MEGA LECTURE

IB DP BIOLOGY

Theme B: Form and Function

B2.2 Organelles and Compartmentalization

Revision Notes · Standard and Higher Level

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Original notes prepared for the IB Diploma Programme Biology course (2025 syllabus)

What the syllabus requires

B2.2 asks you to understand cells as compartmentalised systems. Use this checklist as a final revision sweep before the exam.

Understanding	You should be able to...
Organelles as subunits of cells	Define an organelle and distinguish membrane-bound from non-membrane-bound organelles.
Advantage of a nucleus	Explain how separating the genetic material from the cytoplasm benefits the eukaryotic cell.
Advantages of compartmentalization	State how internal membranes let cells run several incompatible processes efficiently at once.
Structure fits function	Relate the detailed structure of each organelle to the job it performs.
Adaptations of compartments (HL)	Describe how the properties of a compartment (pH, enzymes, surface area) suit its function. (HL)
Origin of organelles (HL)	Recognise mitochondria and chloroplasts as semi-autonomous, endosymbiotic in origin. (HL)

> **Exam note:** B2.2 is common to SL and HL. HL papers push the same ideas further - linking compartment conditions to enzyme activity, and drawing on the endosymbiotic origin of mitochondria and chloroplasts. HL-only points below are flagged (HL).

1. What is an organelle?

An **organelle** is a specialised subunit within a cell that carries out a particular function - the cellular equivalent of an organ in a body. Just as a division of labour between organs makes a whole organism efficient, a division of labour between organelles makes a cell efficient.

Membrane-bound vs non-membrane-bound

Organelles fall into two groups depending on whether a phospholipid membrane encloses them.

Type	Meaning	Examples
Membrane-bound	Enclosed by one or two phospholipid membranes that separate their contents from the cytoplasm	Nucleus, mitochondria, chloroplasts, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuole, peroxisomes
Non-membrane-bound	Have no surrounding membrane; built directly from protein and/or nucleic acid	Ribosomes, centrioles, the cytoskeleton, the nucleolus

The advantage of internal membranes

Prokaryotes (B2.1) have no membrane-bound organelles, so all their reactions share one cytoplasm. Eukaryotes evolved an extensive system of internal membranes, and this is the single most important difference between the two cell types. Internal membranes allow a cell to build many separate **compartments**, each with its own chemical environment. This is the basis of compartmentalization,

developed in Section 3.

> **Key idea:** Non-membrane-bound structures are still organelles. A common exam error is to claim ribosomes are not organelles because they lack a membrane - they are simply non-membrane-bound organelles.

2. Structure and function of the organelles

The table below is the core of B2.2. For each organelle, learn the structural feature named in the middle column, because exam marks are awarded for linking that feature to the function, not merely for naming the function.

Organelle	Key structural features	Function
Nucleus	Enclosed by a double membrane (nuclear envelope) pierced by nuclear pores; contains chromatin (DNA + protein) and one or more nucleoli	Stores the genetic material; controls the cell by regulating transcription; the pores let mRNA out and proteins in
Nucleolus	A dense, non-membrane-bound region inside the nucleus	Site where ribosomal RNA is made and ribosome subunits are assembled
Nuclear envelope + pores	Two membranes continuous with the rough ER; pores are protein-lined channels	Separates DNA from the cytoplasm; pores control the exchange of molecules with the cytoplasm
Ribosomes	Two subunits of rRNA and protein; 80S in eukaryotic cytoplasm, smaller 70S in prokaryotes, mitochondria and chloroplasts; no membrane	Site of translation - assembling amino acids into polypeptides
Rough ER	A network of membrane sacs (cisternae) studded with ribosomes; continuous with the nuclear envelope	Synthesises and folds proteins destined for secretion or membranes; buds off transport vesicles
Smooth ER	Membrane tubules with no ribosomes	Synthesises lipids and steroids; stores and releases calcium ions; detoxifies (e.g. in liver cells)
Golgi apparatus	A stack of flattened, curved membrane sacs with a cis (receiving) and trans (shipping) face	Modifies, sorts and packages proteins and lipids; buds off secretory vesicles and lysosomes
Mitochondrion	Double membrane; inner membrane folded into cristae; fluid matrix inside; own 70S ribosomes and circular DNA	Aerobic respiration - the Krebs cycle in the matrix and oxidative phosphorylation on the cristae (link C1.2)
Chloroplast	Double membrane; internal thylakoid membranes stacked into grana; fluid stroma; own 70S ribosomes and DNA	Photosynthesis - light-dependent reactions on the thylakoids, the Calvin cycle in the stroma (link C1.3)
Lysosome	Single membrane vesicle holding hydrolytic (digestive) enzymes at acidic pH	Breaks down worn organelles, engulfed material and, on cell death, the cell itself

