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The big picture

? Guiding question(s)

- How are organelles in cells adapted to their functions?
- What are the advantages of compartmentalisation in cells?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

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Figure 1. An animal cell showing examples of compartmentalisation.

Credit: enot-poloskun, Getty Images

More information for figure 1

The image is a diagram of an animal cell. It shows a cross-section of the cell with various organelles, each distinctly colored and shaped. In the center is the nucleus, depicted in red, absorbing the viewer's immediate attention. Surrounding the nucleus are other organelles: mitochondria, shown in yellow, visibly oval-shaped; the endoplasmic reticulum, illustrated in purple, winding fluidly adjacent to the nucleus; and ribosomes, tiny dots scattered throughout. Also present are green spherical lysosomes, blue vesicles, and other variously colored and shaped organelles, indicating compartmentalization within the cell. The cell membrane encloses these structures, maintaining the integrity of the cell's interior. This detailed illustration emphasizes how different compartments allow for specialized cellular functions, much like distinct rooms in a building designed for different purposes.

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Student view

Compartmentalisation allows cells to work more effectively than they would be able to without compartments. In many ways, this is similar to the school you are in now. The cafeteria is probably located next to the kitchen where the food is made, and it has tables at

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which to sit and eat. It is beneficial for all groups because the kitchen has equipment for making great food, while the cafeteria is a communal place to enjoy the food. This works because schools are compartmentalised. One space creates an environment that is good for some activities, while other spaces create different environments for different activities.

Cells work through the same principle of compartmentalisation. As shown in **Figure 1**, cells have a lot of different compartments. The metabolic reactions of catabolism (or breaking substances down) must be separated from the metabolic reactions of anabolism (or building new substances). Much like the spaces of the school, these reactions must take place in different physical locations that have the right environment. What compartments can you remember that are found in cells?

Prior learning

Before you study this subtopic make sure that you understand the following:

- Differences in eukaryotic and prokaryotic cell structure (subtopic A2.2 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43253/)).
- Membrane structure and function (subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/)).
- Membrane fluidity and the formation of vesicles (HL) (subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/)).

B2. Form and function: Cells / B2.2 Organelles and compartmentalisation

Compartmentalisation and organelles

B2.2.1: Organelles as discrete subunits of cells B2.2.2: Separation of the nucleus and cytoplasm

B2.2.3: Advantages of compartmentalisation

Learning outcomes

By the end of this section you should be able to:

- State, with examples, that organelles are structures that are separate subunits of cells and perform a specific function.
- Explain the advantages, using phagocytic vacuoles and lysosomes as examples, of the compartmentalisation of cytoplasm.

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- Explain the advantage of the separation of the nucleus and the cytoplasm in regard to protein synthesis.

Organelles are subunits of cells that perform specific functions. In many ways, they act like the organs of your body in that they perform specific functions for the cells, just like your organs do for your body. For example, the digestive system helps you digest your food, a role similar to lysosomes in your cells. What other organelles in cells are like organs in your body?

Nature of Science

Aspect: Experiments

Discoveries in science often follow advances in new techniques. The study of cellular structures was limited due to the limitations of light microscopes. The electron microscope allowed scientists to look inside the cell with much greater resolution. The use of ultracentrifuges in biology allowed biologists to study the function of individual organelles. This required the development of a new technique called cell fractionation, which separates the parts of cells by size.

Organelles

Organelles are structures within a cell that perform specific functions. Compartmentalisation in cells refers to the organisation of different functions and processes within specific areas or structures within the cell that are separated by plasma membranes. Compartmentalisation allows for the development of specialised cell structures such as the chloroplasts and mitochondria.

International Mindedness

Science is often a global endeavour that requires cooperation among scientists and builds on the works of other scientists. Belgian-American Albert Claude's work on cell fractionation earned him a Nobel Prize in medicine and helped advance our understanding of cell organelles. Friedrich Miescher, a Swiss scientist, was the first to isolate a cell organelle using centrifugation. Hans Boersch, a German scientist,

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was one of the first to work with electron microscopes. He developed techniques that allowed scientists to look inside organelles with higher resolution. Advances in techniques are essential, as is the cooperation among scientists worldwide.

Organelles can be found in both prokaryotic and eukaryotic cells. However, membrane-bound organelles are only found in eukaryotic cells. Membrane-bound organelles are examples of compartmentalisation in cells. The advantage of compartmentalisation in cells is that the cell can separate chemical reactions and other cellular processes. This allows the cell to increase the rate of chemical reactions.

Compartmentalisation allows specific reactions to occur in specific places. For example, lysosomes are compartments that break down and recycle waste materials within the cell. Macrophages use phagocytic vacuoles, which are joined by lysosomes, to break down pathogens into parts, which can then be used to develop an immune response (see section C3.2.5 (/study/app/bio/sid-422-cid-755105/book/adaptive-immune-responses-id-44256/)) The breakdown of waste in cells requires the use of enzymes. These enzymes could be damaging to other parts of the cell. Isolating these enzymes in the phagocytic vacuoles protects the rest of the cell and allows the waste to be broken down safely.

Additionally, using lysosomes and phagocytic vacuoles, the cell can use the required enzymes in a smaller space. This allows a faster and more efficient reaction as the enzymes are in a higher concentration. Specialised structures such as lysosomes are only possible with compartmentalisation. **Interactives 1** and **2** show some of the membrane-bound organelles found in animal and plant cells and their functions.

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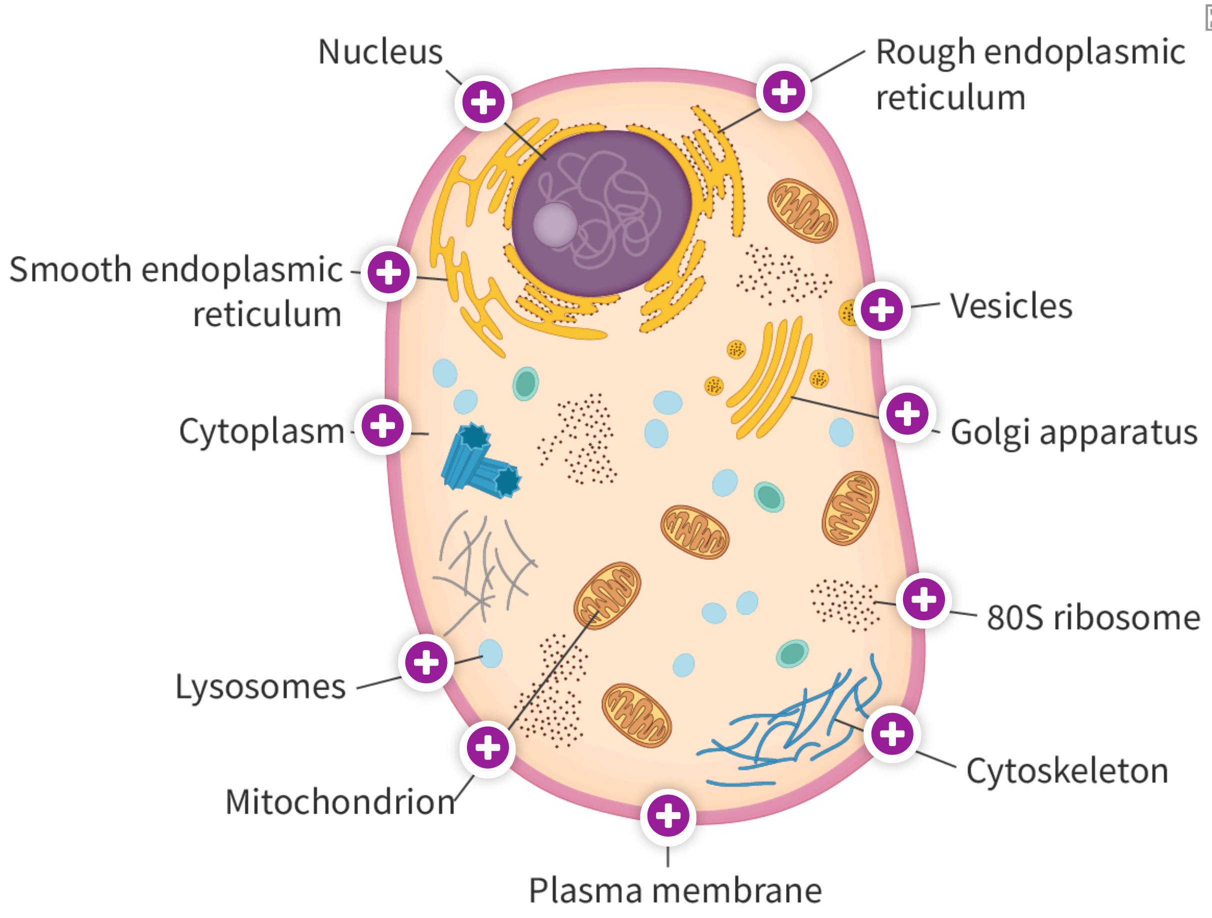

Interactive 1. Cell Functions of Structures Found in Animal Cells.

More information for interactive 1

The interactive image is a colorful labelled diagram of an animal eukaryotic cell, shown in a three-dimensional, cross-sectional view. The “Fullscreen” icon at the top right allows users to view the illustration in full screen.

The cell is shaped like a soft, rounded blob, representing the flexible outer membrane. Inside the cell, various organelles are illustrated in different colors and shapes to differentiate them.This illustration showcases how an animal eukaryotic cell is structured into different compartments, each performing specialized functions essential for life.

There are a total of 11 labelled parts in the image. The labelled parts on the right from top to bottom include Rough endoplasmic reticulum, vesicles, golgi apparatus, 80S ribosome and cytoskeleton. The labelled parts on the left from top to bottom include nucleus, smooth endoplasmic reticulum, cytoplasm, lysosomes, and mitochondrion. Plasma membrane is another labelled part located at the bottom of the interactive. Each labelled part has a clickable hotspot represented by a plus sign. Clicking on these hotspots reveals additional information regarding the corresponding structure.

