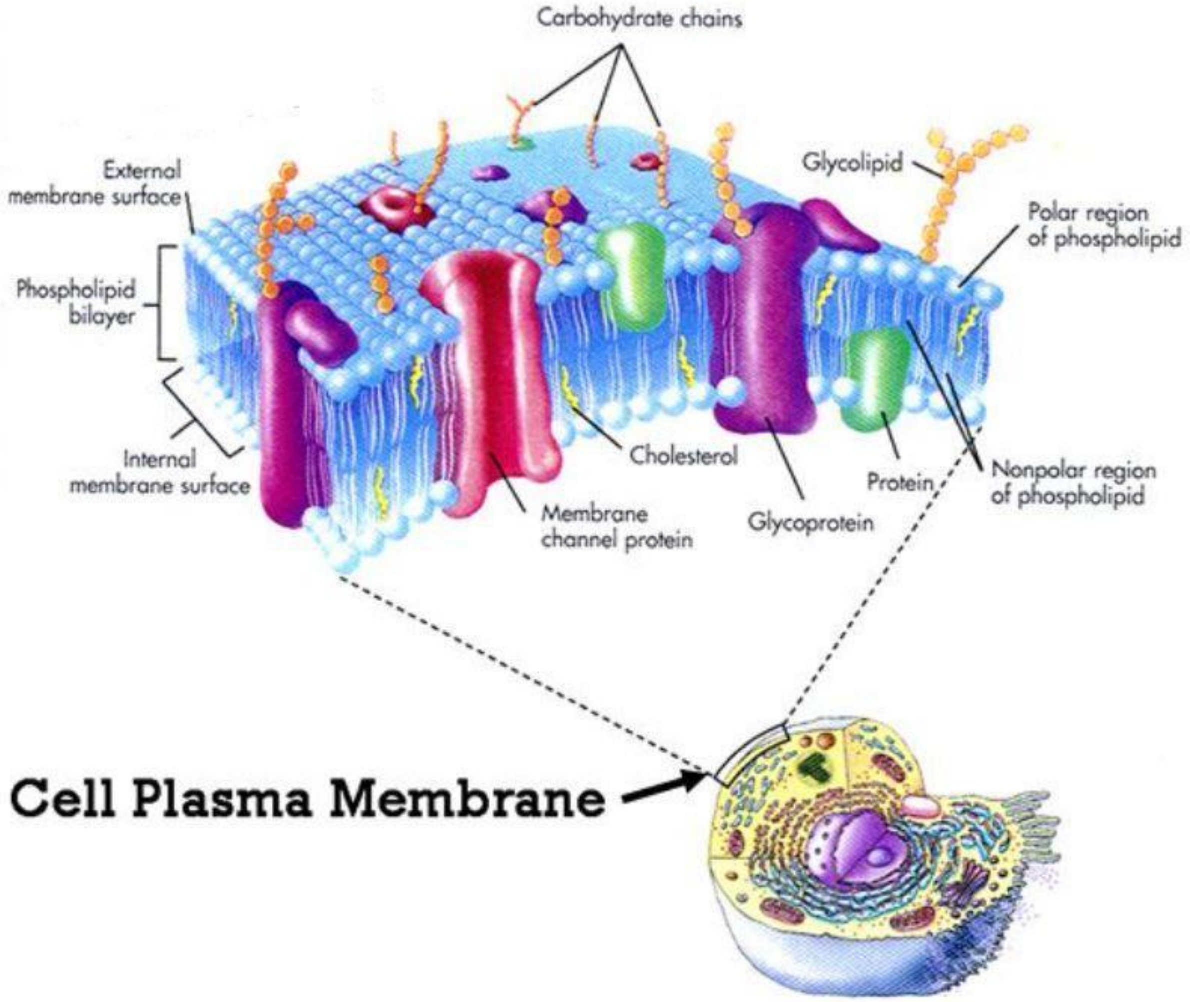


Fig. 1.10 Cell surface membrane

Structure	Function
• The cell surface membrane is made up of phospholipids, arranged into a lipid bilayer in which proteins are embedded.	• It acts as boundary between the cell cytoplasm and the extracellular environment.
• The cell surface membrane is selectively permeable.	• It regulates the movement of molecules into and out of the cell, prevent charged ions and polar molecules from diffusing across the membrane.

Note: You will learn more about the cell surface membrane under the core idea 1.3 membrane and cellular transport.

Nucleus

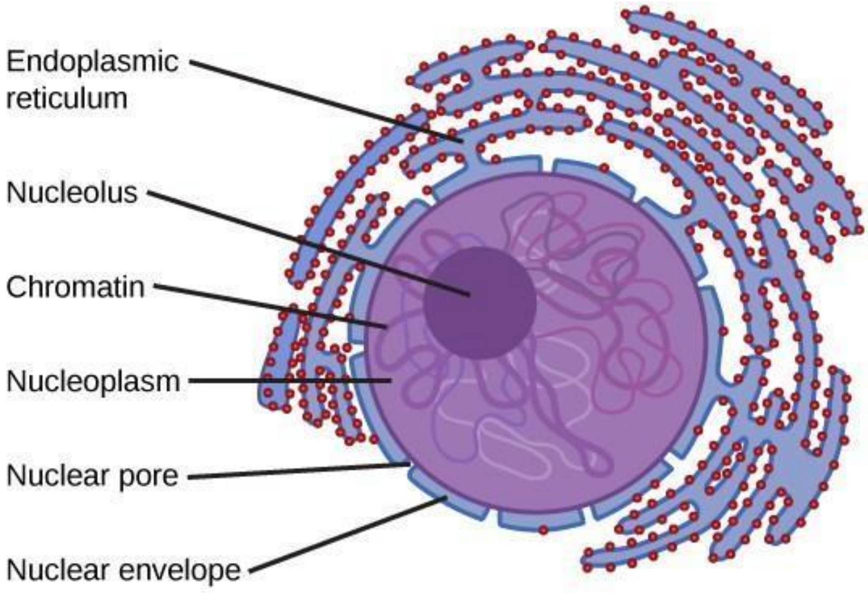


Fig. 1.11(a) Structure of nucleus (schematic drawing)

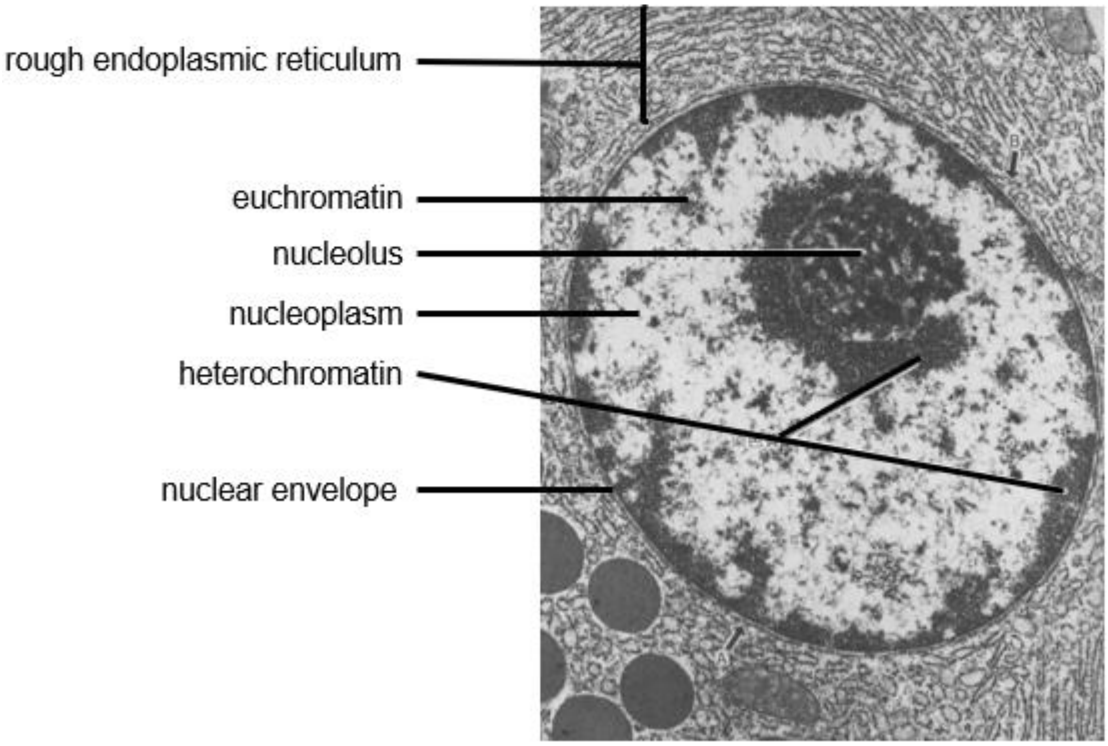


Fig. 1.11(b) Structure of nucleus (electron micrograph)

Structure	Function
• The nucleus is bordered by a double membrane called the nuclear envelope. • Within the nucleus is a fluid-like space known as the nucleoplasm. • The nucleoplasm contains the genetic material (DNA), ribonucleic acid (RNA) and associated proteins and enzymes required for DNA replication and transcription. • DNA containing ribosomal RNA genes clustered together to form the nucleolus in the nucleoplasm.	• The nucleus controls the activities (e.g. DNA replication, gene expression, nuclear division) of the cell. ○ DNA contain genes and enables certain traits to be passed on to the next generation hence it said to carry the hereditary information. **More content will be given in the topic of inheritance.** ○ DNA often occurs in the form of chromosomes. When the cell is not in the process of nuclear division, the chromosomes are not present as visible structures. Instead, the cell's DNA is in the form of chromatin. ○ DNA is usually associated with proteins called histones to form chromatin ○ There are two types of chromatin in the nucleus – euchromatin (less condensed, usually frequently transcribed) and heterochromatin (highly condensed, darkly stained, usually not transcribed due to its compact structure). ○ During nuclear division, chromatin condenses to form chromosomes which are highly condensed **More content will be given in the topic of organisation of (eukaryotic) genome.**

Nuclear Envelope

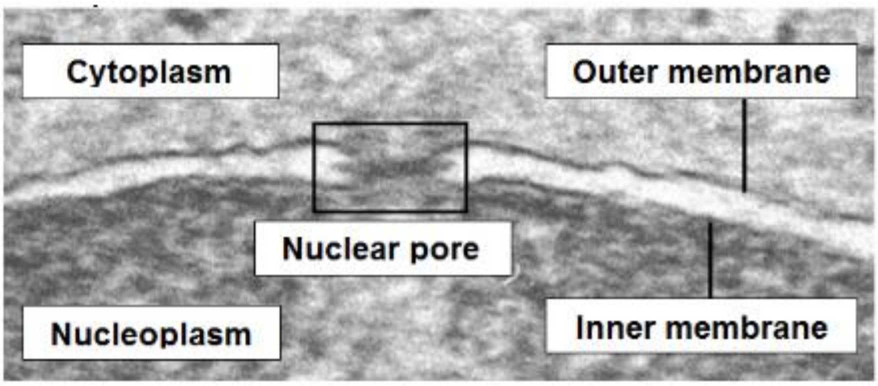


Fig. 1.12 Magnified electron micrograph showing nuclear pore

Structure	Function
• It is a double membrane surrounding the nucleus whereby the outer membrane is continuous with the rough endoplasmic reticulum, inner membrane is smooth and in contact with nucleoplasm	• It enables compartmentalization of the eukaryotic DNA, where DNA can carry out its functions without being affected by processes occurring in other parts of the cell
• It has numerous nuclear pores, each being 40 - 100 nm in diameter.	• It controls the export of mRNA out of the nucleus into cytoplasm and import of ribosomal proteins into the nucleus. • It prevents DNA from being transported out of the nucleus.