Organelle	Key structural features	Function
Vacuole	A single membrane (tonoplast) enclosing cell sap; very large and permanent in plant cells	Maintains turgor pressure; stores water, ions and pigments; some store waste
Peroxisome	Small single-membrane vesicle containing oxidative enzymes including catalase	Breaks down fatty acids; destroys hydrogen peroxide, a toxic by-product of metabolism
Cell wall	External layer of cellulose (plants) outside the plasma membrane; freely permeable	Gives shape and mechanical support; prevents bursting by resisting turgor pressure
Plasma membrane	Phospholipid bilayer with embedded proteins (B2.1)	Forms the cell boundary; controls what enters and leaves (selective permeability)
Cytoskeleton	Network of protein filaments (microtubules, microfilaments); non-membrane-bound	Maintains cell shape; anchors organelles; provides tracks for intracellular transport
Centrosome / centrioles	Pair of cylindrical microtubule structures near the nucleus (in animal cells); non-membrane-bound	Organise microtubules; help form the spindle during cell division

> **Structure-to-function habit:** Whenever you name a feature, add the words “so that” and finish the sentence. “The inner mitochondrial membrane is folded into cristae so that there is a large surface area for the electron transport chain.” That is what earns the mark.

Which organelles are found in which cells

Not every organelle occurs in every cell. Knowing the differences between animal, plant and prokaryotic cells is a frequent exam requirement and helps you identify a cell type from a micrograph.

Organelle	Animal cell	Plant cell	Prokaryote
Nucleus (membrane-bound)	Present	Present	Absent (DNA free in cytoplasm)
Mitochondria	Present	Present	Absent
Chloroplasts	Absent	Present (green parts)	Absent
Cell wall	Absent	Present (cellulose)	Present (peptidoglycan)
Large permanent vacuole	Absent (small only)	Present	Absent
Ribosomes	Present (80S)	Present (80S)	Present (70S)
Golgi, ER, lysosomes	Present	Present	Absent
Centrioles	Present	Usually absent	Absent

Scale and magnification

Because most organelles are only visible under an electron microscope, questions often ask you to work out a real size from a scale bar or a magnification. Use magnification = image size × (1 / actual size), rearranged as actual size = image size → magnification. Always convert to the same units first: 1 mm = 1000 µm and 1 µm = 1000 nm.

> **Typical sizes:** A mitochondrion is roughly 1-10 µm long, a ribosome only about 25 nm across, and a whole animal cell about 10-30 µm. Ribosomes are therefore far too small to see under a light microscope.

3. Compartmentalization

Compartmentalization is the division of a cell into separate regions by membranes, so that each region can be kept chemically distinct. In eukaryotes these regions are the membrane-bound organelles and the cytosol around them. The idea is worth a full section because it is the reasoning behind almost every structure-to-function answer in this topic.

