IB Biology DP

YOUR NOTES ↓

1. Cell Biology

CONTENTS

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YOUR NOTES

1.1 Cells: Theory

1.1.1 Cell Theory

Cell Theory

- Until microscopes became powerful enough to view individual cells, no-one knew for certain what living organisms were made from
- A scientist called **Robert Hooke** came up with the term "cells" in the 1660's after examining the structure of cork
- Matthias **Schleiden** and Theodor **Schwann** were two scientists who studied animal and plant cells
  - In 1837, they came up with the idea that **all living organisms are made of cells**
  - This idea is known as **'cell theory'**
  - The cell theory is a **unifying concept** in biology (meaning it is **universally accepted**)
- The cell theory includes **three main ideas**:
  - **All living organisms** are made up of **one or more cells**
  - Cells are the **basic functional unit** (i.e. the basic unit of structure and organisation) in living organisms
  - **New cells** are produced from **pre-existing cells**
- Although cells vary in size and shape they all:
  - Are surrounded by a **membrane**
  - Contain **genetic material**
  - Have **chemical reactions** occurring within the cell that are catalysed by **enzymes**

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Cell Theory: Atypical Examples

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NOS: Looking for trends and discrepancies; although most organisms conform to cell theory, there are exceptions

- Scientists studying cells (e.g. Robert Hooke, Schwann & Schleiden and Pasteur) discovered **trends** when making **observations** of organisms
- The organisms they examined, using microscopes, all appeared to be made of smaller compartments (which we now refer to as cells). They discovered that even the smallest organisms, such as *Amoeba*, were made from at least one cell
- However, advancements in technology (particularly around what can be detailed and seen under a microscope) have enabled scientists to examine many more organisms and **discrepancies** have been discovered which raise questions about whether cell theory applies to all organisms

Atypical examples

- Striated muscle fibres, aseptate fungal hyphae and giant alga are three examples of cells/tissue with structures that question the integrity of the cell theory

Striated muscle fibres

- **Striated muscle fibres** (fused muscle cells) are:
  - **Longer** than typical cells (up to 300 mm in length in comparison to a cardiac muscle cell which has a length of 100 - 150 µm)
  - Have **multiple nuclei** surrounded by a single membrane (sarcolemma)
- These features question the cell theory because striated muscle cells are formed from multiple cells which have fused together (which is how they have many nuclei rather than one) that work together as a single unit, challenging the concept that cells work independently of each other even in a multicellular organism

Aseptate fungal hyphae

- Fungi have many long, narrow branches called **hyphae**
- Hyphae have cell membranes, cell walls and some have septa
- Aseptate fungal hyphae **do not have septa**, thus these cells are **multinucleated** with continuous cytoplasm
- This questions the cell theory because the cells have no end walls making them appear as one cell

Giant Alga (e.g. *Acetabularia*)

- *Acetabularia* can grow to **heights of 100 mm**, and yet consist of **only one cell** with a single nucleus
- *Acetabularia* have a relatively complex structure. They are divided into three parts: rhizoid, stalk and cap
- The features above question the cell theory because the trend for most unicellular organisms is to be small in size and simple in structure

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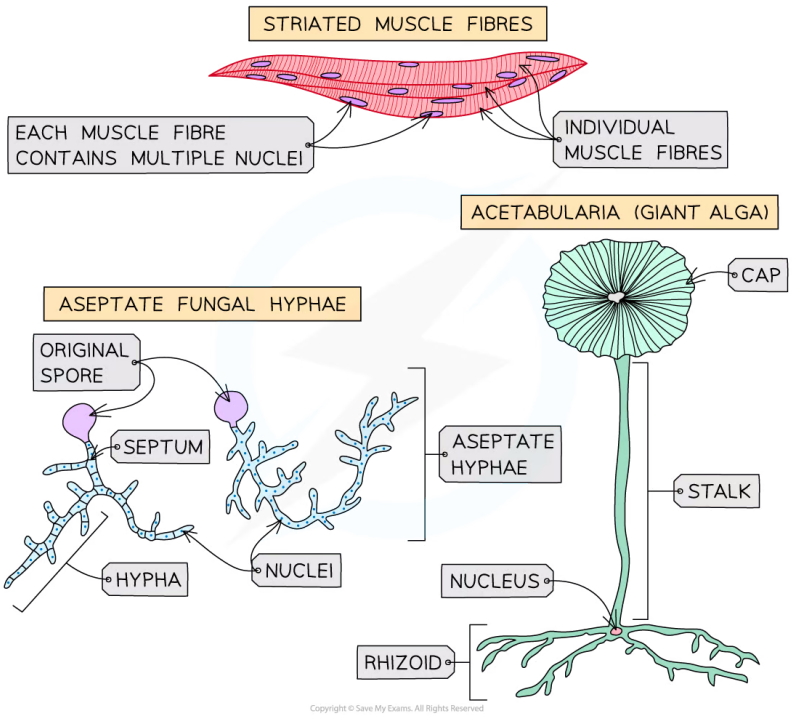

Three atypical examples of the cell theory

Exam Tip

Don't worry about learning the name of the scientists described above or when the cell theory was first described. You just need to know the three main components of the cell theory and why (by looking at trends and discrepancies) scientists have made exceptions to the theory.

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Functions of Life

- Unicellular (single-celled) and multicellular (many cells) organisms must carry out the following functions to stay alive:
  - **M**etabolism - all the enzyme-catalysed reactions occurring in a cell, including cell respiration
  - **R**eproduction - the production of offspring. It may be sexual or asexual
  - **H**omeostasis - the ability to maintain and regulate internal conditions within tolerable limits, including temperature
  - **G**rowth - the permanent increase in size
  - **R**esponse - (or sensitivity), the ability to respond to external or internal changes (stimuli) in their environment. Thus improving their chance of survival
  - **E**xcretion - the disposal of metabolic waste products, including carbon dioxide from respiration
  - **N**utrition - the acquisition of energy and nutrients for growth and development, either by, absorbing organic matter or by synthesising organic molecules (e.g. photosynthesis)

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Functions of Life: Paramecium & Chlorella

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Paramecium

- *Paramecium* are unicellular protozoans commonly found in freshwater. They range in size from 50 to 320 μm

Chlorella

- *Chlorella* is a small (2 to 10 μm) unicellular green alga. They are abundant in freshwater and can be found in a symbiotic relationship with *Paramecium*
- As *Chlorella* are living they carry out all the functions of life, although due to different structures, there are some differences to *Paramecium*

Comparison of the Functions of Life Between Paramecium and Chlorella

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Function	*Paramecium*	*Chlorella*
Metabolism	Metabolic reactions such as respiration and digestion are constantly taking place in the cytoplasm	
Reproduction	Generally asexual. After nuclear division (mitosis) occurs the two nuclei formed are separated by constriction of the cytoplasm	Nuclear division (mitosis) produces autospores that are released when the parent cell wall breaks down
Homeostasis	The **contractile vacuoles** fill up with water and then expel the water through the plasma membrane to maintain a constant osmotic potential	Extra glucose is stored as starch, in pyrenoids, to maintain the osmotic potential of the cell
Growth	After obtaining nutrition and assimilating the nutrients, the organisms increase in size until it divides	
Response	The beating of the cilia moves the *Paramecium* through the water in response to changes in the environment	Chlorophyll pigments located in the chloroplast absorb light
Excretion	Waste products (e.g. carbon dioxide) are expelled or diffuse out through the plasma membrane	Metabolic waste products (e.g. oxygen) diffuse out of the cell through the plasma membrane
Nutrition	Food particles that are swept into the oral groove are packaged into food vacuoles. After the enzymes, contained within the vacuoles, digest the particles the nutrients are absorbed into the cytoplasm	Synthesises carbohydrates through photosynthesis

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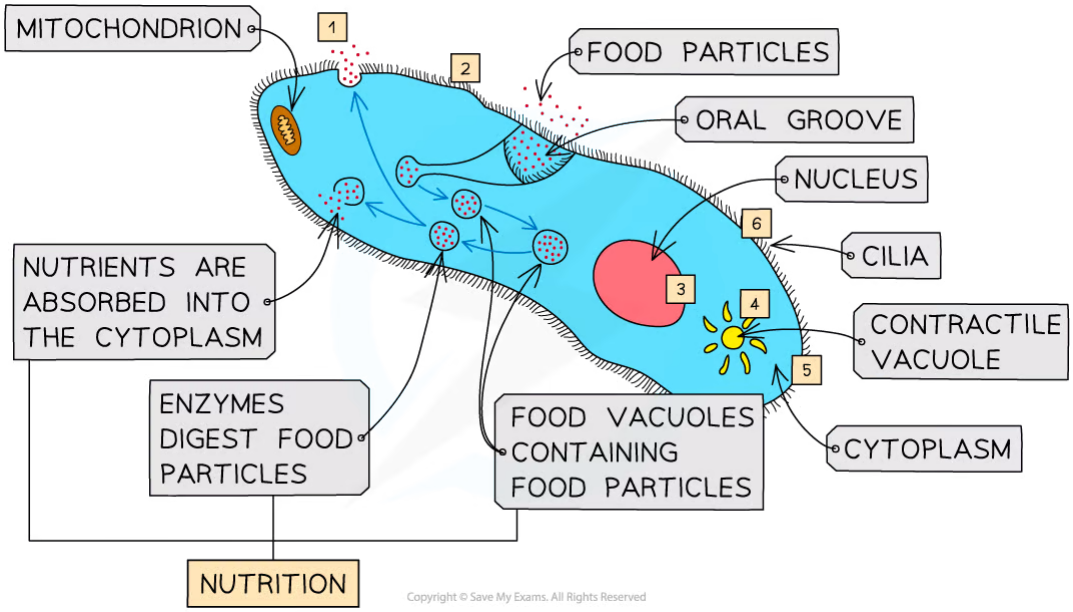

1	EXCRETION: WASTE PRODUCTS ARE EXPELLED OR DIFFUSE OUT THROUGH THE MEMBRANE
2	GROWTH: AFTER OBTAINING NUTRITION AND ASSIMILATING THE NUTRIENTS, THE *Paramecium* INCREASES IN SIZE UNTIL IT DIVIDES
3	REPRODUCTION: COMMONLY ASEXUAL. NUCLEAR DIVISION OCCURS, THE TWO NUCLEI ARE THEN SEPARATED BY THE CONSTRICTION OF THE CYTOPLASM
4	HOMEOSTASIS: FILL UP WITH WATER THEN EXPEL IT THROUGH THE MEMBRANE TO MAINTAIN A CONSTANT OSMOTIC POTENTIAL
5	METABOLISM: METABOLIC REACTIONS SUCH AS RESPIRATION AND DIGESTION CONSTANTLY TAKING PLACE IN THE CYTOPLASM
6	RESPONSE: BEATING OF THE CILIA MOVES THE *Paramecium* THROUGH WATER IN RESPONSE TO CHANGES

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The functions of life in Paramecium

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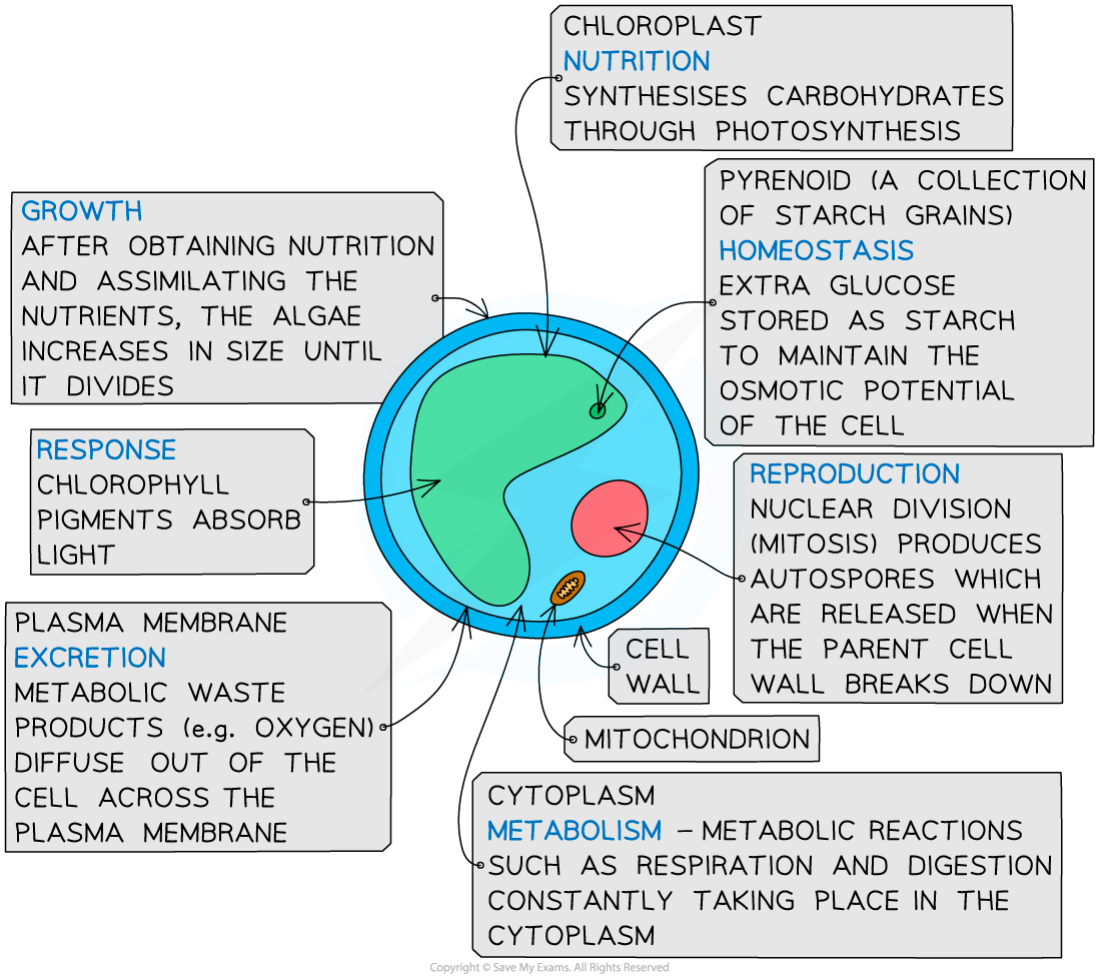

The functions of life in Chlorella

Exam Tip

To remember the functions of life think of **MR H GREN**. Note the similarities in the functions of life between *Paramecium* and *Chlorella*.

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YOUR NOTES

Surface Area to Volume Ratio

- For cells to survive, metabolic reactions must be occurring, these reactions depend on:
  - **Materials** constantly being **exchanged** across the **plasma membrane**
  - The **volume/mass** of cytoplasm (as this is where the reactions take place)
- As organisms **increase in size** their **SA:V ratio decreases**
  - There is **less surface area** for the absorption of nutrients and gases and secretion of waste products
  - The **greater volume** results in a **longer diffusion distance** to the cells and tissues of the organism
- Thus the **rate** at which substances (e.g. oxygen and heat) are **exchanged** across the plasma membrane is dependent on the **surface area** (the **larger** the surface area the **more** substances are exchanged)
- The rate at which a cell **metabolises** is dependent on the **mass/volume** of the cytoplasm (the **larger** the mass/volume the **longer** it takes for metabolic reactions to occur)

Limitations to cell size

- Single-celled organisms have a high SA:V ratio which allows for the exchange of substances to occur via simple diffusion
  - The large surface area allows for maximum absorption of **nutrients** and **gases** and secretion of **waste products**
  - The small volume means the diffusion distance to all organelles is **short**
- A consequence of the SA:V ratio is that cells cannot grow bigger indefinitely. Once the ratio becomes too small, growth must stop and the cells must divide
- To overcome this, large multicellular animals and plants have **evolved adaptations** to facilitate the exchange of substances between their environment
- They have a large variety of specialised cells, tissues, organs and systems
  - Eg. gas exchange system, circulatory system, lymphatic system, urinary system, xylem and phloem

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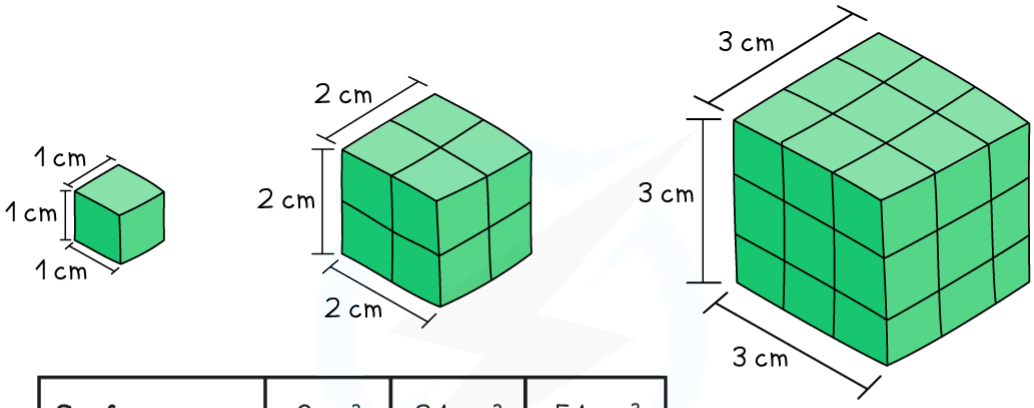

Surface area	6 cm^2	24 cm^2	54 cm^2
Volume	1 cm^3	8 cm^3	27 cm^3
Surface area : volume	6:1	3:1	2:1

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As the size of an organism increases, it's surface area : volume ratio decreases. Notice for this particular shape the distance between the surface and the centre increases with size.

Exam Tip

Remember the rate of metabolism is dependent on the mass/volume of the cell whereas the rate of exchange is dependent on the surface area.

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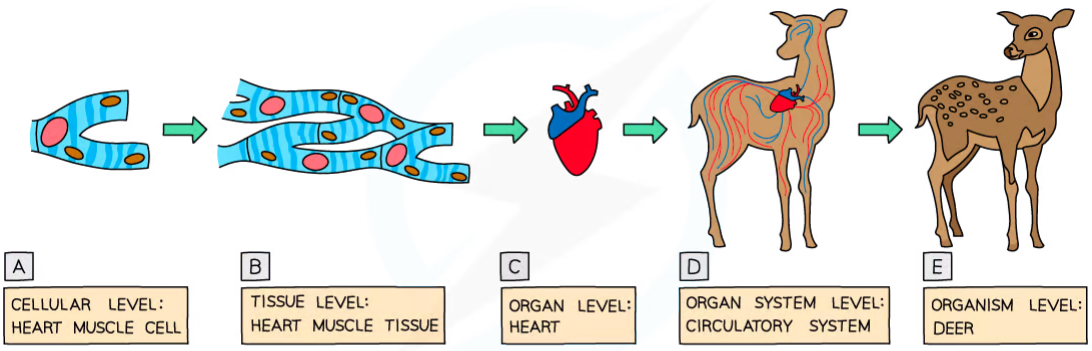
Emergent Properties

- Multicellular organisms are able to undertake functions that unicellular organisms cannot, e.g. move over vast distances and digest large macromolecules
- This is a result of properties emerging when **individual cells organise and interact** to produce living organisms
  - Scientists sometimes summarise this with the phrase "*The whole is greater than the sum of its parts*"
- Traditionally, scientists have approached the study of biology from a reductionist perspective, looking at the individual cells, however, due to emergent properties there is an argument that the **systems approach** should be used

The organisation of multicellular organisms

- In multicellular organisms, **specialised cells** of the **same type** group **together** to form **tissues**
- A tissue is a group of cells that **work together** to perform a **particular function**. For example:
  - Epithelial cells group together to form epithelial tissue (the function of which, in the small intestine, is to absorb food)
  - Muscle cells (another type of specialised cell) group together to form muscle tissue (the function of which is to contract in order to move parts of the body)
- Different tissues **work together** to form **organs**. For example:
  - The heart is made up of many different tissues (including cardiac muscle tissue, blood vessel tissues and connective tissue, as well as many others)
- Different organs **work together** to form **organ systems**
- Organ systems **work together** to carry out the life functions of a complete **organism**



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The organisation of multicellular organisms

Levels of Organisation in Humans Table

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Specialised cell	Tissue	Organ	Organ system
Epithelial cell	Epithelial tissue (made up of epithelial cells)	Stomach (made up of epithelial tissue, muscular tissue and glandular tissue)	Digestive system (made up of all the organs involved in the digestion and absorption of food, including the stomach, small intestine, large intestine and liver, as well as many others)
Muscle cell	Muscle tissue (made up of muscle cells)	Bladder (made up of muscle tissue, epithelial tissue, connective tissue and fatty tissue)	Urinary system (made up of the kidneys, ureters, bladder and urethra)
Neurones (nerve cells)	Nervous (neural) tissue (made up of neurones)	Brain (made up of gray matter tissue, white matter tissue and the tissues that make up the blood vessels in the brain)	Central nervous system (made up of the brain and the spinal cord
Rod cells and cone cells	Retina (made up of rods and cones)	Eye (made up of many tissues, including the retina, cornea, sclera and choroid)	Visual system (made up of the eyes, optic nerves and the visual cortex in the brain)

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Cell Differentiation

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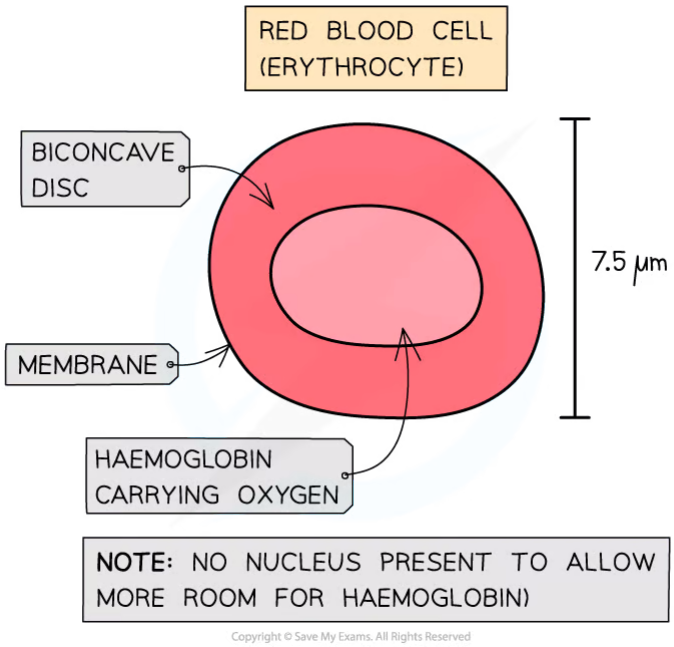
- In complex **multicellular** organisms eukaryotic cells become **specialised** for **specific functions**. This can also be referred to as **the division of labour**
- Specialisation enables the cells in a tissue to function more efficiently as they develop specific adaptations for that role. The development of these distinct specialised cells occurs by differentiation
- 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:
  - Cells that make large amounts of **proteins** will be adapted for this function by containing **many ribosomes** (the organelle responsible for protein production)



The biconcave shape of erythrocytes increases the surface area available for oxygen absorption

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Gene Expression

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- Every nucleus within the cells of a multicellular organism contains the same genes, that is, all cells of an organism have the identical genome
- Despite cells having the same genome, they have a diverse range of functions because during **differentiation** certain genes are **expressed** ('switched' on)
- Controlling gene expression is the key to development as the cells differentiate due to the different genes being expressed
- Once certain genes are expressed the specialisation of the cell is usually fixed so the cell cannot adapt to a new function

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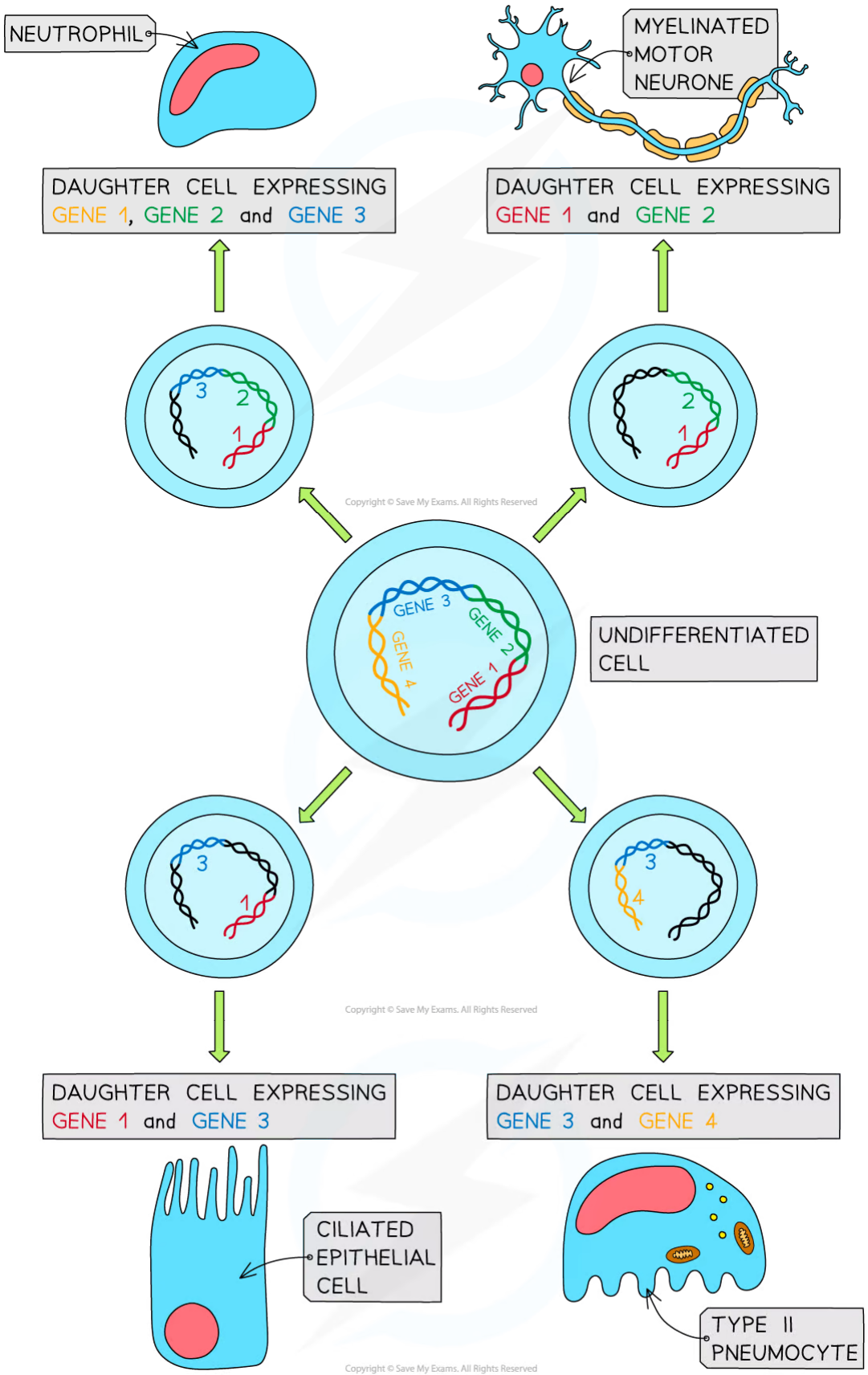

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YOUR NOTES

Expression of genes resulting in cell differentiation

Exam Tip

It's important to start learning some biological examples of each of these levels of organisation. Try and start with an organ system, such as the circulatory system or nervous system, and work your way down the levels of organisation noting down examples of organs, tissues and specialised cells as you go! Alternatively, start with a specialised cell you know of, such as a red blood cell, and work your way up the levels of organisation until you reach an organ system.

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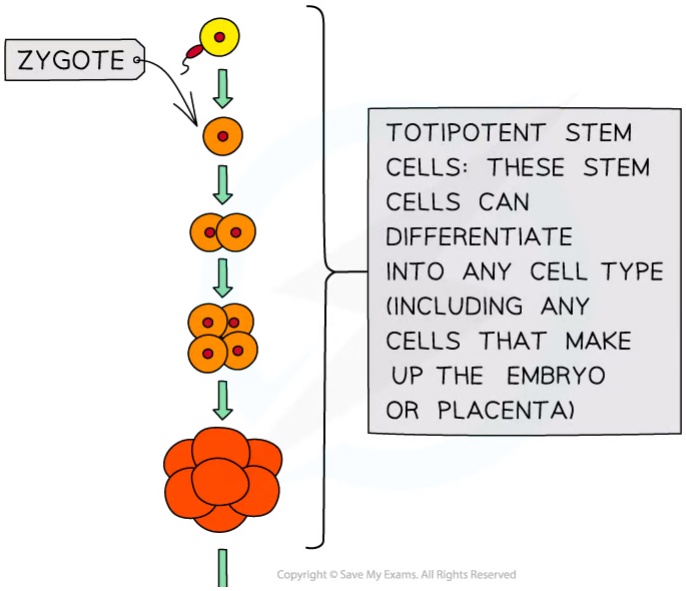
Stem Cells

- A **stem cell** is a cell that can **divide** (by mitosis) an **unlimited number of times**
- Each new cell (produced when a stem cell divides) has the potential to **remain a stem cell** or to develop into a **specialised cell** such as a blood cell or a muscle cell (by a process known as **differentiation**)
- This ability of stem cells to differentiate into more specialised cell types is known as **potency**
- There are four types of potency:
  - **Totipotency** – totipotent stem cells are stem cells that can differentiate into **any cell type found in an embryo, as well as extra-embryonic cells** (the cells that make up the placenta). The zygote formed when a sperm cell fertilises an egg cell is totipotent, as are the embryonic cells up to the 16-cell stage of human embryo development
  - **Pluripotency** – pluripotent stem cells are embryonic stem cells that can differentiate into **any cell type found in an embryo** but are **not able to differentiate into extra-embryonic cells** (the cells that make up the placenta)
  - **Multipotency** – multipotent stem cells are adult stem cells that can differentiate into closely related cell types (e.g. bone marrow stem cells differentiate into different blood cells)
  - **Unipotency** - unipotent stem cells are adult cells that can only differentiate into their **own lineage**, e.g. heart muscle cells (cardiomyocytes) can generate new cardiomyocytes through the cell cycle to build and replace heart muscle. Most cells in animal bodies are unipotent



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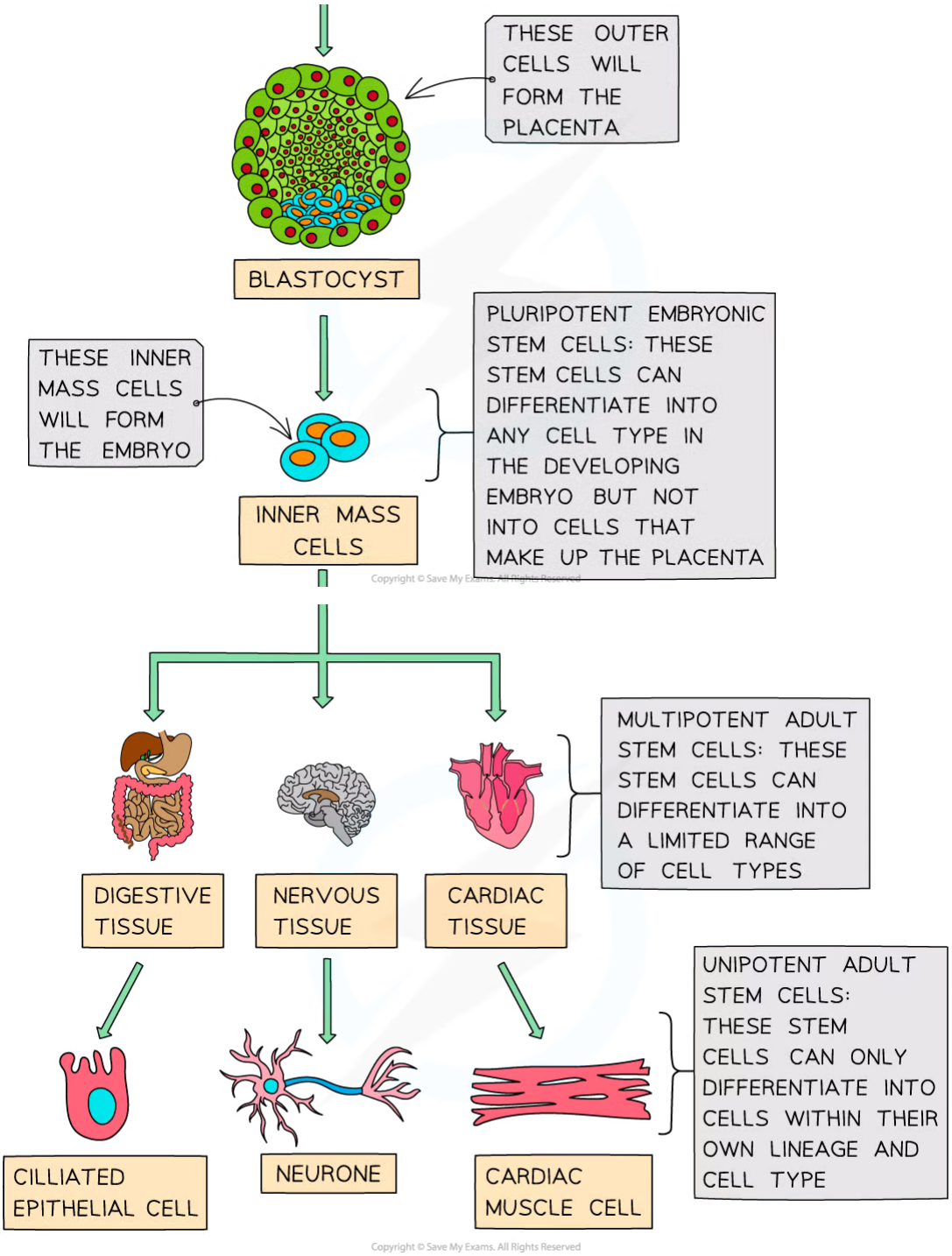

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There are different levels of potency that cells can have. Totipotent cells have the highest potency and can therefore differentiate into any type of cell. Unipotent cells have the lowest potency, only being able to divide into one cell type.

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Exam Tip

Remember the **two** key properties of stem cells are that they can **self-renew** (capacity to divide) and can **differentiate**.Make sure you learn the three levels of potency of stem cells described above, and what range of cell types these stem cells can differentiate into.Don't forget, while still classed as stem cells (as they can divide any number of times), only a limited range of specialised cells can be formed from adult stem cells as they have already partially differentiated. For example, stem cells in bone marrow can only produce cells that differentiate into the different types of blood cells.

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Stem Cells: Therapeutic Use

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- Currently, there are very few therapeutic uses of stem cells, although scientists around the world are actively involved in researching potential therapies
- The research is being carried out on **embryonic** (totipotent and pluripotent) and **adult** (multipotent) stems cells

Use of embryonic stem cells

- Due to their ability to differentiate into multiple cell types, stem cells have huge potential in the therapeutic treatment of disease
- For many countries, such as the USA and some countries within the EU, the use of embryonic stem cells is banned, even for research
- In other countries, such as the UK, the use of embryonic stem cells is allowed for research but is very **tightly regulated**
- Embryonic stem cells can be one of two potencies:
  - **Totipotent** if taken in the first 3–4 days after fertilisation
  - **Pluripotent** if taken on day 5
- The embryos used for research are often the **waste** (**fertilised**) **embryos** from *in vitro* **fertilisation treatment**
  - This means these embryos have the **potential to develop into human beings**
  - This is why many people have **ethical objections** to using them in research or medicine

Stargardt's disease

- Stargardt's disease is the most common inherited form of **juvenile macular degeneration** and mainly affects children and adolescents
- The macula is located in the central region of the retina and damage to this area limits our central vision and colour perception
- The disease is commonly caused by a **mutation of the *ABCA4* gene** resulting in a protein in the retina malfunctioning, eventually leaving the person legally blind
- One treatment that was researched was the **injection** of **retina cells derived** from embryonic stem cells into patients eyes. This treatment had success and no harmful side effects were experienced, however trials are still ongoing

Use of multipotent adult stem cells

- As tissues, organs and organ systems develop, cells become more and more **specialised**
- Having differentiated and specialised to fulfil particular roles, most adult cells gradually lose the ability to divide until, eventually, they are no longer able to divide
- However, small numbers of stem cells (known as **adult stem cells**) remain to produce new cells for the essential processes of **growth, cell replacement and tissue repair**
- Although these adult stem cells can divide (by mitosis) an unlimited number of times, they are only able to produce a **limited range of cell types** – they are **multipotent**
  - For example, the stem cells found in bone marrow (hematopoietic stem cells) are multipotent adult stem cells – they can only differentiate into blood cells (red blood cells, monocytes, neutrophils and lymphocytes)
  - In adults, multipotent stem cells can be found **throughout the body** (eg. in the bone marrow, skin, gut, heart and brain)

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- Research is being carried out on **stem cell therapy**, which is the introduction of adult stem cells into damaged tissue to treat diseases (eg. leukemia) and injuries (eg. skin burns)

YOUR NOTES

Leukaemia

- Leukaemia is the generalised term referring to a group of **cancers** that develop in the **bone marrow**
- It is caused by mutations in genes resulting in the **over-production** of **abnormal white blood cells** (leukocytes)
- To destroy these mutated cells in the bone marrow patients undergo **chemotherapy**
- However, as the chemicals injected into the patient's body during chemotherapy destroy all bone marrow cells, **hematopoietic stem cells (HSCs)**, the adult stem cells found in bone marrow, are removed using a large needle before treatment
- These HSCs are stored frozen and after chemotherapy, they are returned via a transfusion. Once in the body, the HSCs re-establish themselves in the bone marrow where they begin producing blood cells

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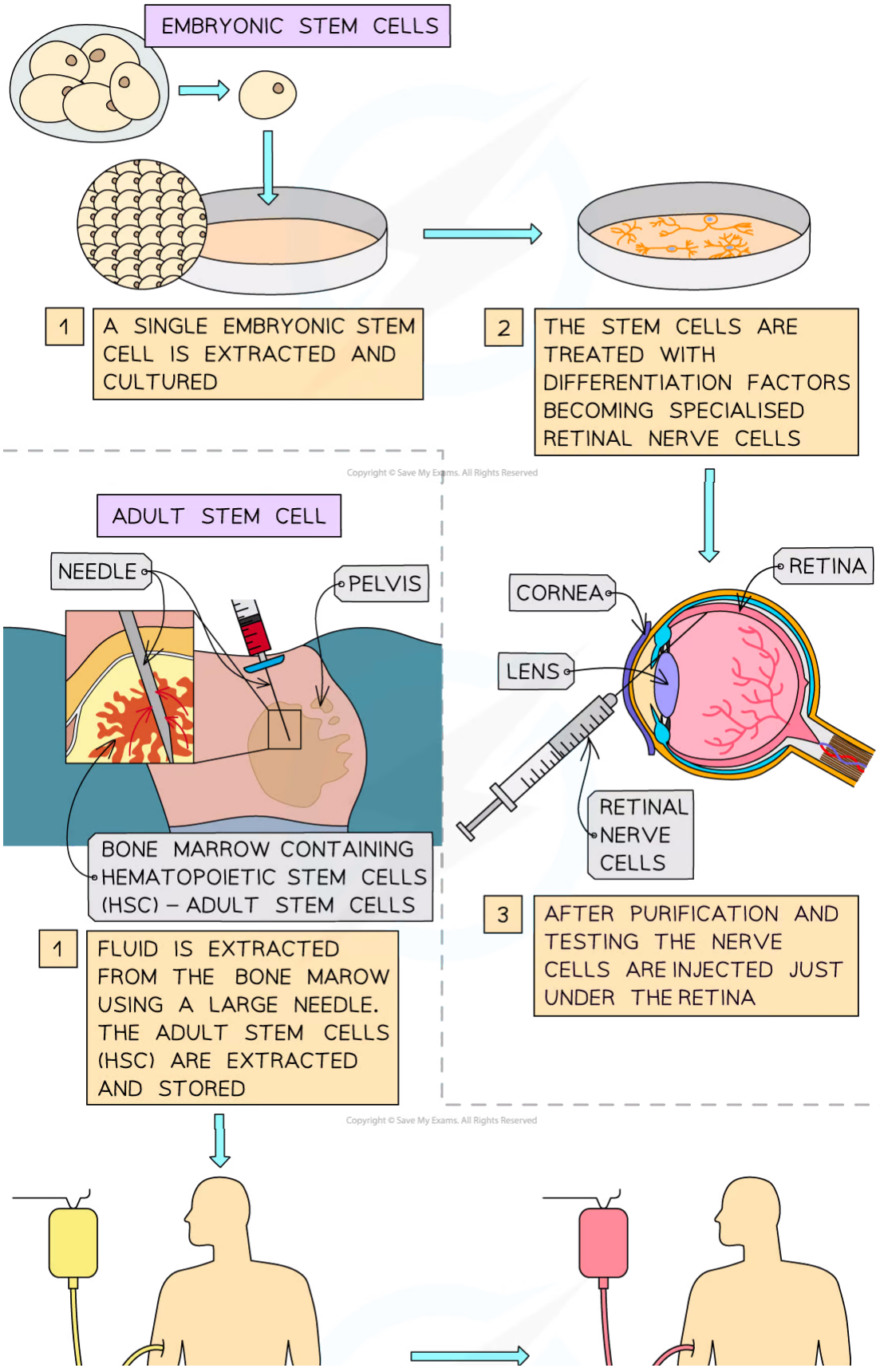