Nucleolus

- One or more nucleoli are present in the nucleus.

Structure	Function
• tiny, rounded, darkly-stained structure	• A site where rRNA are synthesised via transcription of rRNA gene • Site where ribosomal subunits are assembled by associating the ribosomal ribonucleic acid (rRNA) and ribosomal proteins

Endomembrane system

The endomembrane system is the system of internal membranes within eukaryotic cells.

The membranes of this system are related

- either through direct physical continuity (e.g. nuclear envelope is continuous with endoplasmic reticulum)

- or by the transfer of membrane segments as vesicles (e.g. transfer of proteins from Golgi apparatus to cell surface membrane via secretory vesicles)

The endomembrane system is involved in protein and lipid synthesis and transport.

The following organelles are part of the endomembrane system:

- ○ Endoplasmc reticulum (rough and smooth)
- ○ Golgi apparatus
- ○ Vesicles
- ○ Lysosomes
- ○ Cell surface membrane
- ○ Outer membrane of nuclear envelope

Endoplasmic Reticulum (ER)

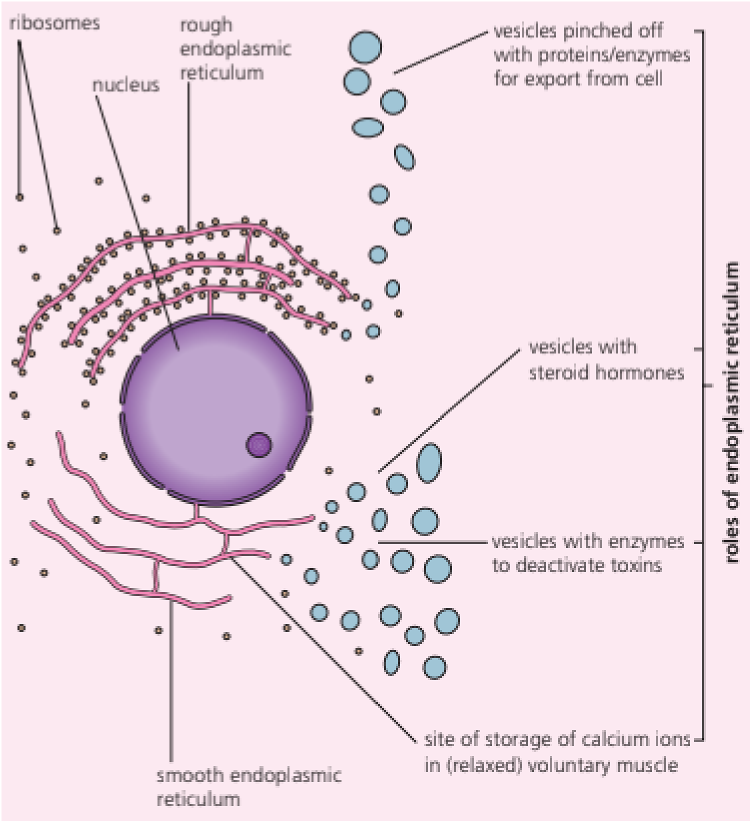


Fig. 1.13(a) Smooth endoplasmic reticulum (sER) and rough endoplasmic reticulum (rER) in cytoplasm, showing origin from outer membrane of nucleus

- There are two distinct types of endoplasmic reticulum - rough endoplasmic reticulum and smooth endoplasmic reticulum.

Structure
• The endoplasmic reticulum consists of extensive network of folded membranes formed into sheets, tubes or sacs that are interconnected. • The ER membrane enclosed to form the cisternae / lumen of the ER. • Endoplasmic reticulum originates from the outer membrane of the nuclear envelope, continuous with the outer membrane of nuclear envelope

Rough Endoplasmic Reticulum (rER)

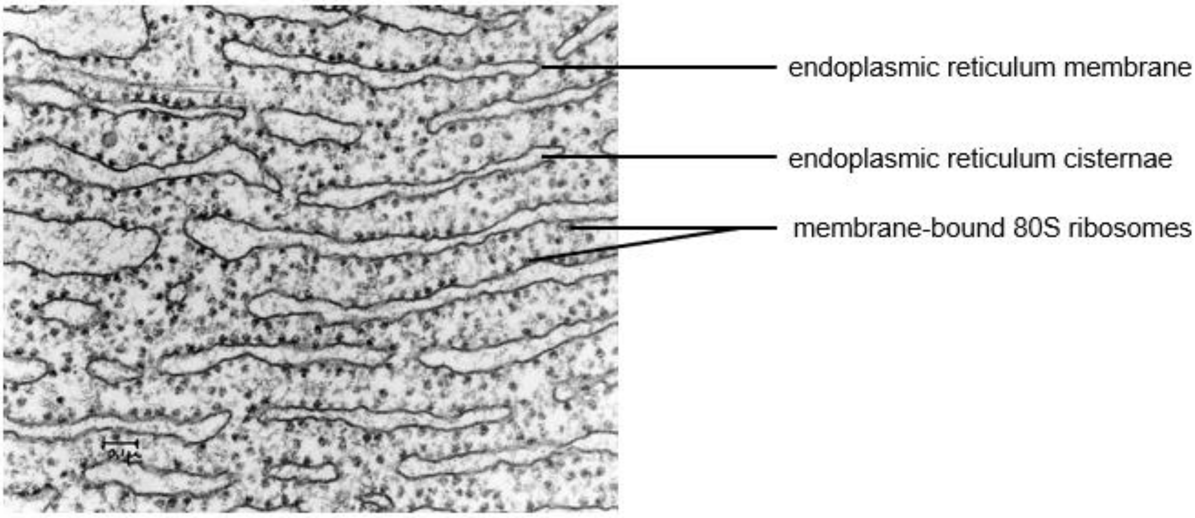


Fig. 1.13(b) Rough endoplasmic reticulum

Structure	Function
• Cisternae usually flattened	
• rER has ribosomes bound to the membrane of the endoplasmic reticulum. This gives the endoplasmic reticulum a granular appearance.	• Membrane-bound ribosomes are the site of synthesis of proteins for transport to other parts of the cells via vesicles
• Presence of various proteins embedded	• Channel proteins provide binding sites for ribosomes to dock and synthesise polypeptides directly into the cisternae • Chaperon proteins in the cisternae of the rER assist in the correct folding of newly synthesised polypeptides • Enzymes involved in glycosylation of proteins to form glycoproteins

Smooth Endoplasmic Reticulum (sER)

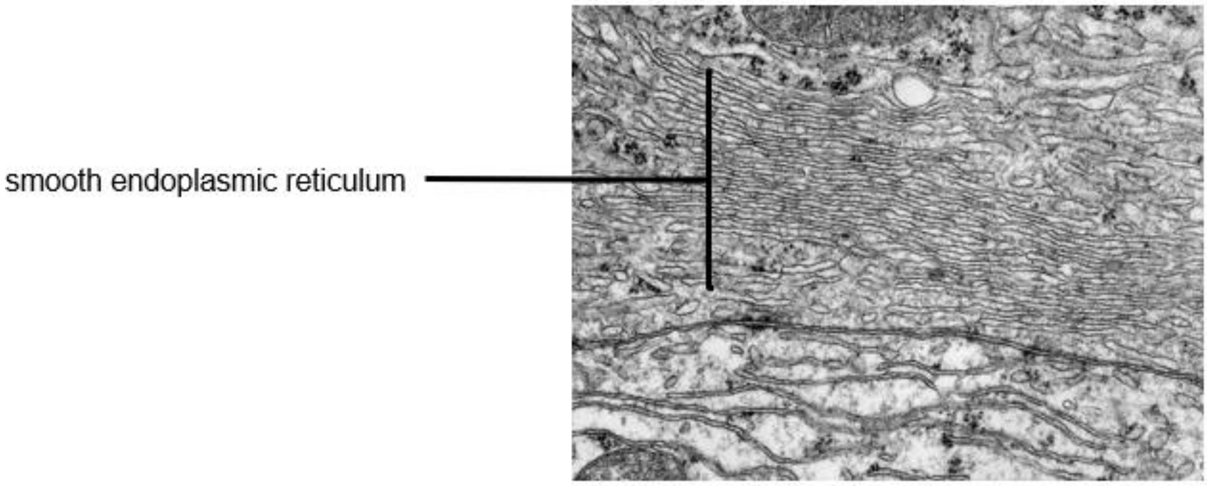


Fig. 1.13(c) Smooth endoplasmic reticulum

Structure	Function
• Cisternae usually more tubular • sER has <u>no</u> ribosomes bound to the membrane of the endoplasmic reticulum. This gives the endoplasmic reticulum a smooth appearance	• Production and transportation of membrane phospholipids, cellular lipids and steroid hormones such as testosterone and oestrogen • Detoxification of drugs in the liver cells via chemical modification ○ E.g. hydroxylation via the addition of OH groups • Storage of calcium ions in muscle cells (Ca^{2+} are needed for contraction of muscle cells) • Helps the liver cells to carry out metabolism of carbohydrates

Golgi Apparatus (Golgi body)

