Cell Structure and Function

1. Overview of Topic

The study of cells is known as **cytology**. This branch of biology studies the different structures and functions of the cell and is based on the concept of the cell as the basic unit of life. Knowledge of cell biology helps to explain the relationship between structure and function of cell organelles, their physiological properties, metabolic processes, signalling pathways, life cycle and interactions with the environment. This study can be done both on a microscopic and level, involving prokaryotic and eukaryotic cells. Viruses, which are considered as non-living and non-cellular, have long challenged the cell concept. Yet, understanding viruses is necessary as they have had and will continue to exert a far reaching impact on our lives, especially when it comes to infection and diseases. Topics related to cell structure are: **Biomolecules of Life** topic in Core Idea 1, Core Idea 2: **Genetics and Inheritance**, Core Idea 3: **Energy and Equilibrium** and Extension Topics A: **Infectious Diseases** and B: **Impact of Climate Change on Animals and Plants**.

2. Learning Outcomes

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 a graticule)

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)

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

3. References

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Contents

4. The Cell Concept

According to the **cell theory** or **cell doctrine** credited to Schleiden and Schwann in 1938 with contributions from discoveries by other scientists:

Notes to Self:

a. **Cells are the basic building unit of life**

b. **All living things or organisms are made of cells**

c. **New cells are created by old cells dividing into two**

5. Overview of Eukaryotic Cell Structure

Eukaryotic cells (*Greek: eu – true; karyon – kernel*) 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 the rough and smooth endoplasmic reticulum and Golgi apparatus, is responsible for protein processing and vesicular transport within the cell.

A typical **eukaryotic** cell consists of the following:

1. **Plasma membrane or cell surface membrane** (*ref to cell membrane notes*)

   This structure defines the boundary of a cell and retains its contents.

   It acts as a barrier which controls the movement of various substances in and out of the cell.

2. **Nucleus**

   It contains the hereditary material that directs cellular activities – DNA.

3. **Cytoplasm**

   This consists of:

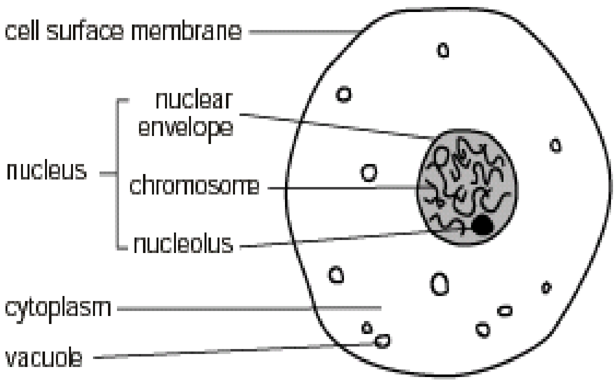
   - **Cytosol** → semi-fluid jelly like substance. Contains ions & organic compounds e.g. sugars, amino acids, proteins
   - **Organelles** → means 'little organs'; discrete subcellular structures with a specific function. Include: ribosomes, endoplasmic reticulum, Golgi body, lysosome, mitochondrion, chloroplast, centriole
   - **Cytoskeleton** → a framework of protein filaments, such as microtubules, microfilaments and intermediate filaments that give eukaryotic cells their shape

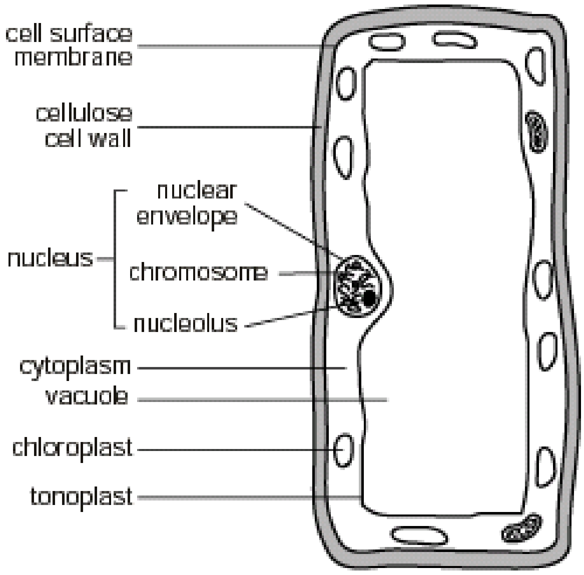
4. **Cell wall**

   This is present in plant cells (and in bacterial cells but not in animal cells), external to the plasma membrane

Compared to the light microscope, subcellular contents are seen in greater detail under the electron microscope. The term ***cell ultrastructure*** refers to a cell's anatomy revealed under an electron microscope.

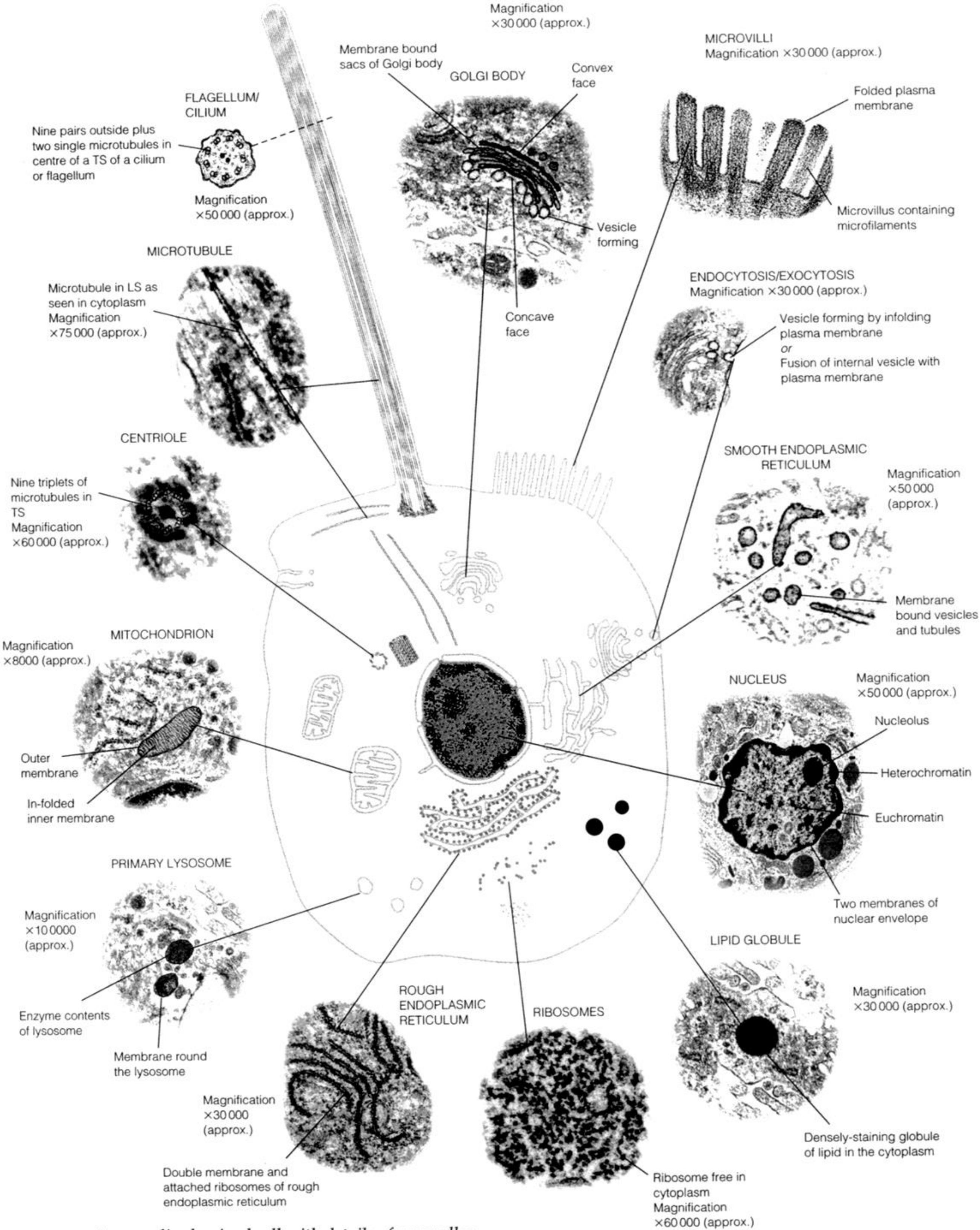
Animal and Plant Cells





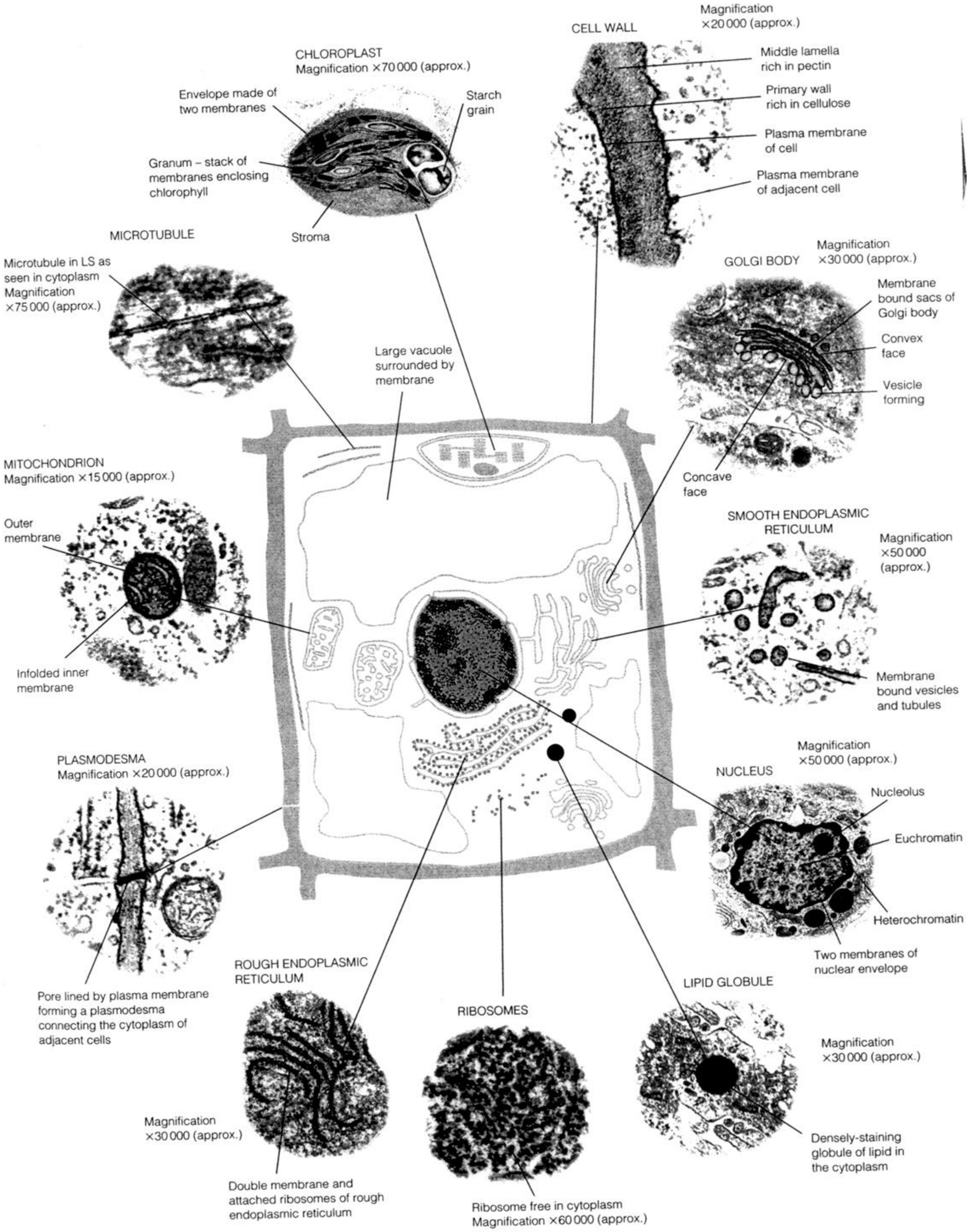
An animal and plant cell as seen under the light microscope.

