HL IB Biology

Your notes

Organelles & Compartmentalisation

Contents

Cell Organelles

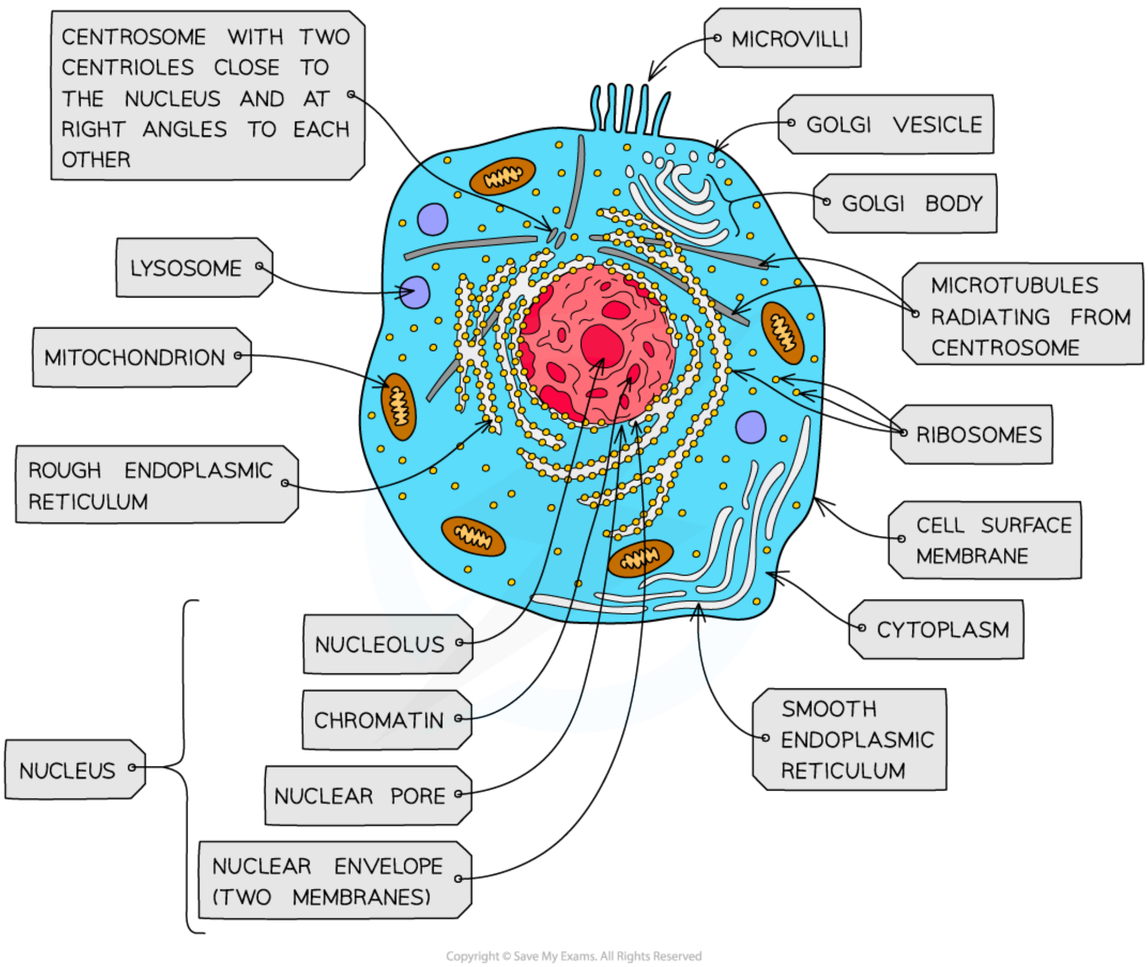
Your notes

Cell Organelles

Compartmentalised 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**
- Due to the absence of a membrane the following structures are **not considered organelles**
  - Cell wall
  - Cytoskeleton
  - Cytoplasm
- Eukaryotic cells have a number of **compartmentalised organelles** including:
  - The nucleus
  - Vesicles
  - Ribosomes
  - The plasma membrane
- The **compartmentalisation** 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