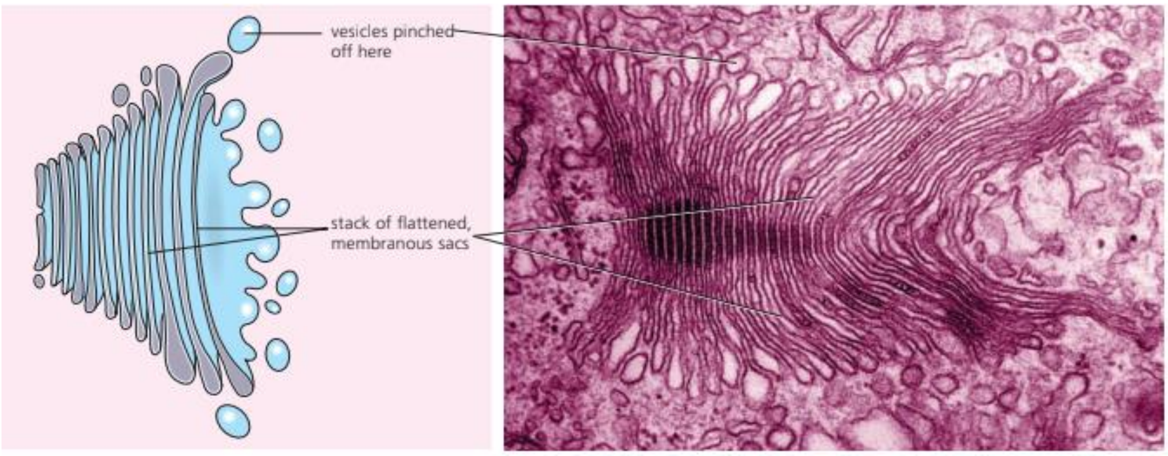


Fig. 1.14(a) Electron micrograph of Golgi apparatus, in section

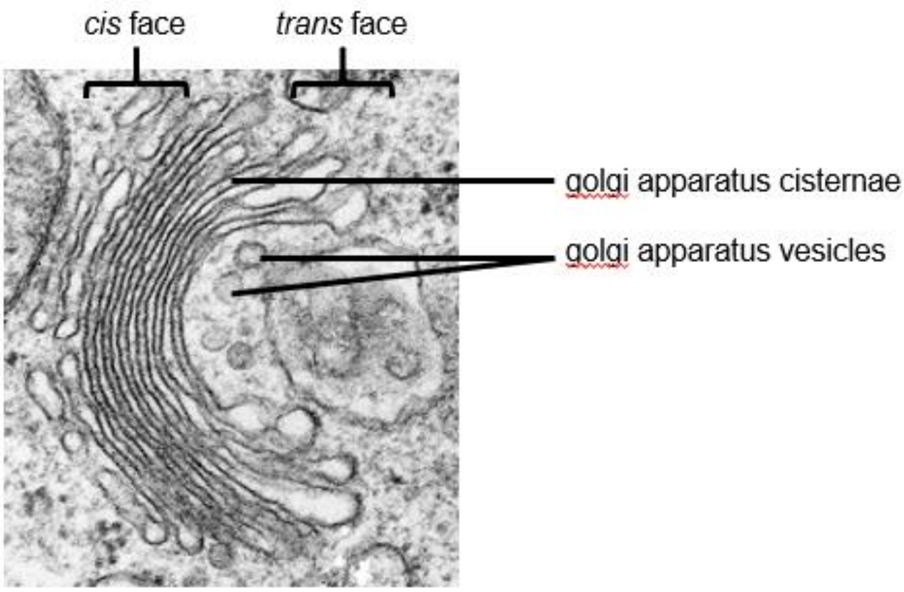


Fig. 1.14(b) Electron micrograph of Golgi apparatus

Structure	Function

• The Golgi apparatus consists of flattened membrane bound sacs called cisternae, which are stacked one on top of another.
 	
• Usually associated with Golgi vesicles
 	
• Consist of *cis* face, which is nearest to nucleus and endoplasmic reticulum
    ○ Vesicles from endoplasmic reticulum fuse with Golgi apparatus at the *cis* face to add to its membrane and deposit its content
 	
• Consist of *trans* face, which is nearest to the cell surface membrane
    ○ Vesicles bud off from Golgi apparatus to form vesicles which may move toward the cell surface membrane to secrete contents out of cell
	• Modification of proteins and lipids by glycosylation (adding of oligosaccharides to proteins and lipids to form glycoproteins and glycolipids)
	You will learn about glycoprotein and glycolipid in the core idea 1.3 cellular transport.
	
	• Addition of a molecular identification tag e.g. phosphate groups to the finished product via phosphorylation
	
	• Sorting and packaging Golgi products and targeting them for various parts of the cell via addition of molecular identification tag e.g. phosphate groups to the finished product via phosphorylation
	
	• Forms lysosomes which are vesicles containing hydrolytic enzymes
	
	• Replace cell surface membrane lost through endocytosis
	
	• Synthesis of plant polysaccharides e.g. pectins

FUN FACT!	Golgi apparatus especially prevalent in glandular cells, e.g. α-cells and β-cells of islets of Langerhans in the pancreas, which manufacture and secrete glucagon and insulin respectively.

Lysosomes

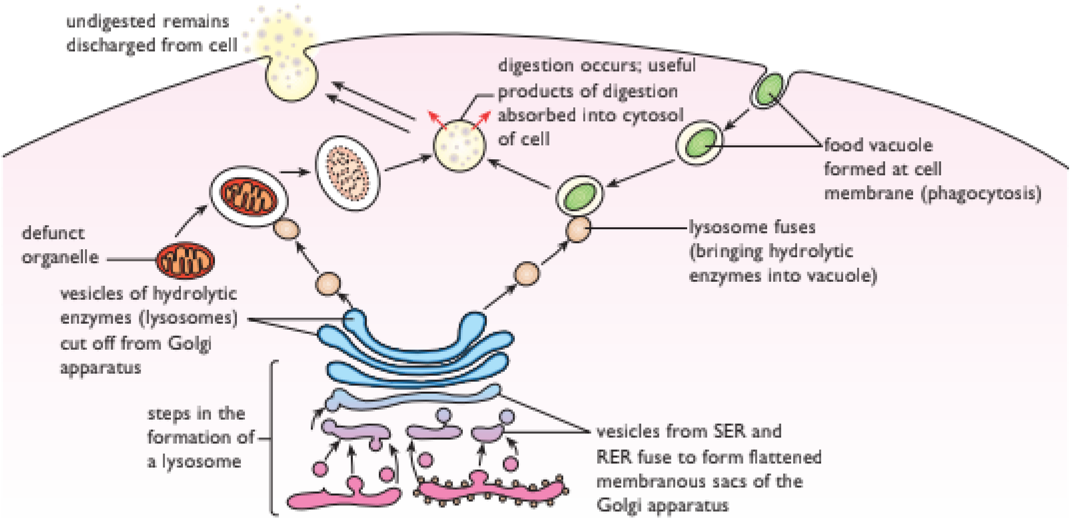


Fig. 1.15 Function of lysosome

Structure	Function
• Lysosomes are tiny spherical vesicles bound by a single membrane. Usually 0.2um to 0.5um in diameter	
• They contain a concentrated mixture of hydrolytic enzymes. ○ Hydrolytic enzymes are produced by both the rough ER and Golgi apparatus.	• Carry out intracellular hydrolysis of biomolecules via the action of hydrolytic enzymes • Hydrolytic enzymes catalyse the hydrolysis of proteins, nucleic acids, lipids, and carbohydrates.
• The interior environment of a functioning lysosome is acidic; this acidic environment is necessary for the enzymes to hydrolyse large molecules.	• Lysosomes fuse with old or damaged organelles from within the cell to break them down, so that recycling of the components can occur. This is known as autophagy. (Fig. 1.14) • Lysosomes are also involved in the breakdown of materials that may be brought into a cell by phagocytosis. (Fig. 1.15) ***You will learn about phagocytosis in the core idea 1.3 cellular transport.***

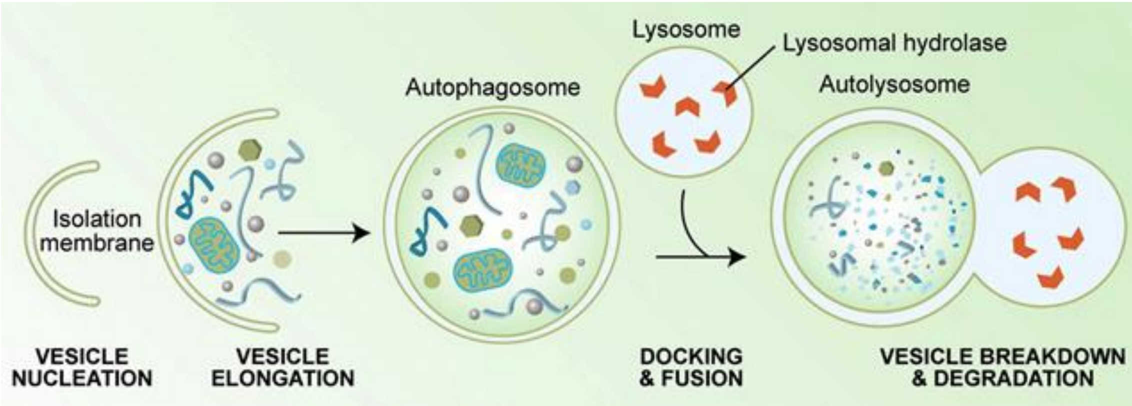


Fig. 1.16 Autophagy process

A vesicle will encapsulate the organelle forming an autophagosome. Lysosome will fuse with the autophagosome, releasing its hydrolytic enzymes into the autophagosome. Hydrolytic enzymes (lysosomal hydrolase) will hydrolyse the content of the autophagosome to recycle the components.