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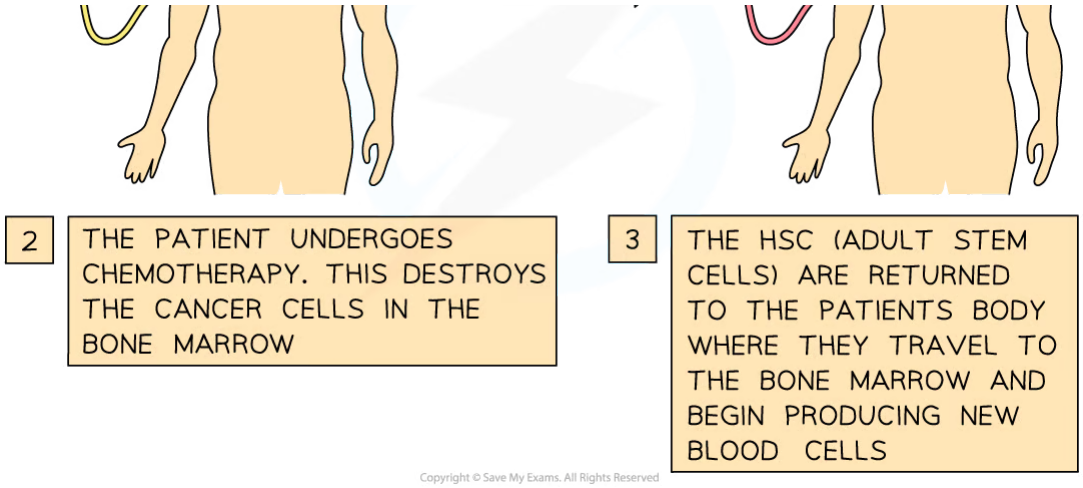

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Therapeutic uses of embryonic and adult stem cells

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Stem Cells: Ethics

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NOS: Ethical implications of research; research involving stem cells is growing in importance and raises ethical issues

- **Ethics** are the rules provided by external sources that allow us to determine whether something is right or wrong
- Before scientists undertake research it is important for them to consider the ethics and consequences
- Research involving stem cells may:
  - Lead scientists to make discoveries and create beneficial technologies that would not have occurred if the research had been banned
  - Cure diseases or disabilities
  - Enable organs to be regenerated or repaired, thus reducing the demand for organ transplants

Sources of Stem Cells

- One of the ethical considerations researchers need to take is to determine what the source of the stem cells is to be. There are **three** possible sources:
  - Embryos, which can be created using therapeutic cloning
  - Cord blood (umbilical) of new-born babies, which can be frozen and stored
  - Specific adult tissues, e.g. bone marrow

Ethics of Using Stem Cells

Arguments for:

- Embryonic stem cells:
  - These cells are totipotent or pluripotent therefore they can differentiate into any cell type and thus give the patient a **higher chance of living a healthy life**
  - Embryonic stem cells are not differentiated. Therefore there is **less chance of genetic damage**, due to an accumulation of mutations, which **improves** the likelihood of a **healthy life** for the patient
  - Any of these cells produced by **IVF** that have been set aside to be **discarded** could instead be used for research into incurable diseases

- Cord blood stem cells:
  - Can be **easily obtained and stored** and therefore are readily available when required
  - Are fully compatible with the tissues of the adult, as they are genetically identical, and therefore **reduce the risk of rejection** if used
  - Would be lost when the umbilical cord is discarded

- Adult stem cells:
  - It is less controversial to use adult stem cells compared to embryonic stem cells because the **donor is able to give permission,** e.g., many people **donate bone marrow** to help treat **leukaemia patients**
  - There is a **lower chance of rejection** as the patient's **own** adult stem cells are being used to treat them
  - A lower chance of developing into tumours
  - Can be removed without any long-lasting side effects to the patient

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Arguments against:

- Embryonic stem cells:
  - These cells have a higher risk of developing into tumours
  - The process involves the creation and destruction of embryos (but at which point are embryos considered alive)
- Cord blood stem cells:
  - The cells are multipotent and therefore have a limited capacity to differentiate into different cell types
- Adult stem cells:
  - Adult stem cells are difficult to obtain as there are a small number of them and so they can be painful to extract as they are buried deep in tissue
  - Are multipotent and therefore have a limited capacity to differentiate into different cell types
  - If adult stem cells are being donated from one person to another they need to be a **close match** in terms of blood type and other body antigens or there is a chance that the cells used will be **rejected** by the patient's **immune system**

Stem Cell Ethics Table

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YOUR NOTES

Source of Stem Cells	For	Against
Embryonic	◦ Are totipotent or pluripotent therefore they can differentiate into any cell type and thus give the patient a **higher chance of living a healthy life** ◦ Are not differentiated. Therefore, there is **less chance of genetic damage**, due to an accumulation of mutations, which improves the likelihood of a **healthy life** for the patient ◦ Those produced by IVF, that might be discarded, could be used in research on incurable diseases	◦ Have a higher risk of developing into tumours ◦ Involves the creation and destruction of embryos (but at which point are embryos considered alive)
Cord	◦ Can be **easily obtained and stored** and therefore are readily available when required ◦ Are fully compatible with the tissues of the adult, as they are genetically identical, and therefore **reduce the risk of rejection** if used ◦ Would be lost when the umbilical cord is discarded so if they are harvested, they are available if required	◦ Are multipotent and therefore have a limited capacity to differentiate into different cell types
Adult	◦ Use is less controversial than embryonic stem cells because the **donor can give permission,** e.g. many people **donate bone marrow** to help treat **leukaemia patients** ◦ Have a **lower chance of rejection** as the patient's **own** adult stem cells are being used to treat them ◦ Have a lower chance of developing into tumours ◦ Can be removed without	◦ Are difficult to obtain as there are few of them and they are painful to extract as they are buried deep in tissue ◦ Are multipotent and therefore have a limited capacity to differentiate into different cell types ◦ If adult stem cells are being donated from one person to another, they need to be a **close match** in terms of blood type and other body

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	destroying the adult that the cells were extracted from	antigens or there is a chance that the cells used will be **rejected** by the patient's **immune system**

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YOUR NOTES

Exam Tip

It is important to learn arguments for and against using the three sources of stem cells for therapeutic uses.

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YOUR NOTES

Practical 1: Using a Microscope

- Many biological structures are too small to be seen by the naked eye
- Optical (light) microscopes are an invaluable tool for scientists as they allow for tissues, cells and organelles to be seen and studied
- For example, the movement of chromosomes during mitosis can be observed using a microscope

How optical (light) microscopes work

- Light is directed through the thin layer of biological material that is supported on a glass slide
- This light is focused through several lenses so that an image is visible through the eyepiece
- The magnifying power of the microscope can be increased by rotating the higher power objective lens into place

Apparatus

- The key components of an optical (light) microscope are:
  - The eyepiece lens
  - The objective lenses
  - The stage
  - The light source
  - The coarse and fine focus
- Other tools used:
  - Forceps
  - Scissors
  - Scalpel
  - Coverslip
  - Slides
  - Pipette

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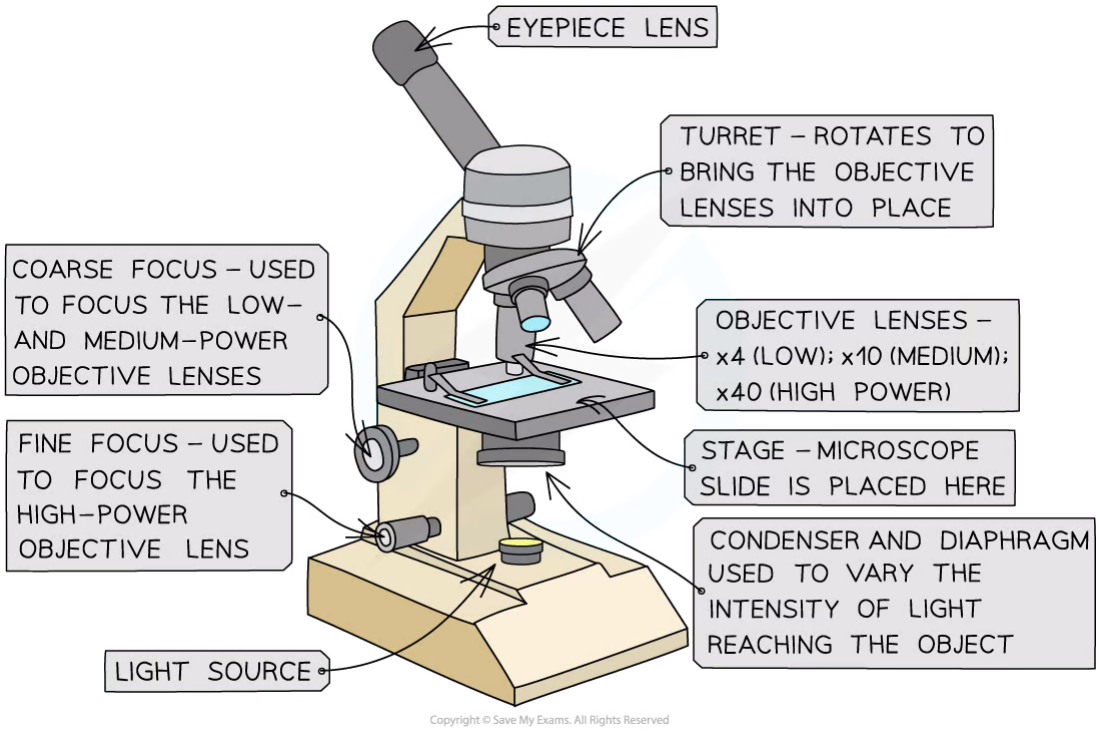

Image showing all the components of an optical (light) microscope

Method

- Preparing a slide using a **liquid specimen**:
  - Add a few drops of the sample to the slide using a pipette
  - Cover the liquid/smear with a coverslip and gently press down to **remove air bubbles**
  - **Wear gloves** to ensure there is no cross-contamination of foreign cells

- Preparing a slide using a **solid specimen**:
  - Use scissors to cut a small sample of the tissue
  - Peel away or cut a **very thin layer** of cells from the tissue sample to be placed on the slide (using a scalpel or forceps)
  - Some tissue samples need be treated with chemicals to kill/make the tissue rigid
  - A **stain** may be required to make the structures visible depending on the type of tissue being examined
  - Gently place a coverslip on top and press down to remove any air bubbles
  - Take care when using sharp objects and wear gloves to prevent the stain from dying your skin

- Place the microscope slide on the **stage**, fix in place using the stage clips (ensure the microscope is plugged in and on)
- When using an optical microscope always **start with the low power objective lens**:
  - It is **easier to find** what you are looking for in the field of view
  - This helps to **prevent damage** to the lens or coverslip incase the stage has been raised too high

- Whilst looking through the **eyepiece lens** move the **coarse focusing knob** until the specimen comes into **focus**. The **fine focusing knob** should be used to sharpen the focus

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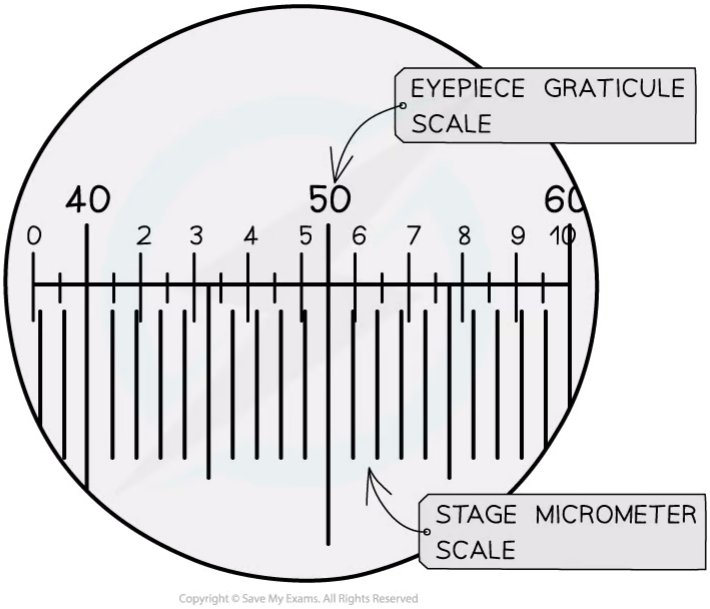
YOUR NOTES ↓

on particular parts (and at higher objective lens only)
- To examine the whole slide move it carefully with your hands (or if using a binocular microscope use the stage adjusting knobs)
- **Once** you have **focused** on the object/structure then carefully **move** to **higher objective lens** (10X and 40X). If resistance is felt do not continue to move the turret. At the **higher objective** powers **only** use the **fine focusing knob**
  - **Do not move** the **stage down** when moving to higher objective lens

- Unclear or blurry images:
  - Switch to the lower power objective lens and try using the **coarse focus** to get a clearer image
  - Consider whether the specimen sample is **thin enough** for light to pass through to see the structures clearly
  - There could be **cross-contamination** with foreign cells or bodies

- Use a **calibrated** graticule to take measurements of cells
  - A **graticule** is a small disc that has an engraved **scale.** It can be placed into the eyepiece of a microscope to act as a ruler in the field of view
  - As a graticule has no fixed units it must be **calibrated** for the objective lens that is in use. This is done by using a scale engraved on a microscope slide (**a stage micrometer**)
  - By using the two scales together the number of micrometers each graticule unit is worth can be worked out
  - After this is known the graticule can be used as a **ruler** in the field of view



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The stage micrometer scale is used to find out how many micrometers each graticule unit represents

Drawing cells

- To record the observations seen under the microscope (or from photomicrographs taken) a labelled biological drawing is often made

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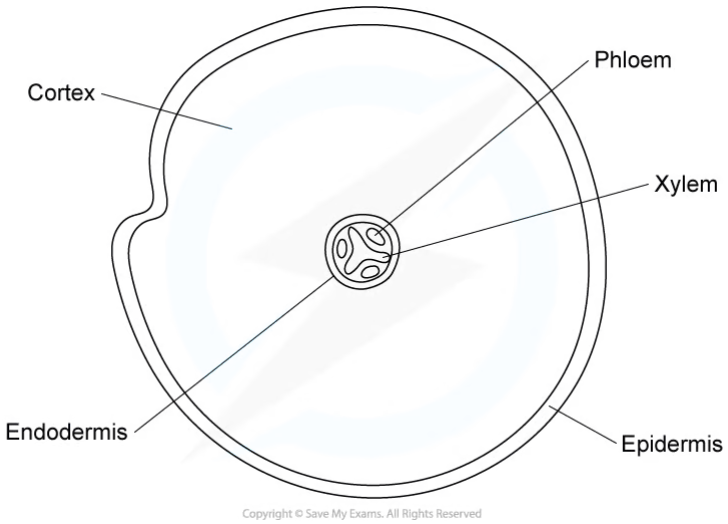
- **Biological drawings** are line pictures which show specific features that have been observed when the specimen was viewed
- There are a number of rules/conventions that are followed when making a biological drawing

Guidelines for microscope drawings

- The conventions are:
  - 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 visualising 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)



An example of a tissue plan drawn from a low-power image of a transverse section of a root. There is no cell detail present.

Magnification calculations

- **Magnification** is **how many times bigger** the image of a specimen observed is in comparison to the actual (real-life) size of the specimen

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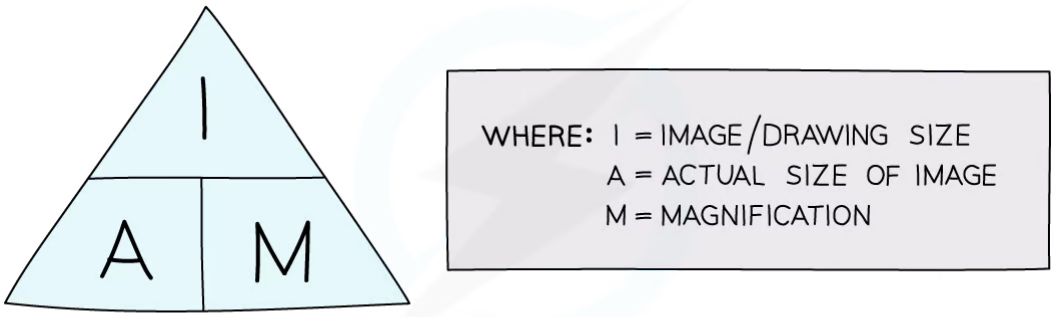
- The **magnification** (*M*) of an object can be calculated if both the size of the image (*I*), and the actual size of the specimen (*A*), is known



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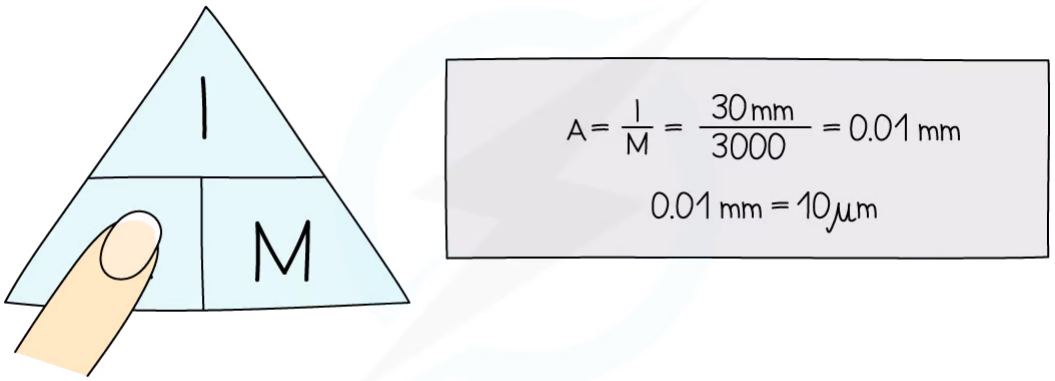
An equation triangle for calculating magnification

Worked Example

An **image** of an animal cell is 30 mm in size and it has been **magnified** by a factor of X 3000.What is the **actual** size of the cell?

To find the **actual** size of the cell:



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Using the appropriate units

- The size of cells is typically measured using the **micrometre** (μm) scale, with cellular structures measured in either **micrometers** (μm) or **nanometers** (nm)
- When doing calculations all measurements must be in the **same units**. It is best to use the **smallest unit** of measurement shown in the question
- To convert units, multiply or divide depending if the units are **increasing or decreasing**
- Magnification does **not** have units

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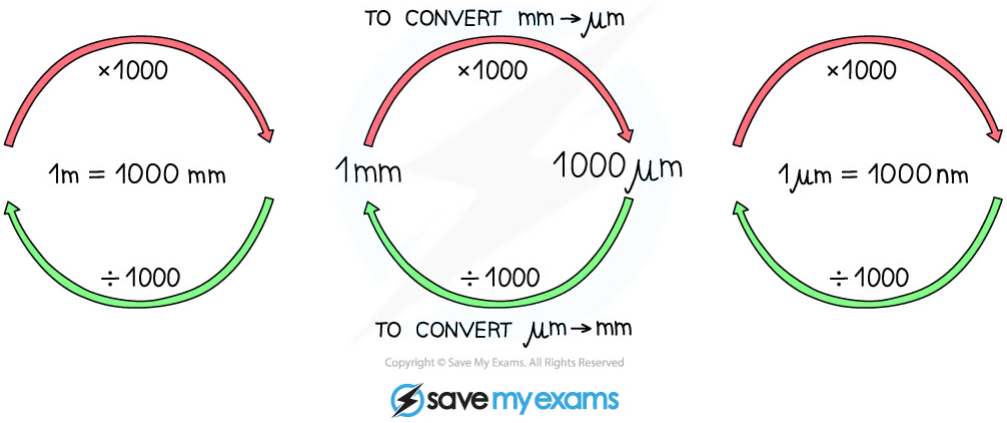

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- There are 1000 nanometers (nm) in a micrometre (μm)
- There are 1000 micrometres (μm) in a millimetre (mm)
- There are 1000 millimetres (mm) in a metre (m)

Using a scale bar

- A scale bar is a straight line on the drawing or micrograph that represents the actual size before the image was enlarged
- If the calculation required includes a scale bar on the micrograph or drawing then follow these steps:

1. Use a ruler to measure the length of the scale bar in millimetres
2. Convert this measurement into the same units as the number on the scale bar
3. Insert these numbers into the magnification formula above (note: the size of the image is the measured length of the scale bar and the actual size is the number on the scale bar)

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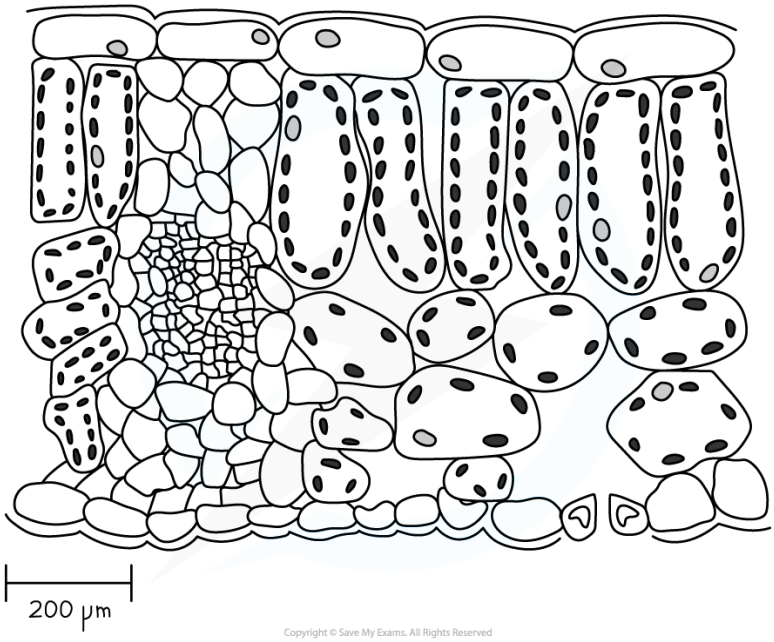
Worked Example

Calculate the magnification of the transverse section of the leaf blade.



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Transverse section of the leaf blade

Step 1: Use a ruler to measure the length of the scale bar in millimetres

Using a ruler the length of the scale bar is equal to 20 mm

Step 2: Convert this measurement into the same units as the number on the scale bar

The units on the scale bar are µm, remember that 1mm = 1000 µm

therefore 20 mm = 20 x 1000 = 20 000 µm

Step 3: Insert these numbers into the magnification formula

$$\text{Magnification} = \frac{\text{measured length of scale bar}}{\text{scale bar label}}$$

Note: the size of the image is the measured length of the scale bar and the actual size is the number on the scale bar

$$\text{Magnification} = \frac{20\,000\mu m}{200\mu m}$$

therefore Magnification = x 100

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Exam Tip

Before doing any calculations make sure that all the measurements have the same units.When doing the calculations it is easier to write the formula, then rearrange it, before you add any measurements, as this helps avoid any possible errors.Note that when you do calculations using a scale bar, the number on the scale bar is informing you how many mm/μm or nm the line actually represents (e.g. if the scale bar has 20 nm above it and the line is 10 mm, then every 10 mm on the diagram is **actually** 20 nm).

YOUR NOTES

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YOUR NOTES

1.2 Cells: Origin & Ultrastructure

1.2.1 Origin of Cells

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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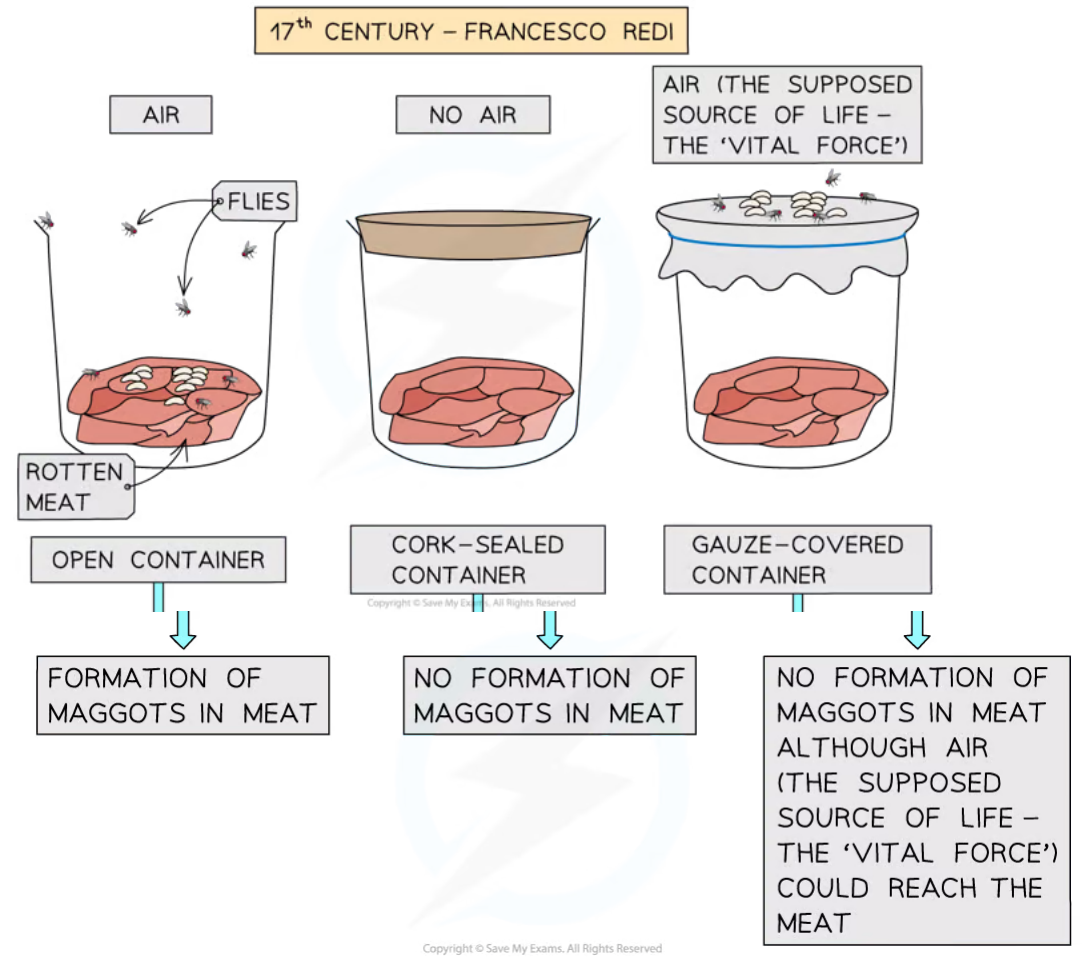

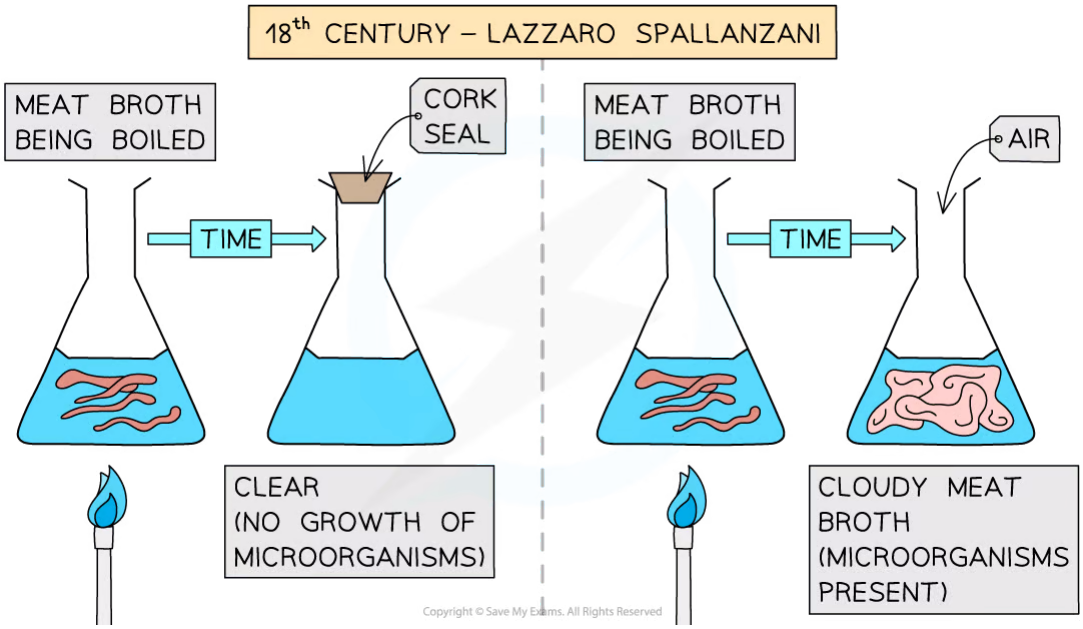

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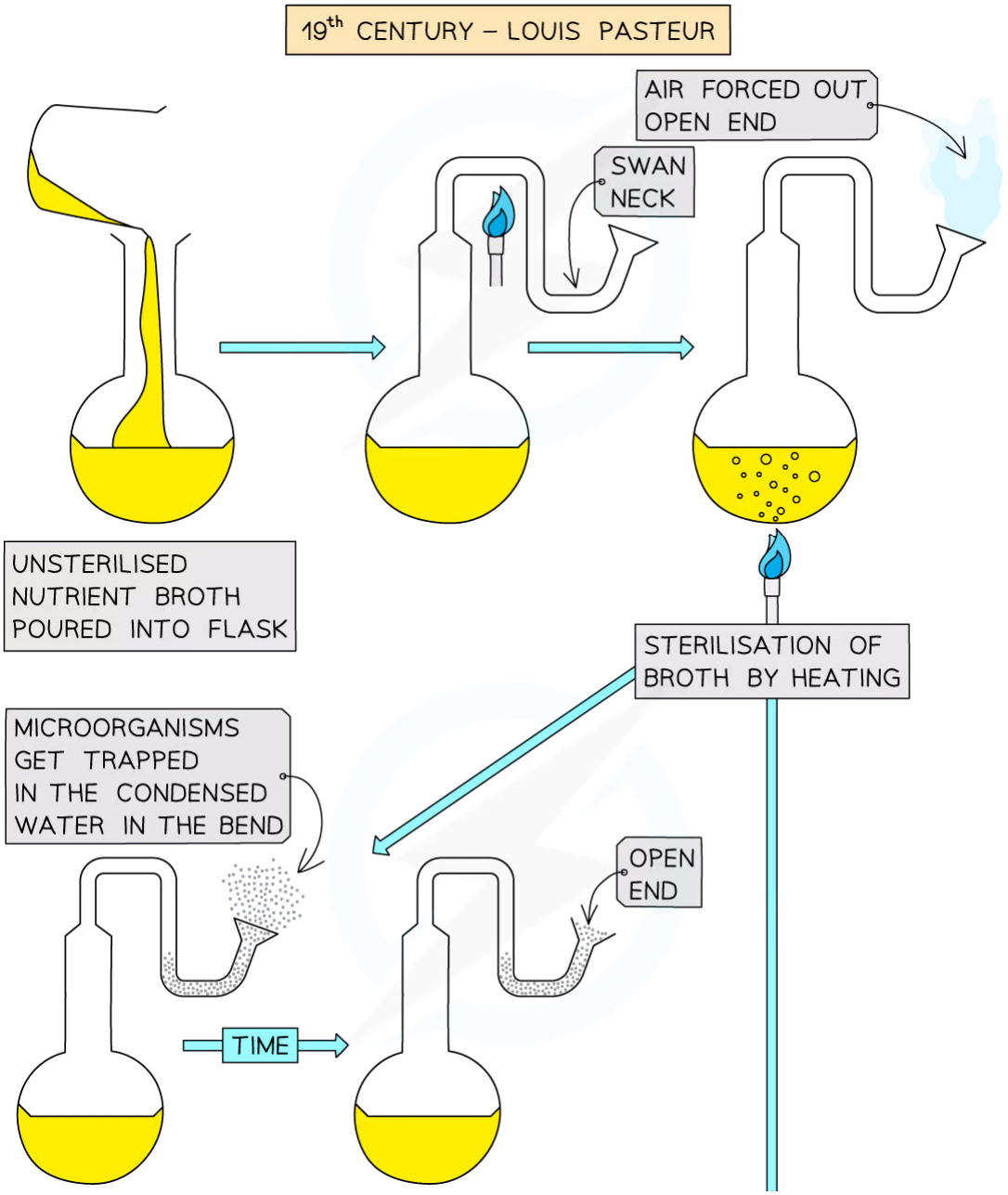

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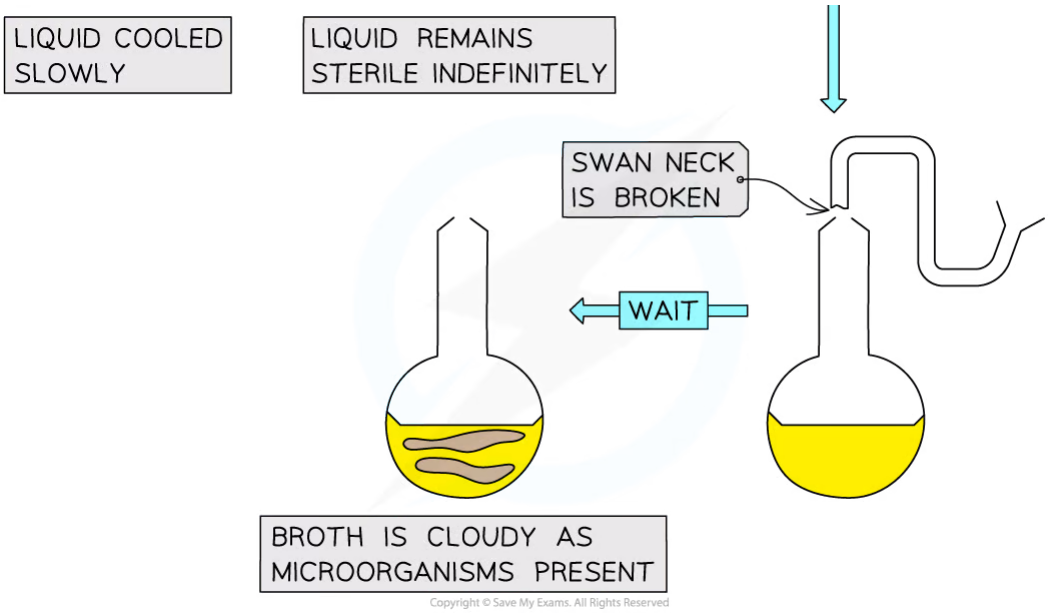

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Experiments disproving spontaneous generation

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

YOUR NOTES

- 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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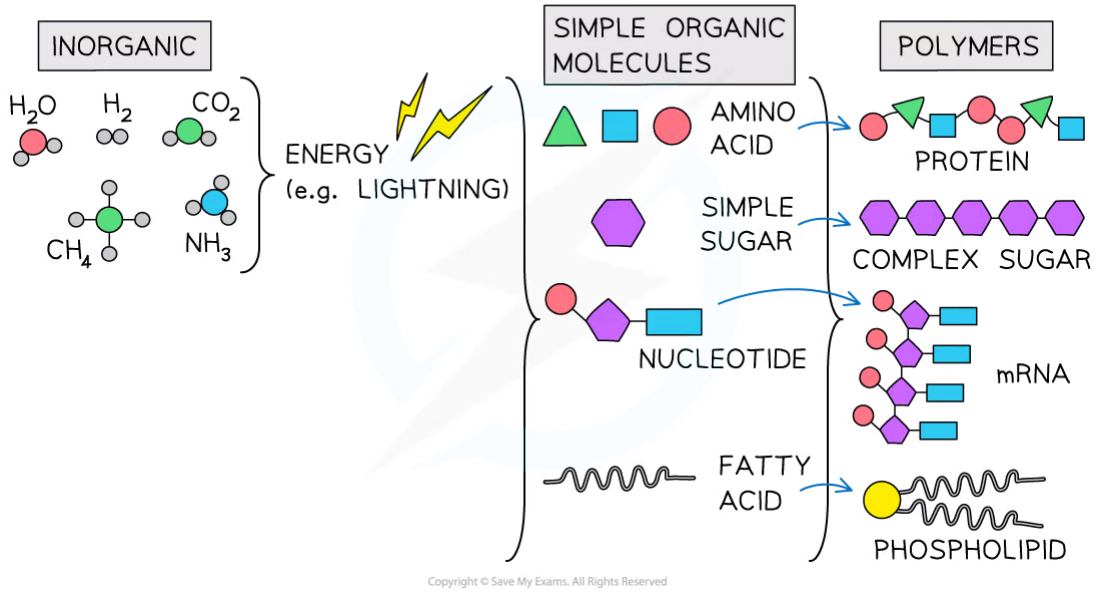
YOUR NOTES

1 & 2 ENERGY SYNTHESISES INORGANIC MOLECULES INTO SIMPLE ORGANIC MOLECULES WHICH THEN ASSEMBLE INTO POLYMERS



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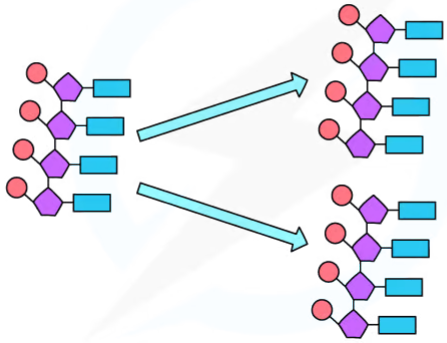
3 SOME POLYMERS DEVELOP THE ABILITY TO SELF-REPLICATE



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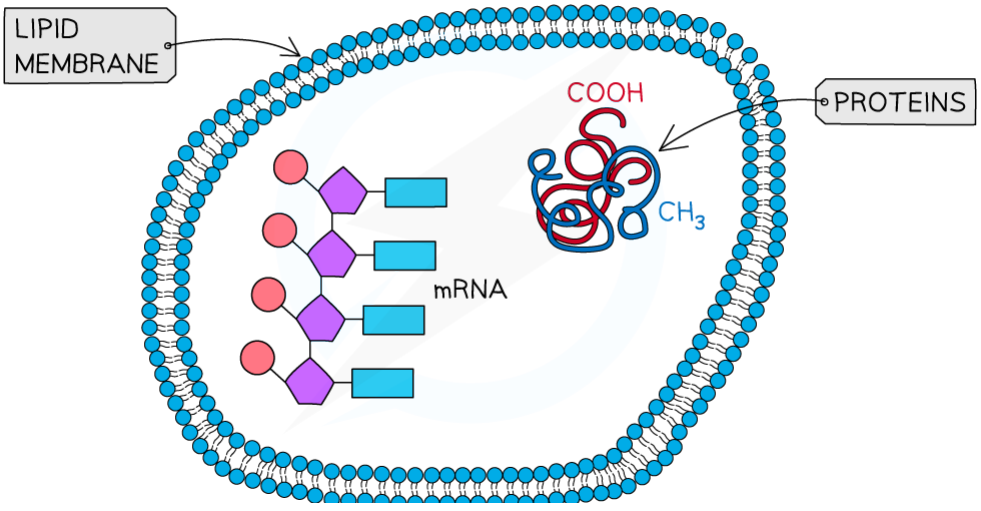
4 MEMBRANES FORM AROUND THE POLYMERS



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YOUR NOTES

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**
  - 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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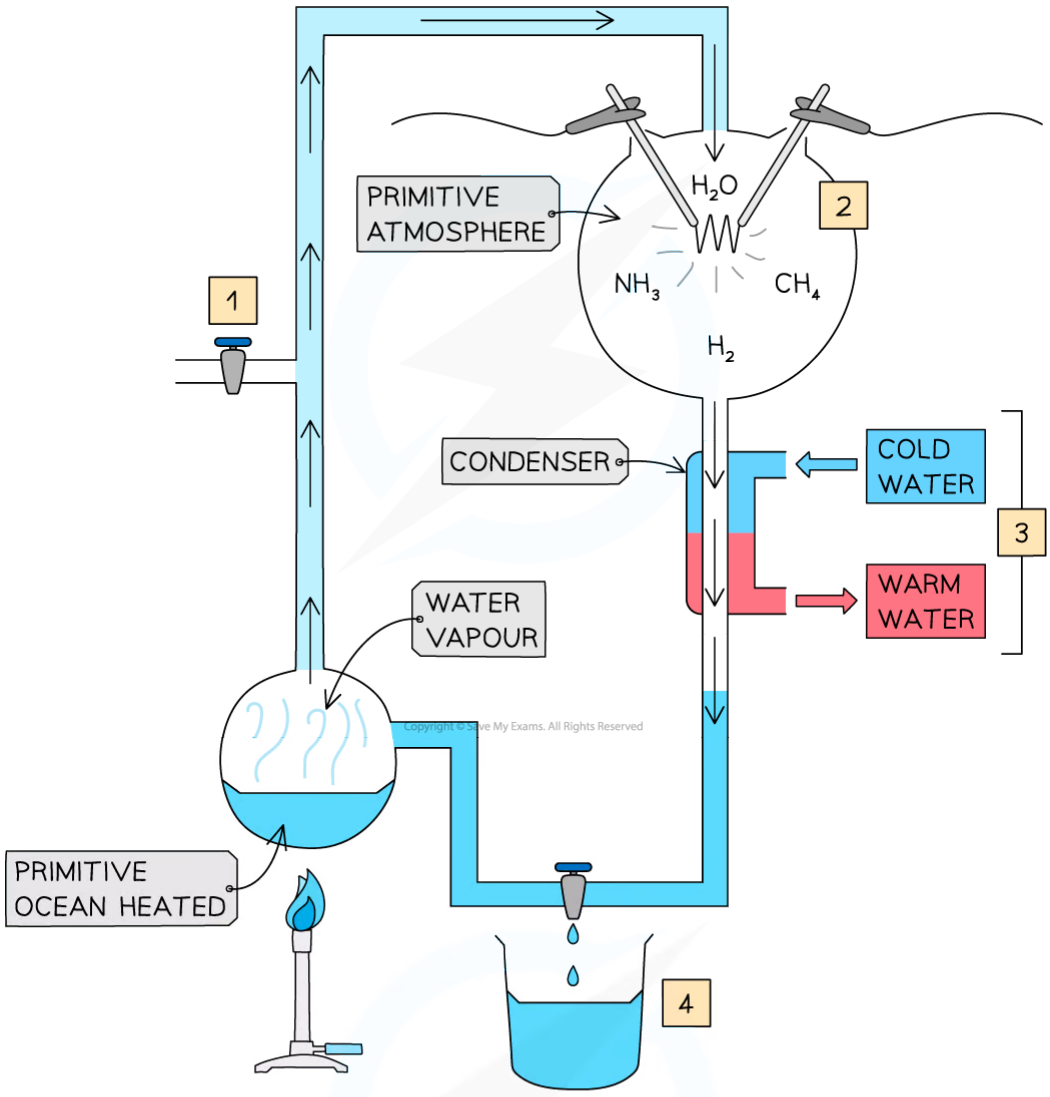