A Generalised Animal Cell (Ultrastructure)



A generalized animal cell with details of organelles

A Generalised Plant Cell (Ultrastructure)



A generalized plant cell with detail of organelles

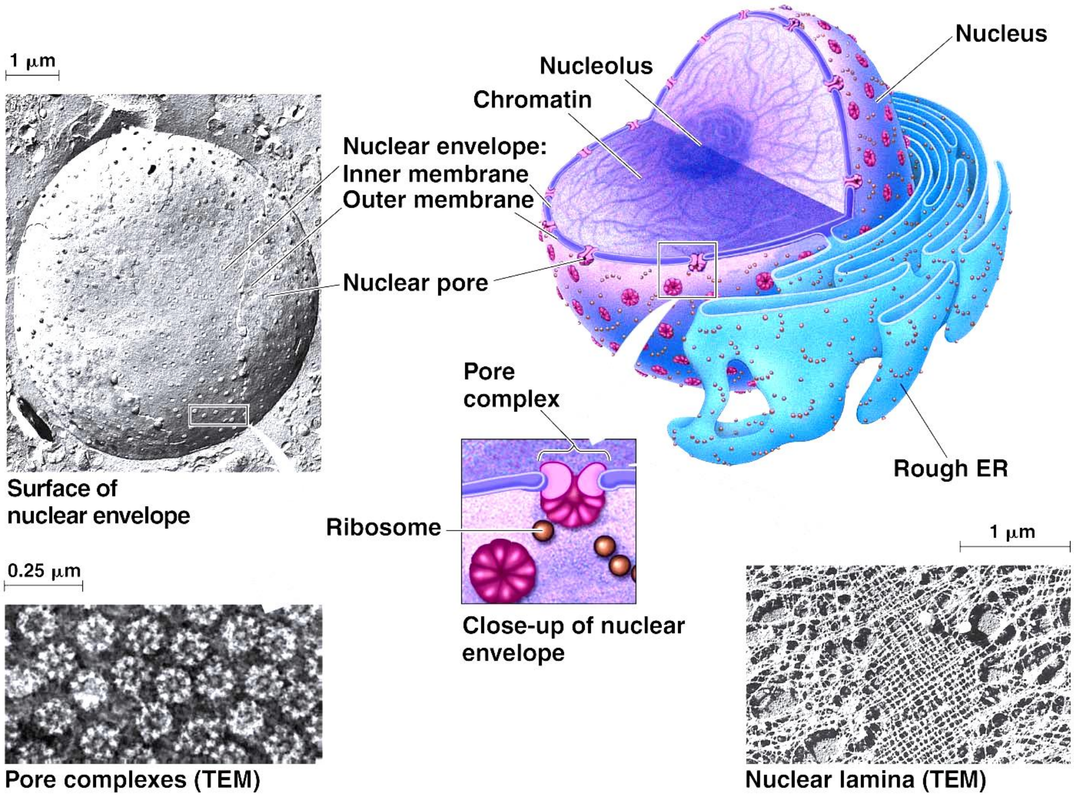
Comparison between animal cells and plant cells

Feature	Animal cell	Plant cell
Cell Wall		
Nucleus		
Cytoplasm		
Tonoplast		
Centrioles		
Vacuoles		
Pits		
Plasmodesmata		
Middle Lamellae		
Plastids		
Lysosomes		
Cilia/Flagella		
Granules		

6. Nucleus (with Nucleolus) and Ribosomes

Notes to Self:

A. Nucleus



Structure:

The nucleus is the largest organelle within the eukaryotic cell, average 5µm in diameter. It usually has a spherical / ovoid shape.

- **Nuclear envelope**

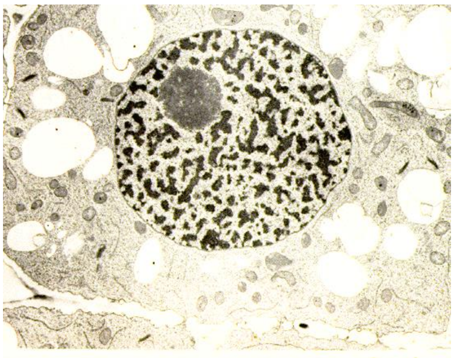
  The nucleus is surrounded by a double membrane (inner + outer membrane). (Each is a phospholipid bilayer). It is perforated by numerous nuclear pores which regulate the passage of substances into or out of the nucleus

Think about it:

What are some substances that are exchanged between the nucleus and the cytoplasm?

RNA, ribosomal subunits, free nucleotides, enzymes for transcription

- **Chromosomes / chromatin**



A. Cell at interphase containing a diffused mass of chromatin

B Cell during prophase.
Chromatin have condensed to form chromosomes, which are thick enough to be distinguished from one another under the microscope

This is the hereditary material of the cell (made up of deoxyribonucleic acid i.e. DNA).

Notes to Self:

When a cell is not dividing, the genetic material exists in the form of thin elongated threads called **chromatin** (a complex of DNA and proteins called **histones**). These appear as a diffused mass under the microscope.

Prior to cell division, the chromatin threads condense to form thicker structures called **chromosomes**.

In a cell at interphase cell (i.e. a cell that is not undergoing cell division), most of the chromatin is in the loosely coiled, extended and diffused state, called **euchromatin**, and is active in the production of mRNA. Some of the chromatin remain tightly coiled and stain intensely, and are called **heterochromatin** which is not active in RNA synthesis.

(More will be covered during the lectures on cell and nuclear division)

- **Nucleolus**

The nucleolus appears under the electron microscope as a spherical mass of densely stained granules and fibers. One or more **nucleoli** may be present within a nucleus.

It contains a large concentration of **DNA, ribosomal RNA and proteins.**

This is where ribosomal RNA, a component of ribosomes are synthesized.

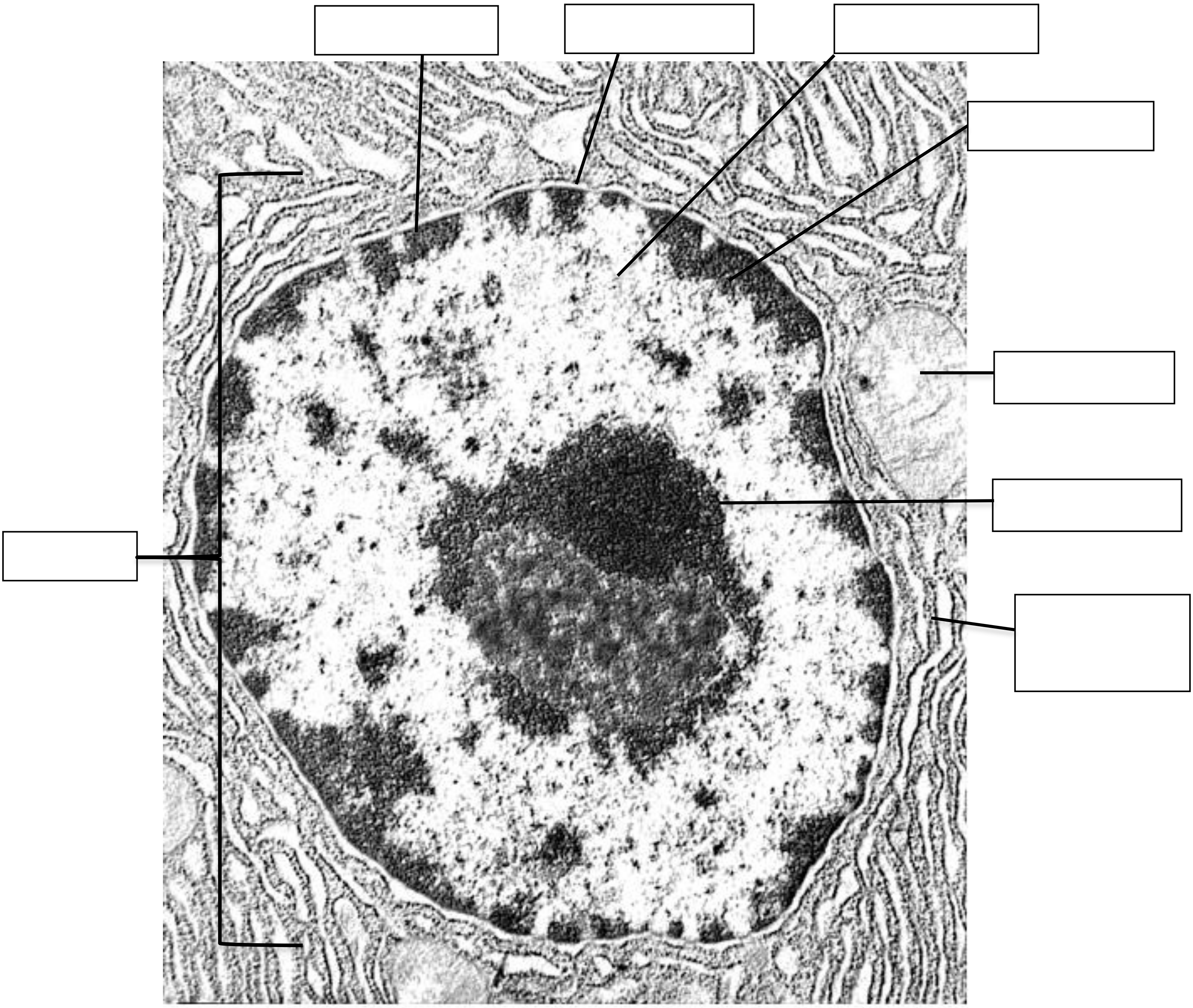
It also assembles the **sub-units of ribosomes** from ribosomal RNA and proteins.

<u>Function of the nucleus</u>:

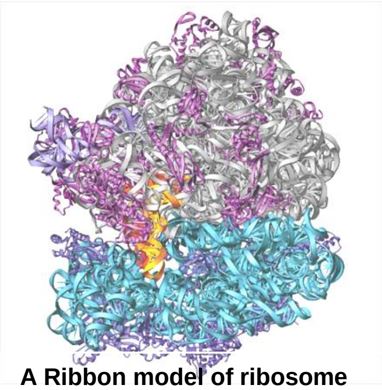
1. Contains the hereditary material (DNA) of an organism.
2. Controls the activities of the cell by regulating protein synthesis (e.g. synthesis of the various enzymes needed for the cell to function optimally)

Pause and Recall:

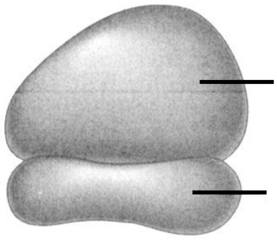
Label the nucleus, nucleolus, nuclear envelope, nuclear pore, euchromatin, heterochromatin and other membrane bound organelles



B. Ribosomes



A Ribbon model of ribosome
http://www-tc.pbs.org/wgbh/nova/photo51/images/pict-2001ribosome.jpg



Notes to Self:

Structure:

It consists of a **small** subunit and a **large** subunit. Each sub-unit is made of **ribosomal RNA and proteins**

Ribosomes are found freely floating in the cytosol ('free ribosomes') or attached to the outside surface of the rough endoplasmic reticulum ('bound ribosomes'). Bound and free ribosomes are structurally identical.

Prokaryotic cells (bacterial cells) have 70S ribosomes, each consisting of a small (30S) and a large (50S) subunit. Eukaryotic cells have 80S ribosomes, each consisting of a small (40S) and a large (60S) subunit. *(S = Svedberg units)*

Prokaryotic cell: A cell lacking a membrane-bound nucleus and membrane-bound organelles. Includes bacteria and archaea.

Eukaryotic cell: A cell with a membrane-bound nucleus and membrane-bound organelles. Includes animal and plant cells.

Function:

1. Site of **protein synthesis**
   (This process will be covered in detail in Protein Synthesis – Transcription and Translation)

Think About It: Why are ribosomes found in two different locations? Do they perform different functions?

