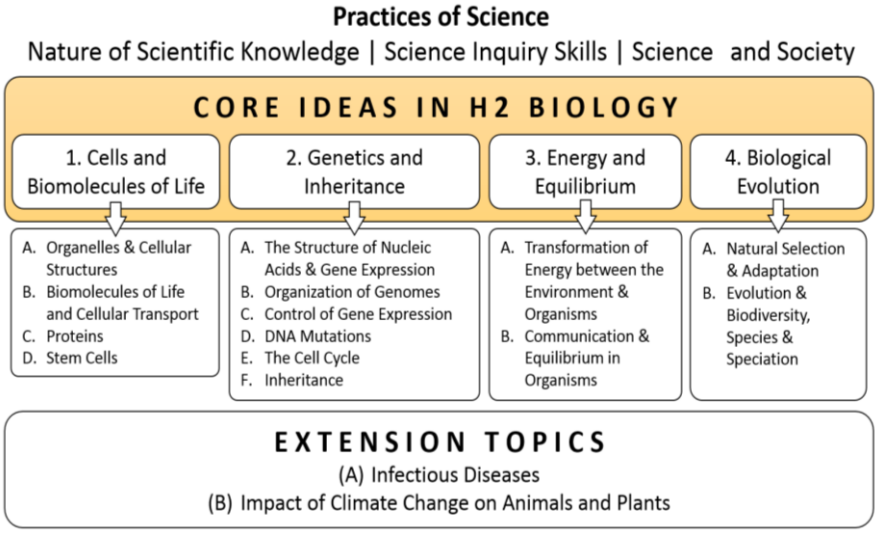
Tampines Meridian Junior College

JC1 H2/9744 Biology 2023

***Note:** complete pre-lecture activity on pg 10 **before** lecture

Core Idea 1A

1. Cell – The Basic Unit of Life



SYLLABUS OVERVIEW		
No.	**Overarching Idea**	**Topics**
1	**Core Idea 1** The Cell and Biomolecules of Life	Cell – The Basic Unit of Life
2		Biomolecules of Life and Cellular Transport
3	**Core Idea 3** Energy and Equilibrium	Transformation of Energy – Photosynthesis and Cellular Respiration
4	**Core Idea 2** Genetics and Inheritance	Genetics and Inheritance (I) – The Cell Cycle
5		Genetics and Inheritance (II) – DNA Replication and Gene Expression
6		Genetics and Inheritance (III) – DNA Mutations and their Consequences
7		Genetics and Inheritance (IV) – Molecular Techniques in DNA Analysis
8		Genetics and Inheritance (V) – Organization of Genome & Control of Gene Expression in Eukaryotes *[Includes Core Idea 1D: Stem Cells]*
9		Genetics and Inheritance (VI) – Organization and Inheritance of Viral Genomes
10		Genetics and Inheritance (VII) – Organization of Genome & Control of Gene Expression in Prokaryotes
11		Genetics and Inheritance (VIII) - Inheritance
12	**Core Idea 3** Energy and Equilibrium	Communication and Equilibrium in Multicellular Organisms
13	**Core Idea 4** Biological Evolution	Biological Evolution
14	**Extension Topic A** Infectious Diseases	Immunity and Infectious Diseases
15	**Extension Topic B** Impact of Climate Change on Animals & Plants	Climate Change – Causes and Impacts on Animals and Plants

TOPIC SYNOPSIS

Core Idea 1 – The Cell and Biomolecules of Life – entails the study of cells, which are the basic units of life.

The following questions should help you frame your learning:

- Why is a cell the basic unit of life and how does it promote continuity of life?
- How is the basic unit crucial in understanding life?
- How are the structures of biomolecules related to their functions?
- How do cells regulate the movement of substances into and out of themselves, and what are the implications of such movements?
- What are the differences between cells of prokaryotes and eukaryotes, between cells of plants and animals, and between cells of unicellular and multicellular organisms?
- In what ways do viruses not fit the cell model?

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. Unlike unicellular organisms which merely undergo cellular division, cells of multicellular organisms undergo division and differentiation to allow them to carry out their specific functions.

Biomolecules make up cells and cells regulate many cellular processes, including the movement of substances into and out of themselves, through membranes

The different classes of biomolecules (sugars, lipids, proteins and nucleic acids) function as molecular building blocks for macromolecules to be assembled. Nucleic acids, which include DNA and RNA, are made from monomers known as nucleotides. Phospholipids, cholesterol, carbohydrates and proteins are important components in biological membranes.

Cells need to regulate the movement of substances into and out of themselves. Substances such as water, oxygen, glucose and minerals are important in the synthesis of new molecules and important cellular processes.

According to the fluid mosaic model, cell membranes are selectively permeable due to the nature of the phospholipids and proteins from which they are made. The movement of different molecules depends on the nature of the substances through transport processes such as osmosis, diffusion and active transport.
Membranes allow cells to create and maintain internal environments that are different from external environments.

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.

In contrast to eukaryotic and prokaryotic cells, viruses lack several of those cellular structures. They rely on eukaryotes and prokaryotes to reproduce. In this regard, viruses are considered obligate parasites and there is debate as to whether viruses are living or non-living organisms.

LEARNING OUTCOMES

Core Idea 1A: Organelles and Cellular Structures
This concept discusses the typical cell model of prokaryotes and eukaryotes, including plants and animals. A strong understanding of the structure of the following organelles and cellular structures in relation to their function is necessary: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus.

Candidates 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 recognize 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, students 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 LO1A(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).

e) Describe the structural components of viruses, including enveloped viruses and bacteriophages, and interpret drawings and photographs of them.

f) Discuss how viruses challenge the cell theory and concepts of what is considered living.

LECTURE OUTLINE

1 **Overview of Cells**
- 1.1 The Cell Theory
- 1.2 Cell fractionation

2 Eukaryotic Cells
- 2.1 What are the organelles and structures that eukaryotic cells possess?
  - 2.1.1 Cell Surface Membrane
  - 2.1.2 Nucleus
  - 2.1.3 Ribosomes
  - 2.1.4 Endoplasmic Reticulum
  - 2.1.5 Golgi Apparatus/ Golgi Body
  - 2.1.6 Lysosomes
  - 2.1.7 Mitochondria
  - 2.1.8 Chloroplasts
    [Endosymbiotic theory – Origin of mitochondria and chloroplasts]
  - 2.1.9 Centrioles
  - 2.1.10 Cytoskeletons
  - 2.1.11 Plant Cell Wall
- 2.2 Functional relationship between organelles
- 2.3 Comparison between plant and animal cells

3 Prokaryotic Cells
- 3.1 What are prokaryotes?
- 3.2 What are the structures of bacteria cell, the main type of prokaryotes?
- 3.3 Differences between eukaryotic and prokaryotic cells

4 Viruses
- 4.1 What are viruses?
- 4.2 What are the structural components of viruses?
- 4.3 How to classify viruses?
- 4.4 Are viruses living or non-living?

REFERENCES

1) Campbell 9th Edition Textbook pg 140 – 170 (eukaryotic cells), 556 – 559 (bacterial cells), 381 – 383 (viruses)

2) Online text resources

1. A tour of the cell	2. Module 4: Cellular Structure	3. Notes, application questions, connection to concepts on cell ultrastructure	4. Collection of Electron Micrographs of organelles

3) Online animation/ video/ game resources

1. Introductory animation on Cell structure	2. 3D animation of a cell	3. PLAY THE GAME Cell Craft and challenge your ability to survive as a cell: http://www.kongregate.com/games/CellCraft/cellcraft	4. Animation on polyribosomes
5. Video on cytoplasmic streaming	6. Animation on Endosymbiotic theory	7. Animation on Microtubules	8. Animations on functional relationship between organelles (vesicle budding)
9. Animation on Prokaryotic vs Eukaryotic cells	10. A Level Biology Revision: Cell Fractionation		

1. Overview of Cells

1.1 The Cell Theory

- The term 'cell' was coined by Robert Hooke in 1665 when he looked at thin slices of cork (a type of wood) under his microscope (Fig. 1.1) and discovered that cork comprised many regular box-like structures (dead cells).

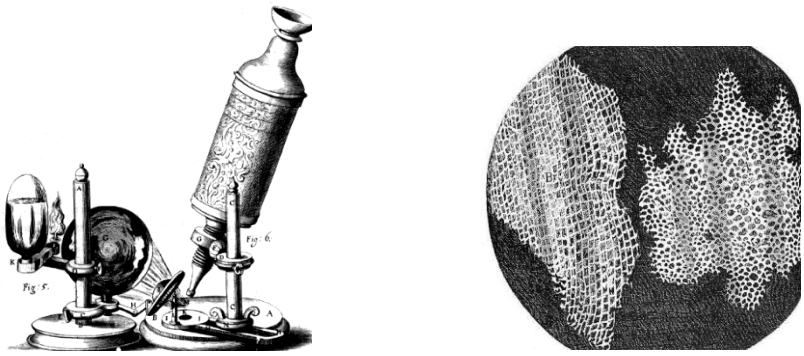


Fig. 1.1: The microscope used by Robert Hooke and the box-like structures he observed

- However, it was only in 1838 when the idea that all living things are made of cells was put forward. In 1858 came the 'Cell Theory' – i.e. 'cells only come from other cells'.

- The 'Cell Theory' contradicted the earlier theory of 'Spontaneous Generation' which stated that living forms can be generated from non-living matter, because of observations of living organisms arising 'spontaneously' from decaying matter (e.g. maggots on rotting meat).

- Many arguments went back and forth to try to disprove the 'Cell Theory', until a definitive experiment (Fig 1.2) by Louis Pasteur in 1859 convinced the scientific world of the presence of airborne microorganisms.

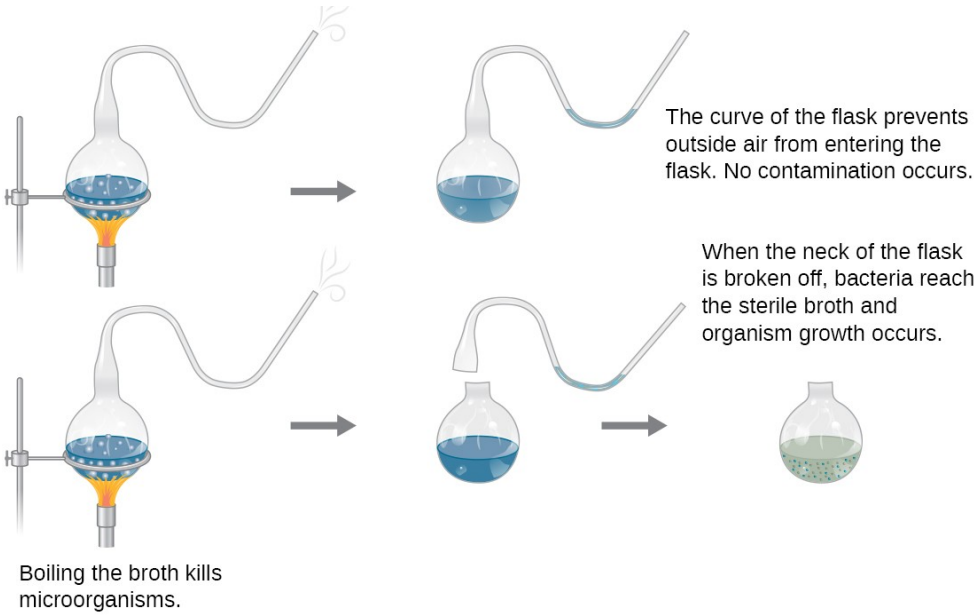


Fig. 1.2: Louis Pasteur's classic experiment to prove that living organisms arise only from other living organisms.

  - The unique swan-neck feature of the flasks used in Pasteur's experiment allowed air to enter the flask but prevented the entry of bacterial and fungal spores.
  - Pasteur's experiment consisted of two parts. In the first part, the broth in the flask was boiled to sterilize it. When this broth was cooled, it remained free of contamination. In the second part of the experiment, the flask was boiled and then the neck was broken off. The broth in this flask became contaminated.

Key Concept 1:

This experiment provided a solid argument for the **Modern Cell Theory**, which suggests that

- A cell is the **smallest, basic unit of life**
- All living organisms are made up of one (**unicellular** organism) or more (**multicellular** organism) cells.
- All cells arise from pre-existing cells by **cell division**.
- Cells contain **genetic material** which is passed from parent cells to daughter cells.
- All **metabolic processes** occur within cells.

- All cells have several features in common.
  - They are all bound by a membrane, called **cell surface membrane/ plasma membrane**.
  - Within the membrane is a semi-fluid substance, **cytosol**.
  - All cells contain **genetic material** (DNA), on which **genes** are carried.
  - All cells have **ribosomes**, very small organelles which manufacture proteins

- Many biochemical reactions take place in the cell for it to maintain alive, and to enable the cell to carry out its specialized function(s).

- Cells are subdivided into **eukaryotic cells** (Fig. 1.3a) and **prokaryotic cells** (Fig. 1.3b), predominantly based on the **presence or absence of the nucleus** and **membrane-bound organelles**.

  - **Eukaryotic cells** have a **membrane-enclosed nucleus** and **membrane-enclosed organelles**. Organisms with eukaryotic cells are called eukaryotes (e.g. plants, fungi, animals).

  - **Prokaryotic cells lack** a **membrane-enclosed nucleus** and **membrane-enclosed organelles**. They are mainly bacteria and cyanobacteria.

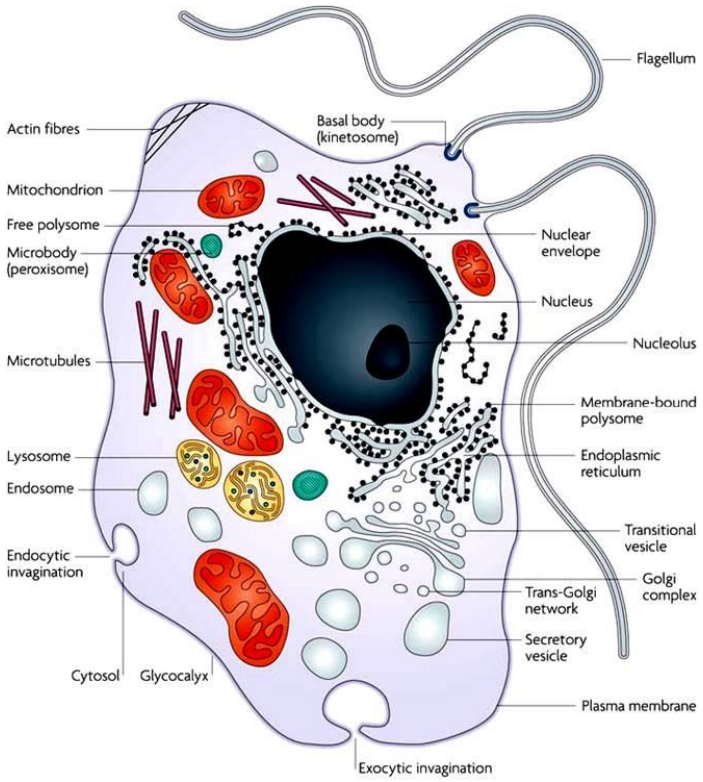


Fig. 1.3a: A typical eukaryotic cell

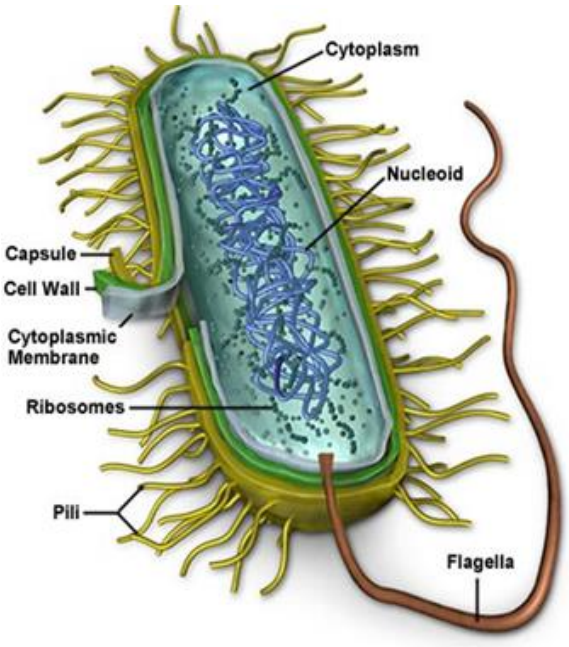


Fig. 1.3b: A typical prokaryotic cell

- Cells are extremely small and can be seen only with a microscope. The approximate diameters of cells and their components are as shown (Table 1):

Cells and their components	Diameter	
Plant cell	40 µm	Largest ↓
Animal cell	20 µm	
Nucleus	10 µm to 20 µm	
Bacterium	1 µm	
Mitochondrion	0.5 µm to 1.5 µm	
Lysosome	0.2 µm to 0.5 µm	
Cilium and flagellum	0.2 µm	
Microtubule	24 nm	
Ribosome	20 nm	
Microfilament	7 nm	
DNA molecule	2 nm	Smallest
1 micrometer (µm) = 10^{-3} mm 1 nanometer (nm) = 10^{-3} µm		

Table 1: Approximate diameters of cells and their components *(FYI).*

- When appropriately stained, the following structures can be clearly visible under a light microscope:
  - Nucleus
  - Chloroplast
  - Starch grain
  - Vacuole
  - Cell membrane
  - Cell wall
  - Cytoplasm

TEST YOURSELF

Which of the following is **NOT** one of the main components of the cell theory?

A. cells must contain DNA

B. all living things are made of cells

C. cells can only come from other cells

D. cells are the basic unit of life

1.2 Cell fractionation

- To study the anatomy and components of the cell, it needs to be first broken up / **homogenized.** This can be done by using a blender (Fig. 1.4), chemicals or ultrasonic waves, while suspending the cells in an isotonic solution.

- During homogenization, most organelles stay intact, except the endoplasmic reticulum which is broken into small pieces (due to its extensive membrane). These small pieces of membrane tend to reseal into vesicles known as microsomes**.**

- After homogenization, **cell fractionation** techniques can then be used to separate the various cell components, while preserving their individual functions so that they can be studied.

- The most common fractionation method is **centrifugation** (Fig. 1.5), which spins homogenised samples at very high speeds, thus subjecting them to centrifugal force and separating organelles **based on their size and/or density**.

    - The **larger** or **denser** the organelle/molecule, the **faster** it **sinks** to the bottom of the centrifuge tube to form a pellet (sediment).

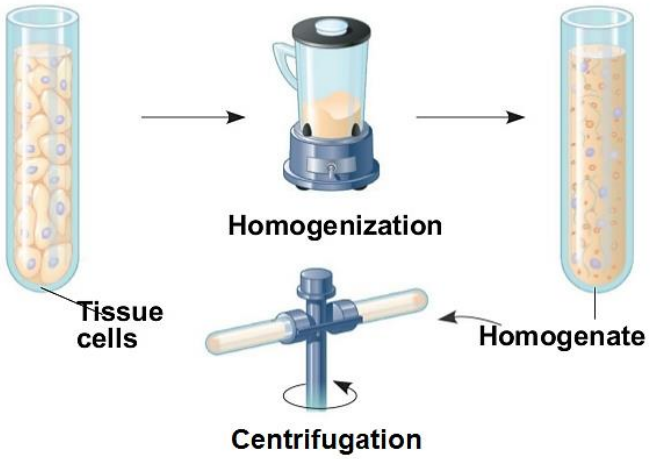


Fig. 1.4: Cells are broken up (homogenised), followed by centrifugation of cell homogenate to separate organelles.

- E.g. **Differential centrifugation** (separation by size) (Fig. 1.5):

    - the cell homogenate is subjected to centrifugation with **progressively higher speeds**, thus **isolating organelles of progressively smaller sizes** after each round of centrifugation.

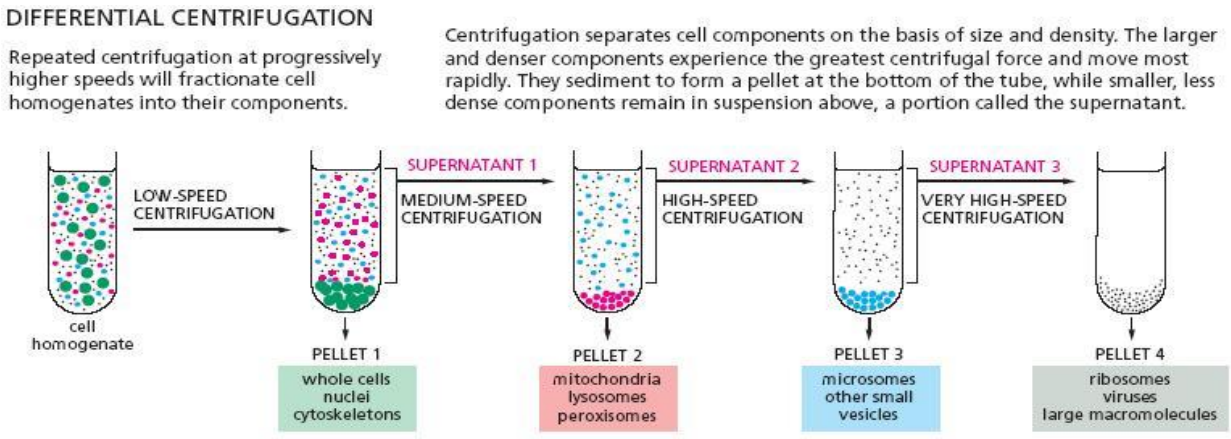


Fig. 1.5: Centrifugation is done by increasing the speed progressively, which isolates increasingly smaller components of the cell.