Why compartments help - five advantages

- **Incompatible processes can run at the same time.** Digestion by lysosome enzymes and protein synthesis on ribosomes need very different conditions; membranes keep them apart so both proceed without interfering.
- **Reactants and enzymes are concentrated.** Enclosing enzymes and their substrates in a small volume raises their local concentration, so reactions run faster than if the same molecules were spread through the whole cell.
- **Local conditions can be optimised.** Each compartment can hold the pH or ion concentration its enzymes prefer - for example lysosomes are kept acidic (about pH 4.5-5) for their hydrolytic enzymes.
- **Membrane surface area is greatly increased.** Folded internal membranes (cristae, thylakoids, ER) provide vast surfaces on which membrane-bound enzymes and electron carriers can be embedded.
- **Harmful substances are contained.** Damaging molecules and enzymes are shut away so they cannot injure the rest of the cell - digestive enzymes stay inside lysosomes, and hydrogen peroxide is confined to peroxisomes.

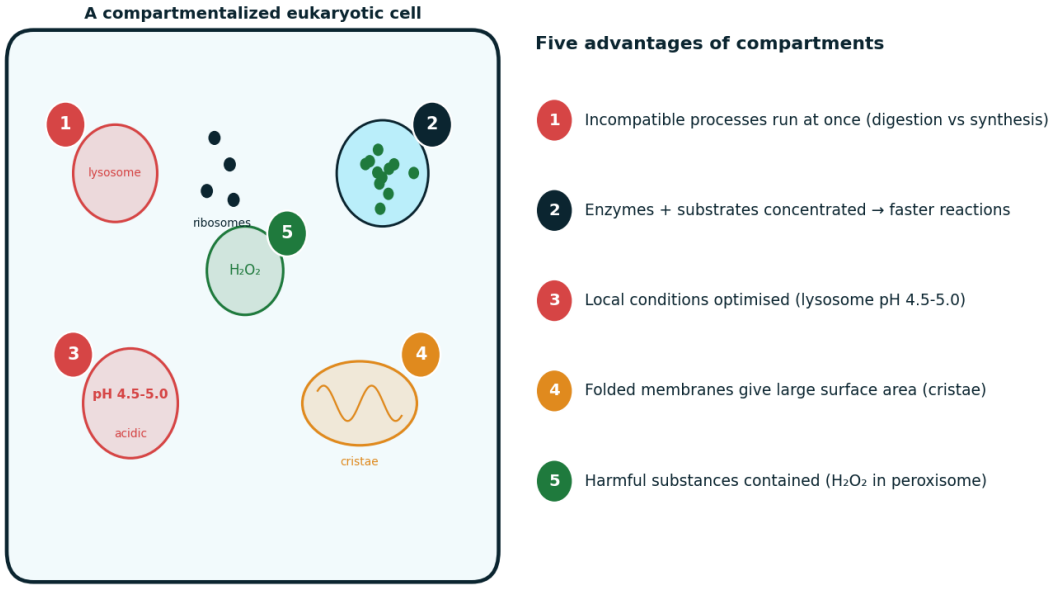

Figure 2. Five advantages of compartmentalization. Each numbered compartment illustrates one benefit; for example the lysosome is held at pH 4.5-5 so its hydrolytic enzymes work well and stay safely contained.

> **Advantage of the nucleus:** Enclosing DNA in a nuclear envelope keeps transcription (making mRNA) physically separate from translation (making protein). This protects the DNA and allows the mRNA to be edited before it is used, giving the eukaryotic cell finer control over gene expression.

The cytosol is a compartment too

It is easy to forget that the fluid **cytosol** surrounding the organelles is itself a compartment. Reactions that do not need special conditions - glycolysis, the first stage of respiration, and much of protein synthesis on free ribosomes - take place here. Compartmentalization is therefore not only about building organelles but about keeping the general-purpose cytosol chemically separate from the specialised interiors of the organelles.

A small cost to weigh against the benefits

Compartmentalization is not free. Molecules must be actively moved between compartments, often across membranes and inside vesicles, which uses energy and requires transport proteins and recognition signals. Evolution has retained compartmentalization because the gains in speed, control and safety outweigh this cost - a good example of structure being shaped by function.

4. The endomembrane system and protein secretion

Several organelles work together as one connected unit, the **endomembrane system**: the nuclear envelope, rough and smooth ER, the Golgi apparatus, vesicles, lysosomes and the plasma membrane. Their classic joint task is exporting a protein - for example a digestive enzyme or a hormone such as insulin.