1	TO REPRESENT THE PRIMITIVE ATMOSPHERE METHANE, AMMONIA, HYDROGEN ARE ADDED TO THE WATER VAPOUR
2	ELECTRICAL DISCHARGE TO MODEL LIGHTNING (PROVIDES ENERGY TO SYNTHESISE) NEW COMPOUNDS
3	THE CONDENSER COOLS THE 'ATMOSPHERIC GASSES', WHICH CONDENSE
4	THE CONDENSER LIQUID IS COLLECTED AND ANALYSED

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The apparatus used by Miller and Urey

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Exam Tip

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

YOUR NOTES

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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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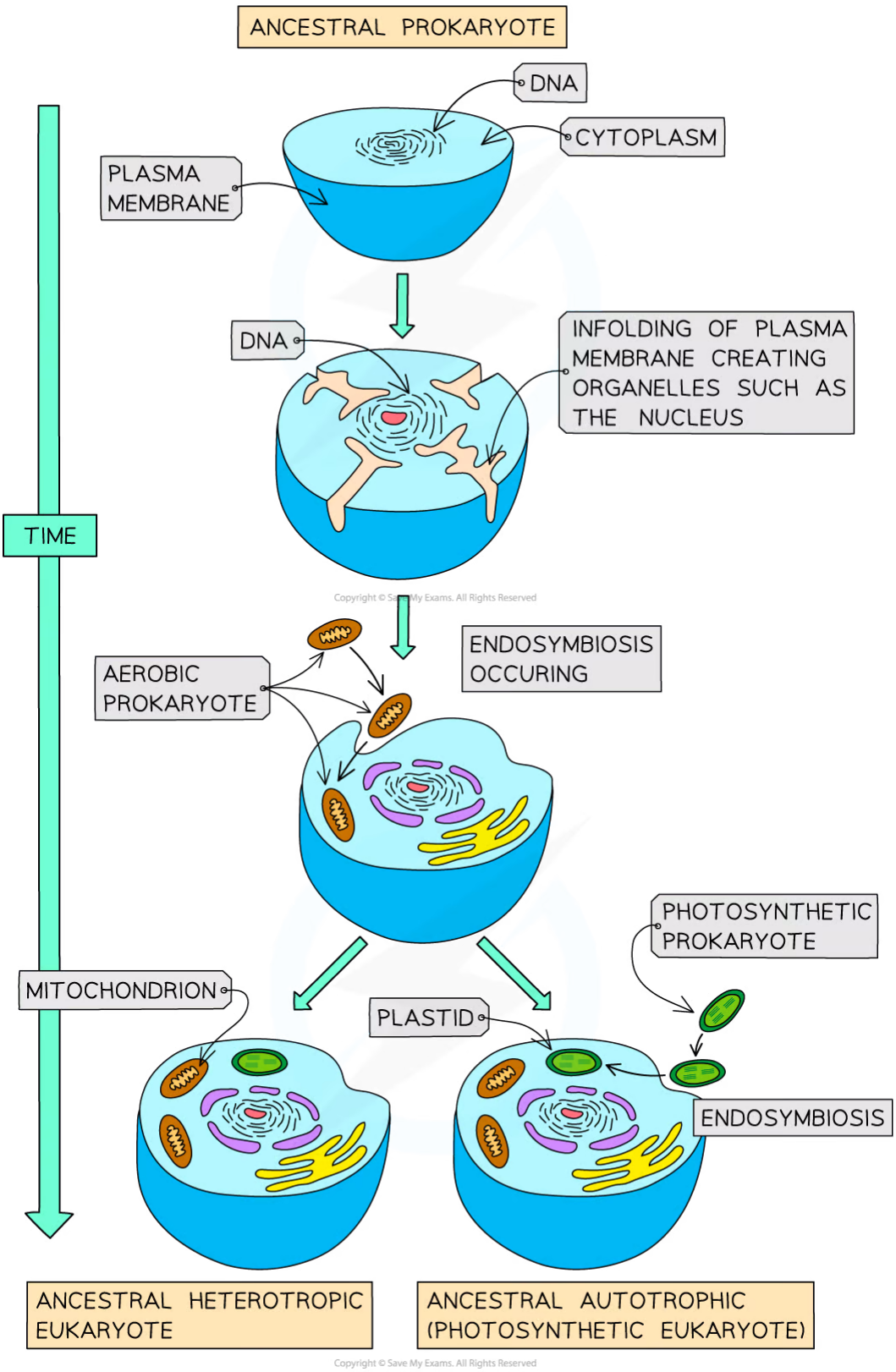

The endosymbiotic theory – an explanation for the evolution of eukaryotic cells

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Evidence to support the endosymbiotic theory

YOUR NOTES

- 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**

Exam Tip

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

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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
- 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**

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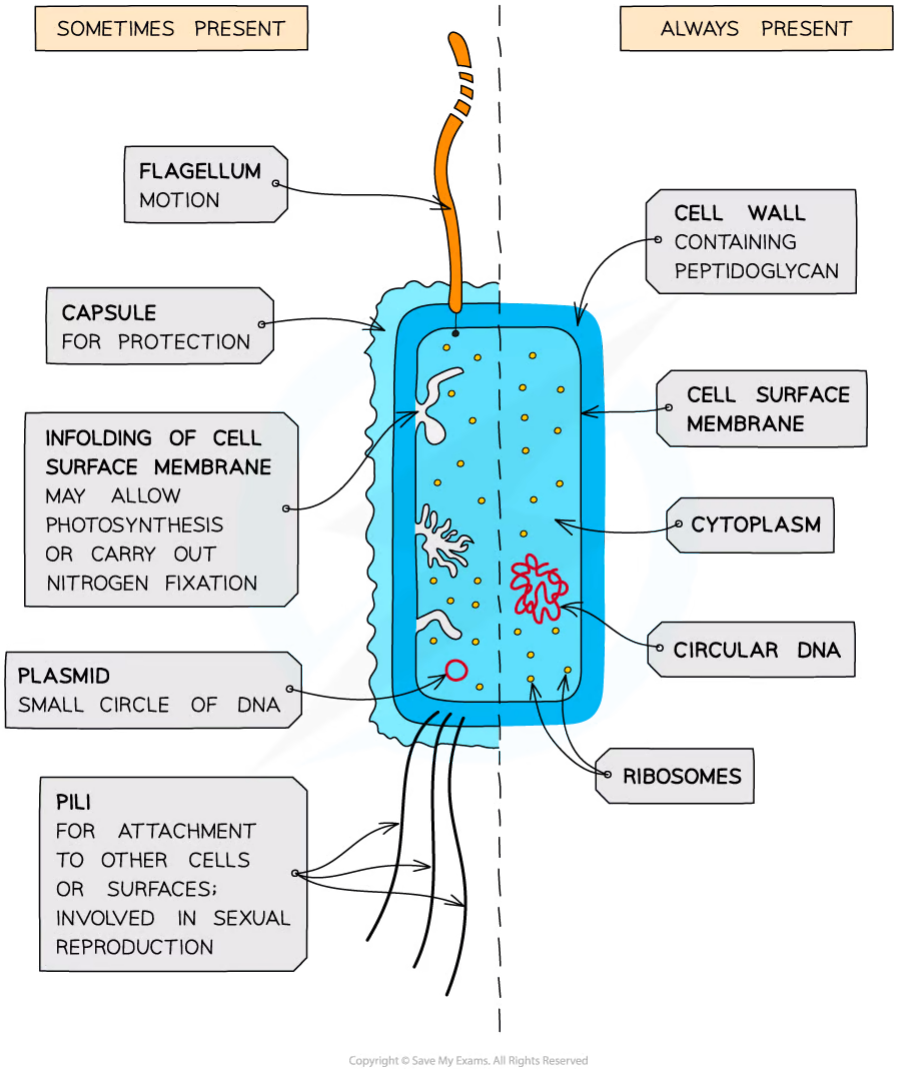
YOUR NOTES

- 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

Exam 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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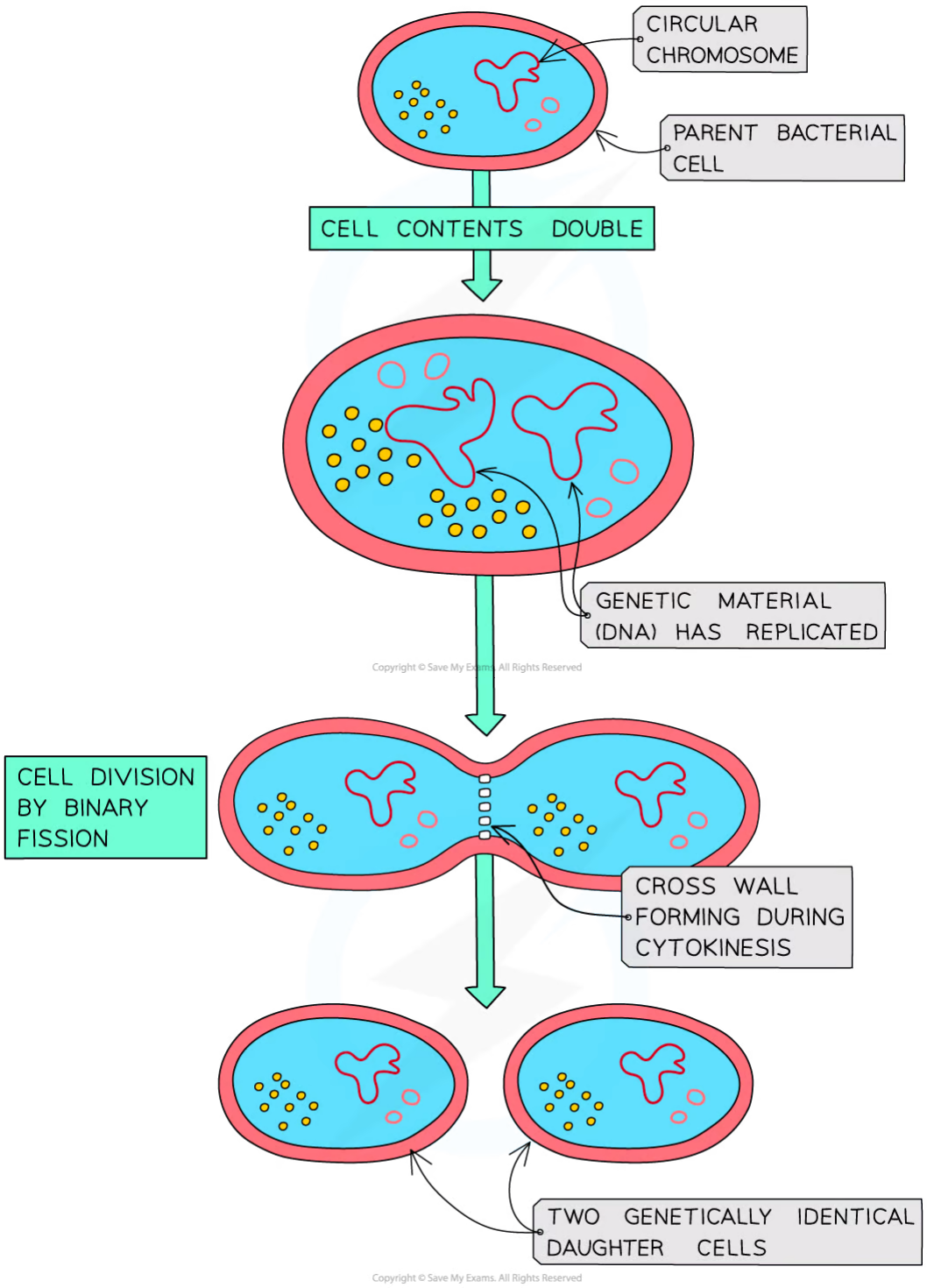

Prokaryotes divide by binary fission

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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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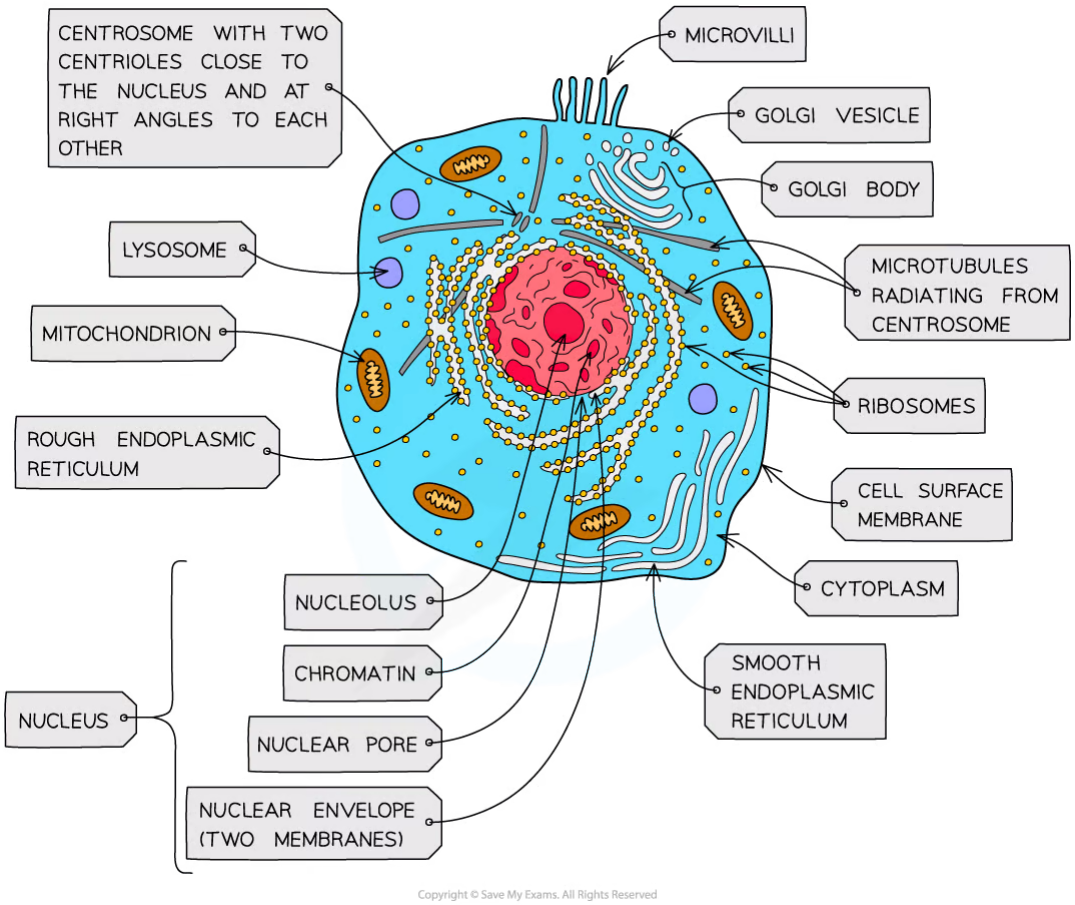

The ultrastructure of an animal cell shows a densely packed cell – the ER and RER and ribosomes form extensive networks throughout the cell in reality

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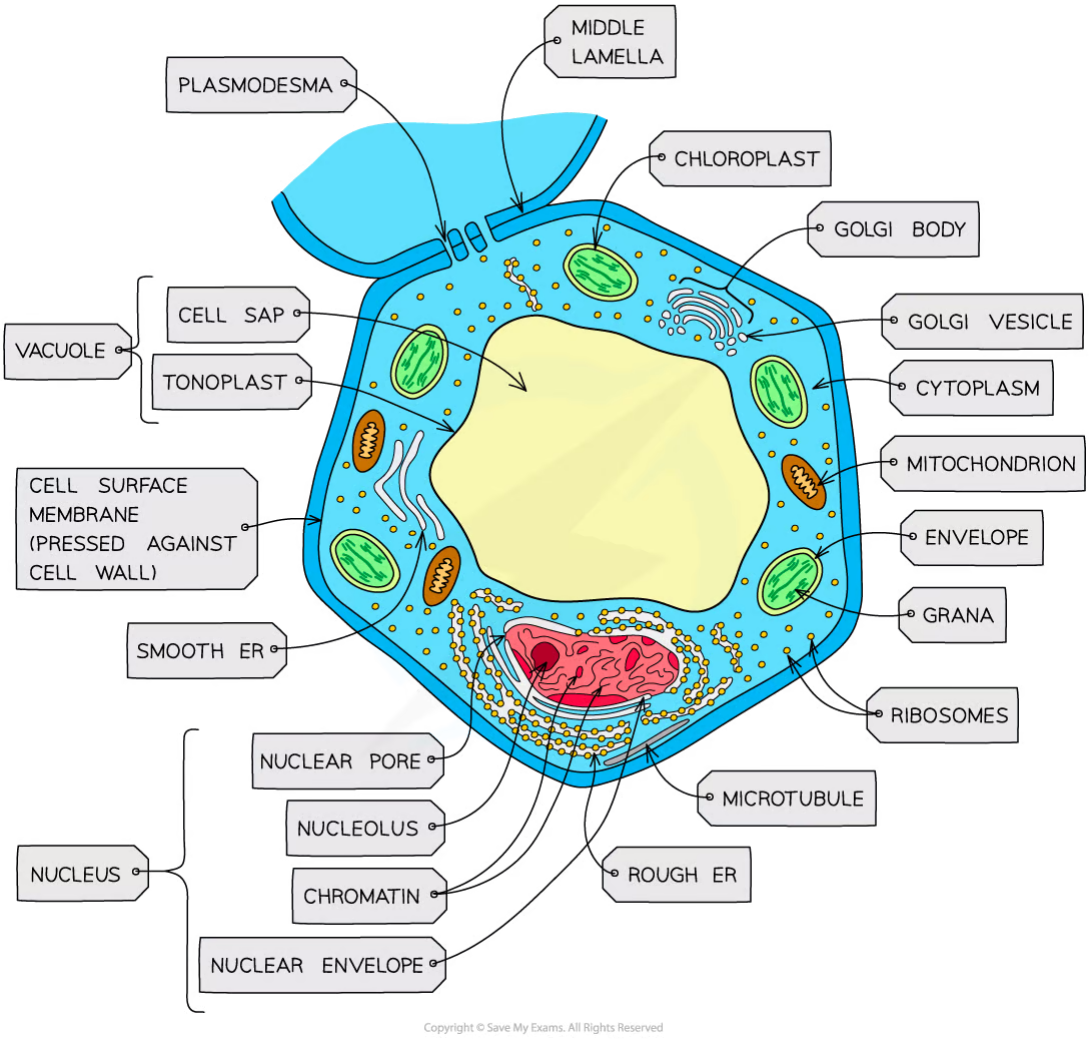

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Plant cells have a larger, more regular structure in comparison to animal cells

- 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:
  - 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)

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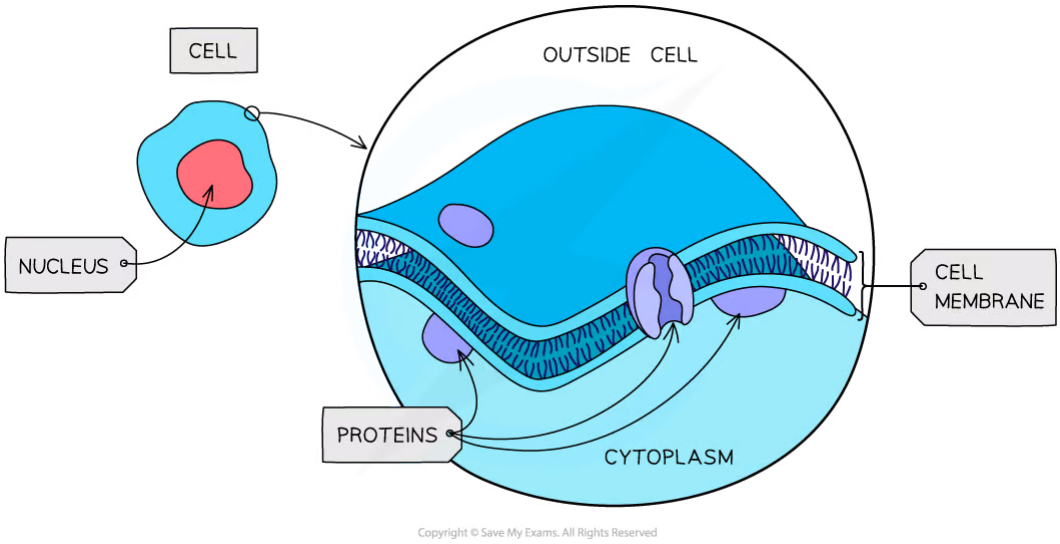
Organelles

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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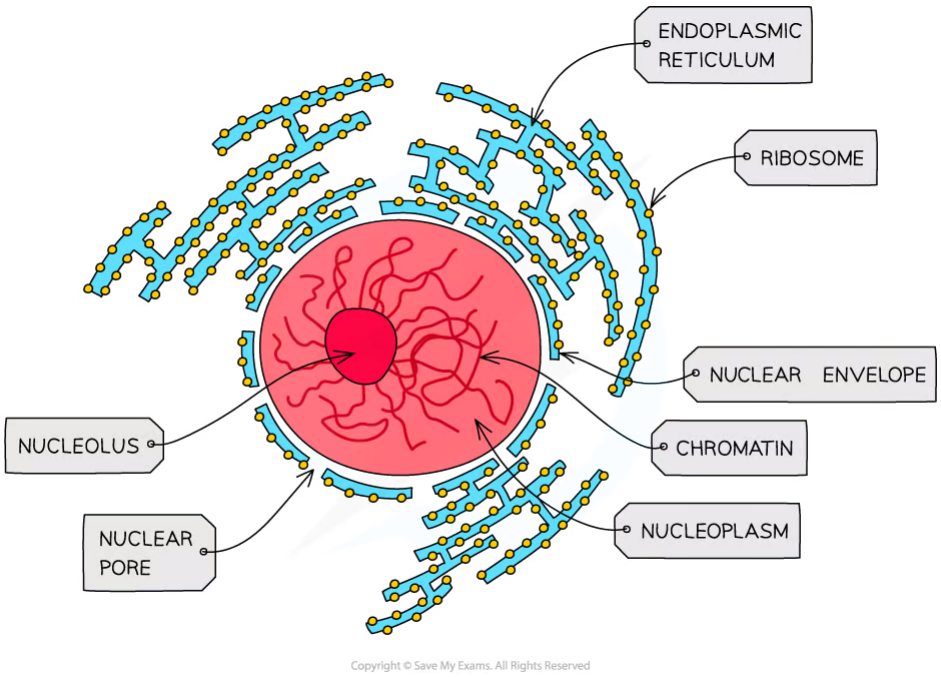

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The nucleus of a cell contains chromatin (a complex of DNA and histone proteins) which is the genetic material of the cell

- 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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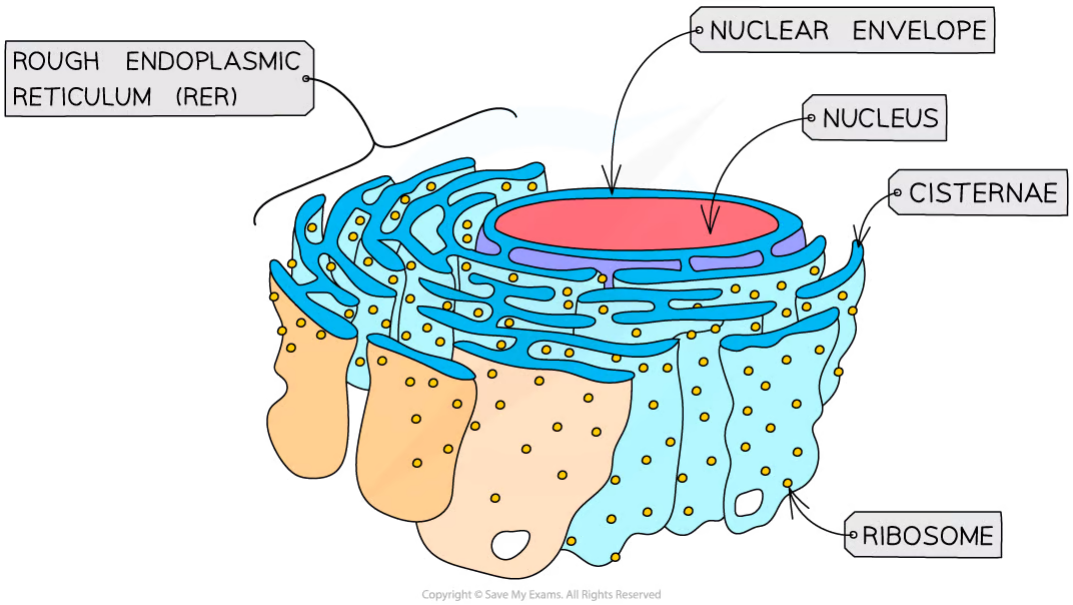

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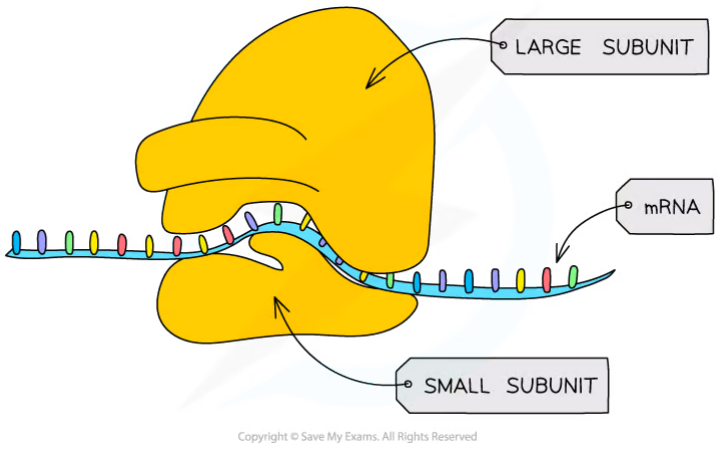
The rough endoplasmic reticulum (RER) – the attached ribosomes enable this structure to be identified in electron micrographs

- 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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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

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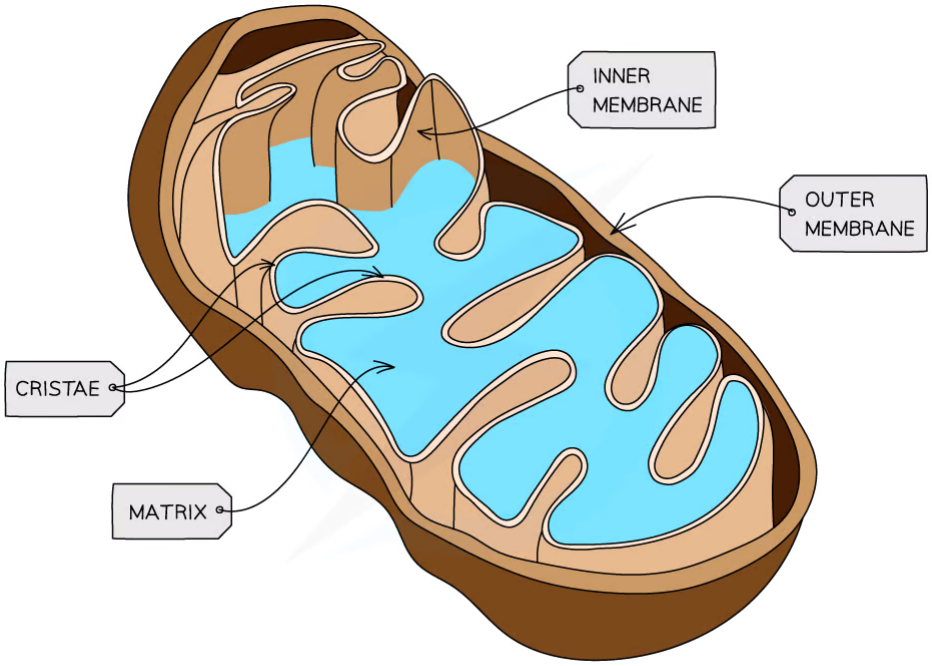
YOUR NOTES

- 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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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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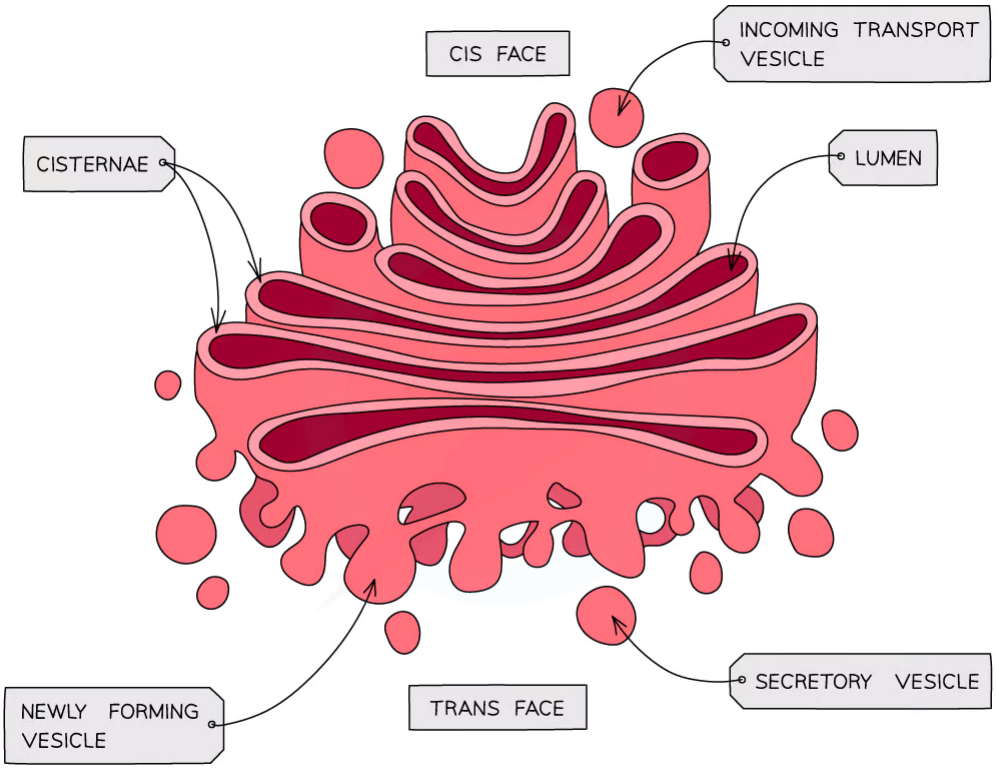

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The structure of the Golgi apparatus

- 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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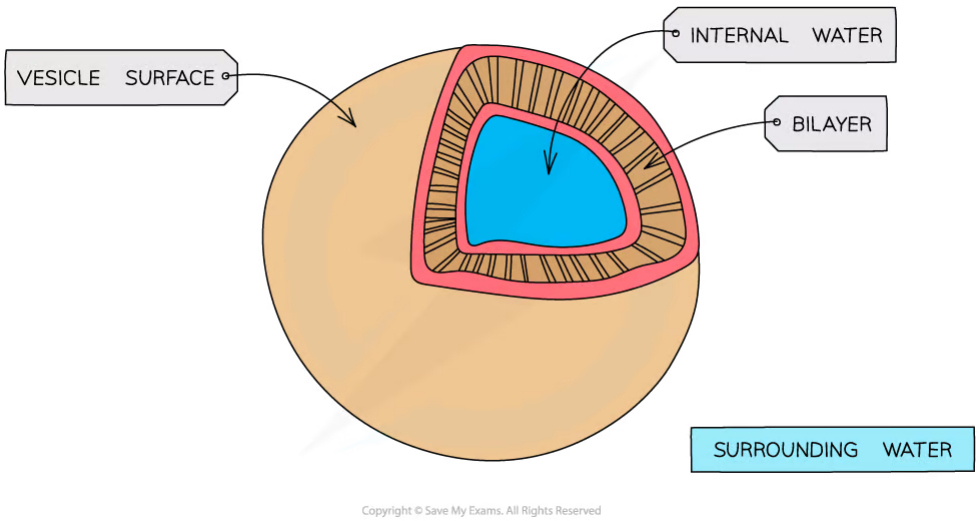
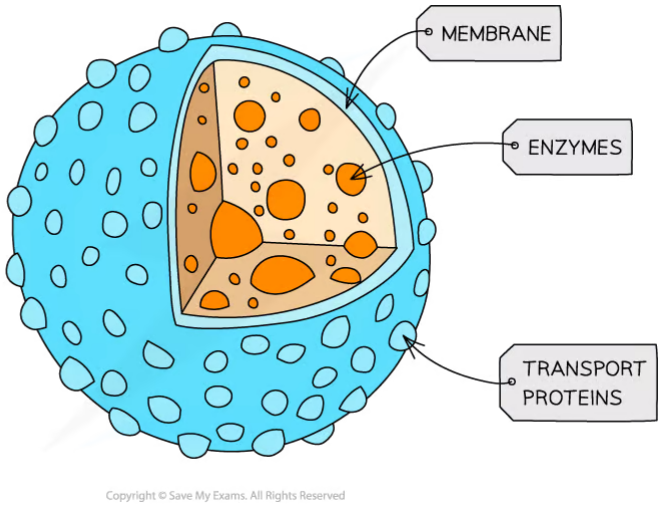


The structure of the vesicle

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

Chloroplasts

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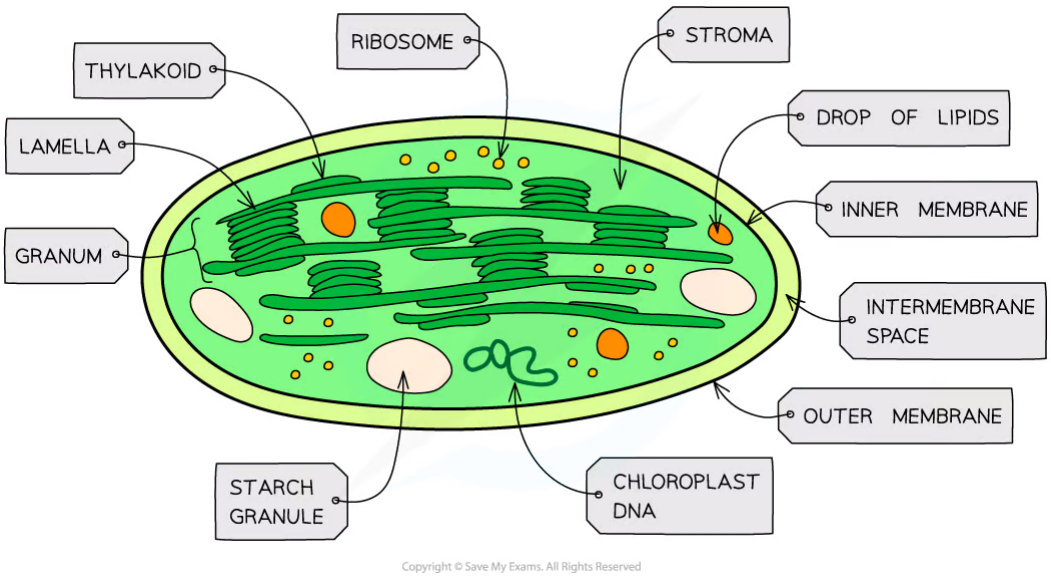
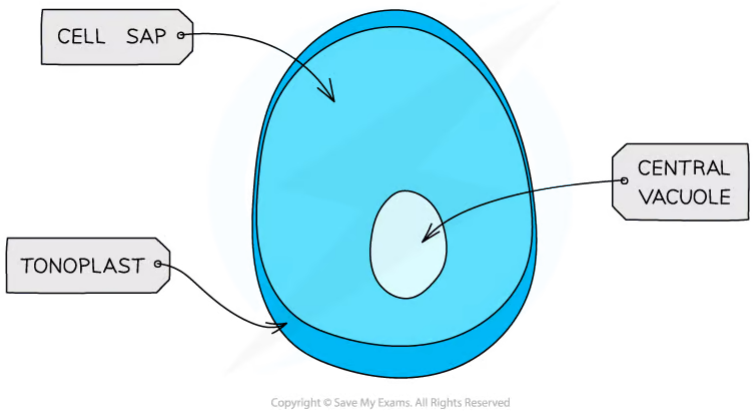


Chloroplasts are found in the green parts of a plant – the green colour a result of the photosynthetic pigment chlorophyll

- 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



The structure of the vacuole

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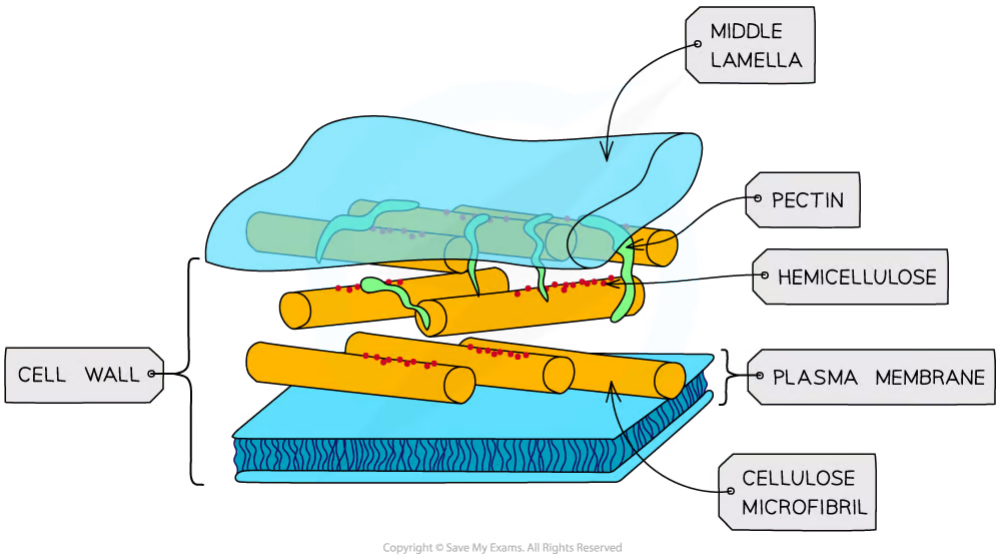
- A sac in **plant cells** surrounded by the **tonoplast**, selectively permeable membrane
- Vacuoles in animal cells are not permanent and small

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



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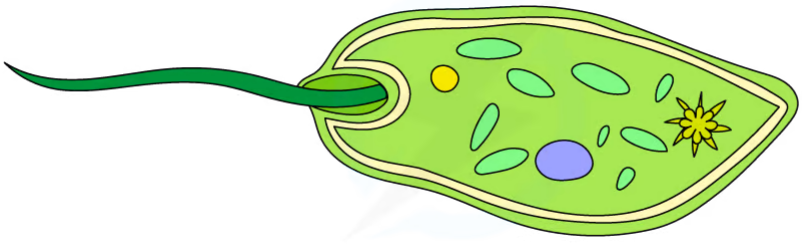
The cell wall is freely permeable to most substances (unlike the plasma membrane)