2. Eukaryotic Cells

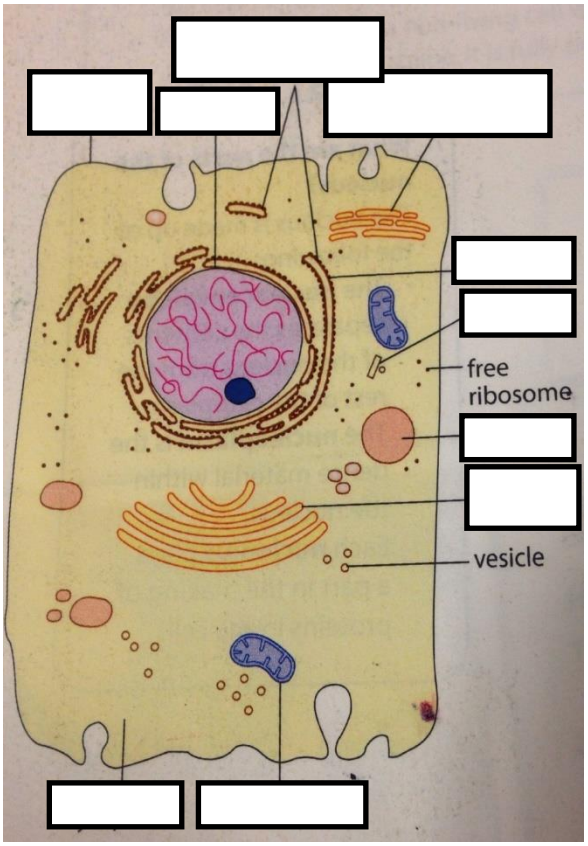
Pre-lecture activity (to be completed before the lecture)

1. Introductory video on Cell Structure (highly recommended)

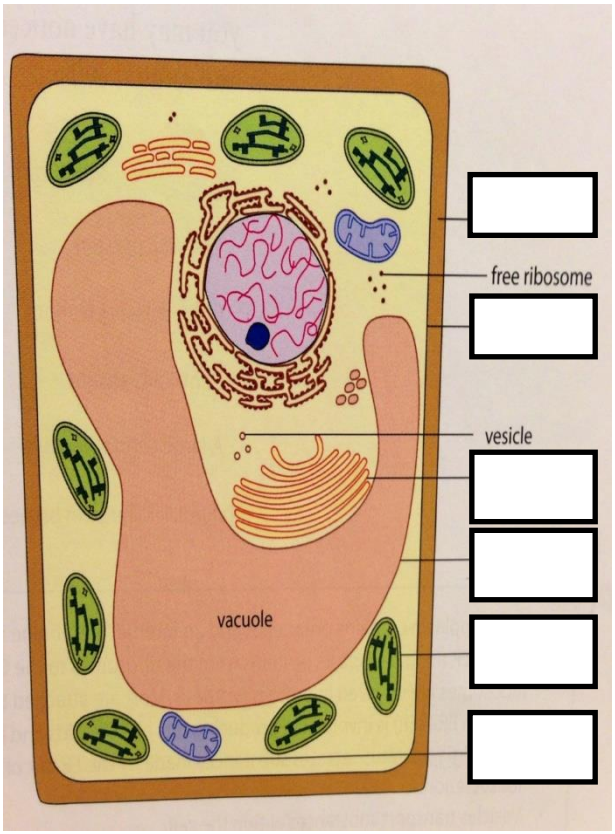
Watch the animation at: https://www.youtube.com/watch?v=URUJD5NEXC8

2. Quiz

The diagrams below are taken from your 'O' level textbook. Label the following structures and mark your answers (refer to answer key uploaded on Biology website).



Animal cell



Plant cell

Key Concept 2:
Interpret and recognize drawings, photomicrographs and electronmmicrographs 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.

Task: Complete the labelling of the diagrams shown in Fig. 2.1a and Fig. 2.1b.

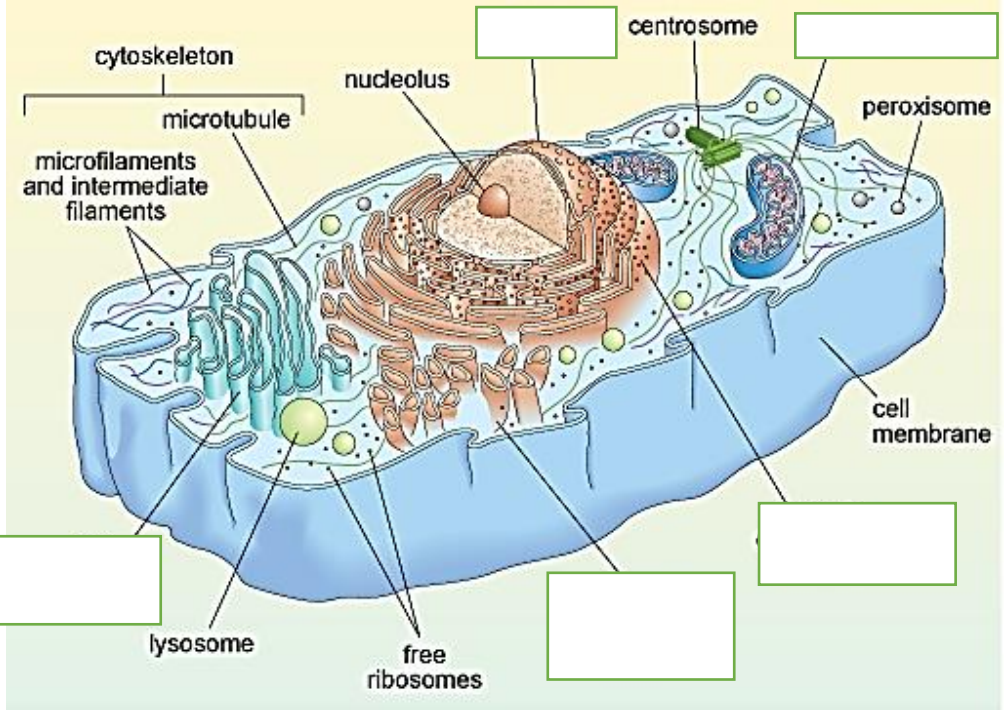


Fig. 2.1a: Schematic diagram of a 'typical' animal cell

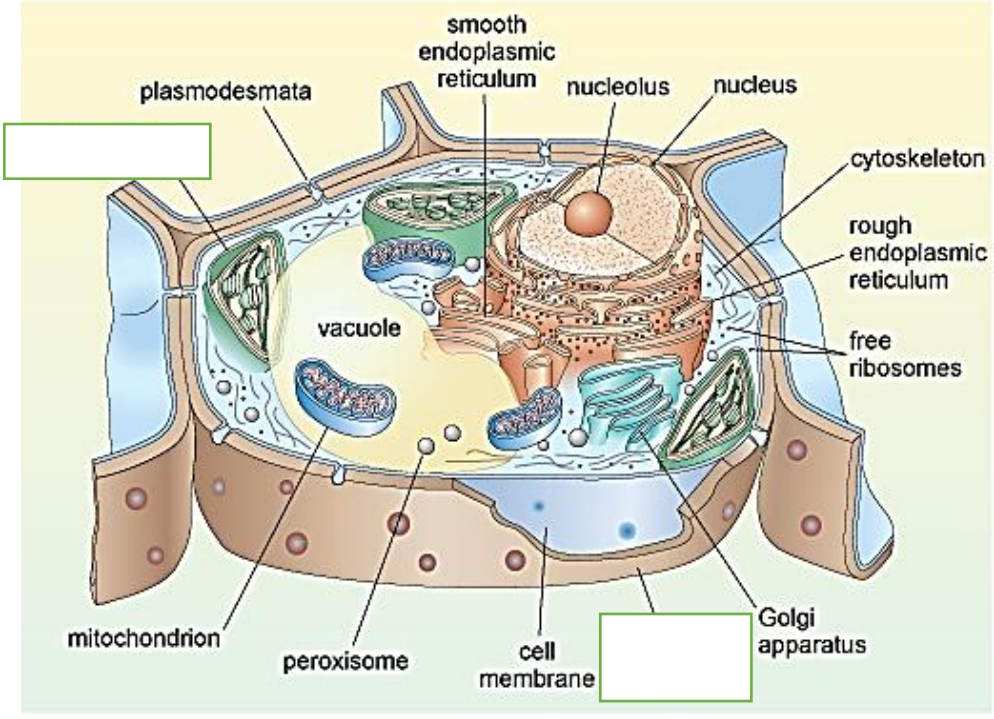


Fig. 2.1b: Schematic diagram of a 'typical' plant cell

Animal and plant cells share many structures and organelles. Structures present in the cells of plants but not animals include the cell wall and the chloroplasts. Plants do not have centrioles. Note that the electron micrographs are two-dimensional “slices,” whereas cells are three-dimensional.

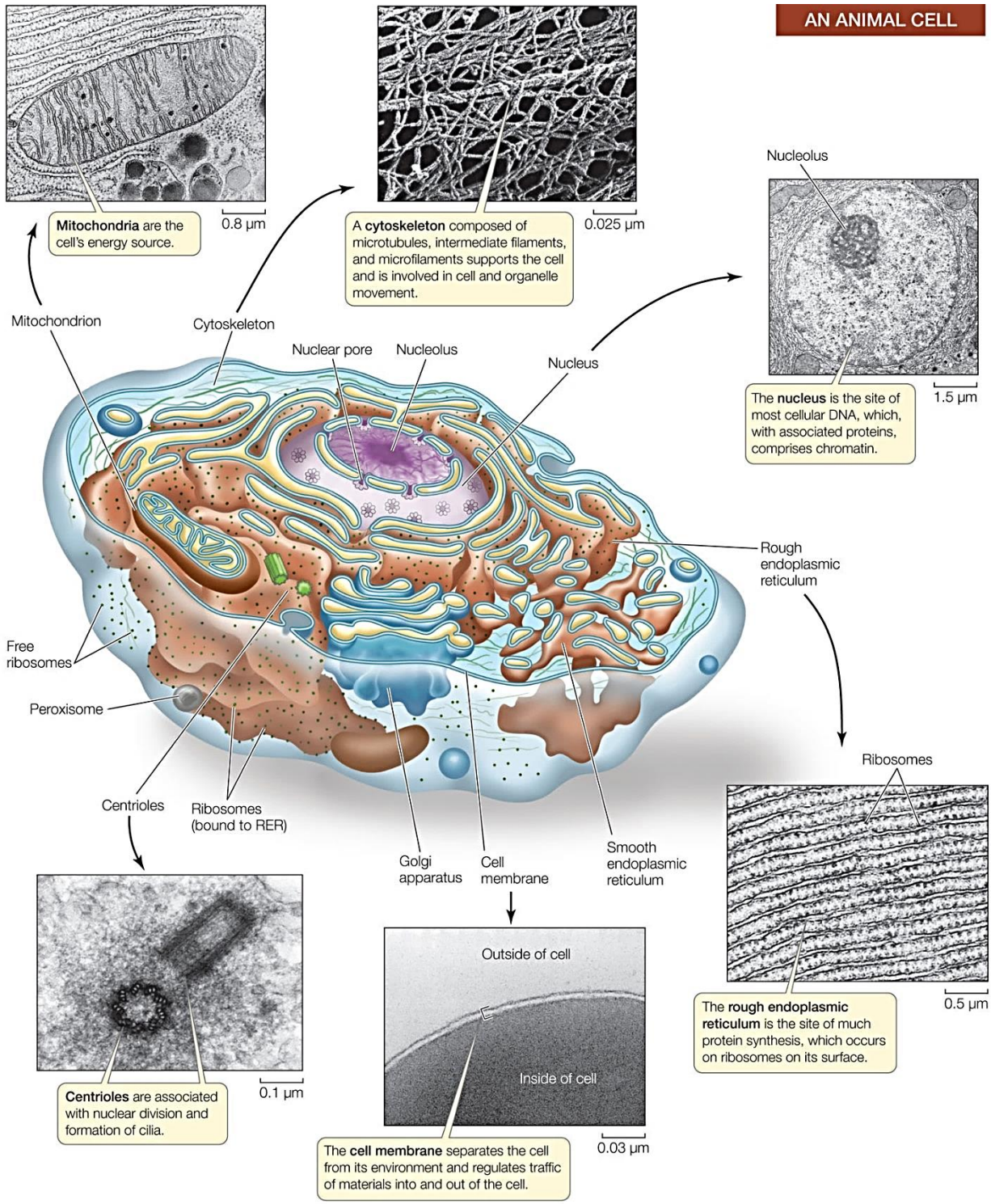


Fig. 2.2a: Eukaryotic Cells – Animal cell

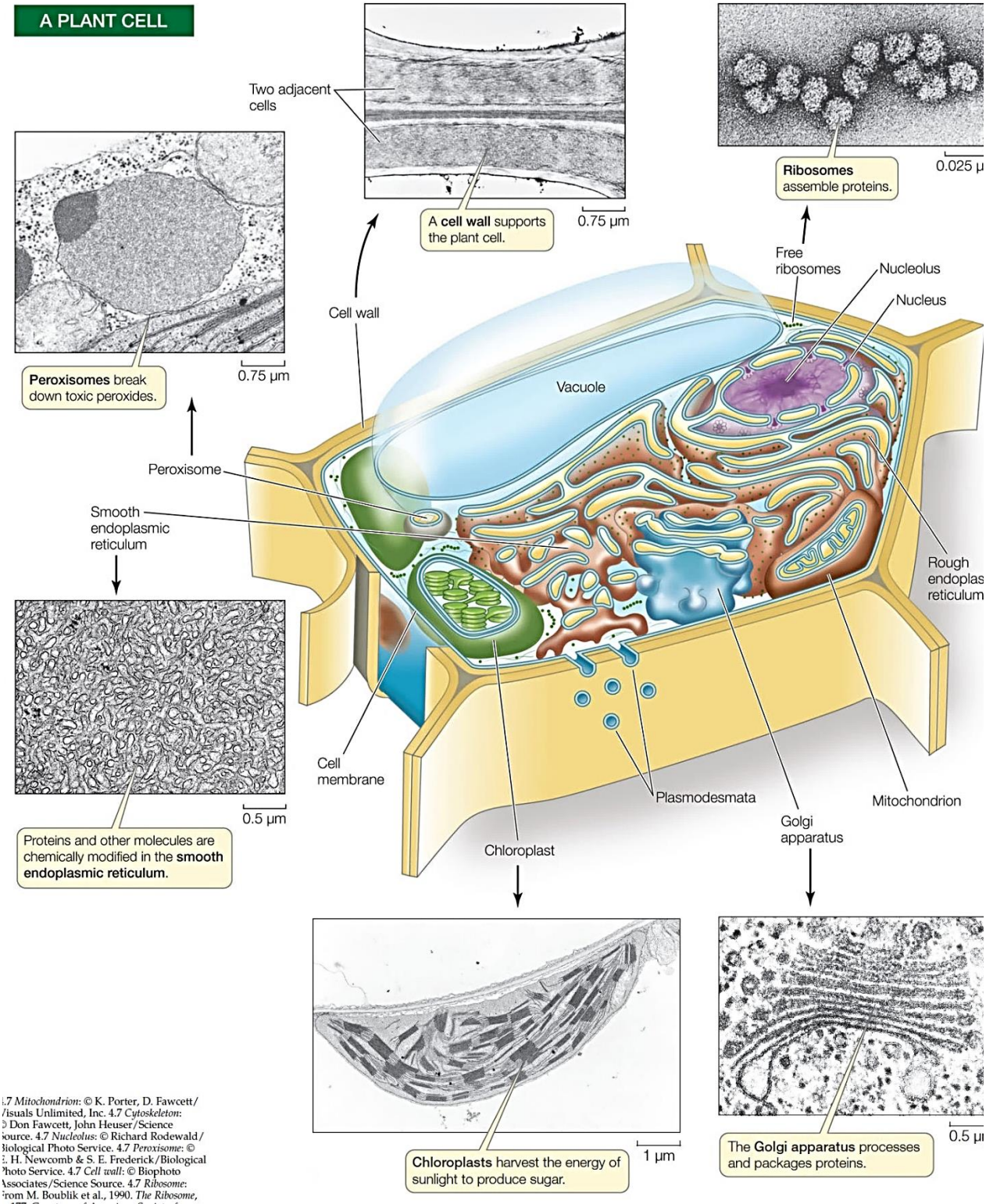
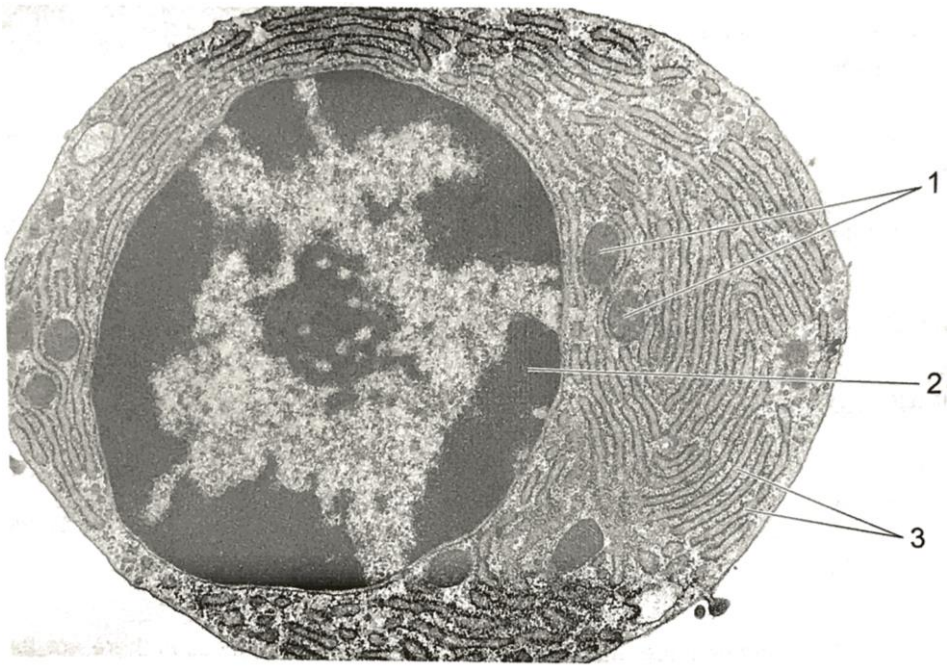


Fig. 2.2b: Eukaryotic Cells – Plant cell

TEST YOURSELF

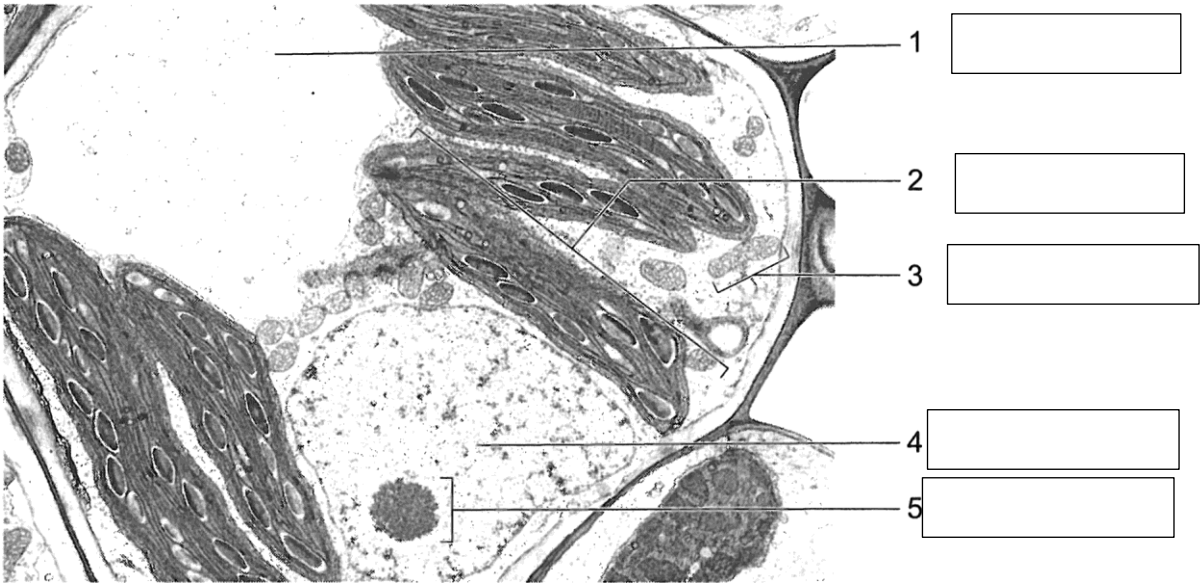
1 The electron micrograph below shows a metabolically active cell.

- Identify the type of cell shown. _____
- Complete the labelling of the electron micrograph.



2 The electron micrograph below shows a cell.

- Identify the type of cell shown. _____
- Complete the labelling of the electron micrograph.



Key Concept 3:
In eukaryotic cells, organelles are present to perform specialized functions inside the cell.