Read below to learn about each part in detail:

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Nucleus

The cell consists of a large round nucleus in the top center of the cell, colored in purple. The nucleus houses the cell's genetic material. It also consists of the nucleolus, a small dense spot inside the nucleus, involved in producing ribosomes.

Clicking on the hotspot for the nucleus reveals the text: "Organelle? Yes Function: contains the DNA, which is associated with histone proteins and is organised into chromosomes. The nucleus contains the nucleolus, which is involved in the production of ribosomes and has a double membrane."

Rough Endoplasmic Reticulum

Rough endoplasmic reticulum (Rough ER) is a network of tubes studded with dots (ribosomes), involved in protein synthesis. It is connected to the nuclear envelope.

Clicking on the hotspot for Rough ER reveals the text: "Organelle? Yes Function: contains ribosomes, which produce proteins that are usually destined for use outside the cell."

Smooth Endoplasmic Reticulum

Smooth endoplasmic reticulum (Smooth ER) is also a network of tubes continuous with the nuclear envelope. But smooth ER does not contain ribosomes and is involved in lipid production.

Clicking on the hotspot near the label smooth ER reveals the text: "Organelle? Yes Function: produces and stores lipids, including steroids. It is also involved in detoxification."

Cytoplasm

The cytoplasm is the fluid filling the space inside the cell, where all organelles float.

Clicking on the hotspot near the label cytoplasm reveals the text: "Organelle? No Function: a water-based jelly-like fluid that fills the cell, suspends ions, organic molecules, organelles, and ribosomes, and is the site of metabolic reactions."

Vesicles

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These are small, bubble-like sacs found floating within the cytoplasm, represented as tiny yellow circles, near the Golgi apparatus or the cell membrane.

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Clicking on the hotspot near vesicles reveals the text: “Organelle? Yes Function: a small sac that modifies and assists in the transport of proteins and other substances produced by the cell by fusing with various membranes in the cell.”

Golgi apparatus

It is a stack of flattened sacs, shown like a series of pancakes, responsible for packaging and transporting proteins.

Clicking on the hotspot near vesicles reveals the text: “Organelle? Yes Function: processes and packages proteins, which are then released in Golgi vesicles.”

80S ribosome

80S ribosomes are represented as tiny brown dots floating freely in the cytoplasm.

Clicking on the hotspot for 80S ribosomes reveals the text: “Organelle? Yes Function: where translation (protein synthesis) occurs. Eukaryotic 80S ribosomes are larger and have a higher mass than 70S prokaryotic ribosomes.”

Lysosomes

Lysosomes are represented as small, circular organelles of light blue colour, floating freely in the cytoplasm and containing enzymes for digestion.

Clicking on the hotspot for lysosomes reveals the text: “Organelle? Yes Function: membrane-bound compartments inside a cell containing enzymes which can break down cellular components.”

Mitochondrion

Mitochondria (plural) are bean-shaped structures with squiggly lines (cristae) inside them, representing the powerhouse of the cell where energy is made.

Clicking on the hotspot for mitochondrion reveals the text: “Organelle? Yes Function: double membrane-bound organelles that convert glucose into ATP (the cell’s energy currency) in the process of cellular respiration.”

Cytoskeleton

The cytoskeleton is a network of thin fibers and tubes spread throughout the cytoplasm. In the image, they are represented as thread-like structures.

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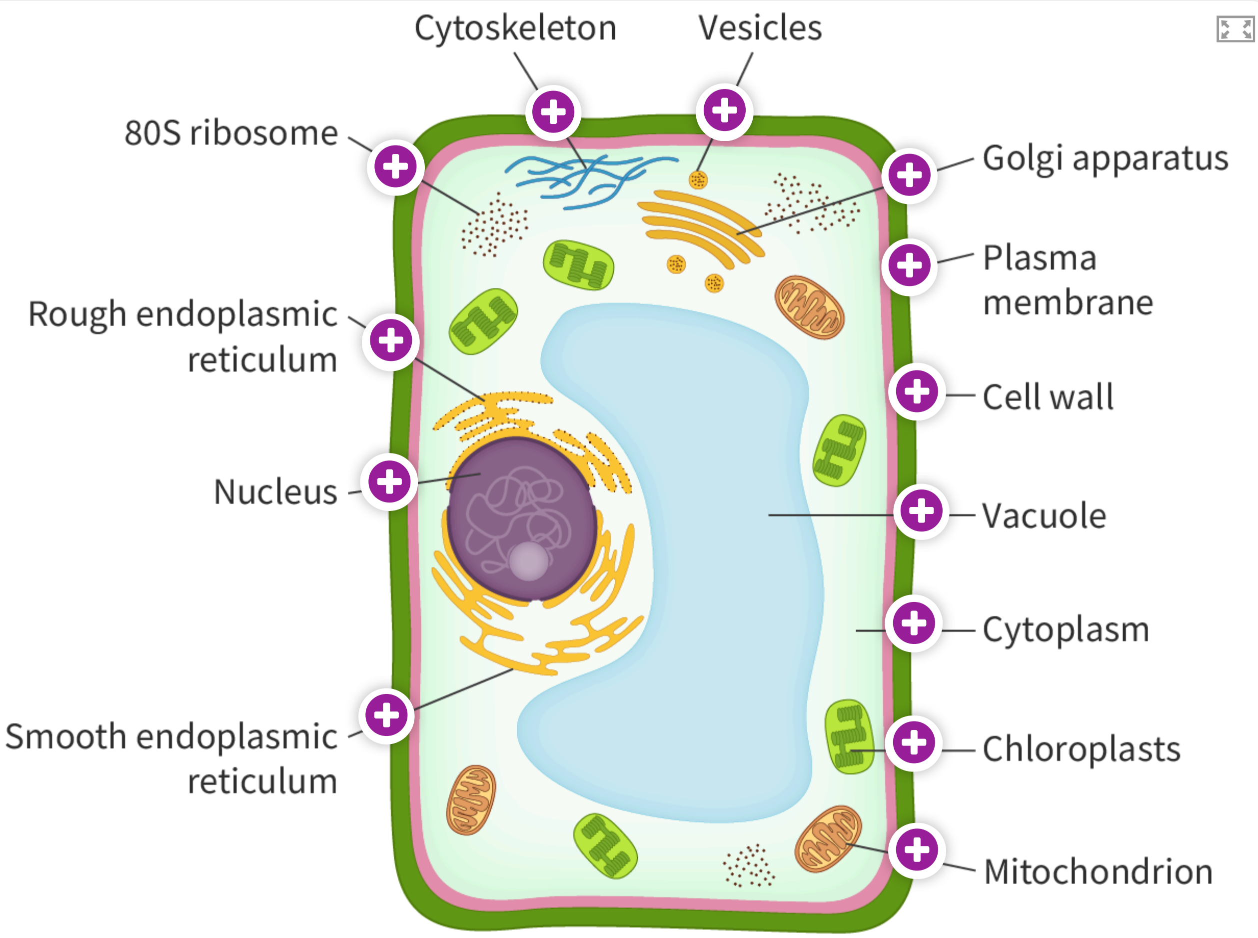
Clicking on the hotspot for cytoskeleton reveals the text: “Organelle? No Function: a system of protein fibres called microtubules and microfilaments. The cytoskeleton helps to hold organelles in place and maintain the structure and shape of the cell.”

Plasma membrane

The plasma membrane or cell membrane is a thin outer layer encasing the cell, controlling what enters and exits. In the image, it is represented by a pink border surrounding the cell.

Clicking on the hotspot for plasma membrane reveals the text: “Organelle? Yes Function: the plasma membrane separates the cell’s interior from its external environment and controls what can enter and exit the cell.”

Each organelle in the animal eukaryotic cell plays a crucial role in maintaining cellular efficiency, ensuring that the cell functions as an organized and highly specialized unit. The interactive image helps users to learn about eukaryotic cell structure and different organelles inside the cell. The aim of this interactive is to help learners understand the importance of compartmentalization through membrane-bound organelles and how they help separate chemical reactions and the processes inside the cell.



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Interactive 2. Cell Functions of Structures Found in Plant Cells.

More information for interactive 2

The interactive illustration showcases a eukaryotic plant cell with its cellular components or organelles. Each of the organelles performs specialized functions essential for plant life.

The organelles of the plant cell are labeled and marked with specific hotspots. The organelles labeled on the left from top to bottom are 80S ribosome, rough endoplasmic reticulum, nucleus, and smooth endoplasmic reticulum. And, the organelles labeled on the right from top to bottom include the Golgi apparatus, plasma membrane, cell wall, vacuole, cytoplasm, chloroplasts, and mitochondrion. The organelles marked on the top are cytoskeleton and vesicles. The “Fullscreen” icon at the top right allows users to view the illustration in full screen.

Read below to know the organelles in a plant cell and their role.

The plant cell has a double membrane — the cell wall and the plasma membrane. The plasma membrane encloses the organelles and the cytoplasm of the plant cell. The hotspot of the plasma membrane reads: Organelle? Yes. Function: the plasma membrane separates the cell’s interior from its external environment and controls what can enter and exit the cell.

The cell wall, in turn, encloses the plasma membrane. The hotspot of the cell wall reads: Organelle? No. Function: made out of polysaccharides, it protects against mechanical stresses and provides structural support

The cytoplasm is made of protein fibers like microtubules and microfilaments, provides structural support, maintains the cell’s shape, and assists in the positioning of organelles. The hotspot of the cytoplasm reads: Organelle? No. Function: a water-based jelly-like fluid that fills the cell, suspends ions, organic molecules, organelles, and ribosomes, and is the site of metabolic reactions.

The nucleus is the control center of the cell. The nucleus is enclosed by a double membrane, which regulates the movement of molecules in and out. The hotspot of the nucleus reads: Organelle? Yes. Function: contains the DNA, which is associated with histone proteins and is organized into chromosomes. The nucleus contains the nucleolus, which is involved in the production of ribosomes.

