MEGA LECTURE

IB DP BIOLOGY

Theme A: Unity and Diversity

A2.2 Cell Structure

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

A2.2 is the foundation for the whole of Biology: almost every later topic assumes you can name a structure and state its function. Use this checklist to confirm you can do each of the following before the exam.

Understanding	You should be able to...
Cell theory	State the three principles and describe organisms that appear to break them.
Prokaryotes vs eukaryotes	Distinguish the two cell types by nucleus, DNA, organelles, ribosome size and dimensions.
Eukaryotic organelles	Give the structure and function of each membrane-bound and non-membrane organelle.
Plant vs animal cells	List the features unique to each and explain their roles.
Prokaryotic structure	Label a bacterium and give the function of each named part.
Microscopy	Compare light and electron microscopes, and separate magnification from resolution.
Magnification calculations	Apply magnification = image size / actual size with correct unit conversion.
Surface area to volume ratio	Explain why cells are small and calculate SA:V for simple shapes.
Endosymbiotic theory (HL)	Explain the prokaryotic origin of mitochondria and chloroplasts.

> **Exam note:** Most of A2.2 is common to SL and HL. Content flagged **(HL)** — the endosymbiotic origin of eukaryotic cells — is examined at Higher Level only, but every student benefits from understanding it.

1. Cell theory

The cell theory is one of the great unifying ideas of biology. It rests on three principles, all supported by centuries of microscope observation.

- **All living organisms are composed of cells.** The cell is the basic structural unit of every organism, from a single bacterium to a blue whale.
- **The cell is the smallest unit of life.** Nothing smaller than a cell can carry out all the functions of life (metabolism, response, growth, reproduction, homeostasis, nutrition, excretion).
- **Cells arise only from pre-existing cells** by division. Life does not appear spontaneously from non-living matter under present-day conditions.

Evidence and function of life

A useful test of “what counts as a cell” is whether the structure performs the functions of life. Viruses, for example, are not cells: they have no cytoplasm or metabolism of their own and can only replicate inside a host, so they fall outside the cell theory.

Atypical cells — apparent exceptions

Examiners like organisms that seem to challenge the tidy “one cell, one nucleus” picture. They do not overturn the theory, but they show that cells are more varied than a simple diagram suggests.

Atypical structure	Why it looks like an exception
Striated (skeletal) muscle fibre	A single muscle fibre is very long and contains many nuclei (it is multinucleate), formed by the fusion of many cells. It is not divided into separate uninucleate cells.
Aseptate fungal hyphae	Some fungi have hyphae without cross-walls (septa), producing a continuous cytoplasm with many nuclei shared along the thread rather than discrete cells.
Giant algae (e.g. *Acetabularia*)	A single cell can grow several centimetres long — far larger than the "cells are microscopic" expectation — yet remains one cell with one nucleus.

> **Answering exam questions:** When asked how these examples "challenge" the cell theory, say clearly what is unusual (multinucleate, no cross-walls, or unusually large) and then note that the structures are still cellular, so the theory holds.

2. Prokaryotic and eukaryotic cells

All cells share four features: a plasma membrane, cytoplasm, DNA as genetic material, and ribosomes for protein synthesis. Beyond this, cells fall into two fundamental types. The prefix helps: *karyon* means nucleus, so a **pro-karyote** is "before the nucleus" and a **eu-karyote** has a "true nucleus."

Feature	Prokaryotic cell	Eukaryotic cell
Nucleus	Absent — DNA lies free in the cytoplasm in a region called the nucleoid	Present — DNA enclosed by a double nuclear membrane (envelope)
Form of DNA	One circular chromosome, not associated with histone proteins; plus small circular plasmids	Several linear chromosomes wound around histone proteins
Membrane-bound organelles	Absent (no mitochondria, ER, Golgi, etc.)	Present (mitochondria, ER, Golgi, and others)
Ribosomes	Small: 70S	Large: 80S (70S inside mitochondria and chloroplasts)
Typical size	Small: about 1–5 µm diameter	Larger: about 10–100 µm diameter
Cell wall	Usually present, made of peptidoglycan (murein)	Present in plants (cellulose) and fungi (chitin); absent in animals
Cell division	Binary fission	Mitosis or meiosis

> **Memory aid:** "S" stands for Svedberg units, a measure of how fast a particle sediments in a centrifuge — it depends on both size and shape, which is why 70S and 80S do not simply add up. Prokaryote = 70S; eukaryote cytoplasm = 80S.