2.1 What are the organelles and structures that eukaryotic cells possess?

- All eukaryotic cells have the **same basic set of structures and organelles**, which may be membrane-bound or non-membrane-bound.

- The **cell surface membrane** of eukaryotic cells surrounds the cell cytoplasm and separates the cell content from the external environment.

- The **internal membrane system** separates the organelles from the cytosol to allow **compartmentalization of organelles** for specialized functions.

2.1.1 Cell Surface Membrane / Plasma Membrane

(To be covered in detail under Topic 2: Cellular Transport)

- At the boundary of every cell, the cell surface membrane functions as a **selective barrier** that allows passage of enough oxygen, nutrients and wastes to meet the metabolic needs of the entire cell.

- The cell surface membrane comprises **phospholipids** arranged in a **bilayer** with the **hydrophobic fatty acid tails** facing inwards and the **hydrophilic phosphate heads** facing the aqueous environment. (Fig. 2.3a).

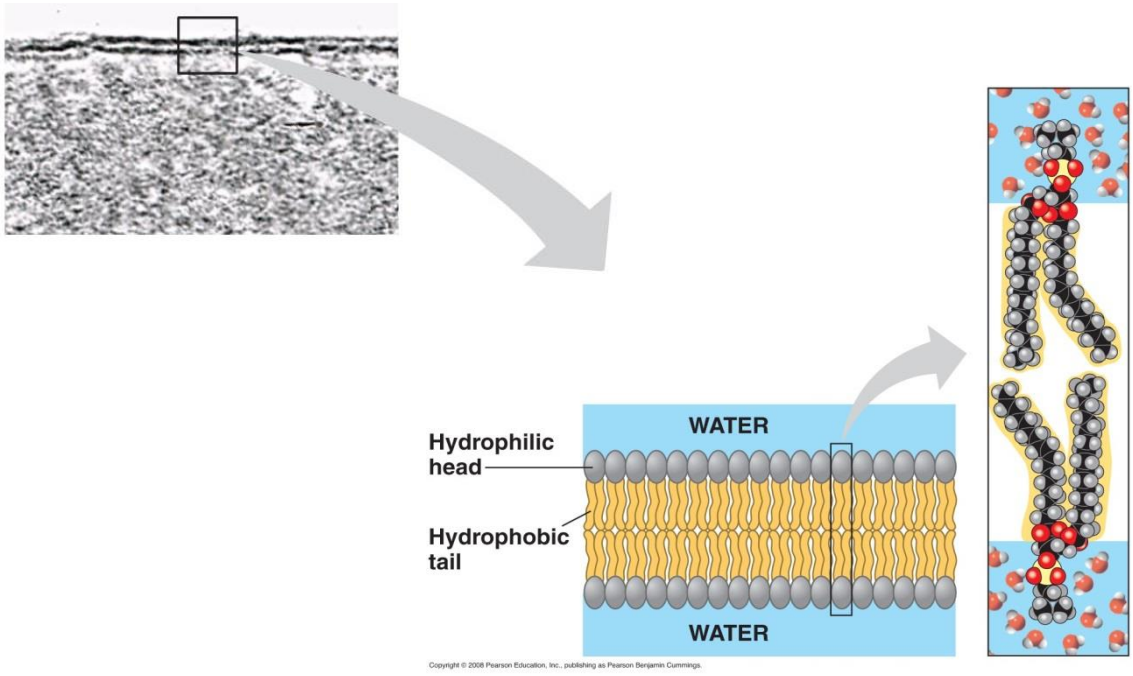


Fig. 2.3a: An electron micrograph and diagram of a phospholipid bilayer

- This bilayer is approximately **7 to 10 nm** in width.

- It exists as a **stable boundary** between two aqueous compartments due to the molecular arrangement sheltering the hydrophobic fatty acid tails of the phospholipids from water while exposing the hydrophilic phosphate heads to water.

- Phospholipids and most other membrane constituents are **amphipathic** molecules, which have both hydrophobic regions and hydrophilic regions. The phospholipid bilayer is stabilized by **hydrophobic and hydrophilic interactions**.

- The amphipathic property of phospholipids allows the membrane to **re-seal** itself when the bilayer is disrupted.

- The bilayer is **dynamic** and its components (such as proteins and cholesterol) are constantly in motion (Fig. 2.3a). Hence the term "**fluid mosaic model**" is used to describe the structure of membranes.

- Functions of the cell surface membrane: *(Refer to Topic 2)*

2.1.2 Nucleus (plural: Nuclei)

Link to Topic 4: The cell cycle & 5: DNA replication and Gene expression

- It is found in **all eukaryotic cells** except in mature red blood cells in mammals and in sieve tubes in plants.

- Cells may be uninucleated, binucleated or multinucleated.

- A nucleus (Fig. 2.3b):
  - is usually **spherical** or **ovoid**
  - is about 10-20 μm in diameter

- It also contains:
  - **A nuclear envelope**, which is a double membrane (i.e. 2 phospholipid bilayers) and perforated by **nuclear pores**
  - **Nucleoplasm**
  - **Nucleolus / nucleoli** (plural)
  - **Genetic material (DNA)** which controls all cellular activities, including cell division and protein synthesis.
  - A **nuclear matrix** (framework of fibres) which extends throughout the nucleus
  - **Nuclear lamina**, a network array of protein filaments lining the inner surface of the nuclear envelope to mechanically support the nucleus

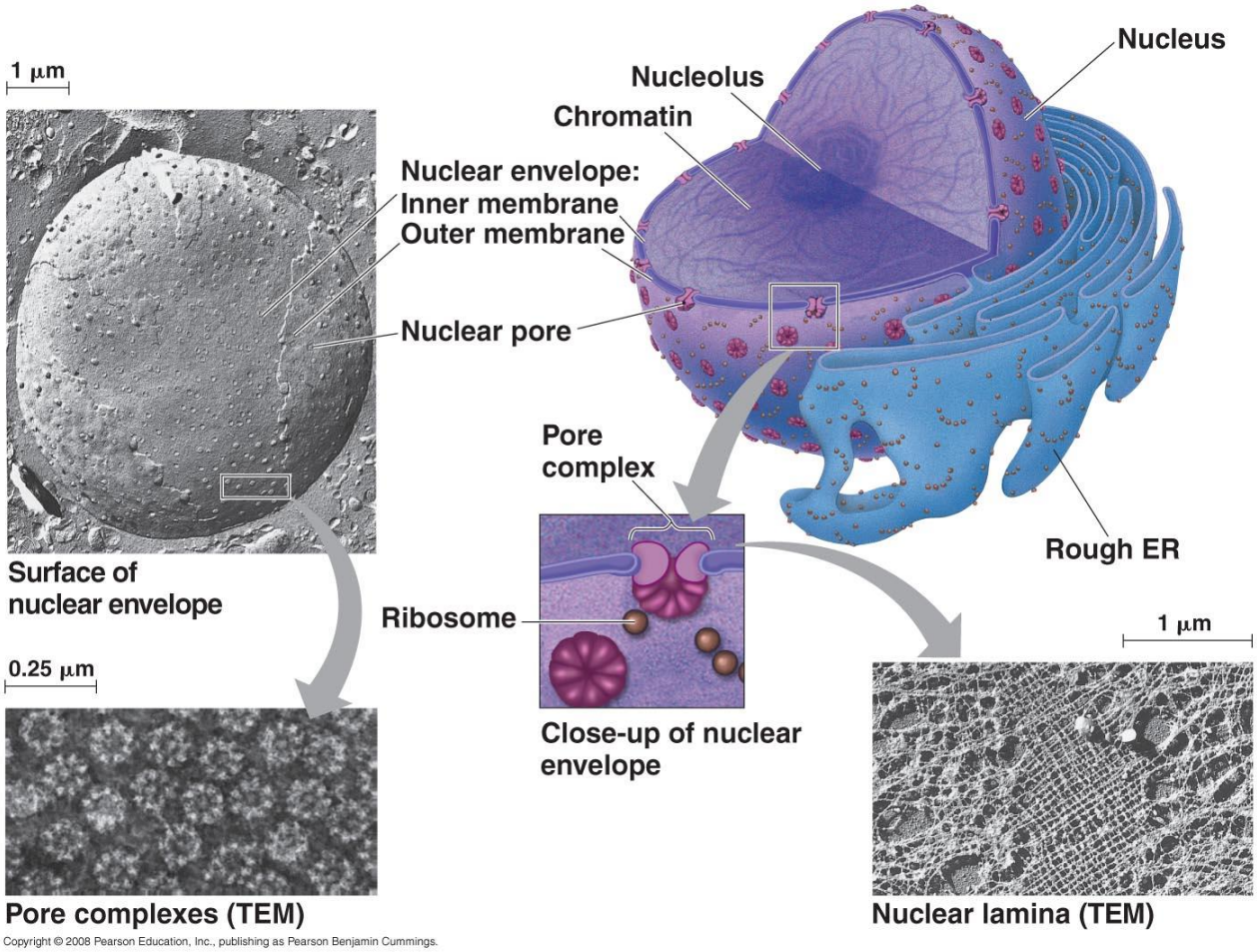


Fig. 2.3b: The nucleus and its sub-structures

a) Nuclear Envelope

- It is a **double membrane** that encloses the nucleus, separating it from the cytoplasm.
- It comprises the **outer membrane**, which gives rise to and is **continuous with the rough endoplasmic reticulum**, and an **inner membrane**.
- An **intermembrane space** exists between the inner and outer membrane.
- The membrane is perforated by **nuclear pores** (about 50nm in diameter), each formed by a protein **pore complex**.
- The nuclear pore complex **regulates the exit of RNAs** and **entry of proteins, ATP and nucleotides**.

b) Nucleoplasm

- A **semi-fluid** material that fills the nucleus.
- Contains chromatin, nucleolus, proteins (enzymes), nucleotides, and ions.

c) Nucleolus (plural: nucleoli)

- A large and **densely–stained area** in the nucleus.
- One or more nucleoli (Fig. 2.3c) can be found in the **nucleoplasm**, depending on cell types and species.

- It contains large loops of DNA where **ribosomal RNA (rRNA) genes** are found (Fig. 2.3d). Transcription of these rRNA genes produces rRNA. Ribosomal proteins that are imported from the cytoplasm are assembled with the rRNA in the nucleolus to form large and small ribosomal subunits.

- Functions of the nucleolus:
    - Site of **transcription of rRNA genes** to produce rRNA.
    - **Assembly of ribosomal proteins with rRNA**, to **form large and small subunits of ribosomes**. *(To be covered in detail under Topic 8: Organisation of Genome and Control of Gene expression in Eukaryotes)*

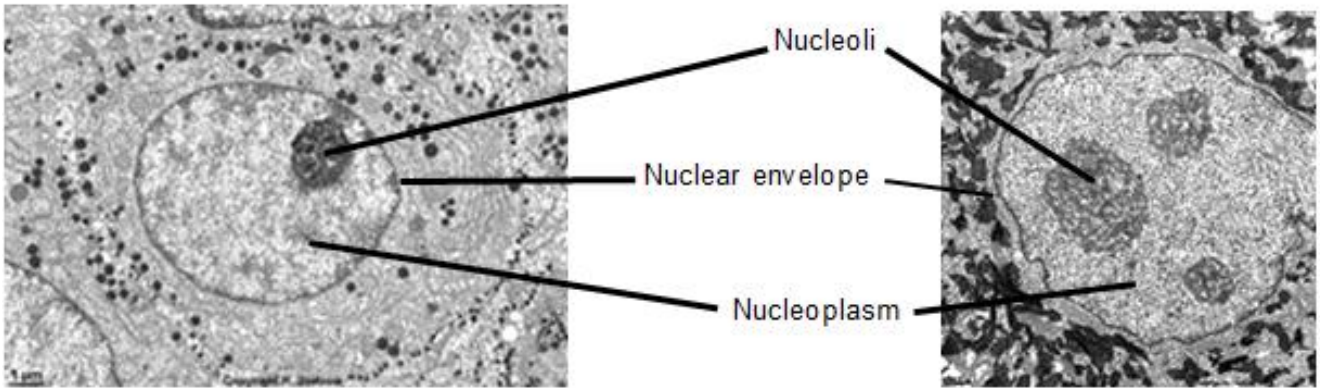


Fig. 2.3c: Cells may contain just a single nucleolus or multiple nucleoli

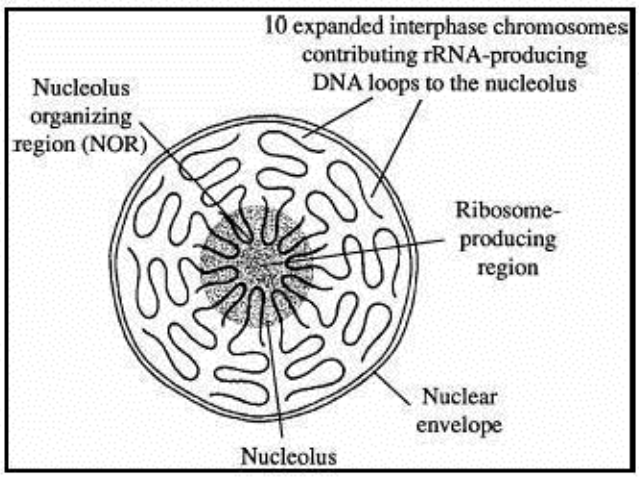


Fig. 2.3d: Drawing of a nucleus. The nucleolus (shaded area) is where rRNA genes are found

d) Chromatin/Chromosomes

- A chromatin thread consists of **a molecule of DNA coiled around** proteins known as **histones**. [Note: eukaryotic DNA is *linear*.]

- In resting/non-dividing cells, the **chromatin** is not visible under the light microscope as they are too fine and highly elongated.
- There are 2 types of chromatin (Fig. 2.3e)
  - **<u>Euchromatin</u>** (lightly stained). Loosely coiled regions, where genes are **transcriptionally active.**
  - **<u>Heterochromatin</u>** (densely stained). Tightly coiled regions, where genes are **transcriptionally inactive.**

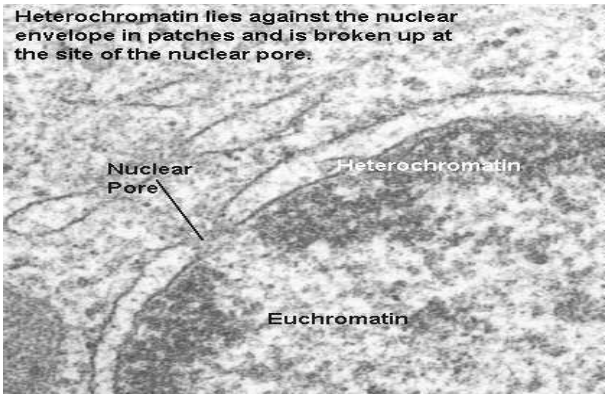


Fig. 2.3e: Euchromatin and heterochromatin in a nucleus

- During nuclear division, chromatin threads undergo **condensation** to become **chromosomes** (Fig. 2.3f), which are visible under light microscope.

- Chromosome number and size are characteristic to each species.

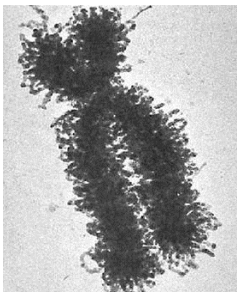
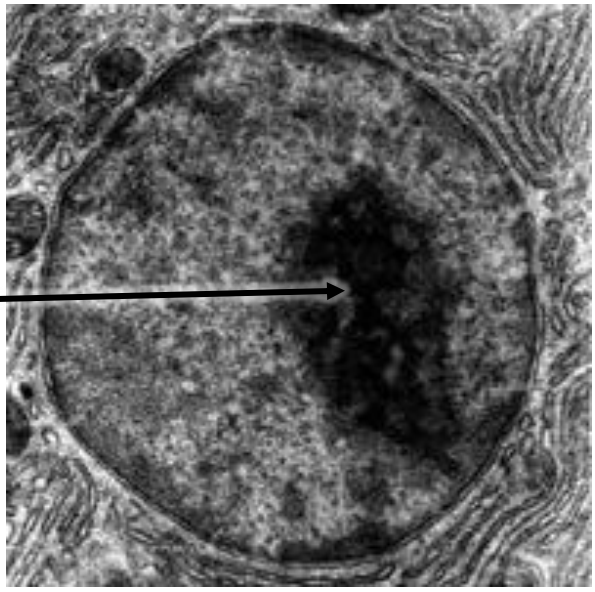


Fig. 2.3f: A chromosome is visible under the light microscope.

Question 1
The figure below shows an electron micrograph of a cell nucleus. Name the labelled structure and state its function.

Structure:

Function:



2.1.3 Ribosomes

- A ribosome is a **complex** of **ribosomal RNA (rRNA)** and **proteins** and **does <u>not</u> have a membrane**.
- It functions as the **site of protein synthesis**.
- Each ribosome is made up of a **large subunit** and a **small subunit**. In eukaryotic cells, **rRNA complexes with ribosomal proteins to form each subunit** in the **nucleolus**.
- The **large and small subunits then assemble together in the cytosol to form a functional ribosome** during translation. (Fig. 2.3g).
- There are two types of ribosomes (Fig. 2.3g):
    - **70S ribosomes**, which are found in prokaryotes, chloroplasts and mitochondria.
    - **80S ribosomes**, which are found in eukaryotes as **free ribosomes** in the cytosol and **bound ribosomes** attached to the rough ER. Free and bound ribosomes are structurally identical and can alternate between the two roles (Fig. 2.3h).

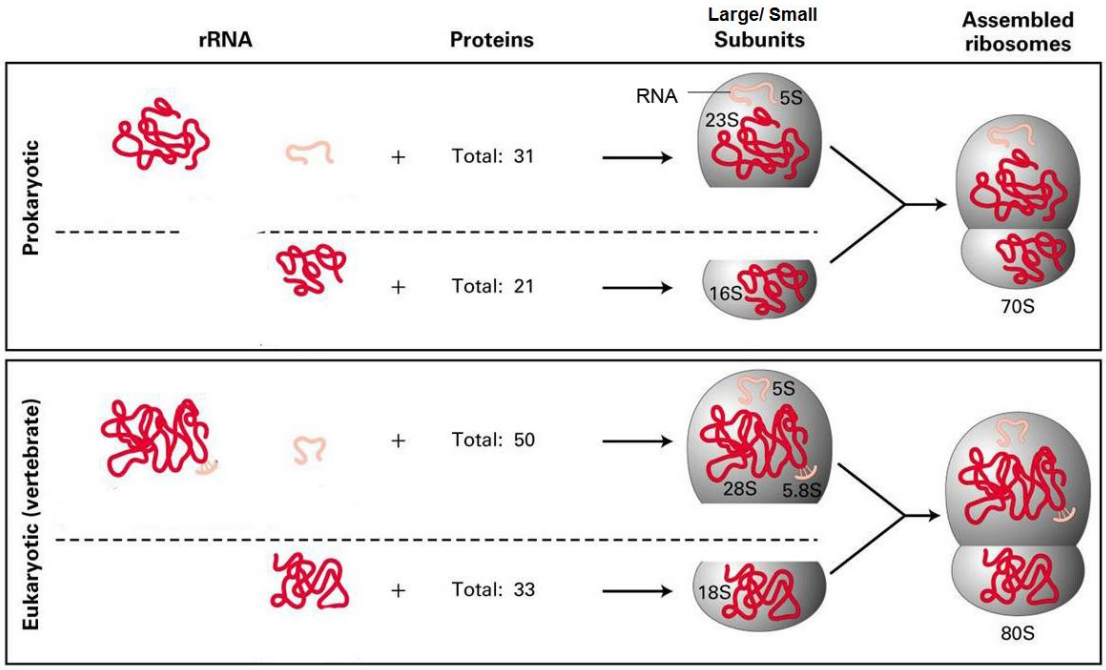


Fig. 2.3g: The components that comprise the prokaryotic 70S ribosome and the eukaryotic 80S ribosome

- Free ribosomes synthesize:
    - proteins that are released in the cytosol and used within cell
      e.g. cytosolic proteins, glycolytic enzymes involved in cellular respiration, histone proteins in nucleus, enzymes in mitochondria & chloroplasts
- Bound ribosomes synthesize:
    - **membrane-anchored proteins** (usually extracellular side e.g. hormone receptors)
    - **proteins destined for secretion** (e.g. insulin hormone)

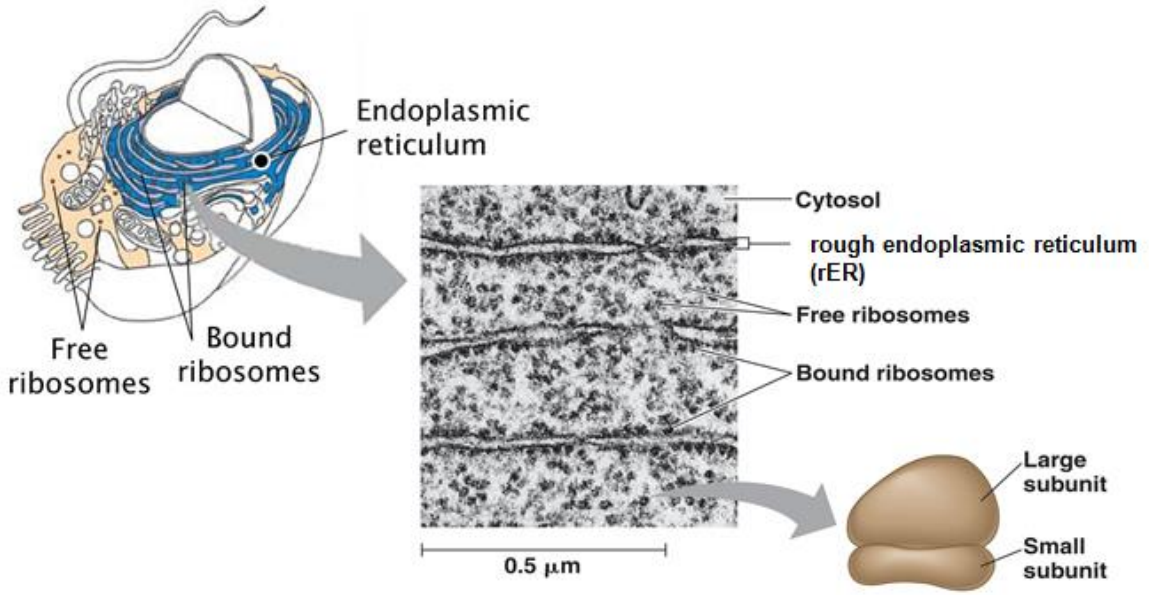


Fig. 2.3h: An electron micrograph of free and bound ribosomes

- Many ribosomes are often found to be attached to a single mRNA molecule during translation. This complex of mRNA and the ribosomes are called **polyribosomes** or **polysomes** (Fig. 2.3i).