Free ribosomes produce proteins that function within the cytosol; bound ribosomes synthesise proteins that are meant for insertion into the membrane, for packaging within certain organelles e.g. lysosomes or for secretion out of the cell

7. The Endomembrane System

Notes to Self:

CELL

- ***Plasma membrane*** (Part of endomembrane system)
- **Cytosol**
- **Organelles**
- **Cytoskeleton**
  - Microtubules
  - Mircofilaments
  - Intermediate filaments

Organelles →

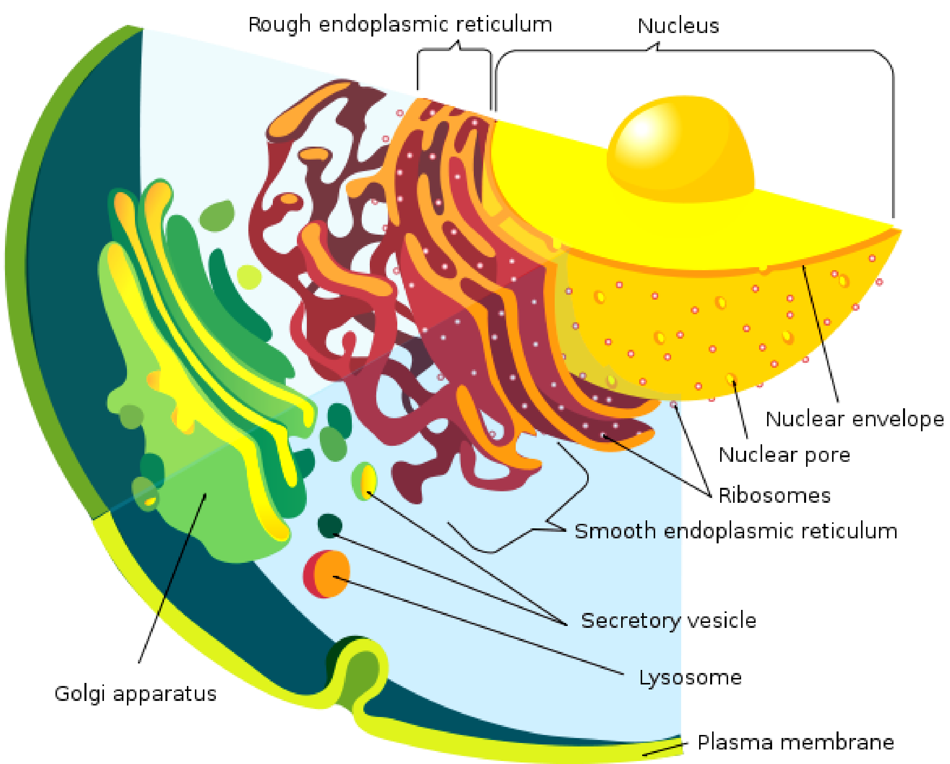
Membraneous Organelles

Non-membraneous Organelles
1. Ribosomes
2. Centrioles

Membraneous Organelles →

Part of endomembrane system
1. *Nucleus (Nuclear membrane)*
2. *Rough Endoplasmic Reticulum*
3. *Smooth Endoplasmic Reticulum*
4. *Golgi Apparatus*
5. *Lysosomes & Various Vesicles*

NOT part of endomembrane system
1. Mitochondrion
2. Chloroplast
3. Vacuole



Notes to Self:

Endomembrane System

Some cell organelles work together to transport materials into, out of, and within the cell. This is the eukaryotic cell's **endomembrane system**, a manufacturing and material transport network that enables the cell to make, move and break down cell products.

The endomembrane system consists of the nuclear envelope, rough and smooth endoplasmic reticulum (ER), the Golgi apparatus as well as the cell's plasma membrane, and includes the vesicles that bud off these membranes for intracellular transport (moving substances around inside the cell), exocytosis (substances leaving the cell) and endocytosis (sustances coming into the cell).
Importantly, the endomembrane system does not include the membranes of mitochondria or chloroplasts.

A. Nuclear Envelope

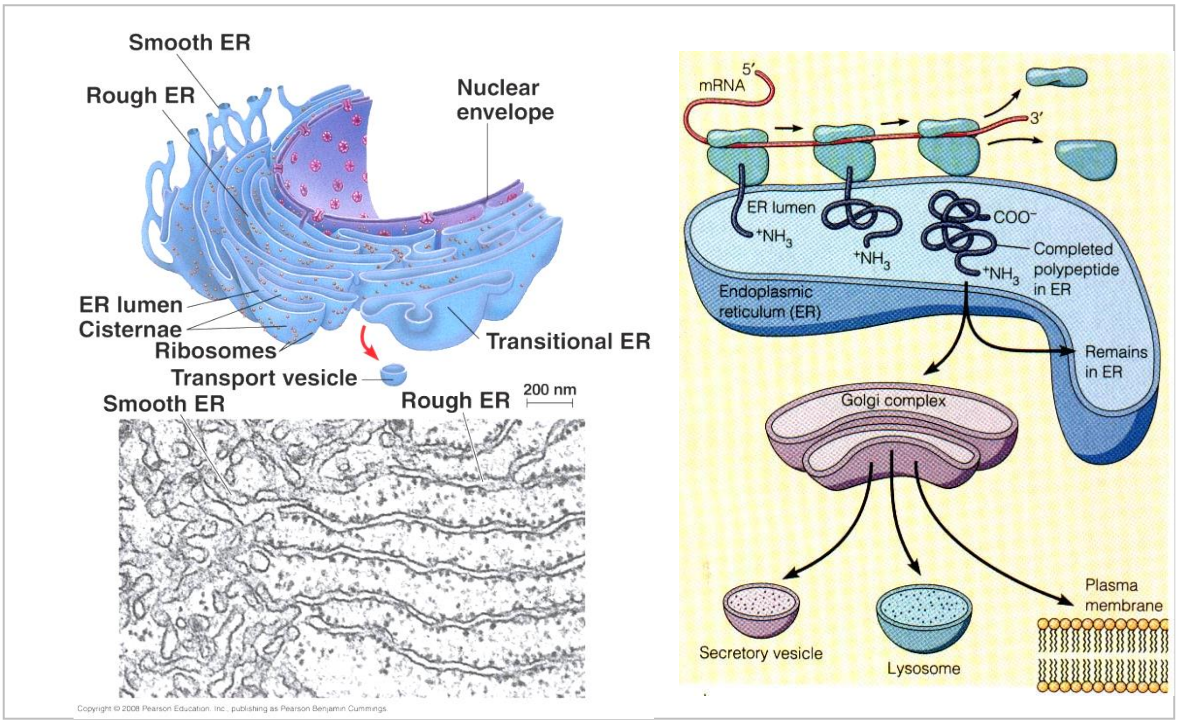
Structure:

It is perforated by numerous nuclear pores. The outer membrane of the nuclear envelope is continuous with the endoplasmic reticulum.

Function:

1. The function of the nuclear envelope is to allow passage of substances into or out of the nucleus.

B. Endoplasmic Reticulum (ER)



Structure:

It consists of an extensive network of **membranous tubules and sacs** called **cisternae** (cistern = tank for holding liquids). *Singular: cisterna*

The ER membrane separates the internal compartment of the ER, (called the ER lumen/ or cisternal space) from the cytosol.

There are two types of ER in a cell:

Notes to Self:

a. Rough ER

Structure:

Rough ER has ribosomes that stud the outer surface of the membrane, therefore appears rough through the electron microscope. The cisternae appear more flattened than cisternae of smooth ER.

Function:

1. Rough ER are involved in the transport of proteins which are synthesised by ribosomes on its surface.

   When proteins form they enter the cisternal space and fold into their native 3D-conformation

2. Carbohydrates may be added to the proteins (**glycosylation**) to form **glycoproteins**

   These proteins are meant for **secretion out of the cell** e.g. digestive enzymes, insulin etc. or **targeted for insertion into the plasma membrane.**

Transport vesicles bud off from the ER, carrying the proteins to their next destination (usually the Golgi apparatus). The rough ER is a membrane factory for the cell; it grows by adding membrane proteins and phospholipids to its own membrane. The ER membrane is transferred in the form of transport vesicles to other components of the endomembrane system.

b. Smooth ER

Structure:

The membrane of smooth ER appears smooth as it lacks ribosomes on its membrane surface. Cisternae appear more tubular than cisternae of rough ER.

Function:

1. The smooth ER contains many embedded enzymes that catalyse the synthesis of a variety of carbohydrates and lipids.

   In liver cells for example smooth ER enables glycogen that is stored as granules on the external surface of smooth ER to be broken down to glucose.

   Synthesis of lipids occur in smooth ER e.g. membrane phospholipids, cholesterol and steroid hormones.

2. One of the main functions of the liver cell is to detoxify products of natural metabolism, drugs and overloads of ethanol (derived from excessive alcoholic drinking).

3. Specialised ER in muscle cells store Ca^{2+} ions. (The contraction of muscle cells is triggered by the orderly release of calcium ions).

Think About it: What kind of cells have an abundance of rough ER?

Cells that are actively synthesising proteins; secretory cell e.g. liver cells, pancreatic cells (secretes pancreatic enzymes) , fibroblasts (secrete collagen), *Think About It:*

Some ribosomes are found free in the cytosol and others are bound to the rough endoplasmic reticulum, yet both of these ribosomes are identical. What determines their location?

(Please refer to the diagram below for the flow)

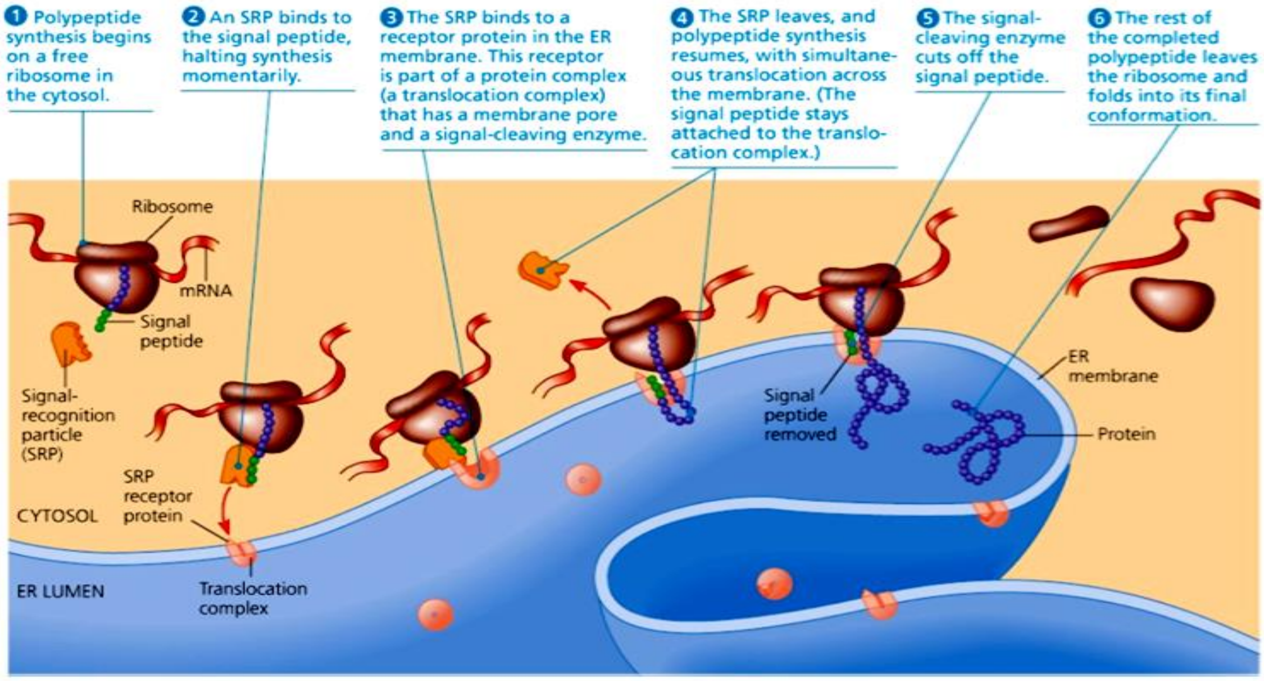
(1) Certain proteins have a stretch of polypeptide coded in their respective genes called the **signal peptide**. When such proteins are being synthesized by the ribosomes, the signal peptide is the first stretch of polypeptide that is synthesized before the rest of the protein.

(2) – (3) The signal peptide is recognized by a **signal recognition particle** in the cytoplasm, which binds to a receptor protein in the Rough ER, bringing the ribosome to the Rough ER.

(4) – (6) The growing polypeptide is translocated into the Rough ER lumen.

