DP IB Biology: HL

Your notes

1.2 Cells: Origin & Ultrastructure

Contents

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1.2.1 Origin of Cells


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Spontaneous Generation

Pre-existing cells

- In 1852 Robert Remak made the conclusion that cells divided to form new cells, that is cells came from **pre-existing cells**
- His conclusion was reached after studying cells from **chicken embryos**
- This discovery is often attributed to Robert Virchow who in 1855 proposed the phrase *omnis cellula e cellula* (all cells come from cells)
- Prior to these announcements, it was believed that life arose **spontaneously** from non-living matter

NOS: Testing the general principles that underlie the natural world; the principle that cells only come from pre-existing cells needs to be verified

- Up until the 17th century, the consensus was that life was **spontaneously generated** (living organisms arose from non-living matter). This was believed due to:
  - The lack of technology - microscopes were not extensively used
  - Observations being made - Aristotle observing insects forming from dew or van Helmont observing a mouse appearing from a jar containing a sweaty shirt and wheat
  - The idea supporting the **cultural and religious beliefs** of the time
- From the 17th century scientists such as Francesco Redi with his maggot and rotting meat experiment began collecting evidence to test and verify that **life required life to exist**
- However, it was Louis Pasteur's experiments involving swan-neck flasks that provided sufficient verification to convince scientists that cells could only come from pre-existing cells
- The universal acceptance that cells come from pre-existing cells also comes from the idea that :
  - The **highly complex ultrastructure** of cells has not been able to be synthesised by humans
  - All the known examples of growth are a result of **cells dividing** by mitosis or meiosis
  - Although viruses have a much simpler structure, they can only be produced inside a host cell
  - The **universality** of the **genetic code** suggests that all life evolved from the **same original cells**
    - The translation of the 64 codons produces the **same amino acids** for nearly all organisms - although there are some rare minor variations that have likely arisen since the common origin of life

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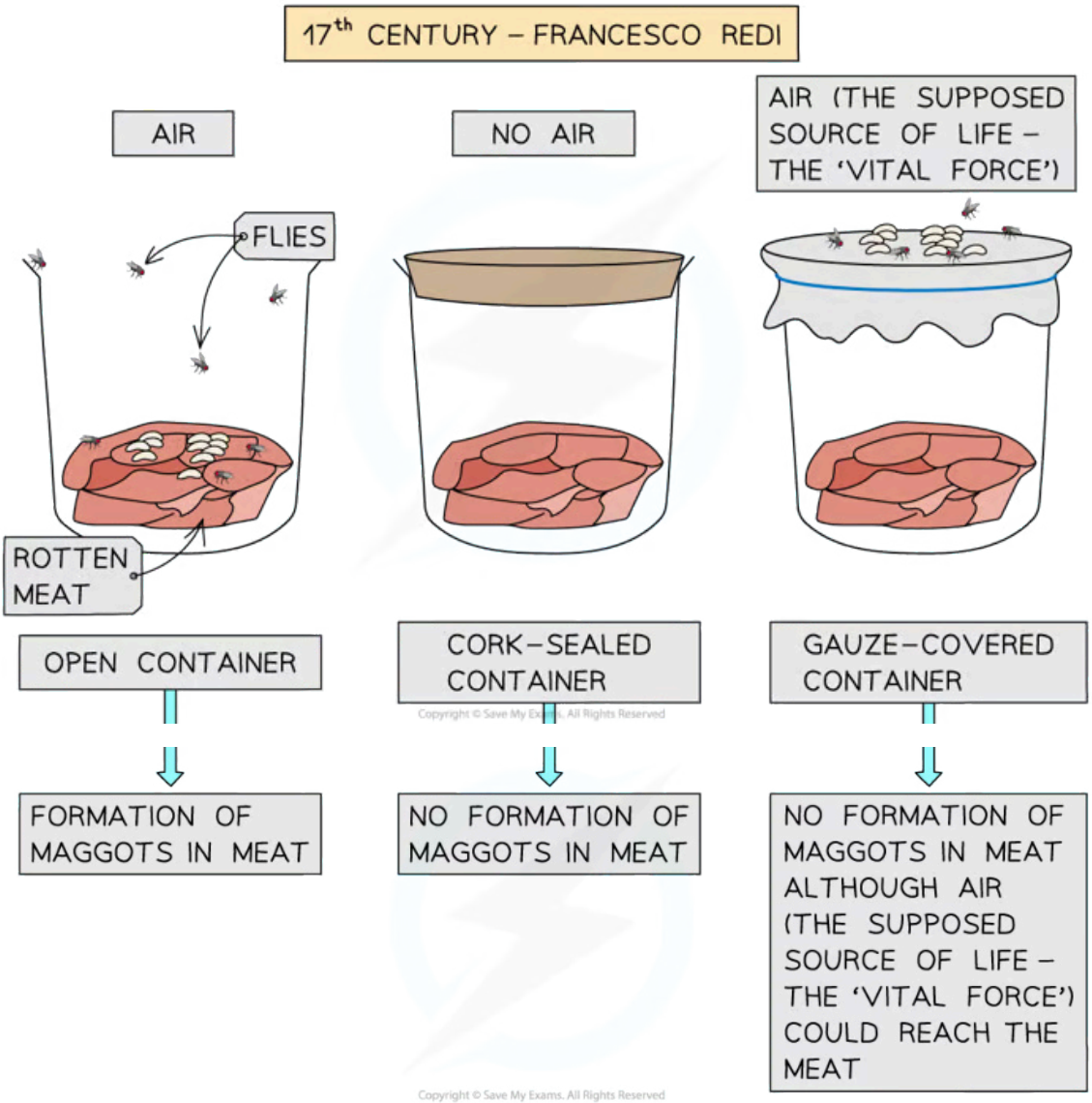

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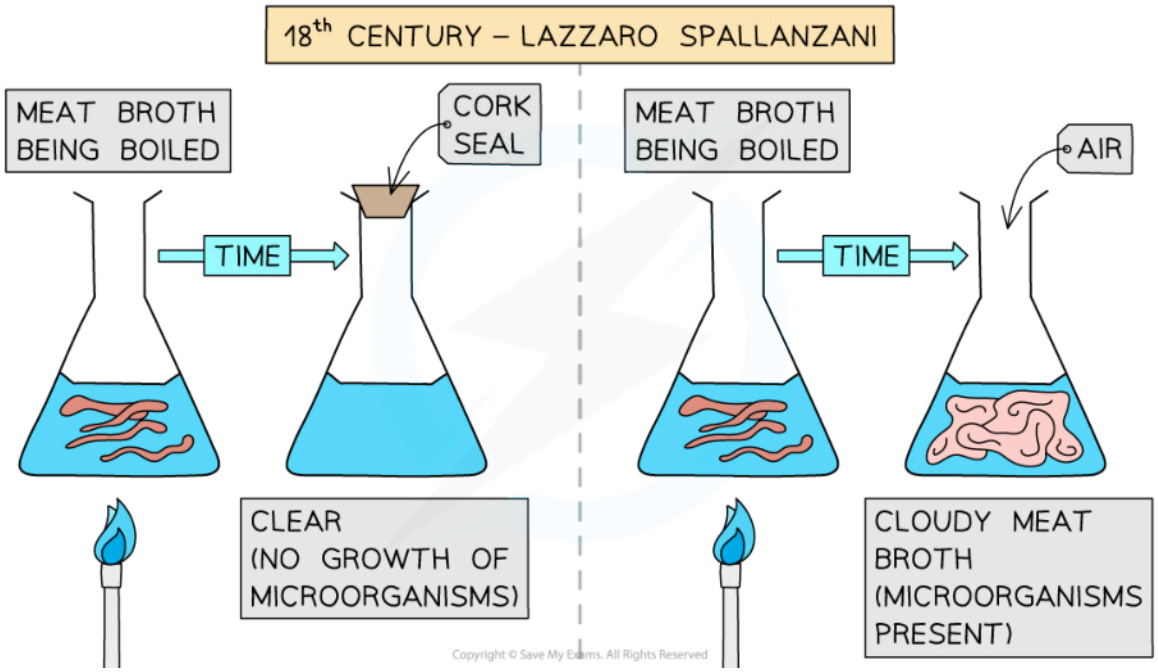

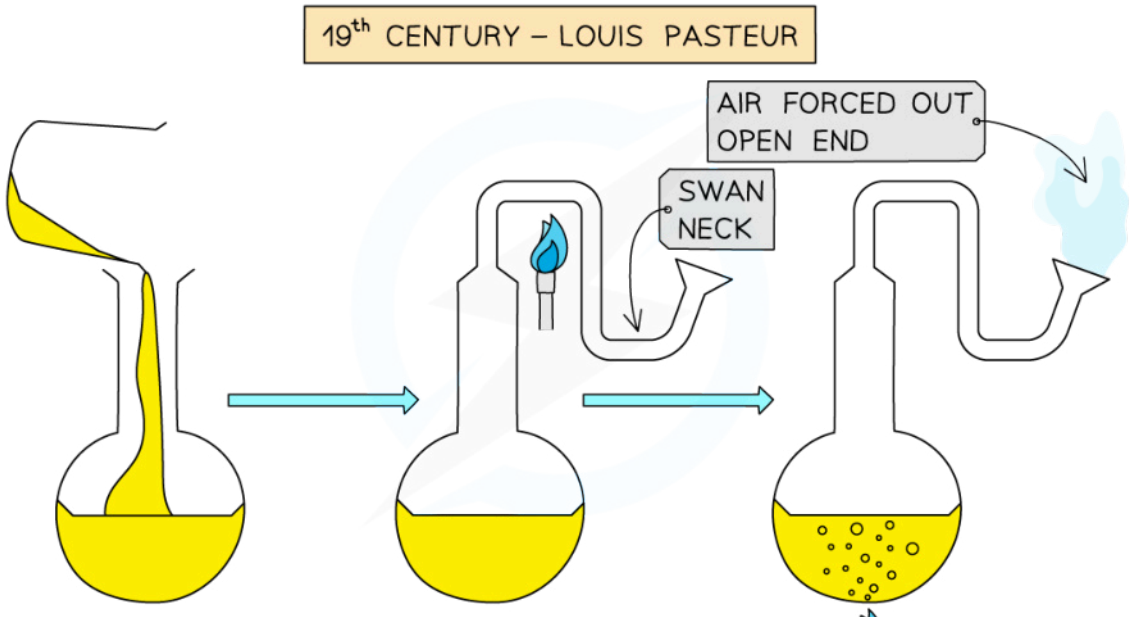

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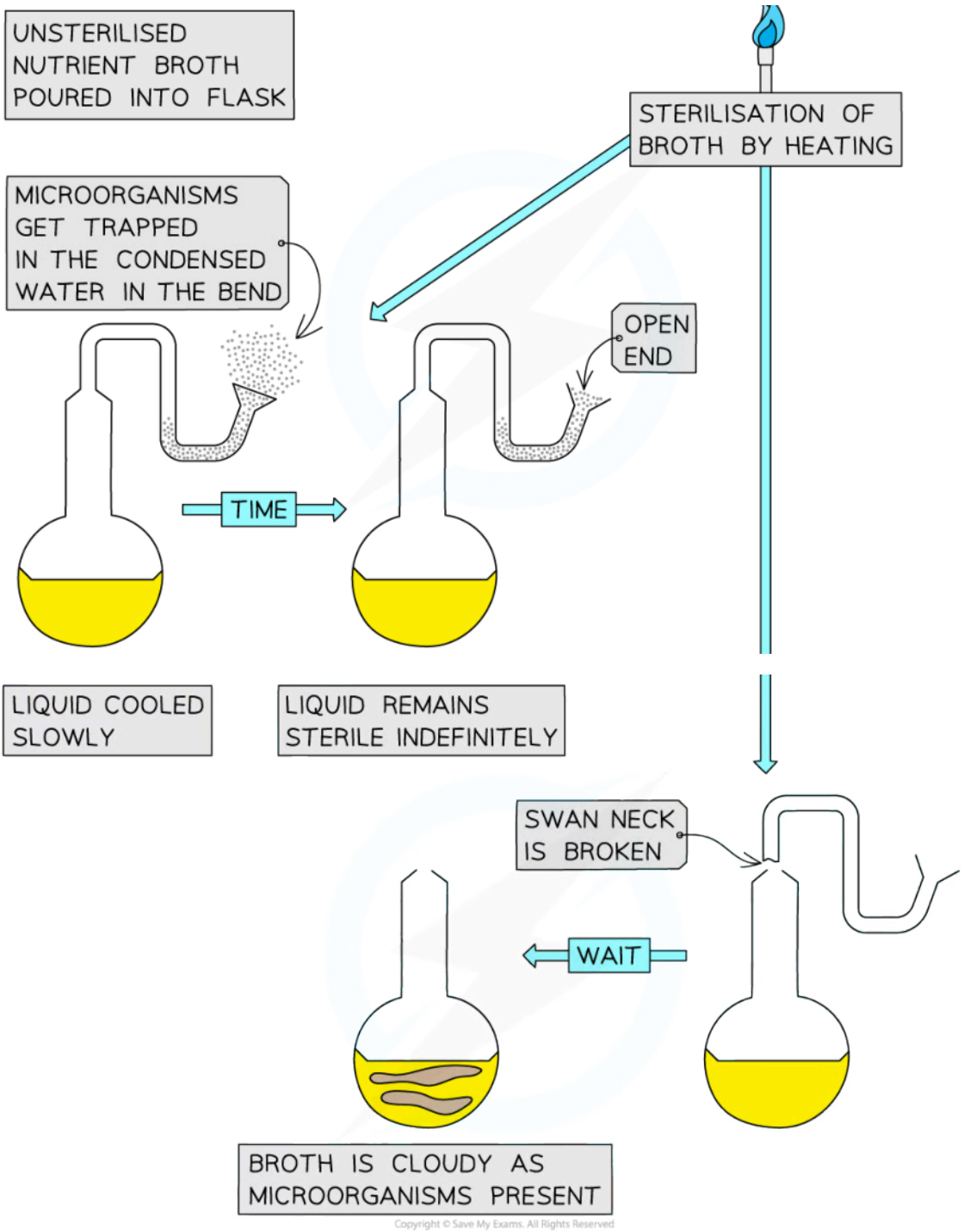

Experiments disproving spontaneous generation

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Pasteur's Experiments

Louis Pasteur's experiments

- Louis Pasteur's experiments were designed to verify the principle that cells can only come from pre-existing cells
- To demonstrate this Pasteur used swan neck flasks (flasks with S-shaped necks) which **trapped the microorganisms in the bend of the neck**
- Pasteur added **nutrient broth** to the flasks then boiled them to **sterilise**
- With some of the flasks, Pasteur broke off the necks (leaving no bend)
- After a long period of time, Pasteur observed that the broth in the flasks with the **snapped necks** had gone **cloudy** whereas the broth in the **swan neck** flasks remained **clear**
- Thus Pasteur had shown that the swan necks prevented microorganisms in the air from entering the broth and that **no organisms appeared spontaneously**


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The First Cells

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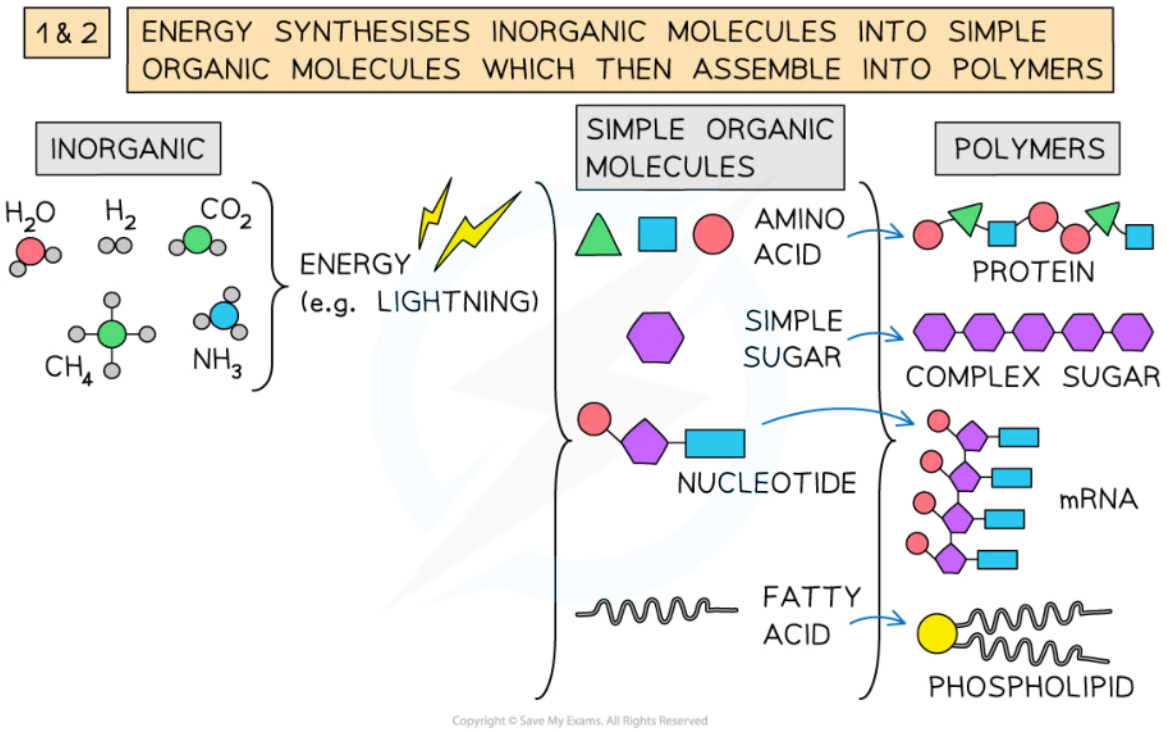
- The **Oparin-Haldine hypothesis** is that, to create the original **first** cells from non-living material, the following four stages occurred:

1. **Simple organic compounds** needed to be synthesised from **inorganic molecules** (this was demonstrated by Stanley **Miller** and Harold **Urey**)
2. Then **assembled** into **polymers**
3. Some of these polymers (it is thought to be RNA) developed the ability to **self-replicate** (which enables inheritance)
4. Formation of **membranes** (by lipids) that surrounded the polymers creating packages with internal chemistry different from the surroundings



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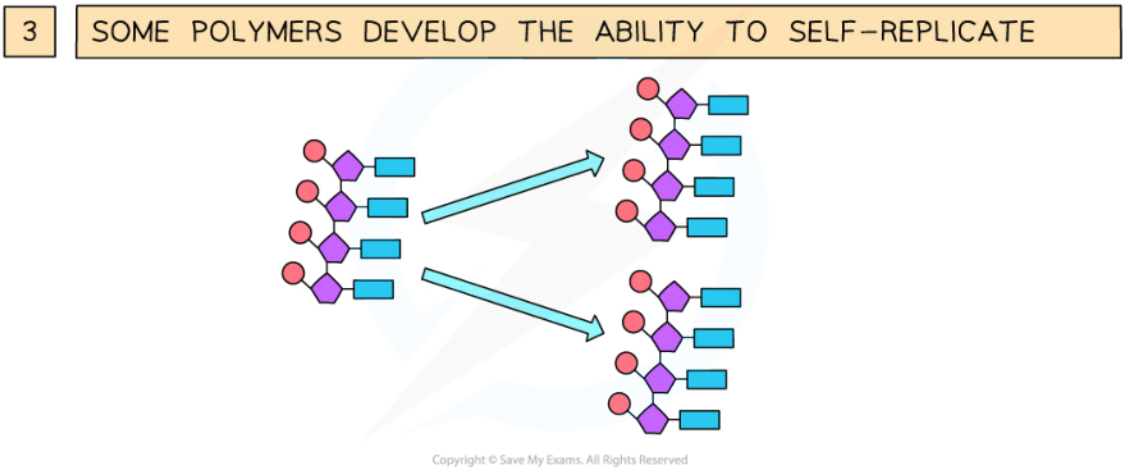

The key stages involved in life arising from non-living materials

Miller-Urey experiment

- Miller and Urey recreated the conditions thought to have existed on Earth prior to life, using a specific piece of apparatus
- The apparatus allowed them to:
  - Boil water to produce **steam** reflecting the early primordial soup **evaporating** in the **high temperatures** that existed on Earth
  - Mix the steam with a mixture of **gases** (including methane, hydrogen and ammonia) that recreated the **atmosphere**

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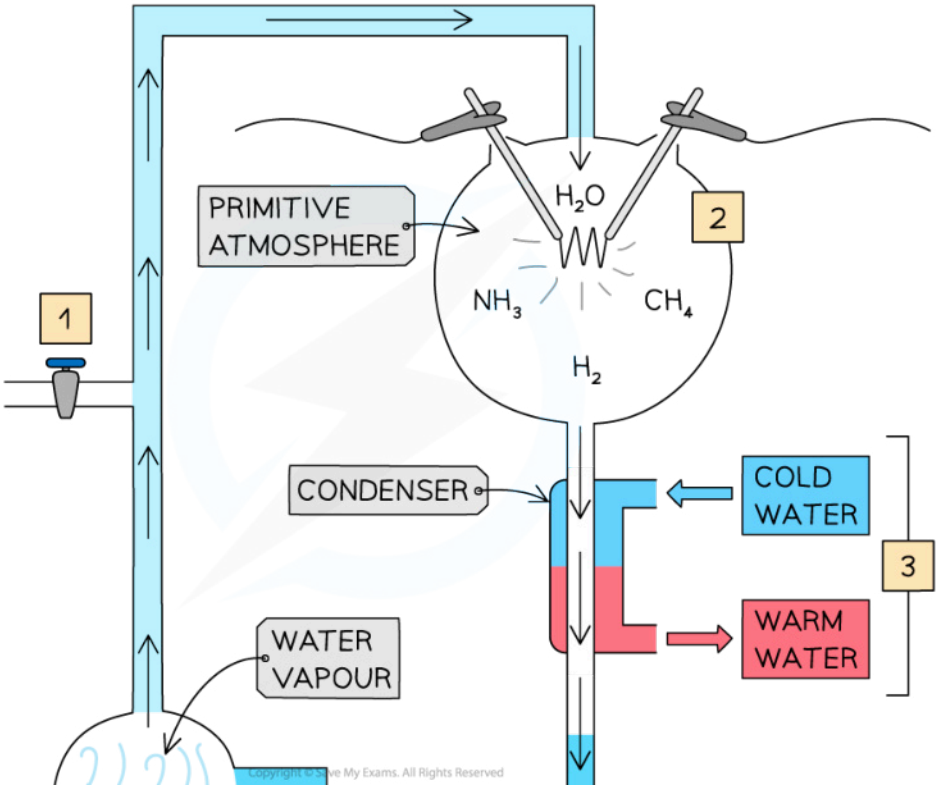
- Add electrical discharges to the gases to stimulate lightning (one of the sources of energy available at the time)
- Cool the mixture (representing the condensation of water in the atmosphere)

- After a week Miller and Urey analysed the condensed mixture and found **traces of simple organic molecules** including amino acids



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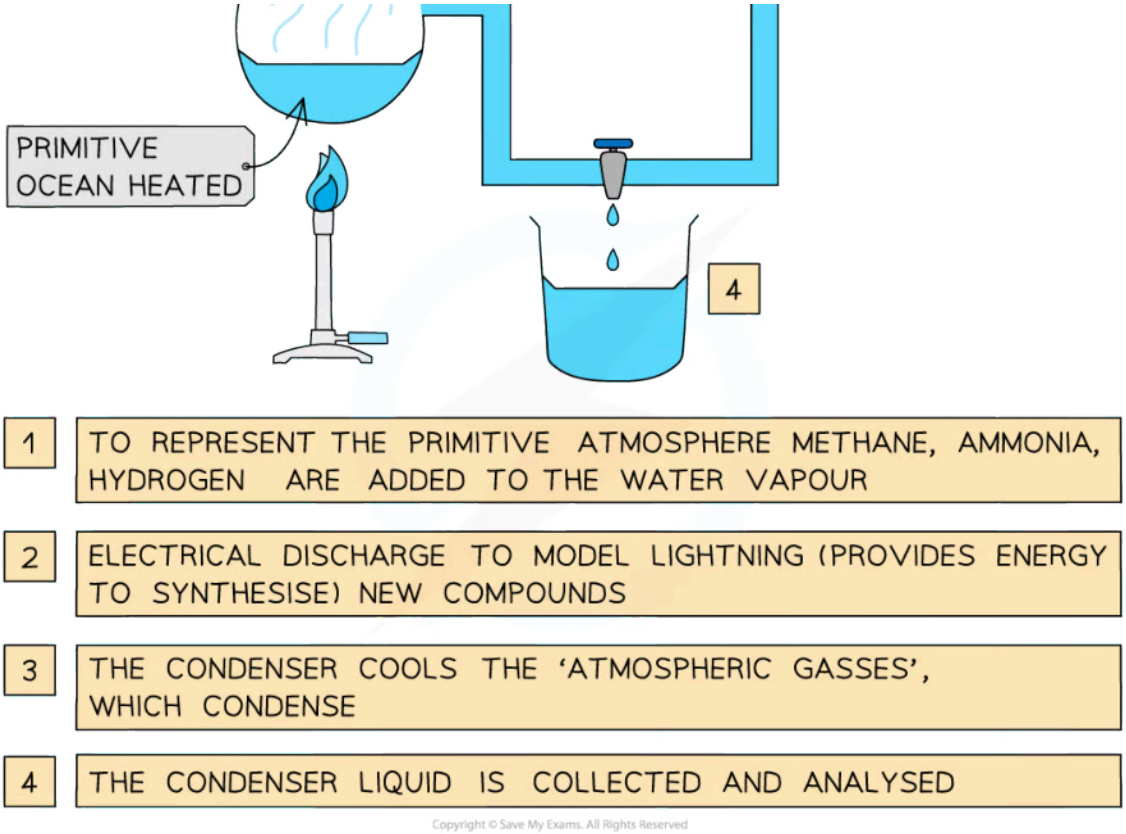

The apparatus used by Miller and Urey

Examiner Tip

It is important to be able to explain how the experiments that Pasteur and Miller & Urey performed demonstrated the origin of cells.

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1.2.2 Endosymbiotic Theory


Your notes

Endosymbiotic Theory

Endosymbiosis

- Endosymbiosis is where one organism lives within another
- If the relationship is **beneficial** to both organisms the engulfed organism is not digested
- For endosymbiosis to occur one organism must have **engulfed** the other by the process of endocytosis

Endosymbiotic theory

- The **endosymbiotic theory** is used to explain the **origin** of **eukaryotic cells**. The evidence provided for this theory comes from the structure of the **mitochondria** and **chloroplasts**
- Scientists have suggested that ancestral prokaryote cells evolved into ancestral heterotrophic and autotrophic cells through the following steps:
- **Heterotrophic** cells:
  - To overcome a small SA:V ratio ancestral prokaryote cells developed folds in their membrane. From these infoldings organelles such as the nucleus and rough endoplasmic reticulum formed
  - A **larger anaerobically respiring** prokaryote engulfed a **smaller aerobically** respiring prokaryote (which is **not digested**)
    - This gave the larger prokaryote a **competitive advantage** as it had a ready supply of ATP and gradually the cell evolved into the **heterotrophic eukaryotes** with **mitochondria** that are present today

- **Autotrophic** cells:
  - At some stage in their evolution, the heterotrophic eukaryotic cell engulfed a **smaller photosynthetic** prokaryote. This cell provided a competitive advantage as it supplied the heterotropic cell with an **alternative source of energy**, **carbohydrates**
  - Over time the photosynthetic prokaryote evolved into **chloroplasts** and the heterotrophic cells into **autotrophic eukaryotic** cells

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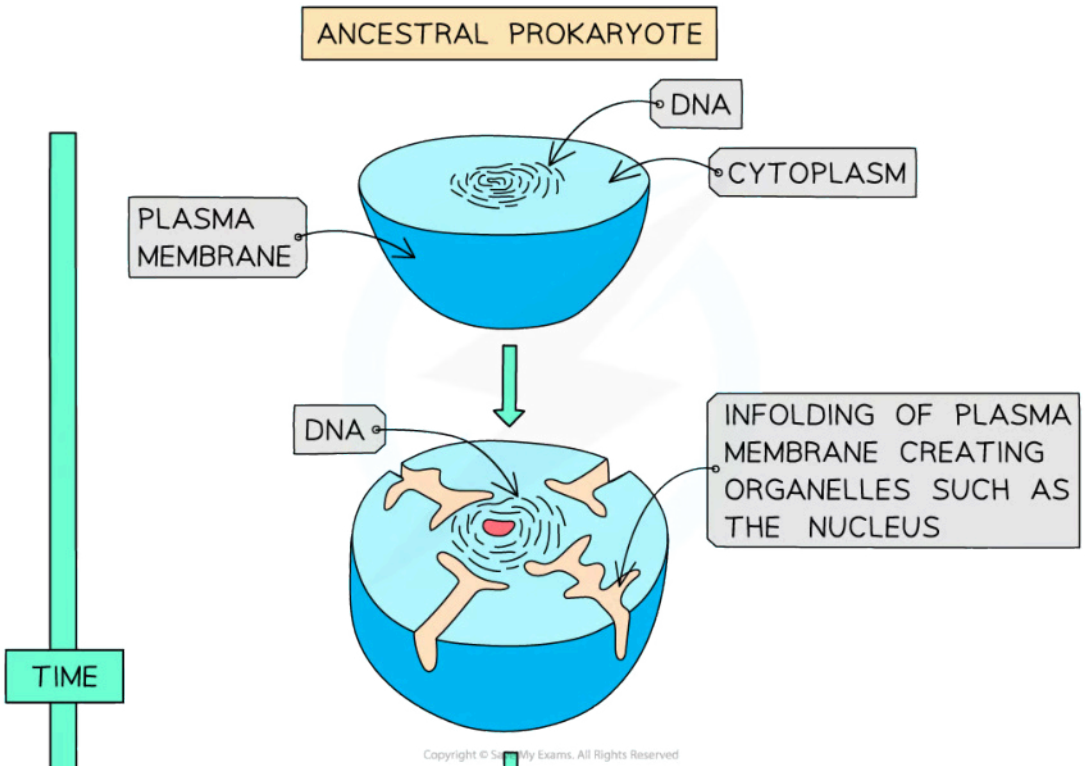

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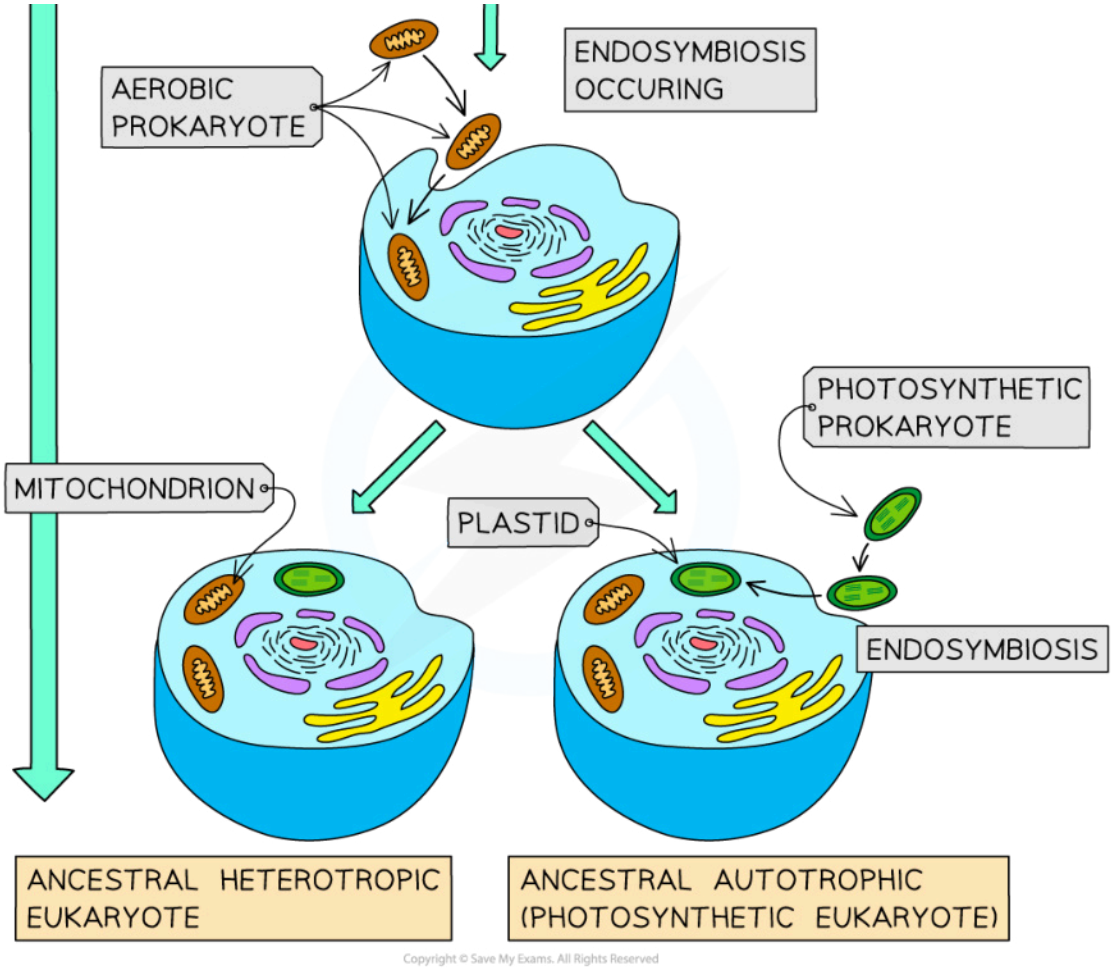

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The endosymbiotic theory – an explanation for the evolution of eukaryotic cells

Evidence to support the endosymbiotic theory

- The evidence to support the endosymbiotic theory arises from the features that the **mitochondria** and **chloroplasts** have in common with **prokaryotes**:
  - Both reproduce by **binary fission**
  - Both contain their **own circular, non-membrane bound DNA**
  - They both **transcribe mRNA** from their DNA
  - They both have **70S ribosomes** to synthesise their own proteins
  - They both have **double membranes**

Examiner Tip

Learn how the structure of the mitochondria and chloroplast support the endosymbiotic theory.