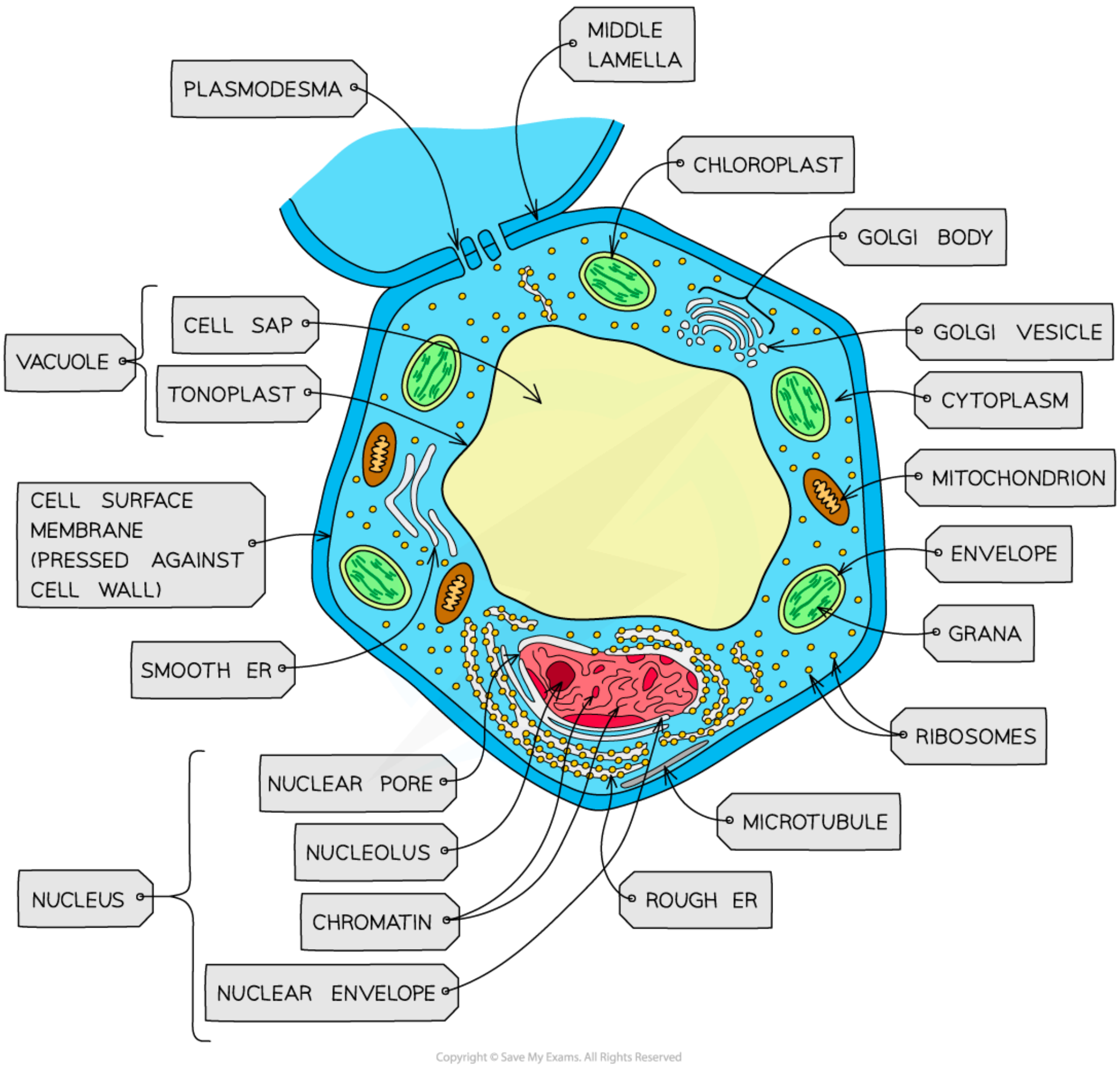
Eukaryotic Animal Cell Structure Diagram



The ultrastructure of an animal cell shows a densely packed cell of compartmentalised organelles

Eukaryotic Plant Cell Structure Diagram

Your notes



Plant cells have a larger, more regular structure in comparison to animal cells which also contains compartmentalised organelles

Organelle Adaptations

- In complex cells **organelles** can become **specialised** for **specific functions**
- These specialised organelles have **specific adaptations** to help them carry out their functions
- For example, the **structure of a organelle** is adapted to help it carry out its **function** (this is why each organelle looks very **different** from each other)
- The separation of organelles from the rest of the cell, via a membrane (sometimes double), is important as it allows the organelle to carry out its own chemical reactions without interference from the rest of the cell

NOS: Students should recognise that progress in science often follows development of new techniques

Your notes

- Study of the function of individual organelles has become possible following the invention of **ultracentrifuges** and methods of using them for **cell fractionation** had been developed
  - In order to study cells at a molecular level we need to be able to separate out each compartment and study them individually in a process called cell fractionation
  - To do this a **pure sample** is needed (containing only the specific organelle being studied)
  - This process involves **breaking up** a suitable sample of tissue and then **centrifuging** the mixture at **different speeds**
  - Cell fractionation can be split into three stages:
    - **Homogenisation** - the cell sample is broken up using a **homogeniser** which is a blender-like machine
    - **Filtration –** the homogenate (containing the homogenised cells) is then filtered through a gauze
    - **Ultracentrifugation –** the filtrate is placed into a tube and the tube is placed in a **centrifuge**
      - A centrifuge is a machine that separates materials by **spinning**
      - This speed can be altered to separate different components of the cell based on their molecular weight
      - Until this was invented, research into separate organelles was limited