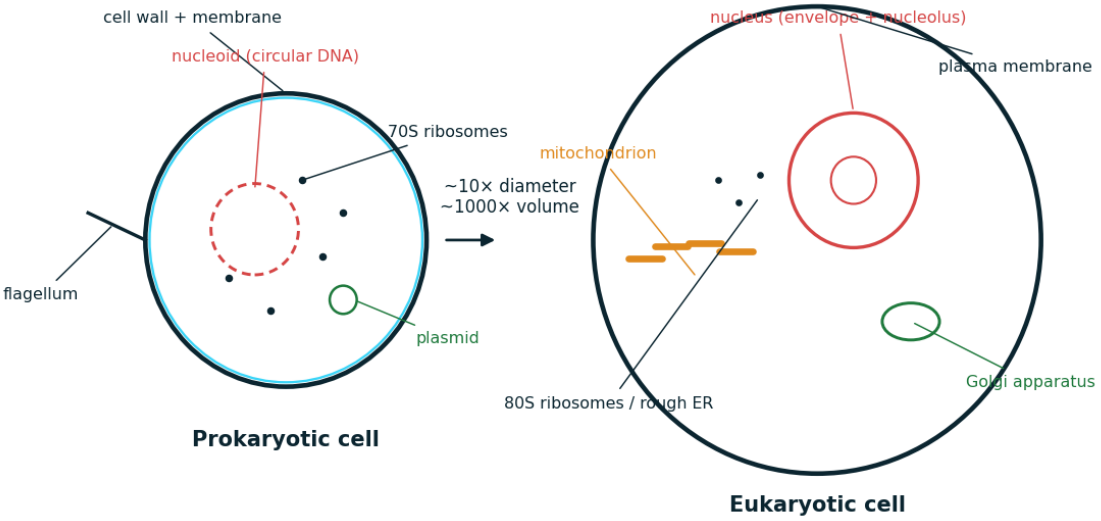

Figure 1. Prokaryotic cell (left) vs eukaryotic cell (right), drawn to relative scale (typical diameters 2 µm and 20 µm): ×10 difference in diameter, ×1000 in volume.

3. Eukaryotic organelles

An organelle is a specialised structure within a cell that performs a particular function — the cellular equivalent of an organ. Membrane-bound organelles allow incompatible reactions to be separated (compartmentalisation). Learn each structure paired with its function; questions almost always ask for both.

Organelle	Structure	Function
Nucleus	Largest organelle; bounded by a double membrane (nuclear envelope) with pores; contains chromatin (DNA + histones) and a nucleolus	Stores genetic information; controls the cell by regulating transcription; the nucleolus makes ribosomes
Rough endoplasmic reticulum (rER)	Network of flattened membrane sacs studded with ribosomes, continuous with the nuclear envelope	Synthesises and transports proteins destined for secretion or membranes
Smooth endoplasmic reticulum (sER)	Membrane tubules with no ribosomes	Synthesises lipids and steroids; stores calcium ions; detoxifies (in liver cells)
Ribosomes	Tiny structures of RNA and protein; 80S free in cytoplasm or on rER	Site of protein synthesis (translation)
Golgi apparatus	Stack of curved, flattened membrane sacs (cisternae) with vesicles at the edges	Modifies, sorts and packages proteins and lipids; forms secretory vesicles and lysosomes
Mitochondrion	Double membrane; the inner one folded into cristae, surrounding a fluid matrix; contains its own 70S ribosomes and circular DNA	Site of aerobic respiration — produces ATP; the cristae increase surface area for the reactions