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1.2.3 Prokaryotic Cell Structure


Your notes

Prokaryotic Cell Structure

- The cell structure of organisms determines whether they are **prokaryotic** or **eukaryotic**
- Prokaryotes have the **simplest cell structure**, being the first organisms to evolve on Earth and have been classified into two **domains**:
  - **Bacteria** or Eubacteria - 'true' bacteria, includes commonly known bacteria such as *E.coli* and *Helicobacter*
  - **Archaebacteria** or Archaea - typically found in extreme environments such as high temperatures and salt concentrations and include methanogens (organisms that exist in anaerobic conditions and produce methane gas)
- Prokaryotic cells are **small**, ranging from 0.1μm to 5.0μm
- Prokaryotes have cells that **lack a nucleus** (the greek roots of prokaryote are 'pro' = before and 'karuon' = nut or kernel, relating to 'before the nucleus')

Cell structure

- The cytoplasm of prokaryotic cells is **not divided** into **compartments**, it **lacks membrane-bound organelles** (except for **ribosomes**)
  - Prokaryotic **ribosomes** are structurally smaller (70 S) in comparison to those found in eukaryotic cells (80 S)
- Prokaryotes do not have a nucleus, but they **do have genetic material**. This is generally in the form of a **single circular DNA molecule** (**not associated with proteins**) located in the **nucleoid** and in smaller loops called **plasmids**
- Prokaryotes have a **cell wall** containing **murein/peptidoglycan** (a glycoprotein)
  - The cell wall acts as **protection**, maintains the **shape** of the cell and prevents the cell from **bursting**
- In addition, many prokaryotic cells have a few other structures that differentiate the species from others and act as a selective advantage, examples of these are:
  - Plasmids
  - Capsules
  - Flagellum
  - Pili
- Plasmids are small **loops of DNA** that are separate from the main circular DNA molecule
  - Plasmids contain **genes** that can be passed between prokaryotes (e.g. genes for **antibiotic resistance**)
- Some prokaryotes (e.g. bacteria) are surrounded by a final outer layer known as a **capsule**. This is sometimes called the **slime** capsule
  - It helps to **protect bacteria** from drying out and from attack by cells of the immune system of the host organism

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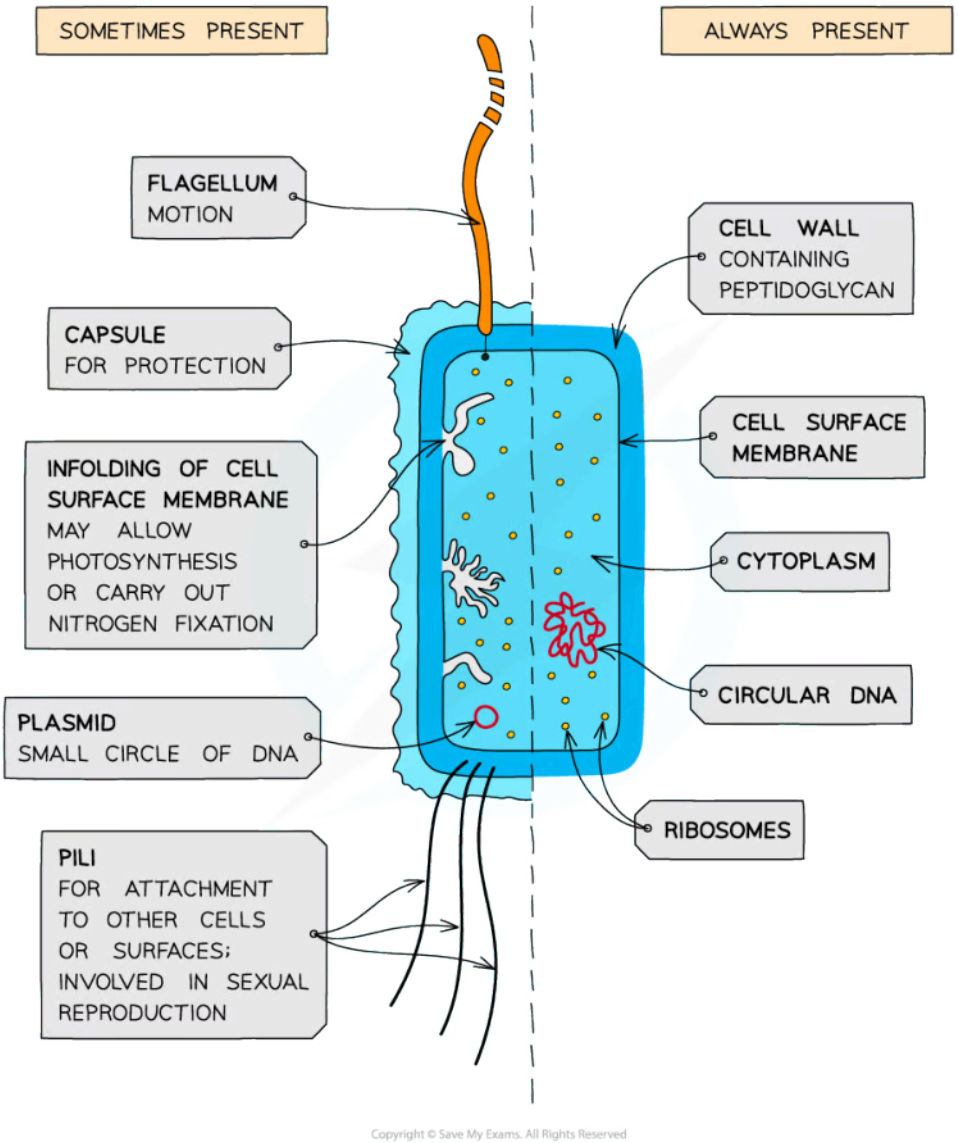
- Flagellum (plural = flagella) are **long, tail-like structures** that **rotate**, enabling the prokaryote to **move** (a bit like a propeller)
  - Some prokaryotes have **more than one**
- Pili are shorter and thinner structures than flagella
  - They assist with movement, avoidance of attack by white blood cells, **conjugation** (the sexual mode for bacteria) and are commonly used to allow bacteria to **adhere to cell surfaces**



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Prokaryotic cells are often described as being 'simpler' than eukaryotic cells, and they are believed to have emerged as the first living organisms on Earth

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Examiner Tip

Make sure you learn the typical **structures** and **organelles** found in prokaryotic cells, as well as their **functions**.

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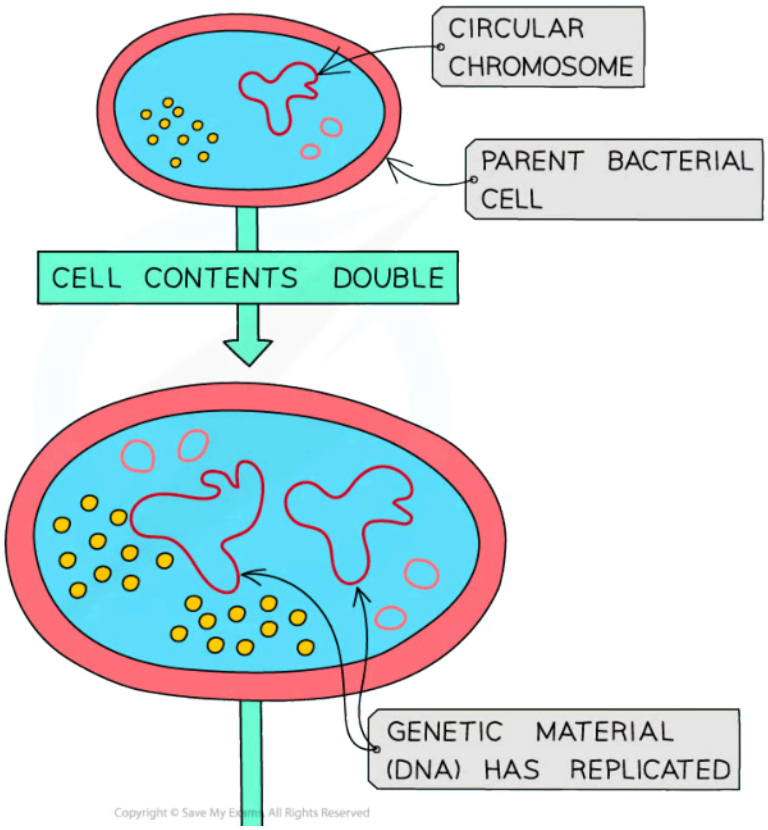
Binary Fission

Your notes

Prokaryotes divide by binary fission

- Binary fission is a type of **asexual** reproduction where the parent cell splits into two daughter cells, roughly equal in size
- During the binary fission process in prokaryotes:
  - The single circular chromosome **replicates** when signalled
  - The cell **elongates** resulting in the chromosome copies separating
  - A **cross wall** (septum) forms in the middle of the cell dividing the cytoplasm (cytokinesis)
  - **Two daughter cells** are formed
- As each daughter cell contains an exact copy of the parental circular chromosome they are **clones**



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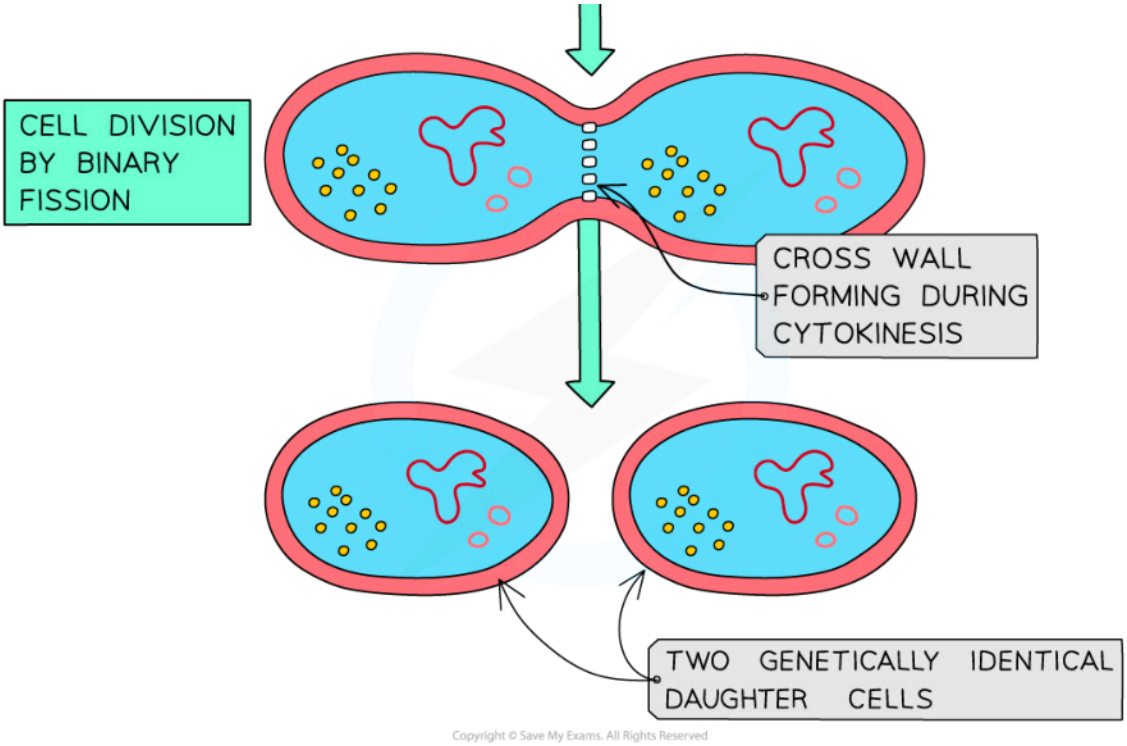

Prokaryotes divide by binary fission

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1.2.4 Eukaryotic Cell Structure


Your notes

Eukaryotic Cell Structure

Compartmentalized cell structure

- Eukaryotic cells have a more **complex ultrastructure** than prokaryotic cells
- The cytoplasm of eukaryotic cells is divided up into **membrane-bound** compartments called **organelles**. These compartments are either bound by a **single** or **double membrane**
- The **compartmentalization** of the cell is **advantageous** as it allows:
  - Enzymes and substrates to be localised and therefore available at higher concentrations
  - Damaging substances to be kept separated, e.g. digestive enzymes are stored in lysosomes so they do not digest the cell
  - Optimal conditions to be maintained for certain processes e.g. optimal pH for digestive enzymes
  - The numbers and location of organelles to be altered depending on requirements of the cell
- **Eukaryotic** cells have a key compartment called the **nucleus**

Animal and plant cells

- Animal and plant cells are both types of eukaryotic cells that share key structures such as:
  - Membrane-bound organelles, including a nucleus
  - Larger ribosomes (80S)
- However, there are key differences:
  - Animal cells contain **centrioles** and **microvilli**
  - Plant cells have a cellulose **cell wall,** large permanent **vacuoles** and **chloroplast**

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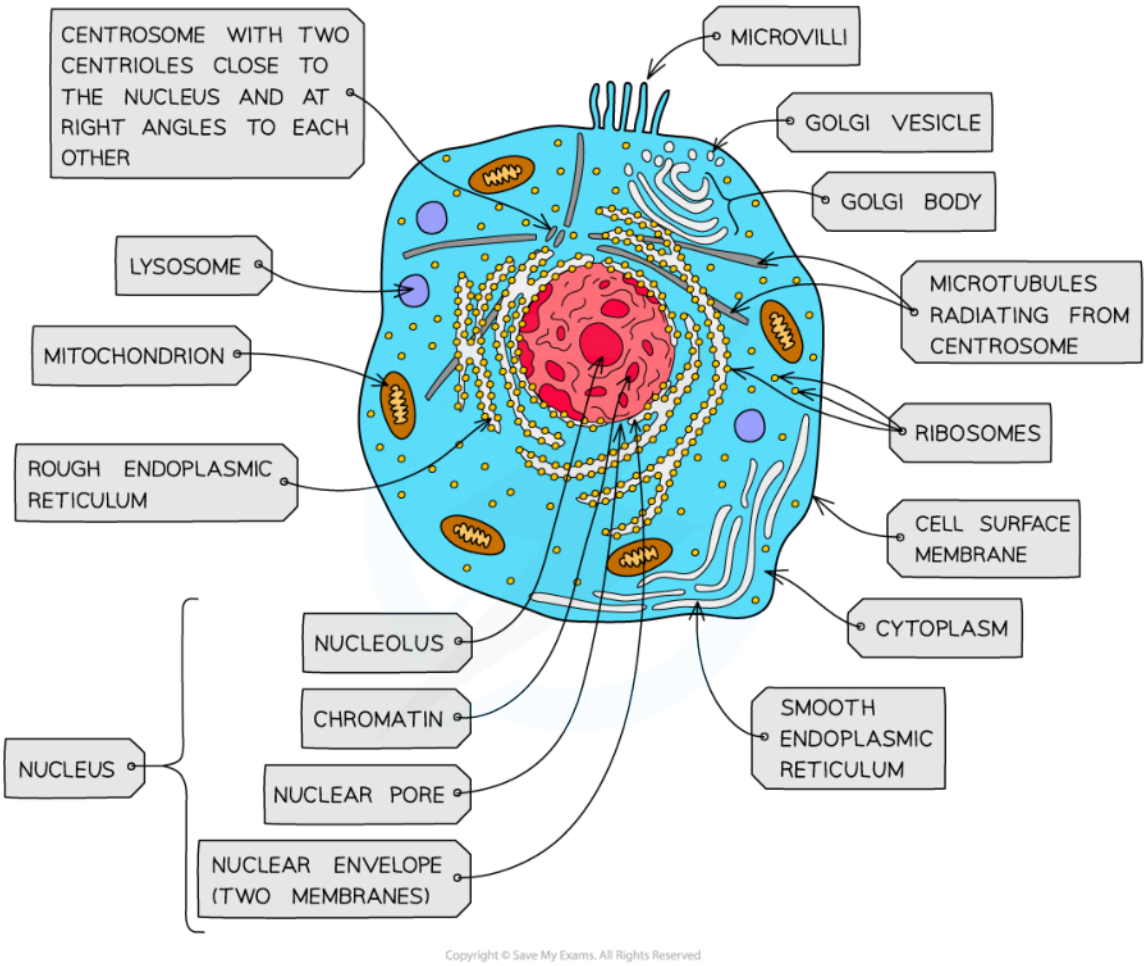

The ultrastructure of an animal cell shows a densely packed cell – the ER and RER and ribosomes form extensive networks throughout the cell in reality

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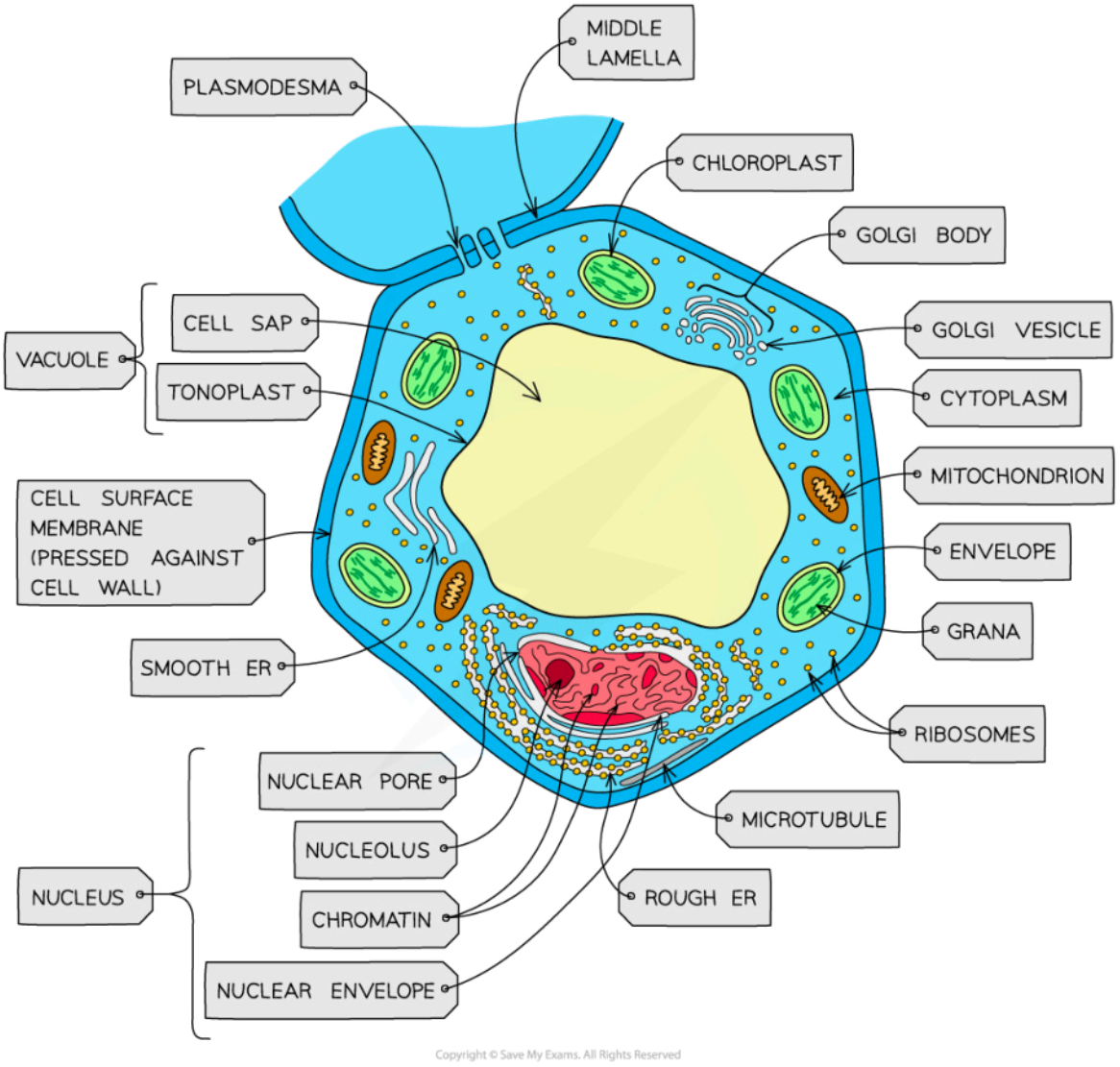