Cell Compartmentalisation

Your notes

Separating The Nucleus & Cytoplasm

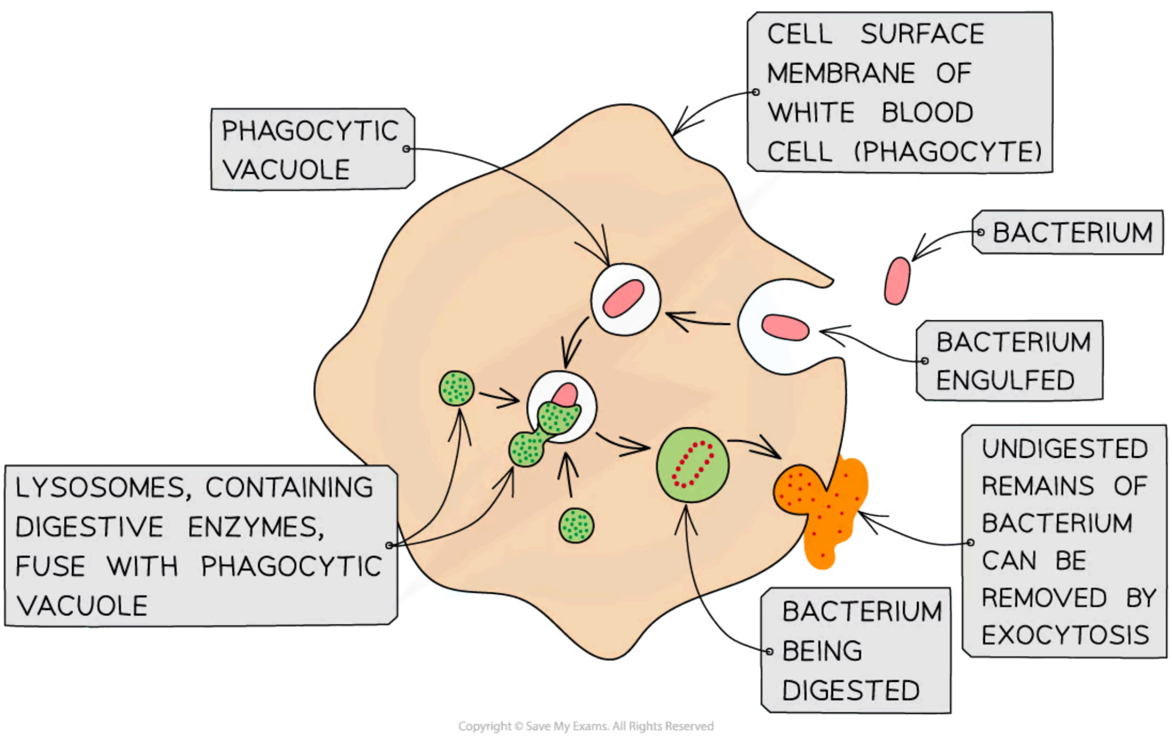
- The **nucleus** is one of the key organelles that distinguishes eukaryotic cells from prokaryotic cells
- It allows many cell processes to take place more efficiently than in prokaryotes
  - Gene transcription and translation are two process that occur in both eukaryotes and prokaryotes
  - In **prokaryotes** these processes take place **simultaneously** which allows for rapid responses to an environmental stimuli
  - In **eukaryotes** these processes occur **separately** due to the **compartmentalisation of the nucleus**
    - During transcription, mRNA is formed using a template strand of DNA; the mRNA needs some modification before it can be used for translation
    - **Modification** can take place in isolation within the nucleus before it comes into contact with a ribosome (this is where translation occurs) unlike in prokaryotes where the mRNA immediately meets a ribosome
    - This step **reduces the chance of errors occurring in the mRNA code** and therefore in the resulting protein following translation

Your notes

Compartmentalisation In The Cytoplasm

- The **cytoplasm** is not considered an organelle, but it's **separation from organelles** via their membranes is an advantage for the cell
- Organisation of the eukaryotic cell into discrete membrane-bound organelles allows for the **separation of incompatible biochemical processes**
- This ensures that pathways requiring specific **enzymes or metabolites** run smoothly and are not at risk from interference from other cell structures or chemicals
  - Such reactions can coexist within one organelle by **localising conflicting reactions**, for example in plant cells a type of enzyme called nitrogenase (used for nitrogen fixation) is particularly sensitive to oxygen so it is positioned in an anaerobic part of the cytoplasm away from aerobic reactions
  - Lysosomes require lytic enzymes which could be harmful to the cell if they were not contained by the lysosome membrane
  - During endocytosis a **phagocytic vacuole** forms around potentially toxic and harmful substances, such as bacteria; this keeps the contents separate from the cytoplasm and rest of the cell until a lysosome can safely digest the material

Endocytosis and Phagocytosis Diagram



The formation of a phagocytic vacuole ensures harmful substances, such as bacteria, are kept separate from the cytoplasm and the rest of the cell

Adaptations of Mitochondria & Chloroplasts (HL)