The secretory pathway, step by step

1. **Nucleus.** The gene coding for the protein is transcribed into mRNA, which leaves through a nuclear pore.

2. **Rough ER.** Ribosomes on the rough ER translate the mRNA; the new polypeptide is threaded into the ER lumen, where it folds into shape.

3. **Transport vesicle.** A piece of rough ER membrane buds off, enclosing the protein, and carries it to the Golgi apparatus.

4. **Golgi apparatus.** The vesicle fuses with the cis face; the Golgi chemically modifies the protein (for example adding carbohydrate) and sorts it.

5. **Secretory vesicle.** The finished protein is packaged into a vesicle that buds from the trans face and moves to the plasma membrane.

6. **Plasma membrane.** The vesicle fuses with the membrane and releases the protein outside the cell by **exocytosis**.

In one line: nucleus → rough ER → transport vesicle → Golgi → secretory vesicle → plasma membrane (exocytosis).

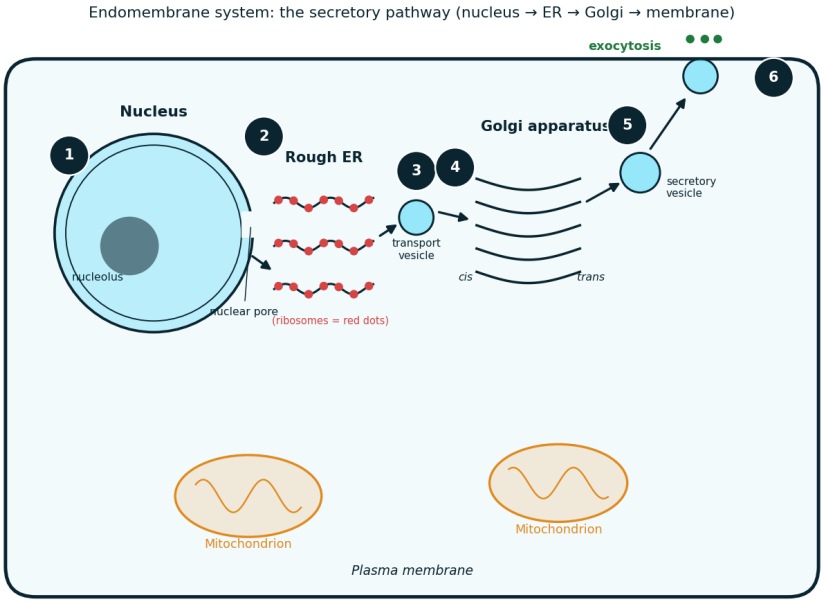

Figure 1. The endomembrane system and secretory pathway: a protein travels nucleus → rough ER → transport vesicle → Golgi → secretory vesicle → plasma membrane, then leaves the cell by exocytosis.

Worked walkthrough - secreting insulin

Trace the path of an insulin molecule from gene to bloodstream in a pancreatic beta cell, naming the organelle at each stage.

The insulin gene is transcribed in the **nucleus**; mRNA exits via a nuclear pore. On the **rough ER** the mRNA is translated and the polypeptide folds. A **transport vesicle** carries it to the **Golgi apparatus**, which processes it into mature insulin and packs it into a **secretory vesicle**. That vesicle fuses with the **plasma membrane** and releases insulin by exocytosis into the blood.

Marks are for the correct *order* and for naming exocytosis at the end.

5. Mitochondria and chloroplasts: energy conversion

Both of these organelles convert energy from one form to another, and both share a revealing design feature - a highly folded internal membrane that maximises surface area. This links directly to C1.2 (cell respiration) and C1.3 (photosynthesis).

Feature	Mitochondrion	Chloroplast
Energy conversion	Chemical energy in glucose → chemical energy in ATP	Light energy → chemical energy in glucose
Folded membrane	Inner membrane folded into cristae	Thylakoid membranes stacked into grana
Fluid interior	Matrix (holds Krebs-cycle enzymes)	Stroma (holds Calvin-cycle enzymes)
Why folded?	Large surface area for the electron transport chain and ATP synthase	Large surface area holds many chlorophyll molecules and electron carriers

The pattern to remember: a folded membrane provides the **surface** for the reactions that pump protons and make ATP, while the enclosed **fluid** (matrix or stroma) provides the compartment for the reactions that are

catalysed by free enzymes in solution. Structure and compartment together make the conversion efficient.