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

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**

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Centrioles

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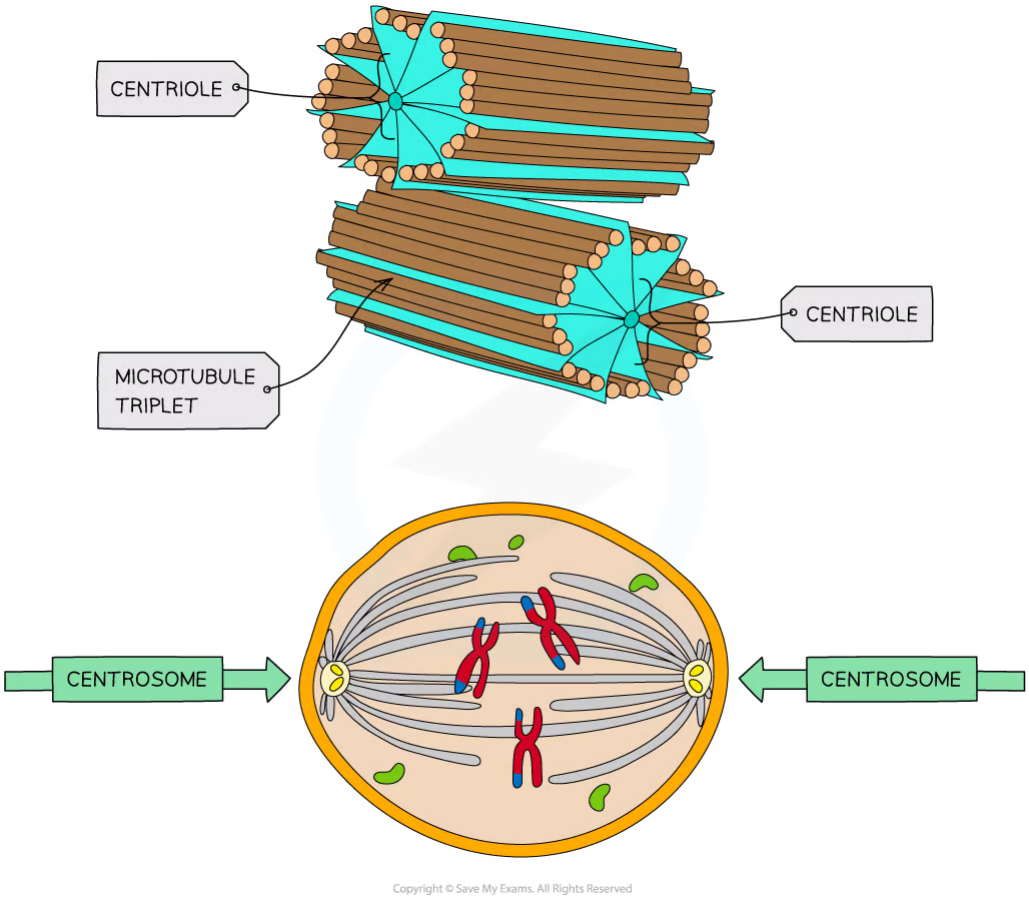

The structure of the centriole

- 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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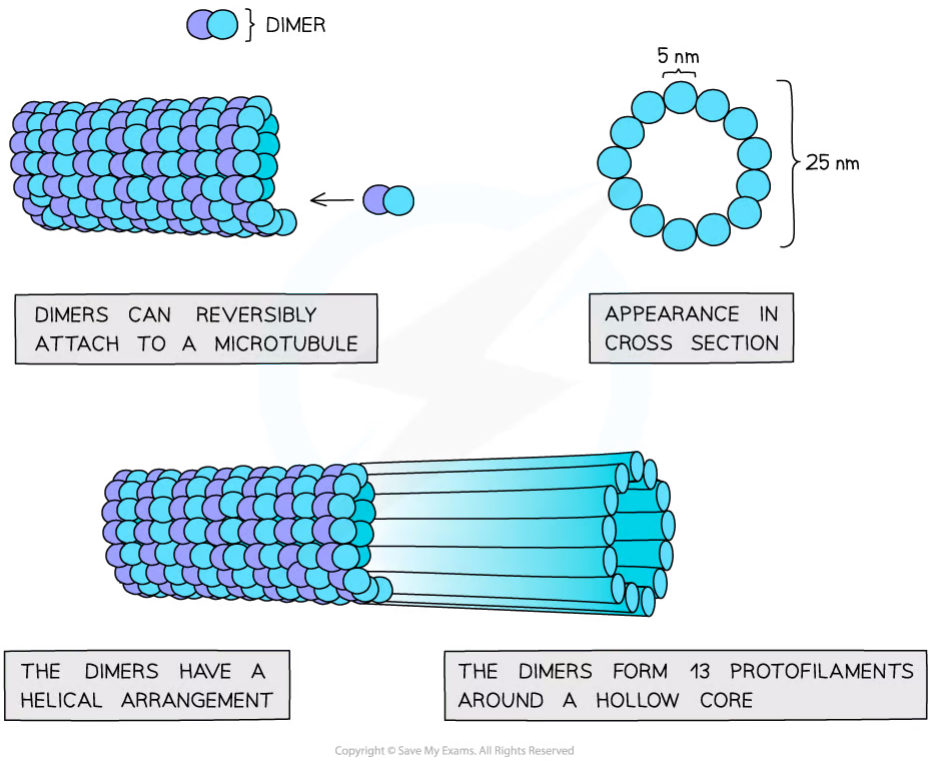

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The structure of the microtubule

- 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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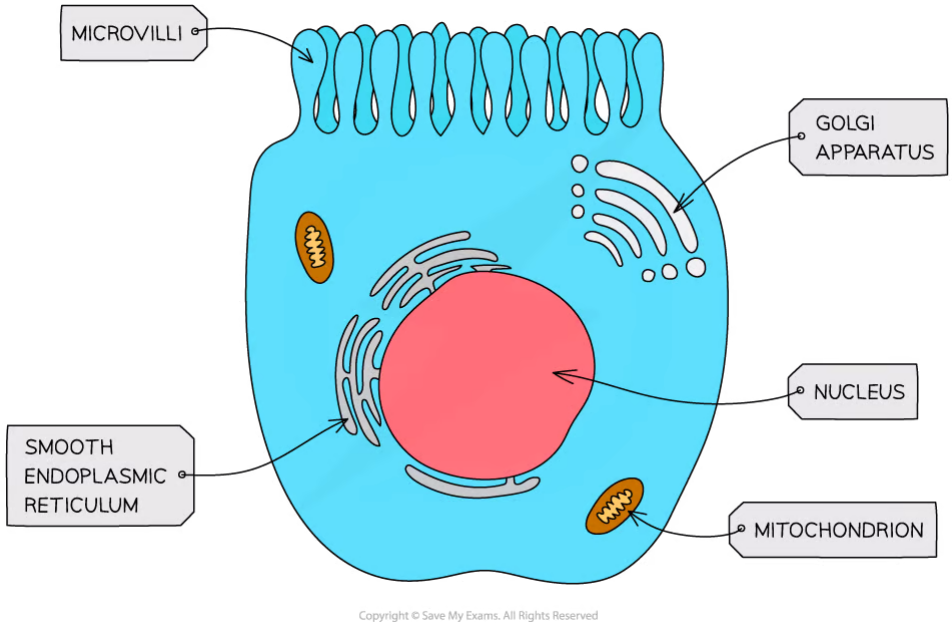

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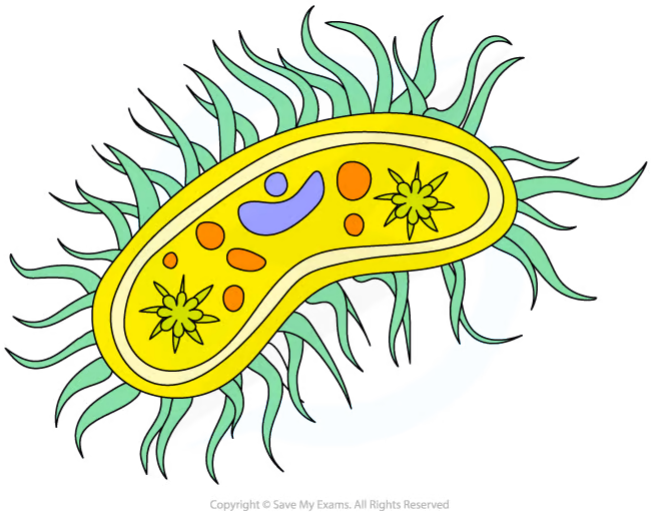
The structure of the microvilli

- 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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The structure of the cilia

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

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Exam 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)!

YOUR NOTES

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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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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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Exam 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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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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YOUR NOTES

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
- **Disadvantages** of TEMs:
  - They can only be used with **very thin specimens** or **thin sections** of the object being observed

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YOUR NOTES

- 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

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

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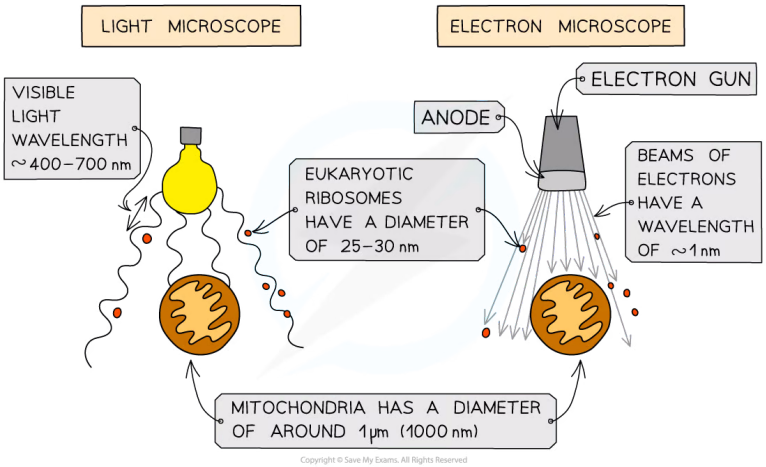
chromosome position within the stages of mitosis are visible

YOUR NOTES



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

Exam Tip

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

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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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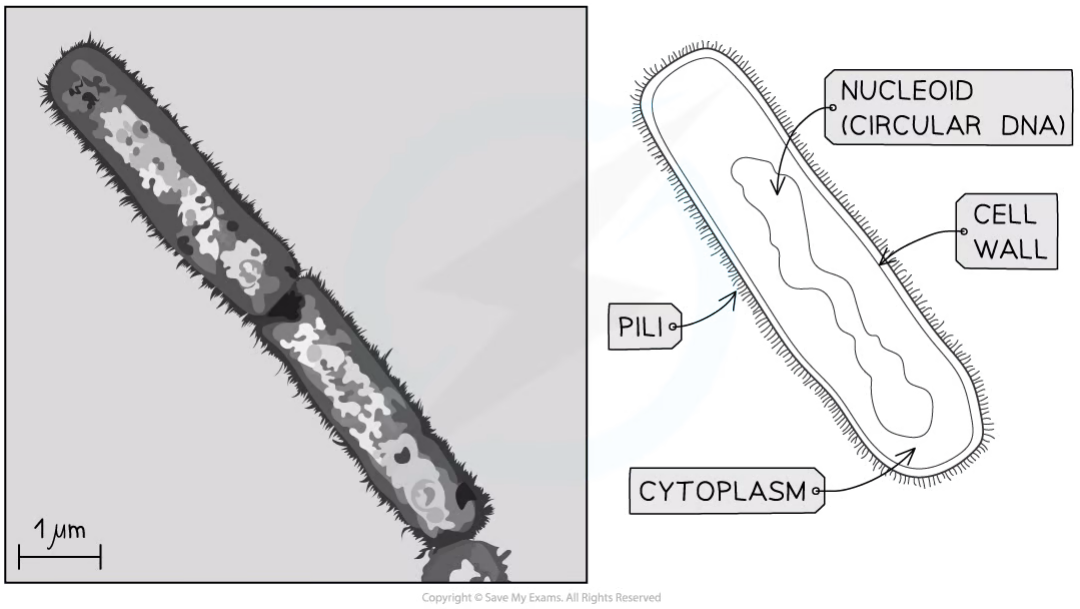
Drawing Prokaryotic Cells

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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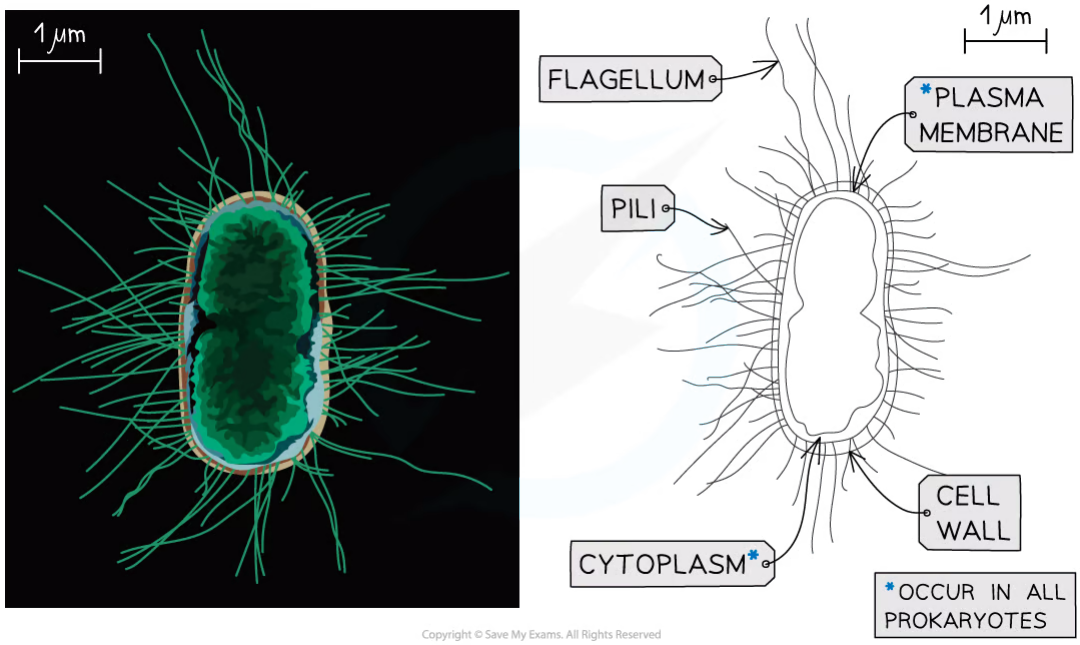
Transmission electron micrograph of a prokaryote and drawing



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Scanning electron micrograph of an E.coli and drawing

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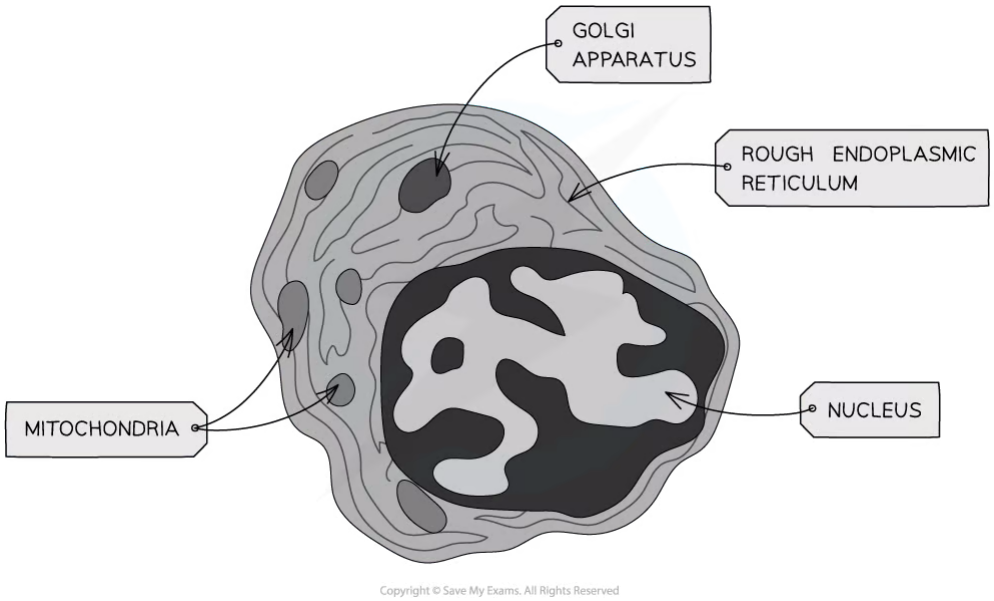
Drawing Eukaryotic Cells

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



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TEM electron micrograph of an animal cell showing key features

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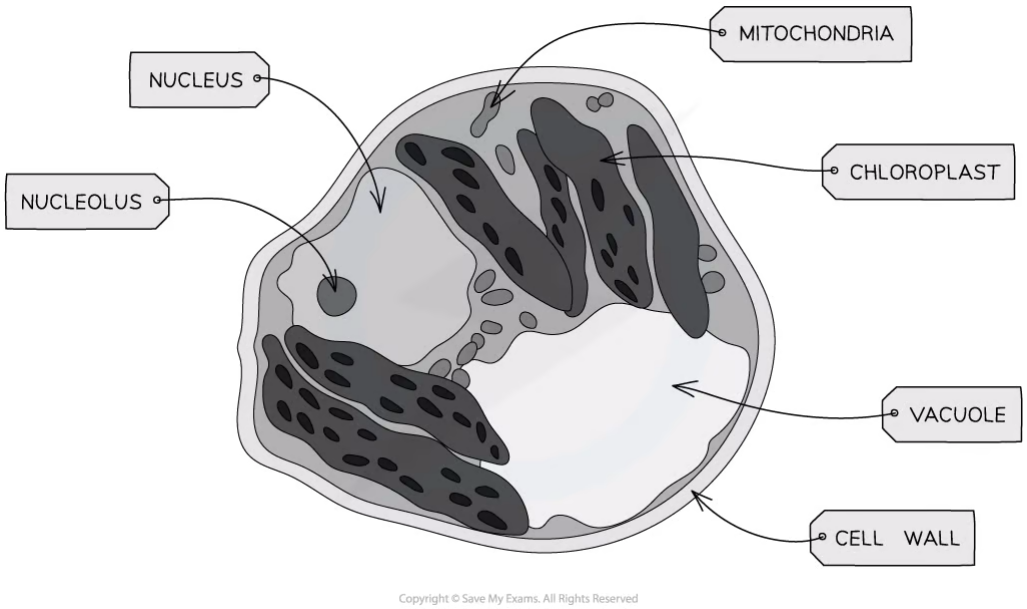

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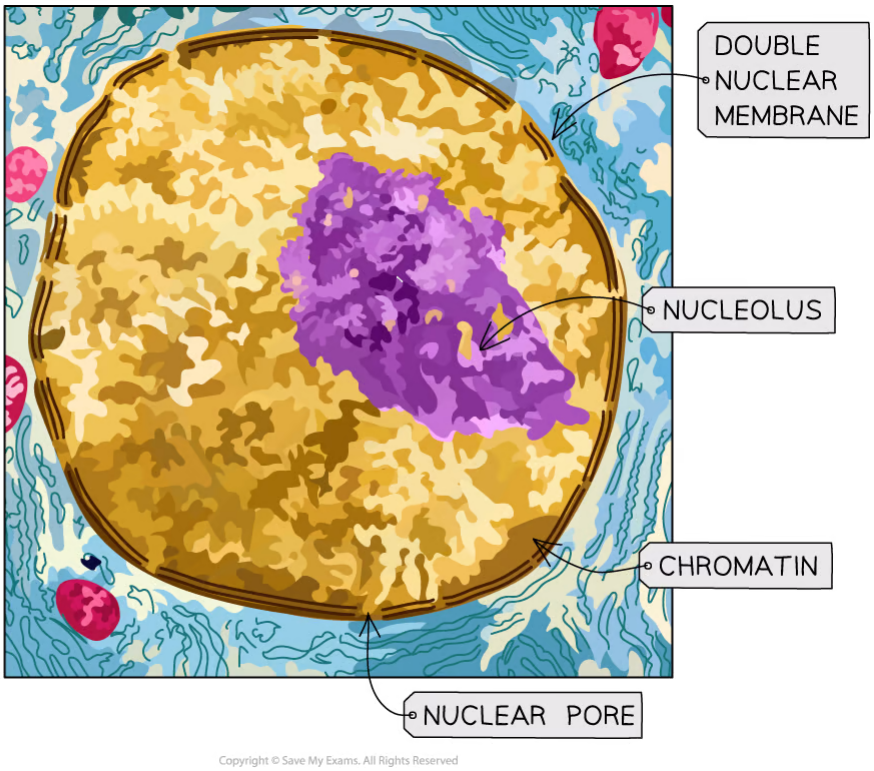
TEM electron micrograph of a plant cell showing key features

- 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 presence of a vacuole in a micrograph is a good indicator of the cell type



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Electron micrograph of the nucleus

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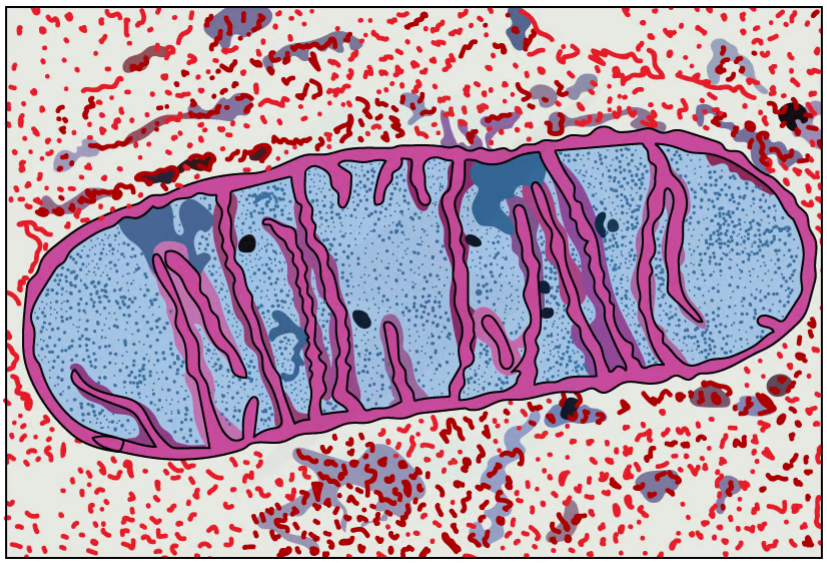
- The nucleus should be clearly identifiable as it is the largest structure in the eukaryotic cell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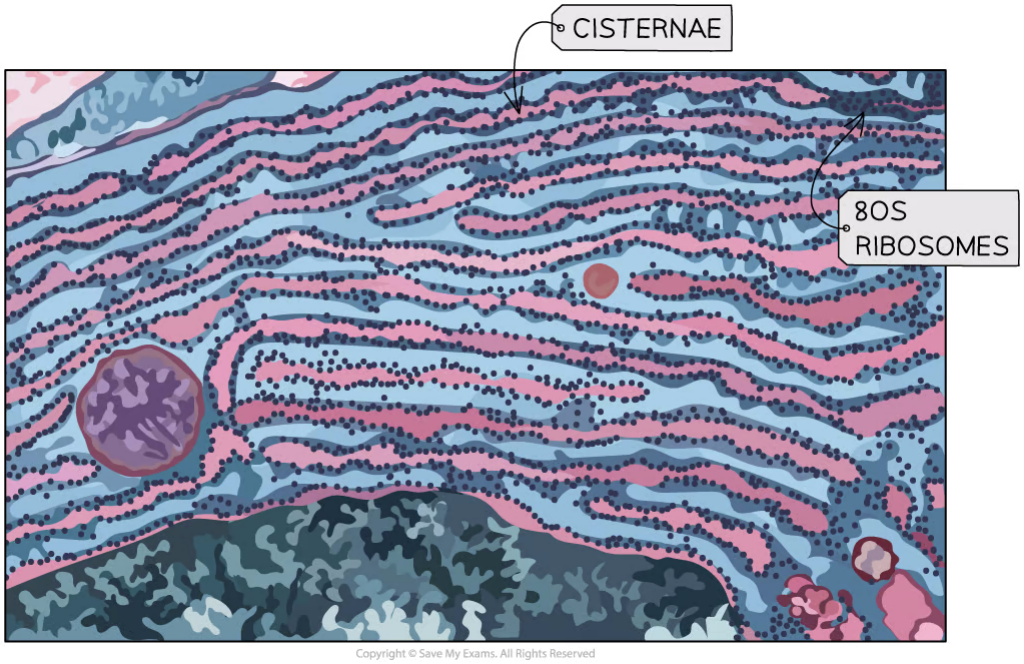
Electron micrograph of the mitochondrion

- 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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Electron micrograph of the rough endoplasmic reticulum

- 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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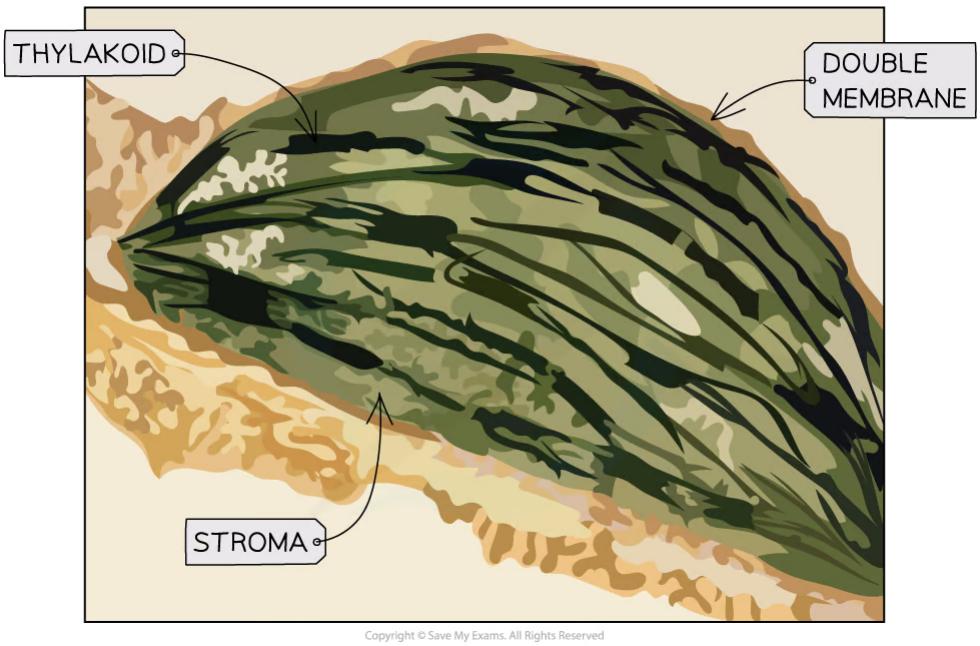

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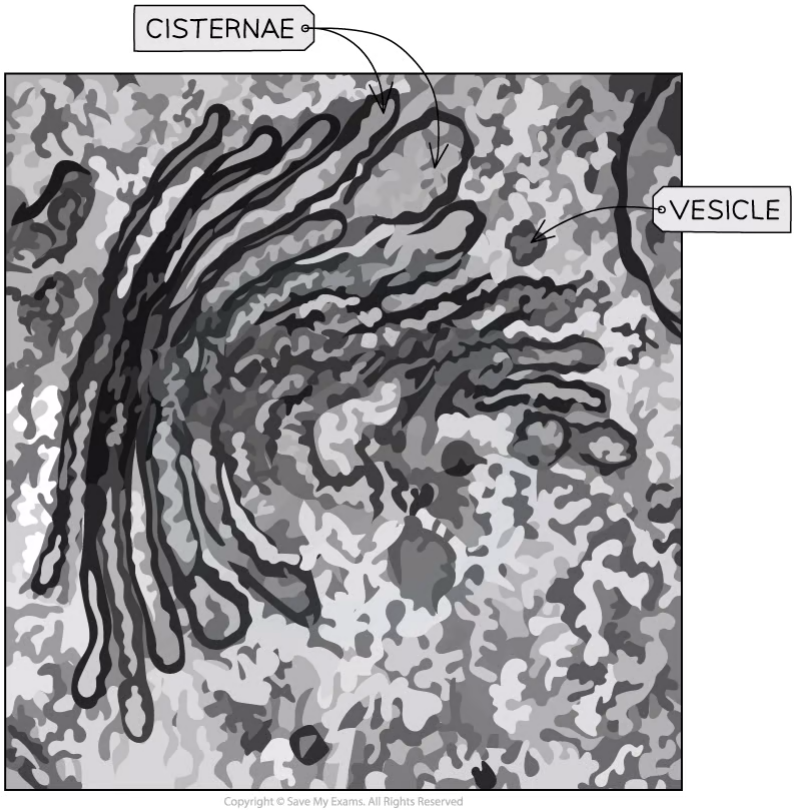
Electron micrograph of the chloroplast

- 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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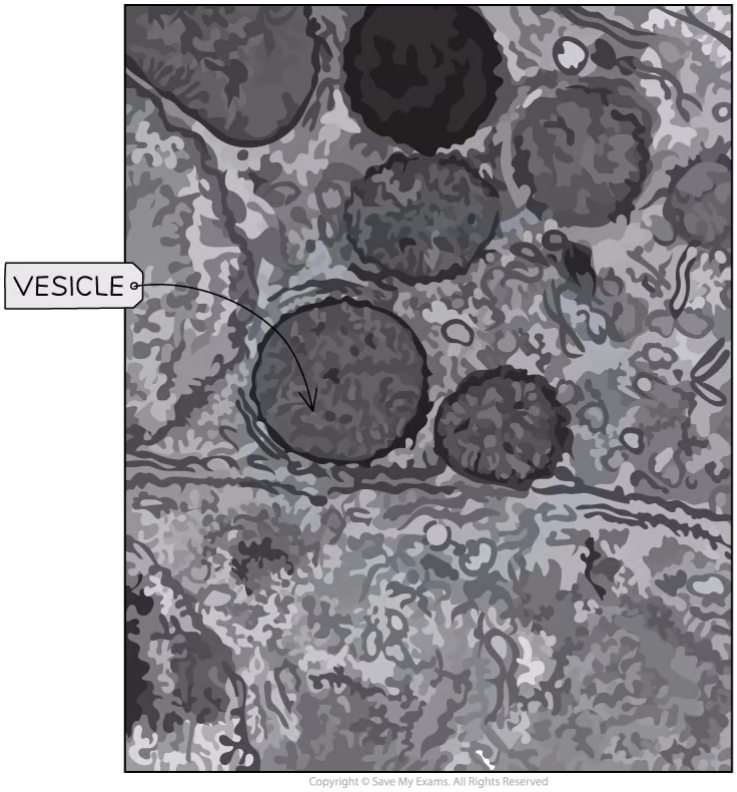
YOUR NOTES

Electron micrograph of the Golgi apparatus

- 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 vesicles

- Vesicles are spherical shapes

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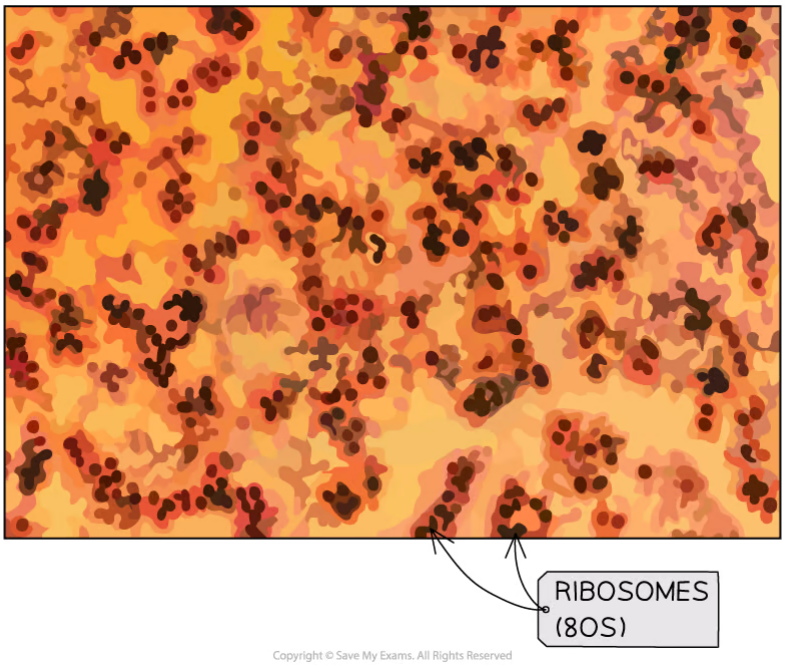

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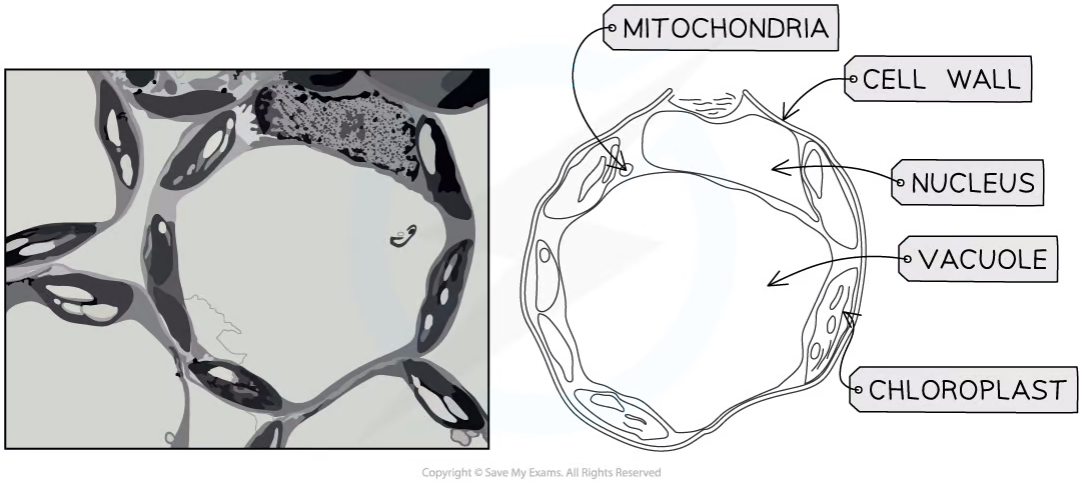
Electron micrograph of the ribosomes

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



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Electron micrograph and drawing of a palisade mesophyll cell

- The palisade mesophyll electron micrograph will have:
  - 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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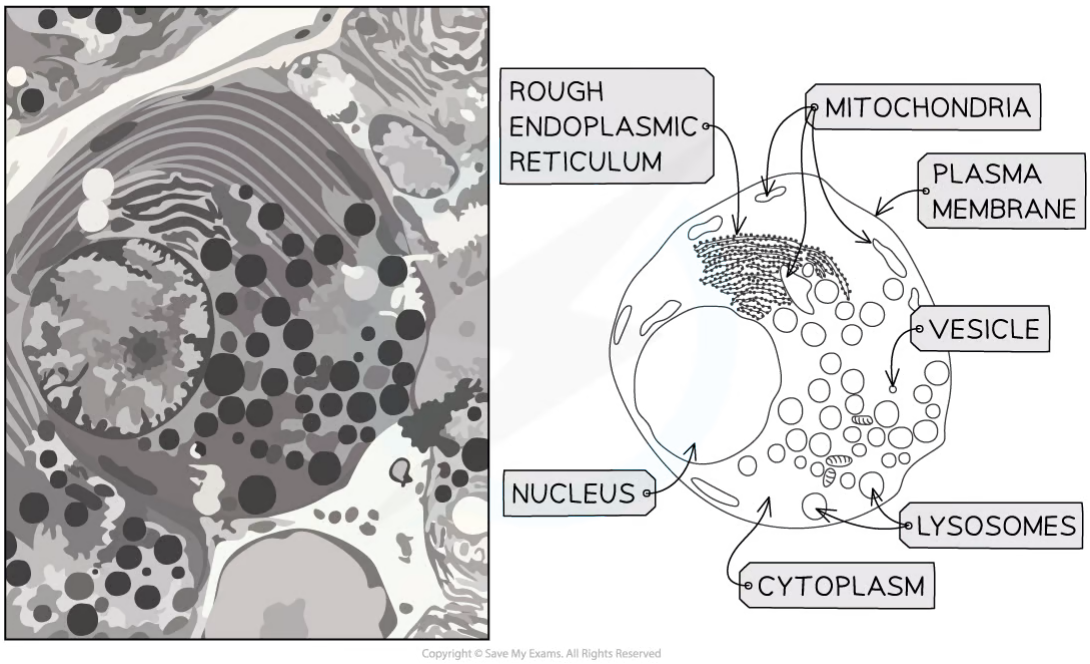

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Electron micrograph and drawing of an exocrine gland cell of the pancreas

- An exocrine gland cell of the pancreas will:
  - Have many large secretory vesicles (carrying the digestive enzymes)
  - Have many **mitochondria**
  - Be densely packed with rough endoplasmic reticulum

Exam 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 the palisade mesophyll cell 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 the exocrine pancreatic gland cell look for the presence of secretory vesicles carrying the digestive enzymes and the large numbers of rough endoplasmic reticulum.