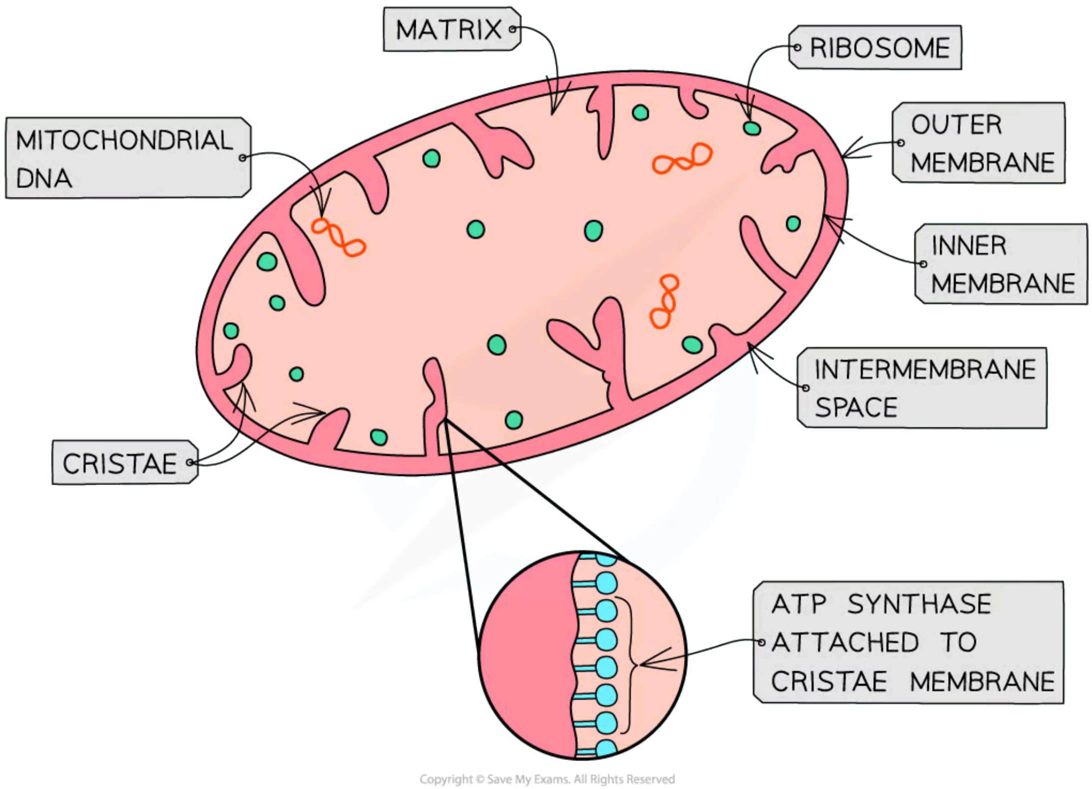
Adaptations of Mitochondria

- Mitochondria are rod-shaped organelles 0.5 - 1.0 μm in diameter
- They are the site of **aerobic respiration** in eukaryotic cells
- The function of mitochondria is to **synthesize ATP**
- Synthesis of ATP in the mitochondria occurs during the last stage of respiration called oxidative phosphorylation
  - This relies on membrane proteins that make up the 'electron transport chain' and the ATP synthase enzyme – the details of this are covered under the subtopic of oxidative phosphorylation

Structure

- Mitochondria have **two phospholipid membranes**
- The outer membrane is:
  - Smooth
  - **Permeable** to several small molecules
- The inner membrane is:
  - **Folded** (cristae)
  - **Less permeable**
  - The site of the **electron transport chain** (used in oxidative phosphorylation)
  - Location of **ATP synthase** (used in oxidative phosphorylation)
- The intermembrane space:
  - Has a low pH due to the **high concentration of protons**
  - The concentration gradient across the inner membrane is formed during **oxidative phosphorylation** and is **essential for ATP synthesis**
- The matrix:
  - Is an aqueous solution **within the inner membranes** of the mitochondrion
  - Contains ribosomes, enzymes and circular mitochondrial DNA necessary for mitochondria to function

Structure of Mitochondria Diagram



The structure of a mitochondrion facilitates the process of aerobic cell respiration

Relationship between structure & function

- The structure of mitochondria makes them well **adapted to their function**
  - They have a **double membrane** and a **small volume of intermembrane space**; this means that this space can be used for the concentration build up of hydrogen ions required for respiration reactions
  - They have a **large surface area** due to the presence of **cristae** (inner folds) which enables the membrane to hold many electron transport chain proteins and ATP synthase enzymes
  - More active cell types can have larger mitochondria with longer and more tightly packed cristae to enable the **synthesis of more ATP** because they have a **larger surface area**
  - The **number** of mitochondria in each cell can vary depending on cell activity
    - Muscle cells are more active and have more mitochondria per cell than fat cells
  - **Compartmentalisation of enzymes and substrates** using the matrix ensures that respiration reactions, like the Krebs cycle, can happen more efficiently

Examiner Tip

Exam questions can sometimes ask you to explain how the structure of a mitochondrion helps it carry out its function effectively. Make sure to follow through with your answer.

It is not enough to say that cristae increase the surface area of the inner membrane. You need to explain that an **increased surface area** of the inner membrane means there are **more electron transport chain** carriers and ATP synthase enzymes which results in **more ATP** being produced.