> **Common link mark:** If a question asks why mitochondria have cristae, the expected answer is "to increase the surface area of the inner membrane for the electron transport chain / ATP synthase," not simply "to make more ATP."

6. How compartment structure suits function (HL)

At HL you are expected to reason in more detail about *why* a particular internal environment fits the reactions housed there. Two examples make the point.

Thylakoid space vs stroma (HL)

During the light-dependent reactions, protons are pumped into the thylakoid space, making it acidic and building a steep concentration gradient across the thylakoid membrane. Because the thylakoid is a sealed compartment, this gradient can be maintained; the protons then flow back through ATP synthase into the less acidic stroma, driving ATP synthesis. Without a separate enclosed thylakoid space the gradient would simply dissipate.

Mitochondrial matrix vs intermembrane space (HL)

In the same way, respiration pumps protons from the matrix into the intermembrane space. The double membrane keeps these two compartments distinct so a gradient can build, and ATP synthase in the inner membrane harnesses the return flow. The matrix itself is kept at the pH and enzyme concentration that suit the Krebs-cycle enzymes.

Semi-autonomous organelles (HL)

Mitochondria and chloroplasts are described as **semi-autonomous**: each contains its own circular DNA and its own 70S ribosomes (like those of prokaryotes), and each can make some of its own proteins and divide independently of the cell. This is strong evidence for the **endosymbiotic theory** - the idea that these organelles descend from free-living prokaryotes that were engulfed by an ancestral eukaryotic cell and never digested. Their double membrane and prokaryote-sized ribosomes are further evidence.

> **HL exam note:** "Semi-autonomous" means partly, not fully, independent - the organelles still rely on the nucleus for most of their proteins. Quote the three lines of evidence: own DNA, own 70S ribosomes, and a double membrane.

7. Reading organelle abundance from cell function

A cell makes many copies of whichever organelle it uses most, so the mix of organelles visible in an electron micrograph reveals what the cell does. Reasoning in both directions - from job to organelle, and from micrograph to job - is a common exam skill.

Cell / tissue	Organelle in high numbers	Reason
Muscle fibre; liver cell	Many mitochondria	High demand for ATP for contraction / metabolism
Pancreatic / gland cell	Extensive rough ER and Golgi	Large-scale synthesis and secretion of enzymes or hormones

Cell / tissue	Organelle in high numbers	Reason
Palisade mesophyll (leaf)	Many chloroplasts	High rate of photosynthesis in the light
White blood cell (phagocyte)	Many lysosomes	Digestion of engulfed bacteria
Root hair cell	Many mitochondria	ATP for active uptake of mineral ions

To interpret a micrograph, identify the most prominent organelle, then read its function backwards to deduce the cell's role: abundant rough ER and Golgi point to a secretory cell; many mitochondria point to a cell with a high energy demand.

Worked example - magnification from a micrograph

A mitochondrion measures 40 mm long on an electron micrograph taken at a magnification of ×8000. Calculate its actual length in µm.

Actual size = image size → magnification = 40 mm → 8000 = 0.005 mm.

Converting: 0.005 mm × 1000 = **5 µm**, a realistic length for a mitochondrion.