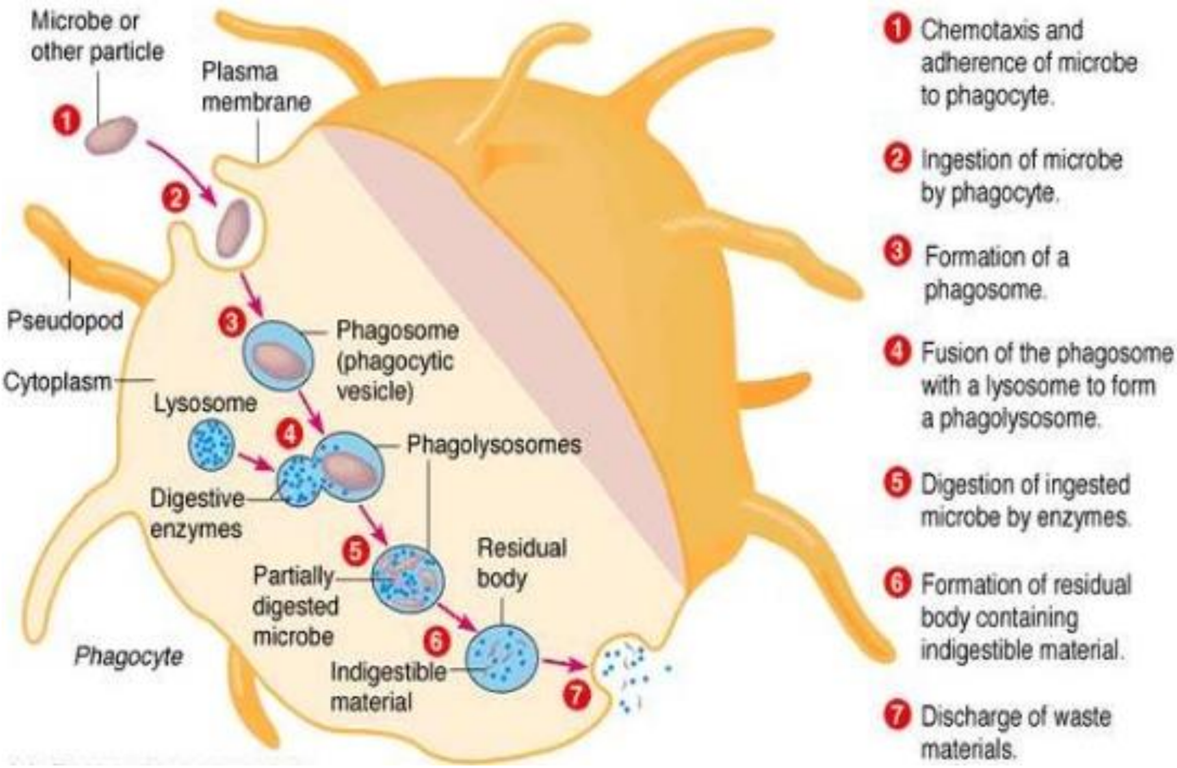


Fig. 1.17 Process of phagocytosis.

Question: How is endoplasmic reticulum related to Golgi apparatus?

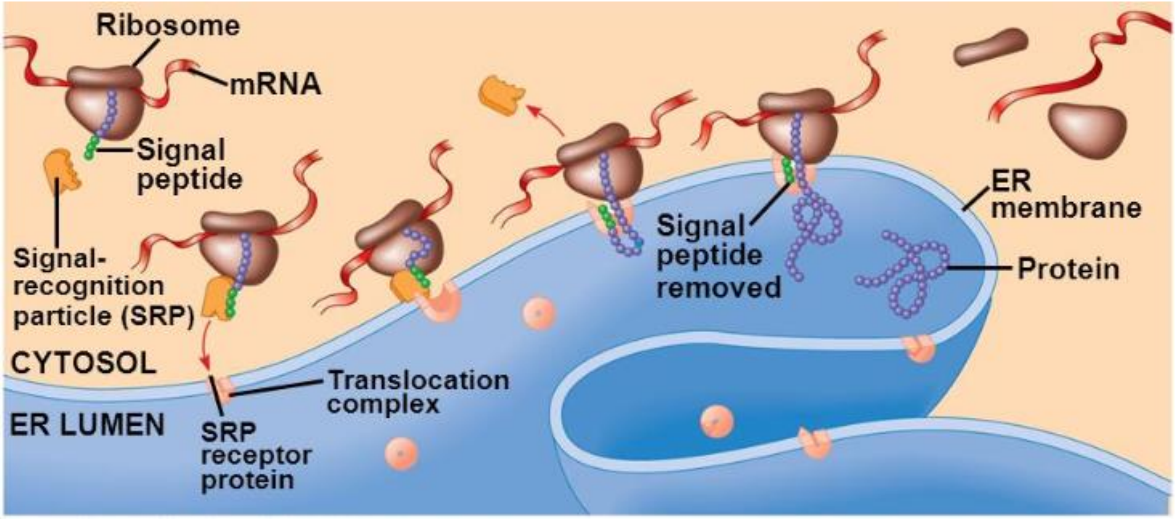


Fig. 1.18 synthesis of polypeptide by RER

- The endoplasmic reticulum, Golgi apparatus, ER transport vesicles, Golgi secretory vesicles and cell surface membrane are involved in the secretory pathway.
- Ribosome translate the messenger RNA (mRNA) and forms a short signal peptide which binds to signal recognition particle (SRP).
    - mRNA is a large family of RNA molecules that convey genetic information from DNA to the ribosome, where they specify the amino acid sequence of the protein products of gene expression. ***You will learn about mRNA in core idea 2.1 structure of nucleic acids.***
    - SRP is a class of protein that is complementary to the signal peptide.
- Complementary binding of SRP to the SRP protein receptor on the membrane of the ER allows ribosome to dock onto the ER membrane.
- Ribosome continues with translation and polypeptide is synthesised into the cisternae (lumen) of ER.
- Polypeptide is folded into its protein 3D conformation with the help of chaperon proteins (not shown).

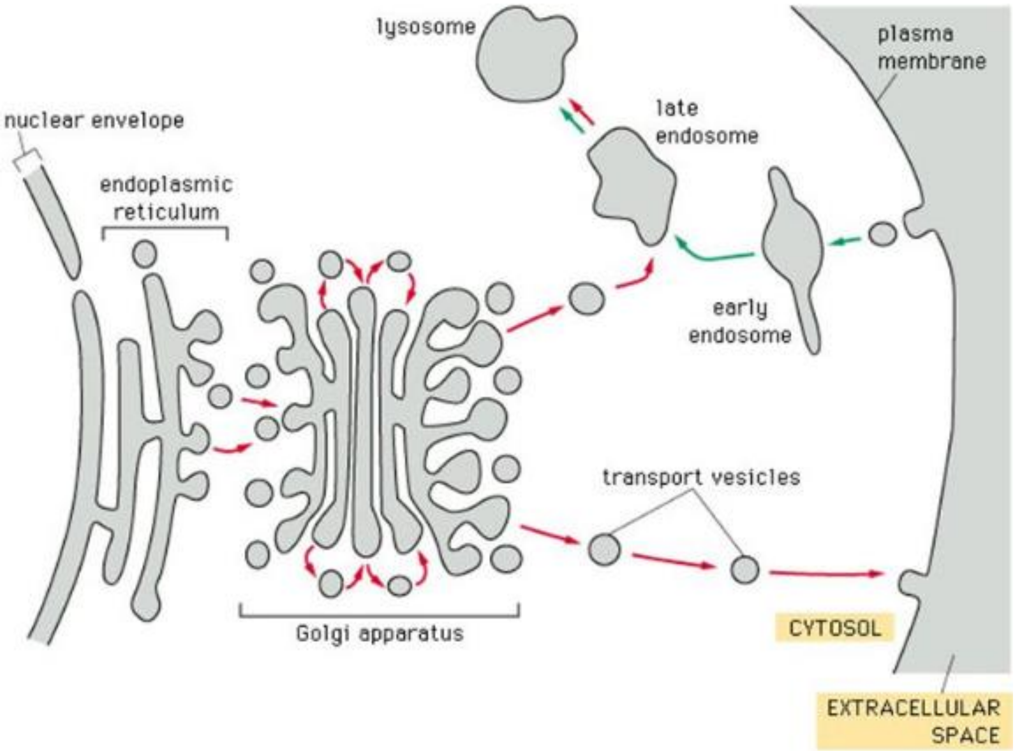


Fig. 1.19 Secretory Pathway

- The proteins are packaged into ER vesicle with buds off from the ER membrane.

- ER vesicle carry the proteins to Golgi apparatus. ER vesicle fuse with the *cis* face membrane to release the proteins into the cisternae of the Golgi apparatus.

- The proteins continue to move to the opposite side, the *trans* face. During this transition, the proteins are chemically modified by the Golgi apparatus.

- The modified proteins reach the *trans* face and are packaged into Golgi secretory vesicles for export via exocytosis at the cell surface membrane. ***You will learn about exocytosis, in particular, regulated and constitutive secretion in core idea 1.3 membranes and cellular transport.***

- The Golgi secretory vesicles bud off from the *trans* face.

Mitochondrion

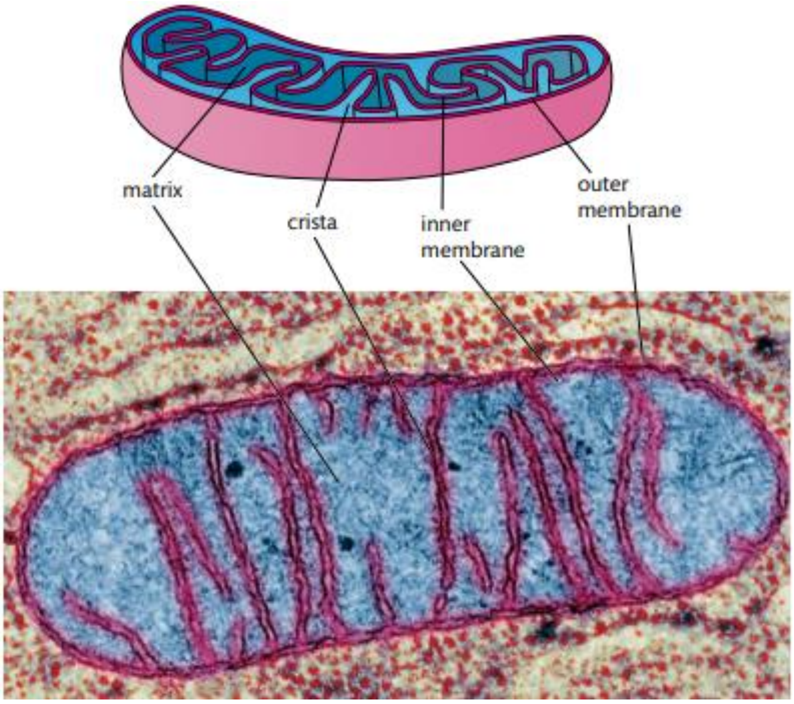


Fig. 1.20 Structure of Mitochondrion

Structure	Function

• Mitochondria (singular: mitochondrion) appear mostly as rod-shaped or cylindrical organelles in electron micrographs.
 	
• They are relatively large organelles, typically 0.5–1.5μm wide, and 3.0–10.0 μm long.
 	
• Mitochondria have their own DNA, a circular chromosome, and 70S ribosomes.
  ▪ Allow them some independence within a cell
    ○ divide independently of the cell (i.e. undergoes DNA replication on its own)
    ○ express genes to produce proteins unique to mitochondrion
	• Most mitochondrial reactions (link reaction, Krebs cycle and oxidative phosphorylation) involve the production of adenosine triphosphate (ATP) during cellular aerobic respiration.