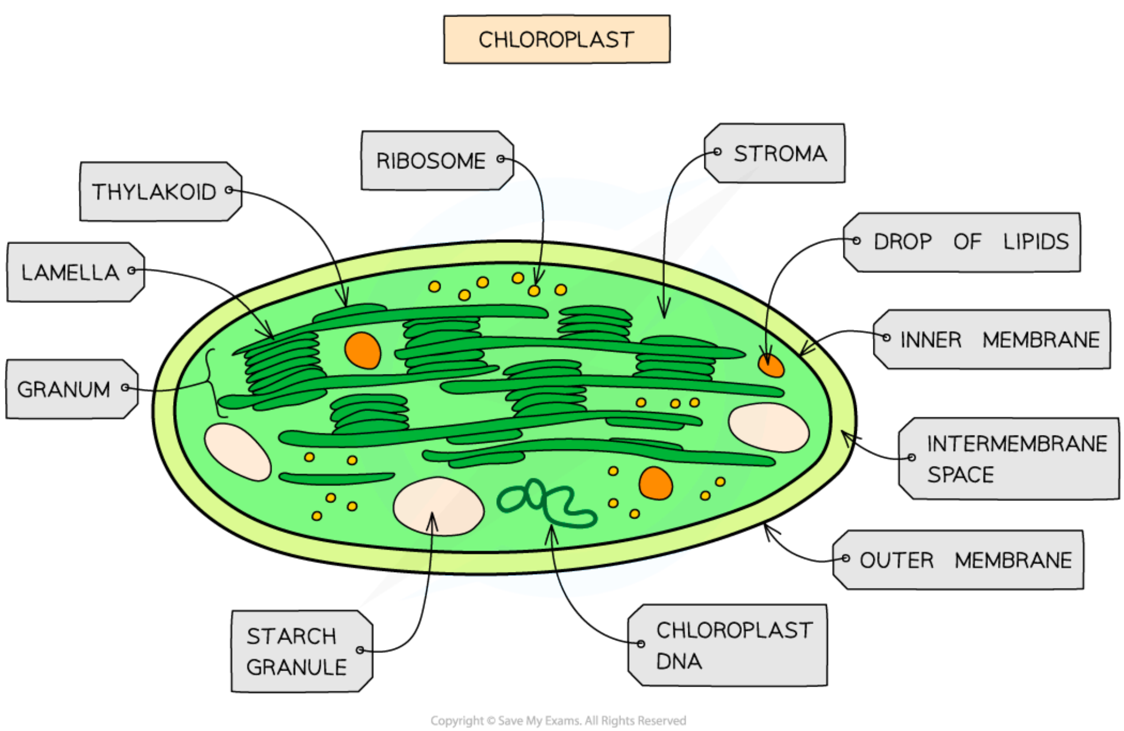
Adaptations of Chloroplasts

Your notes

Structure

- Chloroplasts are the organelles in plant cells where **photosynthesis** occurs
- These organelles are roughly **2 – 10 µm** in diameter (they are larger than mitochondria)
- Each chloroplast is surrounded by a **double-membrane envelope**
  - Each of the envelope membranes is a phospholipid bilayer
  - The **outer membrane** is permeable to a range of ions and small molecules
  - The **inner membrane** contains transport proteins that only allow certain molecules or ions to enter or leave the chloroplast
- Chloroplasts are filled with a cytosol-like fluid known as the **stroma**
  - CO_2, sugars, enzymes and other molecules are dissolved in the stroma
  - If the chloroplast has been photosynthesising there may be **starch grains** or **lipid droplets** in the stroma
- A separate system of membranes is found in the stroma
- This membrane system consists of a series of flattened fluid-filled sacs known as **thylakoids**
  - The **thylakoid membranes** contain pigments, enzymes and electron carriers
  - These thylakoids stack up to form structures known as **grana** (singular – granum)
  - Grana are connected by membranous channels called **stroma lamellae**, which ensure the stacks of sacs are connected but distanced from each other

Chloroplast Structure Diagram



The structure of chloroplasts facilitates the process of photosynthesis

Your notes

- The membrane system provides a large number of **pigment molecules** that ensure as much light as necessary is absorbed
- The pigment molecules are **arranged** in light-harvesting clusters known as **photosystems**
  - In a photosystem, the different pigment molecules are arranged in funnel-like structures in the thylakoid membrane
  - Each pigment molecule passes energy down to the next pigment molecule in the cluster until it reaches the primary pigment reaction centre

Adaptations of chloroplasts to photosynthesis

- **Stroma**:
  - The gel-like fluid contains **enzymes** that catalyse the reactions of the light-independent stage
  - Enzymes and their substrates are **compartmentalised** for reactions of the Calvin cycle
  - The stroma surrounds the grana and membranes, making the **transport** of products from the light-dependent stage into the stroma **rapid**
- **Grana**:
  - The granal stacks create a **large surface area** for the presence of many photosystems which allows for the **maximum** absorption of light
  - It also provides **more membrane space** for electron carriers and ATP synthase enzymes
- **DNA**:
  - The chloroplast DNA contains **genes** that code for some of the proteins and enzymes used in photosynthesis
- **Ribosomes**:
  - The presence of ribosomes allows for the **translation of proteins** coded by the chloroplast DNA
- **Inner membrane of chloroplast envelope**:
  - The selective transport proteins present in the inner membrane **control** the flow of molecules between the stroma and cytosol (the cytoplasm of the plant cell)
- **Thylakoid space**:
  - This is where a **proton gradient develops** (to generate ATP)
  - The space has a very **small volume** so a proton gradient can develop very **quickly**

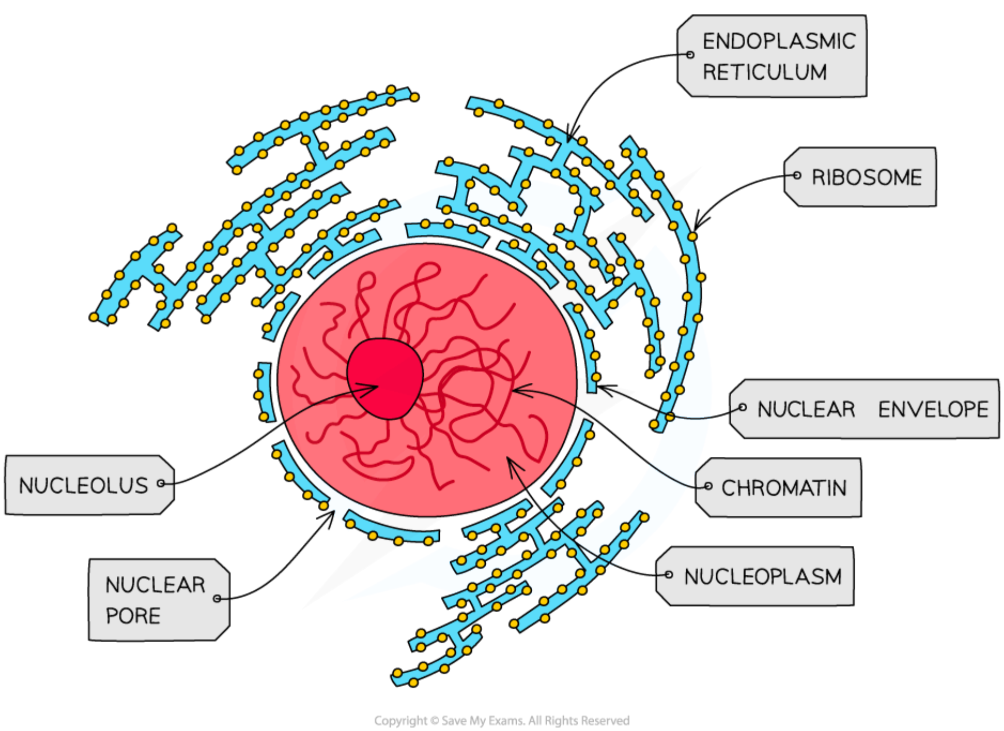
Organelles in Protein Synthesis (HL)