Organelle	Structure	Function
Chloroplast (plant/algae)	Double membrane; internal stacks of thylakoids (grana) in a fluid stroma; own 70S ribosomes and circular DNA; contains chlorophyll	Site of photosynthesis — converts light energy to chemical energy in glucose
Vacuole	Fluid-filled sac bounded by a membrane; large and permanent (tonoplast) in plants, small and temporary in animals	In plants, stores cell sap and keeps the cell turgid; storage and transport generally
Lysosome	Small membrane-bound vesicle filled with hydrolytic (digestive) enzymes	Breaks down worn-out organelles, food particles and pathogens; recycles materials
Plasma (cell) membrane	Phospholipid bilayer with embedded proteins; about 10 nm thick	Controls what enters and leaves the cell (partially permeable); cell recognition and signalling
Cell wall (plant)	Rigid layer of cellulose fibres outside the membrane; fully permeable	Provides support and shape; prevents the cell bursting when turgid
Centrioles (animal)	Pair of cylinders made of microtubules, at right angles, near the nucleus	Organise spindle microtubules during cell division; form the base of cilia and flagella
Cytoskeleton	Network of protein filaments (microtubules, microfilaments) through the cytoplasm	Maintains shape, anchors organelles, and drives movement and intracellular transport

> **Watch out:** The rough ER makes and transports **proteins**; the smooth ER makes **lipids**. Mitochondria and chloroplasts are the only organelles with their own DNA and 70S ribosomes — a fact that becomes important in the HL endosymbiotic theory (section 8).

Compartmentalisation

The great advantage of membrane-bound organelles is **compartmentalisation**: each is a separate compartment in which conditions can be controlled independently. This lets incompatible processes occur at once (for example, lysosomes hold digestive enzymes safely away from the cytoplasm), concentrates enzymes and substrates so reactions run faster, and increases the total membrane surface area available for membrane-bound reactions. Prokaryotes, lacking these compartments, are limited to simpler metabolism.

The protein secretion pathway

A favourite synoptic question asks you to trace a protein (such as a digestive enzyme or a hormone) from gene to secretion. The organelles cooperate in a clear sequence — learn the order and the role of each stage.

Stage	Organelle	What happens
1	Nucleus	The gene is transcribed into mRNA, which leaves through a nuclear pore
2	Ribosome on rER	The mRNA is translated; the protein enters the rER as it is made

Stage	Organelle	What happens
3	Rough ER	The protein is folded and pinched off in a transport vesicle
4	Golgi apparatus	The vesicle fuses with the Golgi, which modifies (e.g. adds sugars) and packages the protein
5	Secretory vesicle	A vesicle buds off the Golgi and moves to the plasma membrane
6	Plasma membrane	The vesicle fuses with the membrane and releases the protein by exocytosis

> **Exam technique:** Mitochondria supply the ATP for this pathway (especially the movement of vesicles and exocytosis), so a secretory cell is typically rich in rER, Golgi *and* mitochondria — a detail worth mentioning for the final mark.

4. Plant and animal cells compared

Both are eukaryotic and share the nucleus, mitochondria, ER, Golgi, ribosomes and plasma membrane. The differences below are a reliable source of exam marks.

Feature	Plant cell	Animal cell
Cell wall	Present — cellulose, outside the membrane	Absent
Chloroplasts	Present in photosynthetic cells	Absent
Vacuole	One large, permanent central vacuole	Small, temporary vacuoles if any
Storage carbohydrate	Starch	Glycogen
Centrioles	Absent in most higher plants	Present
Shape	Fixed and regular (box-like), set by the wall	Rounded and variable
Plasmodesmata	Present — cytoplasmic channels linking cells	Absent

> **Exam technique:** If asked to identify a cell from a micrograph, look first for a cell wall, chloroplasts and a large central vacuole — all three point to a plant cell. Their absence, plus a rounded shape, points to an animal cell.

5. Prokaryotic cell structure

The bacterium *Escherichia coli* is the standard example. A prokaryote is small and simple, with no membrane-bound organelles, yet it carries out all the functions of life.