Plant cells have a larger, more regular structure in comparison to animal cells

- In complex **multicellular** organisms, **eukaryotic** cells become **specialised** for **specific functions**
- These specialised eukaryotic cells have **specific adaptations** to help them carry out their functions
- For example, the **structure of a cell** is adapted to help it carry out its **function** (this is why specialised eukaryotic cells can look extremely **different** from each other)
- Structural adaptations include:
  - The **shape** of the cell
  - The **organelles** the cell contains (or doesn't contain)

- For example:

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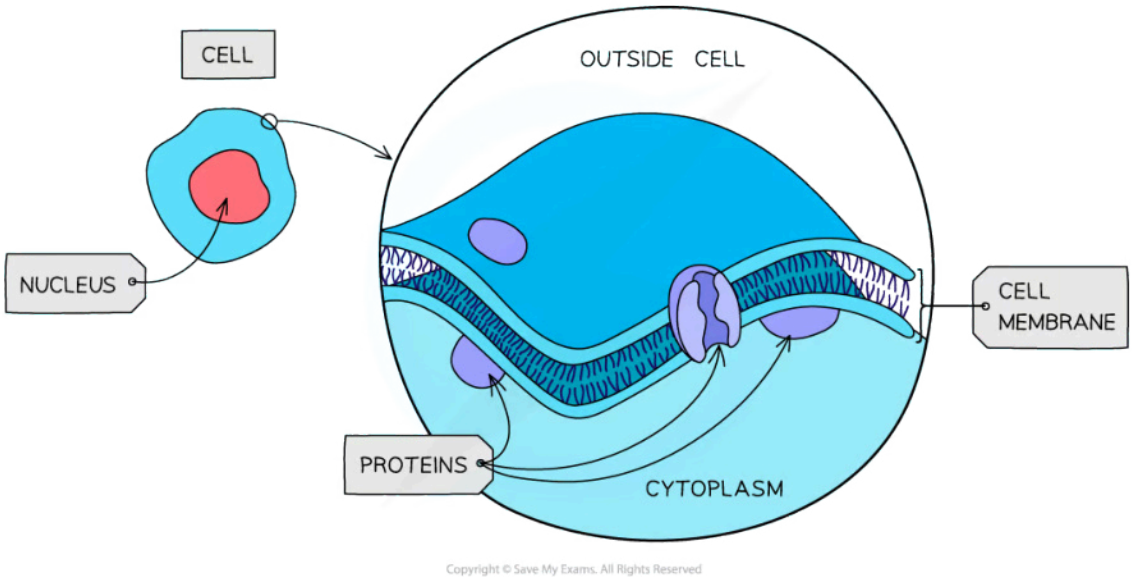
- Red blood cells are **biconcave** and **do not contain a nucleus.** This makes **more space** inside the cell so that they can transport as much **oxygen** as possible
- Cells that make large amounts of **proteins** will be adapted for this function by containing **many ribosomes** (the organelle responsible for protein production)

Your notes

Organelles

Plasma membrane



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The structure of the cell surface membrane – although the structure looks static the phospholipids and proteins forming the bilayer are constantly in motion

- **All cells** are surrounded by a plasma membrane which controls the exchange of materials between the internal cell environment and the external environment
  - The membrane is described as being 'partially permeable'
- The plasma membrane is formed from a **phospholipid bilayer** of phospholipids spanning a diameter of around 10 nm

Nucleus

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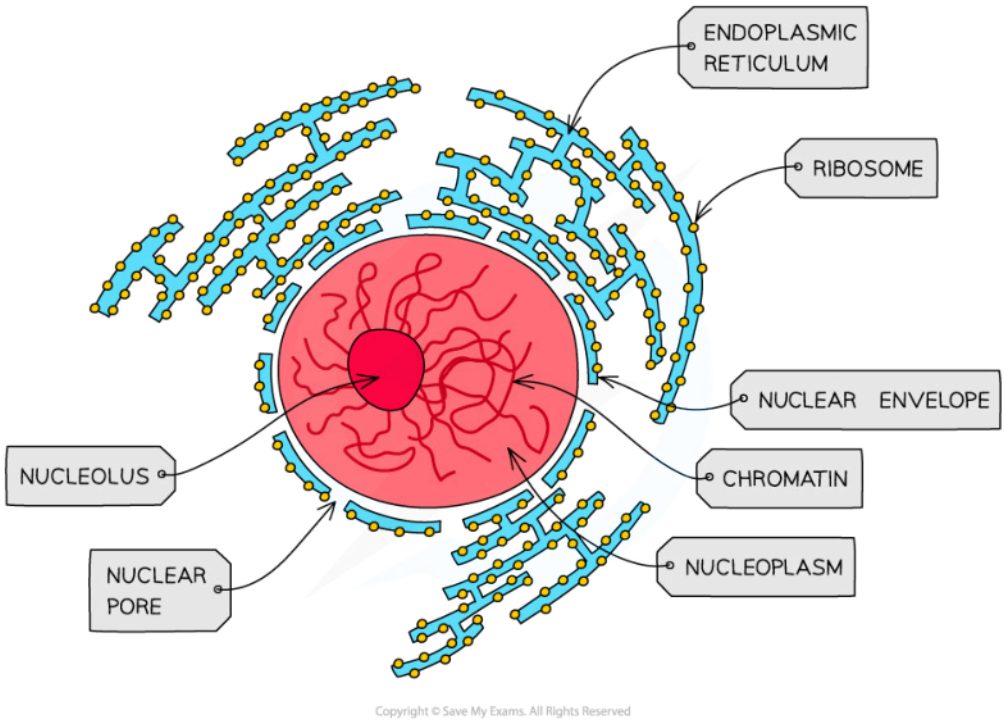

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The nucleus of a cell contains chromatin (a complex of DNA and histone proteins) which is the genetic material of the cell

- Present **in all eukaryotic cells** (except red blood cells), the nucleus is relatively large and separated from the cytoplasm by a double membrane (the **nuclear envelope)** which has many pores
- Nuclear pores are important channels for allowing mRNA and ribosomes to travel out of the nucleus, as well as allowing enzymes (eg. DNA polymerases) and signalling molecules to travel in
- The nucleus contains **chromatin** (the material from which chromosomes are made)
  - Chromosomes are made of sections of **linear DNA** tightly wound around proteins called **histones**
- Usually, at least one or more darkly stained regions can be observed – these regions are individually termed '**nucleolus**' (plural: nucleoli) and are the sites of **ribosome production**

Rough endoplasmic reticulum

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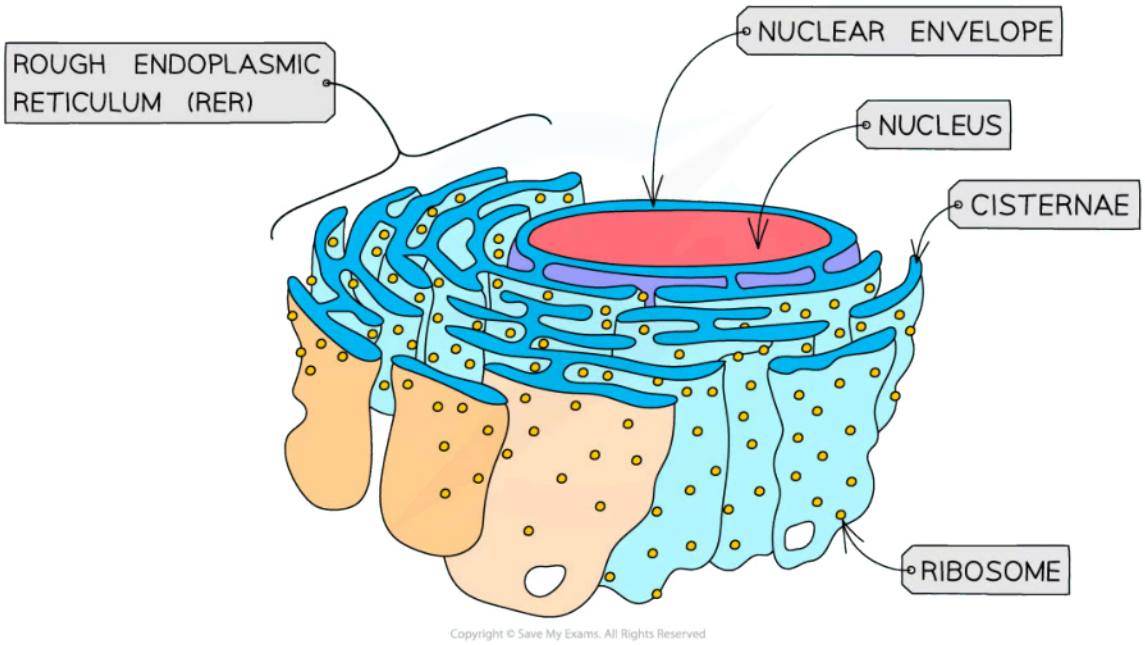

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The rough endoplasmic reticulum (RER) – the attached ribosomes enable this structure to be identified in electron micrographs

- Found in plant and animal cells
- Surface covered in **ribosomes** (80S)
- Formed from continuous folds of membrane continuous with the **nuclear envelope**. These flattened membrane sacs are called **cisternae**
- Processes proteins made by the **ribosomes**
- The **proteins** synthesised by the ribosomes, move to the cisternae, bud off into vesicles that carry the proteins to Golgi apparatus before being **secreted out** of the cell

Ribosomes

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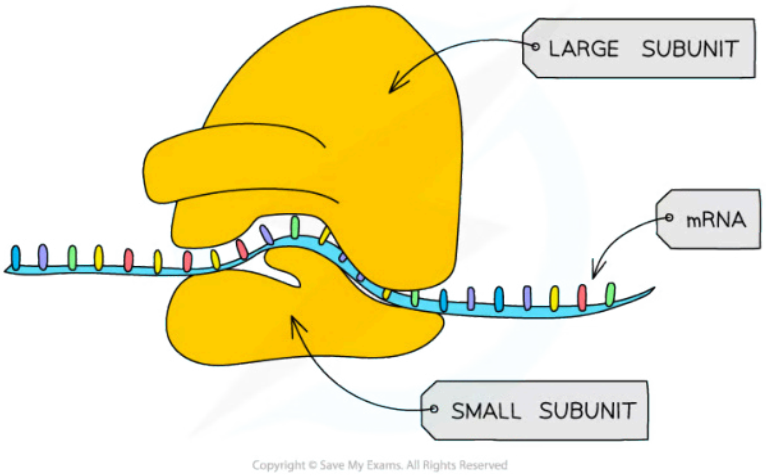

Your notes

Ribosomes are formed in the nucleolus and are composed of almost equal amounts of RNA and protein

- Found freely in the cytoplasm of **all cells** or as part of the **rough endoplasmic reticulum** in eukaryotic cells
- Each ribosome is a complex of **ribosomal RNA (rRNA)** and proteins. They are constructed in the nucleolus (a region in the nucleus)
- 80S ribosomes (composed of 60S and 40S subunits) are found in eukaryotic cells
- Site of translation (**protein synthesis)**

Mitochondrion

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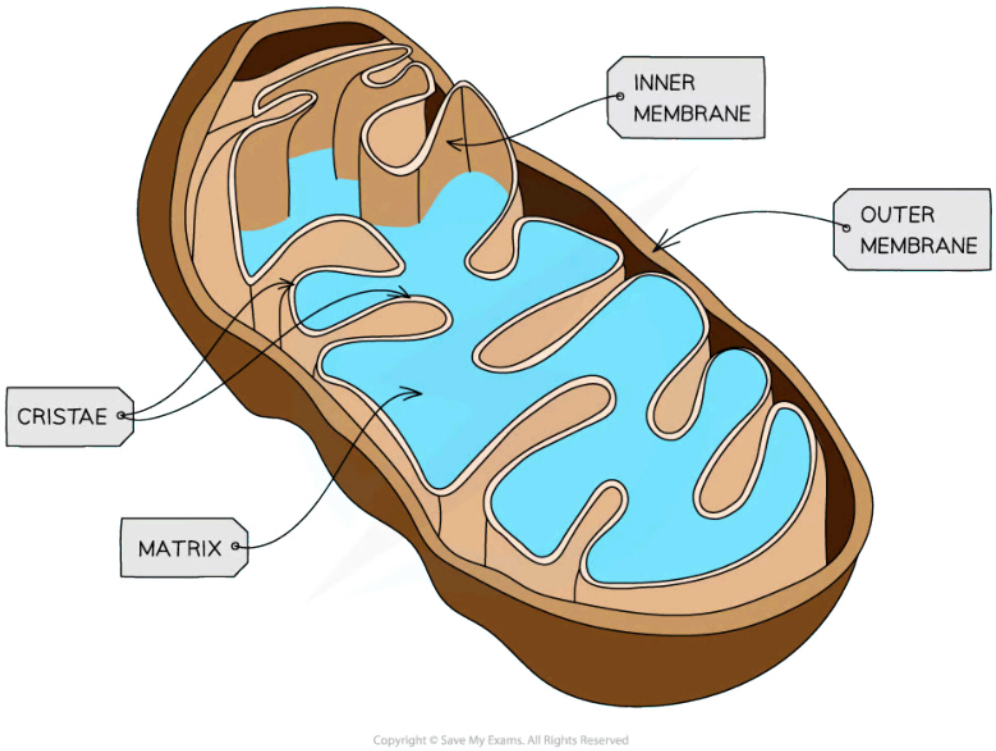

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A single mitochondrion is shown – the inner membrane has protein complexes vital for the later stages of aerobic respiration embedded within it

- The site of aerobic respiration within **all eukaryotic cells**, mitochondria are just visible with a light microscope
- Surrounded by **double-membrane** with the inner membrane folded to form **cristae**
- The matrix formed by the cristae contains enzymes needed for **aerobic respiration,** producing **ATP**
- Small circular pieces of **DNA** (mitochondrial DNA) and ribosomes are also found in the matrix (needed for replication)

Golgi apparatus

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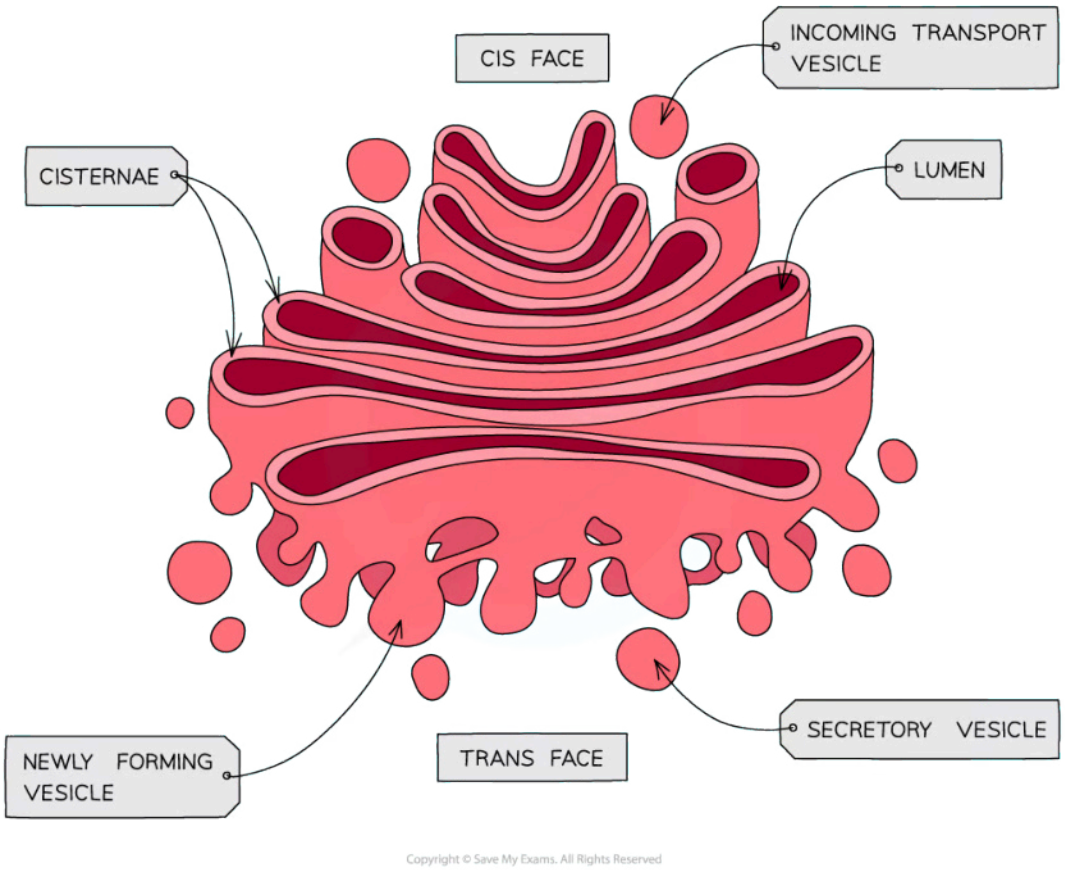