The smooth endoplasmic reticulum (SER) is attached to the nucleus on one side. The hotspot of SER reads: Organelle? Yes. Function: produces and stores lipids, including steroids. It is also involved in detoxification.

The rough endoplasmic reticulum (RER), on the other hand, is attached on the opposite side to the SER on the nucleus. The hotspot of RER reads: Organelle? Yes. Function: contains ribosomes, which produce proteins that are usually destined for use outside the cell.

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The mitochondrion is also called the powerhouse of the cell. The hotspot on the mitochondrion reads: Organelle? Yes. Function: double membrane-bound organelles that convert glucose into ATP (the cell's energy currency) in the process of respiration.

Golgi apparatus is a membrane-bound organelle with flattened, stacked pouches. The hotspot on the Golgi apparatus reads: Organelle? Yes. Function: processes and packages proteins, which are then released in Golgi vesicles.

The hotspot of chloroplasts read: Organelle? Yes. Function: double membrane-bound organelles where photosynthesis takes place.

The hotspot of vesicles read: Organelle? Yes. Function: a small sac that transports and releases substances produced by the cell by fusing with the cell membrane.

The hotspot of vacuole reads: Organelle? Yes. Function: double membrane-bound organelles where photosynthesis takes place.

The cytoskeleton is located at the top of the plant cell. The hotspot of the cytoskeleton reads: Organelle? No. Function: a system of protein fibers called microtubules and microfilaments. The cytoskeleton helps to hold organelles in place and maintain the structure and shape of the cell.

The 80S ribosomes are found only in eukaryotic cells. The hotspot of 80S ribosome reads: Organelle? Yes. Function: where translation (protein synthesis) occurs. Eukaryotic 80S ribosomes are larger and have a higher mass than 70S prokaryotic ribosomes.

In the past, you may have learned about several other parts of the cell being organelles but these are now not considered to be organelles. This is because they are not membrane-bound and/or do not have a specific function:

- The cytoskeleton is a network of proteins that provides shape and allows for movement of molecules around the cell. This is not considered to be an organelle because the proteins are not enclosed by a membrane and are not involved in metabolic processes like other organelles. [See note on ribosomes below.]
- The cell wall protects against mechanical stresses and provides structural support. It is not considered to be an organelle because it is not surrounded by a membrane and, like the cytoskeleton, is not involved in metabolic processes.

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- The cytoplasm is a matrix that surrounds the organelles and other structures in the cell. It is not a discrete structure with a specific function. Still, it is essential for the cell's survival as it contains all the organelles and structures of the cell.

However, ribosomes are structures that make proteins. Ribosomes are not membrane-bound and are considered to be organelles because they have a specific function.

Theory of Knowledge

What is and is not an organelle is an excellent example of shared knowledge and the role of language in Theory of Knowledge. Organelles are determined as such, based on characteristics that biologists find plausible. 'Organelles' is descriptive language. However, as shown by the examples of the cytoplasm, cell wall and cytoskeleton, shared knowledge can change. The fact that you probably learned that cytoplasm and cell walls are organelles shows how difficult it can be to change shared knowledge and the language used to communicate that knowledge.

Nucleus and cytoplasm

One key feature of eukaryotic cells is the presence of a nucleus. A double membrane surrounds the eukaryotic nucleus, with the outer membrane part of the rough endoplasmic reticulum. The compartmentalisation of the nucleus from the cytoplasm has several advantages. The nucleus contains the cell's DNA and it regulates genes through the transcription of DNA into mRNA. The cytoplasm is responsible for metabolic processes, including the translation of mRNA into proteins on the ribosomes (see subtopic D1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43547/)). In prokaryotic cells, transcription and translation occur in the cytoplasm. This means that the protein is produced soon after the mRNA is finished.

In eukaryotic cells, post-transcriptional modification (see section D1.2.15 (/study/app/bio/sid-422-cid-755105/book/modification-and-splicing-hl-id-44257/)) is a common occurrence. In this case, the mRNA that is produced in the nucleus needs to be changed by removing pieces of the mRNA. A working protein can only be made after this has been done. Compartmentalising the nucleus and the cytoplasm allows the post-transcriptional changes to occur before translation. This separation is not possible in prokaryotic organisms as they lack a nucleus.

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Additionally, compartmentalisation of the nucleus and cytoplasm allows the cytoplasm to send signals to the nucleus. The cytoplasm receives an extracellular signal, such as a hormone or growth factor. The message is then passed on to the nucleus to change gene expression through increased or decreased transcription. Altering gene expression allows the cell to adjust to produce different amounts or types of proteins to adjust to different conditions.

Try this activity to check your understanding of compartmentalisation.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

Table 1. Relative amounts of plasma membranes in liver and pancreatic cells.

Membrane type	Liver cell (Relative Amounts)	Pancreatic (Relative Am
Cell membrane	2	5
Rough ER membrane	35	60
Smooth ER membrane	16	<1
Golgi apparatus membrane	7	10
Mitochondria	39	21
Nuclear membrane	0.2	0.7
Secretory vesicle membrane	0	3
Lysosome membrane	0.4	Not determ

Student view

Source: Data taken from 'The Compartmentalization of Cells' in Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. and Walter, P., *Molecular Biology of the Cell*, 4th edition, New York: Garland Science, 2002.

The pancreas makes many proteins for export around the body. The liver's job is diverse, but its main function is to break down toxic chemicals. Using the information in **Table 1**, answer the following questions.

1. State, with a reason, which cell has a larger nucleus.
2. The smooth ER has a number of functions, including the breakdown of toxic molecules. Suggest why the pancreas has less smooth ER compared with the liver cell.
3. Deduce which process, detoxification or protein synthesis, requires more energy.
4. Pancreatic cells have almost double the amount of rough ER. Suggest a reason for this.
5. Lysosomes are involved in the breakdown of toxic molecules. The relative cell membrane count was not determined for pancreatic cells. Deduce, with a reason, if the relative cell membrane count would be higher or lower than that for a liver cell.

1. The pancreatic cell as it contains more nuclear membrane suggesting a larger nucleus.
2. The liver's function is to break down toxic molecules, and the SER is needed to do this, so it would make sense that the liver cell would have more SER membranes as it requires more SER to break down toxic molecules. The pancreas does not need as much SER as its main job is to make proteins.
3. Detoxification requires more energy as the liver cells have high numbers of mitochondria (approximately 2,000 per cell).
4. Pancreatic cells are involved in protein export, they send proteins outside of the cell, and the RER are involved in the export of molecules.
5. It would be lower as the pancreatic cell would have less need to break down dangerous substances.

5 section questions

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Structure and function of double membranes (HL)

B2.2.4: Adaptations of the mitochondrion (HL) B2.2.5: Adaptations of the chloroplast (HL)
B2.2.6: Double membrane of the nucleus (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Explain, using an annotated diagram, how the structure of the mitochondrion aids in the production of ATP.
- Explain, using an annotated diagram, how the structure of the chloroplast aids in photosynthesis.
- Describe the functional advantages of the double membrane around the nucleus in protein synthesis and cell division.

Section B2.2.1–3 (/study/app/bio/sid-422-cid-755105/book/compartmentalisation-and-organelles-id-44250/) describes how compartmentalisation supports more efficient chemical reactions (**Figure 1**). In your house, the bathroom and kitchen are examples of compartmentalisation that keep processes separate. You certainly would not like to prepare your dinner in your bathroom or wash your face in your kitchen. There are different reasons for compartmentalisation of the mitochondria, chloroplasts and nuclear membrane. What do you think these reasons might be?

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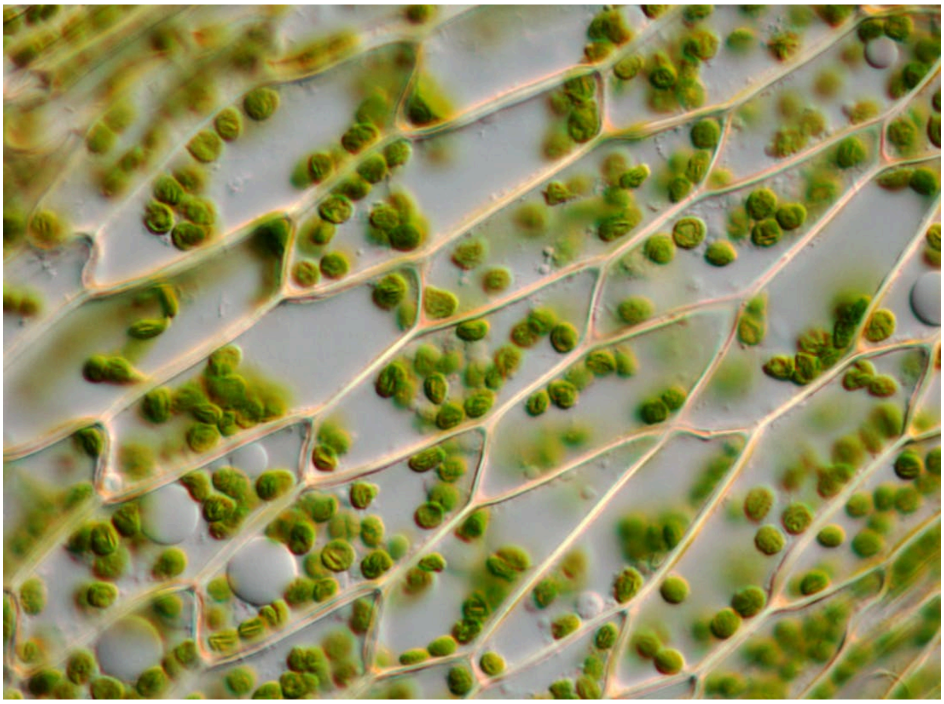

Figure 1. A microscope image of a moss cell showing chloroplasts. The compartmentalisation of chloroplasts allows the plant to carry out photosynthesis more efficiently.