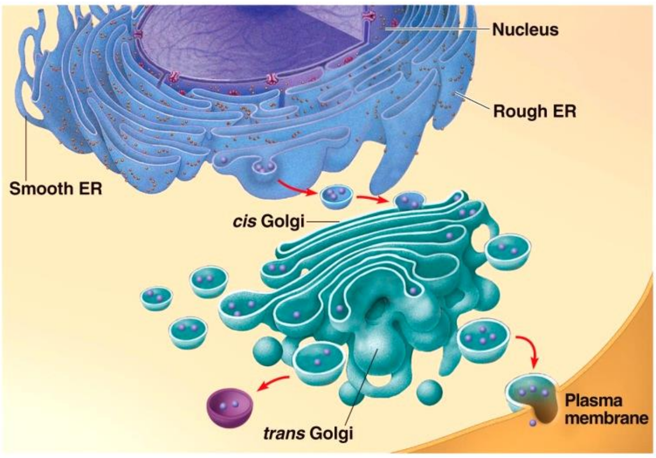
Proteins without this signal peptide coded in their genes will not be recognized by the signal recognition particle.

Hence, it is the signal peptide in proteins that determines if ribosomes are free or bound to the Rough ER.



(Note: the following term is not in the syllabus – “translocation complex”. There is no need to understand the process of translocation at part 4)

C. Golgi Apparatus



TEM of Golgi apparatus

Notes to Self:

<u>Structure</u>:

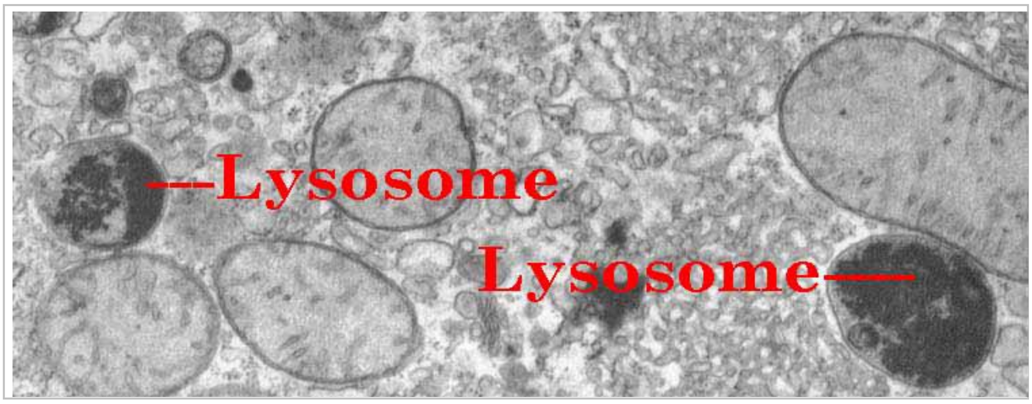
It consists of a stack of flattened, membrane-bound sacs called **cisternae** + associated vesicles called **Golgi vesicles.** It has a convex 'forming' **or 'cis' face**, where vesicles from the ER fuse to add new cisternae to the Golgi apparatus. The concave 'maturing' **or 'trans' face** – give rise to vesicles which pinch off and travel to other sites.

<u>Function</u>:

1. Cells synthesize a large number of different macromolecules. The Golgi apparatus is integral in modifying, sorting, and packaging these macromolecules for cell secretion or use within the cell:
   - It adds short sugar chains to proteins and **lipids** to form glycoproteins and glycolipids.
   - It modifies existing glycoprotein and glycolipids made in the ER by cleaving cleaving a sugar molecule from their sugar chain or modifying their sugar(s).
   - It produces polysaccharides (e.g. pectin) which are secreted from the *trans* face of the Golgi, inside transport vesicles that eventually fuse with the plasma membrane.
   - If sorts and targets completed materials to different parts of the cell or for secretion out of the cell.
2. It is involved in the formation of lysosomes.

D. Lysosomes

Notes to Self:



Structure:

Lysosomes are enclosed by a single membrane. They contains **hydrolytic enzymes** (e.g. **proteases (e.g. lysozyme), lipases, nucleases**) used to digest macromolecules. Lysosomal contents are acidic. The enzymes work best in an acidic environment.

Hydrolytic enzymes and lysosomal membrane are made by the rough ER. They are transported via transport vesicles to the *cis* face of Golgi apparatus for further processing.

The vesicles with the processed enzymes bud off from the *trans* face of the **Golgi** apparatus to form lysosomes

Proteins on the inner surface of the lysosomal membrane and digestive enzymes within them are not hydrolysed as the three dimensional conformations of these proteins shield vulnerable bonds from enzymatic attack.

Function

1. **Digestion of material taken in by endocytosis**

   Lysosome fuses with vesicles/vacuoles formed by endocytosis to digest the contents within the vesicles/vacuoles. The contents include food materials, foreign particles (e.g. bacteria) etc.The useful products of hydrolysis are absorbed and assimilated into the cytoplasm. The unwanted products are released into the external medium by exocytosis.

2. **Autophagy**

   This is the breakdown of unwanted structures within the cell e.g. old organelles. The organic products from the breakdown process are returned to the cytoplasm for reuse.

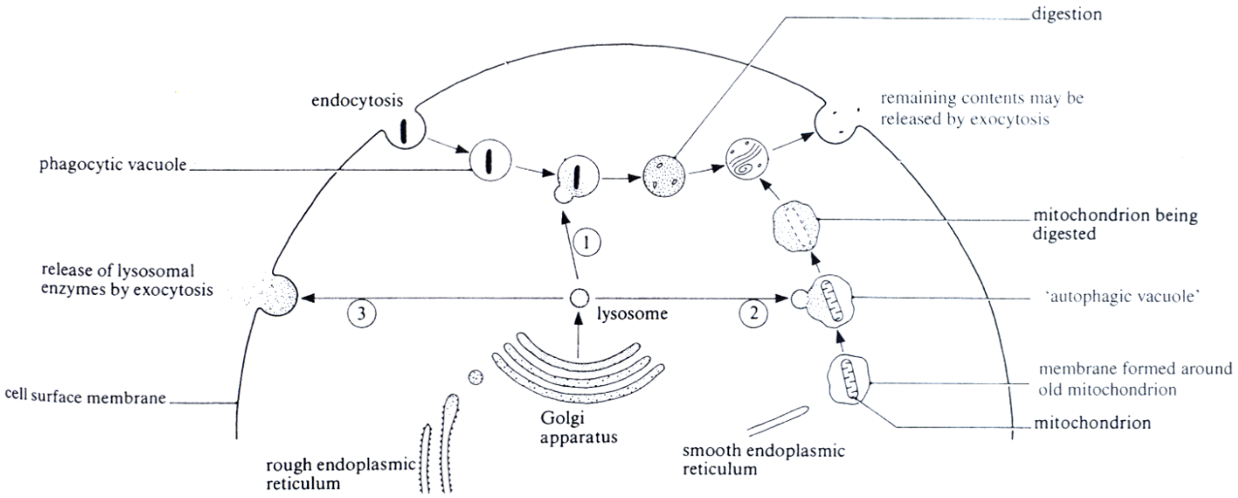
3. **Release of enzymes outside of cell by exocytosis**

   For the breakdown of extracellular content e.g. the sperm releases its hydrolytic enzymes by exocytosis to digest the sheath of nutrient cells surrounding the ovum, in order to facilitate fertilisation.

4. **Autolysis**

   Contents of lysosomes released within the cell; cell undergoes self-digestion or ‘suicide’.

Notes to Self:



Biological Science 1, Cambridge University Press

- **Diagram illustrating 3 possible uses of a lysosome**

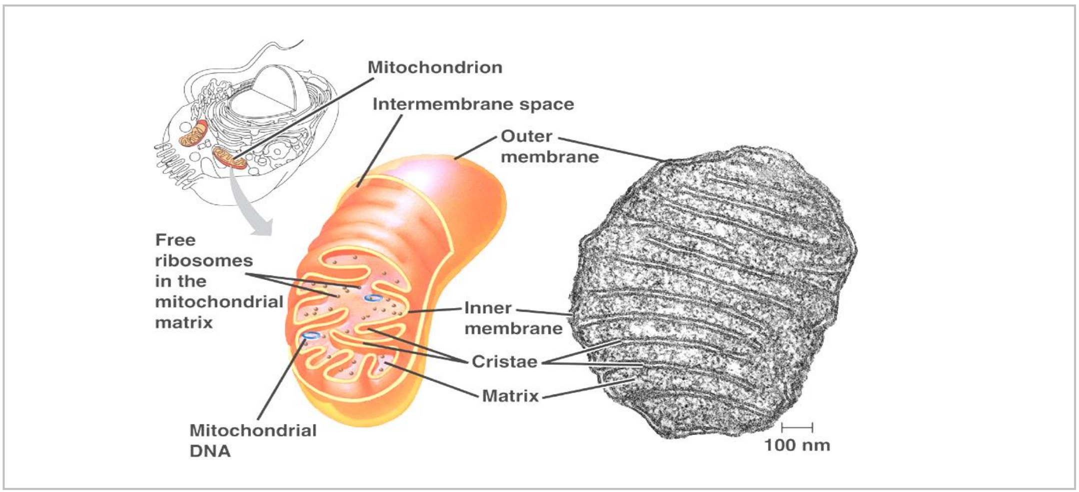
  Biological Science 1, Cambridge University Press

E. Cell surface membrane

Refer to notes on Membranes for a description of the structure of membranes

8. Other Organelles and Structures

A. Mitochondrion



Structure:

Notes to Self:

It is a spherical or rod-shaped organelle enclosed by a double membrane, each a phospholipid bilayer. *(Where else in the notes have you seen a double membrane?)*

The outer membrane is smooth, whilst the inner membrane is highly infolded to form numerous **cristae** (singular: crista).

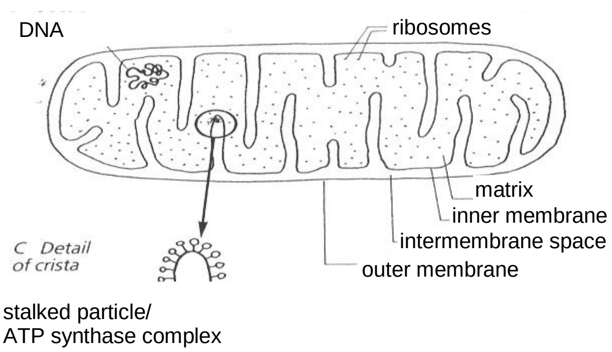
The inner membrane divides the mitochondria into two internal compartments: (a) the **intermembrane space** between the outer and inner membrane and (b) the **matrix** enclosed by the inner membrane

The fluid matrix, containing **70S ribosomes**, **circular DNA** and various **enzymes** involved in the Krebs cycle. *(Where else did you read about 70S ribosomes?)*

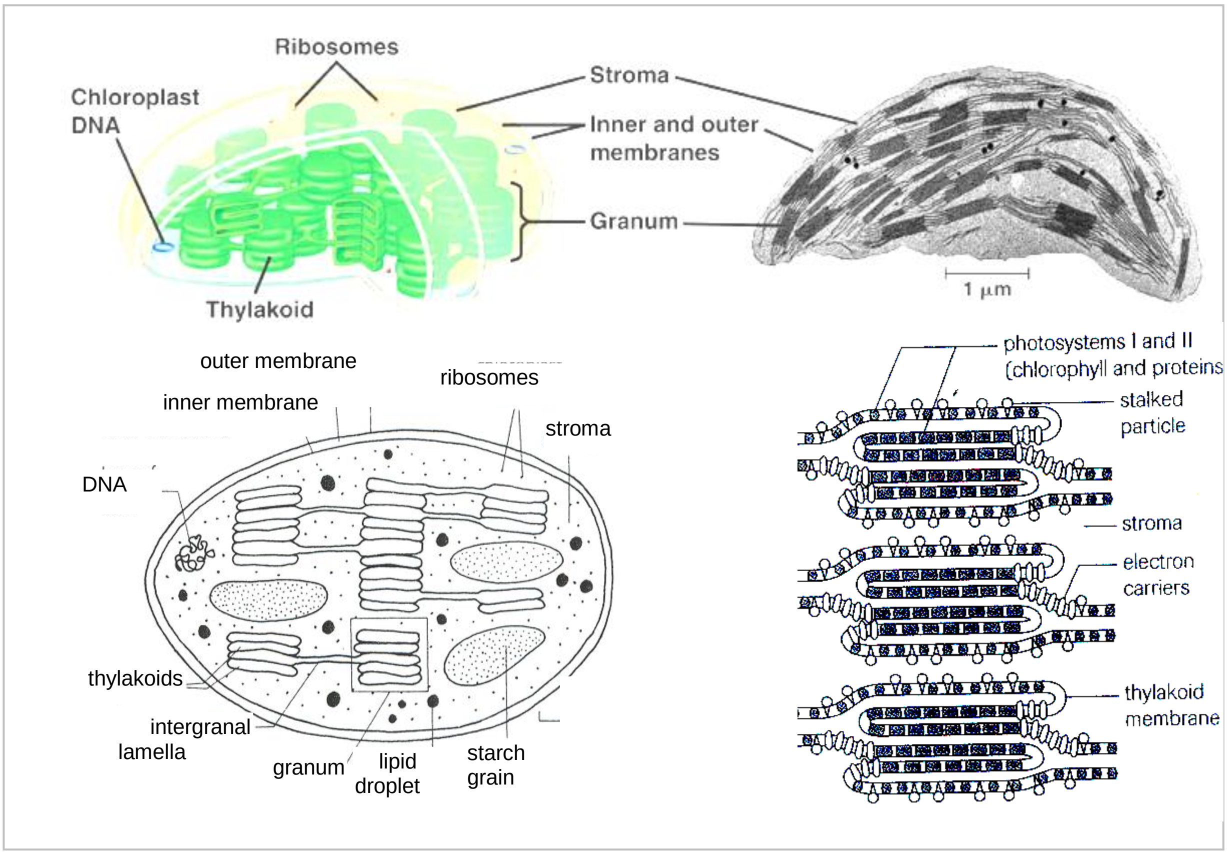
The cristae provide a large surface area for attachment of enzymes that function in oxidative phosphorylation.