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The structure of the Golgi apparatus

- Found in plant and animal cells
- Flattened sacs of membrane called cisternae (like the rough endoplasmic reticulum)
- **Modifies** proteins and lipids before **packaging** them into **Golgi vesicles**
  - The vesicles then **transport the proteins and lipids** to their required destination
  - Proteins that go through the Golgi apparatus are usually exported (e.g. hormones such as insulin), put into lysosomes (such as hydrolytic enzymes) or delivered to membrane-bound organelles

Vesicles

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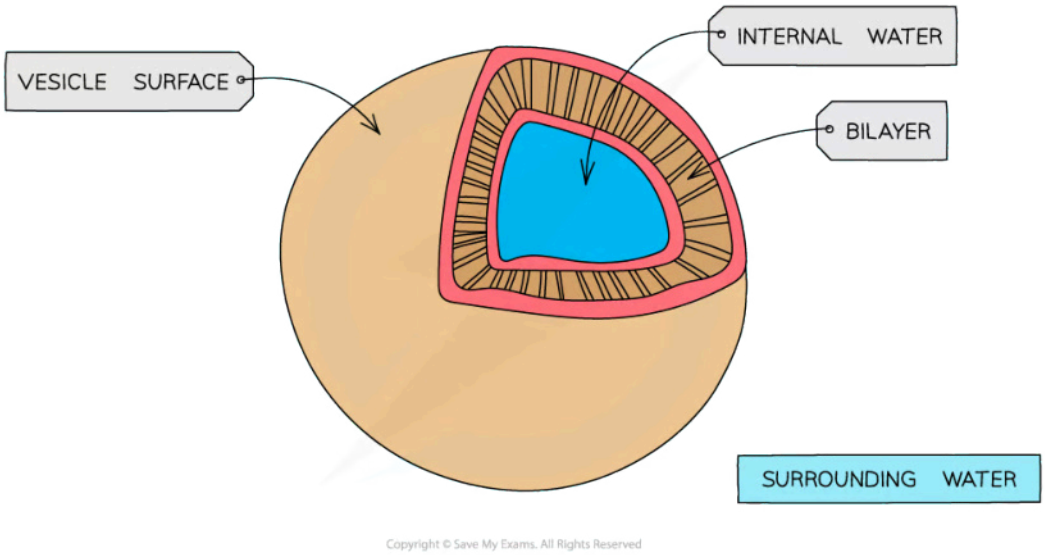
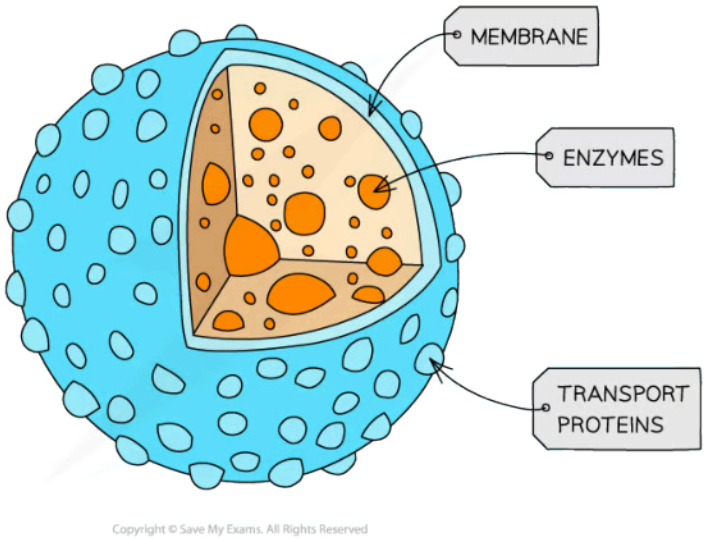


The structure of the vesicle

- Found in plant and animal cells
- A membrane-bound sac for transport and storage

Lysosome



The structure of the lysosome

- Specialist forms of vesicles which contain **hydrolytic enzymes** (enzymes that break biological molecules down)

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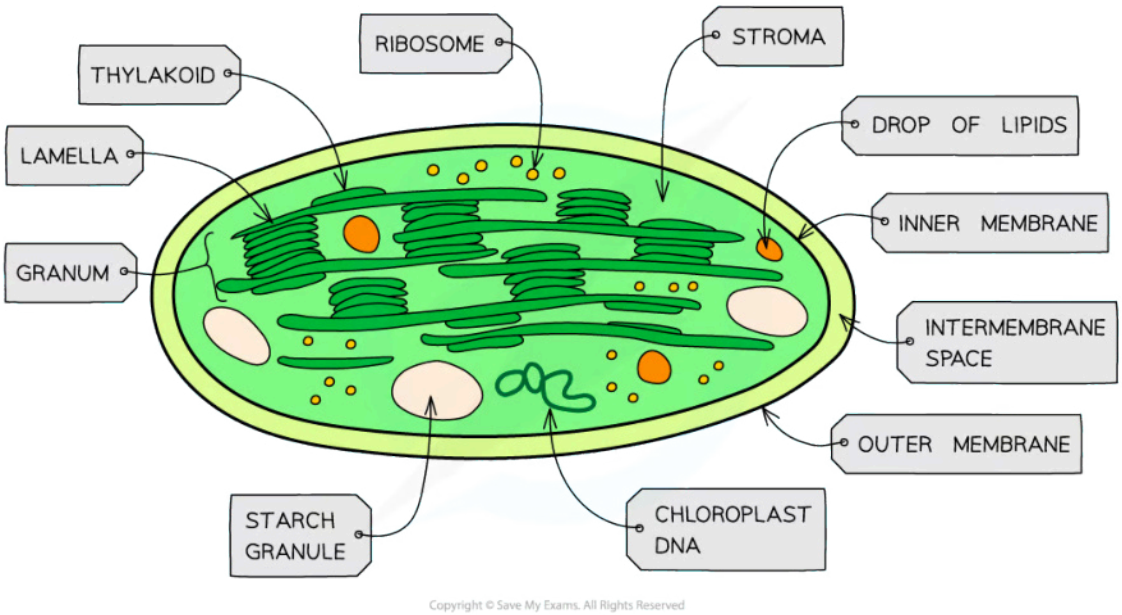
- Break down waste materials such as worn-out organelles
- Used extensively by cells of the **immune system** and in **apoptosis** (programmed cell death)

Your notes

Chloroplasts



Chloroplasts are found in the green parts of a plant – the green colour a result of the photosynthetic pigment chlorophyll

- Found in **plant cells**
- Larger than mitochondria
- Surrounded by a **double-membrane**
- Membrane-bound compartments called **thylakoids** containing chlorophyll stack to form structures called **grana**
- Grana are joined together by **lamellae** (thin and flat thylakoid membranes)
- Chloroplasts are the site of **photosynthesis**:
  - The **light-dependent stage** takes place in the thylakoids
  - The **light-independent stage** (Calvin Cycle) takes place in the **stroma**
- Also contain small circular pieces of **DNA** and ribosomes used to synthesise proteins needed in chloroplast replication and photosynthesis

Large permanent vacuoles

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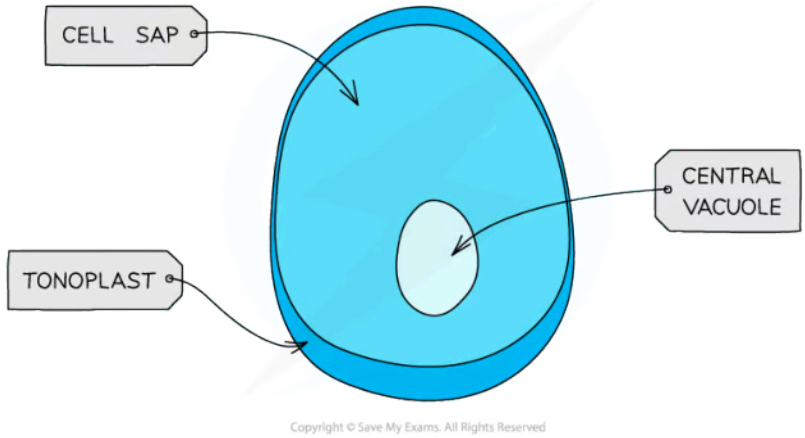
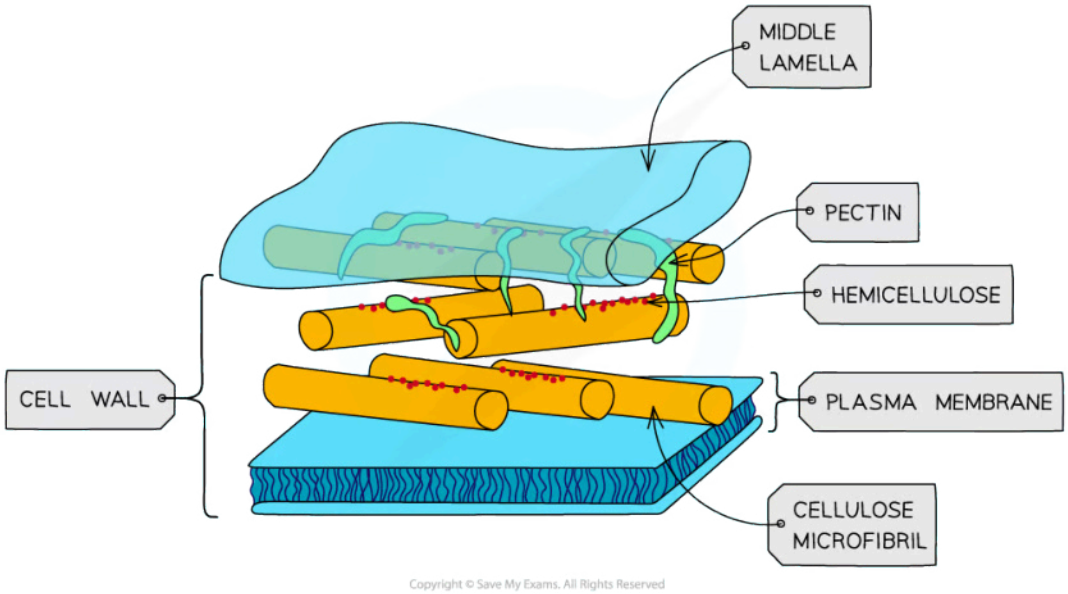
Your notes



The structure of the vacuole

- A sac in **plant cells** surrounded by the **tonoplast**, selectively permeable membrane
- Vacuoles in animal cells are not permanent and small

Cell wall - an extra-cellular component (not an organelle)



The cell wall is freely permeable to most substances (unlike the plasma membrane)

- Found in plant cells but **not in animal cells**
- Cell walls are formed outside of the cell membrane and offer **structural support** to cell
- Structural support is provided by the polysaccharide cellulose in plants, and peptidoglycan in most bacterial cells

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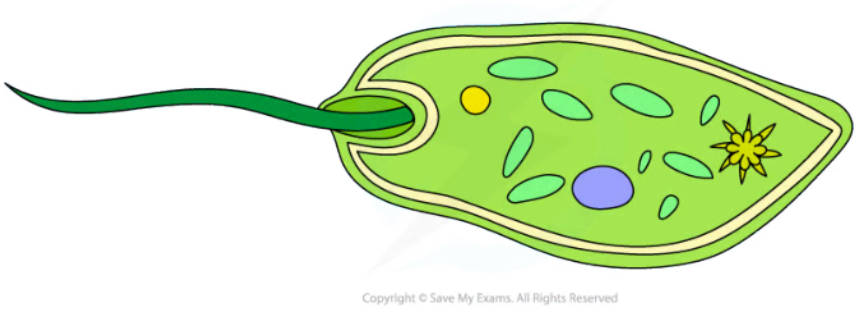
- Narrow threads of cytoplasm (surrounded by a cell membrane) called **plasmodesmata** connect the cytoplasm of neighbouring plant cells

Your notes

Additional organelles

- The below organelles can be found in other specialised cells in eukaryotes

Flagella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The structure of the flagella

- Found in specialised cells
- Similar in structure to **cilia**, made of longer **microtubules**
- Contract to provide cell movement for example in **sperm cells**

Centrioles

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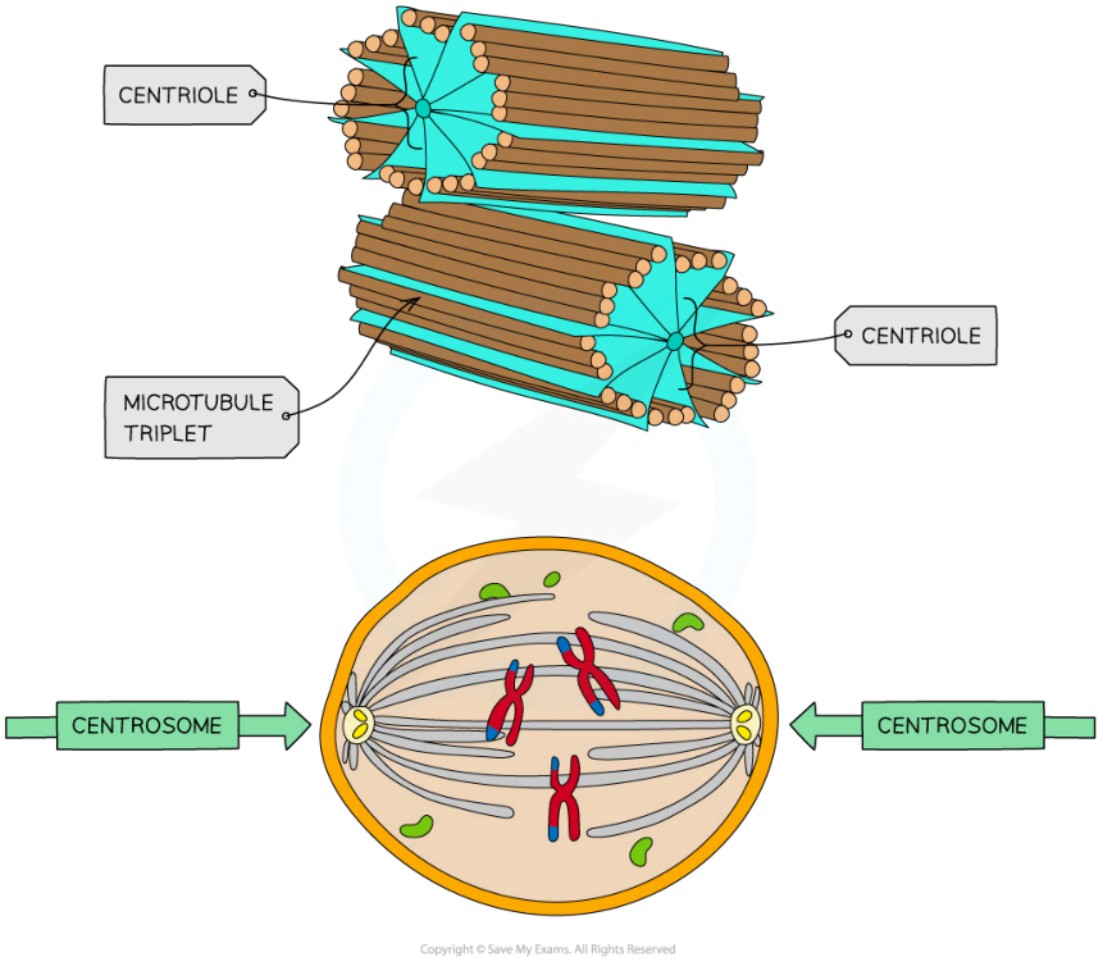
Your notes



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The structure of the centriole

- Hollow fibres made of **microtubules**
- Two centrioles at right angles to each other form a **centrosome**, which organises the **spindle fibres** during cell division
- **Not found** in **flowering plants** and **fungi**

Microtubules

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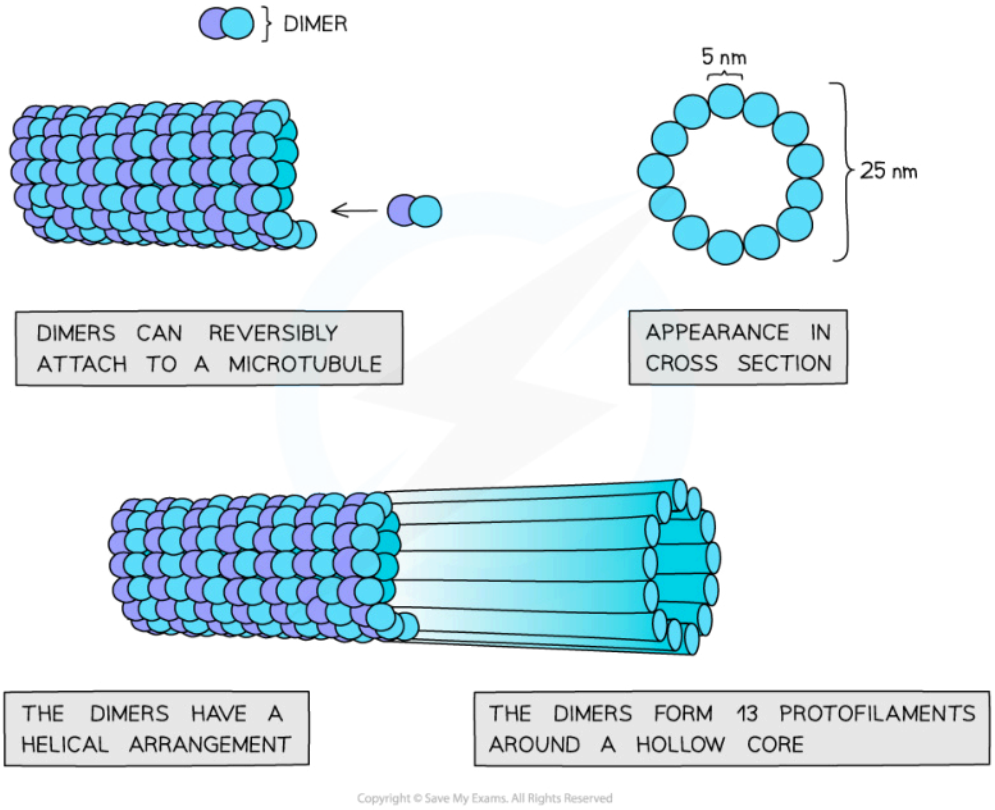
Your notes