Your notes

The Nuclear Membrane

- Present in all eukaryotic cells, the nucleus is relatively large and **separated from the cytoplasm** by a **double membrane** called the **nuclear envelope**
- This provides an area where reactions of DNA and its functions can be carried out separately from the rest of the cell
- The envelop is studded with **nuclear pores**
  - Nuclear pores are important channels for allowing mRNA and ribosomes to travel out of the nucleus, as well as allowing enzymes (e.g. DNA polymerases) and signalling molecules to travel in
- The **outer membrane** of the nucleus is a continuous structure that links to the endoplasmic reticulum, ribosomes can be attached to sections of this forming the rough endoplasmic reticulum
  - The sections of the outer membrane that do not contain ribosomes form the smooth endoplasmic reticulum
- During cellular division (mitosis and meiosis) the nuclear membrane breaks into vesicles
  - This occurs during prophase to allow the chromosomes to separate
  - Once at telophase the nuclear envelope begins to reform

Structure of the Nucleus Diagram



The nucleus of a cell with its double membrane containing pores and continuation into the endoplasmic reticulum

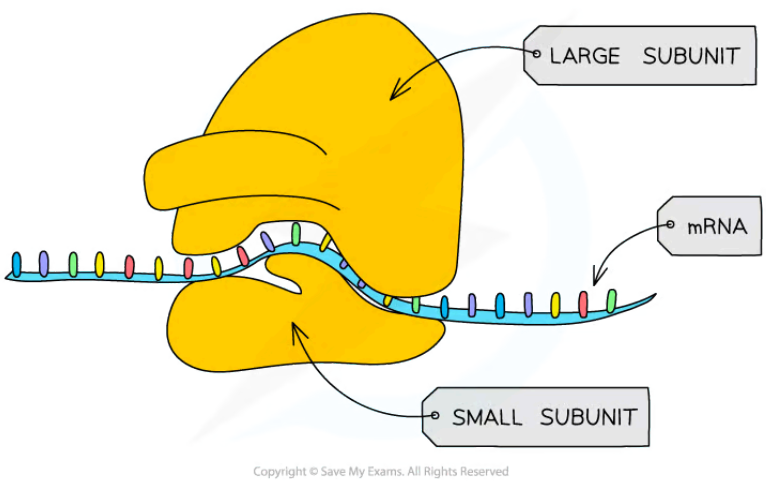
Your notes

Your notes

Ribosomes & RER

- **Ribosomes** are found in cells
  - Either **freely** in the cytoplasm (of all cells)
  - Or bound to the **endoplasmic reticulum** (ER) to form **rough ER** (only in eukaryotic cells)
- Ribosomes are the **site of protein synthesis**
- They consist of a **large** and a **small subunit** composed of **protein** and **ribosomal RNA** (rRNA)
  - Protein provides **structure** to the ribosome
  - rRNA **facilitates the binding of mRNA and tRNA** and catalyses the formation of peptide bonds between amino acids
- Ribosomes have **three tRNA binding sites** and **one mRNA binding site**
- mRNA sits in a **groove** between the two subunits and the **ribosome moves along**, forming a polypeptide as it travels

The Structure of a Ribosome Diagram



A diagram of a ribosome, showing the small and large subunits

Free Ribosomes

- In eukaryotic cells, protein synthesis commonly occurs at **free ribosomes** in the cytoplasm
- Free ribosomes can **move** within the cytoplasm and synthesise proteins for use primarily **within the cell**
  - As opposed to proteins destined to be secreted extracellularly
  - Proteins synthesised on free ribosomes are destined for use **within the cytosol** (the fluid part of the cytoplasm)
    - And within **large organelles** such as mitochondria and chloroplasts