Structure	Function
• They have a double membrane: the outer membrane is smooth, but the inner membrane is folded into cristae (singular crista). ○ An area called the inter-membrane space lies between the two membranes. ○ The inner membrane encloses semi-fluid substance called the matrix.	• The highly folded cristae provide a huge surface area to volume ratio for oxidative phosphorylation to occur. ***You will learn about oxidative phosphorylation in core idea 3.1 respiration.*** • Many respiratory proteins and enzymes are embedded in the inner membrane. • Contains enzymes required for link reaction and Krebs cycle. ***You will learn about Krebs cycle in core idea 3.1 respiration***.

FUN FACT!	Mitochondria are found in all cells and are usually present in very large numbers. Cells that have high energy requirements, such as muscle cells, have large numbers of mitochondria.

Chloroplasts

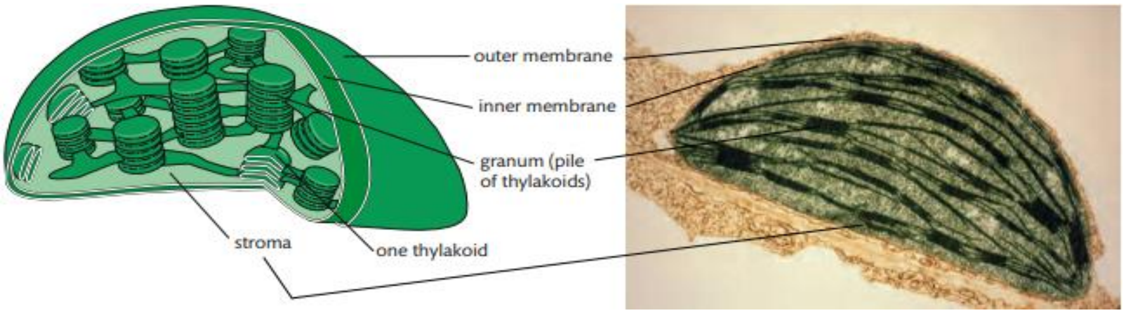


Fig. 1.21 Structure of Chloroplast

FUN FACT!	Chloroplasts are found in green plants, and most are found in the mesophyll cells of leaves. A mesophyll cell may be packed with 50 or more chloroplasts.

- Chloroplasts are large organelles, typically biconvex in shape, about 4–10 μm long and 2–3μm wide.

Structure	Function
• Chloroplasts are large organelles, typically biconvex in shape, about 2.0 – 3.0μm wide and 4.0 – 10.0 μm long	• Acts as site for photosynthesis ○ Comprises of both light-dependent and light-independent reactions ***You will learn about light-dependent and light-independent reactions in core idea 3.2 photosynthesis***.
• Chloroplast is enclosed by a double membrane ○ Both the inner membrane and outer membrane are smooth	

• The interior of a chloroplast contains a third membrane system called the thylakoid membrane
  ○ Thylakoid membranes fold and stack onto each other to form granum (plural: grana).
  ○ Each granum is connected to another granum by intergranal lamella (plural: lamellae)	

○ Photosynthetic pigments and proteins are embedded into the thylakoid membrane	• Pigments and proteins are involved in the light-dependent reactions of photosynthesis
• The thylakoid system is suspended in a fluid substance called stroma	• Stroma contains many enzymes and compounds that are necessary for Calvin cycle (light-independent reactions)

• The chloroplast contains its own circular DNA and 70S ribosomes
  ○ Allow them some independence within a cell
    ▪ divide independently of the cell (i.e. undergoes DNA replication on its own)
    ▪ express proteins unique to chloroplast	

What is the origin of mitochondrion and chloroplast?

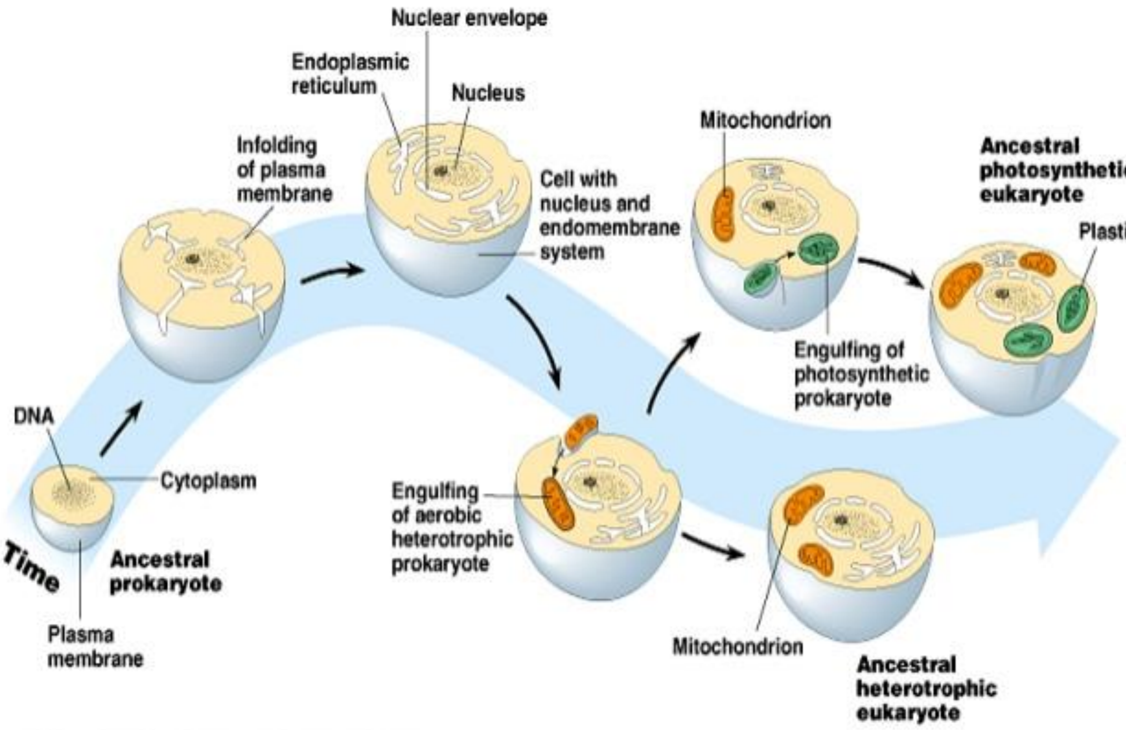


Fig. 1.22 Endosymbiotic Theory

Origin of mitochondrion and chloroplast: Endosymbiotic Theory

- The endosymbiotic theory can explain the origin mitochondrion and chloroplast.
- This theory was presented by Lynn Margulis in 1981.
  - About 2 billion years ago, prokaryotic cells capable of aerobic respiration and photosynthesis were engulfed by another larger ancestral eukaryotic cell.
  - This large ancestral eukaryotic cell, aerobic prokaryotic cell and photosynthetic prokaryotic cell formed a symbiotic relationship.
  - The aerobic prokaryotic cell and photosynthetic prokaryotic cell then went through a series of evolution to ultimately become a mitochondrion and chloroplast respectively.

Ribosomes

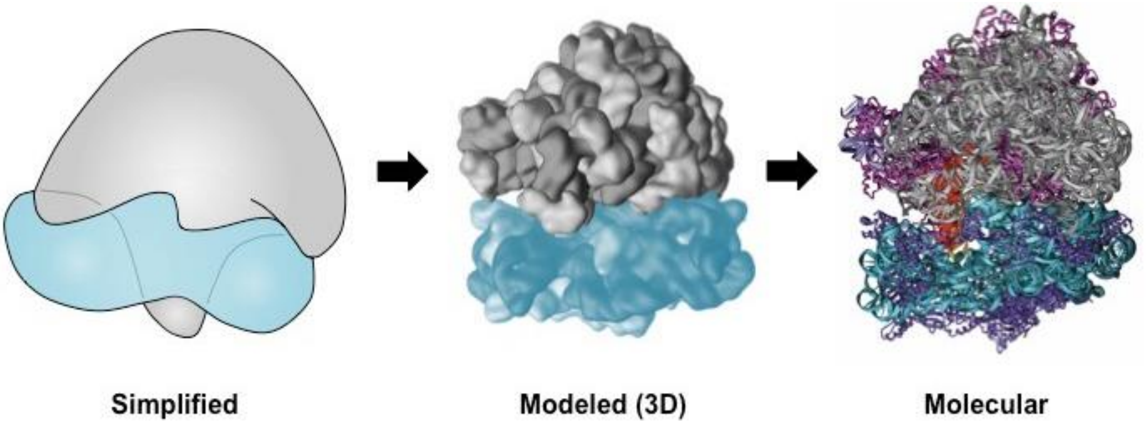


Fig. 1.23 Structure of Ribosome

- Ribosomes are tiny structures, approximately 25 nm in diameter.
  - Ribosome has two subunits.
    - Each subunit is made up of ribosomal protein and ribosomal ribonucleic acid (rRNA).
  - Ribosome does not have membranes.

Structure	Function
Eukaryotes • 80S ribosome, 20 nm in diameter • large 60S subunit and a small 40S subunit • produced & partially assembled in nucleolus, only fully assembled in cytoplasm	• Act as the site for protein synthesis ○ Membrane-bound ribosomes on rough endoplasmic reticulum produce extracellular / secretory and/or membrane proteins ○ Free ribosomes produce intracellular proteins • Large number of ribosomes are present in cells that are active in protein synthesis
Prokaryotes • 70S ribosome • a large 50S subunit and a small 30S subunit	• Act as the site for protein synthesis

FUN FACT!	The letter S used in the measurement of ribosomes refers to Svedberg units, which indicate the relative rate of sedimentation during high-speed centrifugation. The higher the S value, the quicker the structure will become part of the sediment and the more mass it will have.