Function:

The mitochondrion is a site of **cellular respiration**. They carry out metabolic processes that **generate ATP** through oxidation of sugars, fats and other fuels with the uptake of oxygen. The Kreb's cycle occurs in the matrix whereas oxidative phosphorylation occurs on the cristae. *(This topic will be covered in greater detail in the topic of cellular respirations)*



B. Chloroplast



Structure:

Notes to Self:

The chloroplast is a lens-shaped organelle, approximately 2 µm by 5 µm. It is bound by a double membrane.

The space between the double membrane is known as the **intermembrane space.** Within the chloroplast is another membrane system **-** a series of interconnected sacs called the **thylakoids.** Some regions form stacks of thylakoids = **grana** (singular: granum). The fluid outside the thylakoid is the **stroma** (site for Calvin's cycle). It contains **circular DNA**, **70S ribosomes**, **enzymes** and sometimes **starch grains.**

Chlorophyll and photosynthetic pigments and enzymes involved in photophosphorylation are located on the thylakoid membrane. They are organised into photosystems I and II.

Function:
Chloroplasts are the sites of **photosynthesis**. They absorb sunlight and convert solar energy to chemical energy by using solar energy to drive the synthesis of organic compounds such as sugars from carbon dioxide and water. *(This topic will be covered in greater detail in the topic of Photosynthesis)*

Think About It: In what type of cells is there an abundance of mitochondria?

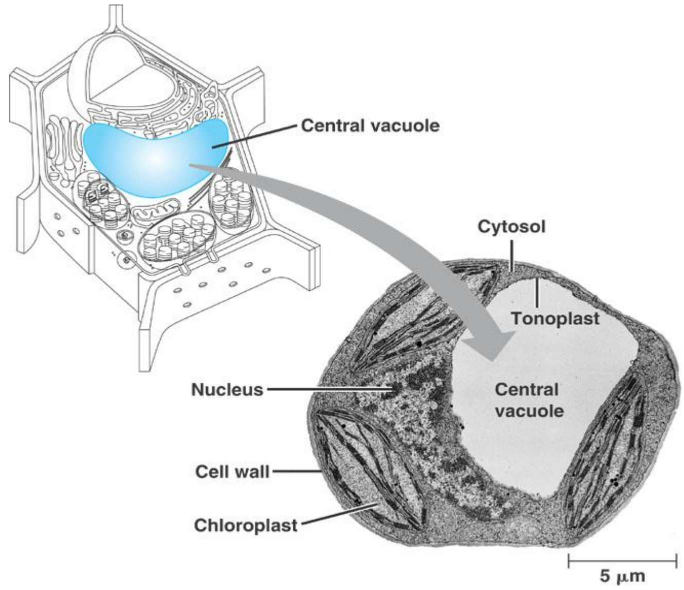
Abundant in cells with high-energy requirements e.g. liver cells (may contain up to 2,500 mitochondria per cell) and muscle cells

Think About It: Are there cells without mitochondria?

Answer: Absent in highly specialised cells e.g. mammalian red blood cells

C. Vacuole

Notes to Self:



Structure:

Vacuoles are large vesicles derived from the endoplasmic reticulum and the Golgi apparatus. Each vacuole is a fluid-filled sac bound by a single membrane. Like all cellular membranes, the vacuolar membrane is selective to the solutes they transport.

Animal cells → have smaller and more numerous vacuoles than plant cells.

Plant cells → have a large central vacuole surrounded by a membrane called the **tonoplast** and contains the **cell sap** – a solution of mineral salts, sugars, enzymes, pigments, waste products.

Function:

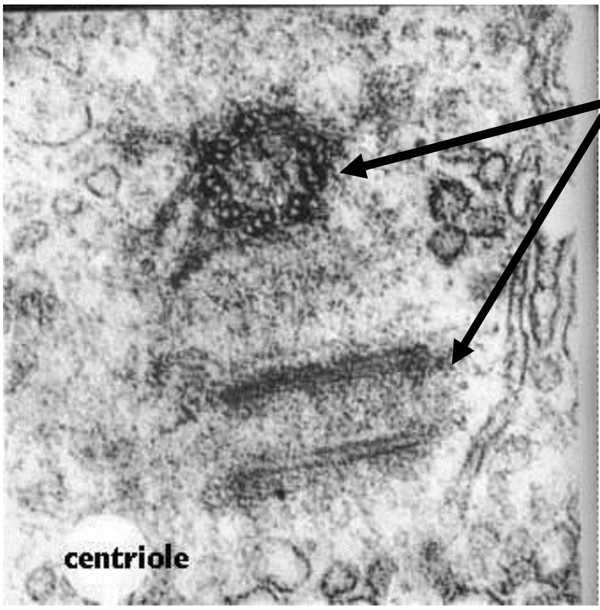
Animal cells

1. Food vacuoles formed by phagocytosis enclose material for digestion by lysosome.
2. Fresh water protists have contractile vacuoles that pump excess water out of the cell, maintaining a suitable ion and molecule concentration in the cell.

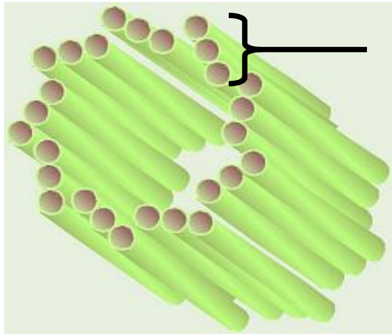
Plant cells

1. Concentrated cell sap draws water into vacuole → helps to **maintain turgor pressure** for support in herbaceous plants. Vacuoles have a role during plant **cell growth** → as a cell increases in size, the vacuole can also enlarge (as it takes in water) with minimal increase in cytoplasm.
2. Vacuoles can also store waste products e.g. calcium oxalate crystals.
3. Vacuoles can used for food storage – e.g. proteins stored in vacuoles of storage cells of seeds.

D. Centrioles



▸ **A pair of centrioles organised at right angles to each other**



a triplet

▸ **The arrangement of the nine triplets of microtubules found within each centriole.**

Notes to Self:

Structure:

Centrioles are a **pair** of cylindrical, rod-like structures positioned at right angles to each other. Each centriole contains **nine triplets of microtubules** arranged in a ring.

Centrioles are found within a region known as the **centrosome**, located close to the nucleus.

Centrosomes are found in all cells but centrioles are **absent in higher plant cells.**

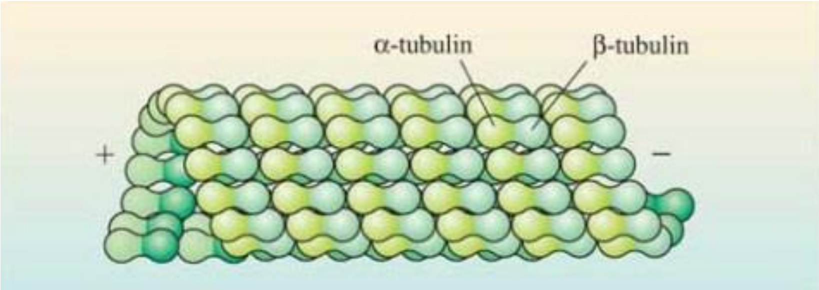
Higher plants: Plants that produce seeds, including angiosperms (flowering plants). Lower plants include ferns and mosses which produce spores instead of flowers.

Function:

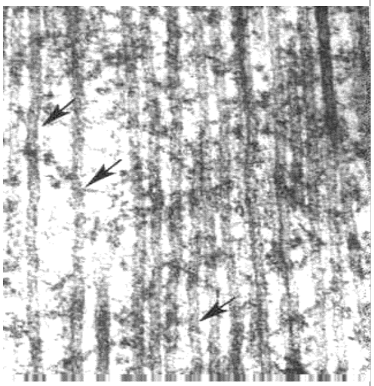
During cell division, the centrioles replicate and move to opposite ends of the cell. They play a role in nuclear division in animal cells, by helping to organise the formation of spindle fibres. Spindle fibres are needed for the separation of chromosomes during mitosis & meiosis.

Microtubule-organizing center (MTOC)
In animals, the two most important types of MTOCs are the basal bodies associated with cilia and, and the centrosome associated with spindle formation.

E. Microtubules (related to spindle fibres)



Model showing the structure of a microtubule formed by the addition of tubulin



Electron micrograph of microtubules

Structure:

These are hollow rods (about 25 μm in diameter). The wall is made of a globular protein caller **tubulin.** Each tubulin is a **dimer –** a molecule made of **two subunits.**

Microtubules grow in length by addition of tubulin subunits and decrease in length by disassembling units. Their growth can be inhibited by chemicals, e.g. colchicine

They have a certain degree of stiffness and run a straight course in the cytoplasm.

Function:

1. **Help maintain the shape of cells** - They are often found beneath the plasma membrane, providing rigidity to parts of the cell where they occur. i.e. acting as **cytoskeleton.**
2. **Intracellular transport -** They serve as tracks along which organelles equipped with motor proteins can move. (e.g. cytoplasmic streaming of chloroplasts, movement of Golgi vesicles and lysosomes).
3. **Chromosome movement in cell division -** Spindle fibres composed of microtubules which help in the movement of chromosomes to opposite poles in nuclear division (refer to centrioles).
4. **Form structural component of centrioles, cilia and flagella.**

Nature of Science

Historial Perspectives on the Study of Cells

We should know how our modern ideas of the cell developed through the centuries, showing the way of how scientific knowledge on the cell and its functions was derived.