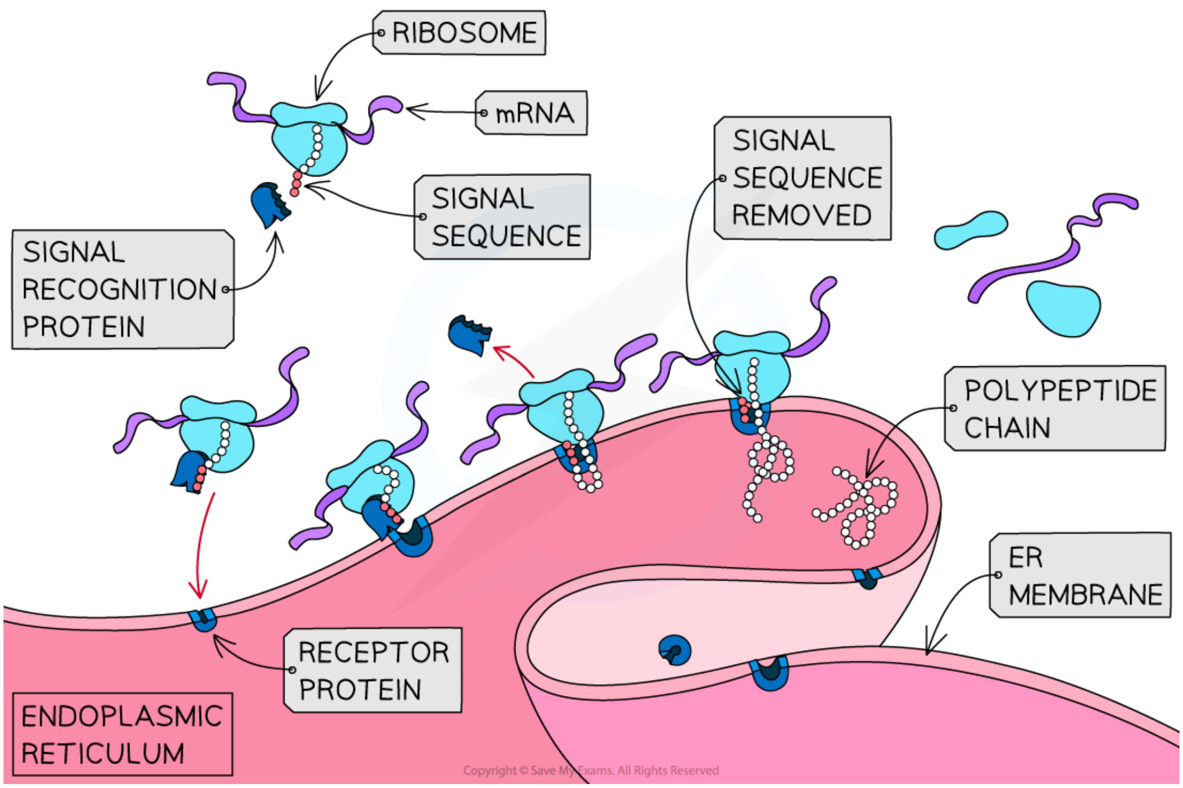
Membrane Bound Ribosomes

- Eukaryotic cells make thousands of proteins that need to be **delivered to the correct location**, sometimes in different tissues/organs altogether

Your notes

- When free ribosomes make proteins destined for lysosomes, or secretion from the cell, the ribosome becomes **bound to the endoplasmic reticulum (ER)**
- Signal sequences in the growing polypeptide chain dictate whether the free ribosome needs **to move to the ER**
  - The signal sequence occurs at the beginning polypeptide
  - Signal recognition proteins bind to the polypeptide, pausing translation
  - The free ribosome binds to a receptor on the ER, **forming rough ER**
  - **Translation is re-initiated** and the polypeptide chain **moves inside the ER**
- The synthesised protein can be **carried via a vesicle** to the **Golgi** apparatus before being **secreted out** of the cell

Membrane Bound Ribosome Protein Synthesis Diagram



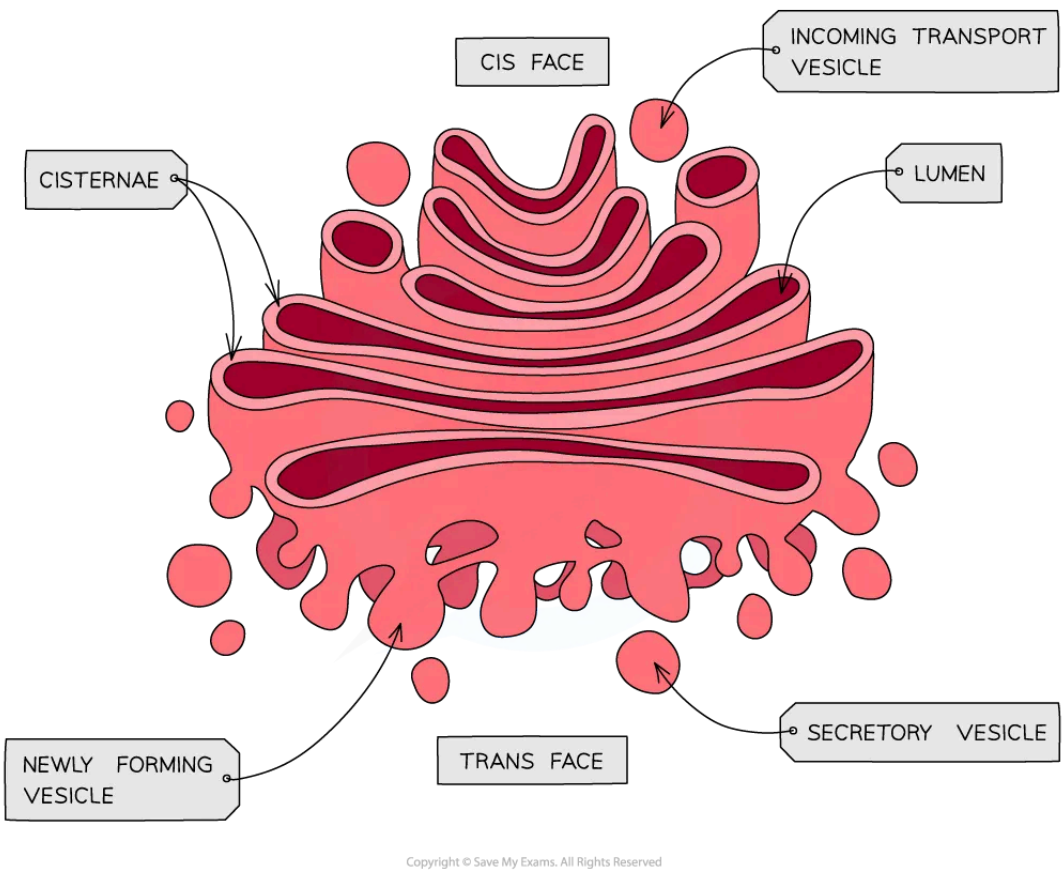
Proteins destined for lysosomes or secretion out of the cell are synthesised by ribosomes bound to the endoplasmic reticulum