Centrioles

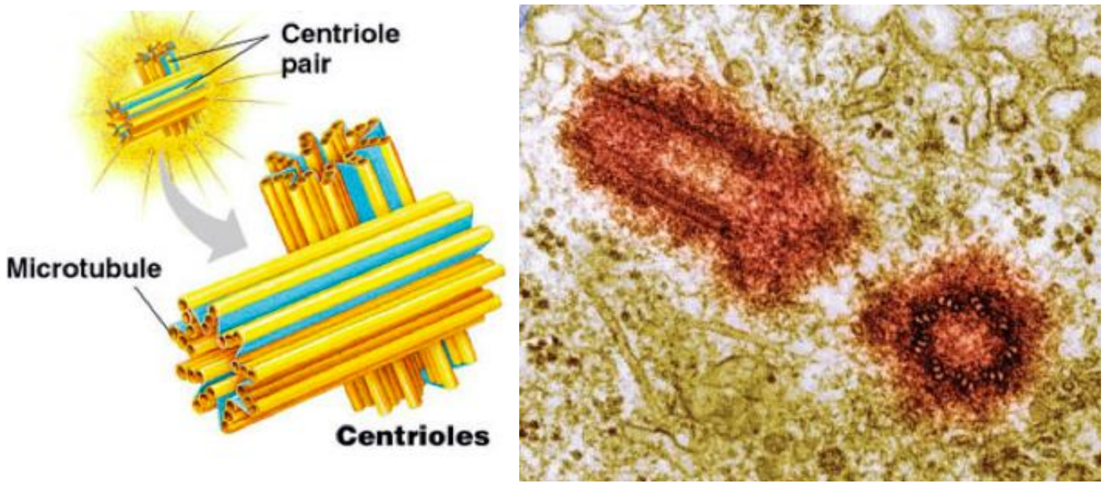


Fig. 1.24 Structure of Centrioles

Structure	Functions
• A pair of hollow cylinders at right angle to each other	• To act as microtubule organising centre (MTOC)
• Each centriole consists of a pair of nine set of triple microtubules arranged in a ring • Located in a distinctly stained region of the cytoplasm called centrosome. Centrosome is usually located beside the nucleus .	• The centrioles replicate at the beginning of nuclear division and each pair of centrioles move to opposite poles of the nucleus to establish the poles for nuclear division. ***You will learn about this process in the topic of cell & nuclear division.*** • They help to organise the spindle fibres from microtubules cytoskeleton which are made up of tubulins to guide the movement of chromosomes
• Only present in animal cells and lower plant cells	• However, centrioles are not mandatory in the formation of spindles as (higher) plant cells which lack centrioles are still capable of spindle formation.

Cytoskeleton

- The cytoskeleton is a network of fibres extending throughout the cytoplasm.
- It organises the structures and activities within the cell.
- There are 3 main types of fibre in the cytoskeleton namely, microtubules, microfilaments and intermediate filaments.

Microtubules	
Structure	**Function**
• Microtubules are the thickest class of the cytoskeletal fibres • They are, hollow, unbranched, cylindrical fibres • They are made up of a helically arranged globular protein called tubulin • They are able to lengthen and shortened by polymerisation and depolymerisation of tubulin	• The movement of chromosomes during nuclear division is facilitated by the lengthening and shortening of microtubules • It provides mechanical support and maintains the shape of the cell ○ It is also dynamic and can be quickly dismantled and reassembled at another part of the cell, changing the shape of the cell
• They have a certain degree of stiffness and run a straight course in the cytoplasm	• The movement of vesicles is facilitated by motor proteins carrying vesicles along the microtubules to their destination ○ For e.g. microtubules guide secretory vesicles from the *trans* face of Golgi apparatus to the cell surface membrane

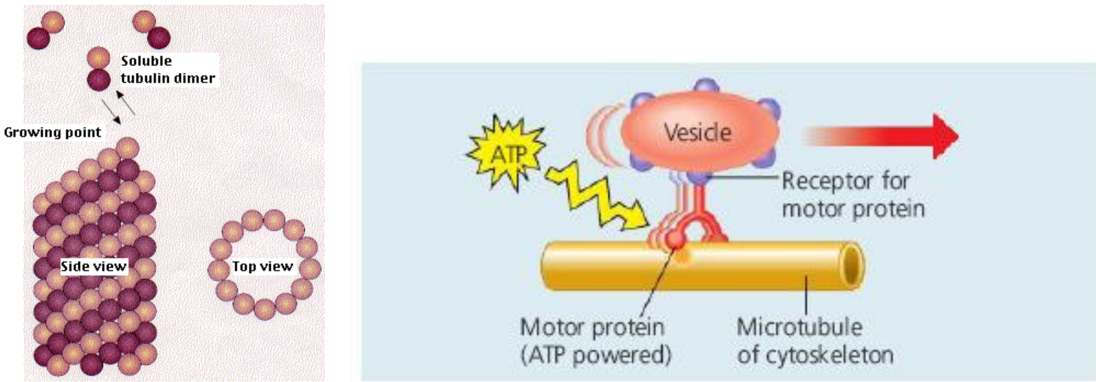


Fig. 1.25 Structure & Assembly of Microtubule

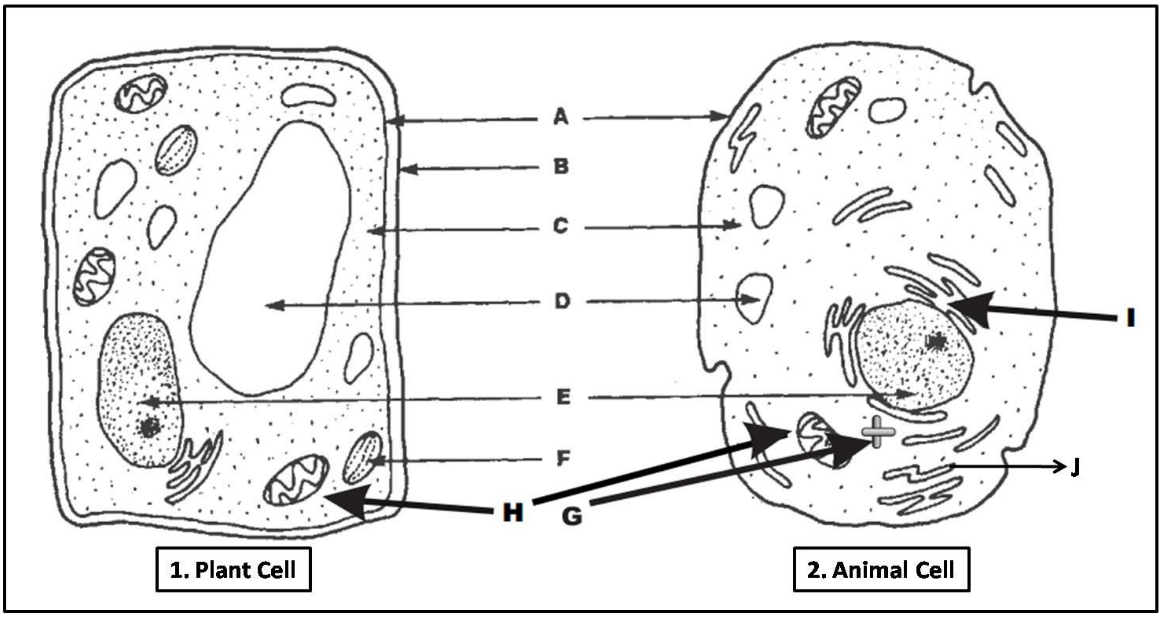
A bridge to O Level Biology
(6093 syllabus and 5078 syllabus)

You should have learnt:

D. compare the structure of typical animal and plant cells

Check Your Understanding (3)

Question: With reference to the diagram below, complete the table below by stating which structure(s) are found in plant cell only, animal cell only or both. Structure **G** had been completed for you.



Plant cell only	Both	Animal cell only
		G centrioles

Structure of a Typical Bacterial Cell

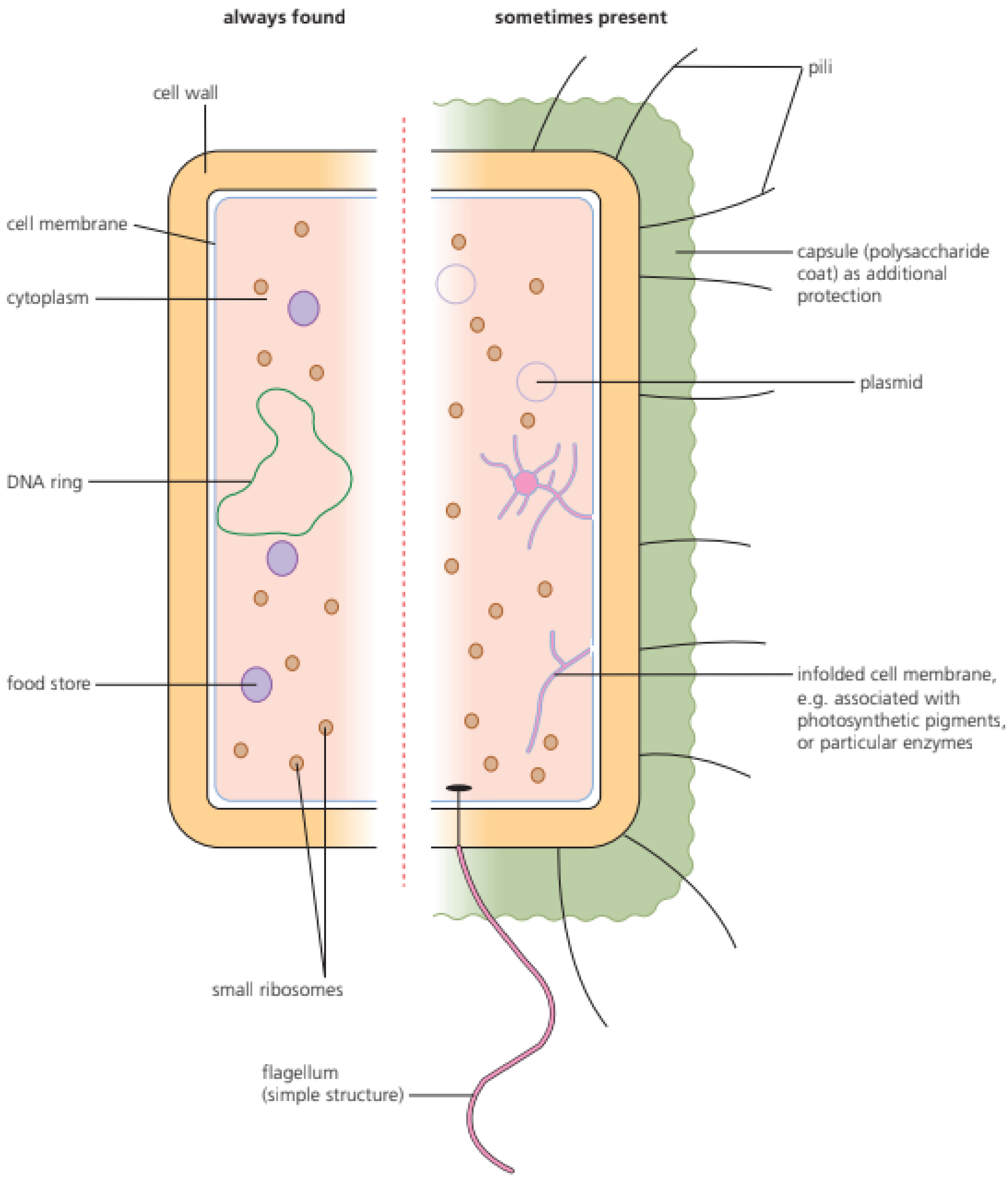


Fig. 1.26 Structure of Prokaryotic Cell

- Bacteria and cyanobacteria are prokaryotes.
- The distinctive features of the prokaryotes are:

Peptidoglycan cell wall

- The prokaryotic cell wall protects and maintains the shape of the cell.
  - Composed of a carbohydrate–protein complex called peptidoglycan

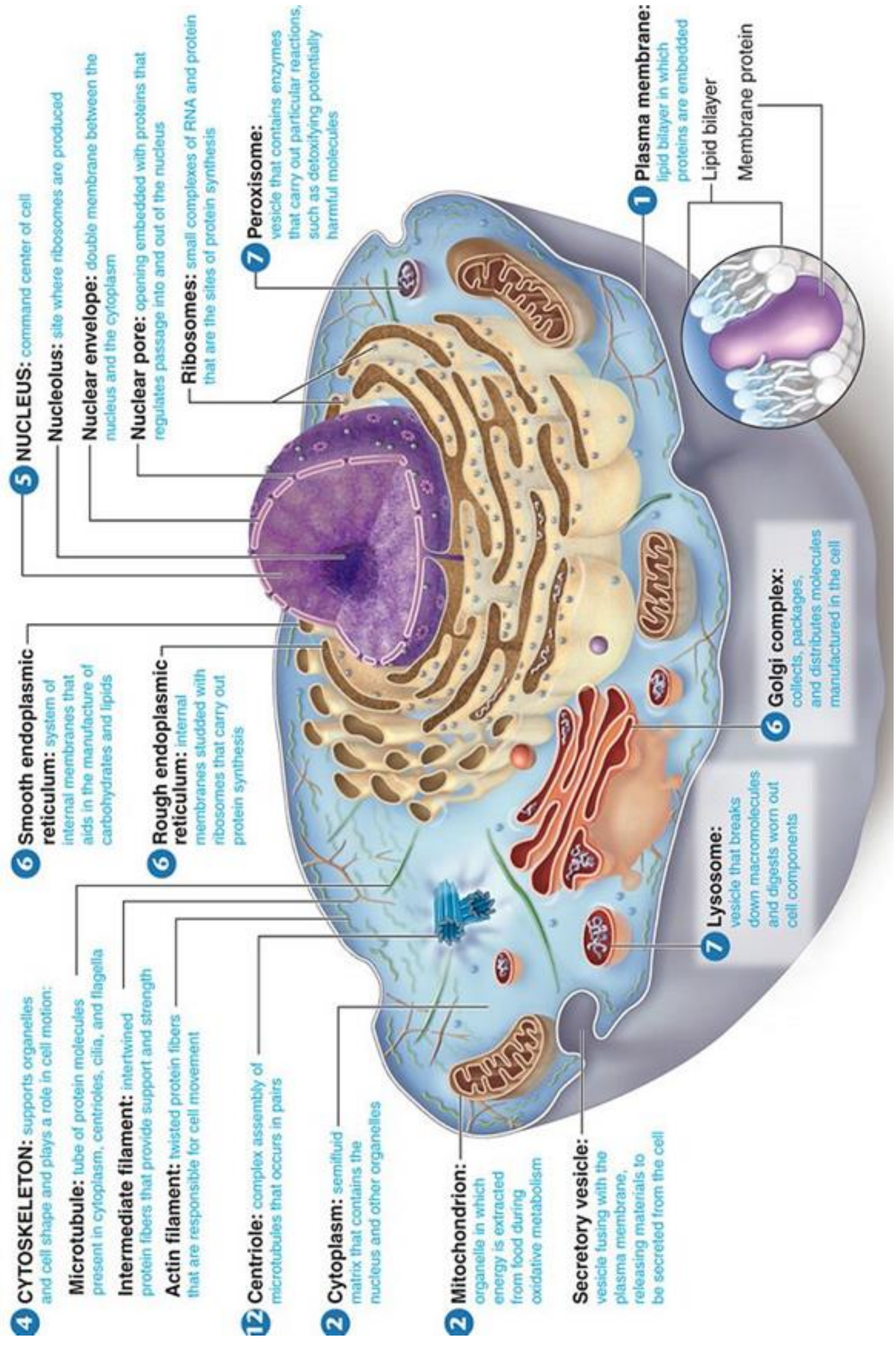
Circular DNA

- The nucleoid region of a bacterial cell is non-compartmentalized and contains a single, long, continuous, circular thread of DNA, the bacterial chromosome.
  - Therefore this region is involved with cell control and reproduction.
- In addition to the bacterial chromosome, bacteria may also contain plasmids.
  - Small, circular, DNA molecules are not connected to the main bacterial chromosome
  - Replicate independently of the chromosomal DNA
  - Not required by the cell under normal conditions but it may help the cell adapt to unusual circumstances, i.e. allows cell to gain selective advantage

70S ribosomes

- Ribosomes occur in all prokaryotic cells and they function as sites of protein synthesis.
  - Occur in very large numbers in cells that produce a lot of protein
  - When numerous, they give the cytoplasm a granular appearance

Summary: Overview of an animal cell ultrastructure with the associated functions



Annex A: Microscopy ***You can refer to Practical 01 and Practical 02 for an in-depth content on Microscopy.***

- The use of microscopes with a high magnification and resolution are needed to observe cells and especially their subunits.
    - Magnification refers to the size of the image observed relative to the original size of the specimen.
    - Resolution refers to the clarity of a viewed object.
- There are two types of microscopes - light microscope and electron microscope.
    - Light microscopes use light, passing through living or dead specimens, to form an image. Stains may be used to make it easier to see any details.
    - Electron microscopes use electrons passing through a dead specimen to form an image and provide us with the greatest magnifications (over x100 000) and resolution.

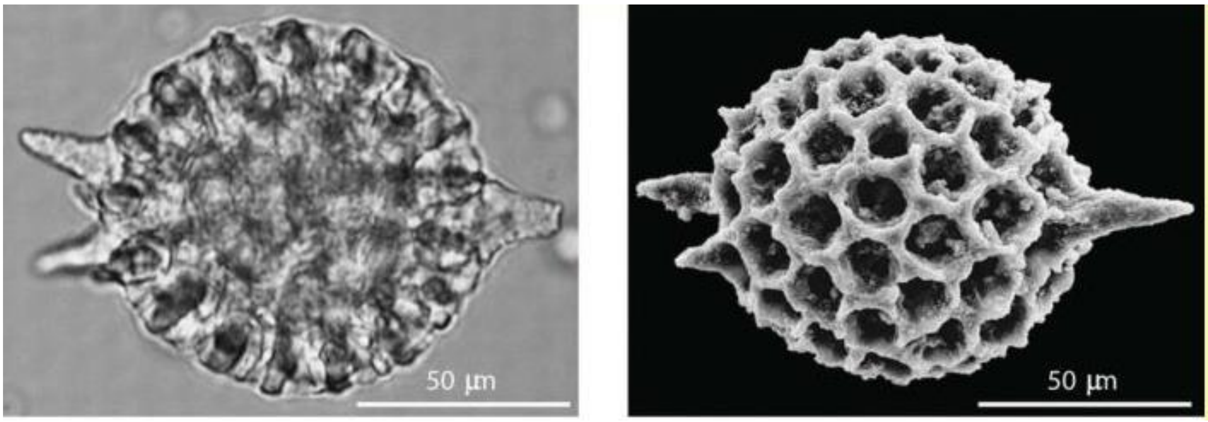


Fig. 1.4 shows low resolution image by light microscope (left) and high resolution image (right) by electron microscope.

Note: You will learn to operate a light microscope, mount slides and use a graticule in practical lessons.

Annex B: Cell Fractionation

- Cell fractionation is used to separate and isolate (fractionate) cell components based on size and density.

1. Homogenisation

   - Intact cells are disrupted in a blender to break them up and the resulting mixture (homogenate) is centrifuged

2. Differential Centrifugation

   - Homogenate is placed into a centrifuge, an instrument that can spin test tubes containing homogenate at various speeds (and duration) to separate cell components based on size and density

   - The supernatant (the liquid above the pellet) is poured into another tube and centrifuged at a higher speed for a longer period.

   - This process is repeated several times and this "differential centrifugation" results in a series of pellets, each containing different cell components.