Credit: alanphillips, Getty Images

Concept

Structure and function are recurring themes throughout this course. The structure of bird wings allows for the function of flight, and the structure of a protein matches its function. As you will see, the structures of the chloroplast and mitochondrion follow this pattern.

Structure and function of mitochondrial membranes

The mitochondria's main function is to produce ATP through the breakdown of molecules, the most common being glucose. The details of cellular respiration are discussed in subtopic C1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43538/). Mitochondria contain two membranes, an inner and an outer membrane.

The outer membrane is permeable to many small molecules and ions. It contains transport proteins that assist in moving larger molecules into the mitochondria. The inner membrane is highly folded, and forms structures called cristae. The cristae increase the surface area (see subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/)). The chemical reactions that occur on this

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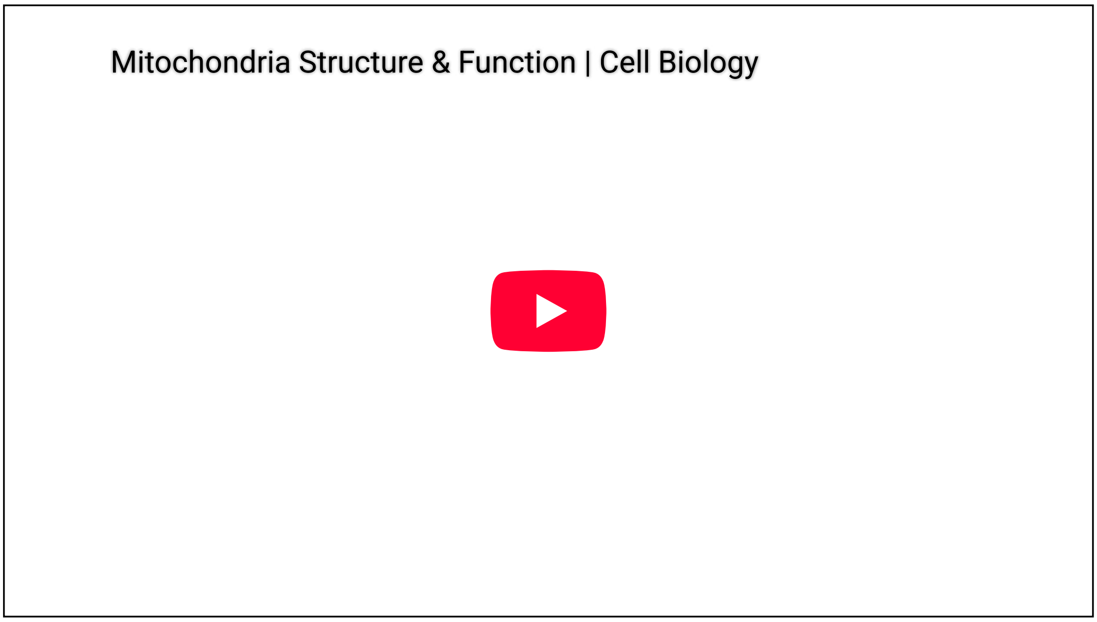
membrane are vital for producing ATP in cell respiration (see subtopic C1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43538/)). The cristae allow more of the enzymes needed for ATP production to be present on the membranes by increasing the surface area. This adaptation also increases the efficiency and speed of cell respiration by increasing the number of enzymes available for the various reactions.

Watch **Video 1** for more details on mitochondria.



Video 1. The structure and function of mitochondria.

These cristae also create an enclosed space between the inner membrane called the matrix. The matrix space contains a lot of enzymes and other molecules in high concentration needed for the Krebs cycle, a key pathway in cell respiration (see section C1.2.12 (/study/app/bio/sid-422-cid-755105/book/link-reaction-and-krebs-cycle-hl-id-44258/)).

The space between the outer membrane and the inner membrane, called the intermembrane space (**Figure 2**), is relatively small, allowing high concentrations of molecules to accumulate. This creates a concentration gradient across the inner membrane that is used to generate ATP (see section C1.2.15 (/study/app/bio/sid-422-cid-755105/book/electron-transport-chain-and-chemiosmosis-hl-id-44259/)).

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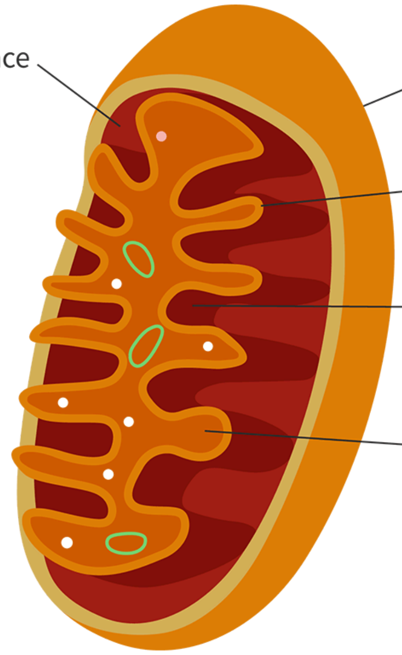

Figure 2. A diagram of a mitochondrion showing the outer membrane and the inner membranes.

More information for figure 2

The image is a detailed illustration of a mitochondrion, the energy-producing organelle found in most eukaryotic cells. It presents a cross-sectional view, revealing the organelle's inner structure. The diagram depicts the outer membrane and the intricate folds of the inner membranes, also known as cristae, which increase the surface area for chemical reactions. The narrow intermembrane space, situated between the outer and inner membranes, is highlighted. Labels identify these parts, providing a clear representation of their relationships and functions within the cell in the context of ATP generation. Details on the exact positions and shapes are visualized, emphasizing the flow of information between the mitochondrial components.

[Generated by AI]

Structure and function of chloroplast membranes

Like the mitochondria, chloroplasts have a number of adaptations that allow more efficient photosynthesis. The chloroplast contains three distinct membranes: the outer membrane, the inner membrane and thylakoid membranes (**Figure 3**). This creates three distinct compartmentalised areas: the intermembrane space, the stroma and the thylakoid space.

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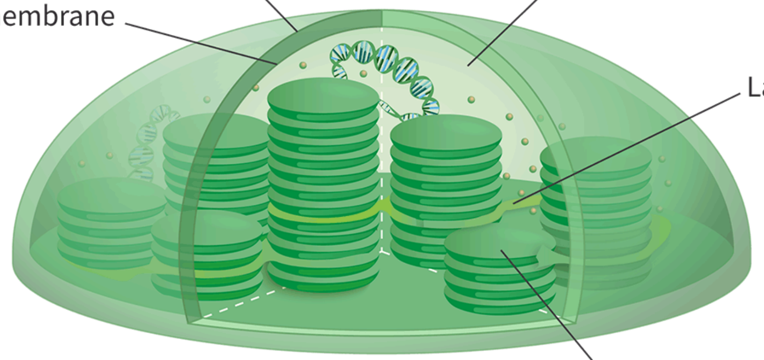

Figure 3. A diagram of the chloroplast showing the two outer membranes and the inner membranes.

More information for figure 3

The diagram illustrates a chloroplast, showing its key internal components. The outermost part is labeled as two outer membranes. Within these membranes lies the stroma, a fluid-filled space containing the chloroplast DNA and ribosomes. In the center, multiple thylakoid membranes form stacks called grana, which resemble stacked pancakes. These grana are interconnected by structures known as lamellae. Photosystems situated on the thylakoid membranes absorb light energy, enabling the light-dependent reactions of photosynthesis to occur. ATP generated through these reactions helps drive the photosynthesis process. The diagram highlights the spatial relationships between these chloroplastic structures and their roles in photosynthesis, maximizing light absorption and energy conversion.

[Generated by AI]

The thylakoid membranes form thylakoids, which look like stacked pancakes, and are where the light-dependent reactions of photosynthesis take place. Photosystems on the thylakoid membranes absorb light energy and use that energy to generate ATP to power photosynthesis. Many thylakoids together form a stack and this stack-like structure is referred to as a granum (plural, grana). Grana maximise the amount of sunlight absorbed as the sunlight passes through the stack of thylakoids. The grana are connected by thylakoid membranes called lamellae, which create a continuous thylakoid space. The disk-like structure of the thylakoid maximises surface area and increases the amount of chlorophyll and other enzymes on the thylakoid membranes (see subtopic C1.3 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43539/)). The more chlorophyll and enzymes, the faster the rate of photosynthesis.

Video 2 summarises the structure and function of a chloroplast.

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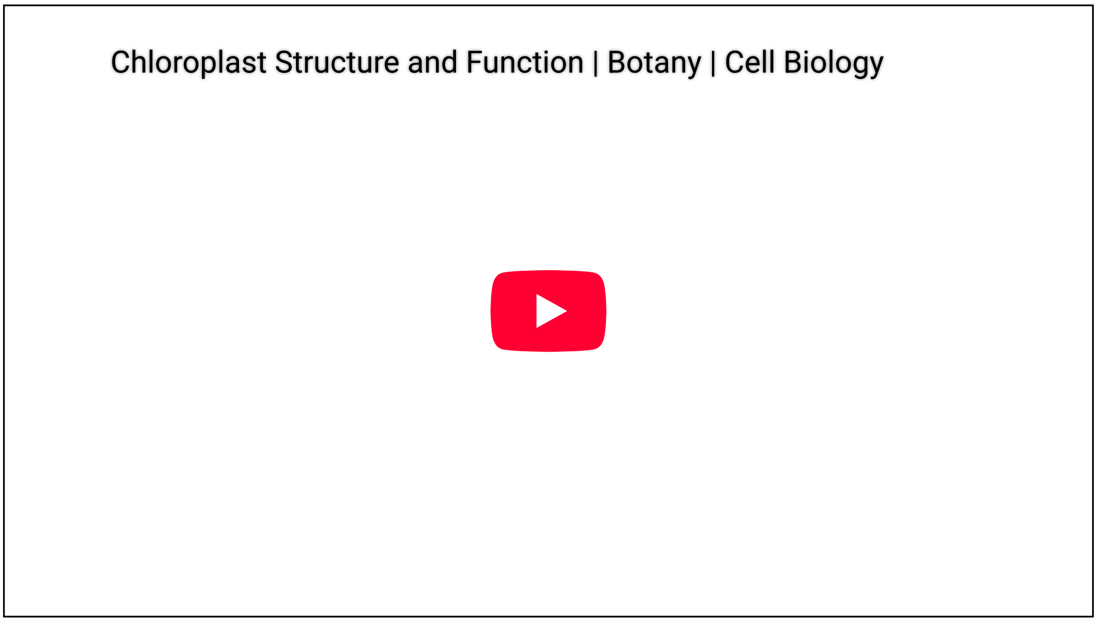

Video 2. The structure and function of the chloroplast.