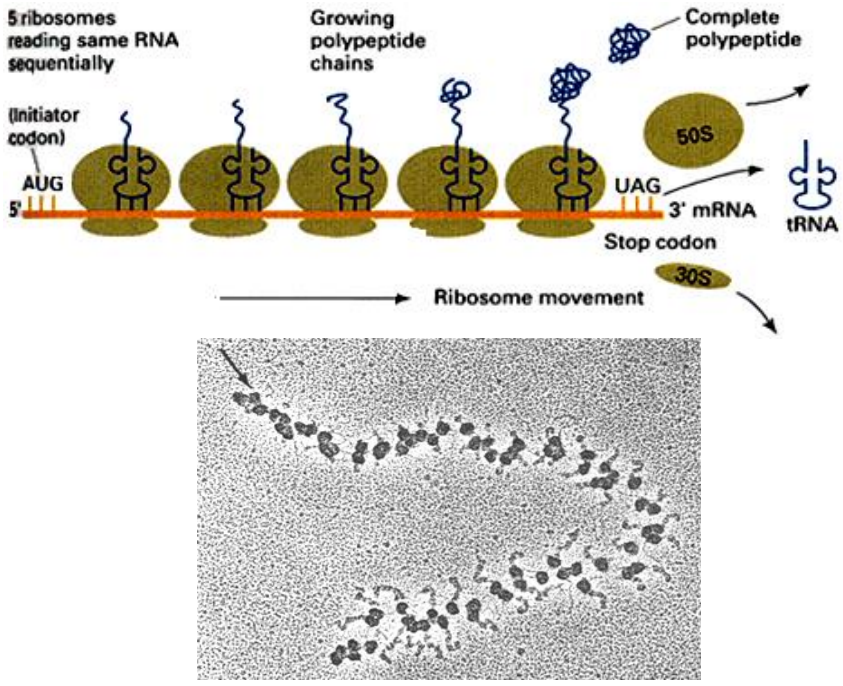


Fig. 2.3i: A drawing and an electron micrograph of a polysome. Arrow on the micrograph indicates entry of ribosome to mRNA. Note the growing polypeptide chain as the ribosomes move along the mRNA

What is the functional advantage of a polysome?

Key Concept 4:

- **Different organelles work together to accomplish the functions of life.**
- **The endomembrane system comprises the nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes and vesicles.**
- **The endomembrane system regulates protein traffic and performs metabolic functions in the cell.**

2.1.4 Endoplasmic Reticulum (ER)

- ER is a **single membrane-bound** organelle consisting of a system of **sacs** called **cisternae** (plural) (singular: cisterna).
- The ER is continuous with the outer nuclear membrane.
- The ER membrane separates the internal compartment of the ER, called **ER lumen**, from the cytosol.
- There are 2 types of ER: the **rough ER** and the **smooth ER** (Fig. 2.3j), each of which has a different role in the synthesis and packaging of proteins and lipids respectively.

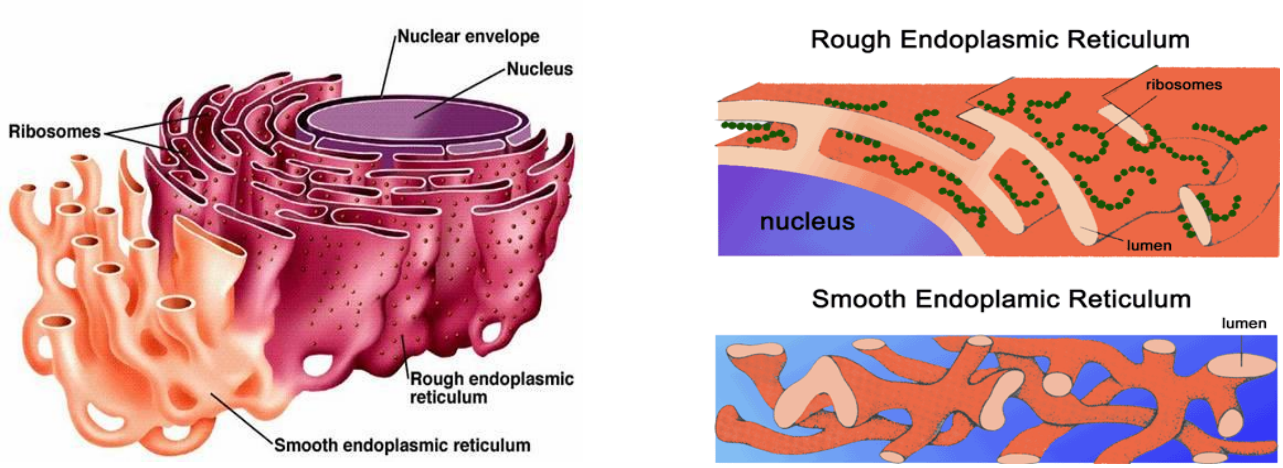


Fig. 2.3j: The structural difference between the rough and smooth ER

a) Rough Endoplasmic Reticulum

- Cisternae are **flattened** sacs, which are **interconnected** with each other and are continuous with the outer membrane of the nuclear envelope.
- It bears **ribosomes** on the surface for **protein synthesis.**
- Functions of the rough ER include:
    - Bound by **ribosomes** which are the sites for **protein synthesis** (Fig. 2.3k, l).
    - Polypeptide chains **enter the rER lumen**, where they **fold** into its 3D conformation and undergo **biochemical modification**. An example of biochemical modification is **glycosylation** (addition of oligosaccharides to proteins) to form glycoproteins.
    - **ER / transport vesicles** are formed from the ER to transport proteins to the Golgi apparatus for further modification.

- It provides **large surface area** of cisternae and serves as a cytoplasmic framework where **enzymes** of metabolic pathways and other chemical reactions (e.g. enzymes involved in protein modification) are **bound**.

- It also allows degradation of misfolded proteins.

- Like the smooth ER, the rough ER also **makes membrane phospholipids** from precursors in the cytosol via enzymes embedded in its membrane.

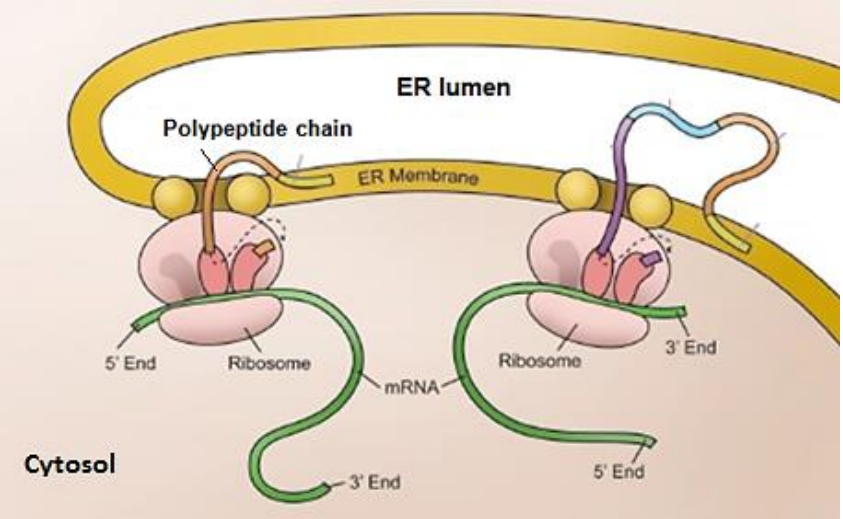


Fig. 2.3k: Proteins enter the rER lumen, where they fold and undergo biochemical modification.

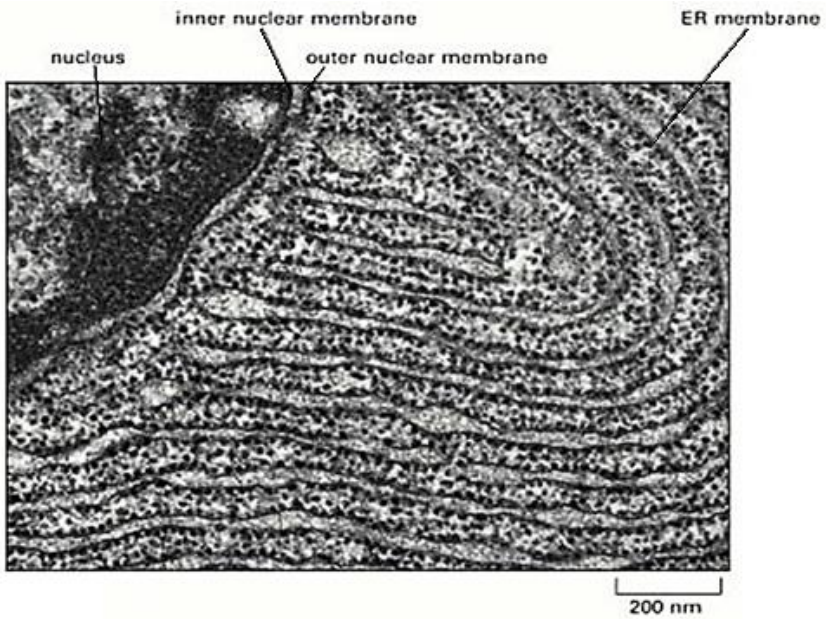
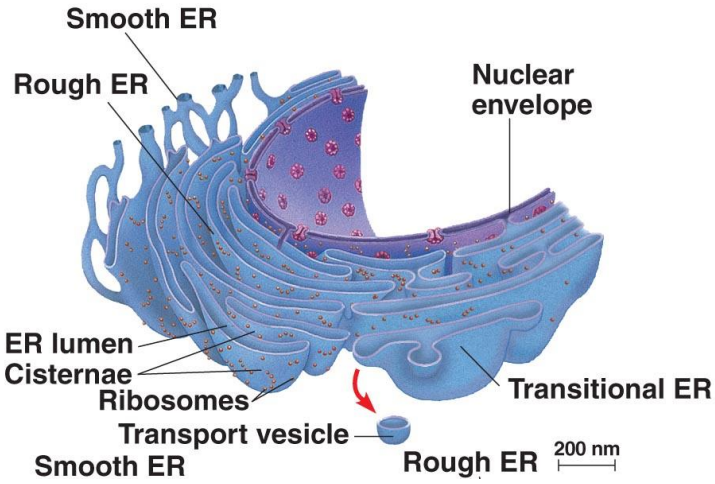


Fig. 2.3l: An electron micrograph of the rough ER in a pancreatic exocrine cell that makes and secretes large amounts of digestive enzymes. The cytosol is filled with closely packed sheets of ER membrane bound with ribosomes. At the top left is a portion of the nucleus and its nuclear envelope; note that the outer nuclear membrane, which is continuous with the ER, is also bound with ribosomes.

b) Smooth Endoplasmic Reticulum (Fig. 2.3j, Fig. 2.3m)

- The smooth ER **lacks ribosomes**.
- It consists of **tubular cisternae**.
- It has a different set of membrane-bound proteins (eg. enzymes).
- Functions of the smooth ER include:
    - **Synthesis and transport of lipids** (e.g. oils, steroids, phospholipids).
    - The sER membrane contains enzymes that make membrane phospholipids (assembled from their precursors in the cytosol). This contributes to the **replenishment** and increase in surface area of the **phospholipid bilayer of the cell surface membrane**.
    - **Metabolism of carbohydrates** e.g. synthesis of glycogen in liver cells
    - **Detoxification of drugs and poisons** in liver cells. This usually involves adding hydroxyl groups to drug molecules, making them more soluble and easier to flush from the body.
    - **Storage of Ca^{2+}** e.g. in muscle cells, where calcium ions act as signaling molecules to trigger muscle contraction.



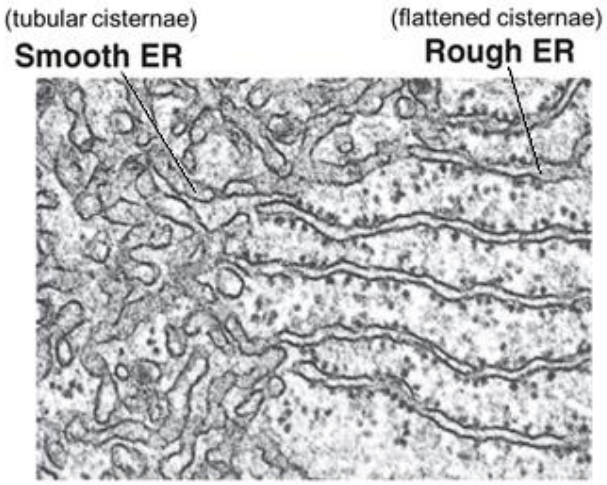


Fig. 2.3m: A diagram and an electron micrograph of the sER and rER

2.1.5 Golgi Apparatus (GA) / Golgi body

- The GA is made up of **a stack of flattened** and **curved single membrane-bound sacs** called **cisternae** (Fig. 2.3n).

- Compared to the ER, the GA has a slight curvature, with its *cis* face usually being nearer to the nucleus, and the *trans* face pointing away from the nucleus.

- At the ***cis* face** or the outer convex face, new cisternae are constantly formed by the **fusion of vesicles** from the rough ER and smooth ER.

- As the products of the ER move from the *cis* face to the *trans* face of the GA by **repeated budding and fusing of vesicles**, the products undergo **biochemical modification**. Different cisternae contain unique teams of enzymes to catalyse these reactions.

- At the ***trans* face** or the inner concave face, various vesicles **bud off** from the Golgi Apparatus. Depending on their content and function, these vesicles could be:
  - **Primary lysosomes**,
  - **Secretory vesicles** (containing products destined for secretion out of the cell), or
  - **Other** kinds of **Golgi vesicles**.

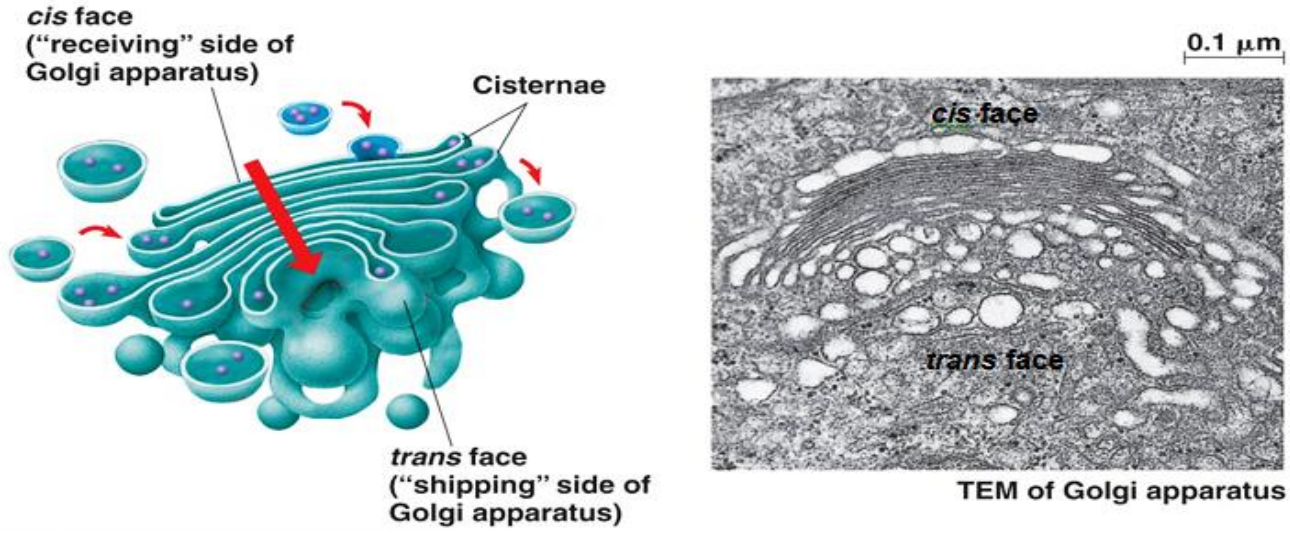


Fig. 2.3n: A diagram (left) and electron micrograph (right) of the Golgi apparatus

- The functions of the Golgi apparatus include:

  - At the *cis* face, it receives products (proteins and lipids) from the ER and **further biochemically modifies** them as they travel through the GA through repeated fusion and budding of vesicles. Depending on the cell type, this modification may vary:

    - For example in phagocytes, which are white blood cells that help the body fight infections, the GA modifies large amounts of hydrolytic enzymes to be packaged in primary lysosomes.

    - One example of modification is **glycosylation** to form glycoproteins and glycolipids in cells. Glycoproteins and glycolipids formed in the ER have their carbohydrates modified in GA to produce a larger variety of carbohydrates.

    - The GA in many fibroblast cells also function to add hydroxyl groups (**hydroxylation**) to collagen polypeptide chains, which is crucial for collagen assembly *(See topic 2: Biomolecules of life).*

- At the *trans* face, modified proteins and lipids are **sorted**, **packaged** into Golgi vesicles and are **transported** to various cellular destinations.

  There are 3 main different cellular destinations:
  1) Cell exterior *via* secretory vesicles
  2) Plasma membrane e.g. receptor proteins embedded in cell surface membrane
  3) Primary lysosomes containing hydrolytic enzymes in the cytosol

  For example, the hormone insulin is packaged into secretory vesicles and transported to the plasma membrane for secretion/exocytosis (Fig. 2.3o).

- **Replenishment** of **cell surface membrane** which has been lost via endocytosis *(Topic 2: membrane transport)*. When Golgi vesicles fuse with the cell surface membrane, their membranes become part of the cell surface membrane.

- Formation of **primary lysosomes** in <u>some</u> animal cells involved in phagocytosis (e.g. certain white blood cells) (Fig. 2.3o).

- Synthesis of certain **macromolecules**, e.g. pectin (found in the cell wall) in plant cells.

- Formation of **cell plate** in **plant cells** during cytokinesis. Golgi-derived vesicles containing cell wall materials (pectin and hemicelluloses) move to the middle of the cell, where they fuse to form the cell plate. The lengthening cell plate eventually forms the new cell wall that divides the cell into two daughter cells. *(See topic 4: Cell cycle).*

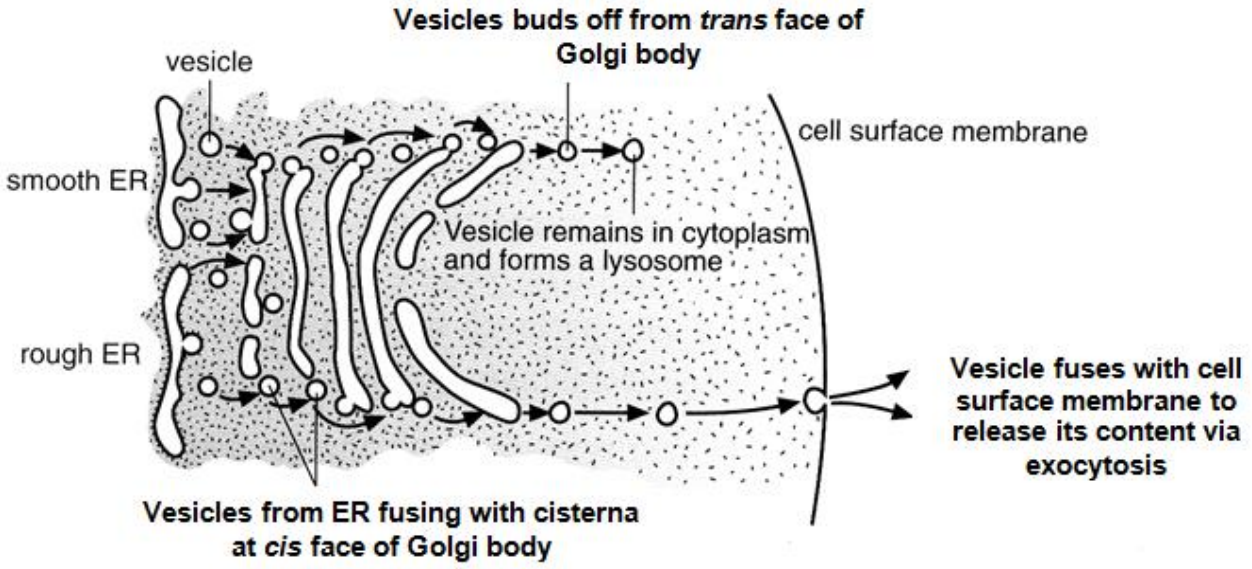


Fig. 2.3o: Vesicles from the Smooth and Rough ER fuse with the *cis* face of the Golgi body, where lipids and proteins respectively are modified as the vesicles continuously bud and fuse, finally budding off from the *trans* face of the Golgi body.