Structure	Description	Function
Cell wall	Rigid layer of peptidoglycan (murein) outside the membrane	Protects the cell and prevents it bursting; maintains shape
Plasma membrane	Phospholipid bilayer inside the wall	Controls entry and exit of substances; site of some respiration reactions

Structure	Description	Function
Cytoplasm	Watery gel filling the cell, containing enzymes	Site of the cell's metabolic reactions
Nucleoid	Region containing the single circular chromosome (naked DNA), not membrane-bound	Holds the main genetic information controlling the cell
Plasmid	Small circular loop of DNA separate from the chromosome	Carries extra genes (e.g. antibiotic resistance); can be transferred between bacteria
Ribosomes (70S)	Small ribosomes free in the cytoplasm	Site of protein synthesis
Flagellum	Long protein filament projecting from the surface (one or more)	Rotates to move the cell (locomotion)
Pili (fimbriae)	Short hair-like protein projections	Attachment to surfaces and to other cells; sex pili transfer DNA in conjugation

> **Common confusion:** A **flagellum** moves the cell; **pili** mainly attach it (and some transfer DNA). Do not confuse the bacterial flagellum with the eukaryotic flagellum — they have completely different internal structures.

6. Microscopy

Cells are studied with microscopes. Two properties matter, and they are not the same thing.

- **Magnification** is how many times larger the image is than the real object. It has no units.
- **Resolution** is the smallest distance between two points that can still be seen as separate. Higher resolution means finer detail.

Increasing magnification alone (“empty magnification”) just makes a blurry image bigger; only better resolution reveals more detail.

Light versus electron microscopes

Feature	Light microscope	Electron microscope
Radiation used	Visible light	Beam of electrons (much shorter wavelength)
Maximum magnification	About ×2000	Up to about ×500 000 or more
Resolution	About 200 nm	About 0.5–1 nm — far higher
Specimen	Living or dead; can show natural colour	Dead only; in a vacuum, often coated/stained
Image	Coloured, 2-D	Black and white (false colour added); TEM 2-D, SEM 3-D

There are two kinds of electron microscope. The **transmission** electron microscope (TEM) passes electrons through a very thin section to show internal detail in two dimensions at the highest resolution. The **scanning** electron microscope (SEM) reflects electrons off a surface to give a three-dimensional view at somewhat lower resolution.

The magnification equation

Magnification = image size / actual size

Rearranged, this gives the two other forms you will need:

actual size = image size / magnification image size = actual size × magnification

Image size is what you measure on the drawing or micrograph (usually with a ruler, in mm). *Actual size* is the true size of the specimen. Both must be in the **same unit** before you divide, so unit conversion is where most marks are lost.

Convert	Multiply by	Example
millimetre (mm) → micrometre (µm)	× 1000	1.5 mm = 1500 µm
micrometre (µm) → nanometre (nm)	× 1000	2 µm = 2000 nm
millimetre (mm) → nanometre (nm)	× 1 000 000	0.02 mm = 20 000 nm
µm → mm	/ 1000	500 µm = 0.5 mm

Scale bars

Instead of stating magnification, many micrographs carry a **scale bar** — a short line labelled with the real length it represents (for example “10 µm”). To use it: measure the bar on the page, then the specimen; the ratio gives you what you need. Magnification of the image = measured length of bar / real length of bar (in the same units).

Worked example 1 — magnification from measured sizes

A drawing of a cell is 60 mm wide. The real cell is 30 µm wide. Find the magnification.

Step 1 — convert to the same unit: 60 mm = 60 × 1000 = 60 000 µm.

Step 2 — apply the equation: magnification = image / actual = 60 000 / 30 = ×**2000**.

Magnification has no units — write it as “×2000”, not “2000 µm”.

Worked example 2 — actual size from a scale bar

On a micrograph, a scale bar labelled 10 µm measures 25 mm. A mitochondrion in the same image is 5 mm long. Find (a) the magnification, (b) the real length of the mitochondrion.

(a) Convert the bar to one unit: 10 µm = 0.010 mm. Magnification = length on page / real length = 25 / 0.010 = ×**2500**.

(b) actual size = image size / magnification = 5 mm / 2500 = 0.002 mm = **2 µm** (2000 nm).

Check: a mitochondrion is typically 1–5 µm long, so the answer is sensible.