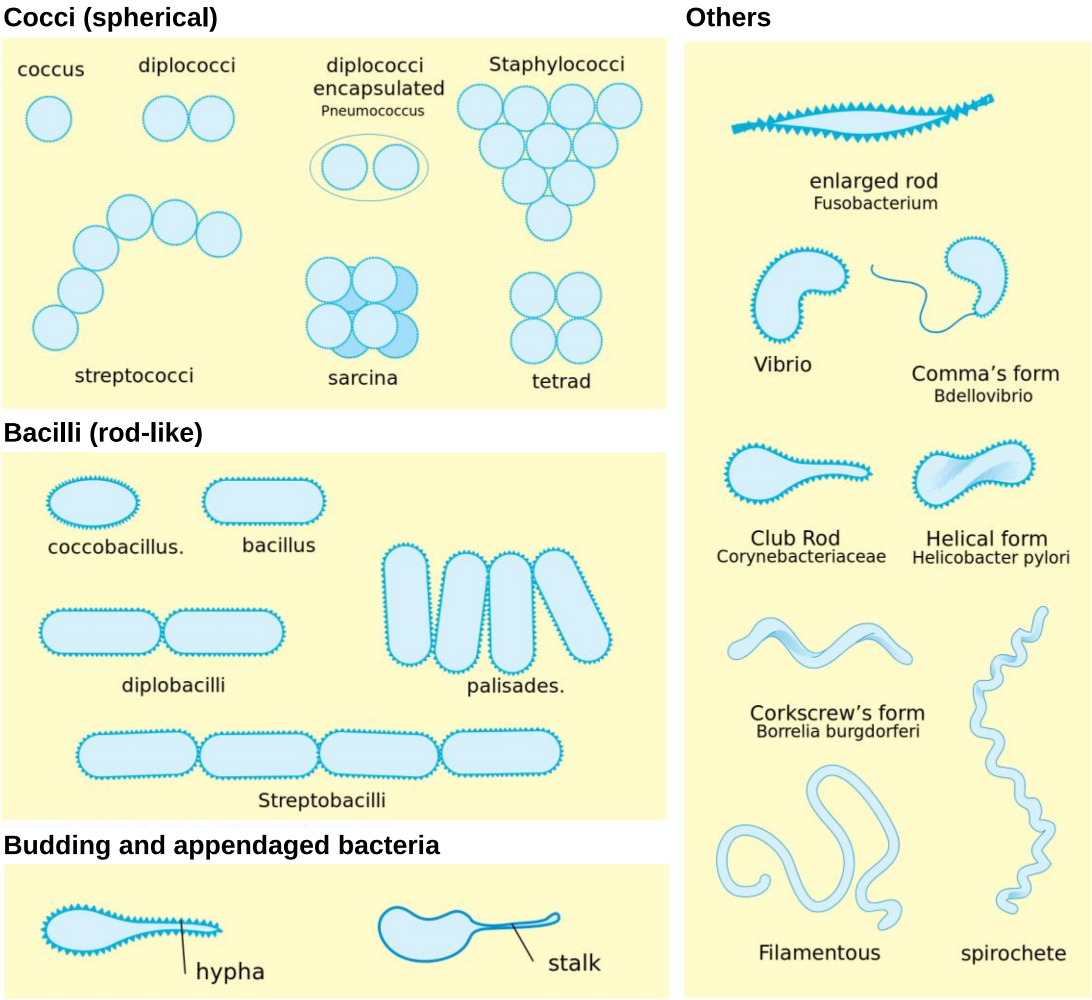
1590	Invention of the light microscope
1665	Discovery of cells by **Robert Hooke**, who examined cork tissue and observed box-like structures, now known to be dead cells. He gave the name *cellulae* (Latin for small rooms) to these structures.
1824	French botanist **Dutrochet** suggested that the various tissues of organisms are composed of 'globular cells of extreme smallness', with all organs being made up of cellular tissues variously modified. He recognized that growth was a result of increase in cell volumes and the addition of new cells.
1820s-1830s	English botanist **Robert Brown** observed an opaque spot in egg, pollen cells and cells of growing tissues of orchids. He called this spot a *nucleus.*
1835	**Dujardin** reported that cells were not hollow but filled with a thick, jelly-like fluid.
1840	**Purkyne** gave the name protoplasm to the content of cells, after realising that the latter were living material and not the cell walls. Later the term more commonly used today - *cytoplasm* - was introduced (cytoplasm+nucleus = protoplasm).
1855	**Rudolf Virchow** concluded that every cell comes from an already existing cell - *'Omnis cellula e cellula'* (all cells from cells).
1866	**Haeckel** established that the nucleus was responsible for storing and transmitting hereditary characters.
Mid-19thCentury	Microscopic analyses established the cell as the smallest unit of life, with the continuity of life coming directly from cell growth and division.
1875	**Waldeyer** discovered the partition of chromosomes during cell division
1880	**Flemming** showed that the mechanism of mitosis ensured the continuity between one generation of cells and another.
1880-1883	Discovery of plastids e.g. chloroplasts
1890	Discovery of mitochondria. Discovery by **Hertwig** that the development of an embryo starts with the fusion of two nuclei, one from an egg and the other from a sperm cell.
1898	Discovery of the Golgi apparatus by biologist **Camillo Golgi**.

9. Bacterial Cells (Prokaryotic Cells)

Prokaryotes generally lack membrane-bound organelles and the endomembrane systems; but they still survive and reproduce. In the endosymbiont 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 eukaryotes and prokaryotes.

A. Morphology

Most bacterial cells are very **small** (about 0.2µm in diameter and 2-8µm in length) and are **unicellular**. Bacteria may be classified based on their morphology ("*morphe*" = "form", "shape", "outward appearance"), amount of peptidoglycan in the cell wall or phylogeny (phylogeny = the organization of species to show their evolutionary relationships). Based on morphology, bacteria may be classified into: (a) coccus (spherical), (b) bacillus (rod-like), (c) spiral and (d) filamentous (elongated).



Different morphology of bacterial cells.

B. General Bacterial Structure (Ultrastructure)

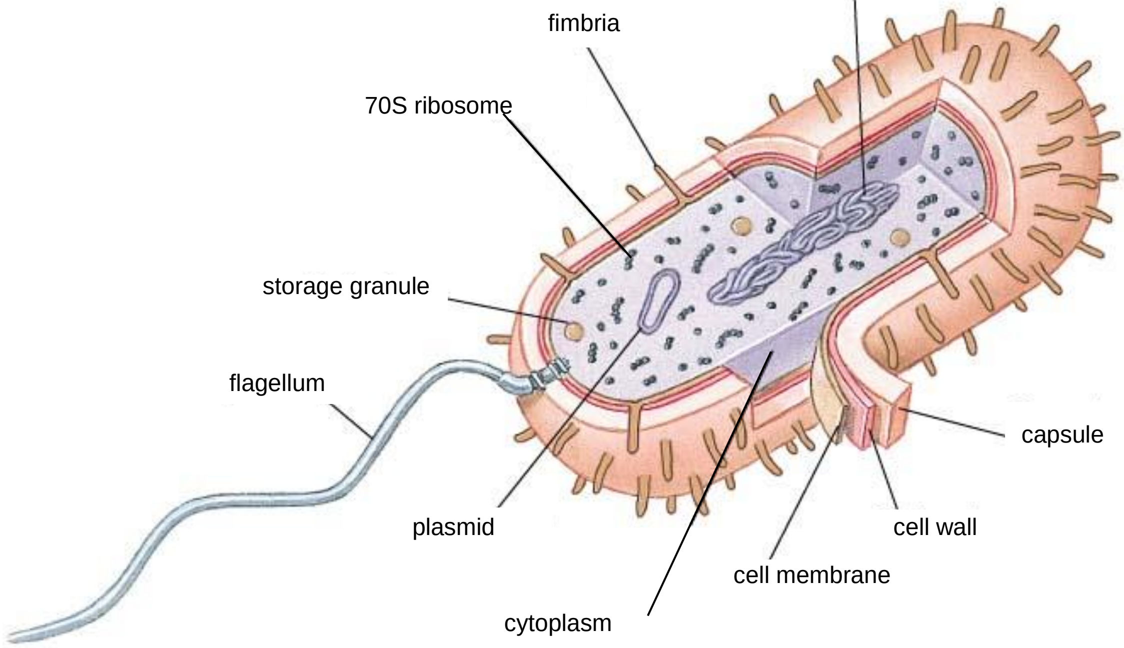


Diagram of a bacterial cell

Internal Structure

Notes to Self:

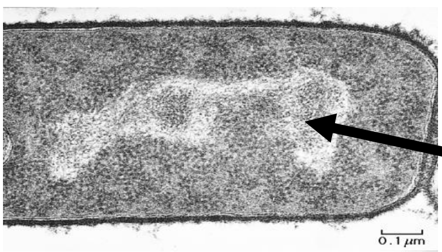
Bacteria are prokaryotes and have a very simple internal structure with <u>no membrane-bound organelles</u>. Structures present include:

- **The Bacterial Chromosome** (more details in Genetics and Inheritance)

  The main component of the genome in most bacteria is one ***double-stranded, circular DNA molecule*** that is ***associated with proteins*** (they are not called histones!). The entire structure is referred to as the *bacterial chromosome*.

  The bacterial chromosome makes up a dense region within the cell called the ***nucleoid***, which is not bound by a membrane. In addition to the chromosome, some bacteria may also have ***plasmids***, which are much smaller rings of autonomously replicating circular DNA.

a)



Nucleoid

a) The nucleoid region of a bacterial cell is stained less densely than the surrounding cytoplasm

b) Condensation of the bacterial DNA is made possible through its association with proteins

- **Nucleoid:**

  This is a region in the bacterial cell where chromosomal DNA is generally confined to. It is not bound by a membrane but is visibly distinct from the rest of the cell interior.

- **Ribosomes:**

  70S ribosomes (vs.80S in eukaryotes). They are needed for protein synthesis. The ribosomes give the cytoplasm of bacteria a granular appearance in electron micrographs.

- **Storage granules:**

  Nutrients and chemical reserves may be stored in the cytoplasm in the form of granules e.g. granules of glycogen, lipids and ions like phosphorous and magnesium.

- **Plasmid(s) (may be present)**

  These are small, ***circular autonomously replicating DNA molecule*** that is separate from the chromosome of the bacterial cell. The plasmid contains genes which may confer advantages on bacteria living in stressful environments e.g. antibiotic resistance genes. Multiple copies are usually present in a cell.

  Plasmids are used extensively in genetic engineering as vectors for carrying and expressing foreign DNA in bacterial cells.

<u>Surface Structure</u>

- **Cell Membrane**

  This is a phospholipid bilayer like the cell membrane of other cells.

  In addition to the roles of a cell membrane which you have learned (See Notes on *Cell Membranes*), the membrane of a bacteria is also where the proteins and enzymes used during photosynthesis and/or respiration are found. (How is this different from an eukaryotic cell?)

- **Cell Wall**

  Consists of a polymer called **peptidoglycan –** long chains of sugars cross-linked by short peptide chains. (compare: what is the cell wall in plants made up of?)

  It protects the bacterial cell from osmotic lysis.

  Bacteria may be classified as gram-positive or gram-negative bacteria (depending on whether they get stained by Gram stain which indicates the nature of the cell wall). See diagram on next page.

- **Capsule** (may be present in some bacteria)

  Some bacteria have a layer of polysaccharides known as glycocalyx (= sugar coat) just beyond the cell wall. In some bacteria, the glycocalyx is organized into a distinct layer, and is thus referred to as the capsule. Otherwise it is a diffused mass known as the slime layer.

  The capsule may also contain proteins. The capsule protects the bacteria from being engulfed via phagocytosis by the white blood cells which are unable to recognize the bacteria due to the capsule. It also enables bacteria to adhere to particular surfaces e.g. mucous membrane or to one another.

Appendages (may be present in some bacteria)

Notes to Self:

Both fimbriae and pili are hollow, hair-like structure composed of protein.

- **Fimbriae** (singular: fimbria)

  These are short, bristle-like fibres extending from the cell surface and are usually evenly distributed over the entire cell surface or at poles of cells. They are involved in the attachment to surfaces or other bacteria/organisms.

- **Pili** (singular: pilus)

  Pili are longer and fewer in numbers than fimbriae. They play roles in motility and DNA transfer:

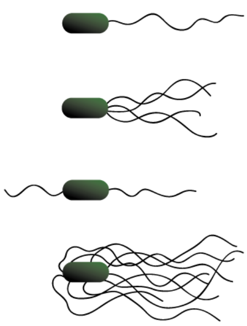
  Motility – a pilus makes contact with a surface and retract to pull the bacteria forward in a jerky, intermittent movement

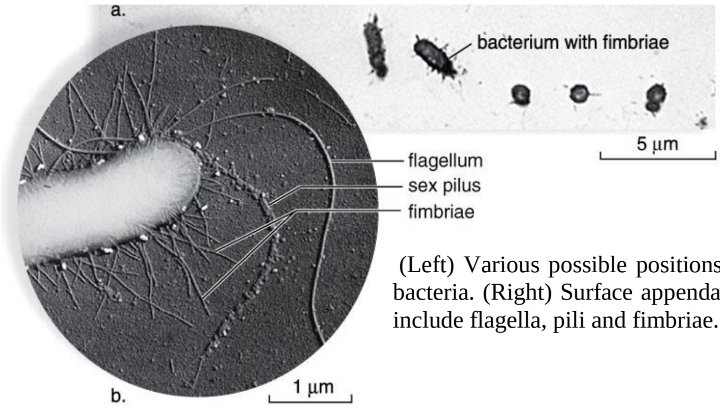
  DNA transfer - a specialised pilus like the sex pilus, allows two bacterial cells to be drawn close to each other so that a mating bridge can be formed for the transfer of genetic material.