2.1.6 Lysosomes

- Lysosomes are **spherical sacs** of 0.2 - 0.5µm in diameter, formed from the GA.
- It is bound by a **single membrane**.
- It contains **hydrolytic enzymes (acid hydrolases)** that **digest all the major classes of macromolecules**, e.g. proteases, carbohydrases, lipases and nucleases.
- It also serves as a storage vesicle to **keep the enzymes apart** from the rest of the cell, hence preventing it from destroying the cell.
- Its contents are **acidic**; the enzymes have an optimal pH of about 5. The acidic internal pH of lysosomes is maintained by a **proton (H^+ ions) pump** on the lysosomal membrane, which actively transports protons from the cytosol into the lysosome.
- There are 2 types of lysosomes:
    - **Primary lysosomes** are those that bud off from the Golgi Apparatus.
    - **Secondary lysosomes** arise from the fusion of the primary lysosomes with the endocytic vesicles/endosomes such as food vacuole, or phagocytic vesicle/phagosome, or pinocytic vesicles.
- Functions of lysosomes include:
    - **Intracellular digestion** (digestion of materials taken into the cell) (Fig. 2.3p-r)
        - Enables the cell to digest food materials taken in *via* **endocytosis**, which includes **phagocytosis** (solid particles), **pinocytosis** (fluid particles) and **receptor-mediated endocytosis** *[See topic 2: Cellular transport].*
        - Primary lysosomes fuse with the phagocytic/food/pinocytic vesicles so that the digestive enzymes could mix with the contents and carry out digestion.
        - The useful products (e.g. amino acids, sugars, nucleotides) are released into the cytosol for reuse, while residues are discharged by exocytosis.
    - **Autophagy** (Fig. 2.3p-r)
        - **Destruction of worn-out organelles.**
        - Primary lysosomes **fuse** with vesicles containing worn-out organelles to form **secondary lysosomes**. The digested products are returned to the cytosol for re-use.
    - **Autolysis**
        - **Self-destruction of the cell** by the release of the lysosomal contents within the cell.
        - For example, transformation of tadpoles into frogs involves autolysis of cells making up the tail muscles of the tadpoles.

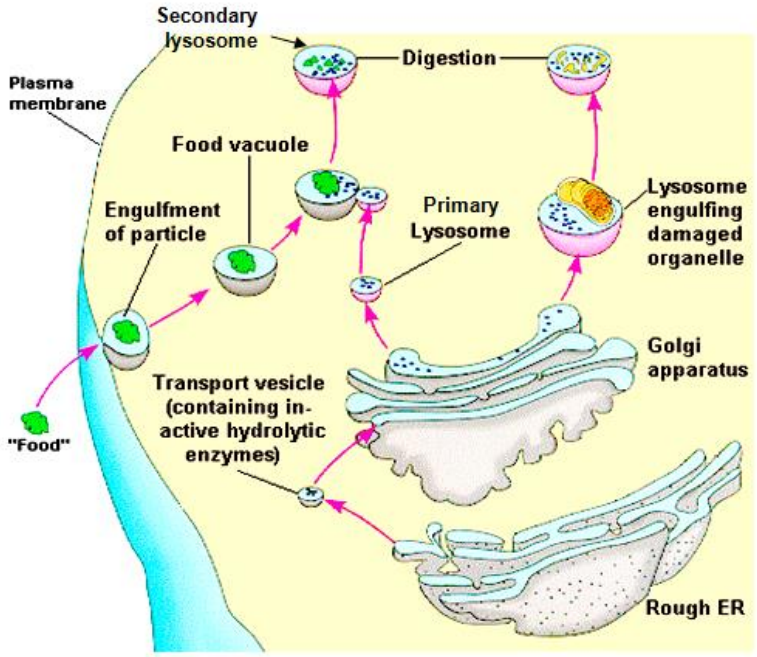


Fig. 2.3p: The digestion of materials ('food') by lysosomes

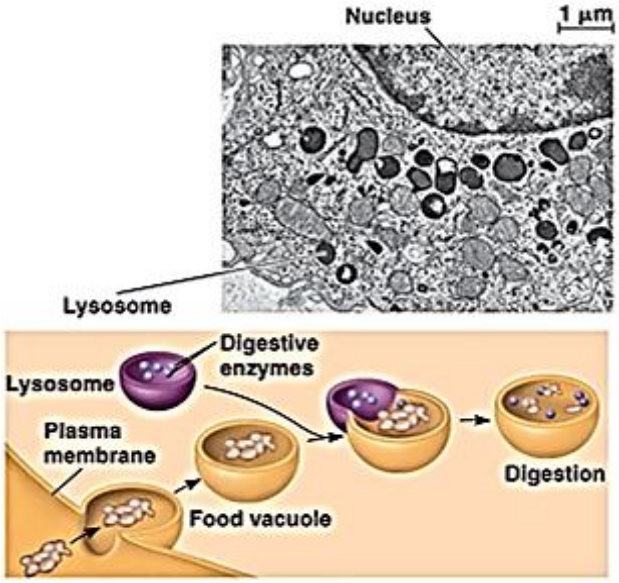


Fig. 2.3q: Phagocytosis

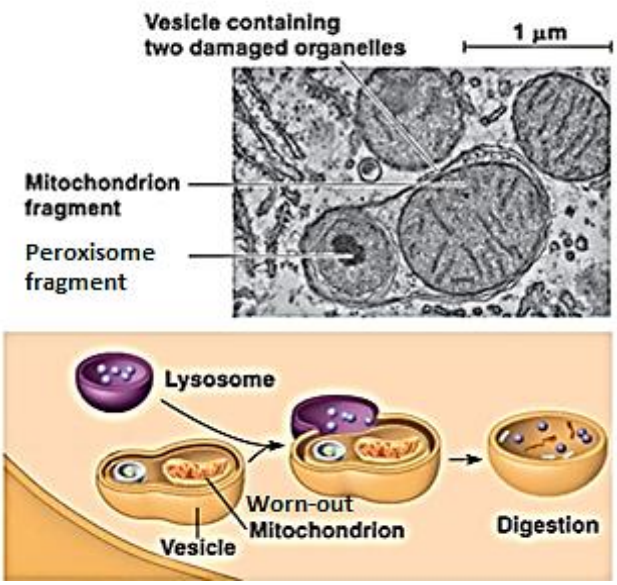


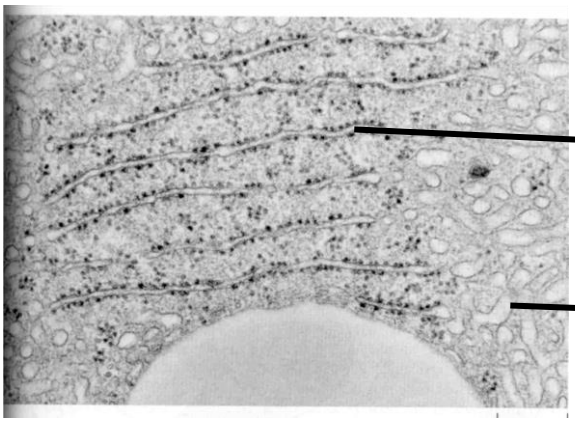
Fig. 2.3r: Autophagy

Consolidation Exercise – Endomembrane system

1. What are the differences between ER vesicles, Golgi vesicles and lysosomes? Complete the table below.

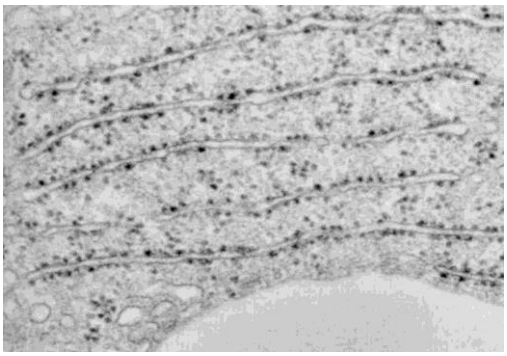
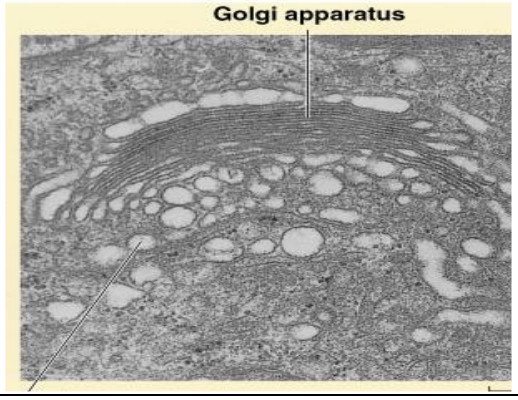
Features	ER vesicles	Golgi vesicles	Lysosomes
Origin			
Structure	Phospholipid bilayer	Phospholipid bilayer	Phospholipid bilayer with embedded proton pumps
Function	ER vesicles functions as transport vesicles for transport of _____ or _____ between the ER and the GA.	Golgi vesicles functions as transport vesicles for the transport of **modified substances within the cell** or for **secretion to outside of the cell**	Lysosomes contain _____ _____ for **intracellular digestion/autophagy/ autolysis**. The enzymes are **not** released out of the cell.

2. Label the identity of the structures labelled A and B below. How to distinguish between them in electron micrographs?

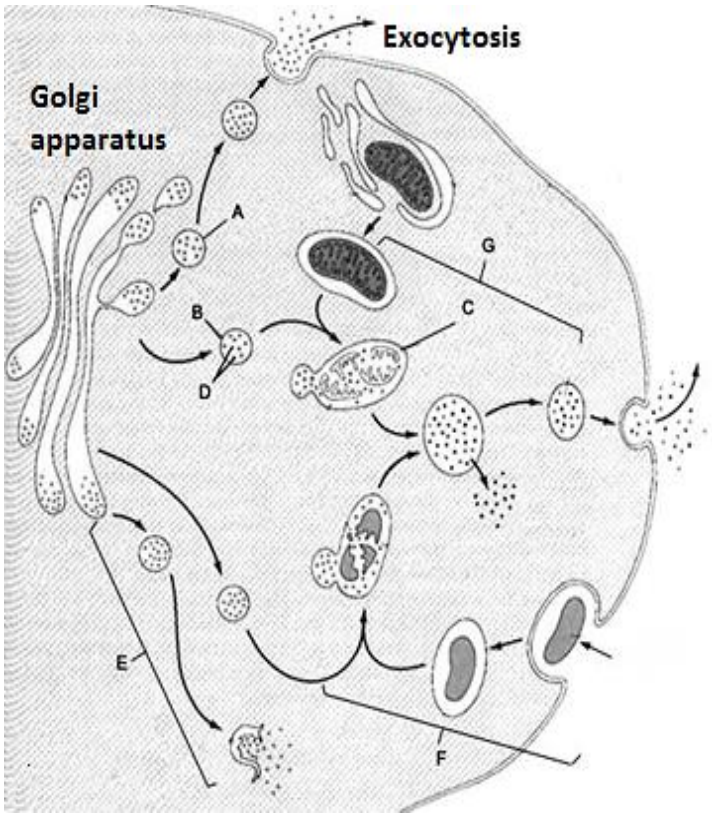


Features	A	B
Ribosomes present/absent?		
Cisternae		

3. How to distinguish between Rough ER and Golgi apparatus in an electron micrograph?

Rough ER	Golgi apparatus
• _____ sacs, with ribosomes on its surface 	• _____ stacks, with *cis* and *trans* face 

4. The diagram below shows part of the endomembrane system in a cell.



1. Label the structures A - D:

A:

B:

C:

D:

2. Cellular processes E, F, G are associated with the functions of lysosome. Name these processes.

E:

F:

G:

2.1.7 Mitochondrion (plural: mitochondria) (Fig. 2.3s-t)

Link to Topic 3: Respiration

- The mitochondrion is 1.5 – 10 μm in length and 0.25 - 1.00 μm in width.
- It is a **double membrane-bound** organelle found in *all* **eukaryotic cells**.
- The **outer membrane** is smooth and is permeable to small molecules of molecular mass < 21000 daltons.
- The **inner membrane** is selectively permeable and extensively folded into shelf-like **cristae (plural)** [singular: crista]. This increases the surface area for enzyme attachment needed for the electron transport chain and oxidative phosphorylation during **cellular respiration**. Cellular respiration generates energy in the form of ATP, by extracting energy from sugars, fats, and other fuels
- The outer and inner membranes enclose the **intermembrane space**, which holds **high concentration of protons (H^+)** for the establishment of a **proton gradient**, required for oxidative phosphorylation during cellular respiration *[See topic: Respiration].*
- The **mitochondrial matrix** is semi-fluid and finely granular. It contains:
    - A mixture of proteins and lipids.
    - **Circular DNA** of the mitochondria, which carries **genes** that encode enzymes and proteins that are responsible for cellular respiration.
    - **70S ribosomes**, which synthesizes proteins (eg. enzymes) required in the mitochondria.
    - RNA and enzymes that control the Kreb's cycle and fatty acid oxidation.

- **Stalked particles** are present on the inner membrane on the side facing the matrix. Each particle contains a head piece, stalk and base. The head piece (F_1 portion) contains **ATP synthase** for adenosine triphosphate (ATP) synthesis.

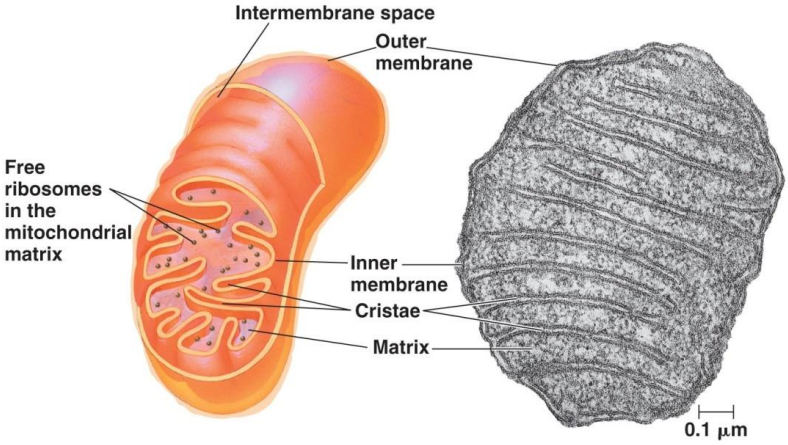


Fig. 2.3s: A diagram (left) and electron micrograph (right) of a mitochondrion.

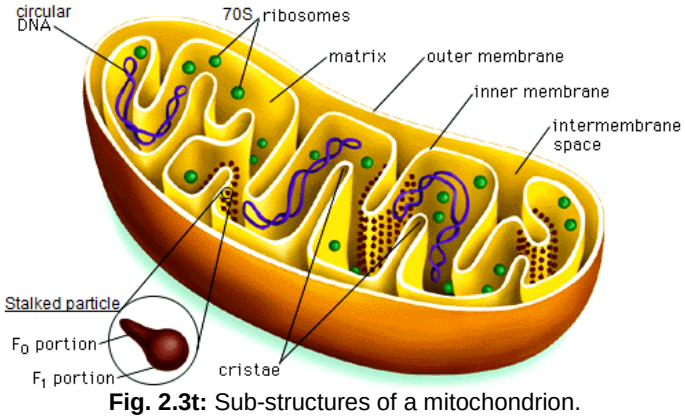


Fig. 2.3t: Sub-structures of a mitochondrion.

- **Functions of the mitochondrion include:**
    - Site of **synthesis of ATP** (cellular energy) for all cellular functions.
    - **Lipid metabolism**. Fatty acids are broken down to acetyl CoA in the matrix and on the inner membrane of the mitochondrion.
    - **Lipid synthesis**. Synthesis of fatty acids from acetyl-CoA precursors by fatty acid synthases in mitochondria
    - **Apoptosis**. Release of certain mitochondrial proteins into the cytosol can initiate programmed cell death.
- The organelle moves by **cytoplasmic streaming** (circular flow of cytoplasm within cells) to areas where more ATP is required.

2.1.8 Chloroplast (Fig. 2.3u)

Link to Topic 3: Photosynthesis

- This organelle is found in photosynthetic organisms such as plants.
- The chloroplast is 3 – 10 μm in length
- It has 3 membranes: Outer membrane, inner membrane and thylakoid membranes
- A **double membrane** (outer membrane and inner membrane) encloses the **intermembrane-space**.
- Inside the chloroplast is a system of **flattened, interconnected sacs** known as **thylakoids**. **Stacks of thylakoids** are called **granum (singular)** or **grana (plural)**. Protein complexes embedded on the thylakoid membrane are involved in the conversion of light energy to chemical energy during the light-dependent stage of photosynthesis.
- The fluid surrounding the thylakoid membrane is the **stroma**. It contains:
    - **Circular DNA** of the chloroplast, which contains **genes that code for enzymes and proteins** responsible for photosynthesis.
    - **70S ribosomes**, which synthesizes proteins (eg. enzymes) required in the chloroplast.
    - Proteins/enzymes involved in photosynthesis.
    - Starch grains/granules.
- Functions of the chloroplast include:
    - The chloroplasts are the **sites of photosynthesis**. The light-dependent reactions of photosynthesis occur at the thylakoid membrane while the light-independent reactions occur in the stroma.

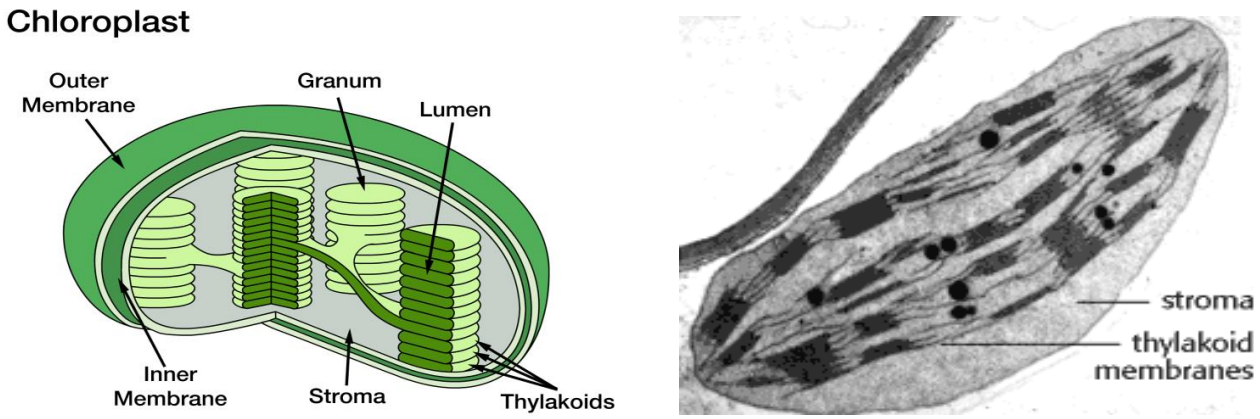


Fig. 2.3u: A drawing (left) and an electron micrograph (right) of a chloroplast.

Important: Endosymbiotic theory (Origin of mitochondria and chloroplasts)

Evolutionary studies suggest that both **mitochondria** and **chloroplasts** were once free living bacteria, which gets engulfed by an ancestral eukaryotic cell, and eventually became part of it (i.e. became an endosymbiont, a cell living within another cell).

Over the course of evolution, the host cell and its endosymbiont merged into a single organism. This gives rise to the modern eukaryotic cell with a mitochondrion (and chloroplast - for plant cells) (Fig. 2.1v).

Evidence that support the endosymbiotic theory are:

1. Presence of _____ in prokaryotic cells and these two organelles, while eukaryotic DNA are **linear** in nature.

2. Presence of _____ in prokaryotic cells and these two organelles, while cytosolic free ribosomes and ER-bound ribosomes in eukaryotic cells are **80S** in nature.

3. These two organelles are enclosed by **double-membrane** - the ancestor eukaryotic cells engulfed bacteria by phagocytosis/endocytosis, and the bacteria eventually become the mitochondria or chloroplast. The outer membrane is derived from the ancestral eukaryotic cell's plasma membrane and the inner membrane from the bacteria.