The thylakoid membranes separate the stroma from the thylakoid space (**Figure 4**). Like the intermembrane space in the mitochondria, this is a small space. This small space allows the chloroplast to quickly generate a high concentration gradient. The thylakoid space is another example of compartmentalisation being used to separate potentially damaging chemicals as some of the molecules involved are dangerous to other parts of the cell (see subtopic C1.3 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43539/)).

The space between the inner and thylakoid membranes creates a compartment called the stroma. The stroma contains all the enzymes and substrates required for the remaining steps of photosynthesis, called the Calvin cycle, that will make glucose molecules. By compartmentalising all the required molecules in the stroma, the efficiency of the chemical reactions is maximised.

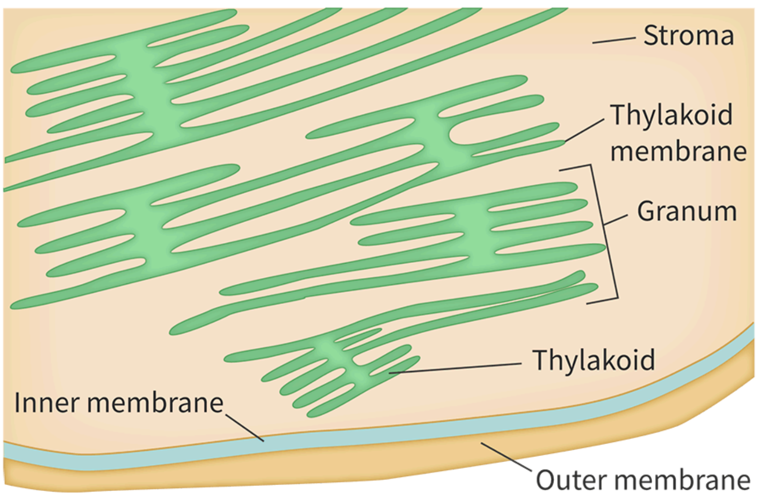

Figure 4. A diagram of part of a chloroplast.

Student view

More information for figure 4

This is a diagram showing a section of a chloroplast, illustrating the internal structures and their arrangement. Key components are labeled, including the stroma, which is the space between the inner and thylakoid membranes. The thylakoid membrane is shown as a stack of thin, disk-like structures. A granum, which consists of a stack of thylakoid disks, is labeled to the right. The inner membrane is depicted at the lower part of the diagram, forming the boundary of the chloroplast. Each section is clearly marked to show its position and function within the chloroplast, with lines connecting labels to respective parts.

[Generated by AI]

Study skills

Annotated diagrams

You should be able to draw annotated diagrams of the chloroplast and mitochondrion. When drawing annotated diagrams, remember the following:

- Look at the number of points the question is worth as that will give you a good idea of the number of structures you need to draw.
- Your drawings should be simple and clear. Your artistic talent (or lack of!) is not being assessed.
- Lines should clearly point to the correct structures and with the correct labels. The lines should not cross.
- You may want to practise your drawing on a piece of scrap paper.
- Draw your diagrams in pen rather than coloured pencils.

Structure and function of nuclear membranes

The nucleus contains most of the cell's genetic information and regulates gene expression in the cell. The nucleus contains two membranes, the inner and outer membranes (**Figure 5**), which have several essential functions that regulate the cell's activities. The outer membrane has ribosomes attached to it and is continuous, joined with the rough endoplasmic reticulum.

A main function of the double membrane is as a barrier between the genetic material inside the nucleus and the rest of the cell. DNA is highly sensitive to changes in the environment, so the double membrane provides a protective barrier

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to prevent damage to DNA.

The double membrane also has an important role in regulating gene expression. Gene expression is the process by which the information in DNA is translated into proteins. The inner membrane controls the entry and exit of signalling molecules and transcription factors, which are critical components in the regulation of gene expression (see subtopics D1.1 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43546/) and D1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43547/)).

Molecules enter and exit through the nuclear pores of the inner membrane. Nuclear pores are integral proteins that serve as channel proteins that also regulate mRNA leaving the nucleus for the rough endoplasmic reticulum or free ribosomes. The compartmentalisation of molecules and the regulation of entry and exit of molecules that the membranes provide is important in regulating gene expression. This is needed to maintain proper cell function and ensure that the cell functions correctly in response to its environment.

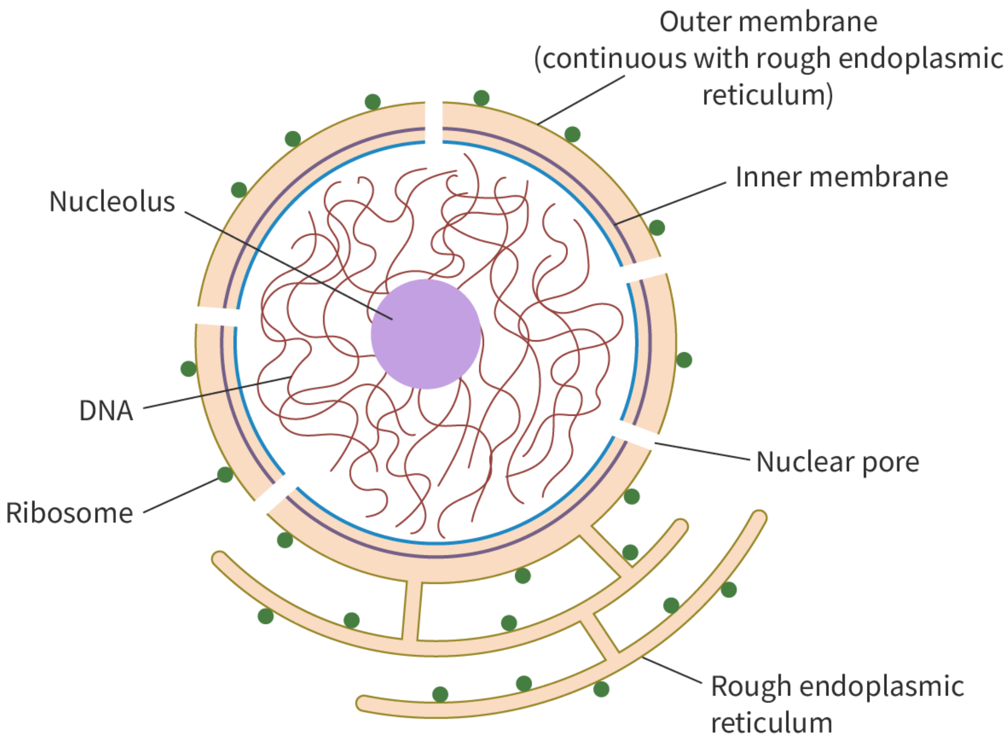

Figure 5. The double membrane of the nucleus.

Watch **Video 3** to see how the mRNA leaves the nuclear membrane to undergo translation.

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Video 3. The mRNA leaves the nucleus through the nuclear pores.

During cell division, the nuclear envelope breaks down to allow for the separation of chromosomes. However, after mitosis and meiosis is complete, the nuclear membranes must reassemble to enclose the newly formed nuclei. This process is initiated by the formation of small membrane-bound vesicles that are derived from the endoplasmic reticulum (ER). These vesicles contain proteins and lipids that are specific to the nuclear membrane and initially bind to the chromosome. The vesicles then join together surrounding the chromosomes. Finally, they fuse together to form the double membrane of the nucleus with the chromosomes inside (**Figure 6**). This process is critical for maintaining the integrity of the genetic material within the nucleus and for ensuring that essential cellular processes can occur.

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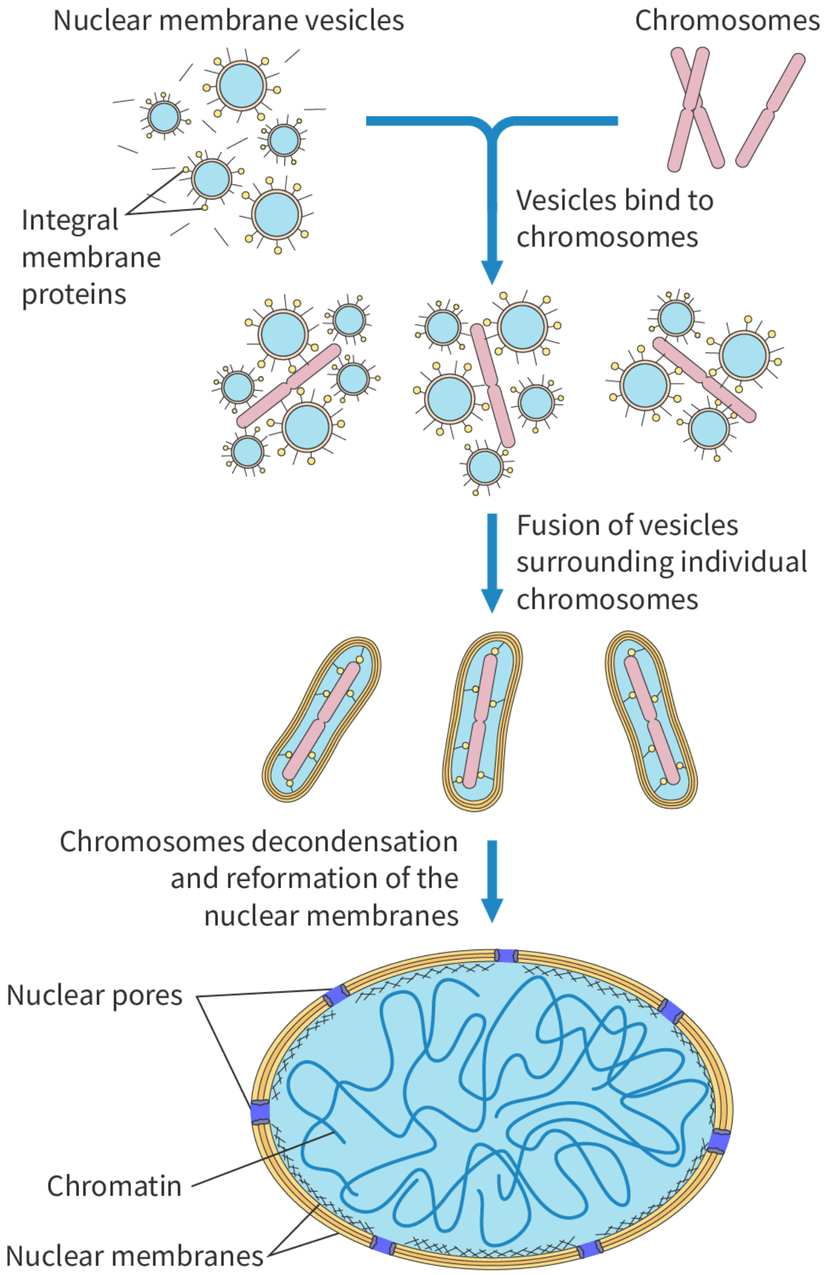