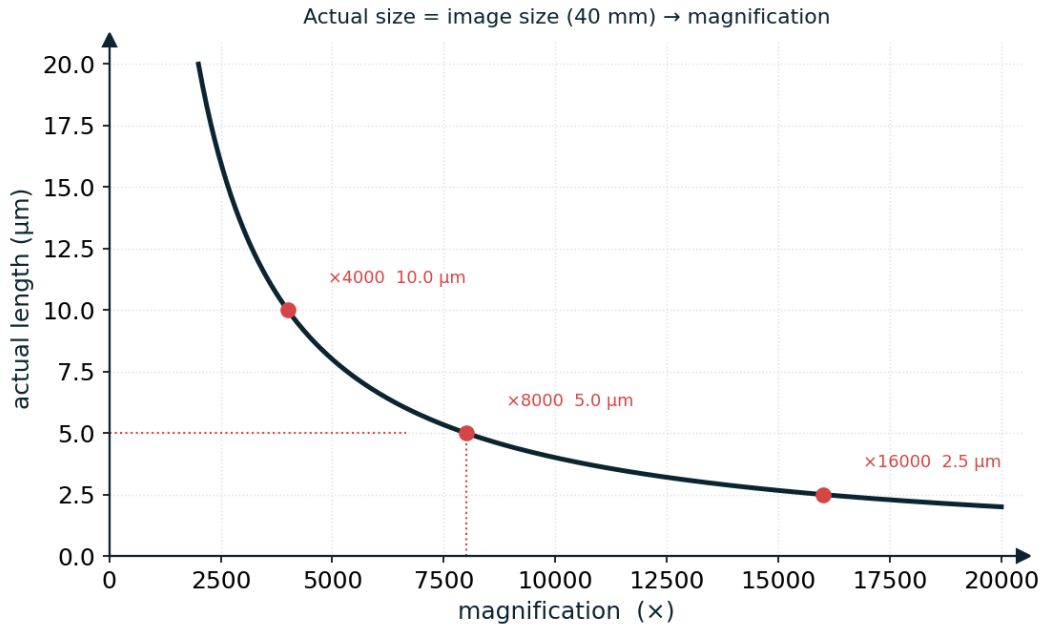

Figure 3. Actual size = image size → magnification. A 40 mm image at ×8000 gives an actual length of 5 µm; the curve follows a 1/magnification relationship.

8. Worked examples, skills and practice

Worked example 1 - identify the organelle

An organelle has a double membrane, an inner membrane folded into shelves, and a fluid centre containing enzymes and small ribosomes. Name it and give its function.

The folded inner membrane (cristae) and fluid matrix identify a **mitochondrion**. Its function is aerobic respiration - releasing energy from glucose to make ATP.

Worked example 2 - order the secretory pathway

Put these in the order a secreted protein passes through: Golgi apparatus, plasma membrane, rough ER, nucleus, secretory vesicle, transport vesicle.

Nucleus → rough ER → transport vesicle → Golgi apparatus → secretory vesicle → plasma membrane.

The two vesicle types are easy to misplace: the **transport** vesicle runs ER → Golgi; the **secretory** vesicle runs Golgi → membrane.

Worked example 3 - predict organelle abundance

A cell in a salivary gland secretes large amounts of the enzyme amylase. Which two organelles would you expect to be especially abundant, and why?

Rough ER (to synthesise and fold the enzyme) and the **Golgi apparatus** (to modify and package it for secretion). Both are needed in quantity because the cell exports protein at a high rate.

Worked example 4 - explain a compartmentalization advantage

Explain the advantage of keeping a cell's digestive enzymes inside lysosomes rather than free in the cytoplasm.

The lysosome membrane **contains the hydrolytic enzymes** so they cannot digest the cell's own organelles, and it maintains the **acidic pH** (about 4.5-5) at which these enzymes work best. This is an example of separating an incompatible process and of optimising local conditions.

Pitfalls to avoid

- **Rough ER makes and folds proteins; the Golgi modifies and packages them.** Do not swap these roles - the ER does not “package for secretion.”
- **Ribosomes are not membrane-bound.** Even the ones on the rough ER sit on the outside of the membrane; the ribosome itself has no membrane.
- **The nucleolus is not a separate organelle with a membrane.** It is a region inside the nucleus, and it makes ribosomes, not proteins.
- **Cristae and grana increase surface area** - do not describe them vaguely as “where ATP is made” without mentioning the surface area for the reactions.
- **Cell wall is not the same as plasma membrane.** The wall is a rigid external cellulose layer; the membrane is the living, selectively permeable boundary inside it.