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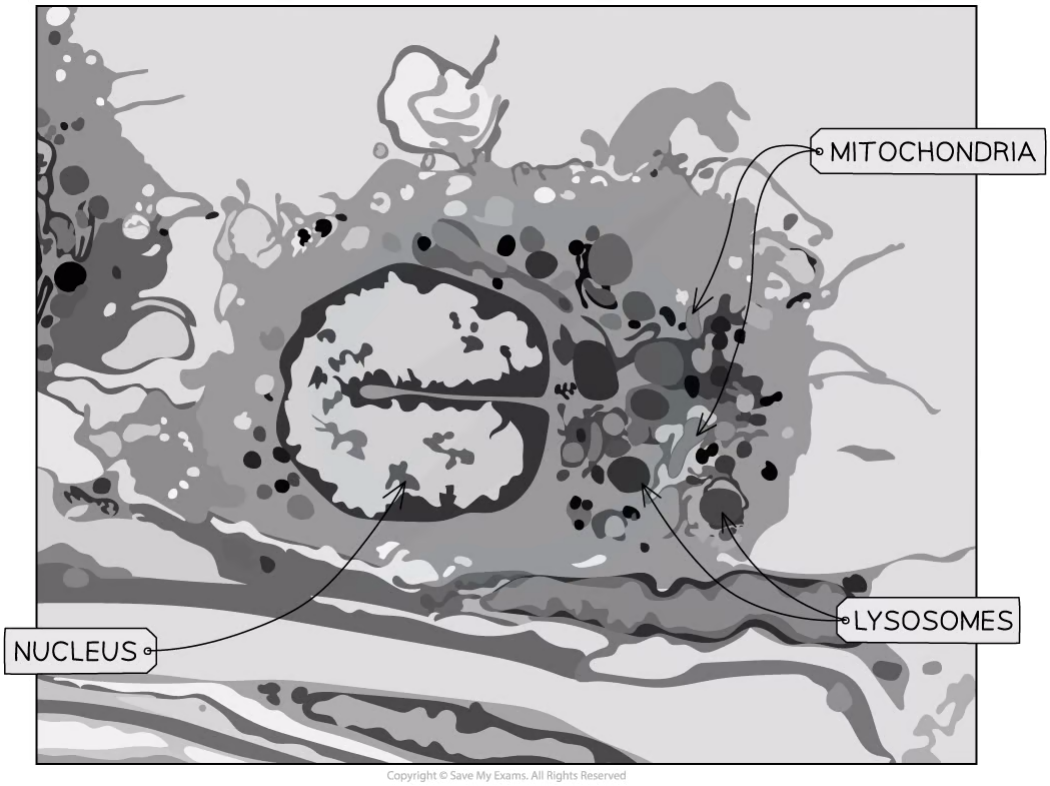
YOUR NOTES

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



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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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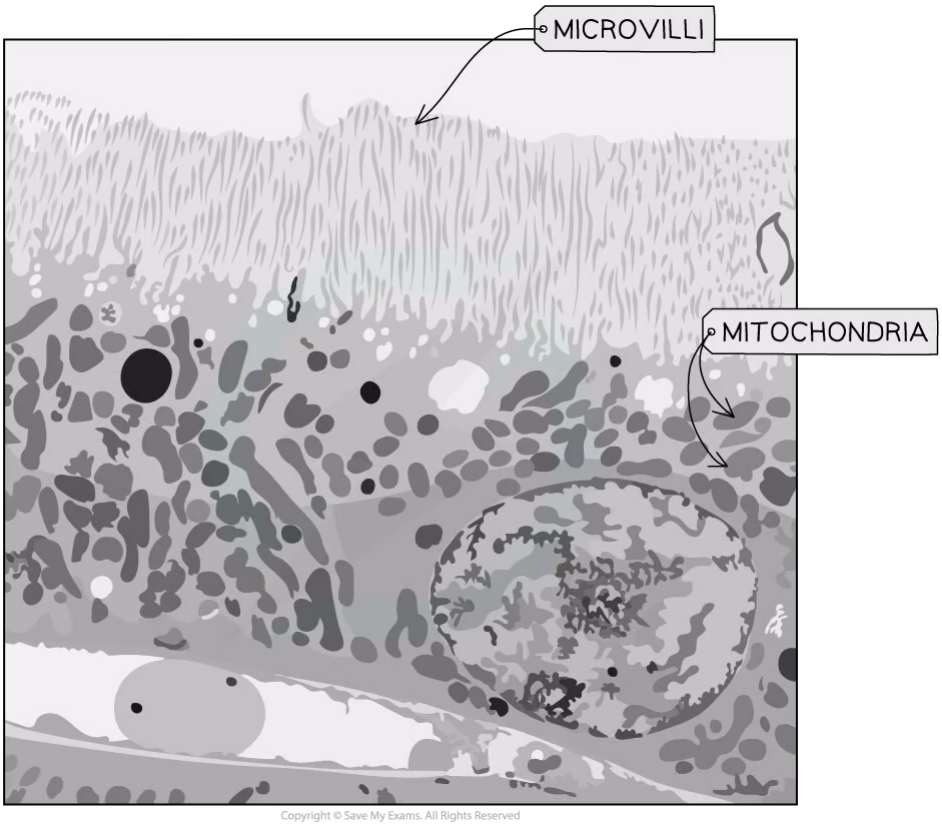

Electron micrograph of cell 2

- 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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YOUR NOTES

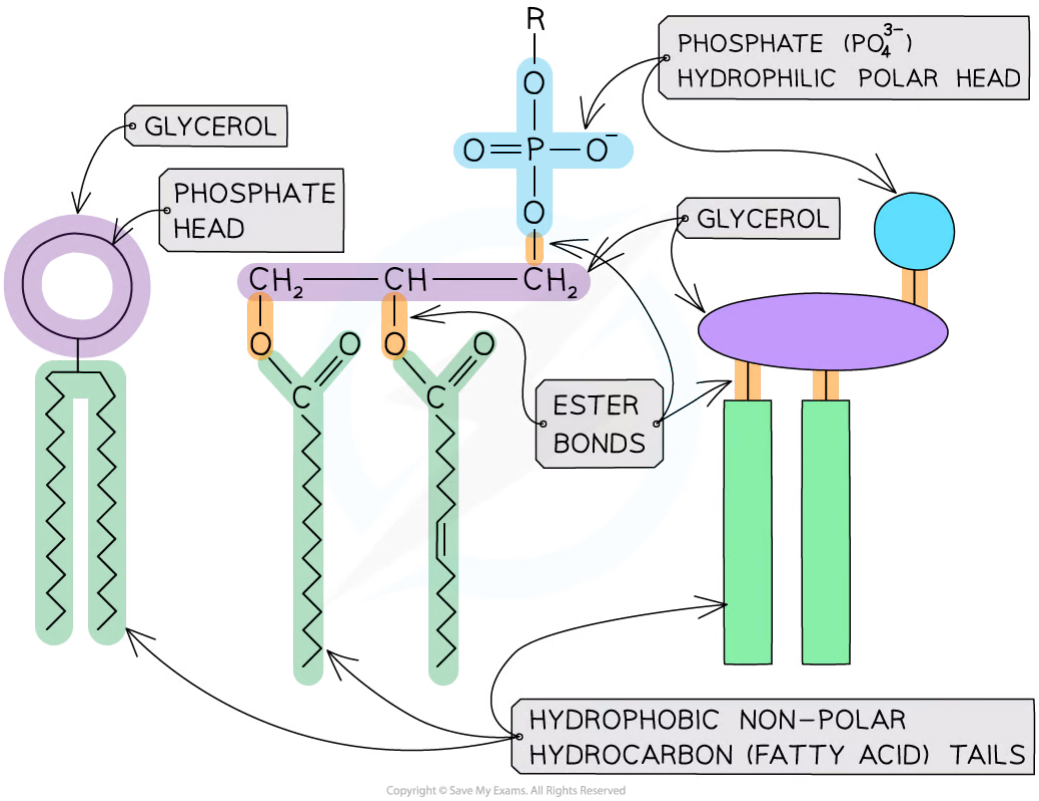
1.3 Cells: Membrane Structure & Transport

1.3.1 Phospholipid Bilayer Properties

Amphipathic Properties

Phospholipids

- Phospholipids form the basic structure of the membrane (the phospholipid bilayer)
- They are formed by a hydrophilic **phosphate head** bonding with two hydrophobic **hydrocarbon (fatty acid) tails**
- As phospholipids have a **hydrophobic** and **hydrophilic** part they are known as **amphipathic**
- The **phosphate head** of a phospholipid is **polar** (hydrophilic) and therefore **soluble** in water
- The **fatty acid tail** of a phospholipid is **nonpolar** (hydrophobic) and therefore **insoluble** in water



The generalised molecular structure of a phospholipid

- Due to their **amphipathic** properties, phospholipids display an **emergent property** when placed into water
- The **hydrophilic** phosphate heads orientate towards the water and the **hydrophobic** hydrocarbon tails orientate inwards (away from the water)
  - They form a **phospholipid monolayer**

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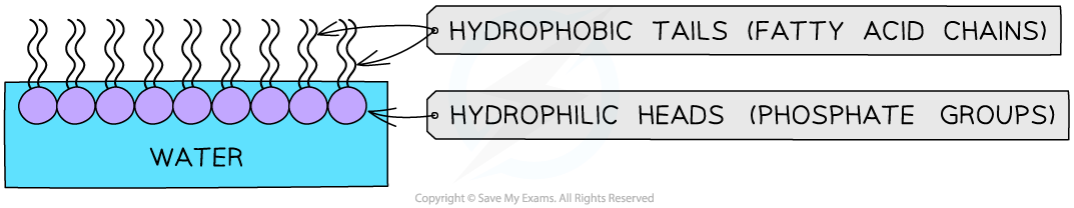
YOUR NOTES



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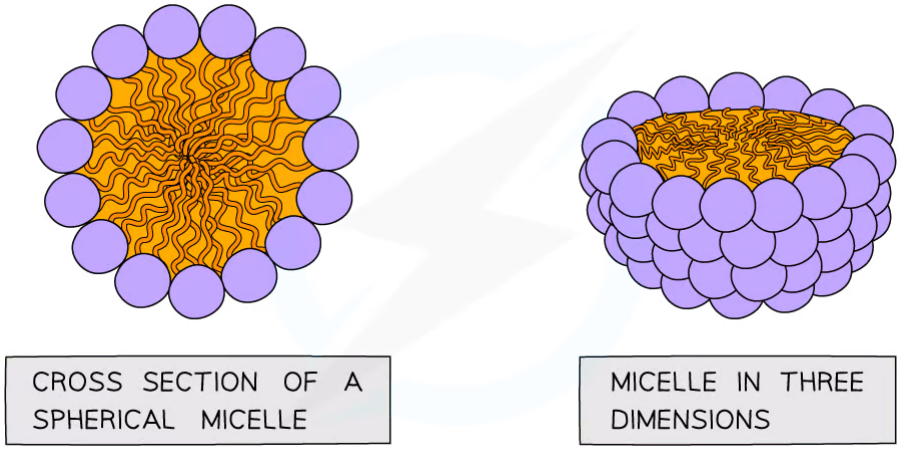
A phospholipid monolayer

- If phospholipids are **mixed/shaken** with water they form spheres with the hydrophilic phosphate heads facing out towards the water and the hydrophobic fatty acid tails facing inwards
  - This is called a **micelle**



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A micelle

- Alternatively, when there is a sufficient concentration of phospholipids present then two-layered structures may form
- These sheets are called **phospholipid bilayers** – this is the basic structure of the cell membrane

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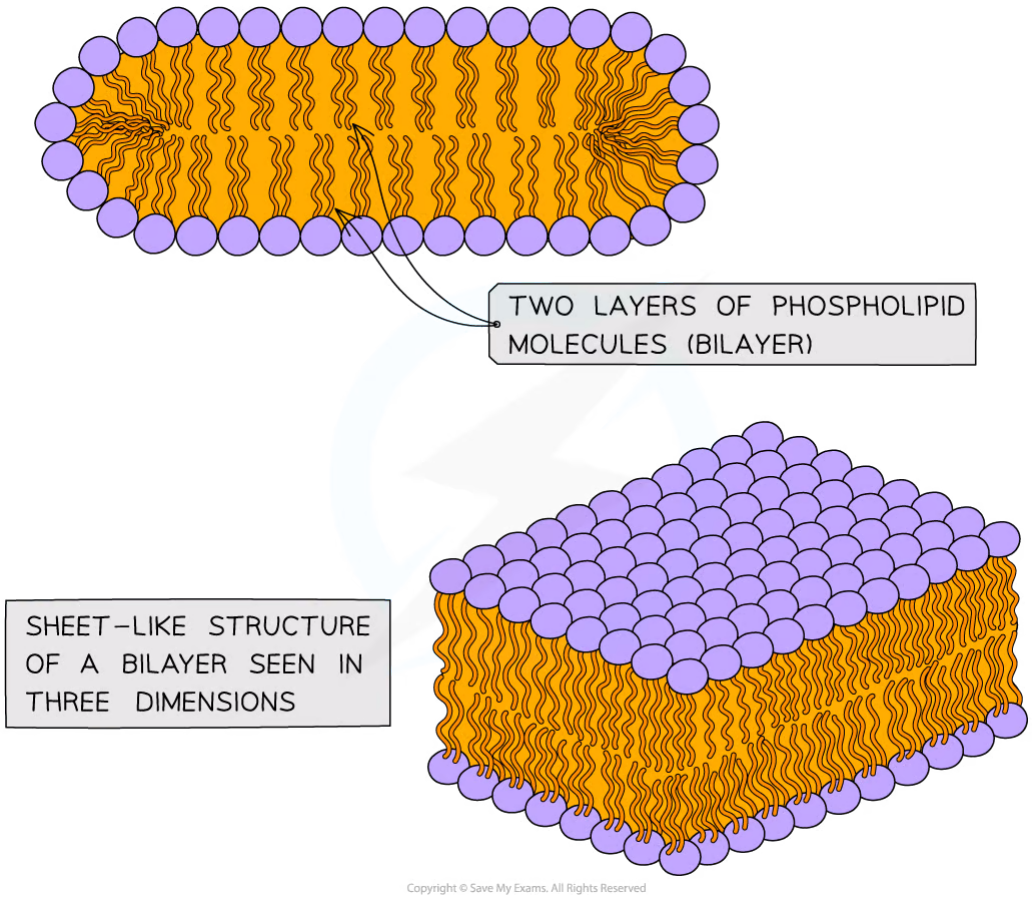
YOUR NOTES



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A phospholipid bilayer is composed of two layers of phospholipids; their hydrophobic tails facing inwards and hydrophilic heads outwards

- The two layers of phospholipids are loosely held together by **weak hydrophobic interactions** between the hydrocarbon tails allowing some membrane fluidity
- The amphipathic properties result in the phospholipid bilayer acting as a **barrier to most water-soluble substances** (the non-polar fatty acid tails prevent polar molecules or ions from passing across the membrane)
- This **ensures water-soluble molecules such as sugars, amino acids and proteins cannot leak out of the cell** and unwanted water-soluble molecules cannot get in

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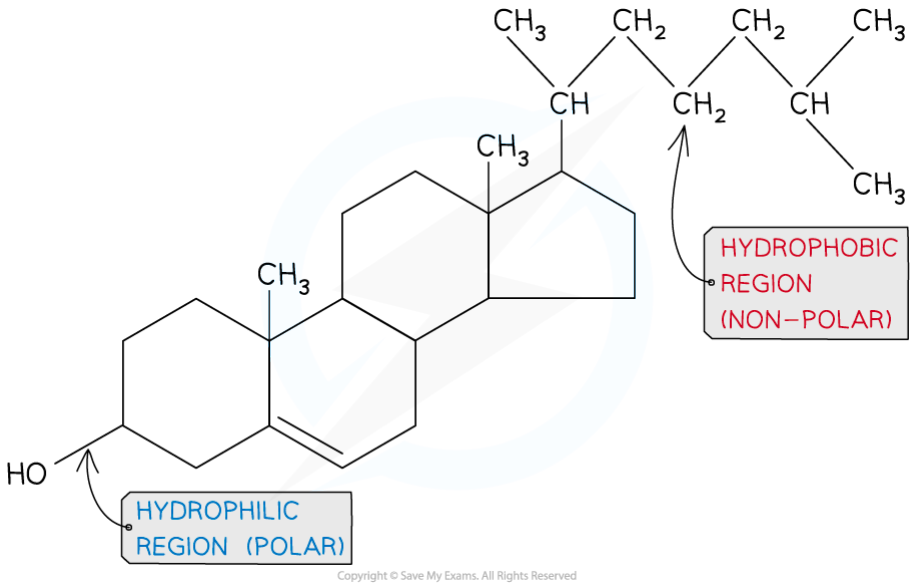
Animal Cell Membranes: Cholesterol

YOUR NOTES

- **Phospholipids** and **cholesterol** are the two main components of **animal cell** plasma membranes (cholesterol is absent in plant membranes)

Cholesterol

- Cholesterol is a **lipid** that belongs to the **steroid** group
- It is **amphipathic**, with the majority of the cholesterol molecule being **hydrophobic** and therefore **attracted** to the hydrophobic **hydrocarbon tails** of the phospholipid
- The **hydroxyl** group of the cholesterol molecule is **hydrophilic**. It is attracted to the **phosphate heads** of the phospholipid
- Therefore in the plasma membrane cholesterol is positioned between phospholipids



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The molecular structure of cholesterol

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Mammalian Membranes: Role of Cholesterol

YOUR NOTES

- The **plasma membrane** is **fluid**, meaning the components are free to move
- The fluidity of the membrane needs to be controlled:
  - If it was too fluid the cell could not regulate what moved in and out
  - If it was not fluid enough then the cell would not be able to move and substances would be unable to move into or out of the cell
- **Cholesterol** helps with the **regulation** of the **membrane fluidity** and **permeability**
  - Interaction between cholesterol and phospholipid tails **stabilises the plasma membrane at higher temperatures** by stopping the membrane from becoming too fluid
    - Cholesterol molecules bind to the hydrophobic tails of phospholipids, stabilising them and causing phospholipids to pack more closely together
  - At **colder temperatures** cholesterol **increases the fluidity of the membrane**, stopping it crystallizing and becoming too rigid
    - This occurs because cholesterol **stops the phospholipid tails packing too closely together**
  - The impermeability of the membrane to hydrophilic ions (e.g. sodium and hydrogen) is also reduced by cholesterol
- Cholesterol **increases the mechanical strength and stability of membranes** (without it membranes would break down causing cells to burst)

Exam Tip

It is important to remember that cholesterol affects membrane fluidity and the permeability of hydrophilic ions (e.g. sodium and hydrogen) in mammal membranes.

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YOUR NOTES

Membrane Proteins

- The phospholipid bilayer carries out the main function of the plasma membrane - to control the movement of substances into and out of the cell
- The other functions are carried out by **proteins** in the membrane
- Plasma membranes are **globular** proteins
- These proteins are grouped into two categories:
  - **Integral** - these are partially **hydrophobic** and therefore are embedded in the phospholipid bilayer (either in both layers or just one)
  - **Peripheral** - these are **hydrophilic** and so are temporarily attached to either the surface of integral proteins (inside or outside the cell) or connected to the plasma membrane via a hydrocarbon chain
- The protein content of membranes can vary depending on the function. Membranes of the mitochondria and chloroplasts have the highest protein content with their many electron carriers

Membrane protein functions

- Membrane proteins carry out many functions: transport, receptors, cell adhesion, cell-to-cell recognition and immobilized enzymes

Transport

- **Transport proteins** create hydrophilic channels to **allow ions and polar molecules to travel through the membrane**
- There are two types:
  - **Channel** (pore) proteins
  - **Carrier** proteins
    - Carrier proteins **change shape** to transport a substance across the membrane e.g. protein pumps and electron carriers
- Each transport protein is **specific to a particular ion or molecule**
- Transport proteins allow the cell to **control** which substances enter or leave

Receptors

- Receptors are for the binding of peptide hormones (e.g. insulin), neurotransmitters or antibodies
- The binding generates a signal that triggers a series of reactions

Immobilized enzymes

- Immobilized enzymes are integral proteins with the active site exposed on the surface of the membrane (can be inside or outside the cell)

Cell adhesion

- Cell adhesion allows **tight junctions** to be formed between cells

Cell-to-cell recognition

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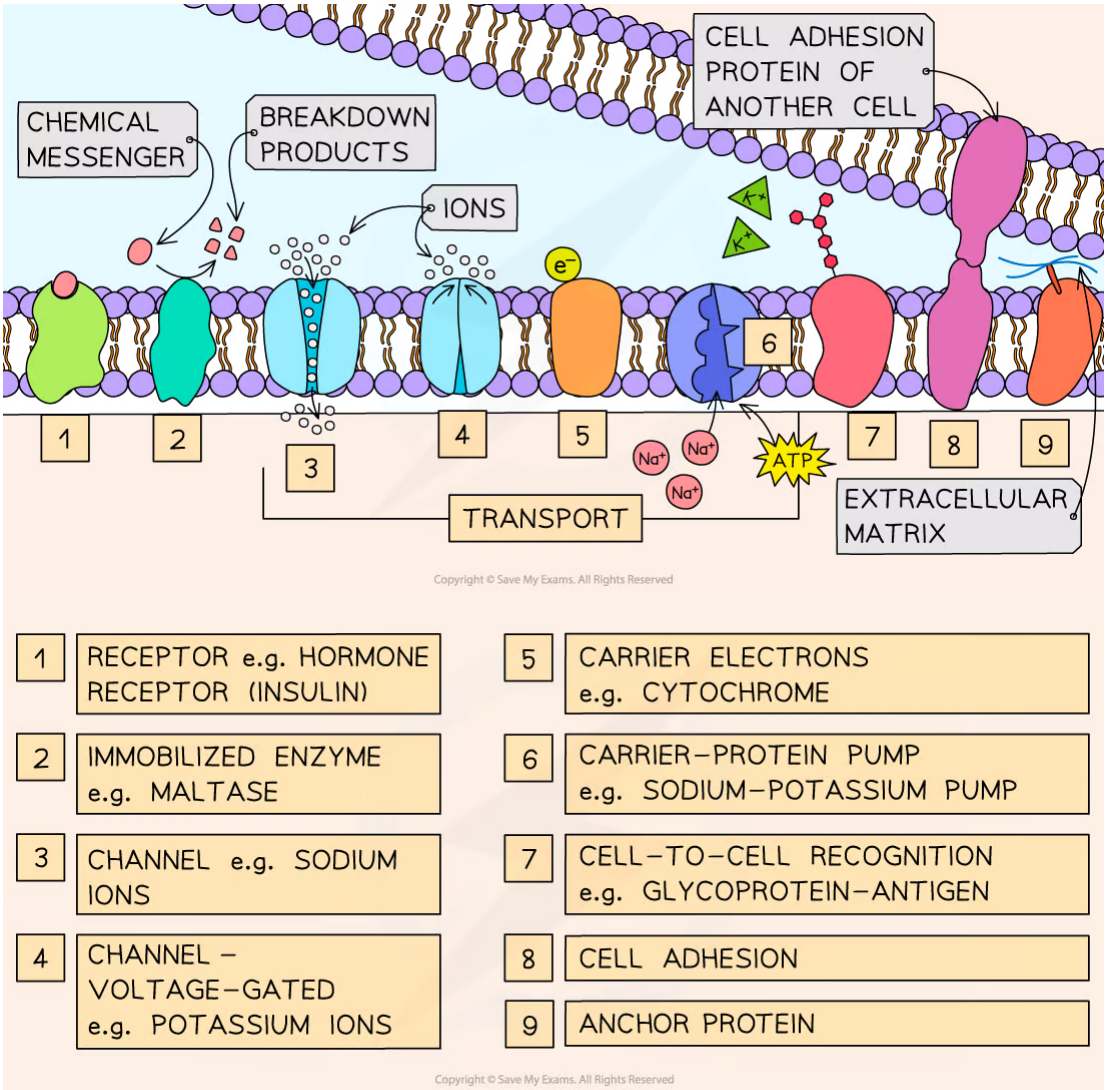
YOUR NOTES

- Glycoproteins act as cell markers or **antigens**, for **cell-to-cell recognition** (eg. the ABO blood group antigens are glycolipids and glycoproteins that differ slightly in their carbohydrate chains)



Examples of the functions of membrane proteins

Exam Tip

As you go through the Biology course you will learn specific examples of how membrane proteins are used so try to make the links, this will help you remember in the exams.

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YOUR NOTES

History of Fluid Mosaic Model

NOS: Using models as representations of the real world; there are alternative models of membrane structure

- Scientists use models to represent real world ideas, organisms, processes and systems that cannot be easily investigated. Scientists can experiment on the models enabling them to test predictions and develop explanations for observations made
- Over time as technological developments have been made the models used to represent the structure of membranes of cells and organelles have changed

1920's Gorter and Grendel

- The **Gorter and Grendel** model showed that the **phospholipids** in the membrane of cells were arranged into a **bilayer**
- **Evidence** for this model:
  - The number of phospholipids extracted from red blood cell membranes was double the area of the plasma membrane if it was arranged as a monolayer
- **Problems** with this model:
  - Their model did not explain the location of proteins or how molecules that were insoluble in lipids moved into and out of the cell

1930's Davson and Danielli

- **Davson and Danielli's** model of the membrane suggested that the **proteins** were arranged in **layers above** and **below** the **phospholipid bilayer**
- **Evidence** for this model:
  - Membranes were effective at controlling the movement of substances in and out of cells
  - Electron micrographs showed the membrane had two dark lines with a lighter band between. In electron micrographs, proteins appear darker than phospholipids
- **Problems** with this model:
  - Freeze-etched electron micrographs of the centre of the membrane showed globular structures **scattered throughout**
  - Improvements in technology used to analyse the proteins in the membranes showed that **proteins** were **globular**, **varied in size** and had parts that were **hydrophobic**
  - These problems suggested it was **unlikely** that the proteins would **form continuous layers**

1970's Singer and Nicolson

- **Singer and Nicolson** proposed the **fluid mosaic model** which stated that membranes were **fluid** and that the globular **proteins** were both peripheral and **integral** (with some crossing both membranes) and **dispersed throughout** the membrane
- **Evidence** for this model:
  - Analysis of **freeze-etched electron micrographs** showed proteins **extending** into the **centre of membranes**
  - **Biochemical analysis** of the plasma membrane components

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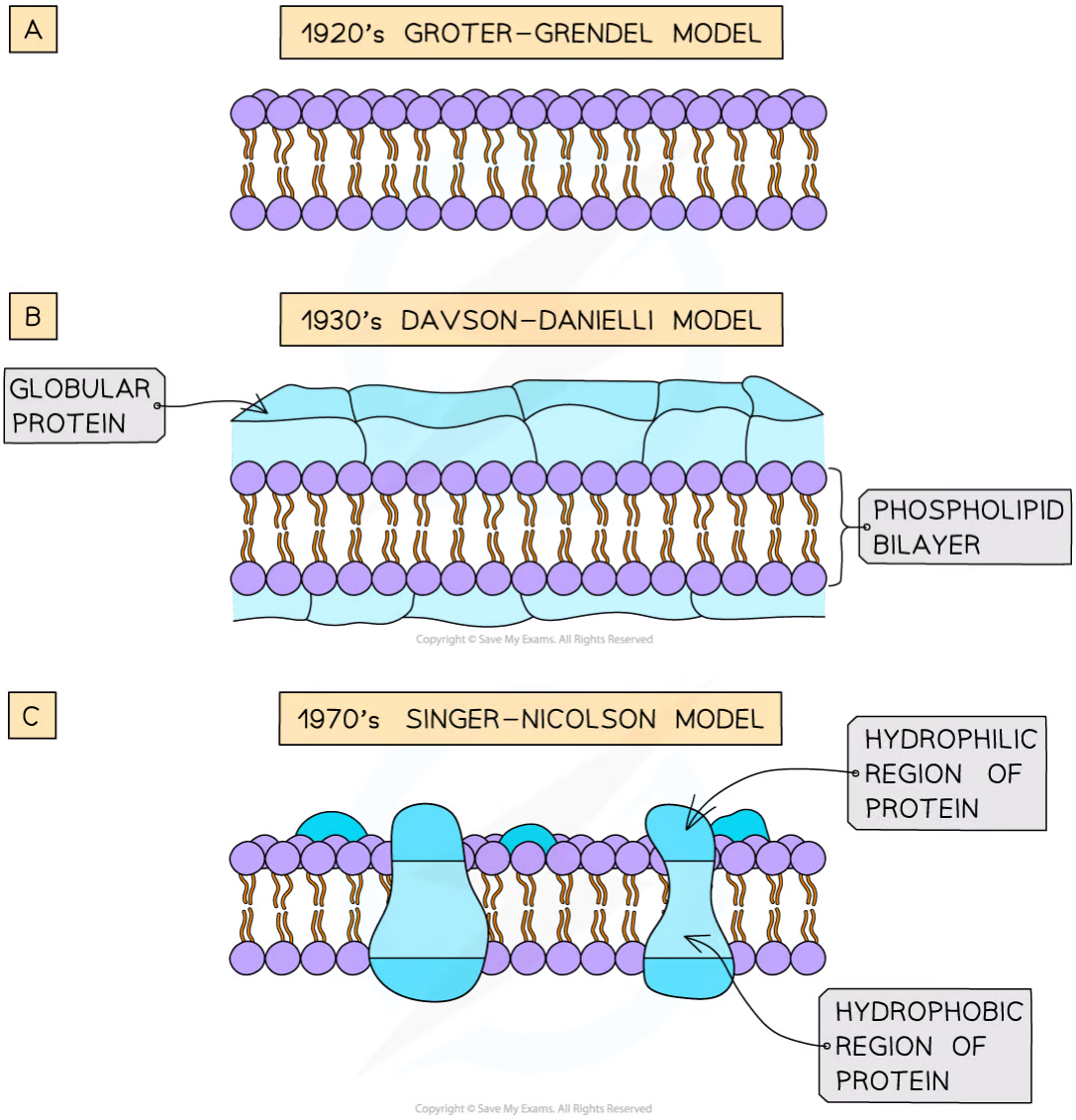
- The use of **coloured fluorescent markers** of antibodies. Antibodies were tagged with red and green fluorescent markers. These antibodies were bound to membrane proteins on different cells. Forty minutes after these cells were fused together the markers were seen to have mixed throughout the fused cells membrane showing that membrane proteins are **free to move** within the layer



Three models of membrane structure

Future models

- With further developments in technology more is still to be discovered about the plasma membrane and so the model we use to represent it continues to evolve
  - e.g. the presence of the cellular cytoskeleton on the inside and the extracellular matrix on the outside makes the membrane less fluid than suggested by the fluid mosaic model

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Exam Tip

You will need to learn the difference between the Davson-Danielli and Singer-Nicolson model of membrane structure and the reasons why they proposed their models.

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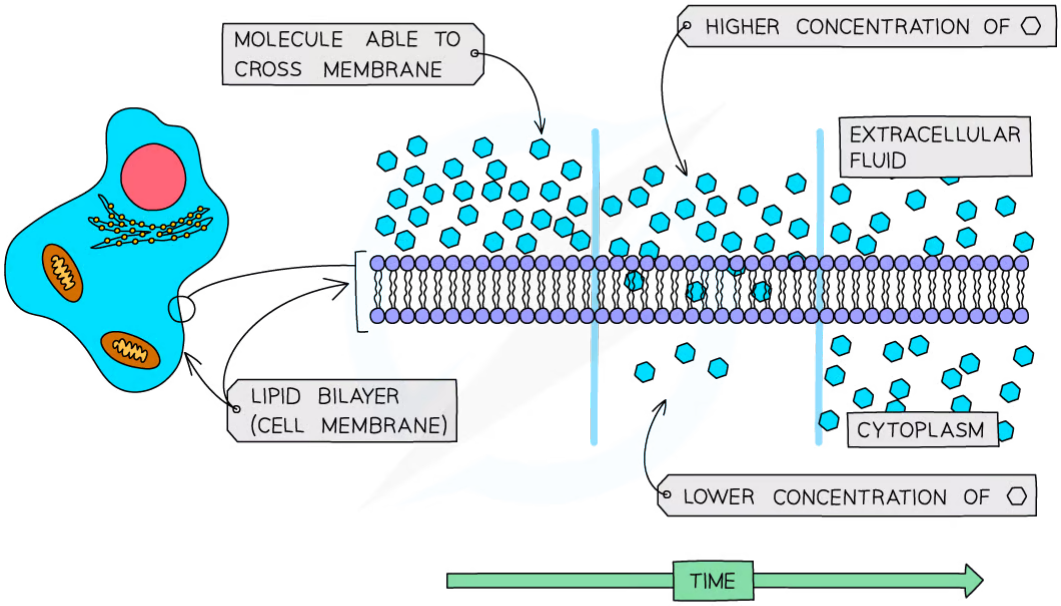
Passive Transport

Simple diffusion

- Simple diffusion is a type of **transportation** that involves particles passing between phospholipids in **the plasma membrane**
- It can be defined as:
  - **The net movement, as a result of the random motion of its molecules or ions, of a substance from a region of its higher concentration to a region of its lower concentration**
- The molecules or ions move **down a concentration gradient**
- The random movement is caused by the natural **kinetic energy** of the molecules or ions
- As a result of diffusion, molecules or ions tend to reach an equilibrium (given sufficient time), where they are evenly spread within a given volume of space



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Diffusion across the cell membrane

- The **rate** at which a substance diffuses across a membrane depends on several factors:
  - **'Steepness' of the concentration gradient** - the greater the difference the higher the rate of diffusion
  - **Temperature** - the higher the temperature the higher the rate of diffusion
  - **Surface area** - the greater the surface area the higher the rate of diffusion
  - **Properties of the molecules or ions**
    - **Large molecules** diffuse more slowly as they require more energy to move

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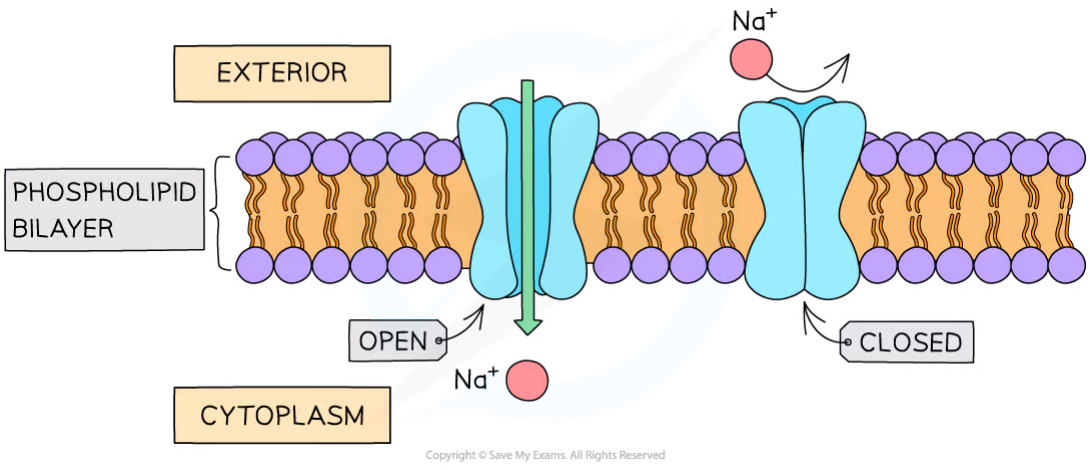
- **Uncharged** molecules (e.g. oxygen) diffuse faster as they move directly across the phospholipid bilayer
- **Non-polar** molecules diffuse more quickly as they are soluble in the non-polar phospholipid bilayer
- Although polar molecules cannot easily pass through the hydrophobic part of the membrane, **smaller polar** molecules (e.g. urea) can diffuse at low rates

Facilitated diffusion

- Certain substances cannot diffuse through the phospholipid bilayer of cell membranes. These include:
  - **Large polar molecules** such as glucose and amino acids
  - **Ions** such as sodium ions (Na^+) and chloride ions (Cl^-)
- These substances can only cross the phospholipid bilayer with the help of certain proteins
- This form of diffusion is known as **facilitated diffusion**
- There are two types of proteins that enable facilitated diffusion:
  - **Channel proteins**
  - **Carrier proteins** (these can also be used during active transport)
- They are **highly specific** (they only allow one type of molecule or ion to pass through)

Channel proteins

- Channel proteins are water-filled **pores**
- They allow **charged substances** (eg. ions) to diffuse through the cell membrane
- The diffusion of these ions does not occur freely, most channel proteins are '**gated**', meaning that part of the channel protein on the inside surface of the membrane can move in order to close or open the pore
- This allows the channel protein to **control** the exchange of ions



A channel protein (open and closed)

Carrier proteins

- Unlike channel proteins which have a fixed shape, **carrier proteins can switch between two shapes**
- Initially, the binding site of the carrier protein is open to one side of the membrane

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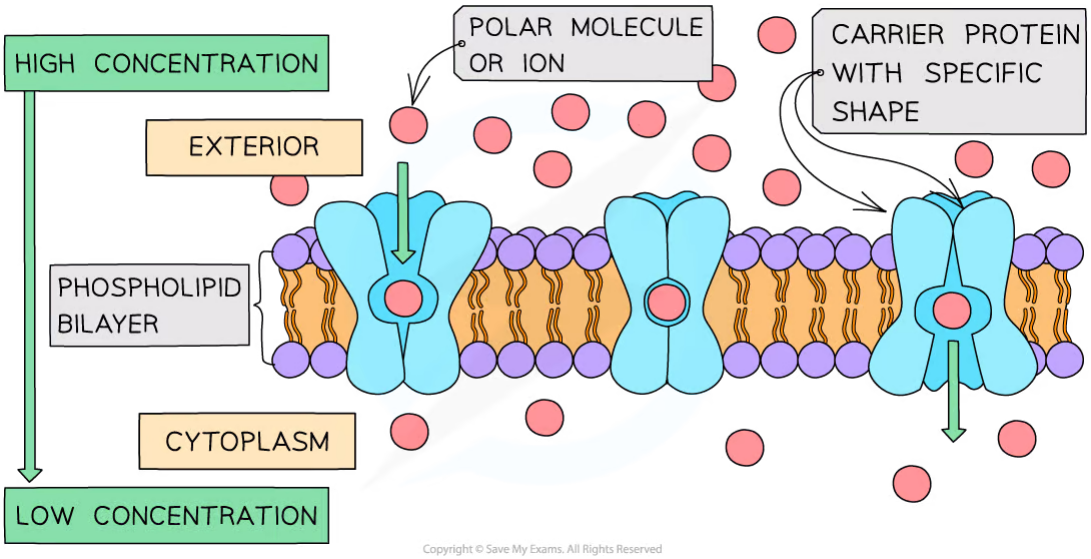
- When the carrier protein switches shape it opens to the other side of the membrane
- The direction of movement of molecules diffusing across the membrane depends on their relative concentration on each side of the membrane
- During **facilitated diffusion**, the net diffusion of molecules or ions into or out of a cell will occur **down a concentration gradient** (from an area containing many of that specific molecule to an area containing less of that molecule)



A carrier protein changing shape during facilitated diffusion

Osmosis

- All cells are surrounded by a cell membrane which is **partially permeable**
- Water can move in and out of cells by **osmosis**
- Osmosis is the **diffusion of water molecules** from a dilute solution to a more concentrated solution across a partially permeable membrane
  - In doing this, water is moving down its **concentration gradient**
    - A dilute solution has a high concentration of water molecules and a concentrated solution has a low concentration of water molecules
- The cell membrane is partially permeable which means it **allows small molecules (like water) through** but not larger molecules (like solute molecules)

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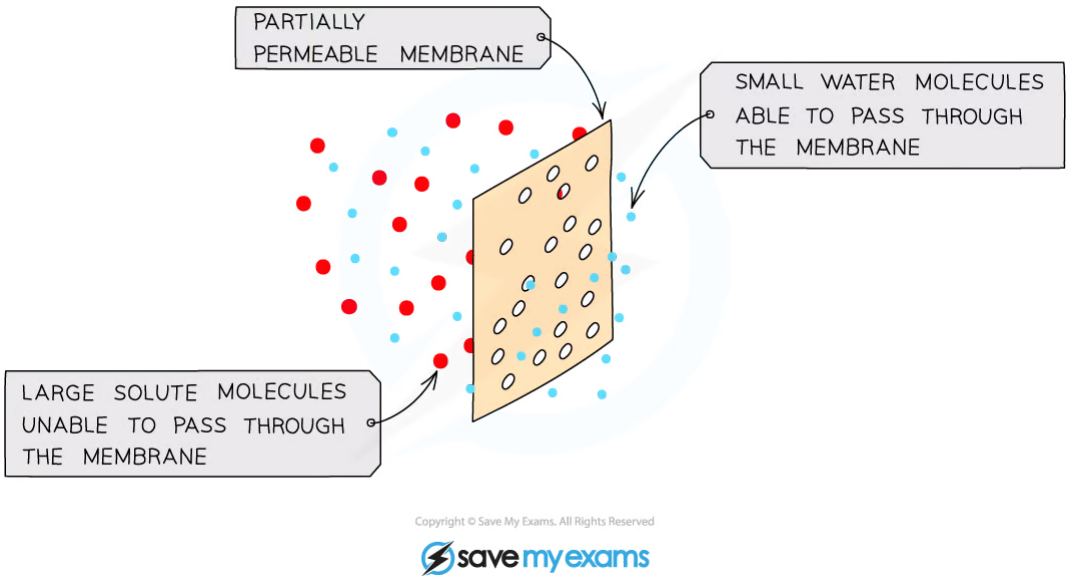

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Osmosis and the partially permeable membrane

- The term **osmolarity** can be used to describe the solute concentration of a solution; a solution with high osmolarity has a high solute concentration and a solution with low osmolarity has a low solute concentration.
  - Water will move **from a solution of low osmolarity to a solution of high osmolarity** across a partially permeable membrane
- Osmosis can also be described as the **net movement of water molecules** from a region of **higher water potential** to a region of **lower water potential**, through a partially permeable membrane
  - Water potential describes the tendency of water to move out of a solution; this term is used to avoid confusion between water concentration and solute concentration of a solution

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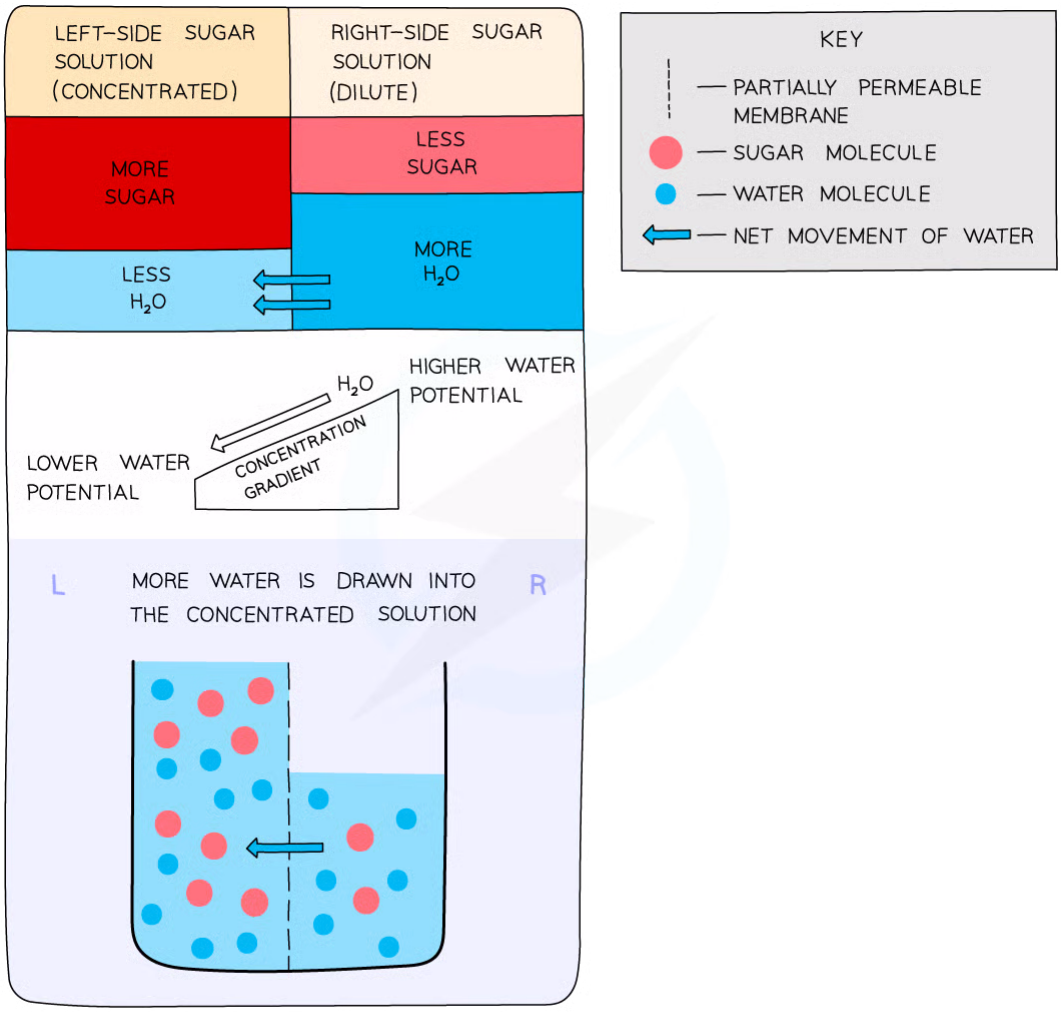

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How osmosis works. The water moves from the region of higher water potential (dilute solution) to the region of lower water potential (concentrated solution).

Exam Tip

Remember that the movement of molecules from high concentration to low concentration is diffusion. If this movement requires the aid of a protein (for example because the molecule is charged and cannot pass directly through the phospholipid bilayer) this is facilitated diffusion, and if it involves the movement of water across a partially permeable membrane it is osmosis.