Figure 6. Reformation of the nuclear membrane from vesicles.

More information for figure 6

The diagram illustrates the process of nuclear membrane reformation from vesicles. It starts with small, circular structures labeled as "nuclear membrane vesicles," which are embedded with small rectangular structures marked as "integral membrane proteins." To the right, there are two pink elongated structures labeled "chromosomes."

The diagram shows arrows pointing from these vesicles to the chromosomes, indicating the step "vesicles bind to chromosomes." The vesicles cluster around the chromosomes, shown in a subsequent illustration, indicating "fusion of vesicles surrounding individual chromosomes." This suggests the vesicles form a protective layer around the chromosomes.

The next step depicted is "chromosomes decondensation and reformation of the nuclear membranes," leading to a larger circular structure labeled "nuclear membranes." Inside, a squiggly line represents "chromatin," and small pore-like features are marked as "nuclear pores," showing the completed structure of the reformed nucleus.

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Try this activity to check your understanding of the structure and function of mitochondria and chloroplasts.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Communication skills — Clearly communicating complex ideas in response to open-ended questions
- **Time required to complete activity:** 15 minutes
- **Activity type:** Individual activity

Using the guidelines from the above box 'Study skills — Annotated diagrams', draw labelled diagrams of the mitochondrion and the chloroplast including the structures listed in **Table 1.** In the space below your diagrams, compare and contrast the structure and function of the mitochondrion and chloroplast.

Table 1. Structures to include.

Chloroplast	Mitochond
Outer membrane	Outer memb
Granum	Inner memb
Thylakoid	Intermembrane
Thylakoid space	Matrix
Stroma	Cristae

5 section questions

Membranes and protein packaging (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Describe the different roles of bound and free ribosomes.
- Outline the function of the Golgi apparatus in the processing and transport of proteins.
- Describe the role of vesicles in cells and the role of clathrin in the formation of vesicles.

Ribosomes, the endoplasmic reticulum, Golgi apparatus and vesicles play a key role in moving proteins around the cell. This is similar to the underground, trains and buses that make up public transport in that there are different ways a protein moves around the cell based on where it needs to go. In some specialised cells, the endoplasmic reticulum and Golgi apparatus (**Figure 1**) can make up a large amount of the total plasma membrane found in the cell. Vesicles can form from many different types of plasma membranes but can only develop when a specific need applies. What is needed to form a vesicle, and what are the roles of the ER and Golgi apparatus in protein transport and vesicle formation?

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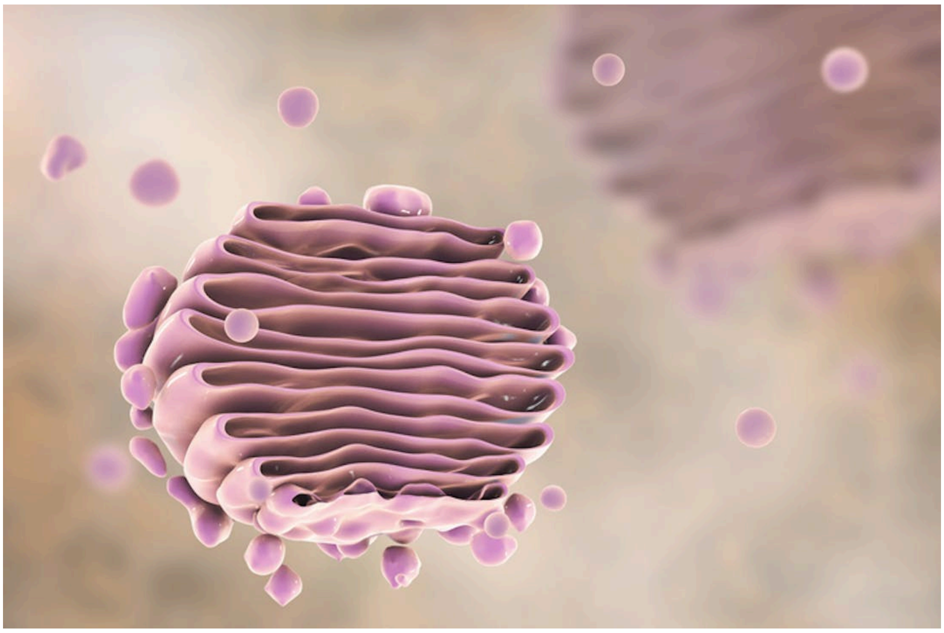

Figure 1. This is a computer-generated image of a Golgi apparatus with transport vesicles. Its primary function is to modify, store and transport proteins and lipids made elsewhere in the cell. The vesicles transport proteins around the cell and can fuse with the plasma membrane to deliver proteins outside of the cell.

Credit: Kateryna Kon/Science Photo Library, Getty Images (https://www.gettyimages.com/detail/illustration/golgi-apparatus-illustration-royalty-free-illustration/909257506)

More information for figure 1

The image is a computer-generated 3D illustration of the Golgi apparatus, a cell organelle, depicted with its characteristic series of flattened, stacked pouches. Surrounding these pouches are small spherical vesicles, which are involved in the transport of proteins and lipids. The Golgi apparatus appears as a wavy structure, giving an impression of layered sheets, with vesicles possibly budding off its surface. The background is blurred to highlight the organelle in the foreground.

[Generated by AI]

Bound and free ribosomes

Ribosomes translate the mRNA from the nucleus into proteins. Ribosomes can be bound or free. If the ribosome is joined to the ER, it is referred to as a bound ribosome, and the endoplasmic reticulum is referred to as the rough ER (RER). If there are no ribosomes on the surface of the ER, it is referred to as smooth ER (SER). If the ribosome is located in the cytoplasm, it is referred to as a free ribosome. Structurally and functionally, they are the same. Only their location is different.

In bound ribosomes, the ribosome is bound to the cytosolic side of the RER and the proteins that it produces end up inside the RER. These proteins will then be exported for use outside of the cell. Pancreatic cells, for example, export many

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different types of proteins for digestion and homeostasis; as a result, they contain higher amounts of RER. As most cells in organisms produce proteins for use in the body, bound ribosomes tend to be more numerous in the cell than free ribosomes. Free ribosomes make proteins that remain inside the cell's cytoplasm and the proteins are used inside the cell.

The mRNA that codes for proteins that need to be exported outside of the cell is transcribed in the nucleus with an ER signal sequence. When joined with a ribosome, this signal directs the ribosome towards the ER membrane. Proteins for use inside the cell do not have this sequence in their mRNA. This allows the cell to direct proteins to the correct locations, which will depend on the protein's function.

Study skills

The processing and transport of proteins is an excellent opportunity to use a diagram to explain or describe a process. With diagrams you should include:

- relevant labels — do not assume others will understand
- descriptions of the processes occurring
- numbering of the processes to aid understanding.

Processing and transport of proteins

The RER is a system of interconnected membranes that forms a series of flattened sacs and tubes. The inside of these flattened sacs is referred to as the ER lumen. It is named 'rough' due to its rough appearance caused by the presence of ribosomes attached to the cytosolic side of the ER membrane. The RER is involved in several vital functions within the cell, including protein synthesis and modification.

When proteins are synthesised on bound ribosomes located on the cytosolic side of the RER membrane, they are immediately transported into the lumen of the RER for further processing and modification. The RER has a variety of enzymes that modify the newly synthesised proteins. Modifications can include adding carbohydrates (to form a glycoprotein), adding phosphate groups and assisting in folding. After modification, the proteins are transported by vesicles to the Golgi apparatus for further processing. This transport is done through a process similar to endocytosis (see section B2.1.11-13 (/study/app/bio/sid-422-cid-755105/book/membrane-fluidity-

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hl-id-44646/)). A piece of the RER membrane, with the protein inside, breaks off the RER membrane to form a vesicle. Instead of leaving the cell, as would happen in exocytosis, the vesicle travels to the Golgi apparatus.