- **Flagella** (singular: flagellum)

  Flagella are long appendages for motility (movement).

  The bacterial flagellum is a hollow cylindrical protein thread that propels the bacterium by rotation. Some bacteria possess more than one flagellum and they may be found distributed all over the cell, at one pole or at opposite poles of a cell.



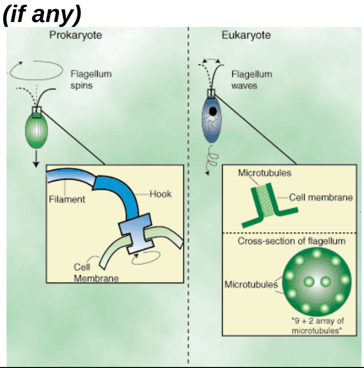


(Left) Various possible positions of flagella on bacteria. (Right) Surface appendages of bacteria include flagella, pili and fimbriae.

C. Characteristics of Bacteria

Characteristic	Information
Cell wall	Prevents osmotic lysis of cell protoplast and confers rigidity and shape to cells - composed of peptidoglycan
Location of chromosome	Found within nucleoid region; no true nucleus
Chromosome	A single, circular, double helix DNA – supercoiled
DNA-associated proteins	Proteins involved in stabilising DNA and gene regulation
Plasmids	Extra-chromosomal DNA that replicates autonomously; quantity can range from 5 - 100s
Organelles	No membrane-bound organelles
Ribosomes	70S (vs 80S in eukaryotes)
Appendages:	see Section D above
a) Fimbriae	Attachment to surfaces and to other bacteria/organisms
b) Pili	(a) Mediates DNA transfer during conjugation (sex pilus) (b) Motility by retraction
c) Flagella	Swimming movement; propulsion
Capsules (organised mass of glycocalyx)	Protection against phagocytic engulfment; attachment to surfaces; contains water to prevent desiccation - composed of polysaccharides and sometimes polypeptides
Slime layers (diffused mass of glycocalyx)	Attachment to surfaces; to form biofilm - composed of polysaccharides and sometimes polypeptides

D. Comparing General Structure of Prokaryotic & Eukaryotic Cells

Feature	Prokaryotic cell	Eukaryotic cell
Cell size	Smaller	Larger
Nucleus	No true nucleus / No nuclear envelope	Nucleus present / Nucleus with nuclear envelope present
Genetic material	Circular DNA lying naked in a region in the cytoplasm known as the nucleoid; DNA is associated with small amount of histone-like proteins	Linear DNA found within membrane-bound nucleus; DNA is associated with large amounts of histones proteins
Ribosome for protein synthesis	70S; No ER present for ribosomes to attach	80S; Ribosomes may be attached to ER or may be free in the cytosol
Organelles	Few e.g. ribosomes No membrane bound organelles	Many; Membrane bound organelles present e.g. nucleus, mitochondria; ➔ double membrane e.g. Golgi apparatus, lysosomes, vacuoles, endoplasmic reticulum ➔ single membrane
Cell walls	Composed of peptidoglycan (murein)	Composed of cellulose in plants Composed of chitin in fungi
Flagella (if any) 	Simple; No microtubules; composed of protein flagellin instead; each is a single strand of protein; Extracellular (not enclosed by plasma membrane);	Complex; composed of tubulin; each is made up of several strands with a 9+2 arrangement of microtubules (read Campbell if interested) Intracellular (surrounded by plasma membrane);
Photosynthesis	Involves plasma membrane of bacteria	Involves chloroplast
Respiration		Involves mitochondrion and cytoplasm

BIOLOGY- READ ON YOUR OWN

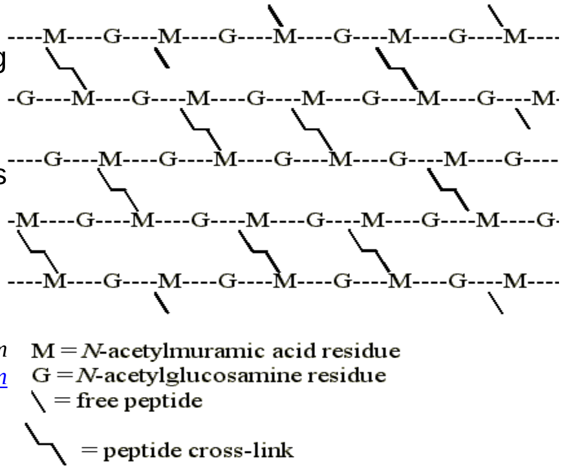
What is the bacterial cell wall made of?

Peptidoglycan

> the sugar component is made up of alternating units of NAG (N-acetylglucosamine) and NAM (N-acetylmuremic acid).

> the sugar is linked by short peptide chains as shown on the right

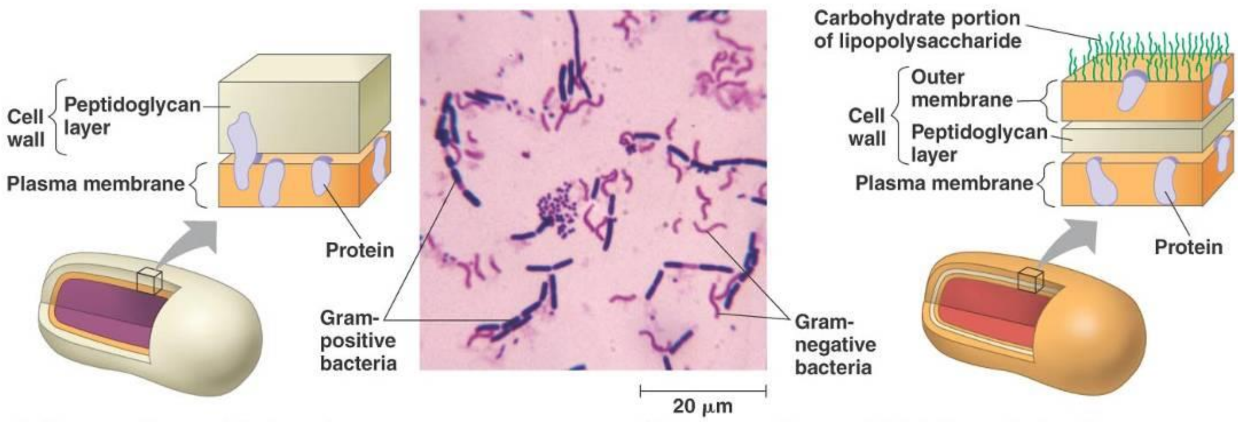
Diagram from *http://www.mikeblaber.org/oldwine/bch5425/lect10/lect10.htm*



> In gram-positive bacteria, the cell wall is a thick peptidoglycan layer.

> In gram-negative bacteria, the cell wall includes a thin peptidoglycan layer, followed by an **additional outer membrane.**

(Peptidoglycan is considered as the constituent of bacterial cell wall.)



(a) Gram-positive: peptidoglycan traps crystal violet.

(b) Gram-negative: crystal violet is easily rinsed away, revealing red dye.

VIDEO LINK on the steps in Gram staining: http://tinyurl.com/kkk7wsf

10. Viruses

In contrast to eukaryotic and prokaryotic cells, viruses lack several 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.

Seven characteristics of living organisms

1. Have a cellular organization
   Regardless of whether they are unicellular or multi-cellular organisms, the smallest level of organization of living organisms is the cell.
2. Show metabolic activity
   All organisms need to acquire and use energy in order to maintain metabolic processes for survival.
3. Grow and develop
   Growth involves both the increase in size and number of cells. When organisms grow, they undergo changes known as development.
4. Reproduce
   Organisms produce offspring like themselves through sexual or asexual means.
5. Have a common hereditary molecule
   All living organisms have a common molecular inheritance based on the nucleic acid, which contains instructions for the structure and function of cells.
6. Respond to stimuli
   Organisms have specialized receptors that detect environmental stimuli to allow their cells to adjust metabolism in response.
7. Adapt to the environment
   Adaptation is the accommodation of a living organism to its environment, which is fundamental to the process of evolution.

Question:
Which of the above characteristics do viruses show?

A. Are viruses living or non-living?

Notes to Self:

Viruses are acellular (contain no cytoplasm or cellular organelles) particles that possess both characteristics of living and non-living organisms.

Outside of host cells they do not carry out any metabolism, move, grow or divide.

While they contain either DNA or RNA as their genome, their replication can only occur within host cells. Viruses depend on their host cells for reproduction because they lack most of the reproductive/metabolic machinery or structures found in host cells (i.e. they lack enzymes for metabolism and ribosomes for protein synthesis) and resources (e.g. amino acids and energy sources like ATP).

Hence, viruses are obligate intracellular parasites.

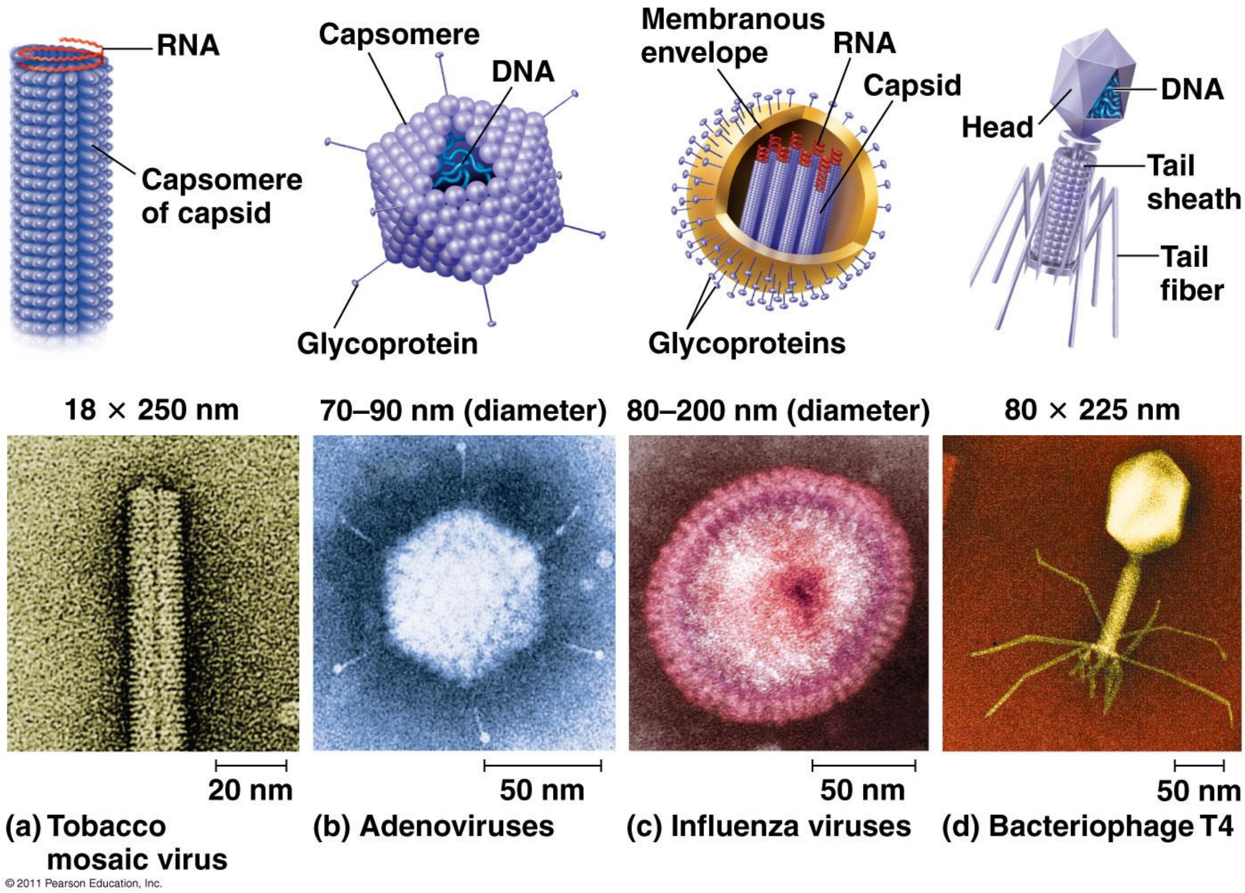
An isolated virus cannot replicate itself; it is only capable of infecting an appropriate host cell. Once they have hijacked their host cell's reproductive/metabolic machinery, viruses are able to reproduce at a fast rate.

