Cell structure

International Baccalaureate · IB Diploma · Biology · SL

Scope and prerequisites

A photograph can make a bacterium look as large as a leaf cell. To compare them, we need a scale; to explain how they live, we need their internal organization.

This unit covers A2.2: cell theory, microscopy and measurements, common cell features, prokaryotic and eukaryotic structure, unicellular life, plant/animal/fungal comparisons, atypical cells, and interpreting and drawing micrographs. SL understandings. Prerequisites: water, DNA/RNA, membranes and basic unit conversions. Numerical examples are original, invented teaching data. Diagrams are models, not micrographs.

Cells as units of life

Cell theory connects three ideas: organisms consist of one or more cells; cells are the basic structural and functional units of organisms; present-day cells arise from pre-existing cells. An organism's activities depend on the coordinated activities of its cells. A single-celled organism must carry out the essential processes within one cell; a multicellular organism distributes work among cells.

A theory can generate a prediction by deduction. If a newly discovered organism is living and cell theory applies, we predict that examination at sufficient resolution will reveal one or more cells. This prediction guides observations; it is not a substitute for examining the organism. Viruses depend on host cellular machinery and are not cells. Exceptions to a typical cell diagram need explanation rather than being hidden.

Typical cells share DNA carrying heritable information, an aqueous cytoplasm in which reactions occur, ribosomes for protein synthesis, and a lipid-based plasma membrane. The membrane separates internal conditions from the surroundings while allowing regulated exchange. These are functional connections: a boundary without exchange could not supply continuing metabolism. Specialized mature cells can lose structures during development, as the red-blood-cell example below shows.

Microscopy: prepare, focus and measure

For a temporary mount, place a thin piece of suitable tissue in a drop of water on a slide. Lower a coverslip at an angle to reduce trapped air. A thick folded specimen hides structures in overlapping layers. Use approved preparations and stains, protect eyes and skin, and handle glass carefully. A stain can increase contrast between structures; it does not make every coloured object a nucleus. Staining or preparation may kill cells or alter their appearance.

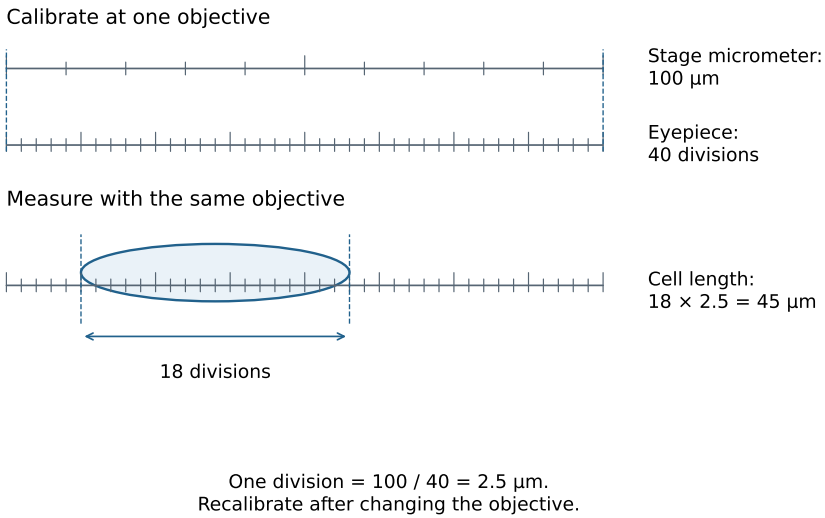
Start with the lowest-power objective and centre the specimen. Use coarse focus to find the image at low power, then fine focus for detail. On changing to high power, use fine focus and avoid driving the objective into the slide. Adjust illumination rather than accepting a bright but washed-out image. Total optical magnification is eyepiece magnification multiplied by objective magnification: a 10× eyepiece and 40× objective give 400×.

magnification is image length divided by actual length. **resolution** is the ability to distinguish close points as separate. Enlarging a blurred photograph increases magnification without recovering detail that was never resolved. Conventional light microscopy resolves details down to roughly $0.2\,\mu$m under favourable conditions; preparation, optics and contrast affect the result. A bacterial outline can be visible while its ribosomes remain unresolved.

> ■ **Worked example: use one unit throughout**
>
> An image is 30 mm long and represents a cell 50 micrometres long. Since $1\,\text{mm} = 1000\,\mu\text{m}$,
>
> $$M = \frac{I}{A} = \frac{30 \times 1000}{50} = 600.$$
>
> The ratio has no unit. A separate photograph with a 10 mm bar representing 20 micrometres has $M = 500$. A cell measuring 25 mm on that photograph is therefore $25\,000/500 = 50\,\mu$m long. Do not transfer the first photograph's magnification to the second.

■ Calibrate an eyepiece graticule

An eyepiece graticule has arbitrary divisions, not fixed micrometres. Superimpose it on a stage micrometer with a known scale. At one objective, suppose 40 graticule divisions align with 100 micrometres. Then one division represents $100/40 = 2.5\,\mu$m. A cell spanning 18 divisions is $45\,\mu$m long. At a different objective, recalibrate: the same graticule division covers a different actual distance.



Calibration belongs to the objective setting. The divisions become distances only after comparison with a known scale.