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The structure of the microtubule

- Found in all eukaryotic cells
- Makes up the cytoskeleton of the cell about 25 nm in diameter
- Made of α and β tubulin combined to form dimers, the dimers are then joined into protofilaments
  - Thirteen protofilaments in a cylinder make a microtubule
- The cytoskeleton is used to provide support and movement of the cell

Microvilli

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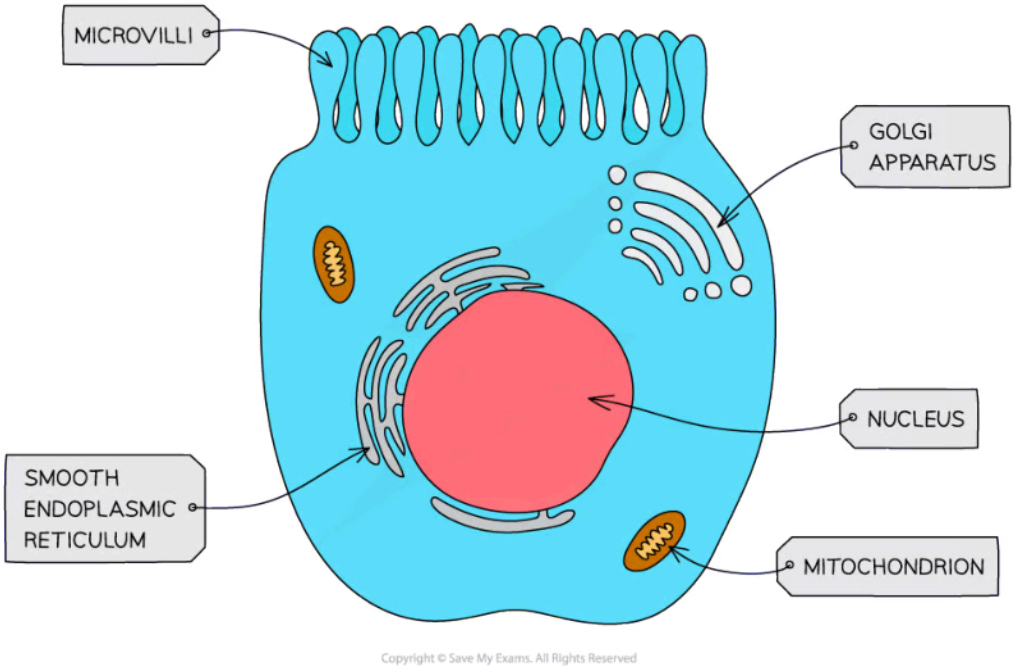
Your notes



The structure of the microvilli

- Found in specialised animal cells
- Cell membrane projections
- Used to **increase the surface area** of the cell surface membrane in order to increase the rate of exchange of substances

Cilia

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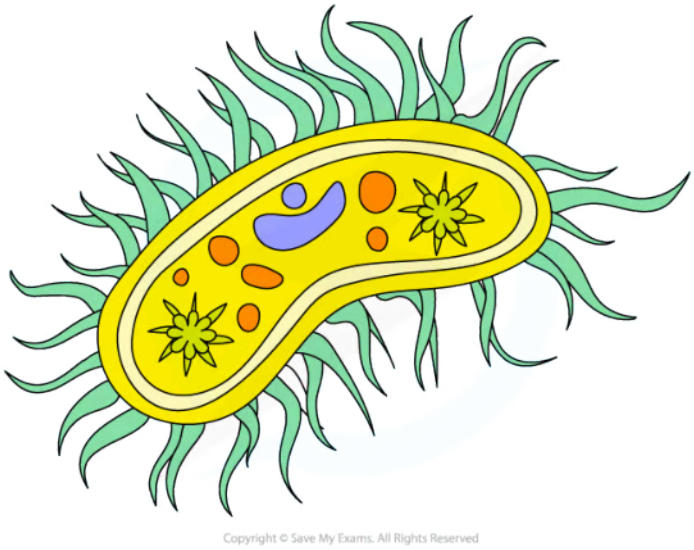
Your notes



The structure of the cilia

- Hair-like projections made from **microtubules**
- Allows the movement of substances over the cell surface

Examiner Tip

In the exam, you could be required to apply your knowledge of organelles to deduce the function of a specialised cell. To answer these questions, just think about what organelles you can see in large numbers, consider the function of that organelle and then think about where this function might need to happen a lot in an organism (e.g. if the cell's main function is to carry out photosynthesis it will need to contain many chloroplasts)!

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1.2.5 Exocrine Pancreatic & Palisade Mesophyll Cells

Your notes

Exocrine Pancreatic & Palisade Mesophyll Cells

Exocrine gland cells of the pancreas

- The pancreas contains two types of gland cells: endocrine and exocrine cells
- The **function** of the **exocrine gland cells** (acinar cells) is to **secrete digestive enzymes** into the pancreatic ducts. These enzymes then travel to the duodenum where digestion occurs
- To perform this function the exocrine gland cells have **organelles** that enable the enzymes (proteins) to be synthesised, processed for secretion, transported to the plasma membrane and released
- Thus the plasma membrane and the following organelles can be seen in electron micrographs of the exocrine gland cells:
  - **Nucleus** - where DNA is transcribed into mRNA (that contains the instructions for building the enzymes)
  - **Rough endoplasmic reticulum** - has ribosomes attached where the enzymes are synthesised
  - **Mitochondria** - provide the ATP required for all the metabolic processes
  - **Golgi apparatus** - where the enzymes (proteins) are processed and packaged ready for secretion
  - **Vesicles** - 'pinch off' the Golgi apparatus and contain the pancreatic digestive enzymes (e.g. pancreatic amylase) that will be released into the ducts (may appear dark in electron micrographs or at least with many dark specks within)
  - **Lysosomes** - contain hydrolytic enzymes that will digest the unwanted substances in the cell

Palisade mesophyll cell

- The palisade mesophyll cells are located in the leaves of plants and are structured to maximise the efficiency of the leaf's function - photosynthesis
- The palisade mesophyll cells are situated towards the **top** of the leaf and are column-like in shape increasing surface area to absorb light, carbon dioxide and water
- Along with the key organelles mentioned for the exocrine gland cell, the palisade mesophyll cell contains the following organelles:
  - **Chloroplasts** - the location of light absorption, it provides the energy for producing glucose and oxygen
  - **Permanent vacuole** - it is large and central pushing the chloroplast to the edge of the cell maximising absorption of light. It also helps maintain water balance

- The palisade mesophyll cell also contains the extra-cellular structure:
  - **Cell wall** - it is mainly made of **cellulose**, is **freely permeable** (allowing carbon dioxide and water to move through easily) and its **strength** gives **support** to the cell (prevents the cell from bursting)

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1.2.6 Comparison of Prokaryotic & Eukaryotic Cells

Your notes

Comparison of Prokaryotic & Eukaryotic Cells

- Animal and plant cells are types of **eukaryotic** cells, whereas bacteria are a type of **prokaryote**
- There are a number of important structural and physiological differences between prokaryotic and eukaryotic cells
  - These differences affect their metabolic processes and how they reproduce

Comparison of Prokaryotes & Eukaryotes Table

FEATURE	PROKARYOTES	EUKARYOTES
SIZE	0.5–5 μm DIAMETER	UP TO 100 μm DIAMETER
GENOME	DNA CIRCULAR WITH NO PROTEINS, IN THE CYTOPLASM	DNA IS ASSOCIATED WITH HISTONES (PROTEINS) FORMED INTO CHROMOSOMES
CELL DIVISION	OCCURS BY BINARY FISSION, NO SPINDLE INVOLVED	OCCURS BY MITOSIS OR MEIOSIS AND INVOLVES A SPINDLE TO SEPARATE CHROMOSOMES
RIBOSOMES	70S RIBOSOMES	80S RIBOSOMES
ORGANELLES	VERY FEW NO MEMBRANE-BOUND ORGANELLES.	NUMEROUS TYPES OF ORGANELLES MEMBRANE-BOUND SINGLE MEMBRANES: LYSOSOMES, GOLGI COMPLEX, VACUOLES DOUBLE MEMBRANES: NUCLEUS, MITOCHONDRIA, CHLOROPLAST NO MEMBRANE: RIBOSOMES, CENTRIOLES, MICROTUBULES
CELL WALL	MADE OF PEPTIDOGLYCAN (POLYSACCHARIDE AND AMINO ACIDS) AND MUREIN	PRESENT IN PLANTS (MADE OF CELLULOSE OR LIGNIN) AND FUNGI (MADE OF CHITIN, SIMILAR TO CELLULOSE BUT CONTAINS NITROGEN)

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Examiner Tip

Become familiar with comparing the differences between prokaryotic and eukaryotic cells. It can be easier to answer comparison questions by drawing a table.

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1.2.7 Microscopes


Your notes

Electron & Light Microscopes

NOS: Developments in scientific research follow improvements in apparatus; the invention of electron microscopes led to greater understanding of cell structure

- In scientific research, **critical developments often follow improvements in scientific apparatus**
  - For example, distant objects in Space often remain undiscovered until a telescope (or some other piece of equipment) powerful enough to detect them is developed
- The fact that scientific research is often held back by a lack of **sufficiently powerful or precise apparatus** is a problem that will continue into the **future**
- In some ways, this is very exciting, as it suggests that our scientific knowledge and understanding of the universe will **continue to expand** as new scientific techniques and technologies are developed
- The discovery of the microscope allowed scientists to discover many things such as:
  - Formulate the cell theory, discover bacteria, see chromosomes, understand fertilisation by witnessing the fusion of gametes and closely examine the complex structure of organs such as the liver
- Due to constraints in technology (light microscopes cannot produce distinguishable clear images of structures smaller than 0.2 μm) developments in scientific research were limited
- This was until a different type of the microscope was invented - **the electron microscope**
- Electron microscopes enabled scientists to view structures 200 times smaller than light microscopes leading to a better understanding of the **ultrastructure** of cells
  - The **grana** of chloroplasts were observed to be constructed of stacks of flattened membrane sacs
  - **Ribosomes and endoplasmic reticulum** were discovered
- Improvements to the design of electron microscopes (electron tomography) and the invention of new types of microscopes (fluorescence) are allowing further developments in scientific research to be made

Microscopes

- **Microscopes** can be used to analyse **cell components** and observe **organelles**
- **Magnification** and **resolution** are two scientific terms that are very important to understand and **distinguish** between when answering questions about microscopy (the use of microscopes):
  - **Magnification** tells you how many times bigger the **image** produced by the microscope is than the **real-life object** you are viewing
  - **Resolution** is the ability to **distinguish between objects** that are close together (i.e. the ability to see two structures that are very close together as two separate structures)
- There are two main types of microscopes:
  - **Optical** microscopes (sometimes known as light microscopes)
  - **Electron** microscopes

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Optical (light) microscopes

- Optical microscopes use **light** to form an image
- This **limits the resolution** of optical microscopes
  - Using light, it is impossible to resolve (distinguish between) two objects that are closer than half the wavelength of light
  - The wavelength of visible light is between 500–650 nanometres (nm), so an optical microscope cannot be used to distinguish between objects closer than half of this value
- This means optical microscopes have a **maximum resolution of around 0.2 micrometres (µm) or 200 nm**
  - Optical microscopes **can be used** to observe **eukaryotic cells**, their **nuclei** and possibly mitochondria and chloroplasts
  - They **cannot be used** to observe **smaller organelles** such as **ribosomes**, the **endoplasmic reticulum** or **lysosomes**
- The **maximum useful magnification** of optical microscopes is about **×1500**

Electron microscopes

- Electron microscopes use **electrons** to form an image
- This **greatly increases the resolution** of electron microscopes compared to optical microscopes, giving a **more detailed image**
  - A beam of electrons has a much smaller wavelength than light, so an electron microscope can resolve (distinguish between) two objects that are extremely close together
- This means electron microscopes have a **maximum resolution of around 0.0002 µm or 0.2 nm** (i.e. around 1000 times greater than that of optical microscopes)
  - This means electron microscopes can be used to observe **small organelles** such as **ribosomes**, the **endoplasmic reticulum** or **lysosomes**
- The **maximum useful magnification** of electron microscopes is about **×1,500,000**
- There are two types of electron microscopes:
  - **Transmission** electron microscopes (TEMs)
  - **Scanning** electron microscopes (SEMs)

Transmission electron microscopes (TEMs)

- TEMs use electromagnets to focus a **beam of electrons**
- This beam of electrons is **transmitted through** the specimen
- Denser parts of the specimen absorb more electrons
  - This makes these denser parts appear darker on the final image produced (produces contrast between different parts of the object being observed)
- **Advantages** of TEMs:
  - They give **high-resolution** images (more detail)
  - This allows the **internal structures** within cells (or even within organelles) to be seen

Your notes

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- **Disadvantages** of TEMs:
  - They can only be used with **very thin specimens** or **thin sections** of the object being observed
  - They **cannot be used to observe live specimens**
    - As there is a vacuum inside a TEM, all the water must be removed from the specimen and so living cells cannot be observed, meaning that specimens must be dead. Optical microscopes can be used to observe live specimens
  - The **lengthy treatment required to prepare specimens** means that **artefacts can be introduced**
    - Artefacts look like real structures but are actually the results of preserving and staining
  - They **do not produce a colour image**
    - Unlike optical microscopes that produce a colour image


Your notes

Scanning electron microscopes (SEMs)

- SEMs scan a beam of electrons across the specimen
- This beam **bounces off the surface of the specimen** and the electrons are detected, forming an image
  - This means SEMs can produce **three-dimensional images** that show the **surface** of specimens
- **Advantages** of SEMs:
  - They can be used on **thick** or **3-D** specimens
  - They allow the **external**, **3-D structure** of specimens to be observed
- **Disadvantages** of SEMs:
  - They give **lower resolution** images (less detail) than TEMs
  - They **cannot be used to observe live specimens**
  - They **do not produce a colour image**

Comparison of the electron microscope & light microscope

- **Light microscopes** are used for specimens **above 200 nm**
  - Light microscopes shine **light** through the specimen, this light is then passed through an **objective lens** (which can be changed) and an **eyepiece lens** (x10) which magnify the specimen to give an image that can be seen by the naked eye
  - The specimens can be **living** (and therefore can be moving), **or dead**
  - Light microscopes are useful for looking at **whole cells**, small plant and animal **organisms**, **tissues within organs** such as in leaves or skin
- **Electron microscopes**, both scanning and transmission, are used for specimens **above 0.5 nm**
  - Electron microscopes fire a **beam of electrons** at the specimen either a broad static beam (transmission) or a small beam that moves across the specimen (scanning)
  - Due to the **higher frequency of electron waves** (a much shorter wavelength) compared to visible light, the magnification and resolution of an electron microscope is much better than a light microscope
  - Electron microscopes are useful for looking at **organelles, viruses** and **DNA** as well as looking at whole cells in more detail
  - Electron microscopy requires the specimen to be **dead** however this can provide a **snapshot** in time of what is occurring in a cell eg. DNA can be seen replicating and chromosome position within

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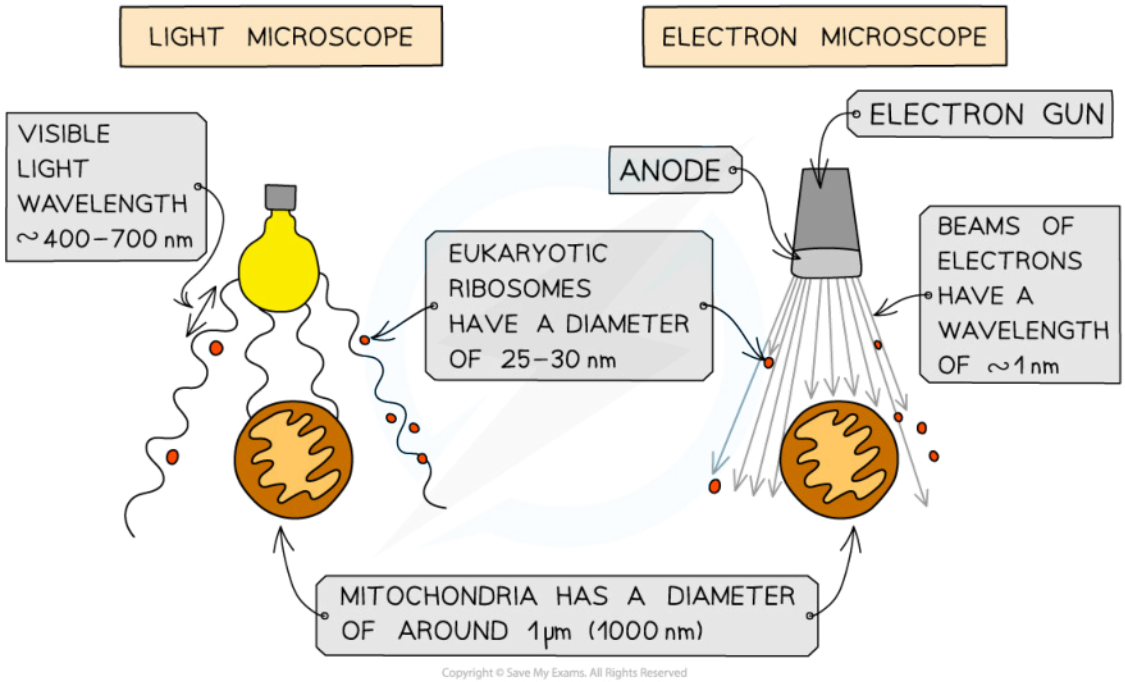
the stages of mitosis are visible



The resolving power of an electron microscope is much greater than that of the light microscope, as structures much smaller than the wavelength of light will interfere with a beam of electrons

Light Microscope vs Electron Microscope Table

ELECTRON MICROSCOPE	LIGHT MICROSCOPE
LARGE AND INSTALLATION MEANS IT CAN'T BE MOVED	SMALL AND EASY TO CARRY
VACUUM NEEDED	NO VACUUM NEEDED
COMPLICATED SAMPLE PREPARATION	EASY SAMPLE PREPARATION
OVER x 500 000 MAGNIFICATION	UP TO x 2000 MAGNIFICATION
RESOLUTION 0.5 nm	RESOLUTION 200 nm
SPECIMENS ARE DEAD	SPECIMENS CAN BE LIVING OR DEAD

Your notes

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Examiner Tip

Learn the difference between resolution and magnification! Also, learn how the light and electron microscope differ in terms of resolution and magnification.