4. Both organelles undergo **binary fission** (mitochondria and chloroplast are able to divide independently) - eukaryotic cells undergo nuclear division while prokaryotic cells undergo binary fission**.**

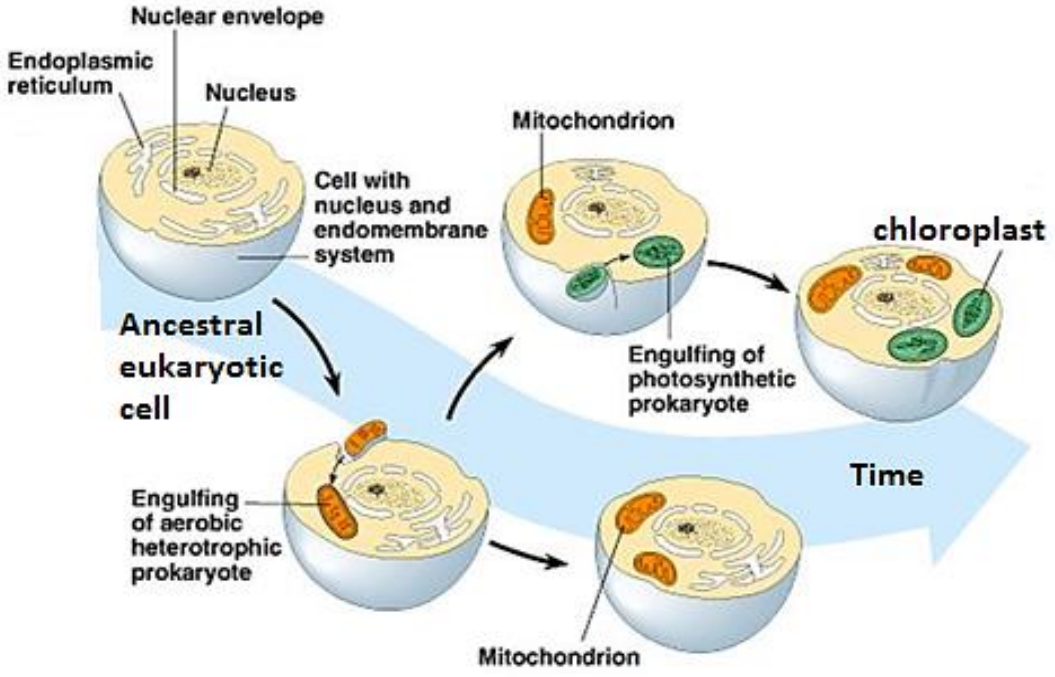
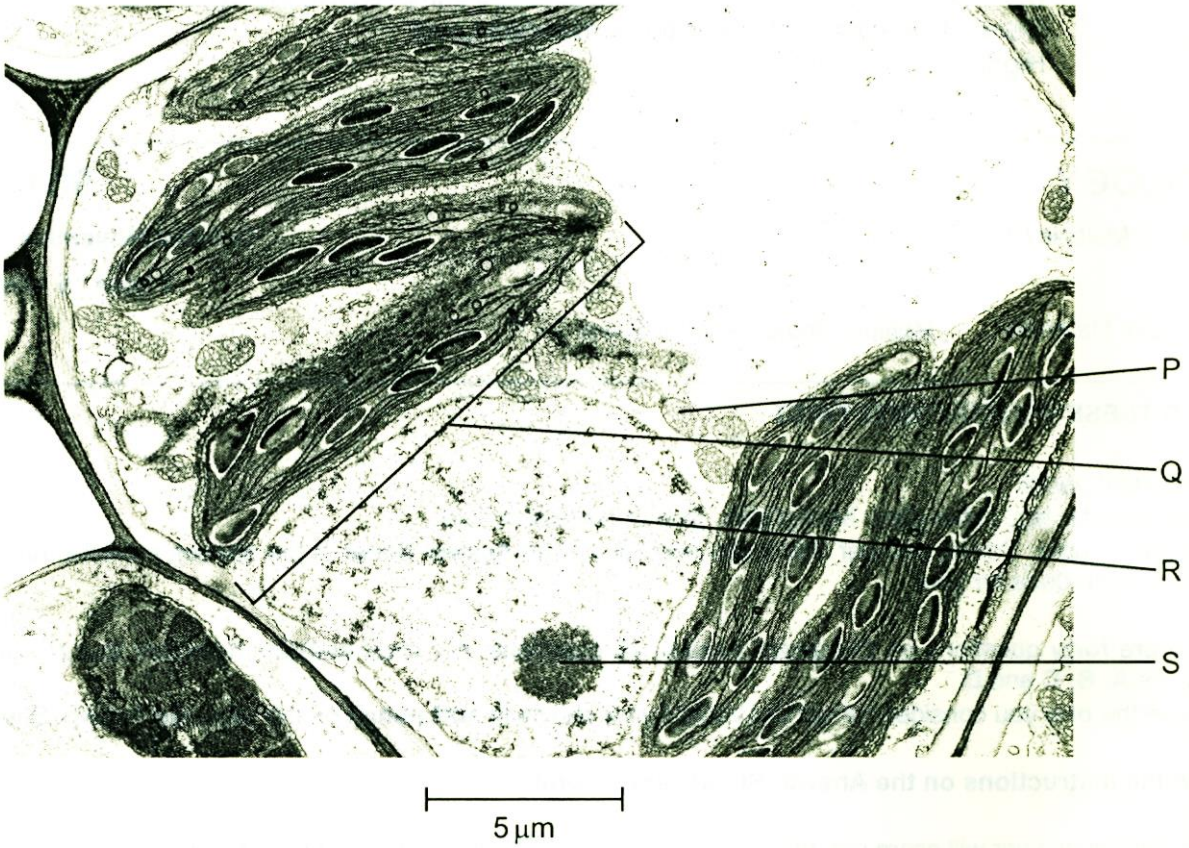


Fig. 2.3v: Illustration of the Endosymbiotic theory.

TEST YOURSELF

The electron micrograph shows a section of a plant cell in which several organelles contain both DNA and RNA.



Which statements correctly describe the activities of the labelled regions of the cell?

1 Both P and Q contain DNA which can be transcribed into messenger RNA (mRNA).

2 Both P and Q contain ribosomal RNA (rRNA) and can translate mRNA.

3 DNA is transcribed at both R and S.

4 At S, DNA is transcribed to rRNA but not to mRNA.

A 1 and 2 only

B 3 and 4 only

C 1, 2 and 4 only

D 1, 2, 3 and 4

2.1.9 Centrioles

- Found in most eukaryotic cells, except in higher plants.
- They measure around 0.2μm in diameter and 0.3 to 0.5μm in length.
- Centrioles are found in **pairs**. Each centriole is positioned at **90° to each other**, and are found in a poorly defined region called the **centrosome** that tends to be located at the **near the nucleus**.
- From the transverse section of a centriole as seen under the Transmission Electron Microscopy (TEM), **9 triplets of microtubules** (9x3) are fused together to give a **rod-like structure** (Fig. 2.3w) which is **not** bound by a membrane.
- Microtubules are cylindrical tubes composed of tubulin (protein). They are part of the cell's cytoskeleton (Section 2.1.10) (i.e. 3D structure that fills the cell cytoplasm).
- The centrosome is regarded as the **microtubule organizing centre (MTOC)** in animal cells. However, it is not required by all eukaryotes. For example, higher plants do not have centrioles but they still have well-organised microtubules.
- Functions of centrioles include:
    - **Organization of spindle fibres/microtubules** during **nuclear division**
    - Single centriole found at the base of cilia and flagella for growth and operation of cilia and flagella **in eukaryotes only**

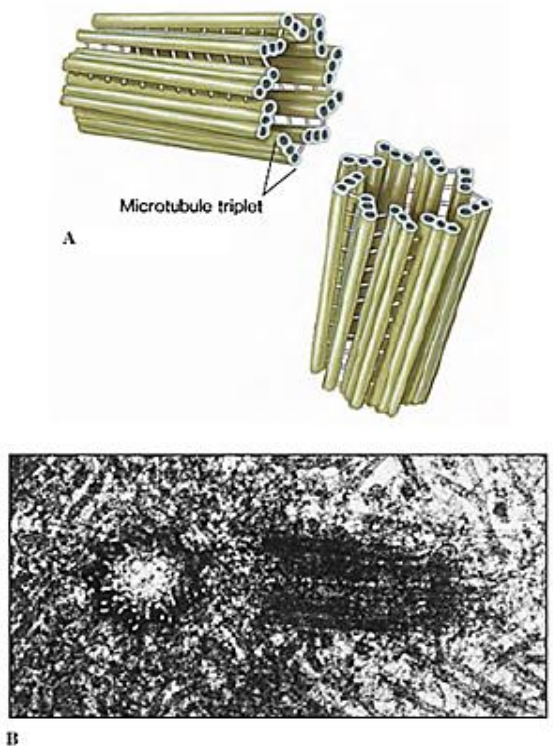


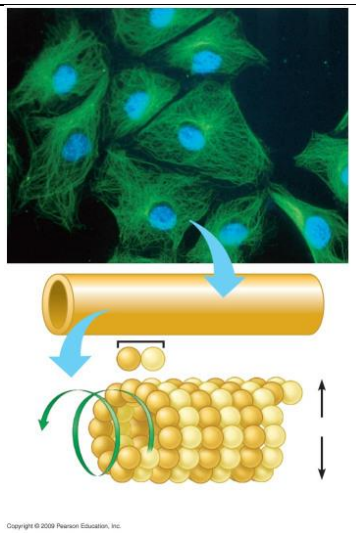
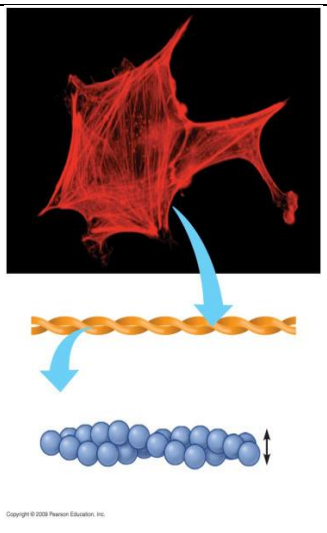
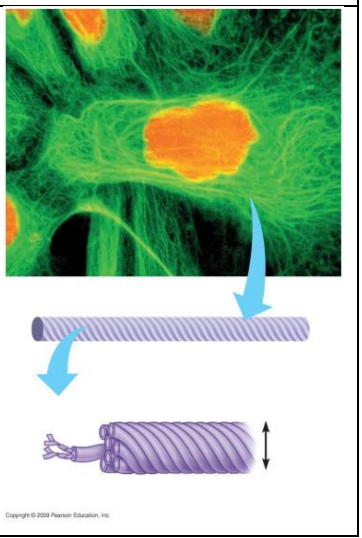
Fig. 2.3w: A pair of 9 x 3 triplets of centrioles are found at 90° to each other

2.1.10 Cytoskeleton

- The cytoskeleton is a network of fibres extending throughout the cytoplasm to maintain cell shape, organise structures and activities in the cell.

- It is composed of three types of molecular structures:
  - **Microtubules**, which form major structures in the cell such as centrioles, spindle fibres *(Topic 4: The Cell Cycle)*, cilia and flagella
  - Actin filaments
  - Intermediate filaments

- Functions of the different cytoskeletal structures:

	Microtubules	**Actin filaments**	**Intermediate filaments**
Main functions	• Maintain cell shape • Forms centrioles • Chromosome movements in cell division (*Topic 4: Cell division)* • Cell motility (as in cilia or flagella for locomotion) • Provide tracks for cell organelles and vesicles movement	• Maintain cell shape • Changes cell shape (e.g. for muscle contraction) • Cytoplasmic streaming • Cell motility (as in pseudopodia *(Topic 2: Transport)* • Cell division (cleavage of furrow formation)	• Maintain cell shape • Anchor nucleus and certain organelles • Formation of nuclear lamina
Fluorescence micrographs			

2.1.11 Plant Cell Wall (Fig. 2.3x)

- The plant cell has an extracellular structure, the cell wall, which distinguishes it from an animal cell.

- It comprises three types of **polysaccharides**: (1) cellulose microfibrils, (2) pectin, and (3) hemicelluloses (Fig. 2.3x).

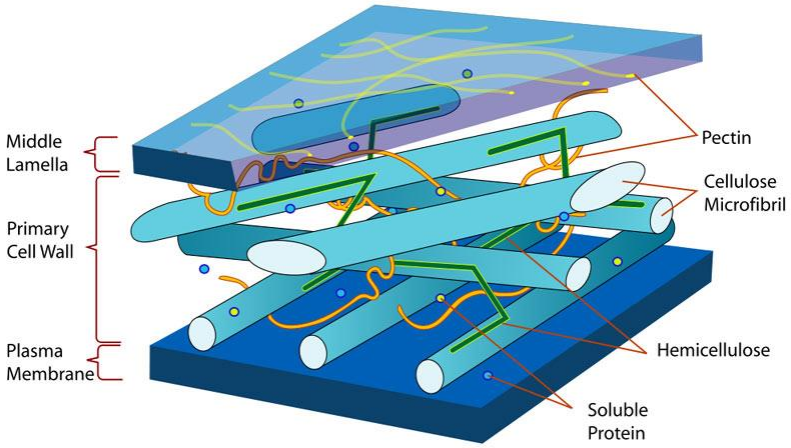


Fig. 2.3x: Structure of the cellulose cell wall. Note the position of pectin, hemicelluloses and cellulose microfibrils.

- Synthesis of cell wall

  - **Pectin and hemicelluloses** are synthesized in the **Golgi apparatus** and transported via Golgi vesicles to the cell surface, where the cell wall is formed *(See section 2.1.4)*

  - On the other hand, **cellulose microfibrils** are synthesized directly on the **plasma membrane**, at the side facing the exterior, using β-glucose in the cytosol. **Cellulose synthases** embedded in the cell membrane catalyse the reaction (Fig 2.3y).

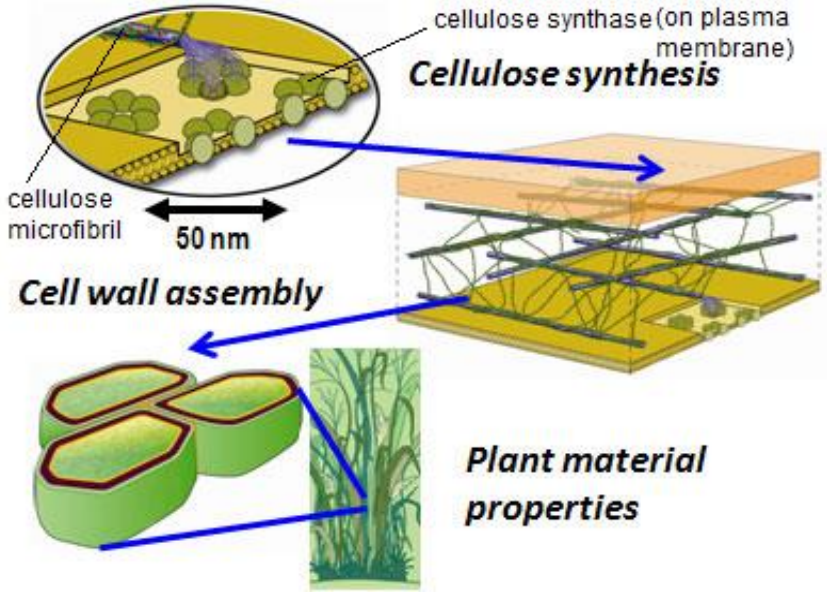
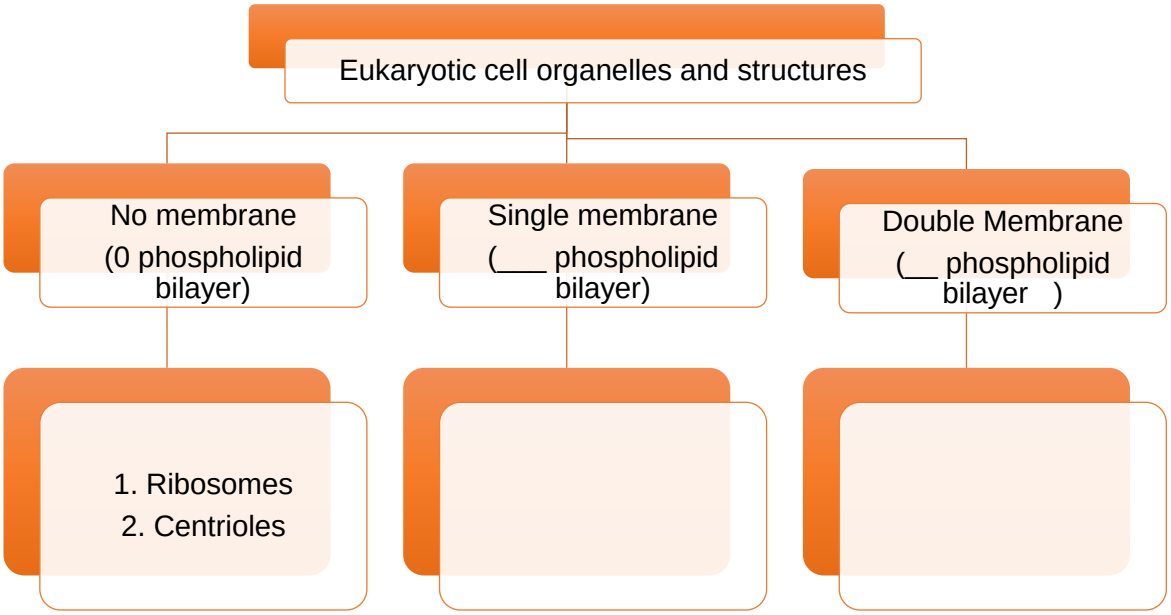


Fig. 2.3y: Cellulose synthase complex on the plasms membrane is responsible for the synthesis of cellulose microfibrils.

- Function of plant cell wall:
  - Provide tensile strength
  - Maintain plant cell shape and structure
  - Protect plant cells against mechanical and osmotic stress

Consolidation Exercise – Eukaryotic cell organelles and structures

Question 1
Categorize the eukaryotic cell organelles and structures (taught in *section* 2.1.1 – 2.1.9) according to the number of membrane they possess. State the number of phospholipid bilayer(s) that are present in each category. The first example has been done for you.



Question 2
Arrange the following organelles according to their sizes, in ascending order (i.e. from smallest to biggest).

1. Nucleus
2. Mitochondrion
3. Ribosome
4. Chloroplast

2.2 Functional relationship between different organelles 2.1.1 to 2.1.6 (Fig 2.4)

1. DNA in the **nucleus** serves as a template to synthesize mRNA, which is then transported out of the **nuclear pore** into the **cytosol**.

2. The mRNA can either be bound by a **free ribosome in cytosol** (if the protein is to be used within the cell) or by a **ribosome on rough ER** (if the protein is to be secreted or membrane-anchored) to form the mRNA-ribosome complex. Protein synthesis begins.

3. The polypeptide chain synthesized enters the ER lumen and **folds** into its tertiary/quaternary structure (3D conformation). The protein may undergo **biochemical modification (e.g. glycosylation).**

4. **ER vesicles** carrying the protein **bud off** from the ER, and travel towards the **cis-face of Golgi apparatus**.

5. ER vesicles **fuse** with the membrane of the Golgi apparatus.

6. As the protein travels through the Golgi apparatus through **repeated budding and fusion of vesicles**, it undergoes further biochemical modification.

7. At the ***trans* face** of the Golgi apparatus, the modified protein is **sorted** and **packaged** into a **Golgi vesicle**, which **buds off** from the Golgi apparatus.

8. Depending on the type of protein that the Golgi vesicle carries, the Golgi vesicle may travel to different parts of the cell. For example:

   i. A **secretory vesicle** that is carrying a **secretory protein** (e.g. insulin in Islet of Langerhans cells of the pancreas) moves towards the cell surface membrane and fuse with it to **secrete** its content out of the cell via **exocytosis**. This is known as the **secretory pathway**.

   ii. A Golgi vesicle with an embedded **transmembrane protein** in its membrane moves towards the cell surface membrane and fuses with it. The transmembrane protein then gets **embedded into the cell surface membrane**.

   iii. Golgi vesicle that is carrying hydrolytic enzymes (e.g. in phagocytic white blood cells) would become a **primary lysosome**.