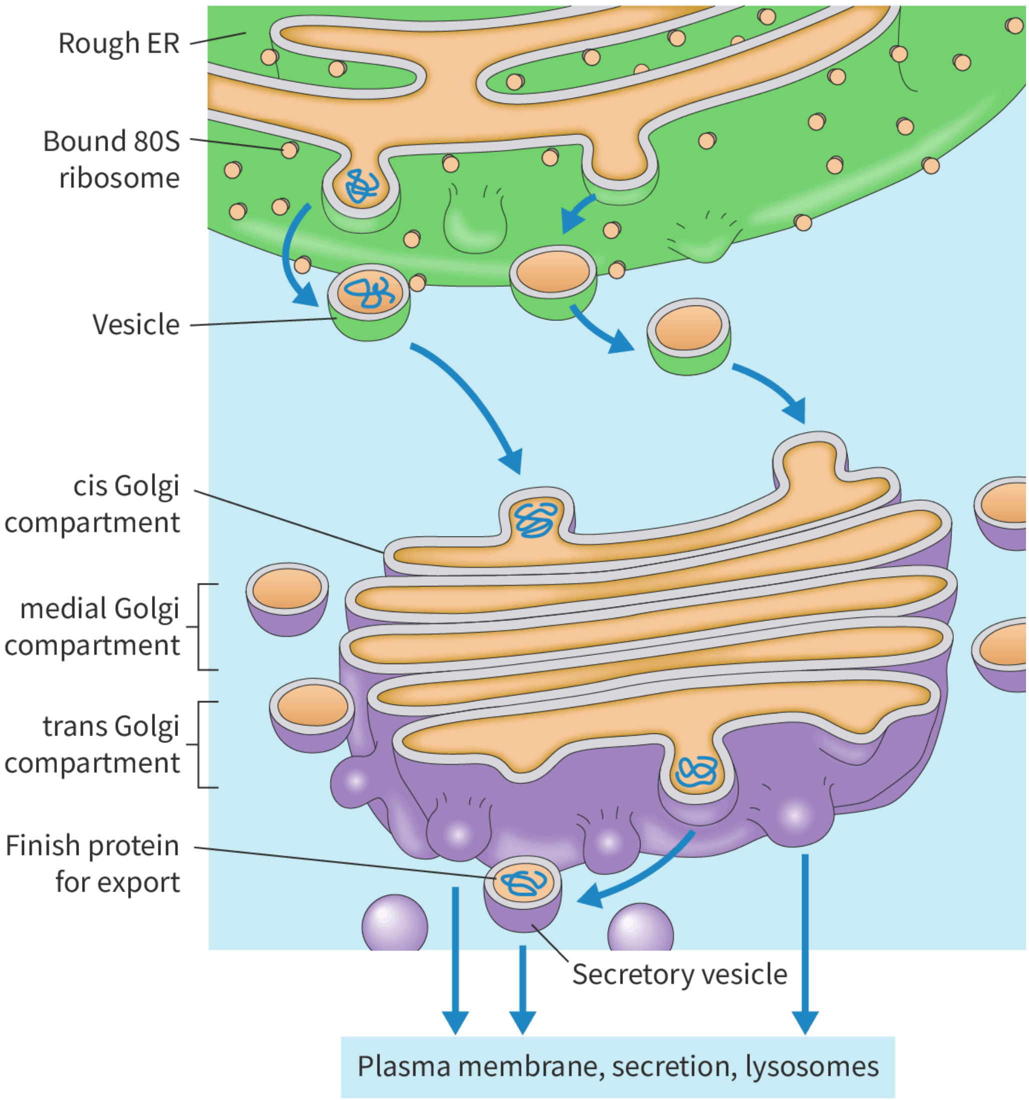

Figure 2. The transport of proteins from the RER to the Golgi apparatus and finally out of the cell.

More information for figure 2

The image illustrates the transport of proteins from the Rough Endoplasmic Reticulum (RER) to the Golgi apparatus and eventually out of the cell. At the top of the diagram, the Rough ER is shown with bound 80S ribosomes. Proteins synthesized on these ribosomes are encapsulated into vesicles, which are depicted as small circular shapes that bud off from the Rough ER. Arrows indicate the direction of vesicle movement toward the Golgi apparatus.

The Golgi apparatus is shown below the Rough ER in a stack of flattened, membrane-bound sacs separated into cis, medial, and trans compartments. Proteins from the vesicles are transported to the cis Golgi compartment, continue to the medial Golgi compartment for further modification, and finally reach the trans Golgi compartment for secretion. The trans Golgi compartment packages the proteins into

Student view

secretory vesicles, with arrows indicating that the vesicles are destined for the plasma membrane, secretion outside the cell, or lysosomes. Each vesicle and compartment is clearly labeled in the illustration.

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The Golgi apparatus is a stack of flattened, membrane-bound sacs that are organised into cis, medial, and trans compartments. The *cis* compartment receives newly modified proteins from the RER. In this case, the vesicle fuses with the *cis* compartment membrane and releases the protein inside the Golgi apparatus. The Golgi apparatus sorts proteins based on their final destination, usually into lysosomes, plasma membrane or vesicles for export outside of the cell. Proteins destined for use within the cell, such as lysosomes, are transported to the *medial* compartment, where they undergo further modification before being sent to their final destination. Proteins destined for export outside of the cell are transported to the *trans* compartment, where they are packaged into vesicles for secretion. Vesicle formation on the Golgi apparatus is similar to how vesicles were formed on the RER.

The RER and Golgi apparatus are further examples of the benefits of compartmentalisation as the different spaces, compartmentalised by membranes, allow the cell to direct proteins to different parts of the cell and outside of the cell. The compartments in the RER and Golgi apparatus allow the cell to concentrate the enzymes and other molecules for specific tasks such as lysosome formation.

Vesicles and the role of clathrin

Vesicles are small, membrane-bound cell structures that play a key role in cellular processes such as the transport and storage of materials. They act as delivery trucks, transporting and releasing proteins, lipids and RNA from one part of the cell to another. Vesicles can also act as storage compartments, holding and isolating substances until they are needed. Four common examples of vesicles are:

- Transport vesicles: these vesicles transport materials from one part of the cell to another. An example is the transport of proteins from the rough endoplasmic reticulum to the Golgi apparatus.
- Secretory vesicles: these vesicles store and transport molecules to be secreted outside the cell, such as hormones, neurotransmitters and digestive enzymes.
- Lysosomes: these vesicles contain hydrolytic enzymes that can break down macromolecules such as proteins, carbohydrates and lipids. They play a key role in

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the degradation of cellular waste products and in removing damaged or aged organelles.

- Peroxisomes: these vesicles are similar to lysosomes but have a different set of enzymes that are involved in the detoxification of harmful compounds and lipid metabolism.

Creativity, activity, service

Strand: Service
Learning outcome: Demonstrate engagement with issues of global significance

Lysosomal storage diseases are rare diseases that affect 1 in 8000 newborns. The rarity of these diseases means that there can be limited support in terms of funding and research into them. John and Aileen Crowley faced this situation when their children were diagnosed with Pompe disease, a type of lysosomal storage disease. John and Aileen started their own company, Novazyme Pharmaceuticals, with the sole purpose of research into Pompe disease. Identifying needs and opportunities to help are important parts of students' CAS journey. John and Aileen's story formed the basis for the 2010 movie, *Extraordinary Measures.*

Find out about a rare disease that has limited support in terms of funding and research. Could you become a champion of the disease by raising funds or awareness of it or encouraging others to do the same?

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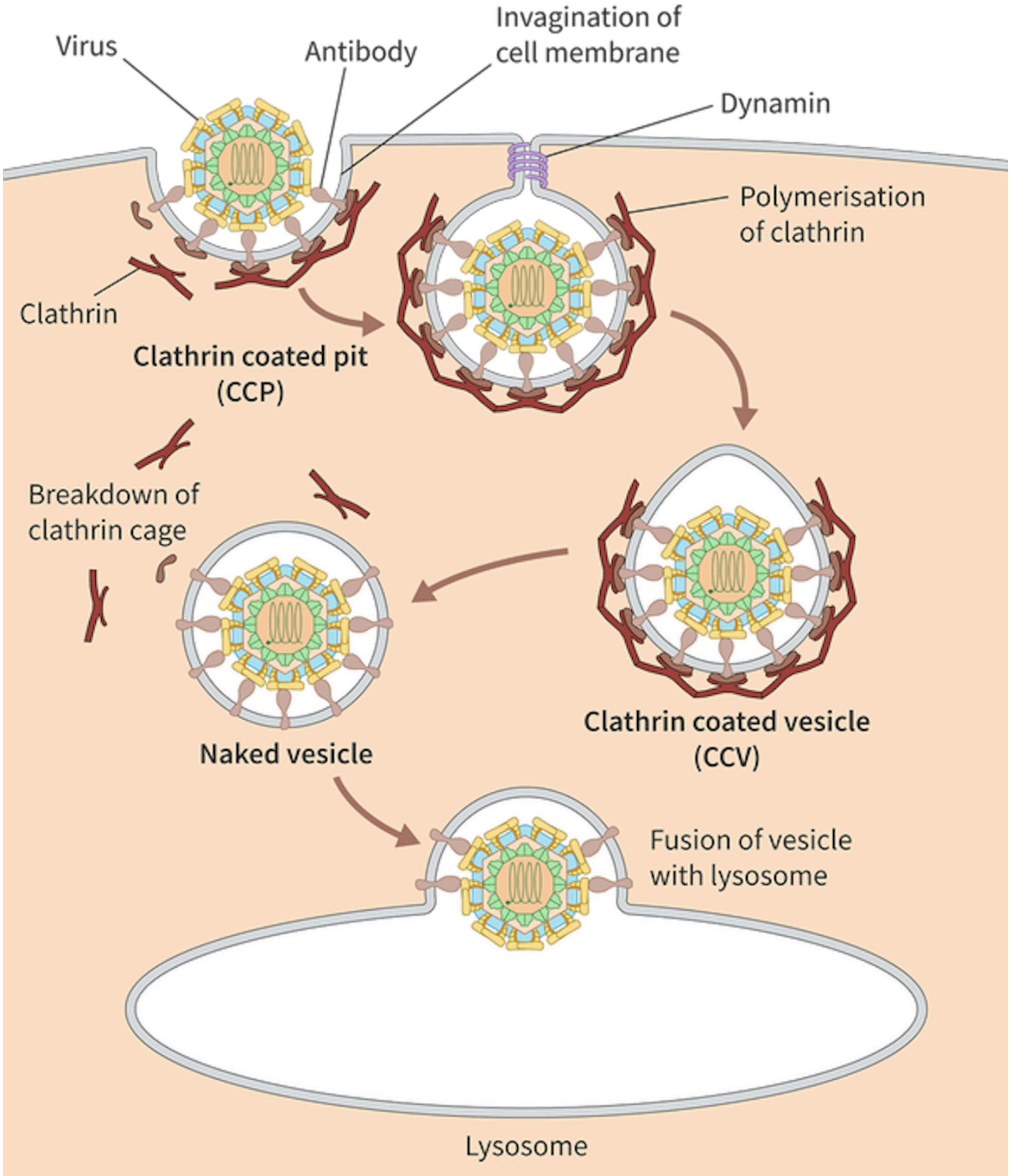

Figure 3. Phagocytosis (a type of endocytosis) of a virus through the formation of a clathrin-mediated vesicle.