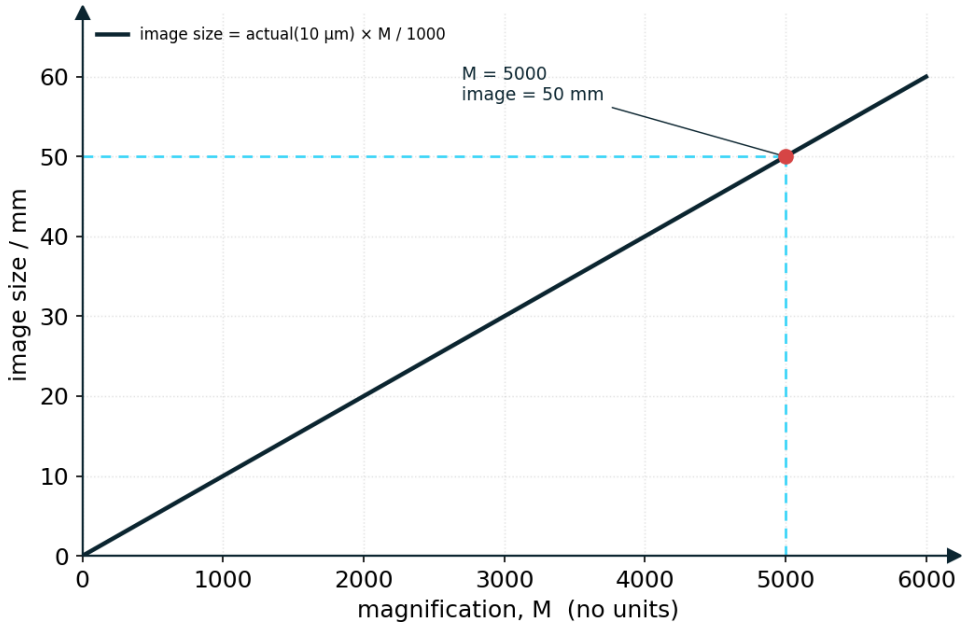

Figure 2. Magnification = image size / actual size, plotted for actual size = 10 µm. The worked point M = 5000 gives image size = 50 mm, matching Worked example 2.

7. Surface area to volume ratio

Every cell must exchange materials with its surroundings — taking in oxygen and nutrients, removing carbon dioxide and waste, and losing heat. These exchanges happen across the plasma **membrane (the surface area)**, while the demand for them depends on the **volume** of living cytoplasm. The balance between the two is the surface-area-to-volume ratio (SA:V).

Why cells stay small

As an object grows, its volume increases faster than its surface area (volume grows with the cube of length, surface area only with the square). So a larger cell has a **smaller** SA:V. Beyond a certain size the membrane can no longer supply the interior fast enough, and the centre would be starved of oxygen or choked with waste. Keeping cells small keeps SA:V high, so exchange keeps pace with demand.

For a cube of side L, surface area = $6L^2$ and volume = L^3, so the ratio $6L^2 / L^3 = 6/L$ — it clearly falls as L rises.

Cube side L	Surface area ($6L^2$)	Volume (L^3)	SA : V ratio
1 unit	6	1	6 : 1
2 units	24	8	3 : 1
4 units	96	64	1.5 : 1

The table shows the ratio halving each time the side doubles — the mathematical reason cells are microscopic, and why larger organisms are made of many small cells rather than a few large ones. Structures that need rapid exchange (root hair cells, the villi of the small intestine, alveoli) are also folded or elongated to raise their surface area.