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Facilitated Diffusion: Example

YOUR NOTES

Axons

- The **axon** is part of a **nerve cell** (neuron)
- It is a long, narrow tube (it can be one metre in length with a diameter of one micron) containing cytoplasm surrounded by a membrane
- Axons transmit **nerve impulses**
- These nerve impulses occur because sodium and **potassium ions** are being moved **across** the **axon membrane** creating a voltage difference

Facilitated diffusion of potassium

- **Voltage-gated channel proteins** (enabling facilitated diffusion) allow the movement of the potassium ions
- Potassium ions **require channel proteins** to diffuse across the axon as they are **charged** and bond with water when they dissolve in the cytoplasm
- Potassium channels are **integral proteins** and **allow only potassium ions** through because:
  - Other positively charged ions are too large to move through the channel
  - Other ions are too small to form bonds with the amino acids located in the channel so they remain attached to water molecules
- The potassium channels in axons are **voltaged gated**
- The channel proteins will **open** (to allow potassium ions to diffuse out) when the charge inside the axon is relatively more **positive** than outside
- However, the channel proteins rapidly close due to the presence of an extra globular protein subunit. This subunit fits inside the open channel within milliseconds of the channel opening blocking any further diffusion out of the potassium ions
- The subunit remains in place until the potassium channel closes

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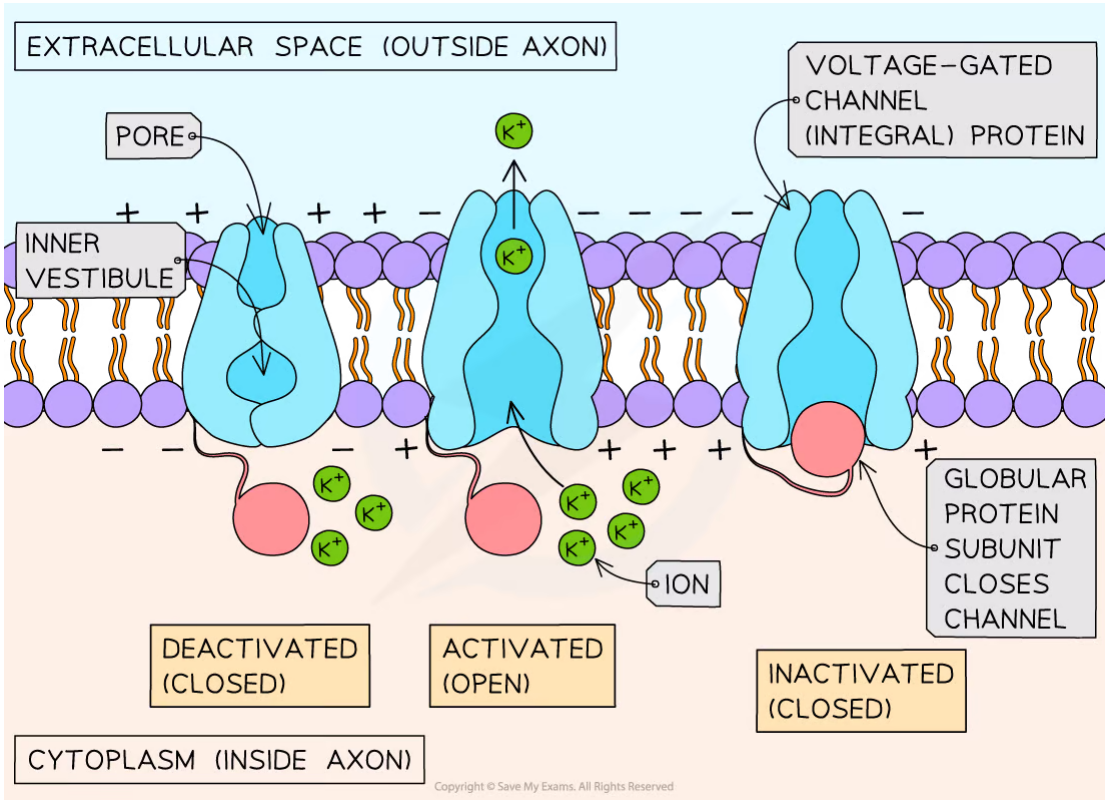

Voltage-gated potassium channels facilitate the diffusion of potassium ions

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Prevention of Osmosis in Medical Procedures

YOUR NOTES

- **Animal cells** can **lose** and **gain water** as a result of **osmosis**
- As animal cells **do not have a supporting cell wall** (unlike plant cells), the results of this loss or gain of water on the cell are **severe**
- This is why a constant water potential **must** be maintained inside the bodies of animals

Animal cells losing water

- If an animal cell is placed in a solution with a **lower water potential** than the cell, water will **leave** the cell through its partially permeable cell surface membrane by **osmosis** and the cell will **shrink** and **shrivel up**
  - This is **crenation** (the cell has become **crenated**), which is usually **fatal** for the cell
- Crenation occurs when the cell is in a **hypertonic environment** (the solution outside of the cell has a **higher solute concentration** than the inside of the cell)

Animal cells gaining water

- If an animal cell is placed in **pure water** or a **dilute solution**, water will **enter** the cell through its partially permeable cell surface membrane by **osmosis**, as the pure water or dilute solution has a **higher water potential**
- The cell will continue to **gain** water by osmosis until the cell membrane is stretched too far and the cell **bursts** (**cytolysis**), as it has no cell wall to withstand the increased pressure created
  - This is **fatal** for the cell
- Lysis occurs when the cell is in a **hypotonic environment** (the solution outside of the cell has a **lower solute concentration** than the inside of the cell)

Animal cells in isotonic environments

- If an animal cell is in an **isotonic environment** (the solution outside of the cell has the **same solute concentration** as the inside of the cell)
- The movement of water molecules into and out of the cell occurs at the **same rate** (**no net movement of water**) and there is **no change to the cells**

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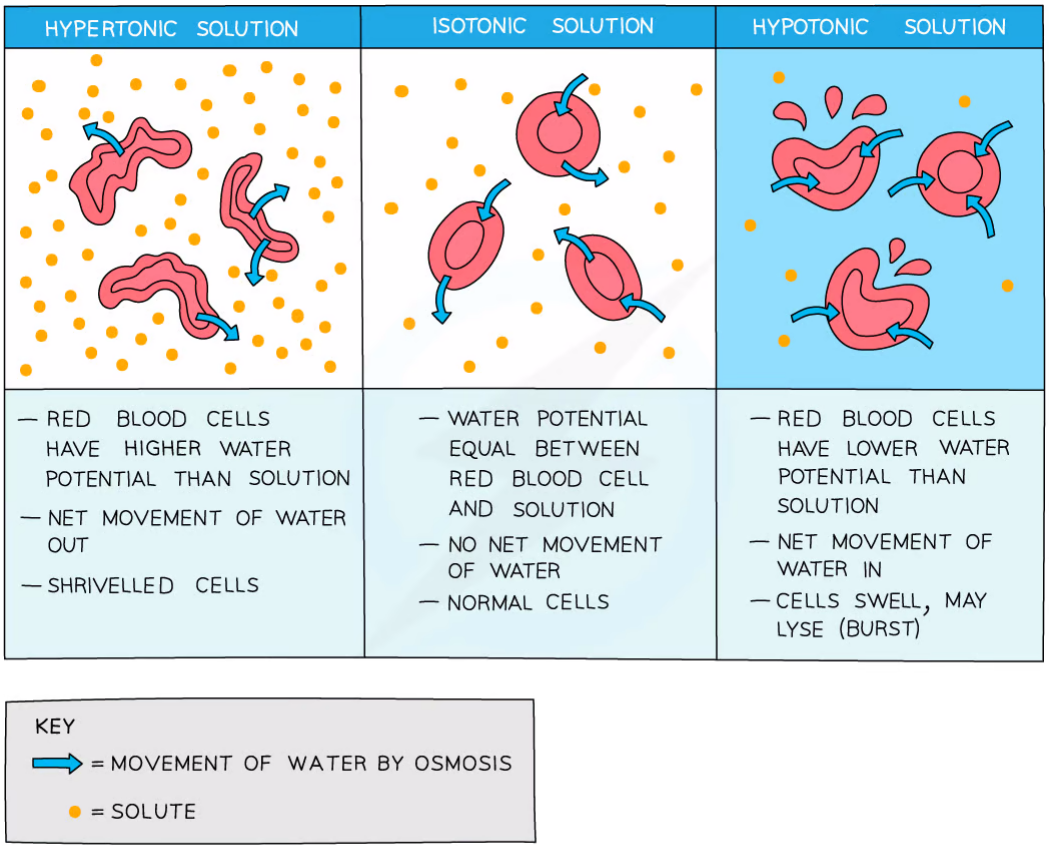

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Effect of osmosis on animal cells

Osmolarity of solutions used in medical procedures

- Tissues and organs that are to be used in medical procedures must be kept in solution to **prevent damage** to the cells
- The osmolarity of the solution is key
- The **osmolarity** of a solution measures the **number of solute particles** (that can form bonds with water) **per 1 L of solvent**
- Osmolarity is expressed as osmoles or milliosmoles per litre of solution (**Osm/L or mOsm/L**)
- Human tissue is normally 306 mOsm/L
  - A solution with the **same osmolarity** = **isotonic**
  - A solution with a **higher osmolarity** = **hypertonic**
  - A solution with a **lower osmolarity** = **hypotonic**
- **Isotonic sodium chloride** solutions (normal saline) are generally used as they can be:
  - Frozen to create a slush used to pack donor organs for transportation
  - Injected into a patient's blood system
  - Used to sterilise wounds
  - Used as eye drops

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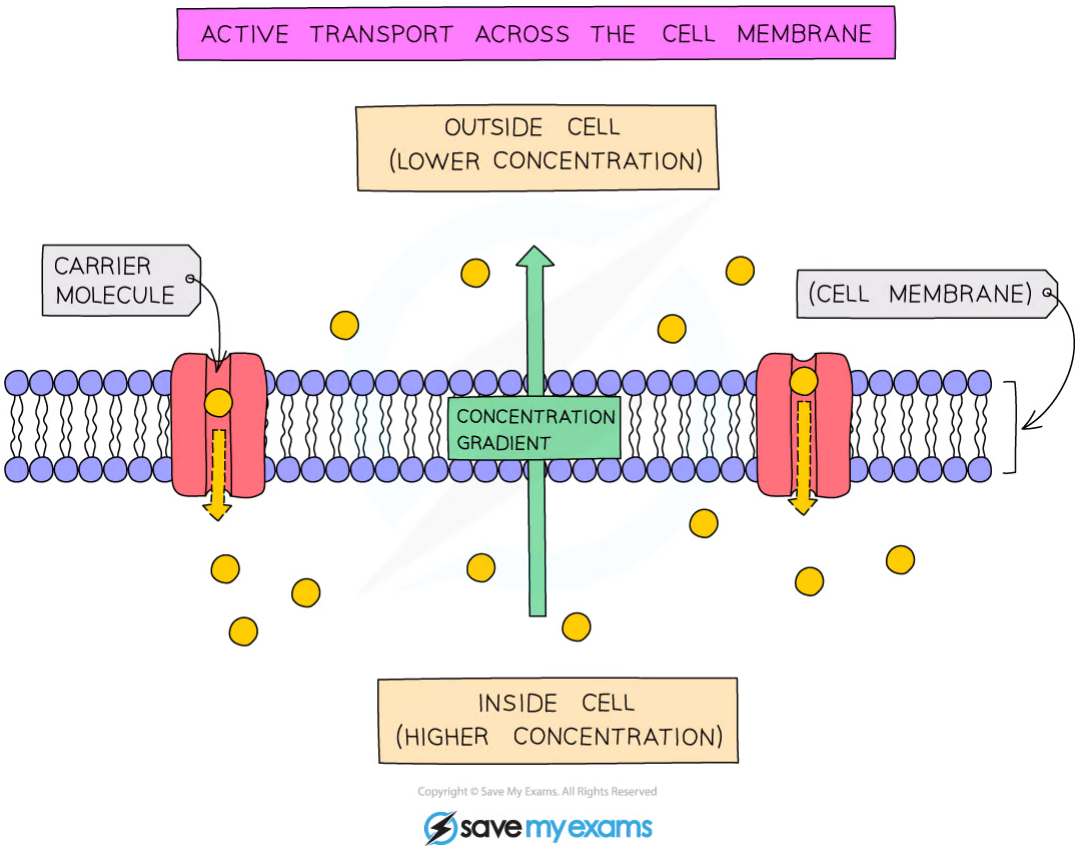
YOUR NOTES

Active Transport

- Active transport is the **movement of molecules and ions through a cell membrane from a region of lower concentration to a region of higher concentration using energy from respiration**
- Active transport requires **carrier proteins** (each carrier protein being specific for a particular type of molecule or ion)
- Although facilitated diffusion also uses carrier proteins, active transport is different as it requires **energy**
- The energy is required to make the carrier protein **change shape**, allowing it to transfer the molecules or ions across the cell membrane
- The energy required is provided by **ATP** (adenosine triphosphate) produced during **respiration**. The ATP is **hydrolysed** to release energy



Active transport across the cell membrane

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Active Transport: Example

YOUR NOTES

Sodium-potassium pumps in axons

- **Sodium-potassium** carrier **pump** proteins are **integral proteins** that enable an electrochemical gradient (resting membrane potential) to be maintained between the inside and outside of the axon
- Nerve impulses that travel along axons are dependent on sodium and **potassium ions** being moved **across** the **axon membrane** to create this gradient
- The **sodium-potassium pumps** move **three sodium ions out** of the axon and **two potassium ions into** the axon using **one ATP molecule** per cycle
- The pumps are **always moving** the ions **against their concentration gradient** via **active transport**
- The cycle continues until the resting membrane potential is reached
- The steps to this cycle are:
  - **Three sodium ions** from the **inside** of the axon **bind** to the **pump**
  - **ATP attaches** to the **pump** and **transfers** a **phosphate** to the pump (phosphorylation) causing it to change shape, resulting in the pump opening to the outside of the axon
  - The three **sodium ions** are **released** out of the axon
  - **Two potassium ions** from **outside** the **axon** enter and **bind** to their sites
  - The **attached phosphate** is **released** altering the shape of the pump again
  - The change in shape causes the **potassium ions** to be **released inside** the axon

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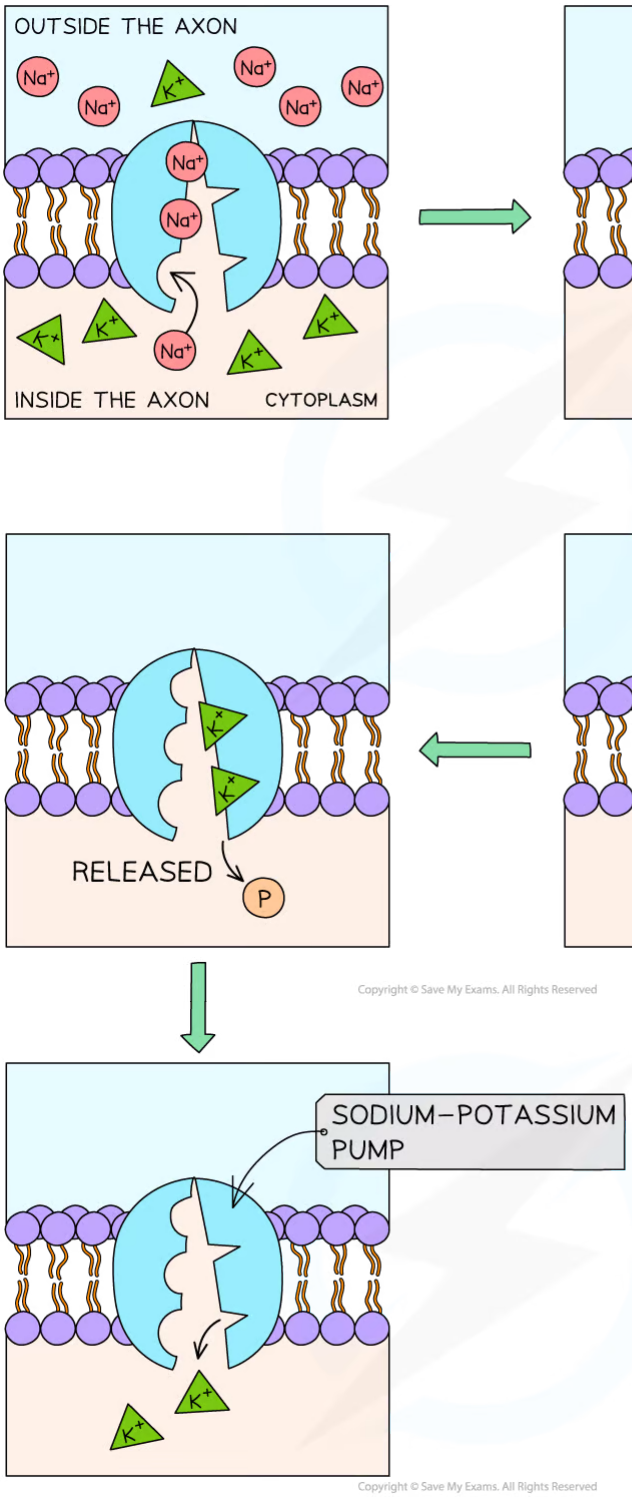

Active transport of sodium and potassium ions in axons using sodium–potassium pump carrier proteins

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Bulk Transport

YOUR NOTES

Bulk transport

- The processes of diffusion, osmosis and active transport are responsible for the transport of **individual molecules or ions** across cell membranes
- However, the **bulk transport of larger quantities of materials** into or out of cells is also possible
- Examples of these larger quantities of materials that might need to cross the membrane include:
  - Large molecules such as proteins or polysaccharides
  - Parts of cells
  - Whole cells eg. bacteria
- Bulk transport **into** cells = **endocytosis**
- Bulk transport **out** of cells = **exocytosis**
- These two processes **require energy** and are therefore forms of active transport
- They also require the formation of **vesicles** which is dependent on the fluidity of membranes

Fluidity of membranes

- The phospholipid bilayer is loosely held together by weak hydrophobic interactions between the hydrocarbon tails
- These weak interactions allow for some degree of membrane fluidity
- The **membrane fluidity** allows **larger substances** to move **in** and **out** of the **cell** in **vesicles** formed when **proteins** and **ATP** are used to pinch off small **regions** of the **plasma membrane**

Vesicles

- **Vesicles** are **small spherical sacs** of **plasma membrane** containing water and solutes
- They will often contain larger molecules that cannot pass across the plasma membrane (e.g. proteins)
- The formation of vesicles is an **active** process requiring **ATP** and **proteins** and involves a small region of the plasma membrane being pinched off
- Vesicles are normally present in **eukaryotic cells**
- Vesicles **move materials within cells**. These materials may be required by other organelles or may be required outside the cell
- An example of materials moved by vesicles out of the cell is digestive enzymes
  - In exocrine pancreatic gland cells, proteins synthesised by ribosomes on the rough endoplasmic reticulum are packaged into vesicles that move them to Golgi apparatus. Here the vesicles fuse with the membrane of the Golgi apparatus and the proteins are modified. New vesicles then pinch off and move to the plasma membrane to secrete the digestive enzymes into the pancreatic ducts
- Vesicles can also be used to move membrane proteins and phospholipids to the plasma membrane so cells can grow or to organelles in the cytoplasm so they can increase in size

Endocytosis

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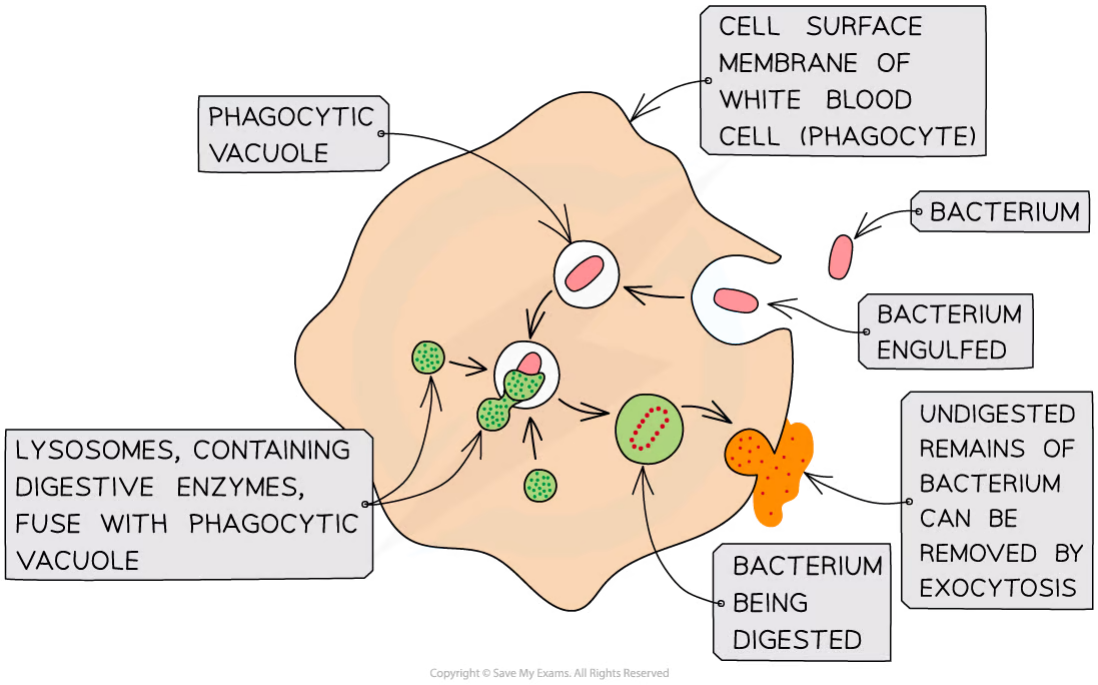
- Endocytosis is the process by which the plasma membrane **engulfs material**, forming a small sac (or '**endocytic vacuole**') around it
- There are two forms of endocytosis:
  - **Phagocytosis**:
    - This is the bulk intake of solid material by a cell
    - Cells that specialise in this process are called **phagocytes**
    - The vacuoles formed are called phagocytic **vacuoles**
    - An example is the engulfing of bacteria by phagocytic white blood cells
  - **Pinocytosis**:
    - This is the bulk intake of liquids
    - If the vacuole (or **vesicle**) that is formed is extremely small then the process is called **micropinocytosis**



The process of phagocytosis of a bacterium by a phagocyte (white blood cell)

Exocytosis

- Exocytosis is the process by which materials are removed from, or **transported out of**, cells (the **reverse of endocytosis**)
- The substances to be released (such as **enzymes, hormones or cell wall building materials**) are packaged into **secretory vesicles** formed from the Golgi body
- These vesicles then travel to the cell surface membrane
- Here they **fuse** with the cell membrane and **release their contents** outside of the cell
- An example is the secretion of digestive enzymes from pancreatic cells

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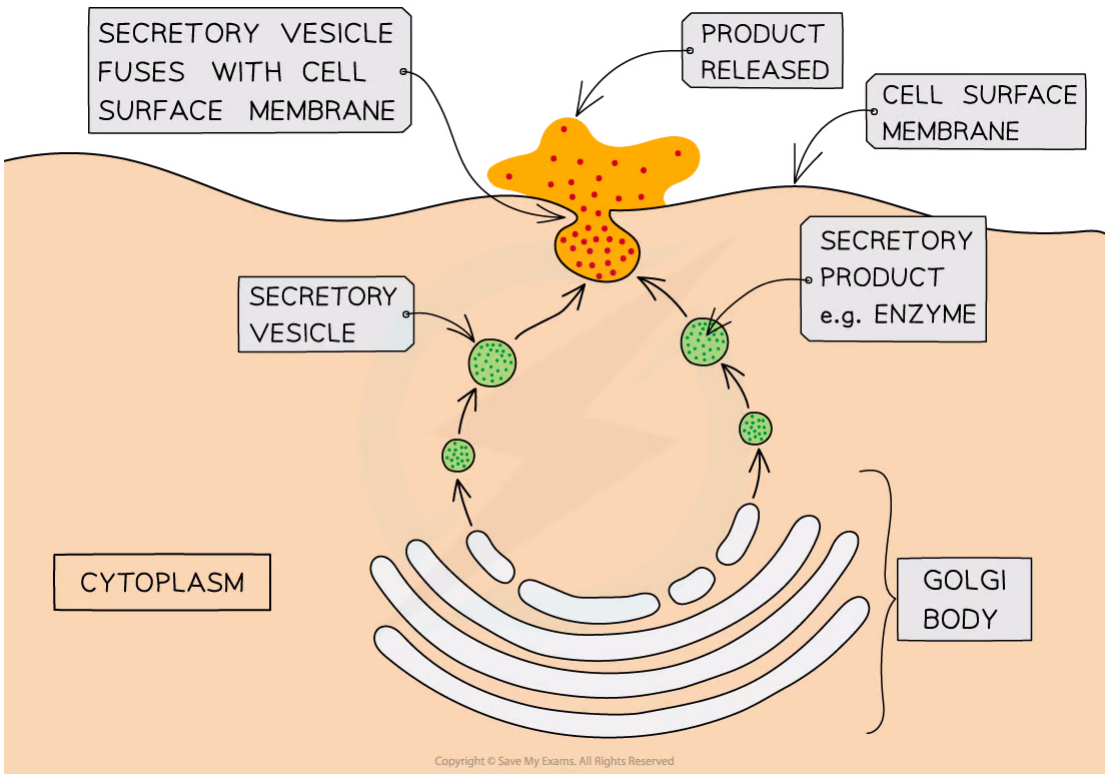

The process of exocytosis

Exam Tip

Remember – active transport, endocytosis and exocytosis all require energy. This energy is provided by ATP produced during respiration.To get the mark in the exam you have to specifically state '**exocytosis**' for bulk transport out of the cell and '**endocytosis**' (or even better: phagocytosis, pinocytosis) for bulk transport into the cell. Simply stating 'bulk transport' is not specific enough, the examiner will want to know **what type** of bulk transport and for this you need to state the scientific name!

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YOUR NOTES

Drawing the Fluid Mosaic Model

Membranes

- Membranes are **vital** structures found in all cells
- The **cell surface membrane** creates an enclosed space separating the internal cell environment from the external environment
- **Intracellular membranes** (internal membranes) form **compartments** within the cell, such as **organelles** (including the nucleus, mitochondria and RER) and **vacuoles**
- Membranes not only **separate** different areas but also **control the exchange of materials** passing through them; they are **partially permeable**
- Membranes form partially permeable **barriers** between the cell and its environment, between cytoplasm and organelles and also within organelles
- Substances can cross membranes by **diffusion, facilitated diffusion**, **osmosis** and **active transport**
- Membranes play a role in **cell signaling** by acting as an **interface** for **communication between cells**

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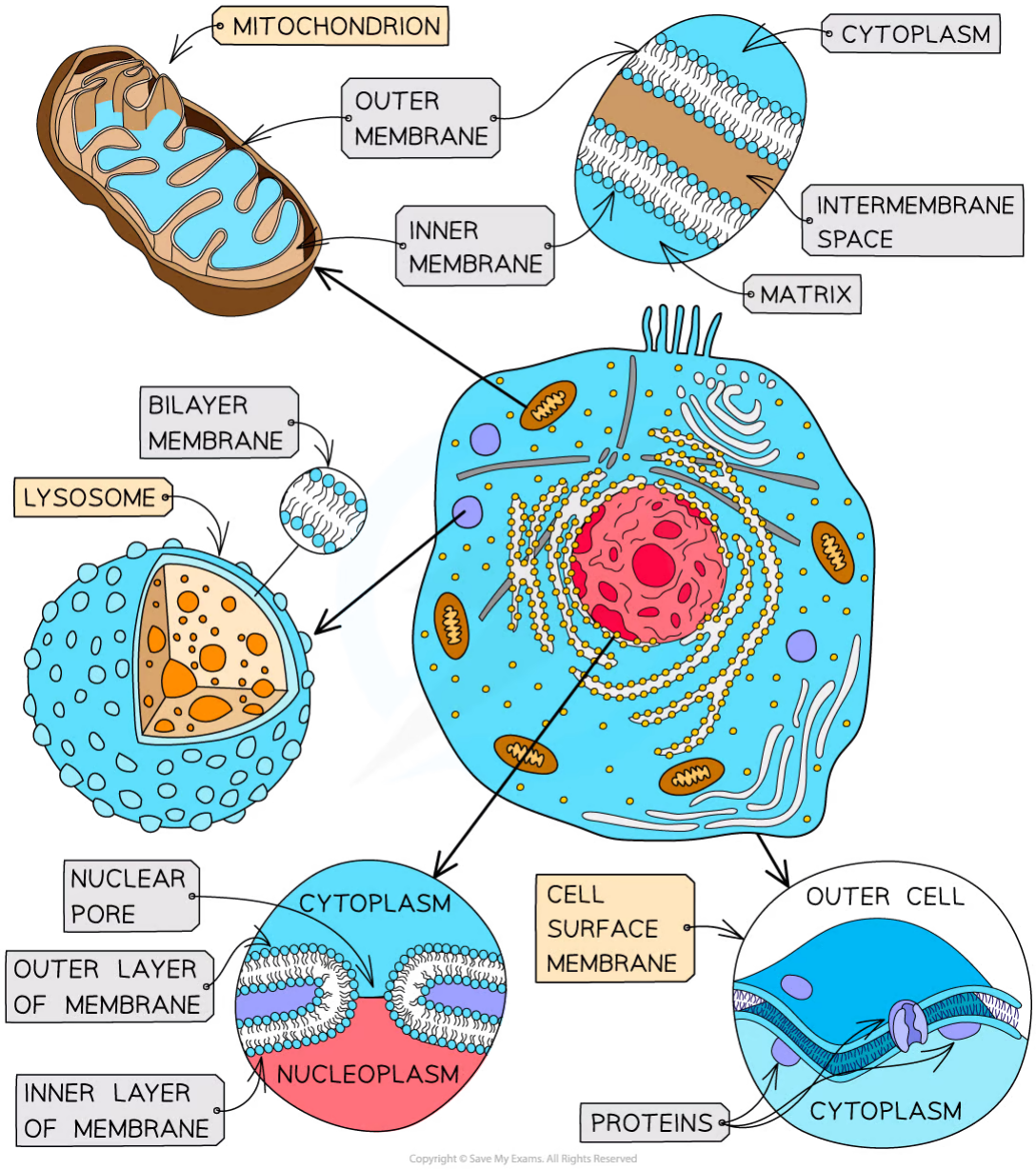

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Membranes formed from phospholipid bilayers help to compartmentalise different regions within the cell, as well as forming the cell surface membrane

Fluid Mosaic Model

- The **fluid mosaic model** of membranes was first outlined in 1972 by **Singer and Nicolson** and it explains how biological molecules are arranged to form cell membranes
- The fluid mosaic model also helps to explain:
  - **Passive and active movement between cells and their surroundings**
  - **Cell-to-cell interactions**
  - **Cell signalling**
- The fluid mosaic model describes cell membranes as '**fluid**' because:
  - The **phospholipids** and **proteins** can **move around** via diffusion

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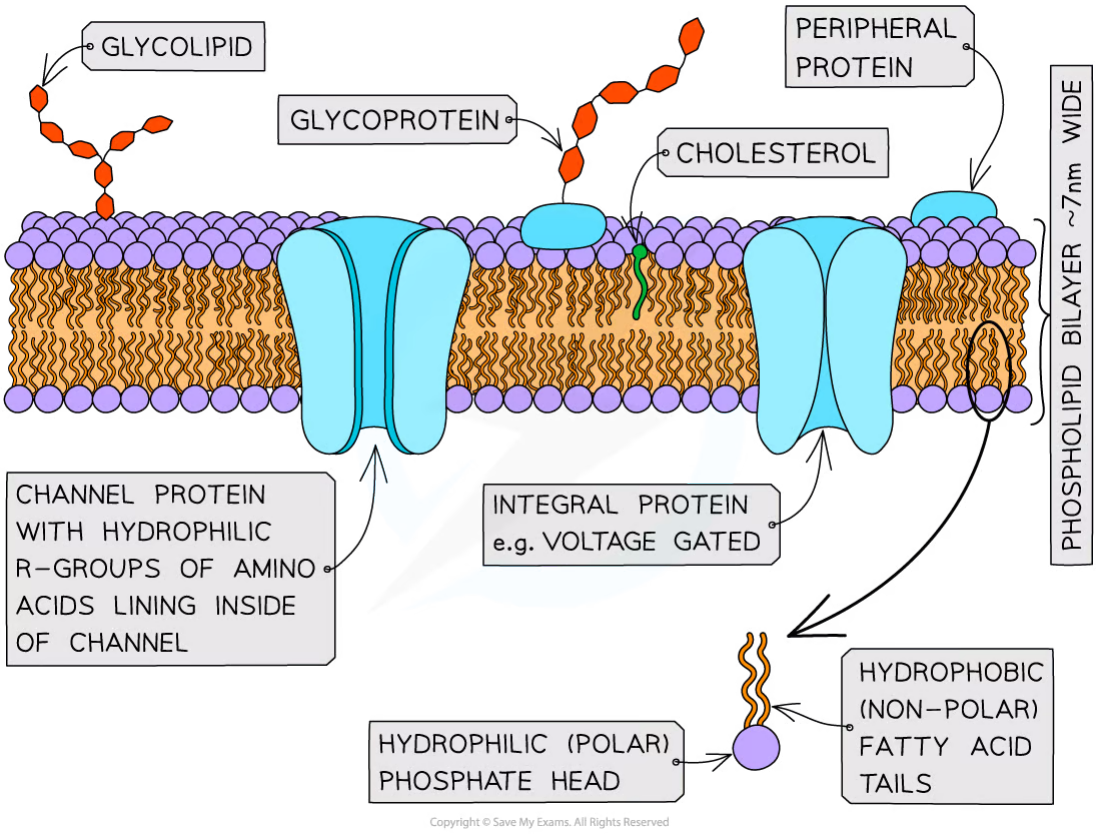
YOUR NOTES

- The phospholipids mainly move sideways, within their own layers
- The many different types of proteins interspersed throughout the bilayer move about within it (a bit like icebergs in the sea) although **some may be fixed** in position

- The fluid mosaic model describes cell membranes as '**mosaics**' because:
  - The **scattered pattern** produced by the **proteins** within the phospholipid bilayer looks somewhat like a mosaic when viewed from above

- The **fluid mosaic model** of membranes includes four main components:
  - Phospholipids
  - Cholesterol
  - Glycoproteins and glycolipids
  - Transport proteins



The main components of cell membranes. The distribution of the proteins within the membrane gives a mosaic appearance and the structure of the proteins determines their position in the membrane.

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YOUR NOTES

Exam Tip

When drawing the fluid mosaic model remember to include (and label) the **phospholipid bilayer** (making it clear which part is the phosphate head and which parts are the hydrocarbon tails), the **thickness of the membrane (7 – 10 nm)**, **integral proteins** (show then embedded in the phospholipid bilayer and include a couple of different types e.g. channel/carrier), **peripheral proteins (do not** extend the protein into the hydrophobic region), **glycoprotein** (with a carbohydrate attached) and finally **cholesterol** (ensure the orientation is correct, OH group next to the phosphate heads and the rest positioned next to the tails).

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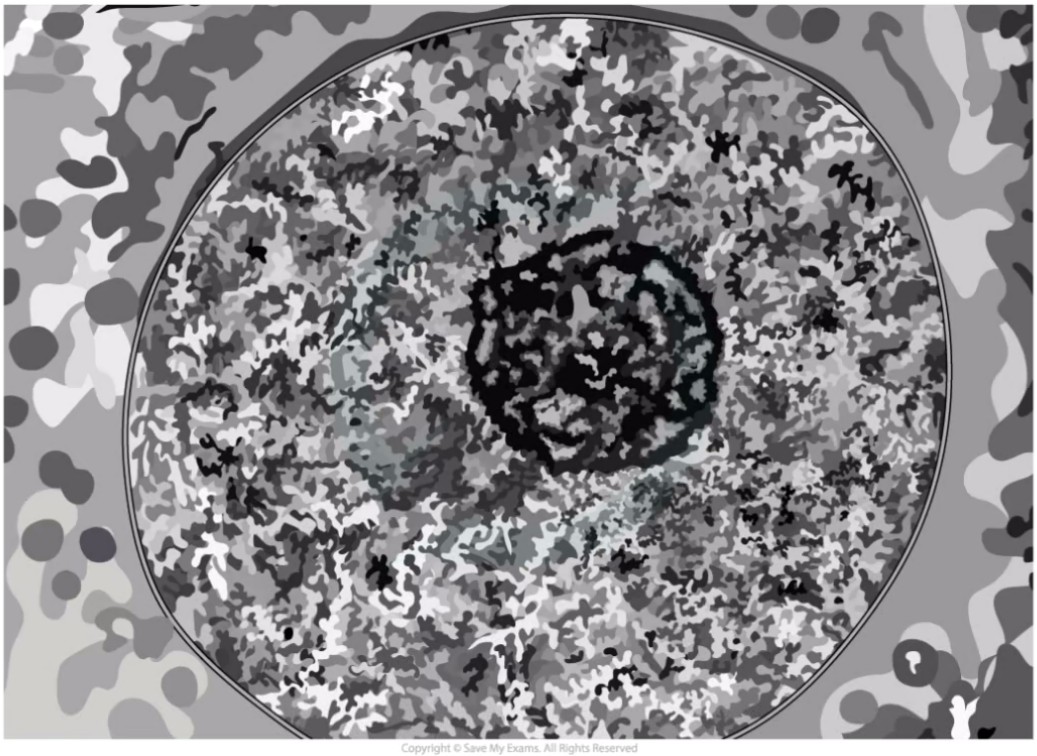
Analysis of Evidence: Davson-Danielli Model

YOUR NOTES

- Analysis of evidence from **electron microscopy** led to the proposal of the Davson-Danielli model
- Other methods were then used to further investigate the model and suggested evidence against the model
  - Freeze-etchings
  - Fluorescent markers of membrane proteins

Transmission electron micrograph (TEM) of the plasma membrane

- When analysing transmission electron micrographs comment on:
  - How the membrane has **two darker layers** surrounding a **lighter** line
  - **Proteins** were known to appear **darker** in electron micrographs
- These were the observations that **supported** Davson-Danielli's model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TEM of a plasma membrane suggests evidence for Davson-Danielli's model

Freeze-etched electron micrographs

- When asked to analyse freeze-etched electron micrographs note that the very **small bumps** seen on the membranes are the **integral proteins**
- This provided evidence **against** Davson-Danielli's model as it showed proteins extending into the **centre** of the membrane
- Be careful if the image is of a nuclear membrane as the larger circles represent the nuclear pores

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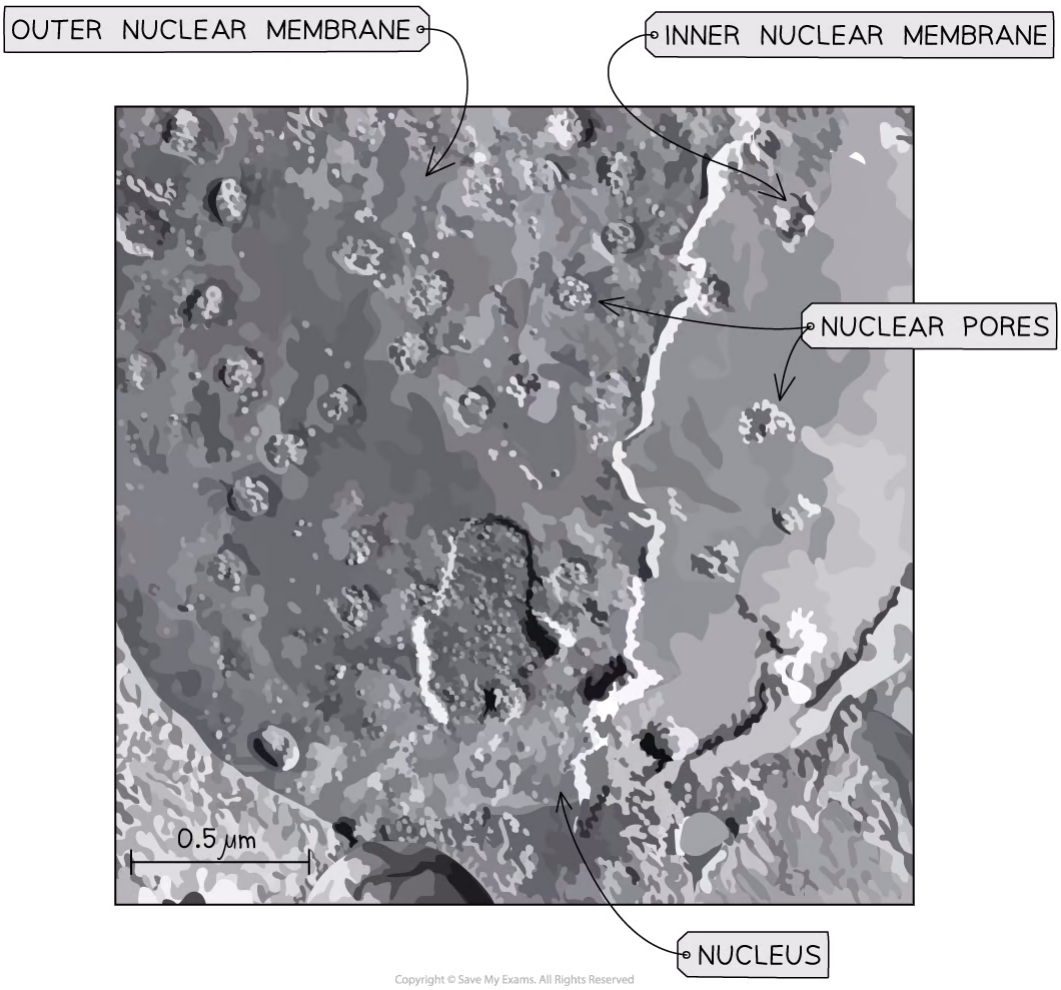

Freeze-etching of a nucleus suggests evidence against Davson-Danielli's model

Fluorescent markers on membrane proteins

- When analysing data on the use of red and green fluorescent markers attached to membrane proteins, the key evidence to note, is that **as time progresses** after the fusion of the different cells with the different markers has occurred, **more mixing** of the markers is observed
- This evidence **did not support Davson-Danielli's model** that the proteins were a uniform layer above and below the phospholipids
- It **supported** the '**fluid**' part of **Singer & Nicolson's** fluid mosaic model as it suggested that membrane proteins can move

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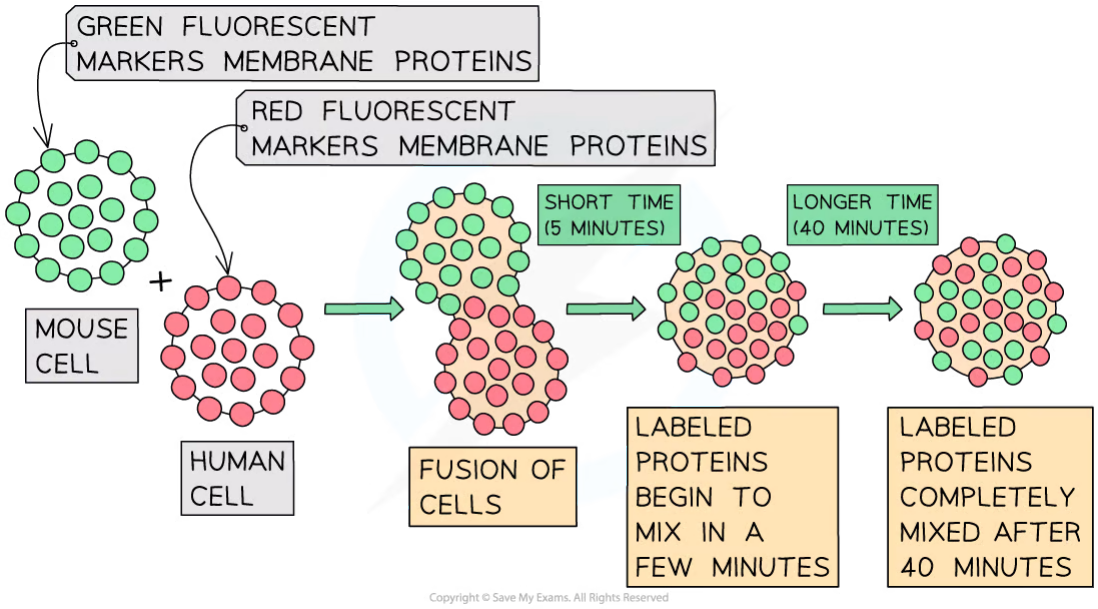

Fluorescent markers on membrane proteins suggest evidence against Davson-Danielli's model

Falsification of Davson-Danielli Model

NOS: Falsification of theories with one theory being superseded by another; evidence falsified the Davson-Danielli model

- For about 30 years the technology available to scientists supported the Davson-Danielli model of membrane structure
- From the 1950's an advancement in technology led to the accumulation of evidence which resulted in the **Davson-Danielli model** being **superseded** by the **Singer-Nicolson 'fluid mosaic model'**
- Analysis of **freeze-etched electron micrographs** showed proteins **extending** into the **centre of membranes**
- **Biochemical analysis** of membranes suggested that it was unlikely proteins formed continuous layers because it showed:
  - **Proteins** were **globular**
  - **Varied in sizes**
  - They had parts that were **hydrophobic**
- The use of **coloured fluorescent markers** of antibodies showed that within forty minutes of fusing cells with different coloured fluorescent markers the markers had mixed
  - This suggested that membrane proteins were **free to move** within the layer

Exam Tip

It is important to be able to provide the reasons why the evidence collected falsified the Davson-Danielli model.