More information for figure 3

The diagram depicts the process of phagocytosis through the formation of a clathrin-mediated vesicle. It starts with a clathrin-coated pit (CCP) where a virus is recognized by an antibody at the cell membrane. Clathrin proteins aggregate around the virus's location, forming a cage-like structure, which is labeled in the diagram. Through the polymerization of clathrin and involvement of dynamin, the cell membrane invaginates, encapsulating the virus and forming a clathrin-coated vesicle (CCV). Arrows indicate that the clathrin cage eventually breaks down, resulting in a naked vesicle, which then fuses with a lysosome for further processing. Each stage is labeled with relevant terms, such as clathrin, dynamin, and invagination of the cell membrane, illustrating the sequential steps and components involved in this endocytosis pathway.

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Clathrin is a protein that plays an important, but not fully understood, role in the formation of vesicles in cells. Clathrin brings together the cytoskeleton and other proteins needed for the budding and scission of vesicles from the plasma membrane and from the membranes of intracellular organelles. Clathrin-coated vesicles are involved in a wide range of cellular processes, including:

- endocytosis
- phagocytosis (**Figure 3**)
- the transport of cargo from the Golgi apparatus to the plasma membrane
- the formation of lysosomes.

Clathrin forms a cage-like structure through the polymerisation of multiple clathrin molecules around the area of a membrane that is about to become a vesicle. As the membrane starts to invaginate, clathrin surrounds the invagination and forms a clathrin-coated pit. This coated pit acts as a scaffold (framework) for the formation of the vesicle. It brings together the necessary molecules needed to shape and pinch off a piece of the membrane to form a vesicle. Once the vesicle has formed, the clathrin coat breaks down, through hydrolysis, back into individual pieces.

Try this activity to apply your knowledge of clathrin-coated vesicles to a new context.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

Huntington's Disease (HD) is a genetic neurodegenerative disease with the main symptoms being dementia, tics and involuntary muscle movement. The condition is caused by a mutation in the huntingtin (*Htt*) gene. Genetic studies have shown a link between *Htt* and endocytosis. In normally functioning neurons, neurotransmitters bind to receptors on the neuron, which start the process of endocytosis to absorb the neurotransmitters back into the neuron. This stops the transmission of the signal to the muscles to contract. This process is similar to phagocytosis as clathrin is also used to form vesicles, but the vesicles are filled with neurotransmitters instead of pathogens.

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The mutated Htt protein has been shown to stick together, inhibiting endocytosis. This prevents the endocytosis of the neurotransmitters into the neuron. This means that the neurotransmitters continue to send the signal to muscles (see subtopic C2.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43541/)), which can be one of the causes of tics and involuntary muscle movement.

- Describe how endocytosis, with clathrin's support, might work in neurons (Hint: this process is similar to phagocytosis).
- The sticking together of the mutated Htt protein has been associated with inhibiting clathrin polymerisation from occurring. Suggest how the mutated Htt protein may inhibit clathrin polymerisation.

5 section questions

B2. Form and function: Cells / B2.2 Organelles and compartmentalisation

Summary and key terms

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- Organelles are specialised structures in cells with specific functions.
- Compartmentalisation allows for the development of specialised cell structures.
- Ribosomes are organelles, but the cytoskeleton, cell wall and cytoplasm are not considered organelles.

Higher level (HL)

- The mitochondria and chloroplasts are organelles with highly folded membranes that increase their surface area, allowing for more efficient production of ATP and glucose through cellular respiration and photosynthesis, respectively.
- The compartmentalisation of molecules in these organelles allows for the concentration of reactants and the separation of potentially damaging chemicals, leading to maximised efficiency.
- The nucleus has a double membrane that serves as a protective barrier for the genetic material and regulates the entry and exit of molecules critical for gene expression.
- The endoplasmic reticulum (ER) is a system of interconnected membranes involved in protein synthesis and modification.

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- The rough ER synthesizes, folds and modifies proteins created by the attached ribosomes. These proteins are either delivered to different organelles within the cell or secreted by the cell.
- Free ribosomes move about the cytoplasm and produce proteins for use inside the cell.
- The smooth ER is involved with the synthesis of lipids and steroid hormones, carbohydrate metabolism, detoxification of the cell and calcium ion storage.
- Vesicles are small membrane-bound structures that transport and store materials in the cell, including proteins, lipids and RNA, and clathrin plays a key role in the formation of vesicles.

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Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. Organelles are parts within a cell that perform specific functions.
2. Compartmentalisation refers to the separation of different functions and processes in a cell into different or structures by plasma membranes.
3. Only cells have membrane-bound organelles.
4. The advantage of is that it helps the cell to increase the speed of chemical reactions and keep specific processes in specific places.
5. Lysosomes are an example of compartmentalised spaces that down waste materials in the cell.
6. The cytoskeleton and cell wall are not considered organelles because they are not surrounded by a and do not have specific metabolic functions.
7. , which make proteins, are considered organelles even though they are not membrane-bound.
8. Eukaryotic cells have a that is separated from the cytoplasm by a double membrane.
9. The compartmentalisation of the nucleus allows for post-transcriptional modification and communication between the and nucleus.
10. Small compartments can increase the of enzymes and other molecules which increase the rate of chemical reaction.

eukaryotic | cytoplasm | compartmentalisation | break | regions | nucleus | specialised | concentration | ribosomes | membrane

Check

Interactive 1. Organelles and Compartmentalisation: Key Terms

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Higher level (HL)

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. The contain an inner membrane with folds called cristae, which provide a large surface area for cell respiration.
2. The within the inner membrane holds high concentrations of enzymes and other molecules.
3. The intermembrane space allows for a concentration of H+ ions, used by ATP synthase to generate ATP.
4. In photosynthesis, thylakoid membranes are stacked for light absorption.
5. The thylakoid membranes separate the from the thylakoid space.
6. The double membrane surrounding the nucleus is called the .
7. The rough endoplasmic reticulum (RER) has attached ribosomes and produces proteins for outside the cell.
8. The smooth endoplasmic reticulum (SER) lacks ribosomes for the production of proteins but is responsible for the synthesis of .
9. plays a key role in the formation of vesicles.

matrix | mitochondria | nuclear membrane | stroma
high | maximum | clathrin | export | lipids

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Interactive 2. Organelles and Functions Key Terms.

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B2. Form and function: Cells / B2.2 Organelles and compartmentalisation

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Checklist

What you should know

After studying this subtopic you should be able to:

- State, with examples, that organelles are structures that are separate subunit of cells and perform a specific function.
- Explain the advantages, using phagocytic vacuoles and lysosomes as examples, of the compartmentalisation of cytoplasm.
- Explain the advantage of the separation of the nucleus and the cytoplasm in regard to protein synthesis.

Higher level (HL)

- Explain, using an annotated diagram, how the structure of the mitochondrion aids in the production of ATP.
- Explain, using an annotated diagram, how the structure of the chloroplast aids in photosynthesis.
- Describe the functional advantages of the double membrane around the nucleus in protein synthesis and cell division.
- Describe the different roles of bound and free ribosomes.
- Outline the function of the Golgi apparatus in the processing and transport of proteins.
- Describe the role of vesicles in cells and the role of clathrin in the formation of vesicles.

B2. Form and function: Cells / B2.2 Organelles and compartmentalisation

Investigation

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- **IB learner profile attribute:** Inquirer
- **Approaches to learning:**

- Thinking skills – Providing a reasoned argument to support conclusions, Engaging with, and designing linking questions
- Research skills – Comparing, contrasting and validating information, Using search engines and libraries effectively

- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual/pair activity

Your task

As you have learned in this subtopic, compartmentalisation is an important feature in cells. In this activity, you will complete **Table 1** with examples of compartmentalisation and advantages for specific functions in different parts of the cell.

Table 1. Examples of compartmentalisation in cells.

Organelle	Compartmentalisation feature	Advantage for specific function
Nucleus	Surrounded by a double membrane	Keeps gene transcription separate from translation activity occurring in cytoplasm

Concept

Compartmentalisation is a vital concept in biology that operates at multiple levels. *Rhizobium* are bacteria that convert nitrogen gas from the air into nitrites and nitrates in soil. Nitrogen is essential for living things, and *Rhizobium* are the main pathway to get nitrogen into the soil and ultimately into all living things. Legumes, a group of plant species including soybeans, have little compartments, called nodules, where *Rhizobium* live. This gives the *Rhizobium* a nice place to live, and the plant gets a constant supply of nitrogen. This is not only an example of symbiosis but also of compartmentalisation. Can you think of other examples in ecosystems or in relationships between organisms?

Reflection

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Reflection

Now that you've completed this subtopic, let's come back to the guiding question introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43532/).

- How are organelles in cells adapted to their functions?
- What are the advantages of compartmentalisation in cells?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?

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- What connections do you see between this subtopic and other parts of the course?

Once you submit your response, you won't be able to edit it.

0/2000

Submit

Rate subtopic B2.2 Organelles and compartmentalisation

Help us improve the content and user experience.

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