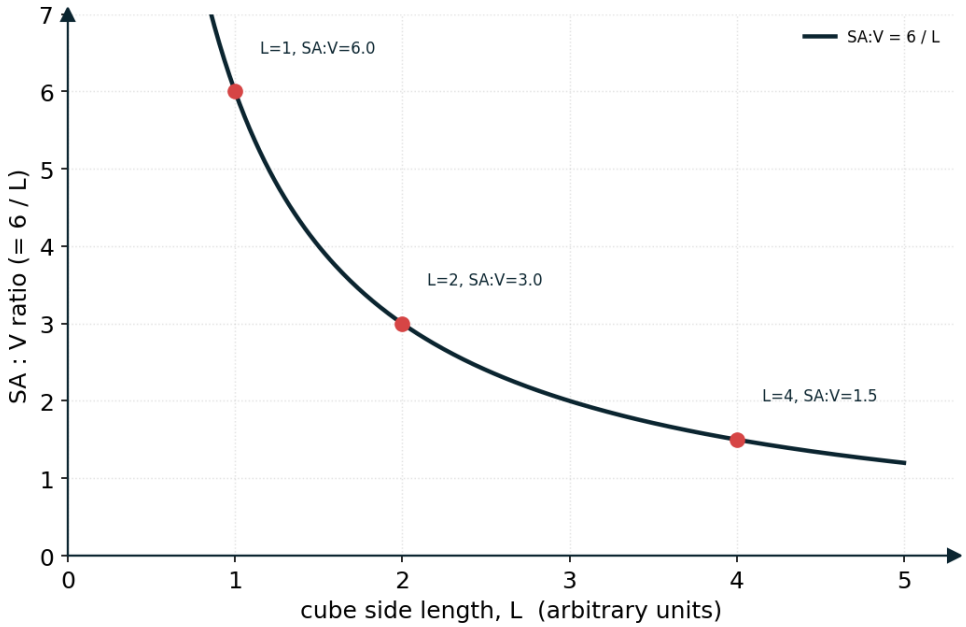

Figure 3. SA:V = 6/L for a cube of side L; the ratio falls as L rises, matching the values in the table above (L=1→6:1, L=2→3:1, L=4→1.5:1).

Worked example 3 — calculating SA:V

Compare the SA:V ratios of a cubic cell of side 10 µm and one of side 20 µm.

Small cell: SA = 6 × 10^2 = 600 µm^2; V = 10^3 = 1000 µm^3; SA:V = 600/1000 = **0.6**.

Large cell: SA = 6 × 20^2 = 2400 µm^2; V = 20^3 = 8000 µm^3; SA:V = 2400/8000 = **0.3**.

Doubling the side halves the ratio, so the smaller cell exchanges materials far more efficiently per unit of cytoplasm.

8. Origin of eukaryotic cells (HL)

(HL) How did the complex eukaryotic cell arise from simpler prokaryotes? The widely accepted answer is the **endosymbiotic theory**. Symbiosis means two organisms living together; *endo* means inside — so this is the idea that some organelles were once free-living prokaryotes that came to live inside a larger host cell.

According to the theory, an early host cell engulfed an aerobic bacterium that was not digested but survived inside it. The bacterium supplied energy (ATP) through respiration; the host supplied shelter and nutrients. Over generations this became the **mitochondrion**. Later, engulfing a photosynthetic (cyanobacterium-like) prokaryote in the same way gave rise to the **chloroplast**.

Evidence from mitochondria and chloroplasts

Both organelles still carry hallmarks of their bacterial ancestry:

- They contain their **own circular DNA**, like a prokaryotic chromosome and unlike the linear DNA of the nucleus.
- They have their own **70S ribosomes** — the prokaryotic size, not the 80S of the eukaryotic cytoplasm.

- They are surrounded by a **double membrane**: the inner one is the original prokaryote's membrane, the outer one from the host's engulfing vesicle.
- They **replicate by binary fission**, independently of the cell, exactly as bacteria divide.
- They are similar in **size** to modern bacteria.

> **Differences that remain:** Mitochondria and chloroplasts are no longer free-living: many of their original genes have moved to the nucleus, so they cannot survive outside the cell and depend on the host to make most of their proteins. This is why the relationship is now obligate.

9. Worked examples and exam practice

The examples below combine the skills of the topic. Cover the answers and try each yourself first.

Worked example 4 — image size from magnification

A chloroplast is 4 µm long and is viewed at ×3000. How long will it appear on the image, in mm?

image size = actual size × magnification = 4 µm × 3000 = 12 000 µm.

Convert to mm: 12 000 / 1000 = **12 mm**.

Worked example 5 — identify the cell type

A cell viewed under an electron microscope is 2 µm across, has no nucleus, a single circular DNA loop, 70S ribosomes and a wall containing peptidoglycan. What type of cell is it?

No nucleus, circular naked DNA, 70S ribosomes and a peptidoglycan wall are all prokaryotic features, and the size fits (1–5 µm). It is a **prokaryotic cell (a bacterium)**.

If instead it had a nucleus, 80S ribosomes and mitochondria, it would be eukaryotic; a cellulose wall and chloroplasts would make it a plant cell.

Worked example 6 — SA:V and exchange

Explain, using SA:V, why a large single-celled organism such as an amoeba relies on diffusion but a mammal needs a specialised gas-exchange system.