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Practical 2: Estimation of Osmolarity

NOS: Experimental design; accurate quantitative measurements in osmosis experiments are essential

- Planning is an essential part of experimental biology, it will help ensure that valid conclusions can be made
- **Preliminary** (meaning "to come before") **research** must be completed to ensure the experiment design considers:
  - The **results** that will be collected
    - **Quantitative data** allows more valid conclusions to be made
    - **Qualitative data** (descriptive) can be useful to support the conclusions
  - How **measurements** will be made so they are as precise and as **accurate** as possible
    - The choice of **apparatus** and **techniques** should be **based on the science** surrounding the issue being investigated
  - How many **repeats** will be undertaken to ensure the data collected is reliable
  - The **variables** that will be **tested** and need to be **controlled**
- Once the preliminary research has been completed then **preliminary studies** can be conducted to further aid the experimental design
- These studies are very important for:
  - Identifying additional variables that affect the experiment
  - Finding the best way to control these variables
  - Deciding on the quantities and volumes of substances that are needed so that you do not run out of reactants/reagents
- Any experiment conducted without preliminary research or studies is likely to be invalid as the other variables that affect the results in the experiment will not have been identified and controlled

Practical 2: Estimation of osmolarity in tissues by bathing samples in hypotonic and hypertonic solutions

- The **osmolarity** of a solution measures the **number of solute particles** (that can form bonds with water) **per 1 L of solvent**
- Osmolarity is expressed as [popover id="XqIR9B3GzVySI6JG" label ="osmoles"] or milliosmoles per litre of solution (**Osm/L or mOsm/L**)
- A **hypotonic solution** has a **lower osmolarity** than the tissue being bathed in it (so the tissue will increase in mass or length) whereas a **hypertonic solution** has a **higher osmolarity** (so the tissue will decrease in mass or length)
- An **isotonic solution** will have the **same osmolarity** as the tissue (so the mass or length will remain unchanged)
- It is possible to investigate the effects of immersing plant tissue in **solutions of different osmotic concentrations (osmolarity)** and to **use the results to estimate the osmolarity of the plant tissue** itself
- The most common osmosis practical of this kind involves cutting **cylinders of potato** and placing them into solutions with a **range of different osmotic concentrations**

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- **Usually sucrose solutions of increasing concentration** – at least 5 different concentrations are usually required

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Apparatus

- Potato x 2 (same variety)
- Cork borer (e.g. 5mm)
- White tile
- Scalpel
- 10cm ruler or vernier calipers
- Weighing balance (2dp)
- 10 cm^3 sucrose solution (0 mol/dm^3, 0.25 mol/dm^3, 0.5 mol/dm^3, 0.75 mol/dm^3, 1.00 mol/dm^3)
- 5 test tubes (in test tube rack)
- 10 cm^3 measuring cylinder
- Paper towels

Method

- The required number of potato cylinders are cut
  - At least 5 for each of the solutions you are testing to ensure you have sufficient repeats
- They are all cut to the **same length** and, once blotted dry to remove any excess moisture, their **initial mass is measured and recorded** before placing into the solutions
- The potato cylinders are left in the solutions for a set amount of time (eg. 30 minutes), usually in a water bath (set at around 30°)
  - The solutions are prepared by serial dilutions of a specific solute concentration determined during the preliminary research/trials)
- The cylinders are then removed and **dried**
  - This is done to **remove excess liquid**
- The **final length and mass** of each potato cylinder is then measured and recorded

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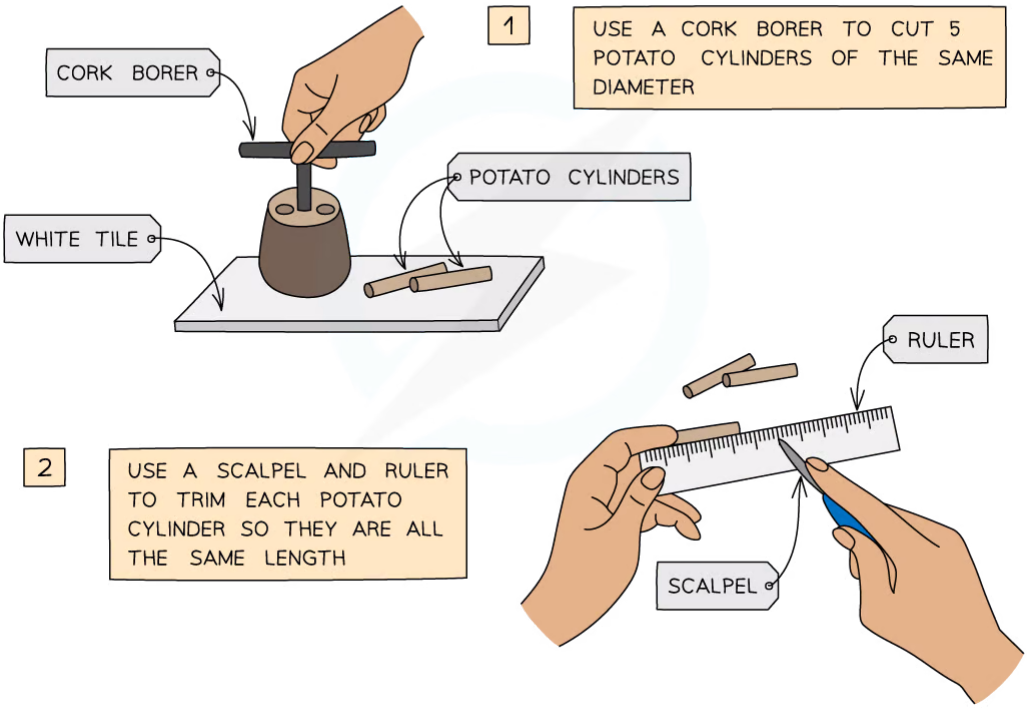
OSMOSIS METHOD



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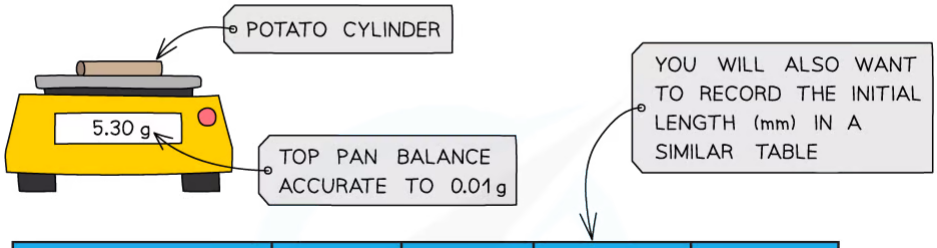
3 MEASURE THE MASS OF EACH POTATO CYLINDER AND RECORD IN A TABLE OF RESULTS



Concentration of sucrose solution mol/dm³	Initial mass (g)	Final mass (g)	Change in mass (g)	% change in mass
0 (distilled water)	5.30			
0.25	5.32			
0.50	5.29			
0.75	5.31			
1.00	5.29			

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4 MEASURE 10 cm³ OF EACH SUGAR OR SALT SOLUTION AND POUR

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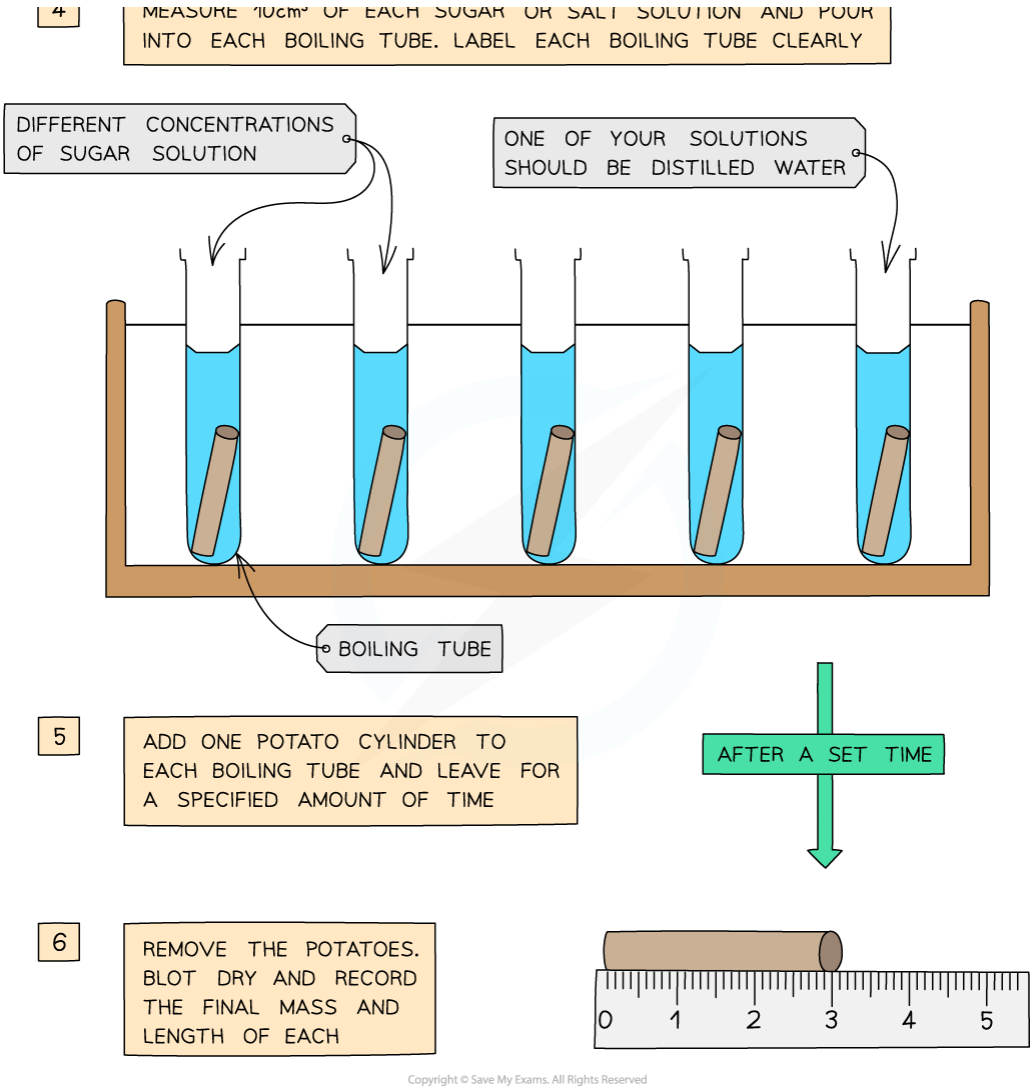

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You will need to use apparatus appropriately to measure out the volumes of your solutions and record your measurements

Analysis

- The **percentage change** in mass for each potato cylinder is calculated and then plotted

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OSMOSIS ANALYSIS

Concentration of sucrose solution mol/dm³	Initial mass (g)	Final mass (g)	Change in mass (g)	% change in mass
0 (distilled water)	5.30	5.80	+0.50	9.4
0.25	5.32	5.42	+0.10	?
0.50	5.29	5.24	−0.05	−1.0
0.75	5.31	5.11	−0.20	−3.8
1.00	5.29	5.02	−0.27	−5.1

1 CALCULATE THE PERCENTAGE CHANGE IN MASS FOR EACH CYLINDER

$$\frac{(\text{FINAL MASS} - \text{INITIAL MASS})}{\text{INITIAL MASS}} \times 100$$

e.g. FOR 0.25 mol dm³

$$= \frac{(5.42 - 5.32)}{5.32} \times 100$$

$$= 1.9\%$$

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To find the percentage change in mass, the change in mass must be divided by the initial mass and then multiplied by 100

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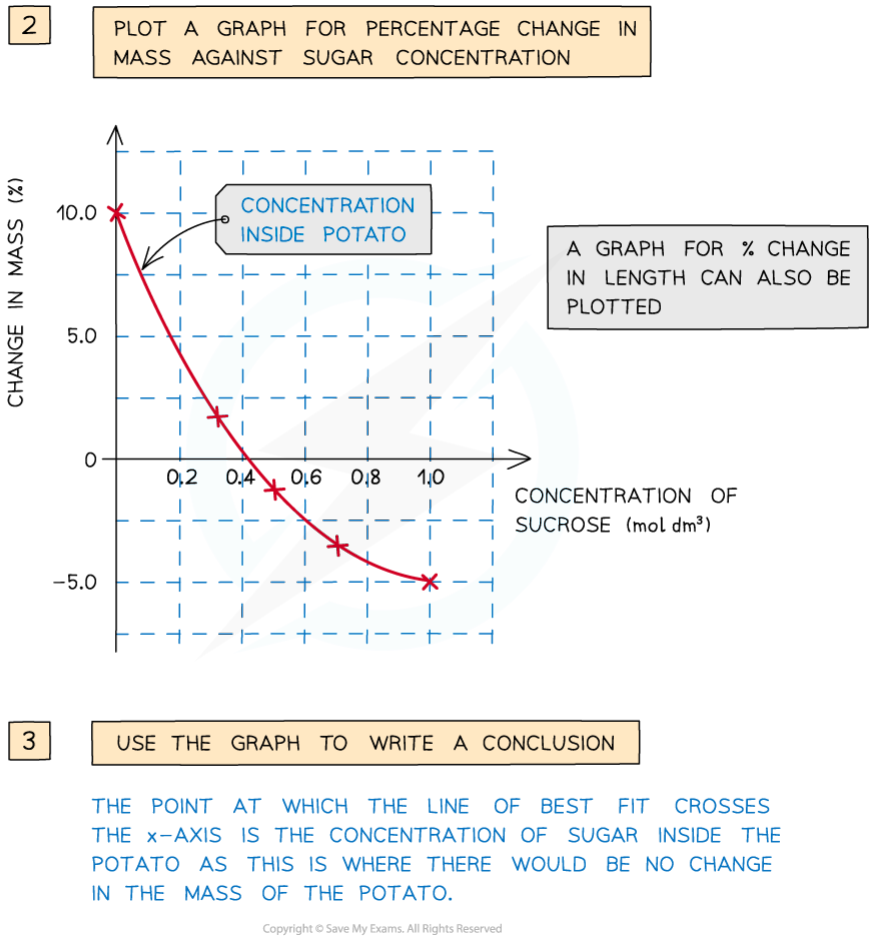

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A positive percentage change in mass indicates that the potato has gained water by osmosis

- A **positive** percentage change in mass indicates that the potato has gained water by osmosis (net movement of water from the solution into the potato) meaning the **solution** had a **lower osmolarity** than the potato
  - The gain of water makes the potato cells **turgid,** as the water exerts turgor pressure (or hydrostatic pressure) on the cell walls – the potatoes will feel hard
- A **negative** percentage change suggests the opposite, that is, the solution had a **higher osmolarity** than the potato
  - The potato cylinder in the **strongest sucrose concentration** will have **decreased in mass** the most as there is the **greatest concentration gradient** in this tube between the potato cells (lower osmolarity) and the sucrose solution (higher osmolarity)
  - More water molecules will move out of the potato cells by **osmosis**, making them **flaccid** and decreasing the mass of the potato cylinder – the potato cylinders will feel floppy
  - If looked at underneath the microscope, cells from this potato cylinder might be **plasmolysed**, meaning the cell membrane has pulled away from the cell wall

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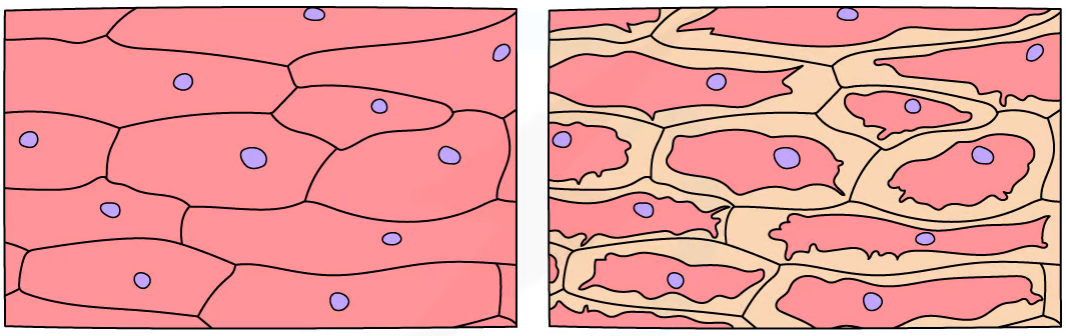
- If there is a potato cylinder that has neither increased nor decreased in mass, it means there was **no overall net movement of water** into or out of the potato cells
- The solution that this particular potato cylinder was in had the **same osmolarity** as the solution found in the cytoplasm of the potato cells, so there was **no concentration gradient** and therefore no net movement of water into or out of the potato cells
- The concentration of sucrose inside the potato cylinders can be found if a graph is drawn showing how the percentage change in mass changes with the concentration of sucrose solution
- The point at which the line of best fit **crosses the x-axis** is the concentration of sucrose inside the potato cylinders

Investigating osmolarity using onion cells

- Evidence of osmosis occurring in plant cells can be shown when the cells undergo **plasmolysis**:
  - If a plant cell is placed in a solution with a **higher osmolarity** than the cell (such as a concentrated sucrose solution), water will **leave** the cell through its partially permeable cell surface membrane by **osmosis**
  - As water leaves the **vacuole** of the plant cell, the volume of the cell **decreases**
  - The protoplast (living part of the cell inside the cell wall) gradually shrinks and no longer exerts pressure on the cell wall
  - As the protoplast continues to shrink, it begins to pull away from the cell wall
  - This process is known as **plasmolysis** – the plant cell is **plasmolysed**
- This process can be observed using **epidermal strips** (sections of the very thin outer layer of tissue in plants)
  - Plants with coloured sap (such as red onion bulbs, rhubarb petioles and red cabbage) make observations easier
- The epidermal strips are placed in a **range of molarities of sucrose solution** or **sodium chloride solutions**, of gradually decreasing water potential
- The strips are then viewed under a light microscope and the **total number** or **percentage** of **onion cells** that have undergone **plasmolysis** can be counted
  - Plasmolysis may take several minutes to occur



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Light micrographs of normal red onion cells alongside those that have plasmolysed (artistic impression). The cells on the left are epidermal cells that have been immersed in distilled water, whilst the cells on the right are epidermal cells that have been immersed in 1.0 mol dm^{-3} sucrose solution.

Exam Tip

Questions involving experiments investigating osmolarity and osmosis are common and you should be able to use your knowledge of osmosis to explain the results obtained. Don't worry if it is an experiment you haven't done – simply figure out where the higher concentration of water molecules is – this is the solution with the lower osmolarity – and explain which way the molecules move due to the differences in osmolarity.

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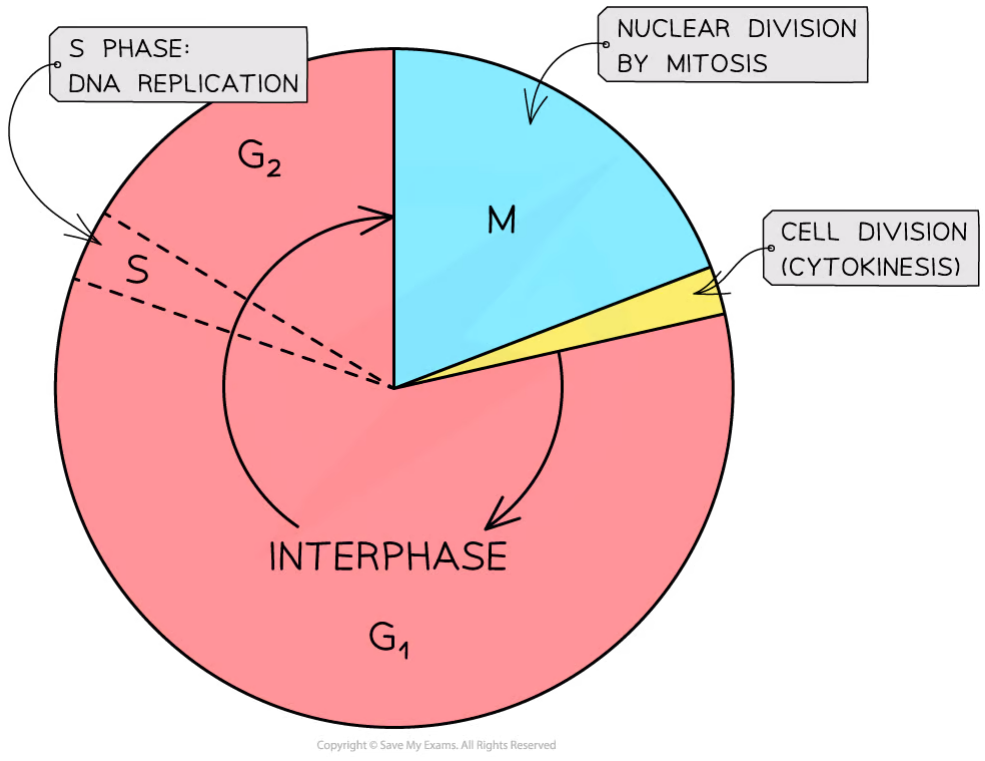
1.4 Cells: Division

1.4.1 Cell Cycle

Interphase

- **Mitosis** is part of a **precisely controlled process** known as the **cell cycle**
- The cell cycle is the **regulated sequence of events** that occurs **between one cell division and the next**
- The cell cycle has three phases:
  - **interphase**
  - **nuclear division (mitosis)**
  - **cell division (cytokinesis)**
- The length of the cell cycle varies depending on:
  - The environmental conditions, the cell type and the organism
  - For example, onion root tip cells divide once every 20 hours (roughly) but human intestine epithelial cells divide once every 10 hours (roughly)
- The movement from one phase to another is triggered by chemical signals called **cyclins**



The cell cycle

S = synthesis (of DNA); G = growth; M = mitosis

Interphase

- **Interphase** is the **longest** and **most active phase** of the **cell cycle**

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- During interphase, the cell:
  - **Increases** in **mass** and **size**
  - Carries out many cellular functions in the nucleus and cytoplasm eg. **synthesising proteins** and **replicating its DNA** ready for mitosis (these only occur during interphase)
  - **Increases** the number of **mitochondria**
  - **Increases** the number of **chloroplasts** (if they are a plant or algae cell)

The phases of interphase

- Interphase consists of **three** phases:
  - **G_1 phase**
  - **S phase**
  - **G_2 phase**
- The gap between the previous cell division and the S phase is called the **G_1 phase** – **G** stands for **growth**
  - Cells make the **RNA, enzymes and other proteins required for growth** during the G_1 phase
- It is at some point during the G_1 phase a **signal** is received telling the cell to **divide** again (although some cells do not receive this signal and will **never divide;** they enter the **G_0 phase**)
- After the G_1 phase of interphase the cell enters the next phase of the cell cycle, the **S phase** – **S** stands for **synthesis** (of DNA)
  - The S phase is relatively short
  - The **DNA in the nucleus replicates,** resulting in each chromosome consisting of two identical sister chromatids
- Between the S phase and next cell division event the **G_2 phase** occurs
  - During the G_2 phase, the **cell continues to grow and the new DNA that has been synthesised is checked** and any errors are usually repaired
  - Other preparations for cell division are made (eg. production of tubulin protein, which is used to make microtubules for the mitotic spindle)
- **Interphase = G_1 + S + G_2**

Exam Tip

Make sure you know the order of the phases of the cell cycle but also what specifically occurs during the different phases. Don't forget, interphase is itself made up of three distinct stages (G_1, S and G_2) and you need to know what happens during each of these.For example, an exam question might ask you to identify the stage of the cell cycle during which a cell would be producing the most mRNA molecules and explain why. The correct answer would be the G_1 phase, as this is when protein synthesis is occurring and the production of mRNA occurs during transcription (the first part of protein synthesis).

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Cyclins

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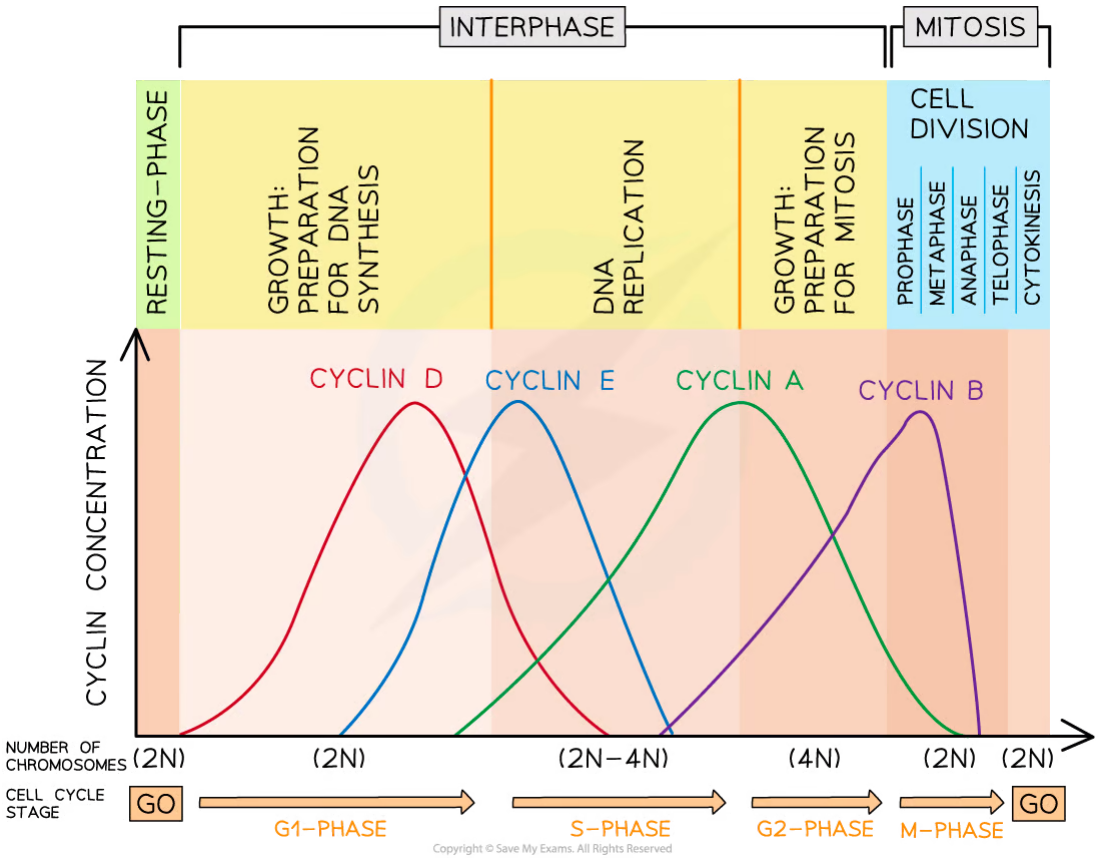
- The **cell cycle** is a sequence of stages including **interphase** (G_1, S & G), **mitosis** and **cytokinesis**
- The cycle is **controlled** by **cyclins** (a group of proteins) and **kinases** (enzymes)
- There are **four different cyclins** (**D, E, A & B**) whose concentrations rise and fall over the cycle:
  - D – **present first**, triggers cells to **move** from **G_1 to S phase**
  - E – **highest** concentration at the start of **S phase**, **prepares** the cell for **DNA replication** during S phase
  - A – **highest** concentration in **G_2 phase** but activates two different kinases that trigger two processes:
    - In the **S phase**, it **activates DNA replication**
    - In **G_2 phase**, it **prepares** the cell for **mitosis**
  - B - **highest** concentration at the **beginning** of **mitosis**, **promotes** the **formation** of the **mitotic spindle**



Cyclins control the cell cycle. The presence of certain cyclins triggers a specific stage of the cell cycle.

- When each of the different **cyclins** reach a **certain concentration** they **trigger the next stage** of the cell cycle

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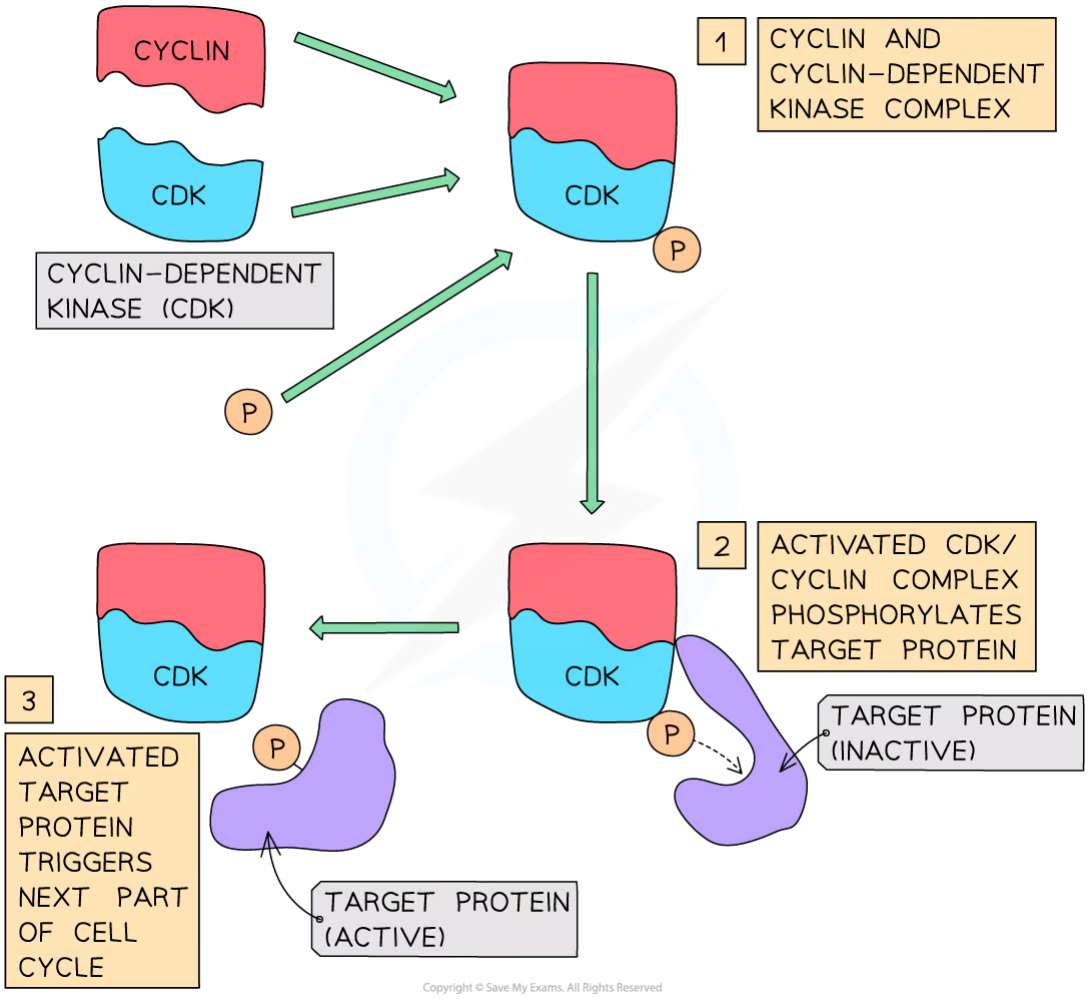
- This ensures **key processes** (e.g. DNA replication, organelle multiplication and protein synthesis) **occur** at the **correct time**
- When a specific cyclin has reached a certain concentration it will **bind** with another group of proteins (**cyclin-dependent kinases**) forming a **complex** which is **activated**
- This complex **phosphorylates** (attaches a phosphate) a **target protein** which **activates it,** causing it to trigger **specific functions** (e.g. DNA replication)
- Once the specific function is complete the phosphate is released, the cyclin breaks down and the cyclin-dependent kinases become inactive



The mechanism for cell cycle control by cyclins

NOS: Serendipity and scientific discoveries; the discovery of cyclins was accidental

- Some scientific discoveries occur by accident, meaning that the scientist might not necessarily have been deliberately searching for information about the particular mechanism, process, molecule or structure that they ended up discovering
- The discovery of the cyclins was **serendipitous** (occurred by chance)
- Tim Hunt and his team were researching protein synthesis in sea urchin eggs, however, whilst doing this research they noticed a protein (later named by Hunt as **cyclin**) that

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repeatedly increased and decreased in concentration and that these coincided with the phases of the cell cycle
- This discovery led to new research which found the presence of other cyclins and their function as a key factor in the regulation of the cell cycle

YOUR NOTES

Exam Tip

It is important to know the order of the cyclins (DEAB - think dead but with a B of course). When answering questions on which cyclins trigger which stage of the cell cycle it may be easier to sketch a graph. In Biology a well-annotated diagram can get you as many marks as a written answer.

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Cytokinesis

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Cytokinesis

- Follows the nuclear division (**mitosis**) phase
- Once the nucleus has divided into two genetically identical nuclei, the **cell divides in two** with one nucleus moving into each cell to **create two genetically identical daughter cells**

Mitosis in animal and plant cells

- The process differs slightly in animal and plant cells
- In **animal** cells:
  - A '**cleavage furrow**' forms and separates the daughter cells
  - The cleavage furrow forms when actin and myosin proteins form a contractile ring just under the plasma membrane
  - This ring is formed at the equator (centre) of the cell
  - As the proteins contract, they pull the plasma membrane towards the centre eventually separating the cell into two daughter cells
- In **plants** cells:
  - A '**cell plate**' (the precursor to a new cell wall) forms at the equator. Once the cell plate reaches the cell walls of the parent cell, new cell walls are produced, separating the new daughter cells
  - The cell plate is formed from vesicles carrying carbohydrates, lipids and proteins fusing together to create the two plasma membranes
  - After this other vesicles, carrying pectin and cellulose, deposit these substances by exocytosis in the gap between the two new membranes leading to the formation of new cell walls

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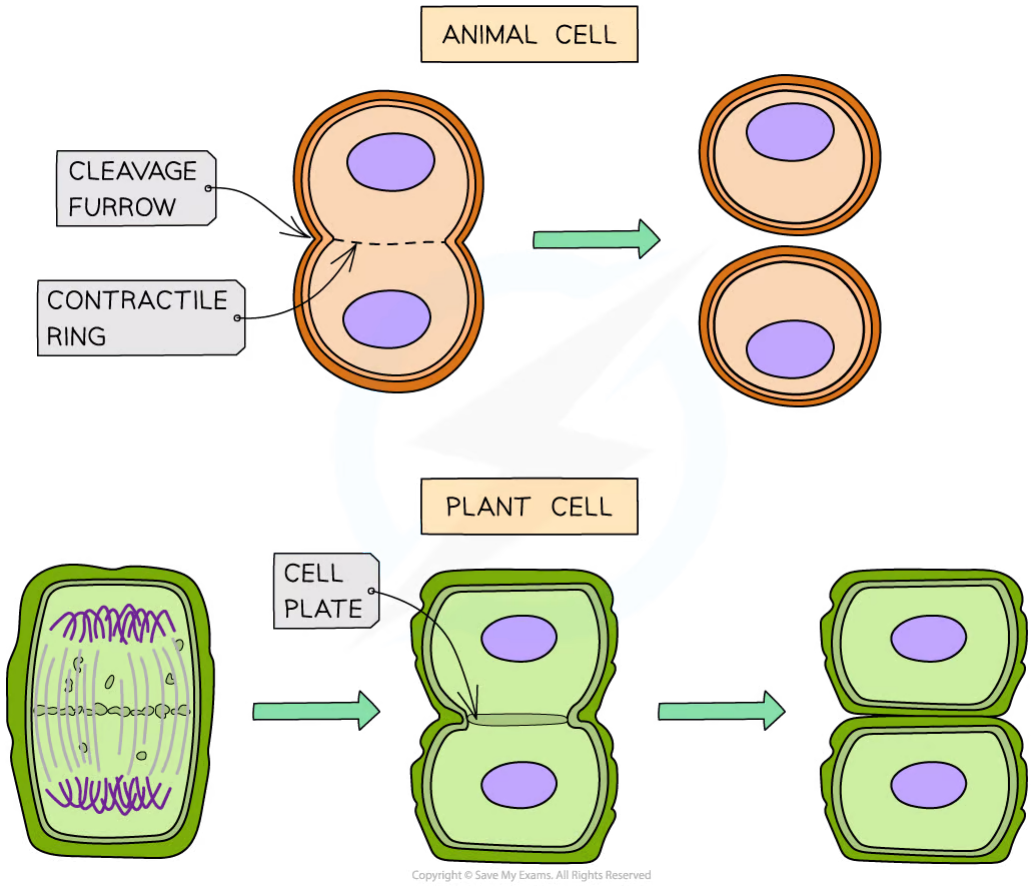

Cytokinesis in an animal cell and a plant cell

Exam Tip

Remember that cytokinesis is **not** a stage in mitosis, it is the last stage of the **cell cycle**.