The Golgi Apparatus

Your notes

- The Golgi apparatus consists of flattened sacs of membrane called cisternae (like the rough endoplasmic reticulum)
- Its role is to **modify 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
- The position of the Golgi apparatus indicates its functions
  - One side of the sacs face the endoplasmic reticulum, this is called the *cis* side
    - It's role is to receive protein or lipid filled vesicles from the endoplasmic reticulum
  - The other faces the plasma membrane and is called the *trans* side
    - Once the received proteins or lipids have been modified the final products are sent out via the *trans* side

Structure of the Golgi Apparatus Diagram



The Golgi apparatus showing the cis and trans sides for receiving and transporting protein or lipid filled vesicles

Vesicle Formation (HL)

Your notes

Vesicles in Cells

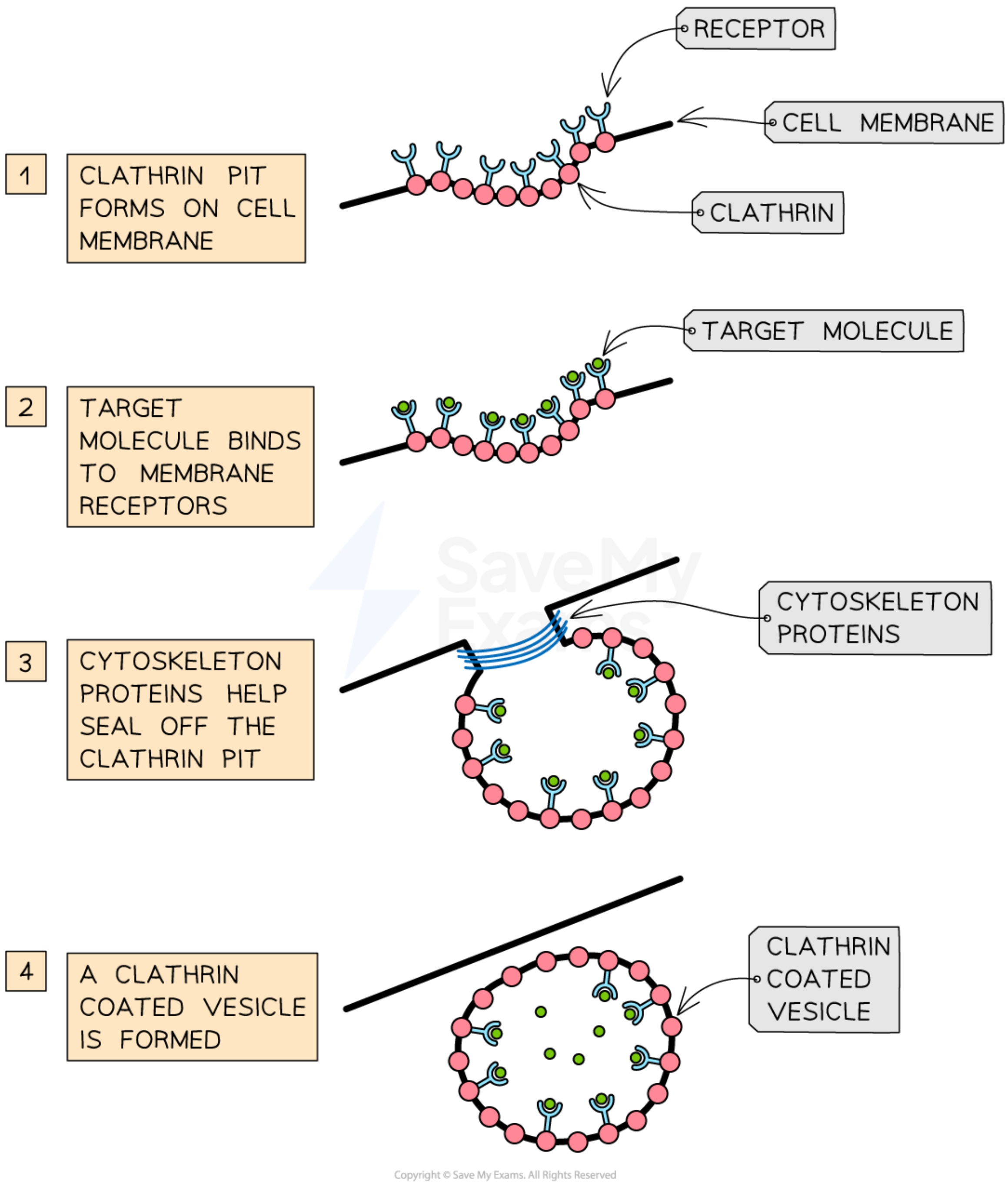
- Vesicles are membrane-bound sacs used for **transport** and **storage**
- There are many sorts of vesicles including:
  - Peroxisomes - these contain enzymes which digest fatty acids
  - Lysosomes - these contain lytic enzymes which digest cellular waste or harmful substances
  - Transport vesicles - these are used to move various molecules within the cell
  - Secretory vesicles - these are responsible for transporting substances out of the cell via exocytosis

Role of Clathrin

- Clathrins are proteins that help with the **formation of vesicles**
- They **line the vesicles** which are transporting molecules between membrane-bound compartments
- The following process takes place:
  1. A clathrin coated pit is formed on the surface of the cell membrane
  2. Receptor proteins on the cell surface bind to the target molecules
  3. Once enough target molecule are attached, cytoskeleton proteins help the clathrin pit to deepen and eventually seal off, trapping the target molecules inside
  4. A vesicle is now formed

Vesicle formation diagram

Your notes



Clathrin proteins play an important role in the formation of vesicles

Examiner Tip

Vesicles are not the same as vacuoles. Vacuoles are larger than vesicles and the membrane of a vacuole cannot fuse with the membranes of other cellular components, like the membrane of vesicles can

Your notes