An amoeba is small, so its SA:V is high and diffusion across the membrane meets its needs. A mammal is large, so its overall SA:V is low; diffusion alone cannot supply the interior. It therefore needs lungs (huge folded surface area) and a circulatory system to transport materials, restoring an effective high surface area for exchange.

Common pitfalls

- **Magnification units.** Magnification is a ratio and has no units. Never write “×500 µm”. Also convert image and actual size to the same unit *before* dividing.
- **70S versus 80S.** Prokaryotes and the organelles of endosymbiotic origin have 70S ribosomes; the eukaryotic cytoplasm has 80S. Getting these the wrong way round loses easy marks.

- **Resolution is not magnification.** A microscope can magnify greatly yet resolve poorly. Detail depends on resolution, set by the wavelength used.
- **Structure and function together.** Marks are usually split, so always pair the two: e.g. cristae (structure) increase surface area for respiration (function).
- **Plant vs animal.** A cell wall is not proof of a plant cell — fungi and bacteria also have walls, but of different materials.

Quick reference

Item	Key fact
Cell theory	Cells make up all organisms; the cell is the smallest unit of life; cells come from pre-existing cells
Prokaryote	No nucleus; circular DNA in nucleoid + plasmids; 70S ribosomes; 1–5 µm; wall of peptidoglycan
Eukaryote	True nucleus; linear DNA with histones; membrane-bound organelles; 80S ribosomes; 10–100 µm
Magnification	image size / actual size (no units); convert to one unit first
Unit ladder	1 mm = 1000 µm = 1 000 000 nm
Light vs electron	Electron microscope: far higher resolution (~0.5 nm) and magnification; specimens dead
SA : V	For a cube = 6/*L*; falls as size rises — the reason cells are small
Endosymbiosis (HL)	Mitochondria and chloroplasts from engulfed prokaryotes: own circular DNA, 70S ribosomes, double membrane, binary fission

Test yourself

Attempt all eight without notes, then check against the worked answers below.

1. State the three principles of the cell theory.

2. Explain how striated muscle fibres appear to challenge the cell theory.

3. Give three structural differences between a prokaryotic and a eukaryotic cell.

4. A cell drawing is 45 mm wide; the real cell is 15 µm wide. Calculate the magnification.

5. A scale bar labelled 20 µm measures 40 mm on a micrograph. A nucleus in the same image is 30 mm across. Find the magnification and the real diameter of the nucleus.

6. Calculate the SA:V ratio of a cubic cell of side 5 µm, and state what happens to this ratio as the cell grows.

7. Distinguish between magnification and resolution.

8. (HL) Give three pieces of evidence that mitochondria evolved from free-living prokaryotes.

Answers

1. All living organisms are made of cells; the cell is the smallest unit of life; new cells arise only from pre-existing cells by division.

2. A single striated muscle fibre is very long and contains many nuclei (multinucleate), formed by cell fusion, so it is not divided into separate uninucleate cells. It is still cellular, so the theory is not overturned.

3. Any three: prokaryotes have no nucleus (DNA in a nucleoid) whereas eukaryotes have a membrane-bound nucleus; prokaryotic DNA is circular and naked while eukaryotic DNA is linear with histones; prokaryotes lack membrane-bound organelles; prokaryotes have 70S ribosomes versus 80S; prokaryotes are smaller (1–5 µm).

4. Convert: 45 mm = 45 000 µm. Magnification = 45 000 / 15 = ×**3000**.

5. Magnification = length on page / real length = 40 mm / 0.020 mm = ×**2000**. Real diameter = image / magnification = 30 mm / 2000 = 0.015 mm = **15 µm**.

6. SA = 6 × 5^2 = 150 μm^2; V = 5^3 = 125 μm^3; SA:V = 150/125 = **1.2 : 1**. As the cell grows the ratio decreases (volume rises faster than surface area), so exchange becomes less efficient.

7. Magnification is how many times larger the image is than the object (no units); resolution is the smallest distance between two points still seen as separate (finer detail). High magnification without high resolution just gives a bigger blurred image.

8. (HL) Any three: they contain their own circular DNA; they have 70S (prokaryote-sized) ribosomes; they are enclosed by a double membrane; they divide by binary fission independently of the cell; they are similar in size to bacteria.