Quick-reference table

Organelle	One-line function	Membrane?
Nucleus	Stores DNA; controls the cell	Double
Ribosome	Translation (protein synthesis)	None
Rough ER	Makes and folds proteins	Single
Smooth ER	Makes lipids; detoxifies	Single
Golgi apparatus	Modifies and packages	Single
Mitochondrion	Aerobic respiration → ATP	Double
Chloroplast	Photosynthesis	Double
Lysosome	Digestion / breakdown	Single
Vacuole	Turgor, storage (plants)	Single
Peroxisome	Breaks down H_2O_2 and fatty acids	Single

9. Test yourself

Attempt these without notes; full worked answers follow.

1. Define the term organelle and give one example of a membrane-bound and one of a non-membrane-bound organelle.

2. State three advantages of compartmentalization in eukaryotic cells.

3. Explain the advantage to a eukaryotic cell of enclosing its DNA within a nuclear envelope.

4. A protein is secreted from a cell. Place the following in the correct order and name the final process: Golgi apparatus, rough ER, plasma membrane, transport vesicle, secretory vesicle.

5. Explain why the inner membrane of a mitochondrion is folded into cristae.

6. A micrograph shows a cell packed with rough ER and Golgi bodies. Suggest the cell's function and justify your answer.

7. Distinguish between the role of the rough ER and the role of the Golgi apparatus.

8. (HL) State what is meant by a semi-autonomous organelle and give two pieces of evidence that mitochondria are semi-autonomous.

Answers

1. An organelle is a specialised subunit of a cell that performs a particular function. Membrane-bound example: mitochondrion (or nucleus, chloroplast, Golgi). Non-membrane-bound example: ribosome (or centriole).

2. Any three: incompatible processes can occur simultaneously; enzymes and substrates are concentrated so reactions are faster; local conditions such as pH can be optimised; folded membranes give a large surface area; harmful substances are contained.

3. The envelope separates transcription from translation, protecting the DNA and allowing mRNA to be modified before use, which gives finer control of gene expression.

4. Rough ER → transport vesicle → Golgi apparatus → secretory vesicle → plasma membrane; the final process is **exocytosis**.

5. Folding into cristae increases the surface area of the inner membrane, providing more space for the electron transport chain and ATP synthase, so more ATP can be made per mitochondrion.

6. It is a secretory cell (for example a gland cell making an enzyme or hormone). Abundant rough ER synthesises and folds large amounts of protein, and abundant Golgi modifies and packages it for export.

7. The rough ER synthesises and folds polypeptides and buds off transport vesicles; the Golgi apparatus receives these vesicles and modifies, sorts and packages the proteins into secretory vesicles or lysosomes.

8. (HL) A semi-autonomous organelle can carry out some activities (protein synthesis, division) independently of the nucleus but still depends on it for most of its proteins. Evidence for mitochondria: they possess their own circular DNA and their own 70S ribosomes (also a double membrane).

10. Exam strategy for B2.2

B2.2 rewards precise, structured answers. Keep these habits in mind under exam conditions.

- **Name the feature, then the consequence.** For any structure question, state the structural feature and the function it makes possible in the same sentence, joined by “so that” or “which allows.”
- **Read the command term.** “State” needs only a fact; “explain” needs a reason; “outline” needs a short sequence. Match the length of your answer to the term and the marks.
- **Use the correct vocabulary.** Write cristae, thylakoids, grana, stroma, matrix, tonoplast and cisternae by name - vague phrases such as “folds” or “bits inside” lose marks.
- **Give one clear example per point.** When listing advantages of compartmentalization, anchor each with a named organelle, such as the acidic lysosome for optimised local pH.
- **Order matters in the secretory pathway.** If you are asked to sequence organelles, write them in order with arrows and finish with exocytosis; an out-of-order list scores zero even with the right names.

> **Final check:** Before you move on, reread the question stem. If it says “plant cell” do not mention centrioles; if it says “prokaryote” do not mention mitochondria or a nucleus. Matching your answer to the cell type is an easy way to protect marks.