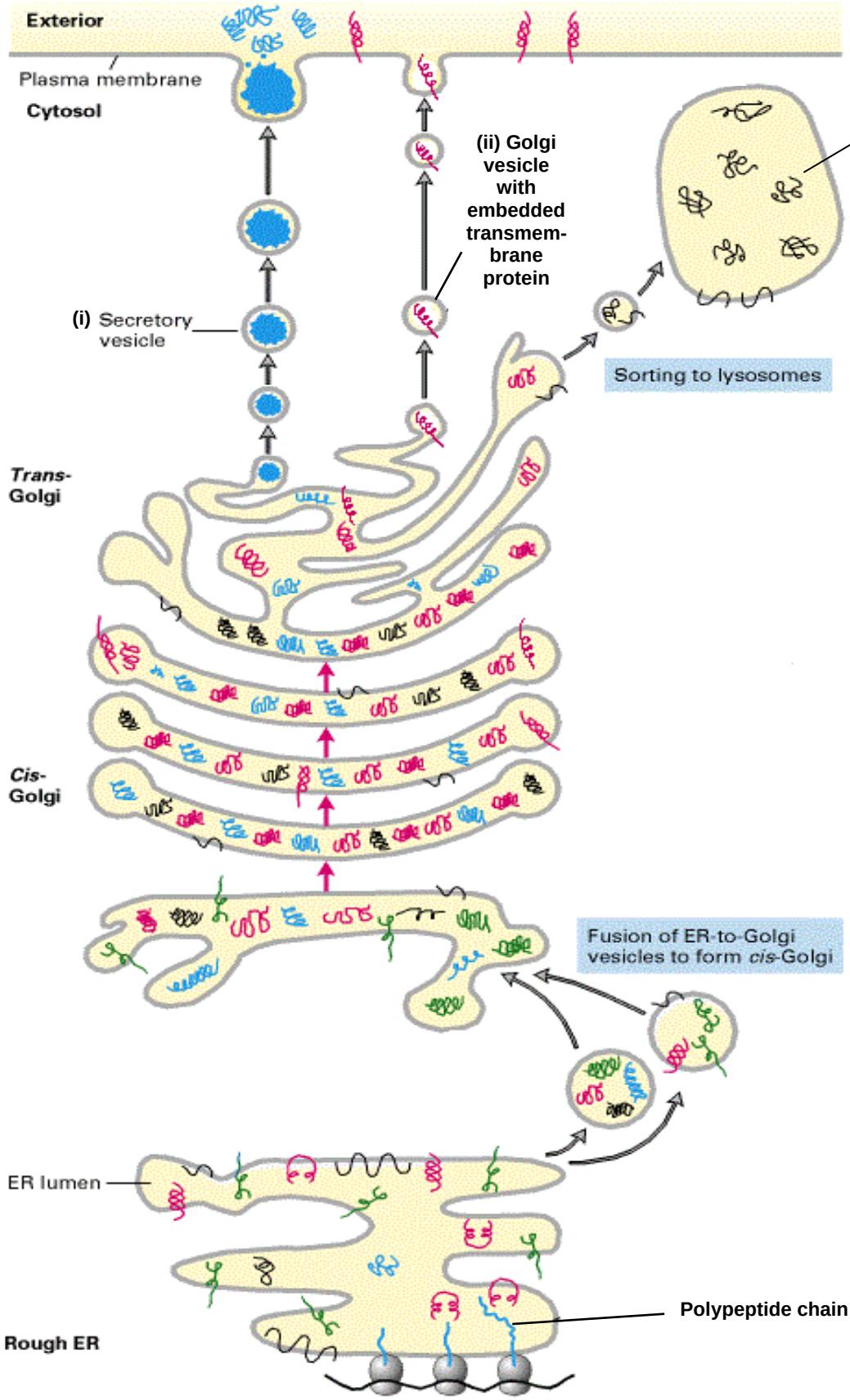


Fig. 2.4: Formation of secretory and transmembrane proteins

2.3 Differences between plant and animal cells

- Plant cells and animal cells are eukaryotic cells. There are several differences between a plant cell and an animal cell (Fig. 2.5a-c)

Feature	Plant cell	Animal cell
Cell wall	**Presence of cell wall** confers rigidity to a plant cell, accounting for its regular shape	**Absence of cell wall** contributes to the irregular shape of an animal cell
Chloroplast	**Presence of chloroplast** in photosynthetic cells (e.g. mesophyll cells, guard cells)	**Absence of chloroplasts**
Vacuoles	A **large central vacuole** (permanent), which contributes to the peripheral location of the nucleus and cytoplasm.	**Numerous small** (transient) **vacuoles**
Centrioles	**Absence of centrioles** in higher plants.	**Presence of centrioles**
Storage granules	Contain **starch** granules	Contain **glycogen** granules
Lysosomes	**Absence of hydrolytic lysosomes** (except in insectivorous plants where hydrolytic enzymes are stored in lysosome-like compartments)	**Presence of hydrolytic lysosomes**
Cilia/flagella	**Absence of cilia or flagella**	**Presence of cilia or flagella** in certain cells (e.g. ciliated tracheal epithelium, flagellated spermatozoan)

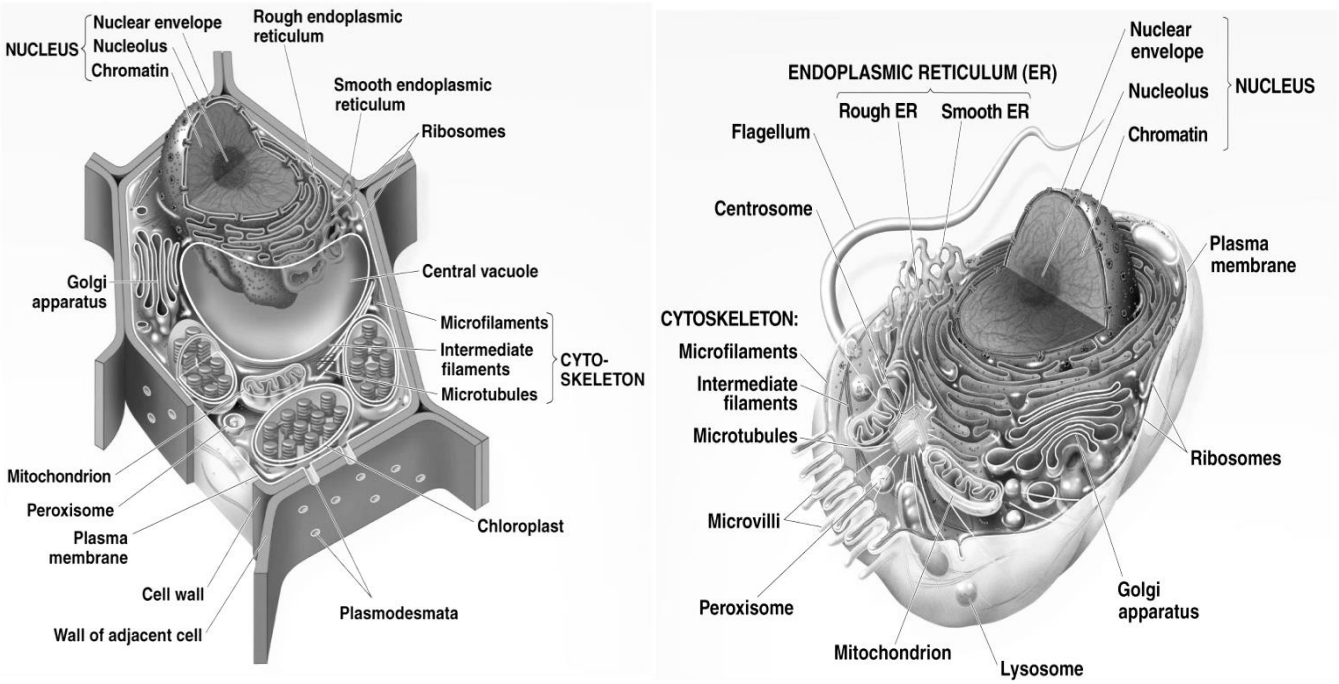


Fig. 2.5a: 3D representations of a typical plant and animal cell

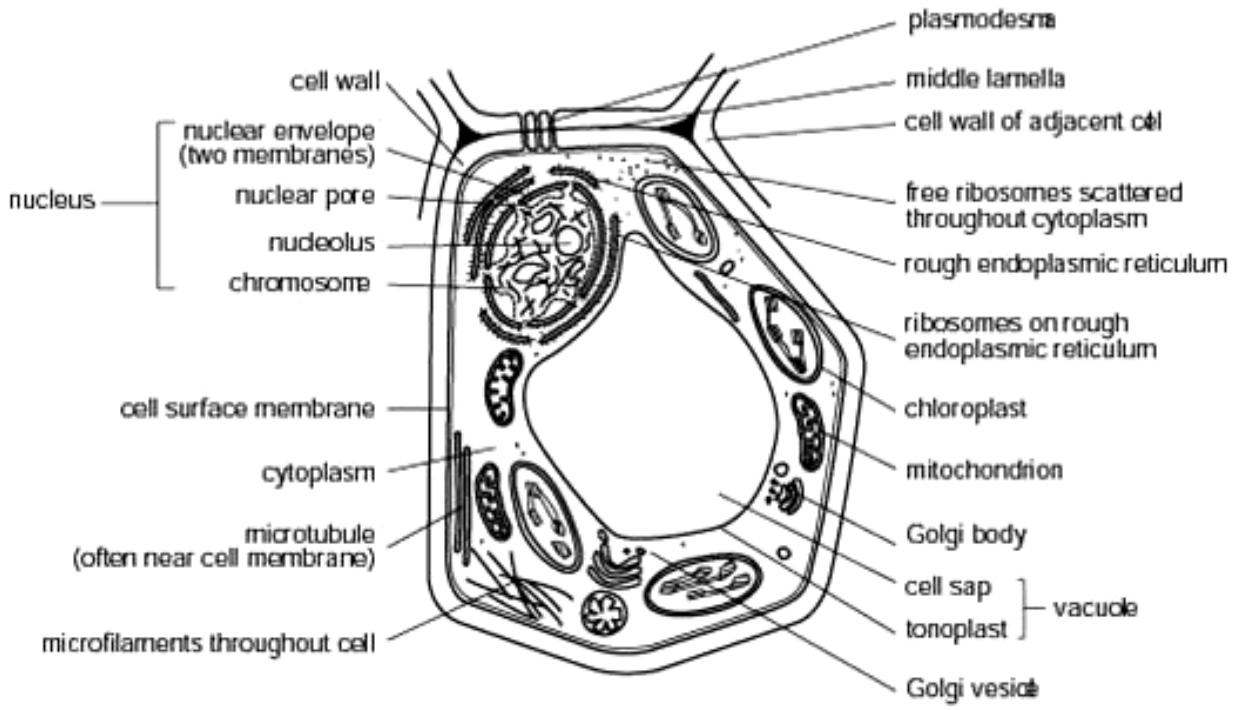


Fig. 2.5b: A 2D representation of a typical plant cell

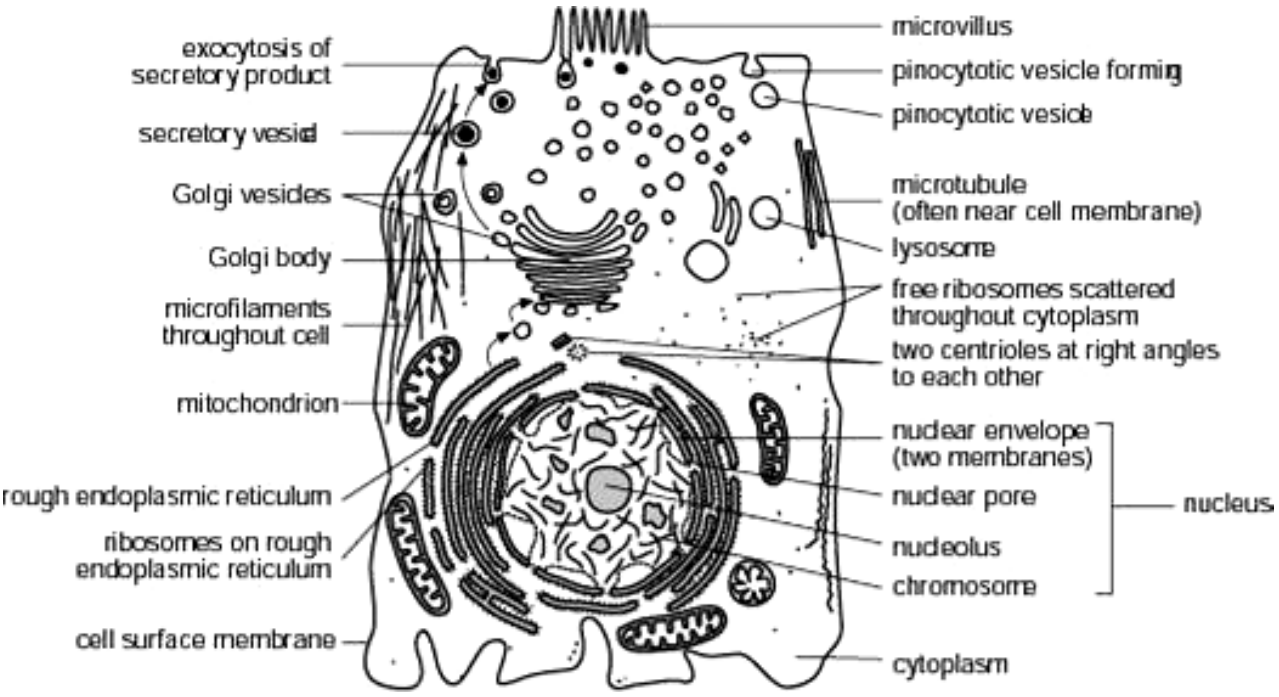


Fig 2.5c: A 2D representation of a typical animal cell

3. Prokaryotic Cells

Key Concept 5:

- **Prokaryotic cells lack membrane-bound organelles.**
- **All bacteria contain cytoplasm, ribosomes, plasma membrane, nucleoid and almost all bacteria have peptidoglycan cell wall**

3.1 What are Prokaryotes?

Link to Topic 10: Organisation of Genome & Control of Gene Expression in Prokaryotes

- A prokaryote is a small, single-celled organism (**unicellular**) that **lacks** a membrane-bound **nucleus** *(Greek: karyon)* and other **membrane-bound organelles**
- The main type of prokaryotes is **bacteria**.
- Bacteria reproduce by **binary fission**.

3.2 What are the structures of a bacterial cell?

- Dimension of bacteria:
  - diameter of ~**1 μm**, length of **0.1 – 10 μm**, as compared to eukaryotic cells (diameter of 10-100 μm)
- Bacterial cells have a variety of shapes, the three most common of which are spheres (cocci), rods (bacilli), and spirals (Fig. 3.1)

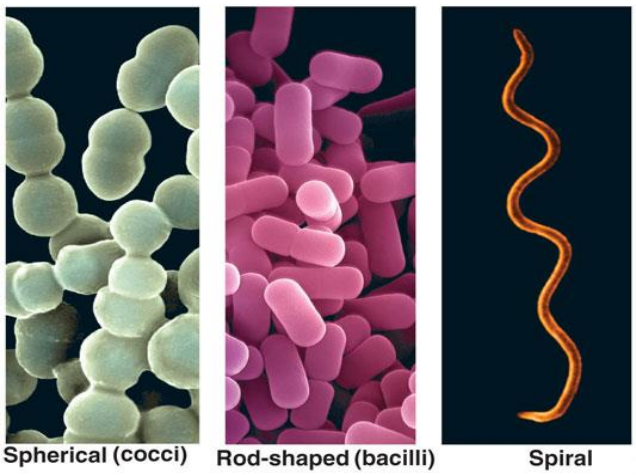


Fig 3.1: Common shapes of bacteria

- Bacteria **do not** have a nucleus; they have a **nucleoid** region (i.e. **not membrane-bound**)
- The nucleoid region contains **one circular double-stranded bacterial chromosome**.
- **Smaller circular double-stranded DNA** known as **plasmids** (Fig. 3.2) can also be found in some bacteria.
- **Most bacterial cell walls** contain **peptidoglycan** to give shape of the bacteria and prevent lysis due to osmosis. (Fig 3.3 & 3.4)

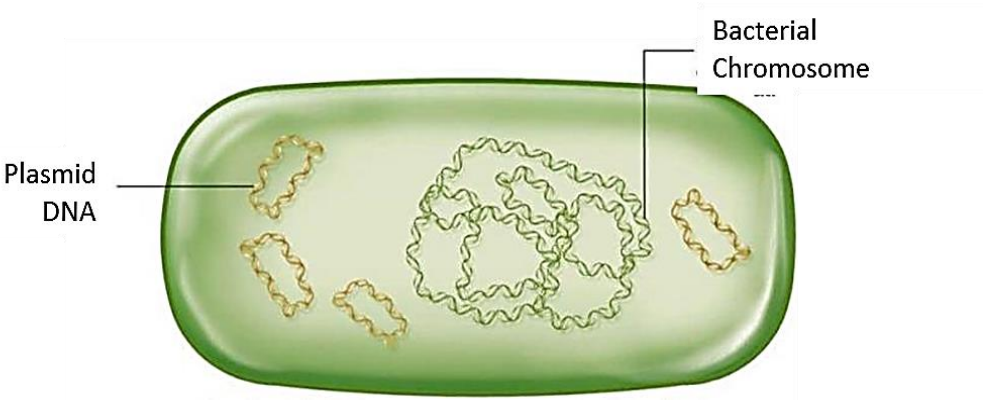


Fig. 3.2: Double-helical plasmids are extra-chromosomal and may exist as one or more copies in bacterial cells. They may replicate independently from the bacteria chromosome.

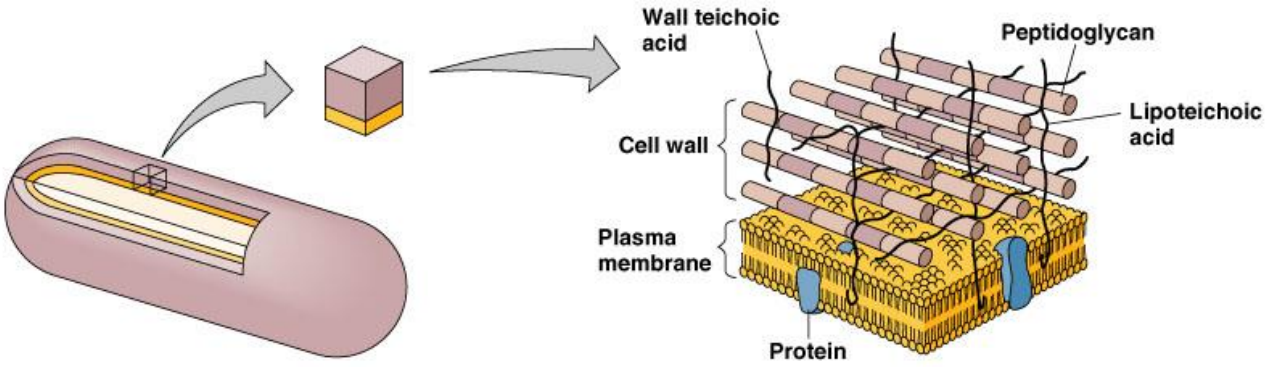


Fig 3.3: Most bacterial cell walls contain peptidoglycan which is complexed with other components to give the cell wall its rigidity. ***(Note:** Details of the cell wall are not required.)*

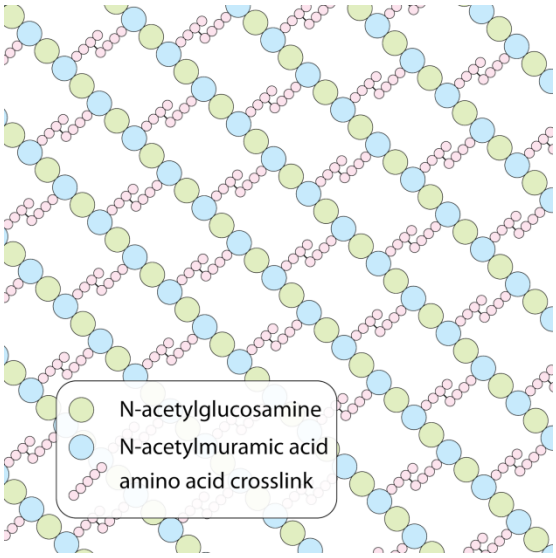


Fig 3.4: Peptidoglycan is a polymer composed of modified sugars (N-acetylglucosamine and N-acetylmuramic acid) cross-linked by short polypeptides. ***(Note:** Details of the cell wall are not required.)*

- Structures present in bacteria include: (Fig 3.5)

(I) Structures present in **ALL** bacteria
○ **Cell membrane** for regulation of substances into and out of cells, energy generation and location of numerous enzyme systems for metabolism and cell signaling
○ **Cytoplasm** containing ribosomes and other proteins for various cellular processes (such as DNA replication, gene expression, etc)
○ **One circular bacterial chromosome**, which contains most or the whole bacterial genome, contained in the nucleoid region
○ **70S ribosomes** for protein synthesis *(see section 2.1.8)*
○ **Most** bacteria contain a **peptidoglycan cell wall** to confer rigidity and shape of the bacteria. It prevents lysis due to osmosis. (Fig 3.3 and 3.4)

(II) Structures present in **SOME** bacteria
○ One or more **plasmids** (Fig. 3.2) which are the *extrachromosomal* DNA in some bacteria, coding for only a few but beneficial, non-essential genes (e.g. breaking down of β-lactam in penicillin, an antibiotic)
○ **Pilus** (plural: pili) and **fimbria** (plural: fimbriae), which are hair-like appendages for attachment to substrates or other bacteria cells. ○ Specialized pili, called the sex pili, link bacteria during conjugation.
○ **Capsules**/slime layers for protection against phagocytes in the host's immune system. They also help prevent desiccation and enable bacteria to stick to surfaces.
○ **Flagellum** (plural: flagella) for mobility / locomotion

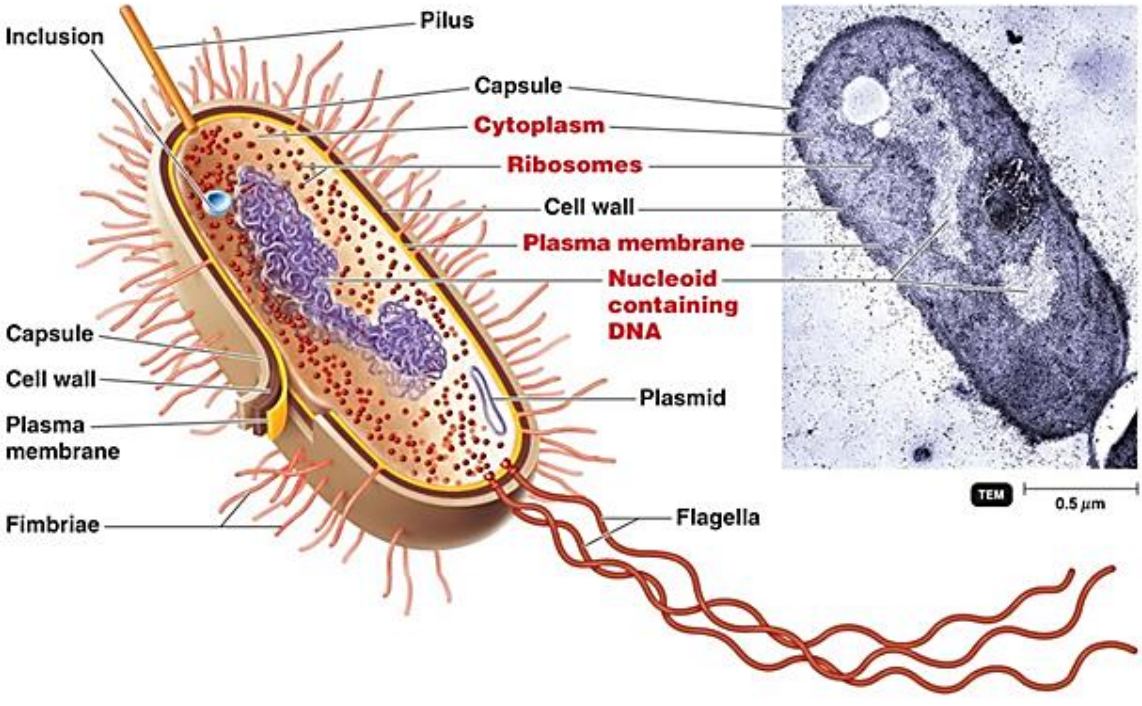


Fig. 3.5: A typical bacteria cell. Bacteria lack membrane-bound organelles.