B. Morphology

Notes to Self:

Viruses may be classified into several different morphological types based on their capsid structure. Other ways of classifying viruses include grouping them based on the type of nucleic acid they possess or the presence or absence of a viral envelope.

In general, four main morphological virus types can be identified: **Helical, Icosahedral, Enveloped & Complex viruses** as shown respectively below:



Different morphological structures of viruses

C. Structure of Viruses (Ultrastructure)

Notes to Self:

The sizes of viruses ranged from 10 to 300nm. An intact **infectious** viral particle is called a **virion.** A virion is a complete, fully developed viral particle composed of the **genome** and surrounded by a protein coat, the **capsid**. A genome is the total genetic content contained in a haploid set of chromosomes in eukaryotes, in a single chromosome in bacteria, or in the DNA or RNA of viruses.

Some types of viruses have an additional outer layer, an **envelope** in which viral **glycoproteins** are embedded in.

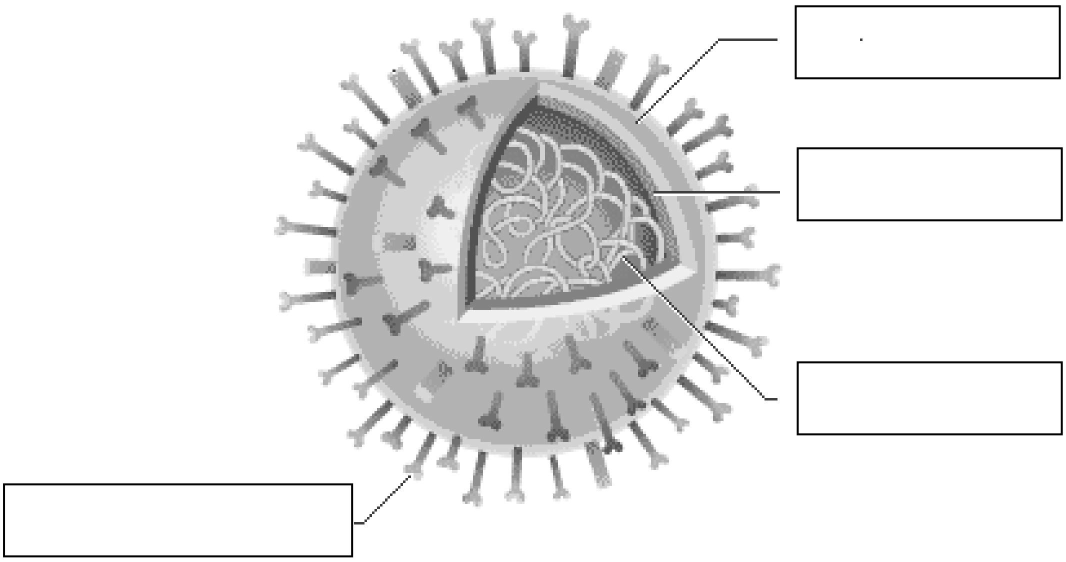


Diagram of a generalized virus

(Picture taken from http://encarta.msn.com/media_461516649_761557270_-1_1/Viral_Structure.html)

D. Structural Components of Viruses

Notes to Self:

- **Genome**

The viral genome is single or several/segmented, circular or linear molecules of nucleic acid that functions as the genetic material of the virus. The nucleic acid can be single-stranded or double-stranded. Thus, in addition to the familiar double-stranded DNA, there are viruses with single-stranded DNA, double stranded RNA, or single-stranded RNA.

The genome codes for the synthesis of **viral components** and **viral enzymes** for **replication** and **assembly**.

The genes are few in number ranging from 3 – 100 depending on the class of virus. The number of genes present in the virus determines the degree of complexity displayed by the virus. This contrasts with the thousands of genes in the bacterial genome.

In contrast to prokaryotic and eukaryotic cells in which DNA is usually the primary genetic material, a virus can have either DNA or RNA but never both.

- **Capsid**

The genome is surrounded by a protein coat called a **capsid**. The capsid is the protein coat or shell of a virus particle, surrounding the nucleic acid or nucleoprotein core. The structure of the capsid is ultimately determined by the viral nucleic acid and accounts for most of the mass of a virus, especially of the small ones.

Each capsid is composed of protein subunits called **capsomeres** (the protein components of capsid).

The capsid serves to **protect, attach** and **introduce the genome into host cells**.

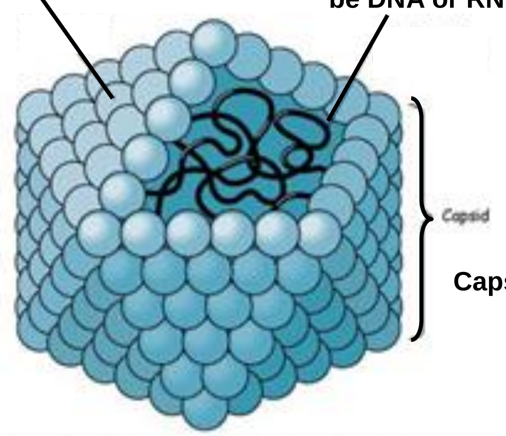


Diagram of a viral capsid surrounding its genome.

Together, the capsid and the nucleic acid form the **<u>nucleocapsid</u>.** The nucleocapsid is a complex of proteins and the viral nucleic acid. An infectious virus particle, a virion, will contain at minimum a nucleocapsid.

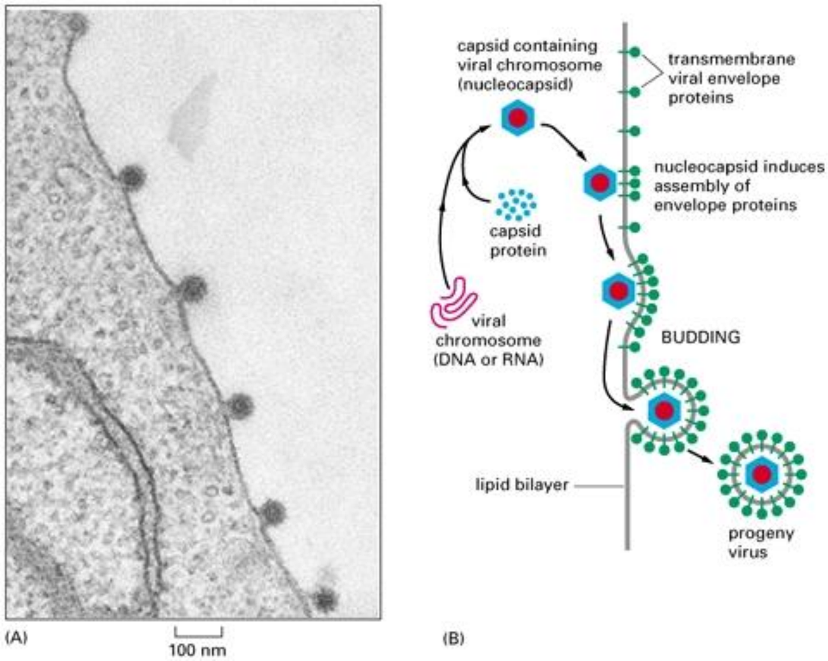
- **Envelope**

Some types of viruses have an additional outer layer, an **envelope** that surrounds the nucleocapsid.

The envelope is composed of **phospholipids** and **glycoproteins** that are arranged to form a **lipid bilayer**. For most viruses, it is derived from the host cell membranes by a process called **budding.** The envelope may come from the host cell's nuclear, vacuolar or plasma membranes.

Although the envelope is usually of host cell origin, the virus does incorporate proteins of its own, often appearing as **glycoprotein spikes**, into the envelope.

Most animal viruses have an envelope surrounding their nucleocapsid.



(A) Newly replicated viruses budding off from host cell. (B) Assembly of viral components at the cell surface membrane of the host cell before budding off.

Viruses that are composed of just the nucleocapsid are called **naked viruses** or **non-enveloped viruses** whilst those viruses whose nucleocapsids are covered by an envelope are termed **enveloped viruses**.

Pause and Recall:
List 3 definitive characteristics of a virus.

1. *As__________________________, they are totally dependent on a host cell for replication.*
2. *The genome is made up of only 1 type of_________________: DNA or RNA but never both.*
3. *Viral ____________must assemble into complete viruses (virions) to go from one cell to another.*

Nature of Science

Historial Perspectives on Virology

1796:	Edward Jenner used cowpox to vaccinate against smallpox. Jenner was the first person to deliberately vaccinate against any infectious disease. Although Jenner is commonly given the credit for vaccination, variolation, the practice of deliberately infecting people with smallpox to protect them from the worst type of the disease, had been practiced in China at least two thousand years previously.
1885:	Louis Pasteur experimented with rabies vaccination, using the term "virus" (Latin, poison) to describe the agent. Although Pasteur did not discriminate between viruses and other infectious agents, he originated the terms "virus" and "vaccination" (in honour of Jenner) and developed the scientific basis for Jenner's experimental approach to vaccination.
1892:	Dimitri Iwanowski described the first "filterable" infectious agent - tobacco mosaic virus (TMV) - smaller than any known bacteria. Iwanowski was the first person to discriminate between viruses and other infectious agents, although he was not fully aware of the significance of this finding.
1898:	Martinus Beijerinick extended Iwanowski's work with TMV and formed the first clear concept of the virus "contagium vivum fluidum" - soluble living germ. Freidrich Loeffler and Paul Frosch demonstrated that foot and mouth disease is caused by such "filterable" agents. Loeffler and Frosch were the first to prove that viruses could infect animals as well as plants.
1915:	Frederick Twort discovered viruses infecting bacteria.
1917:	Felix d'Herelle independently discovered viruses of bacteria and coins the term bacteriophage. The discovery of bacteriophages provided an invaluable opportunity to study virus replication at a time prior to the development of tissue culture when the only way to study viruses was by infecting whole organisms.
1935:	Wendell Stanley crystallized TMV and showed that it remained infectious (Nobel Prize, 1946). Stanley's work was the first step towards describing the molecular structure of any virus and helped to further illuminate the nature of viruses.
1939:	Emory Ellis and Max Delbruck established the concept of the "one step virus growth cycle" essential to the understanding of virus replication (Nobel Prize, 1969). This work laid the basis for the understanding of virus replication - that virus particles do not "grow" but are instead assembled from preformed components.
1940:	Helmuth Ruska used an electron microscope to take the first pictures of virus particles. Along with other physical studies of viruses, direct visualization of virions was an important advance in understanding virus structure.
1961:	Sydney Brenner, Francois Jacob, and Matthew Meselson demonstrated that bacteriophage T4 uses host cell ribosomes to direct virus protein synthesis. This discovery revealed the fundamental molecular mechanism of protein translation.
1970:	Howard Temin and David Baltimore independently discovered reverse transcriptase in retroviruses (Nobel Prize, 1975). The discovery of reverse transcription established a pathway for genetic information flow from RNA to DNA, refuting the so-call "central dogma" of molecular biology.
1970s:	Advances in molecular biology techniques have led to the discovery of many new viruses.
1979:	Smallpox was officially declared to be eradicated by the World Health Organization (WHO). The last naturally occurring case of smallpox was seen in Somalia in 1977.
1983:	Luc Montaigner and Robert Gallo announced the discovery of human immunodeficiency virus (HIV), the causative agent of AIDS.
1990:	First (approved) human gene therapy procedure was carried out on a child with severe combined immune deficiency (SCID), using a retrovirus vector.
1999:	Number of confirmed cases of people living with HIV/AIDS worldwide reaches 33 million. The AIDS pandemic continues to grow. Nucleotide sequence of the largest known virus genome completed: *Paramecium bursaria* Chlorella virus 1. This 330,742 bp sequence represents the technical advances in sequencing which have occurred since the first genome sequence was completed in 1977.
2002-2004:	Outbreak of severe acute respiratory syndrome (SARS) caused by the SARS coronavirus.
2006:	Two vaccines protecting against several cervical cancer-causing strains of human papillomavirus (HPV) were released.