Your notes

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1.2.8 Skills: Drawing Cells


Your notes

Drawing Cells

Drawing the ultrastructure of cells

- To record the observations seen under the microscope (or from photomicrographs taken) a labelled biological drawing is often made
- **Biological drawings** are line pictures that show specific features that have been observed when the specimen was viewed
- There are a number of rules/conventions that are followed when making a biological drawing

Drawing conventions

- The drawing must have a title
- The **magnification** under which the observations shown by the drawing are made must be recorded
- A **sharp HB pencil** should be used (and a good eraser!)
- Drawings should be on plain white paper
- Lines should be **clear**, **single lines** (no thick shading)
- **No shading**
- The drawing should take up as much of the space on the page as possible
- Well-defined structures should be drawn
- The drawing should be made with **proper proportions**
- **Label lines** should not cross or have arrowheads and should **connect directly** to the part of the drawing being labelled
- Label lines should be kept to one side of the drawing (in parallel to the top of the page) and drawn with a **ruler**
- Drawings of **cells** are typically made when visualizing cells at a **higher** magnification power, whereas **plan** drawings are typically made of tissues viewed under **lower** magnifications (individual cells are never drawn in a plan diagram)

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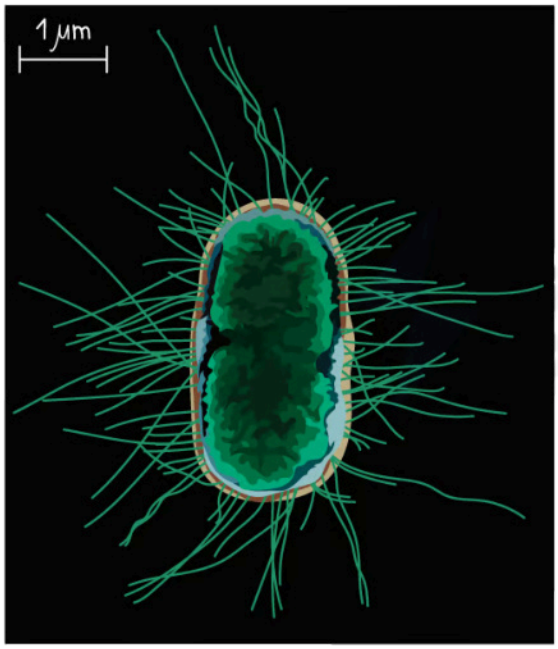
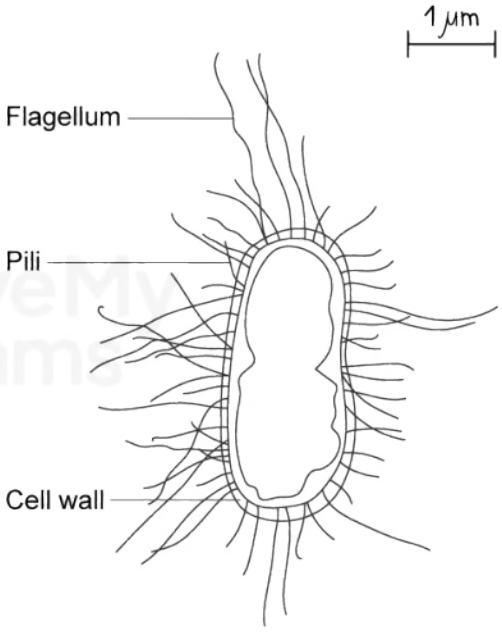
Drawing Prokaryotic Cells

Your notes

- Due to the size of prokaryotes (0.1 to 5 μm) their ultrastructure can only be seen using an electron microscope
- Therefore drawings of prokaryotes are based on electron micrographs
- When viewing an electron micrograph of a prokaryote there is **no distinct dark circular area** within the cell, as there is **no nucleus** and **no organelles** are visible (apart from ribosomes, but as they are 70 S in size these are difficult to distinguish)





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Biological drawings should show only visible structures, and should be labelled using the correct labelling conventions

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Drawing Eukaryotic Cells


Your notes

- When viewing a eukaryotic cell under a light microscope it is possible to identify the nucleus and if it is a plant cell the cell wall and vacuole
- However, under an electron microscope, more detail of the ultrastructure of the eukaryotic cell can be seen
- The following organelles should be able to be identified, although it does depend on whether it is a plant or animal cell and the specialisation of the cell:
  - Rough endoplasmic reticulum
  - Golgi apparatus
  - Lysosomes
  - Vesicles
  - Ribosomes
  - Vacuole (plant)
  - Nucleus
  - Mitochondrion
  - Chloroplast
- The nucleus, mitochondrion and chloroplast all have double membranes
- The cell wall will be present in plant eukaryotic cells. This is an extra-cellular component

Cell structures under an electron microscope

- Electron microscopes can produce highly detailed images of animal and plant cells
- The key cellular structures within animal and plant cells are visible within the electron micrographs above
- The nucleus should be clearly identifiable as it is the largest structure in the eukaryotic cell

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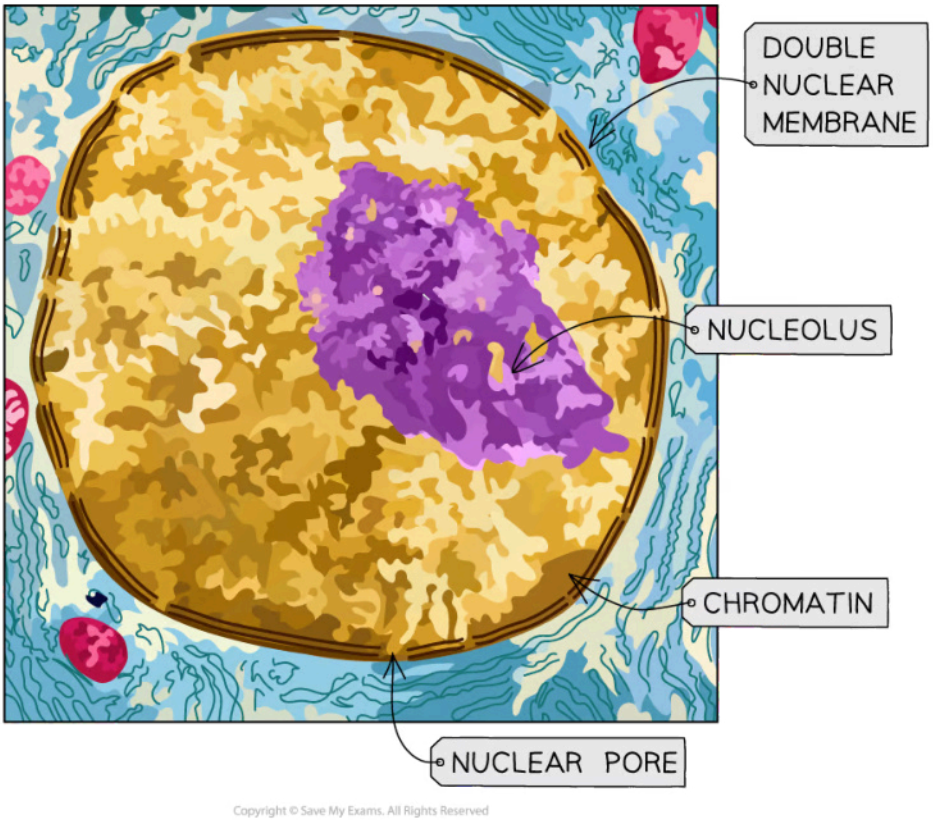
Your notes



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Electron micrograph of the nucleus

- To identify the mitochondrion look for the **crista** (the foldings of the inner membrane) which are often visible in electron micrographs

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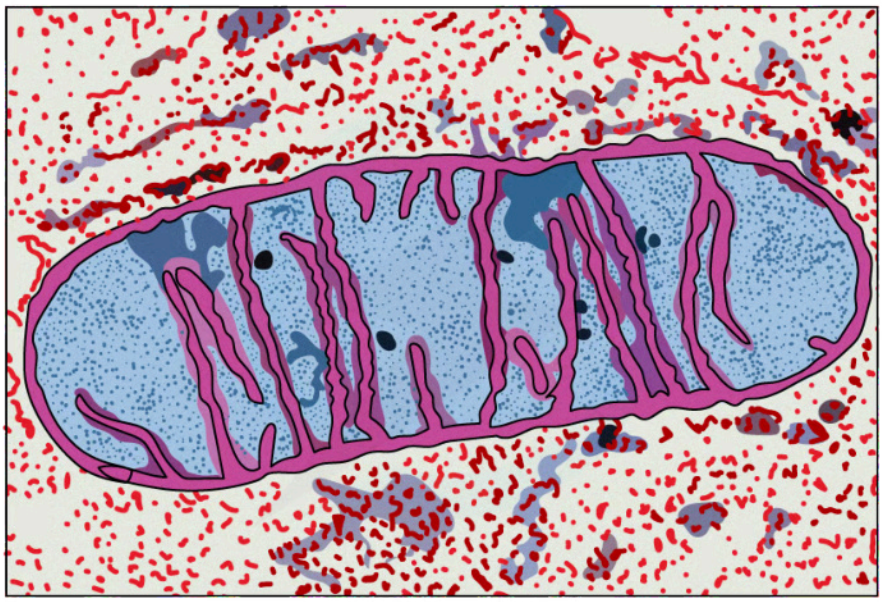
Your notes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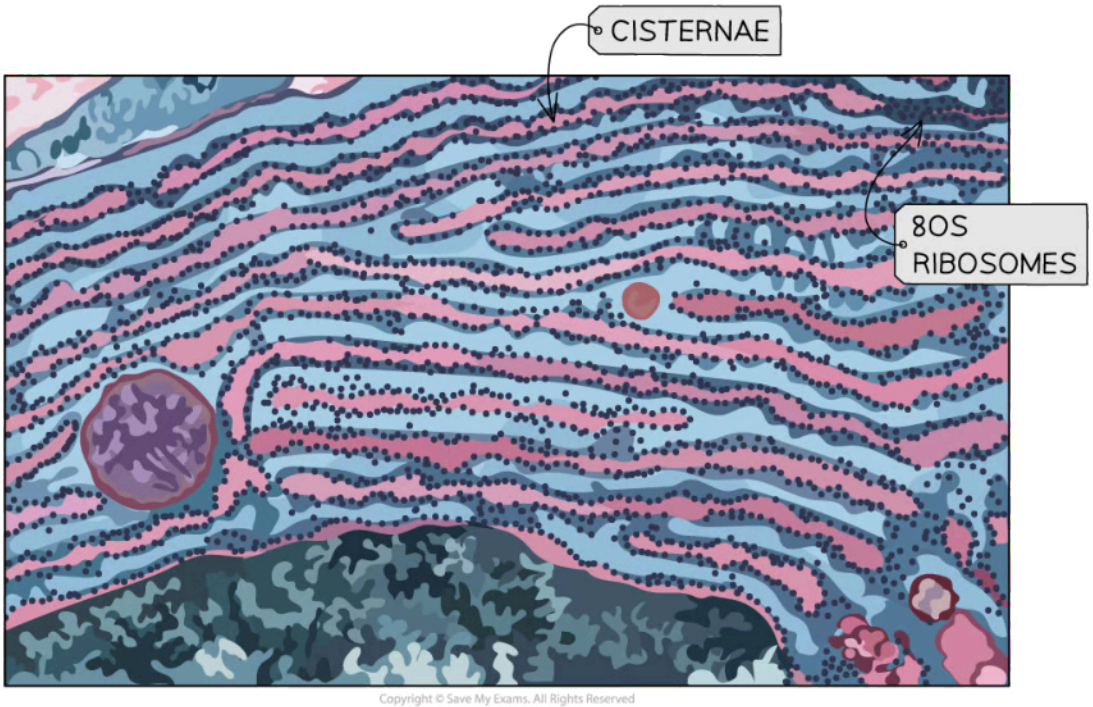
Electron micrograph of the mitochondrion

- The rough endoplasmic reticulum (rER) is located next to the nucleus and the attached ribosomes can be used to identify the rER as they make the membrane appear darker



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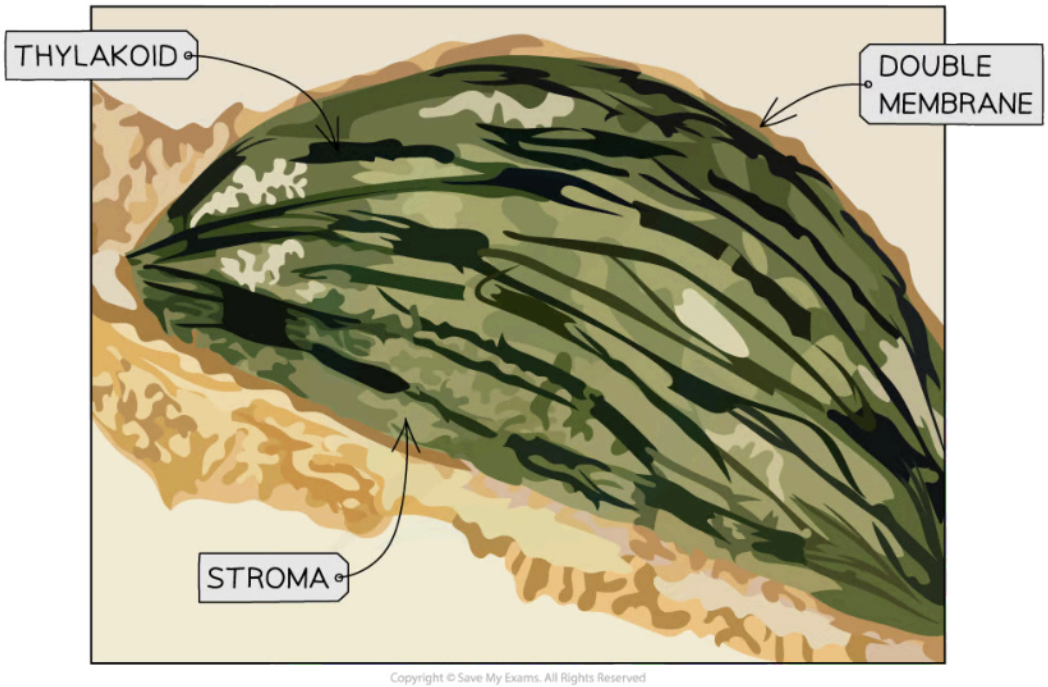
Electron micrograph of the rough endoplasmic reticulum

Your notes

- The chloroplast can be identified by the **thylakoid stacks** (grana), as they appear as dark lines within the organelle
- Chloroplasts are large



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Electron micrograph of the chloroplast

- Golgi apparatus will be located near the endoplasmic reticulum and it:
  - Does not have long membrane sacs
  - The sacs are more curved than the endoplasmic reticulum
  - Does not have ribosomes attached
  - Has many vesicles close by

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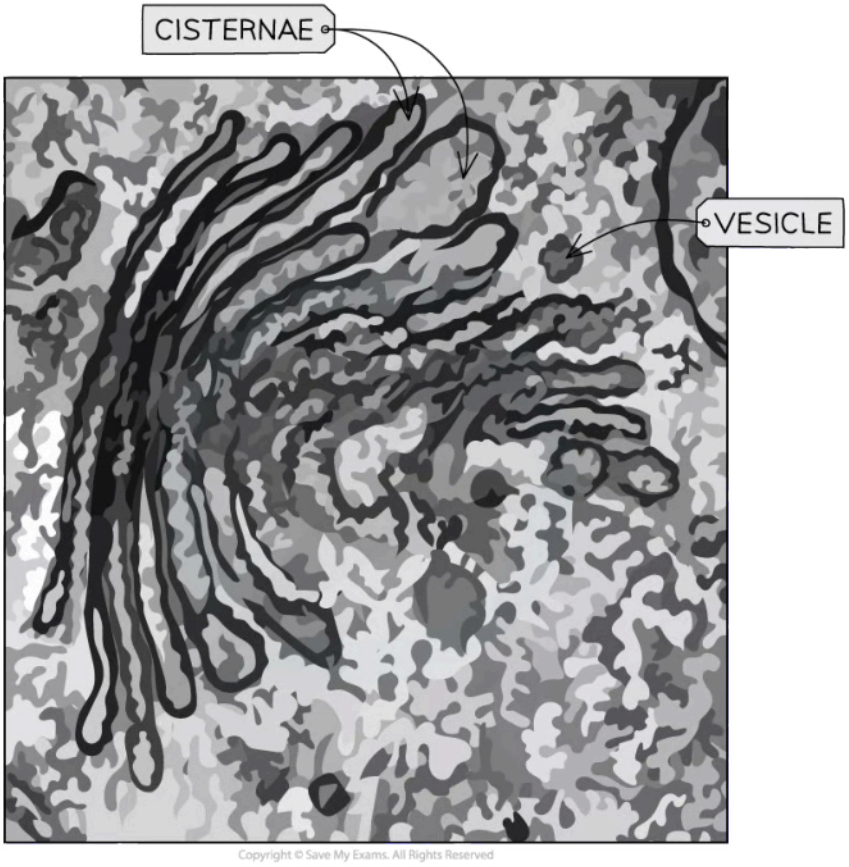