3.3 Differences between eukaryotic and prokaryotic cells

Feature	Eukaryotic cells	Prokaryotic cells
Nucleus	Genetic material is enclosed in the **double membrane-bound** nucleus.	Genetic material is concentrated in a dense region called the _____ region. **No membrane** separates this region from the rest of the cell.
Genetic material	Genomic DNA is **linear**.	Genomic DNA is _____.
Membrane-bound organelles	**Presence** of membrane-bound organelles (single membrane and double membrane).	Membrane-bound organelles are _____.
Ribosomes	Presence of **80S ribosomes** in the cytoplasm and on rER. Presence of **70S ribosomes** in mitochondria and chloroplast (plant cells)	Presence of _____ **ribosomes** in the cytoplasm.
Cell wall	Plant cells contain **cellulose** cell walls	_____ cell wall
Size	**Larger**. Typically **10-100 µm** in diameter	_____. Typically **0.2-2.0 µm** in diameter

TEST YOURSELF

Which of the following is applicable to prokaryotic cells?

	Chloroplasts	Nuclear membrane	Mitochondria	70S Ribosomes
A.	present	present	present	present
B.	absent	present	absent	absent
C.	present	absent	present	absent
D.	absent	absent	absent	present

4. Viruses

4.1 What are viruses?

Link to Topic 9: Organisation & Inheritance of Viral Genomes

- Viruses are the simplest biological systems which *lack* the structures and metabolic enzymes and organelles found in cells.

- They are considered as **infectious particles**, as they are capable of causing a wide variety of diseases and can be spread between organisms.

- Viruses range from about **20 nm to 400 nm** (Fig. 4.1) in length.

  - The tiniest viruses are only 20nm in diameter, smaller than a ribosome.

  - They can only be observed under the electron microscope but not light microscope.

  - They can pass through the small pores of filters. These filters are able to retain bacteria but not virus.

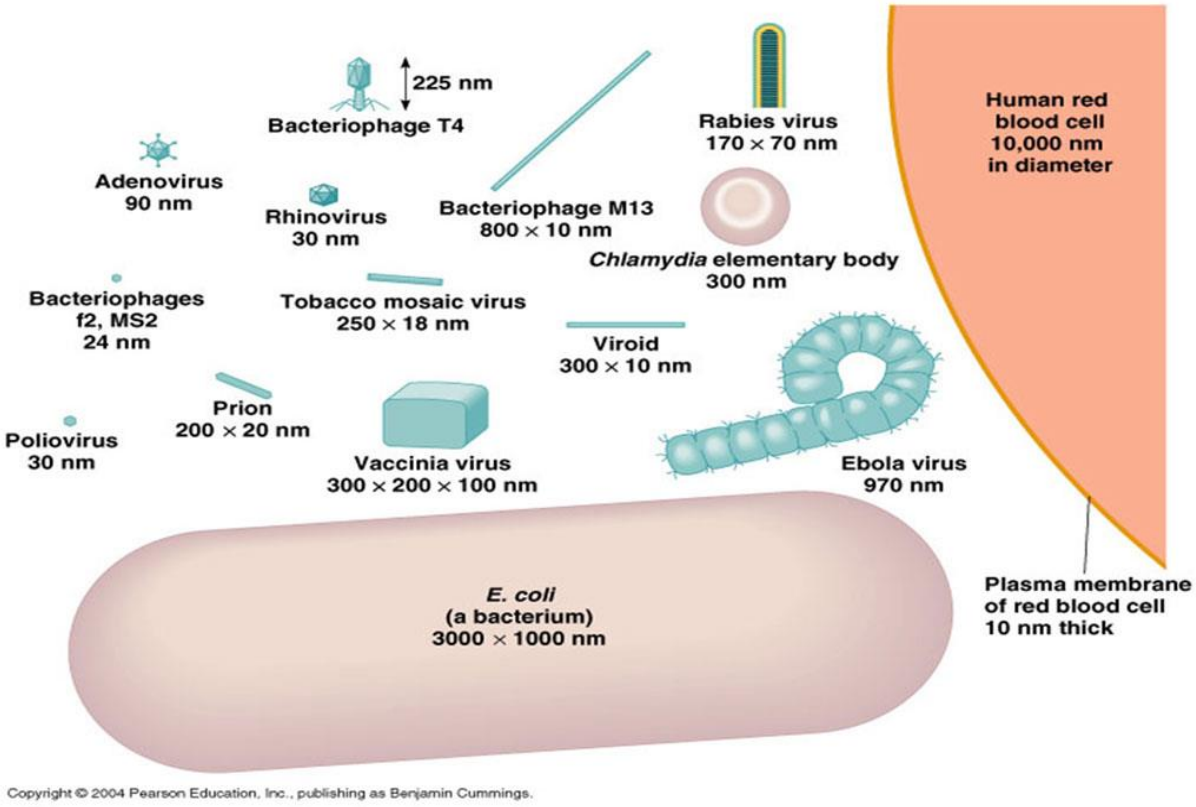


Fig 4.1: Relative sizes of various viruses compared to a bacterial cell and human red blood cell.

- Some uses of viruses:

  a) They serve as **models** for the study of DNA replication, transcription and translation.

  b) Their unique genetic mechanisms help explain their **pathogenicity** (ability to produce an infectious disease in an organism).

  c) Their replication mechanisms promote the development of **genetic engineering** techniques.

4.2 What are the structural components of viruses?

- Viruses generally consist of: (Fig 4.2)

  (1) **nucleic acid (viral genome)** enclosed within a

  (2) **protein coat (capsid)**

  (3) and in some cases, a **membranous envelope (viral envelope)**.

  [The combined structure of the viral genome and capsid is known as a **nucleocapsid**.]

- They **lack cellular organisation** (e.g. no cytoplasm and cellular organelles like ribosomes).

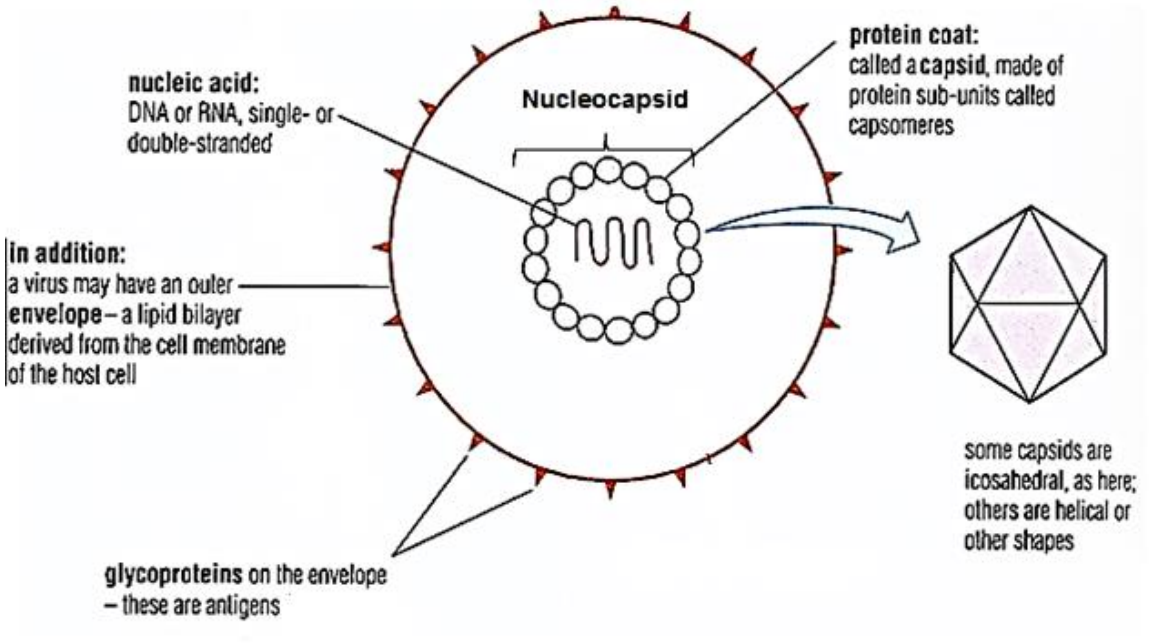


Fig. 4.2: Structural components of viruses in general

- The **viral nucleic acid / genome** may be DNA or RNA, single or double-stranded, and codes for only a few structural proteins (e.g. capsid proteins and viral glycoproteins) and non-structural/regulatory proteins involved in viral reproduction.

- The **viral capsid** is a hollow protein shell which is built from large number of protein subunits known as **capsomeres**.

- The capsid functions to:

  - Enclose and **protect the viral genome** from digestion by enzymes.

  - Contain **proteins** on its surface that aid in the attachment to and penetration of the host cell.

  - Carry viral **enzymes** involved in viral replication.

- Some viruses have a **viral envelope**. These viruses are known as enveloped viruses. (Fig 4.2 and 4.3).

- The viral envelope consists of a **phospholipid bilayer** embedded with **membrane proteins** which surround the capsid. The viral envelope is derived from the host's plasma membrane during budding.

- Some of these membrane proteins in enveloped viruses are **glycoproteins** that project from the viral envelope as spikes. These glycoproteins are encoded by the viral genome.

    - These glycoproteins allow the virus to infect susceptible host cells.

    - Examples of enveloped viruses with glycoproteins are influenza viruses and HIV**.**

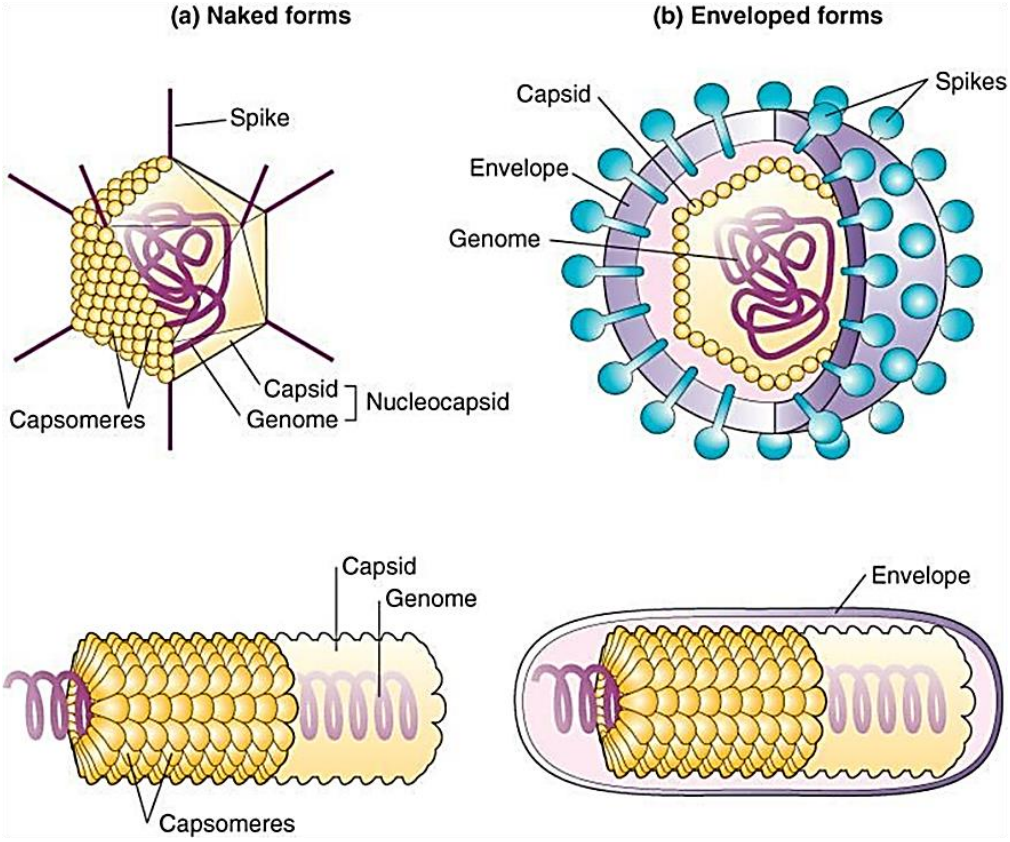


Fig. 4.3: Difference between a naked virus (without envelope) and an enveloped virus.

4.3 How to classify viruses?

- Viruses can be grouped according to:

  a) **Structure** and **chemical composition** of the **genome** (i.e. DNA or RNA viruses)

  - Most effective form of classification as viruses with the same genetic material usually behave in a similar manner.

  b) **Presence or absence** of the **viral envelope**.

  c) **Shape of capsid**, which may be: (Fig. 4.4)

  - **Helical** – Capsid is a **hollow tube** with a protein wall shaped like a **rod** or a **hollow cylinder** which may be either rigid or flexible. (E.g. tobacco mosaic virus)

  - **Icosahedral** – Capsid is a **regular polyhedron** consisting of 20 equilateral triangular faces and 12 vertices which appears spherical. (E.g. adenovirus)

  - **Complex** – Capsid has a **symmetry** that is **neither purely icosahedral nor helical** but is usually a complicated shaped structure with specialized function. (E.g. bacteriophage)

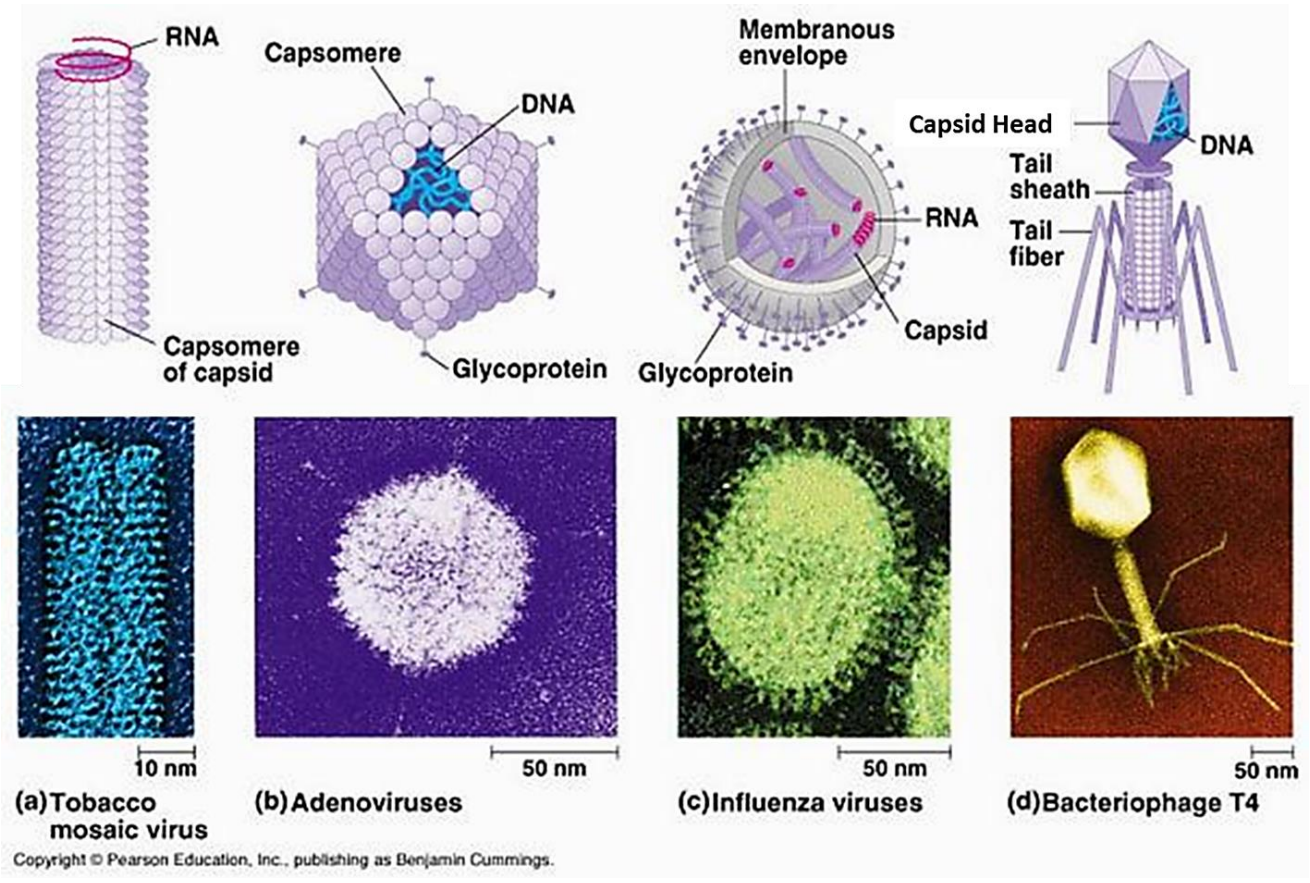


Fig. 4.4: (a) Tobacco moscaic virus with a helical capsid. (b) Adenovirus with a icosahedral capsid. (c) Influenza viruses have an envelope studded with glycoprotein spikes. (d) Bacteriophage T4 has a complex capsid consisting of an icosahedral head and a tail apparatus.

4.4 Are viruses living or non-living?

Recap

- The **Cell Theory** attempts to define what is considered living, and suggests that:
  - A cell is the **smallest, basic unit of life**.
  - All living organisms are made up of one (**unicellular** organism) or more (**multicellular** organism) cells.
  - All cells arise from pre-existing cells by **cell division**.
  - Cells contain **genetic material** which is passed from parent cells to daughter cells.
  - All **metabolic processes** occur within cells.

- Viruses are called **obligate intracellular parasites** (parasites that can only reproduce within a host). Examples of obligate parasites include some bacteria (eg. Chlamydia) and protozoa (eg. Plasmodium).

- Viruses exhibit **BOTH living and non-living characteristics**, so they challenge the cell theory and the concept of what is considered living.

  - Arguments for viruses being **living organisms**:

    - Viruses **possess genetic material** (DNA or RNA).
    - Viruses are capable of **reproducing themselves within host cells.**
    - Viruses can **adapt** to changing environmental conditions (E.g. mutate).

  - Arguments for viruses being **non-living organisms**:

    - Viruses **do not have cellular organization** - contain no cytoplasm or cellular organelles.
    - Viruses **cannot carry out metabolic processes on their own**, due to the lack of metabolic enzymes and organelles (E.g. Viruses lack ribosomes, hence, cannot synthesize proteins for survival).
    - They **cannot reproduce independently by cell division** from pre-existing viruses.

Checklist for Cell – the basic unit of life:
Are you able to confidently answer all the questions?

1. Outline the cell theory.

2. Distinguish between eukaryotic and prokaryotic cells.

3. Explain the advantages of compartmentalization in eukaryotic cells.

4. Describe the structure and function of the nuclear envelope, including the role of the nuclear pores.

5. Briefly explain how the nucleus controls protein synthesis in the cytoplasm.

6. Briefly state how the nucleolus contributes to protein synthesis.

7. Describe the structure and function of a eukaryotic ribosome.

8. Compare the structure and functions of the smooth and rough ER

9. Explain the significance of the *cis* and *trans* faces of the Golgi apparatus.

10. Describe three functions of lysosomes.

11. Explain the relationship between the organelles involved in protein synthesis.

12. Describe the structure of a mitochondrion.

13. Identify the three functional components of a chloroplast.

14. Describe the basic structure of a plant cell wall.

15. Describe the structure of a typical bacterial cell.

16. Describe how a virus may be identified by its structural components.

17. Discuss why a virus challenges the cell theory.

End of lecture notes