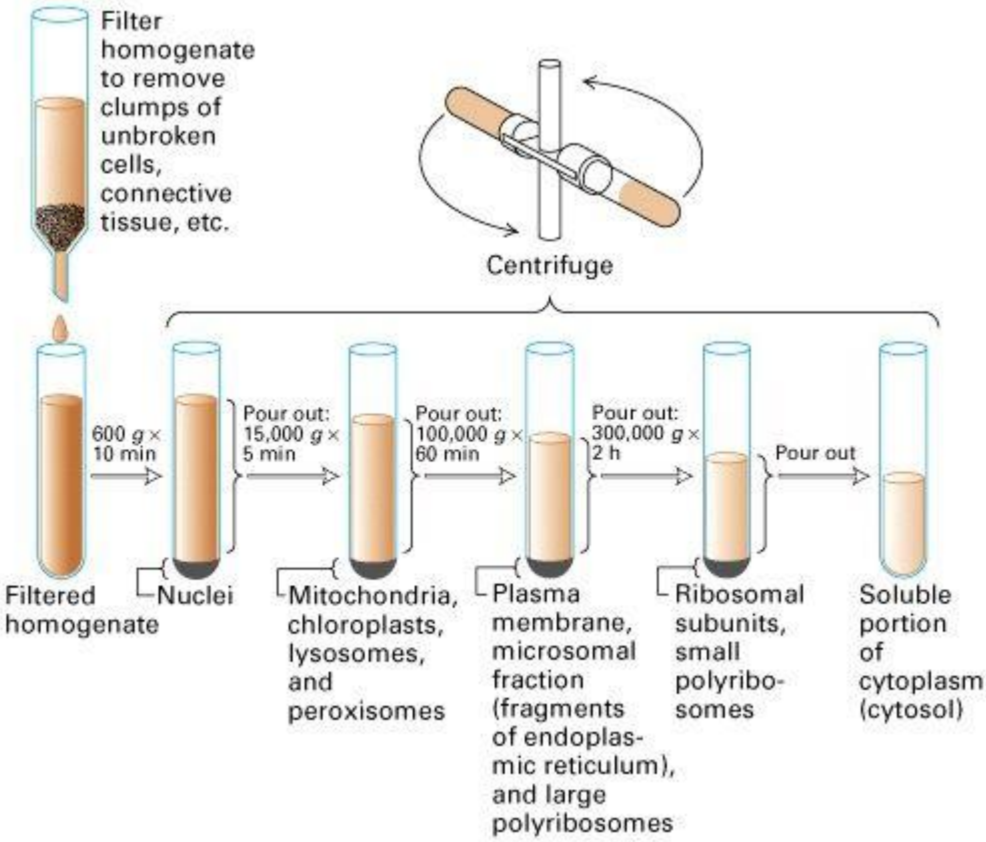


Fig. 1.5 Process of cell fractionation

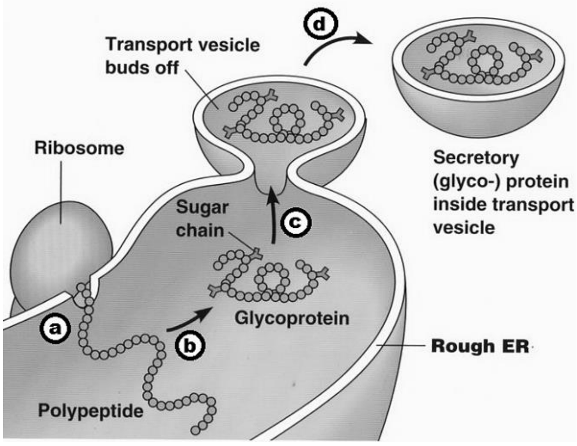
Centrifuge setting (g)	Time	Organelle to separate out in pellet
800 – 1 000	5 – 10 min	Nucleus, cell debris
20 000	15 – 20 min	Chloroplasts, mitochondria, lysosomes
100 000	60 min	Fragments of endoplasmic reticulum, cell surface membranes
150 000	3 hours	Ribosomes

- Cell fractionation enables researchers to prepare specific cell components in bulk and identify their functions, a task not usually possible with intact cells.

- For example, on one of the cell fractions, biochemical tests showed the presence of enzymes involved in cellular respiration, while electron microscopy revealed large numbers of the organelles called mitochondria.

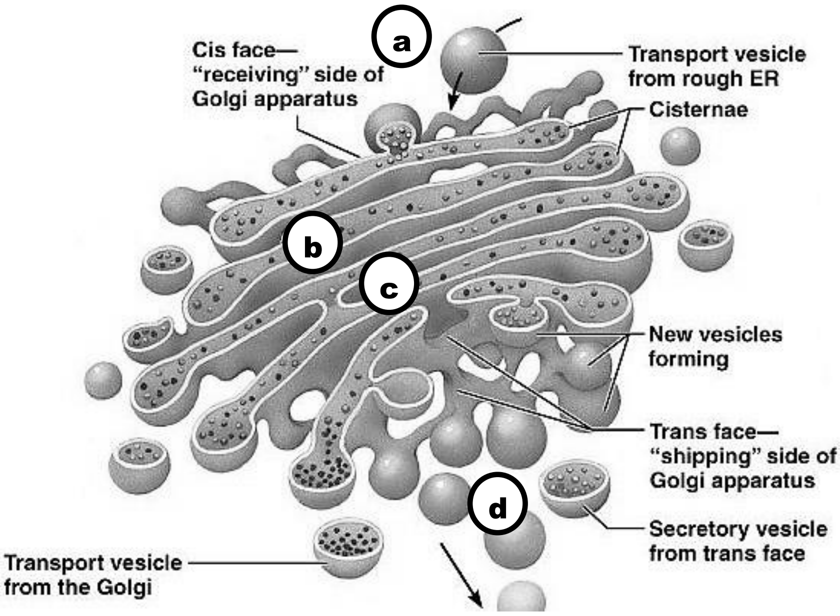
Annex C: Steps involved in the secretory pathway

STEP 1	
LOCATION	Rough endoplasmic reticulum (rER)

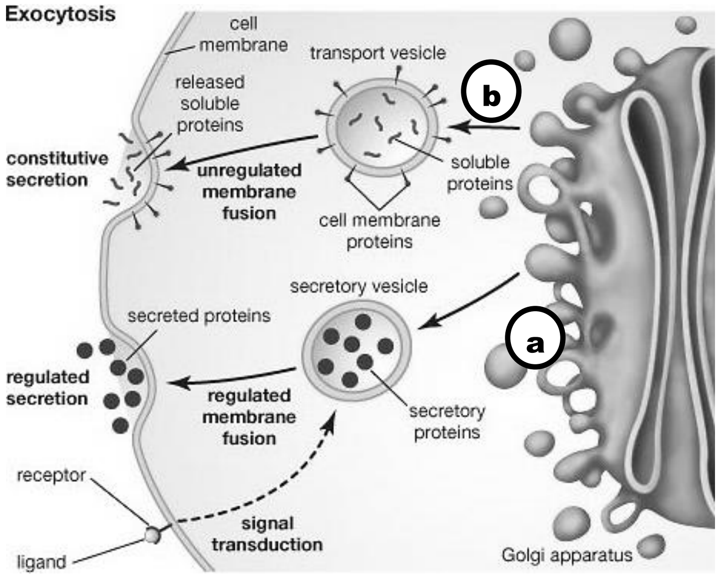


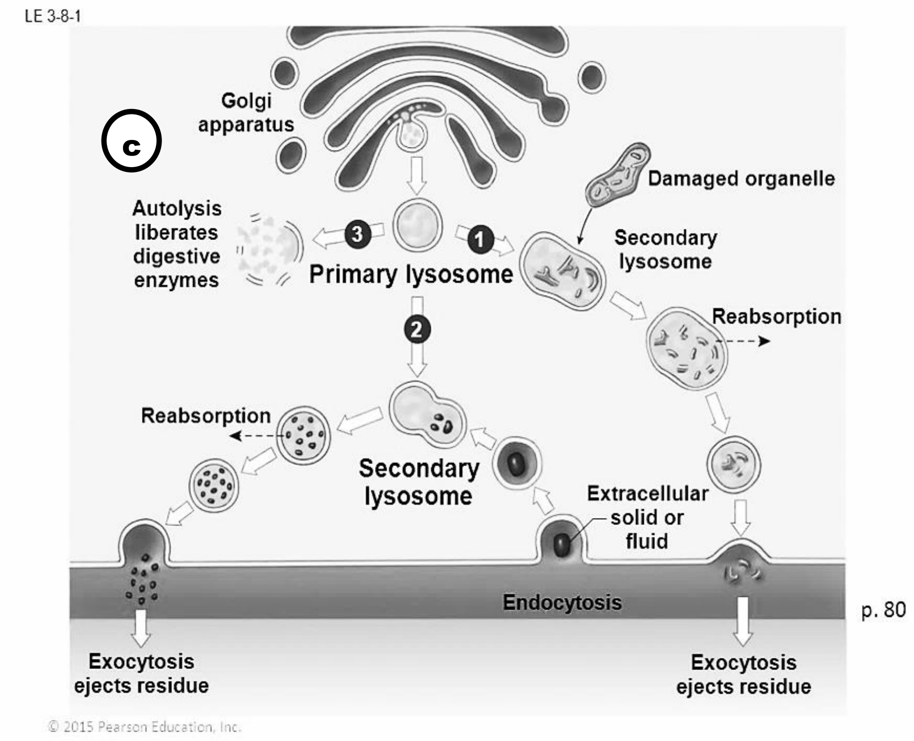
(a)	Polypeptide synthesised by ribosomes on the rER enters the cisternal space via pores in the ER membrane.
(b)	In the rER lumen, linear polypeptide folds into its specific 3D configuration and is glycosylated to form a glycoprotein.
(c)	Glycoprotein is packaged into a transport vesicle.
(d)	Transport vesicle buds off the surface of the rER.

STEP 2	
LOCATION	Golgi apparatus



(a)	Transport vesicle travels through cytoplasm and fuse with the Golgi apparatus at the *cis* face.
(b)	Protein modification (adding phosphate groups/ adding sugar) occurs.
(c)	Modification results in molecular identification tag on the protein.
(d)	Vesicles containing modified protein pinches off from *trans* face of Golgi apparatus.

STEP 3	
LOCATION	Cytoplasm
	
(a)	In regulated secretion, secretory proteins will be packaged into a transport vesicle. Ligand-reception interaction will trigger a signal transduction to signal the secretory vesicle to move along the microtubules cytoskeleton to fuse with the cell surface membrane. The secretory proteins will be released to the external environment via exocytosis.
(b)	In constitutive secretion, secretory and membrane proteins will be packaged into and onto a transport vesicle that will move along the microtubules cytoskeleton to fuse with the cell surface membrane. The secretory proteins will be released to the external environment via exocytosis while membrane proteins will be inserted into the cell surface membrane.

	
(c)	Hydrolytic enzymes will be packaged into a primary lysosome which will remain in the cell. The primary lysosome will then fuse with a food vacuole or a damaged organelle to form a secondary lysosome. Digestion of the particles within the lysosome will result in the release of unwanted materials out of the cell via exocytosis while useful materials will be absorbed by the cell.

Annex D: Answers

Check Your Understanding (1)

A cell surface membrane	**F** chloroplast
B cell wall	**G** centrioles
C cytoplasm	**H** mitochondria
D vacuole	**I** endoplasmic reticulum
E nucleus	**J** golgi body

Check Your Understanding (2)

Structure	Function
A	function as a barrier between cytoplasm and outside of the cell
B	function as both a barrier and structural support to plant cell
C	The fluid, cytoskeleton, and organelles inside a cell
D	function as a storage for inorganic and organic molecules, along with water
E	contains nearly all of the cell’s genetic material used for gene expression
F	produces glucose via photosynthesis
G	function as microtubule organising centre in nuclear division
H	produces ATP via aerobic respiration
I	Rough ER: synthesize protein for secretion Smooth ER: synthesize lipids
J	(chemically) modify proteins from RER and lipids from SER

Check Your Understanding (3)

Plant cell only	Both	Animal cell only
B cell wall	**A** cell surface membrane	**G** centrioles
F chloroplast	**C** cytoplasm	
	D vacuole	
	E nucleus	
	H mitochondria	
	I endoplasmic reticulum	
	J golgi body	