Electron micrograph of the Golgi apparatus

- Vesicles are spherical shapes

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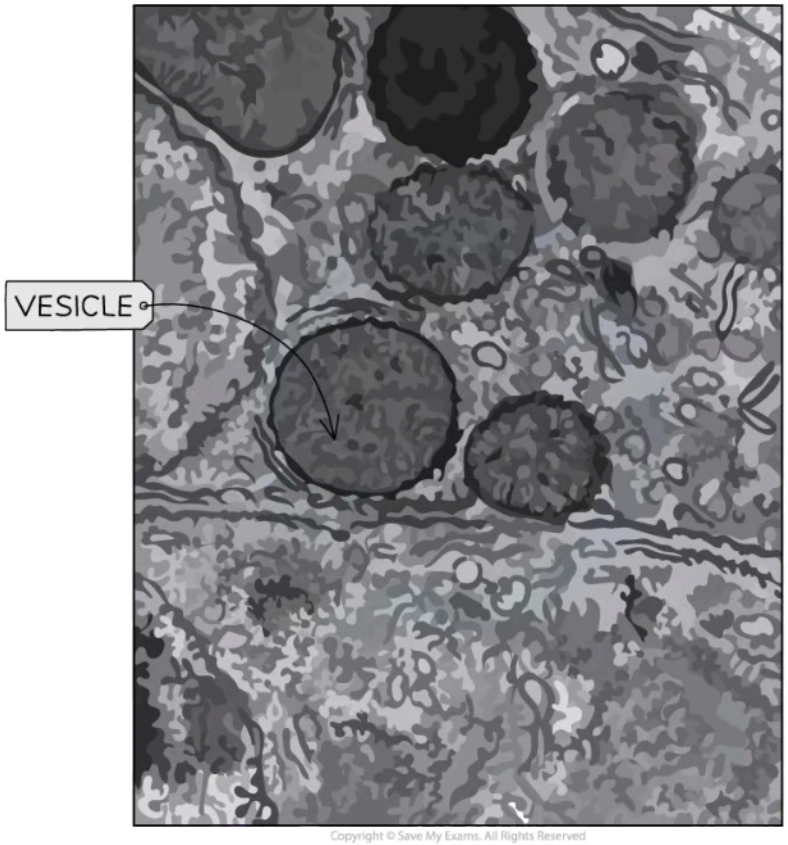

Electron micrograph of the vesicles

- Free ribosomes appear as dark granules (tiny dark dots) in the cytoplasm

Your notes

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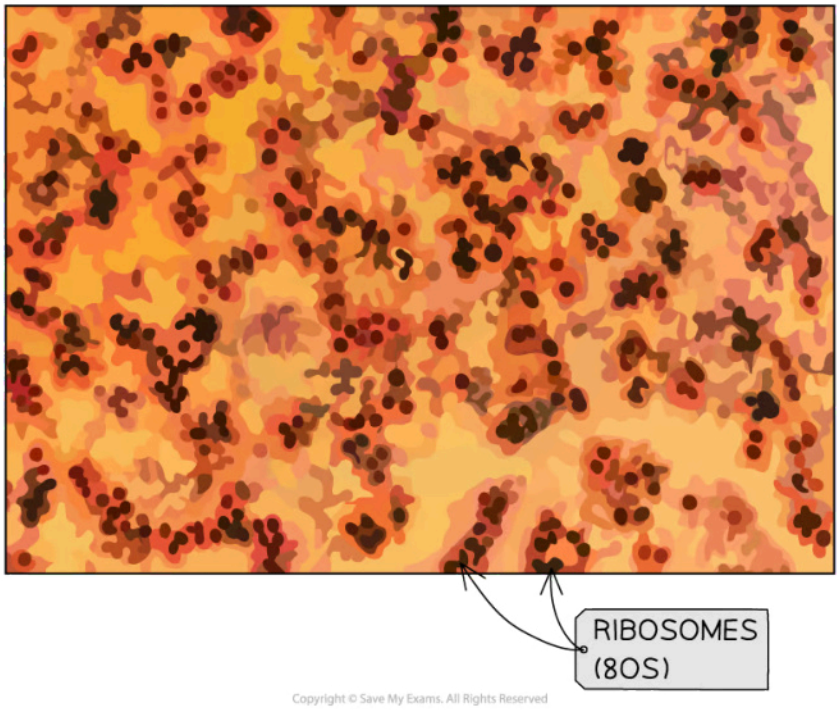

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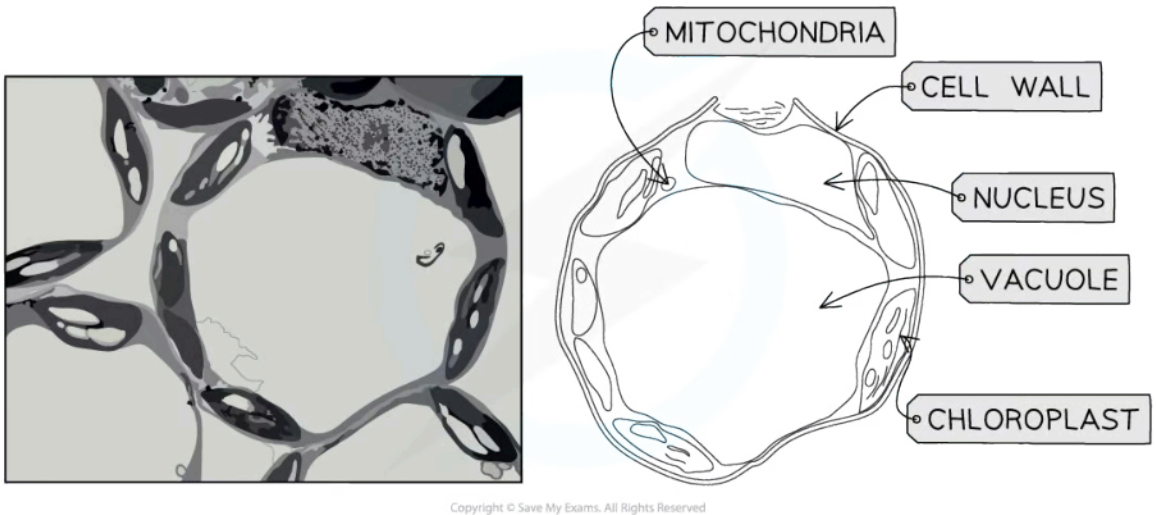
Electron micrograph of the ribosomes

Plant cell electron micrographs

- Electron micrographs of plant cells, such as palisade mesophyll cells, may show:
  - The **chloroplasts** along the plasma membrane, as this is where the most light can be absorbed
  - A large **vacuole** in the centre
  - A cell wall



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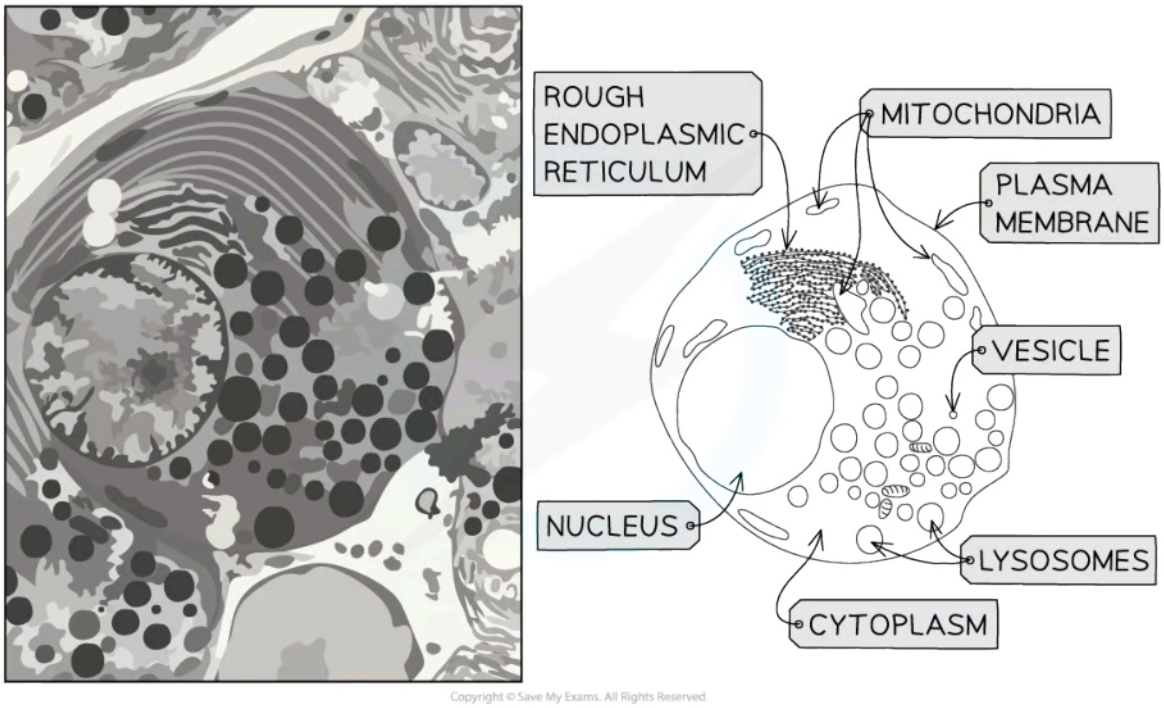
Electron micrograph of a plant cell

Your notes

Animal cell electron micrographs

- An exocrine gland cell of the pancreas may show:
  - Many large secretory vesicles (carrying the digestive enzymes)
  - Many **mitochondria**
  - Rough endoplasmic reticulum



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Electron micrograph of an exocrine gland cell of the pancreas

Examiner Tip

When producing a biological drawing, it is vital that you only ever draw what you see and not what you think you see.

When identifying palisade mesophyll cells, look for the presence of the large central vacuole, cell wall and lots of chloroplasts on the edge of the cell to maximise light absorption.

When identifying exocrine pancreatic gland cells, look for the presence of secretory vesicles carrying the digestive enzymes and the large numbers of rough endoplasmic reticulum.

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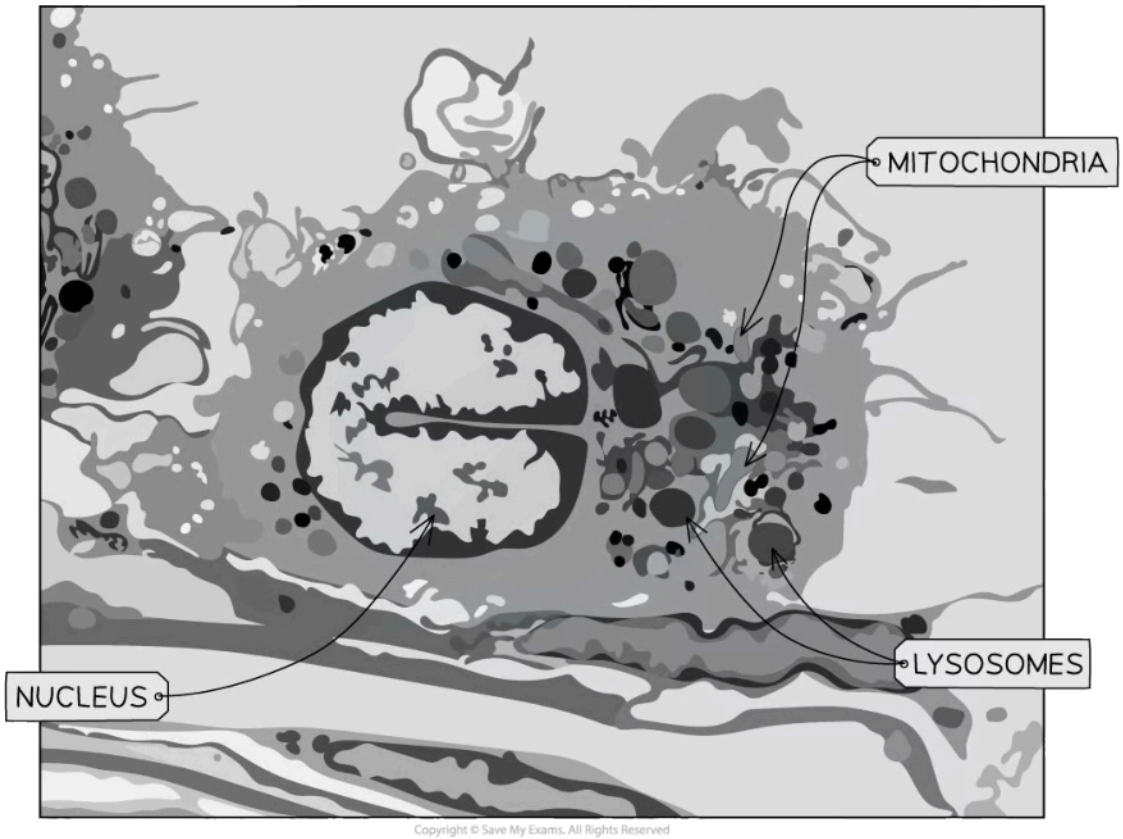
1.2.9 Skills: Cell Origin & Ultrastructure

Your notes

Interpreting Electron Micrographs

- When interpreting electron micrographs to deduce the function of the cell it is important to:

1. Identify whether it is a **prokaryotic or eukaryotic** cell - is a **nucleus** present
2. Identify which eukaryotic cell it is (**plant or animal**) by looking for a **cell wall** or **vacuole**
3. Identify the **organelles present** in the cells and consider their function



Electron micrograph of cell 1

- The cell had a **nucleus** - it is a **eukaryotic cell**
- This cell did **not have** a **cell wall** or **central vacuole** - it is an **animal cell**
- The cell has a **large u-shape nucleus** - it can manipulate itself through small pores
- There are a large number of **lysosomes** in the cell - it can **digest substances** found within the cell
- There are a large number of **mitochondria** - it has sufficient **energy** for the many metabolic reactions
- The deduction, therefore, is that this cell needs a lot of energy to break down substances that enter the cell and that it can move where it wants. This cell is a **macrophage**

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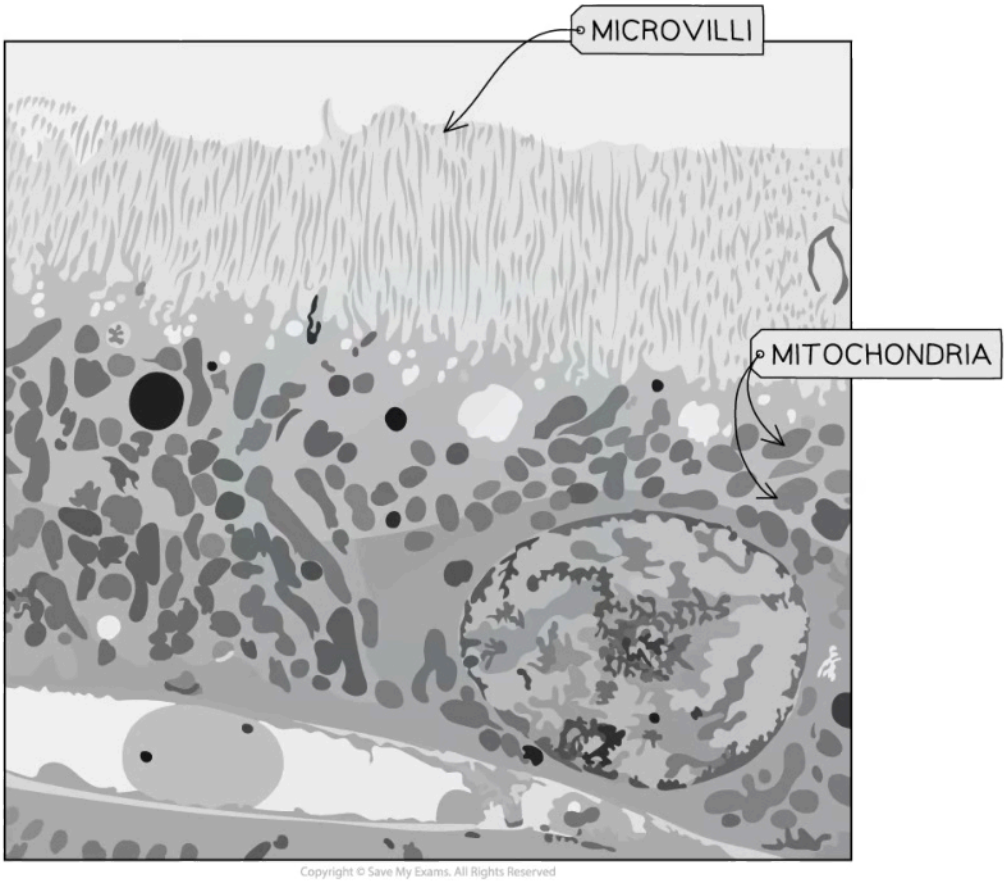
Your notes



Electron micrograph of cell 2

- The cell had a **nucleus** - it is a **eukaryotic cell**
- This cell did **not have** a **cell wall** or **central vacuole** - it is an **animal cell**
- There are a **large number of mitochondria** - it requires significant energy for **many metabolic reactions**
- The cell has **microvilli** packed closely together (brush border) - it needs to **increase the surface area** and prevent any substance from crossing into the cell
- The deduction, therefore, is that this cell needs a lot of energy to control what enters or exits this cell and that the cell requires a lot of the substance to be absorbed. This cell is a **ciliated epithelium of the small intestine**

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