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Phases of Mitosis

- Mitosis is the process of nuclear division by which **two genetically identical daughter nuclei** are produced that are also genetically identical to the parent cell nucleus (they have the same number of chromosomes as the parent cell)
- **Significance of mitosis**: mitosis occurs whenever the production of genetically identical nuclei are required in eukaryotic cells
  - E.g. during embryonic development, growth, tissue repair and asexual reproduction

Embryonic development and growth of multicellular organisms

- **Unicellular zygotes** divide by mitosis in order to **grow in size**
- After a certain amount of growth, they then differentiate **into embryos**
- **Growth** of multicellular organisms occurs as the number of new cells increases due to mitosis
- This growth may occur across the whole body of the organism or be confined to certain regions, such as in the meristems (growing points) of plants

Replacement of cells & repair of tissues

- Damaged tissues can be repaired by mitosis followed by cell division
- As cells are constantly dying they need to be **continually replaced by genetically identical cells**
- In humans, for example, cell replacement occurs particularly rapidly in the skin and the lining of the gut
- Some animals can regenerate body parts, for example, zebrafish can regenerate fins and axolotls regenerate legs and their tail amongst other parts

Asexual reproduction

- Asexual reproduction is the production of new individuals of a species by a **single** parent organism – the offspring are genetically identical to the parent
- For unicellular organisms such as *Amoeba*, cell division results in the reproduction of a **genetically identical offspring**
- For multicellular organisms, new individuals grow from the parent organism (by cell division) and then detach ('bud off') from the parent in different ways
- This type of reproduction can be observed in different plant, fungi and animal species
- Some examples of these are budding in *Hydra* and yeast and runners from strawberries

Phases of Mitosis

- Although mitosis is, in reality, one continuous process, it can be divided into **four main stages or phases**
- These stages are:
  - **Prophase**
  - **Metaphase**
  - **Anaphase**
  - **Telophase**

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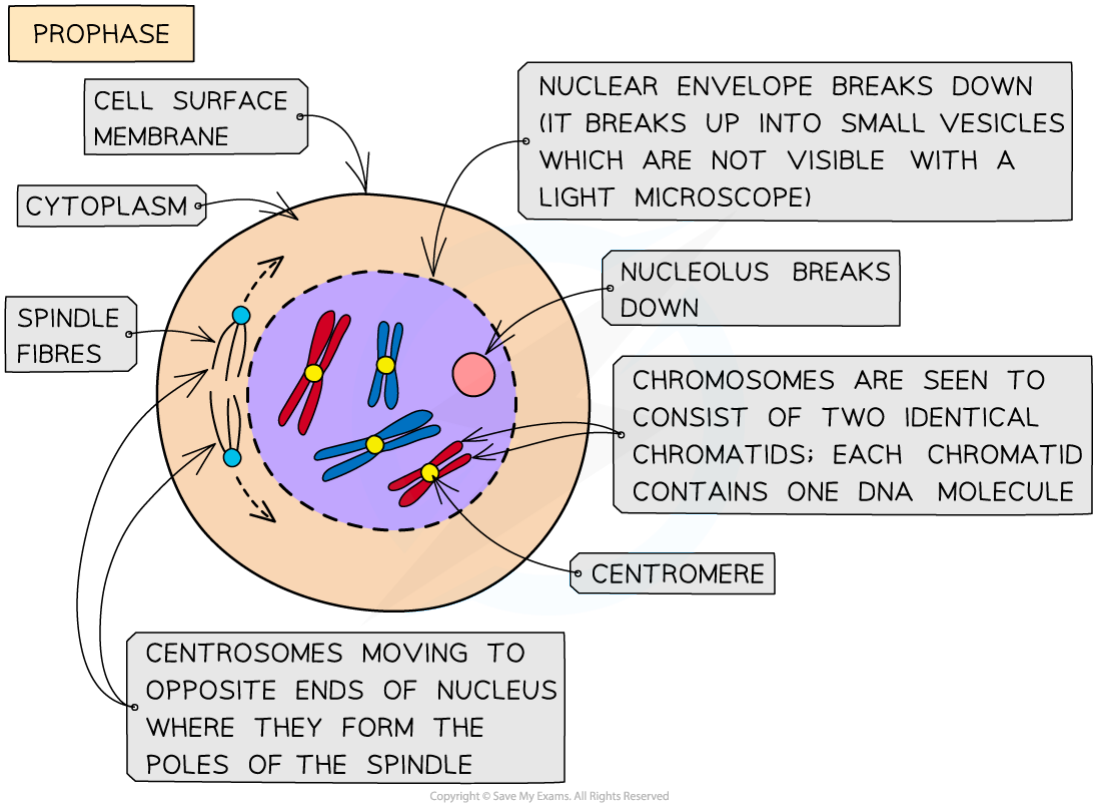
- Most organisms contain many chromosomes in the nuclei of their cells (eg. humans have 46) but the diagrams below show mitosis of an animal cell with only four chromosomes, for simplicity
- The different colours of the chromosomes are just to show that half are from the female parent and half from the male parent

Prophase

- Chromosomes **condense** and are now visible when stained
- The chromosomes consist of **two identical chromatids** called **sister chromatids** (each containing one DNA molecule) that are joined together at the centromere
- The two centrosomes (replicated in the G_2 phase just before prophase) move towards **opposite poles** (opposite ends of the nucleus)
- **Spindle fibres** (protein **microtubules**) begin to emerge from the centrosomes (consists of two centrioles in animal cells)
- The **nuclear envelope** (nuclear membrane) **breaks down** into small vesicles
- The nucleolus disappears



Prophase

Metaphase

- **Centrosomes** reach **opposite poles**
- **Spindle fibres** (protein microtubules) continue to **extend from centrosomes**
- Chromosomes **line up at the equator** of the spindle (also known as the metaphase plate) so they are equidistant to the two centrosome poles

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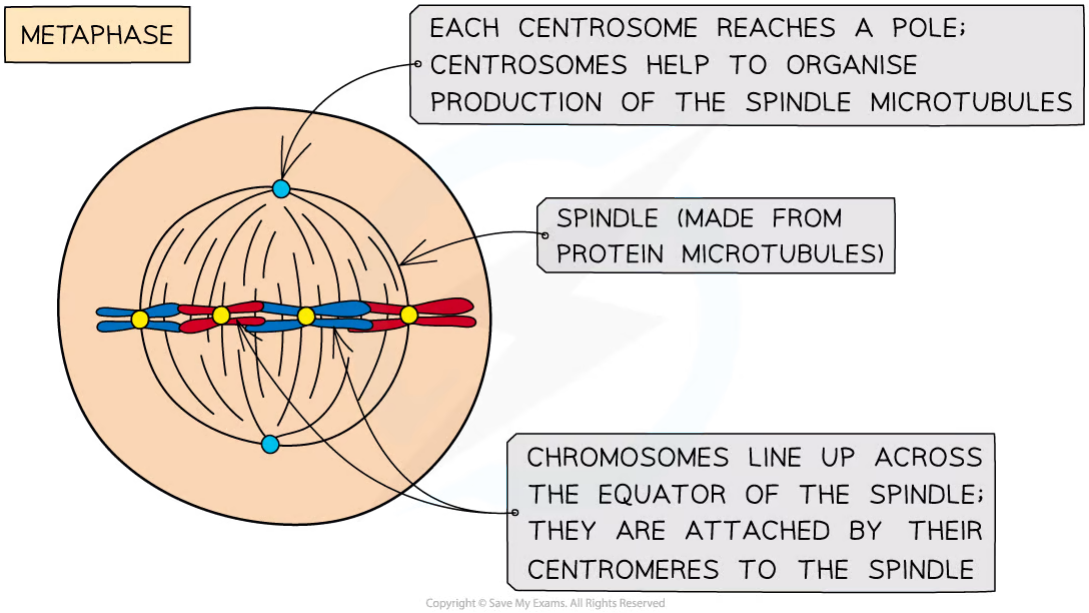
- Spindle fibres (protein microtubules) reach the chromosomes and **attach to the centromeres**
  - This attachment involves specific proteins called **kinetochores**
- Each **sister chromatid** is attached to a spindle fibre originating from **opposite poles**



Metaphase

Anaphase

- The sister chromatids **separate at the centromere** (the centromere divides in two)
- Spindle fibres (protein microtubules) begin to **shorten**
- The separated sister chromatids (**now called chromosomes**) are **pulled to opposite poles** by the spindle fibres (protein microtubules)

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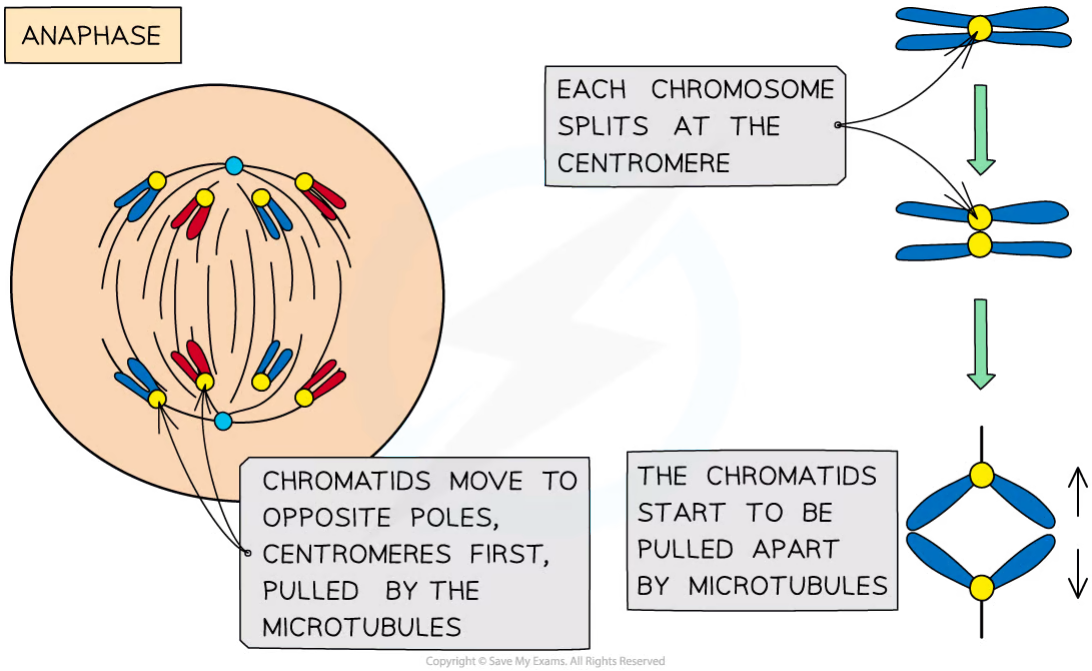

Anaphase

Telophase

- Chromosomes arrive at opposite poles and begin to **decondense**
- **Nuclear envelopes** (nuclear membranes) begin to **reform** around each set of chromosomes
- The **spindle fibres break down**
- New **nucleoli form** within each nucleus

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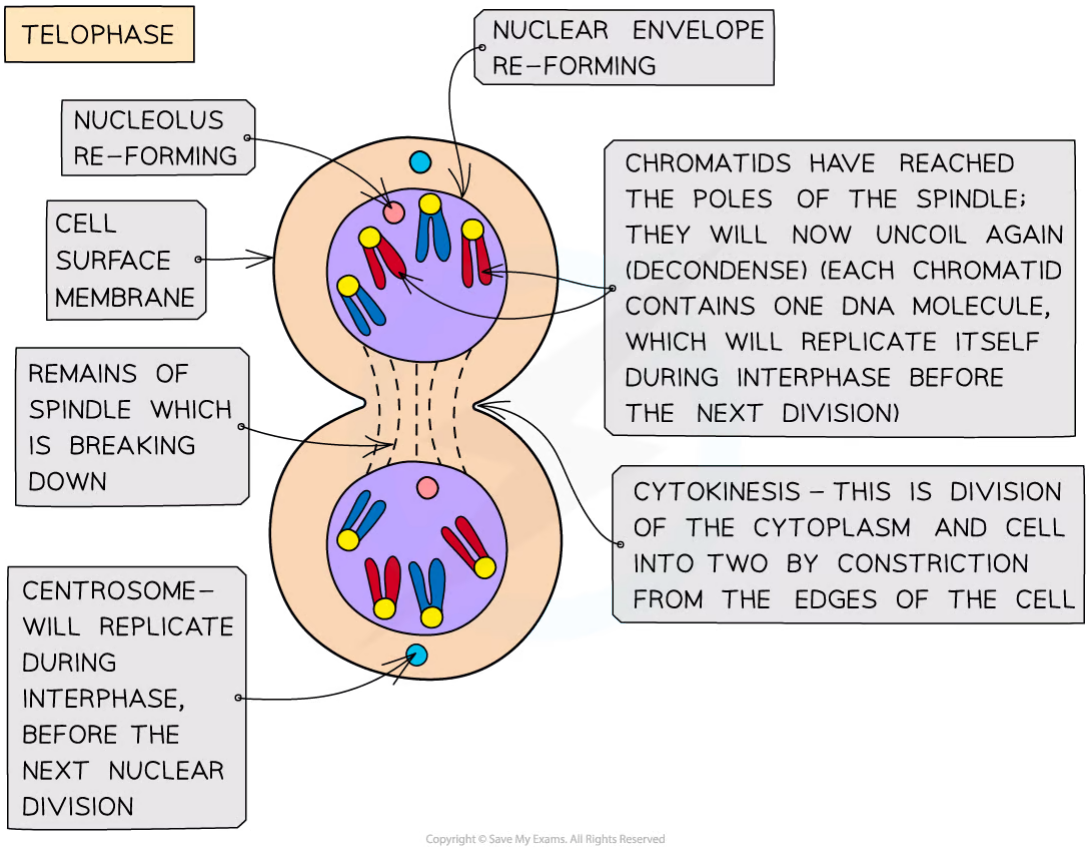

Telophase

Exam Tip

Make sure you learn the four stages of mitosis and what is happening to the DNA molecules (one chromatid contains one DNA molecule) at each stage – learn **'PMAT'** (prophase, metaphase, anaphase, telophase) to help you remember the order of the stages!After interphase but before the parent cell undergoes mitosis, the human parent cell nucleus actually contains 92 DNA molecules! This is because during interphase (S phase), the 46 DNA molecules in the parent cell have replicated to form sister chromatids. As human cells have a diploid number of 46 this replication results in 92 molecules. This ensures the two daughter cells will be diploid (have 46 chromosomes each) when mitosis occurs.Remember to read the questions carefully as **only** human diploid cells have 46 chromosomes so if the question refers to another organism, its diploid number will be different.

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Chromosomes Condense

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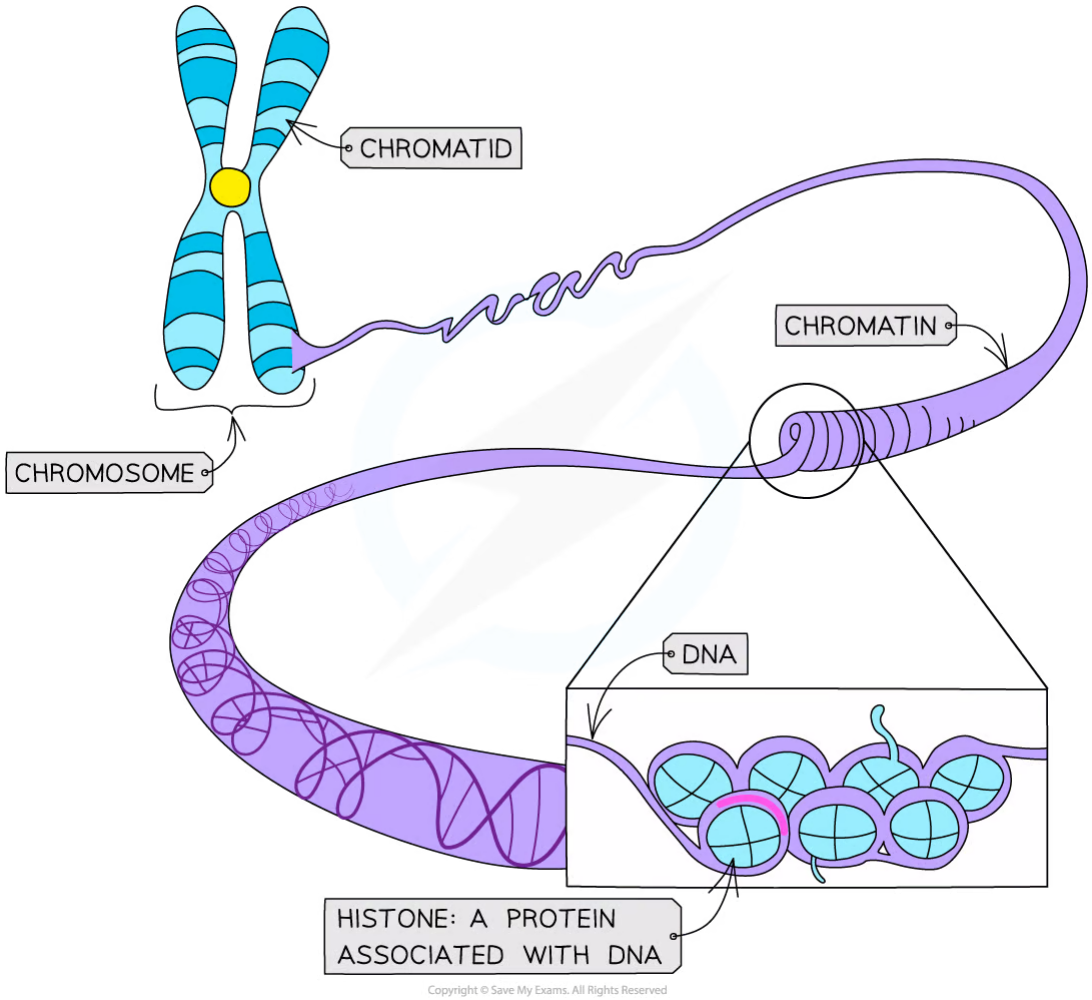
Condensation of chromosomes

- DNA molecules are **very long molecules** (human DNA can be more than 50,000 µm) that need to fit within much smaller nuclei (human nuclei average less than 5 µm)
- Prior to mitosis, the DNA molecules are loosely coiled (around histones in eukaryotic cells) to form a complex called **chromatin**
- During **prophase**, the chromatin gets **condensed** by **supercoiling** to form **chromosomes**
- Condensation occurs by the repeated coiling of the DNA molecule (supercoiling)
- This supercoiling is aided in eukaryotic cells by the presence of histone proteins and enzymes



DNA is coiled around histone proteins to make chromatin

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Tumour Formation

- Cancers demonstrate how important it is that **cell division** is **precisely controlled**, as cancers arise due to **uncontrolled mitosis**
- Cancerous cells divide repeatedly and uncontrollably, forming a **tumour** (an irregular mass of cells)
- Cancers start when **changes occur in the genes that control cell division**
  - A change in any gene is known as a mutation
- If the mutated gene is one that **causes cancer** it is referred to as an **oncogene**
- Mutations are common events and don't lead to cancer most of the time
  - Most mutations either result in **early cell death** or result in the cell being destroyed by the **body's immune system**
  - As most cells can be easily replaced, these events usually have no harmful effect on the body
- The mutations that result in the generation of cancerous cells **do not result in early cell death or in the cell being destroyed by the body's immune system**
- This means that the **harmful mutation** occurring in the original cell can be **passed on** to all that cell's descendants
- A typical tumour contains around a thousand million cancerous cells by the time it is detected

Carcinogens

- **Mutagens** are agents that **alter** the **genetic material** of an organism
  - E.g. biological organisms (viruses), radiation (X-rays, UV light) or chemical substances (tar in tobacco smoke)
- If **mutagens cause cancers** they are called **carcinogens**
- **Carcinogens** are any agents that may cause cancer

Types of tumour

- Some tumours (such as warts) do not spread from their original site – these are known as **benign** tumours and **do not cause cancer**
- Some tumours spread through the body, invading and destroying other tissues – these are known as **malignant** tumours and **cause cancer**
  - Malignant tumours **interfere with the normal functioning** of the organ/tissue in which they have started to grow (eg. they may block the intestines, lungs or blood vessels)
  - Malignant tumour cells can **break off the tumour and travel** through the **blood and/or lymphatic system** to form **secondary growths** in other parts of the body
  - The spreading of cancers in this way is known as **metastasis**
  - Metastasis is very dangerous as it can be **very difficult to detect, locate and remove** secondary cancers

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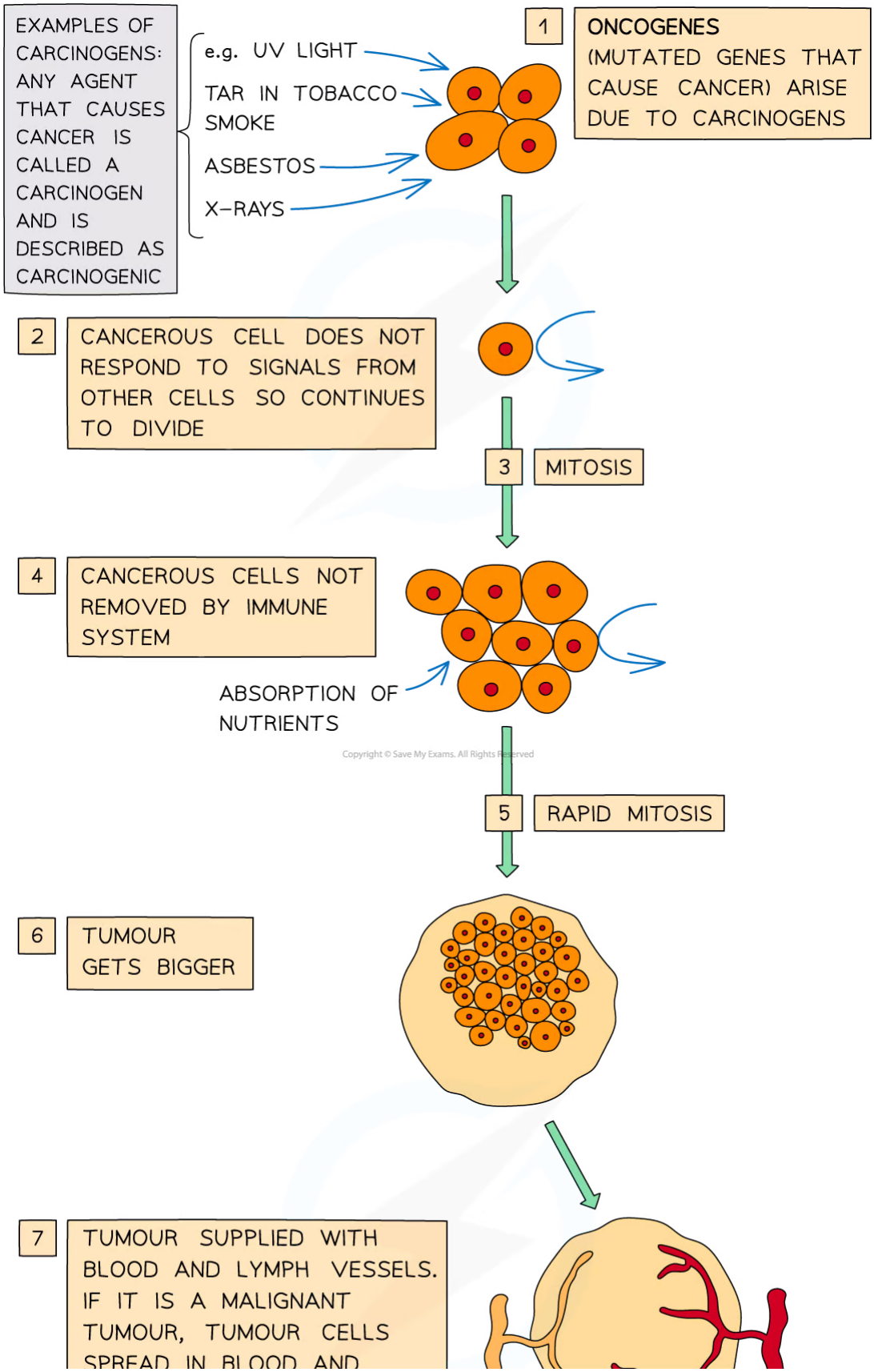

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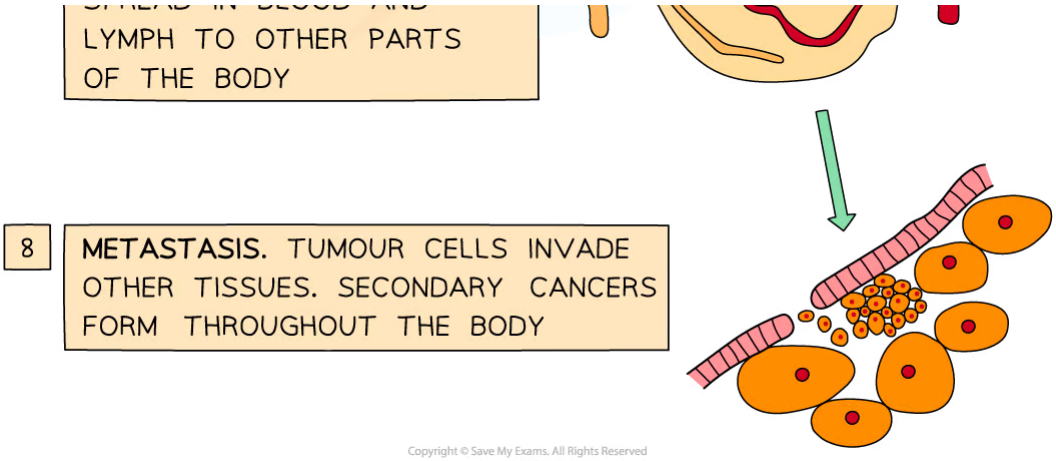

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Stages in the development of cancer

Exam Tip

Make sure you know examples of mutagens. Also, you should know that some viruses (known as oncoviruses) cause cancer and can therefore also be described as mutagens.

Smoking & Cancer

- Scientists studying the incidence and distribution of certain cancers identified links between smoking and cancer
- However, it was only when laboratory investigations showed that cigarette smoke contained more than 4000 chemicals, at least **40** of which were **carcinogens**, that a **correlation** was established
- There is a **positive correlation** between smoking and cancer. The more cigarettes smoked per day the higher the chance of developing certain cancers (e.g. lung and mouth)

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Mitotic Phases: Identification

- Cells undergoing different stages of the cell cycle can be identified using photomicrographs taken from microscope slides
- Cells undergoing certain stages of the cell cycle have distinctive appearances

Interphase

- As cells spend the majority of the cell cycle in this stage then most cells will be in this stage
- The **chromatin** is **visible** so the nuclei have a dark appearance

Prophase

- Chromosomes are **visible**
- The nuclear envelope is breaking down

Metaphase

- **Chromosomes** are lined up along the **middle** of the cell

Anaphase

- **Chromosomes are moving away** from the middle of the cell, towards opposite poles

Telophase

- Chromosomes have arrived at **opposite poles** of the cell
- Chromosomes begin to **uncoil** (are no longer condensed)
- The nuclear envelope is reforming

Cytokinesis

- Animal cells: a **cleavage furrow** forms and separates the daughter cells
- Plant cells: a **cell plate** forms at the site of the metaphase plate and expands towards the cell wall of the parent cell, separating the daughter cells

Identification of phases

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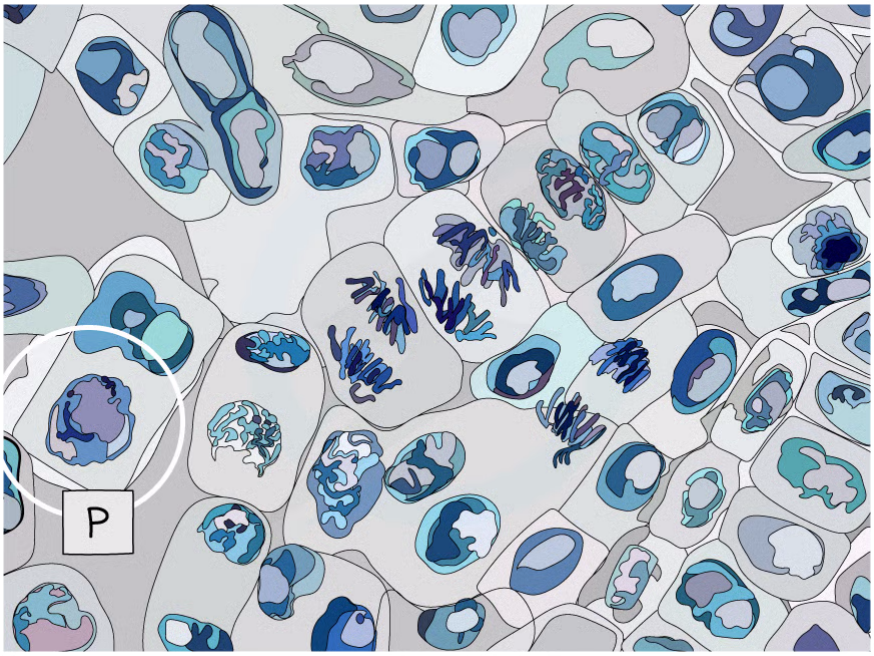

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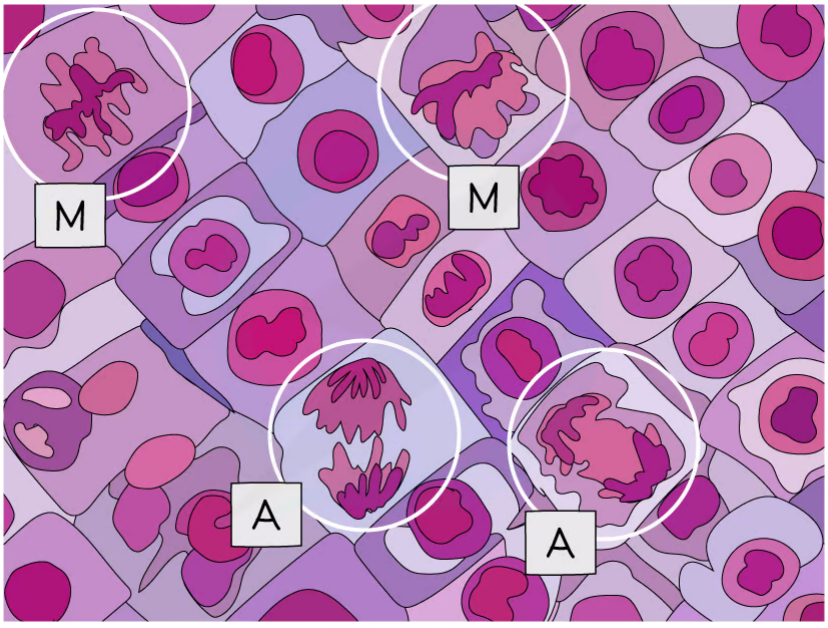
Micrograph showing a cell undergoing prophase (P)



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Micrograph showing cells undergoing metaphase (M) and anaphase (A)

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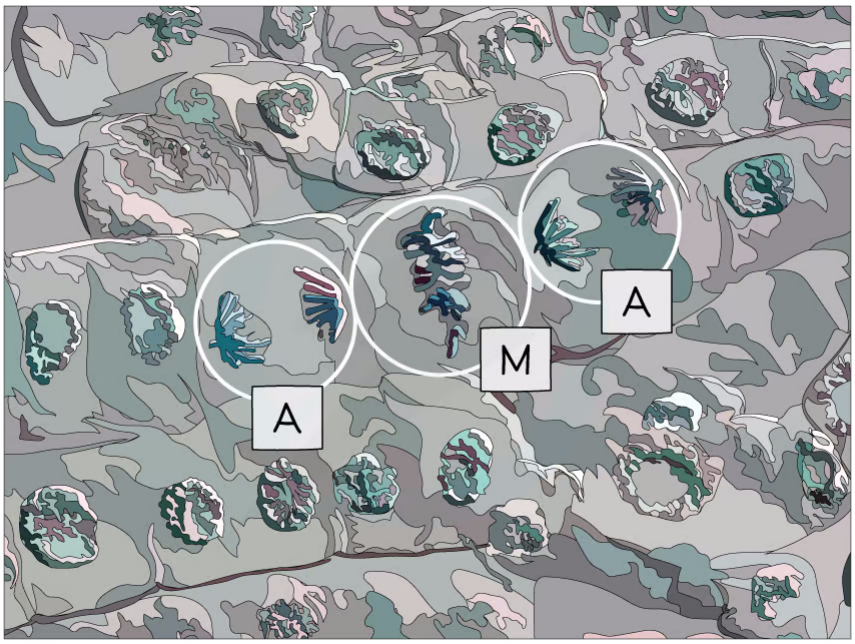

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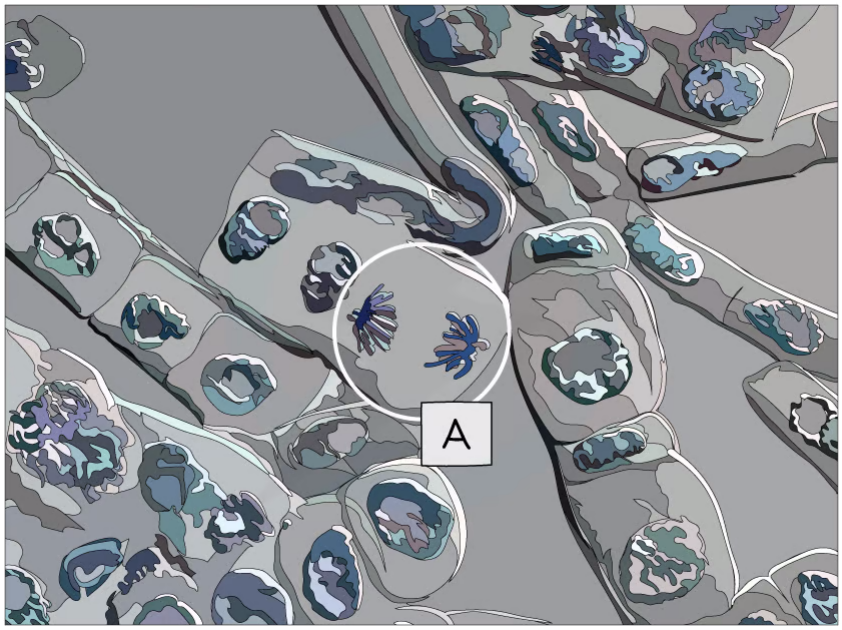
Micrograph showing cells undergoing metaphase (M) and anaphase (A)



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Micrograph showing a cell undergoing anaphase (A)

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Exam Tip

It is important to be able to recognise each mitotic stage from electron micrographs and to be able to explain why that cell is in the stage you have selected.It can be difficult to tell prophase and telophase apart in some photomicrographs. In prophase, there is only one group of chromosomes while in telophase there are two groups, one at each pole.

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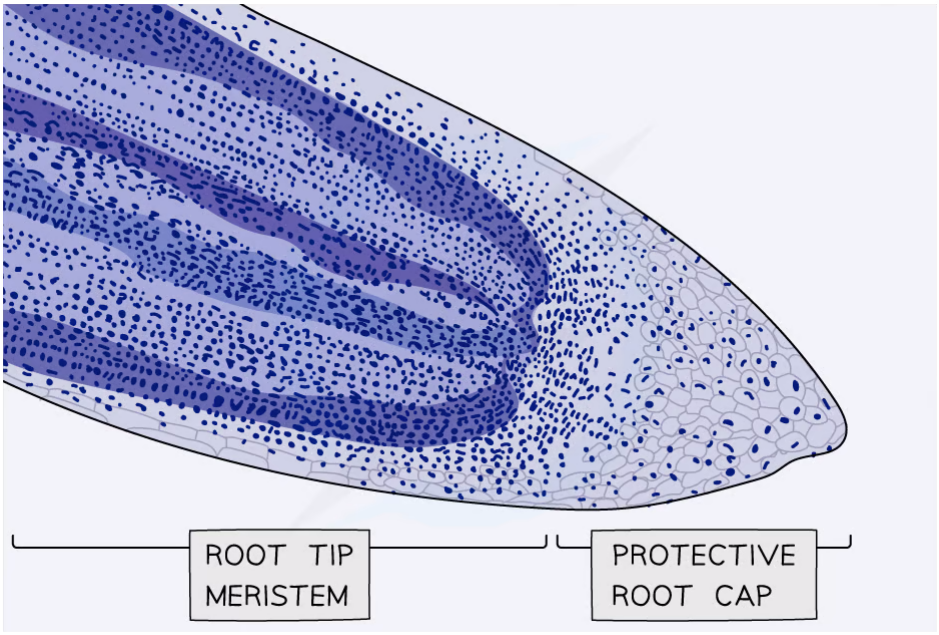
Determination of Mitotic Index

Investigating mitosis in root tissue

- Growth in plants occurs in specific regions called **meristems**
- The root tip meristem can be used to study **mitosis**
- The root tip meristem can be found **just behind the protective root cap**
- In the root tip meristem, there is a **zone of cell division** that contains cells undergoing **mitosis**
- Pre-prepared slides of root tips can be studied or temporary slides can be prepared using the **squash technique** (root tips are **stained** and then **gently squashed**, spreading the cells out into a thin sheet and allowing individual cells undergoing mitosis to be clearly seen)



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Micrograph showing a stained root tip

Analysis

- Cells undergoing mitosis (similar to those in the images below) can be seen and drawn
- Annotations can then be added to these drawings to show the **different stages of mitosis**
- The **mitotic index** can be calculated

The mitotic index

- The mitotic index is the **proportion** of cells (in a group of cells or a sample of tissue) that are **undergoing mitosis**
- The mitotic index can be calculated using the formula below:

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

- You can multiply the answer by **100** if you need to give the mitotic index as a **percentage**

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Worked Example

A student who wanted to observe mitosis prepared a sample of cells. They counted a **total of 42** cells in their sample, **32 of which had visible chromosomes**. Calculate the mitotic index for this sample of cells (give your answer to 2 decimal places).

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{32}{42}$$

mitotic index = **0.76**

Worked Example

The table below shows the number of cells in different stages of mitosis in a sample from a garlic root tip. Calculate the mitotic index for this tissue (give your answer to 2 decimal places).

Stage of mitosis	Number of cells
Interphase	36
Prophase	14
Metaphase	5
Anaphase	3
Telophase	6

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$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{(\text{prophase} + \text{metaphase} + \text{anaphase} + \text{telophase})}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{(14 + 5 + 3 + 6)}{(36 + 14 + 5 + 3 + 6)}$$

$$\text{Mitotic index} = \frac{28}{64}$$

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mitotic index = **0.44**

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Worked Example

The micrograph below shows a sample of cells from an onion root tip. Calculate the mitotic index for this tissue (give your answer to 2 decimal places).

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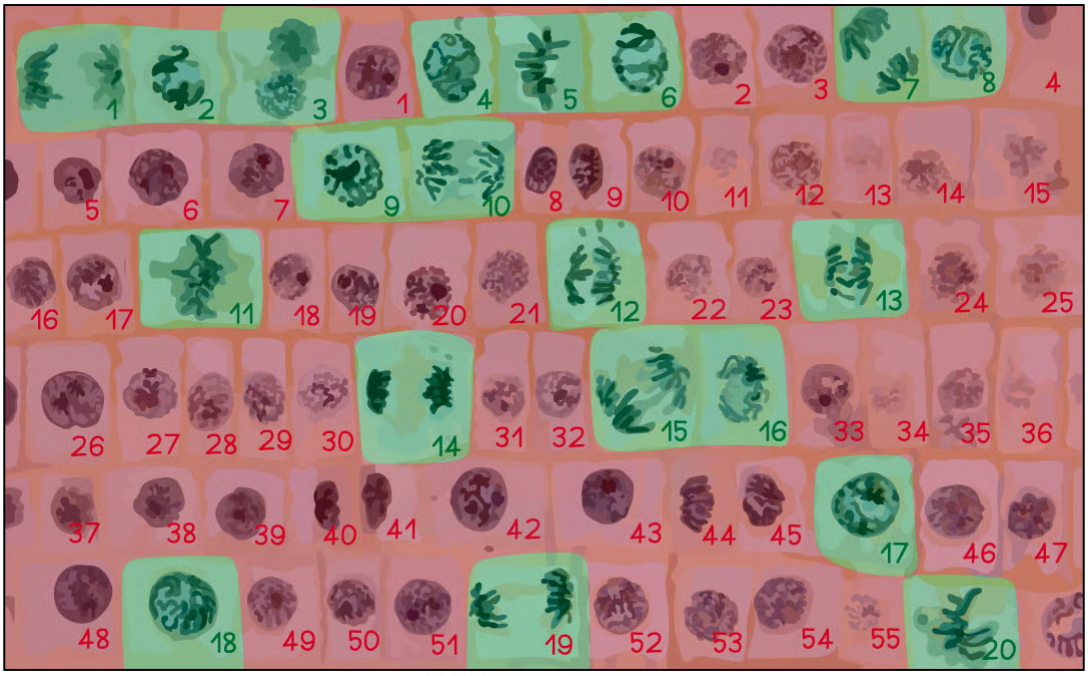
A sample of cells from an onion root tip

Step 1: Identify the cells undergoing mitosis



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Number of cells with visible chromosomes (green) = 20

Step 2: Count the total number of cells

Total number of cells (green + red) = 20 + 55 = 75

Step 3: Substitute numbers into the equation

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{20}{75}$$

mitotic index = **0.27**

Exam Tip

You will need to remember the mitotic index formula as it will not be given to you.

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