To add a scale bar, convert a chosen actual distance using the calibrated image scale. At 500×, a 20 μm bar must be 10 mm long on the printed image. If the image and its bar are resized together, their ratio stays valid. A printed "500×" label becomes wrong after resizing; a correctly attached scale bar remains usable. Take photographs with the objective and calibration recorded, keep the original, and resize the bar with the image.

What better microscopes reveal

Electron microscopes use electrons and can resolve much smaller structures than conventional light microscopes. Transmission electron microscopy (TEM) reveals internal details in thin sections; scanning electron microscopy (SEM) mainly reveals surface form. A section is a two-dimensional cut through a three-dimensional object. The same mitochondrion can look long or round depending on the cutting plane.

Conventional electron-microscope preparation involves conditions unsuitable for living cells. The resulting image is evidence about prepared material, not a film of an undisturbed living cell. Colour in an electron micrograph is usually added later; it is not the specimen's natural visible colour.

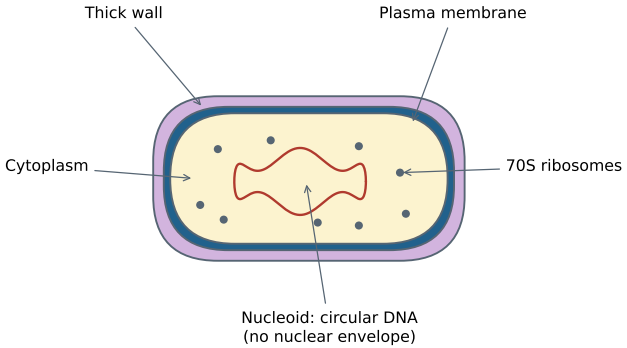
Technique	What it adds	Limit when interpreting evidence
Fluorescence light microscopy	Fluorophores emit light after excitation, highlighting selected components	Signals depend on labelling, background and resolution; colour alone does not identify an unlabelled structure
Immunofluorescence	An antibody binds a target antigen; a fluorescent label locates the binding	Specificity needs controls; failure to label does not automatically prove absence
Freeze fracture	Frozen material is fractured, often splitting membranes; replicas reveal membrane organization	Fracture faces are not simply the outside surfaces of intact living cells
Cryogenic electron microscopy	Rapid freezing can preserve hydrated structures without conventional chemical fixation and heavy-metal staining	It still examines frozen material; processing and reconstruction need evaluation

Choose a method for a question. Following a living cell's movement favours light microscopy. Resolving internal membrane folds favours TEM. Localizing one protein favours a validated fluorescent label. More magnification alone cannot solve every problem.

A prokaryotic cell: a Gram-positive model

Use a typical Gram-positive bacterium, such as *Bacillus*, as the model. Its cell wall contains peptidoglycan and lies outside the plasma membrane. The wall supports the cell and helps resist osmotic bursting; the membrane controls exchange. Gram-positive bacteria have a relatively thick peptidoglycan wall, without the additional outer membrane characteristic of Gram-negative bacteria.

The cytoplasm contains 70S ribosomes that synthesize proteins. The main chromosome is represented as a circular DNA molecule in a nucleoid region, with no surrounding nuclear envelope. "Naked DNA" here distinguishes the bacterial model from DNA packaged on eukaryotic histones; it does not mean that no proteins ever associate with bacterial DNA. Some bacteria also contain plasmids. Plasmids, flagella and capsules are not compulsory features of every bacterium.



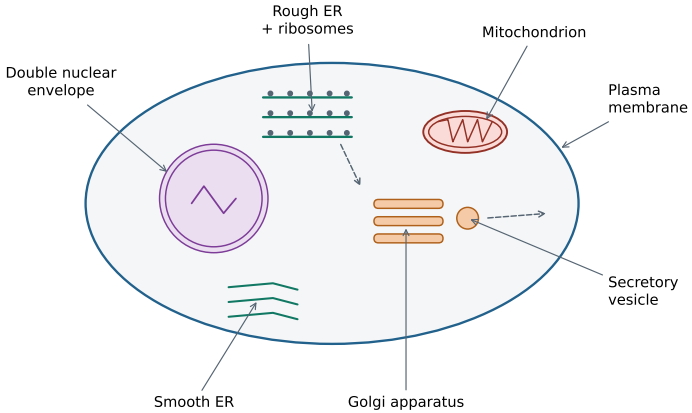
Gram-positive model; schematic, not to scale.
Accessory structures are omitted.

Identify the wall and membrane separately. The nucleoid is a region, not a membrane-bound nucleus.

Prokaryotic cells do not contain the membrane-bound organelles characteristic of eukaryotic cytoplasm. This does not mean that they lack internal organization or cannot respire. Bacterial species vary; the model is not a claim that every prokaryote has the same wall, shape or accessory structures. Never identify a bacterium solely because a blurred image shows no nucleus.

Eukaryotic compartments and their functions

A typical eukaryotic cell has a nucleus bounded by a double nuclear envelope containing pores. Chromosomes contain DNA associated with histone proteins. Pores allow regulated traffic between nucleus and cytoplasm. The cytoplasm outside the nucleus contains 80S ribosomes and membrane-bound compartments. Ribosomes themselves have no enclosing membrane.



Animal-cell model, not to scale.
Dashed arrows trace part of a secretion route.

Trace a secreted protein from a ribosome on rough ER, through vesicles and the Golgi apparatus, to the plasma membrane.

Structure	**Recognition clue in a suitable image**	**Function to annotate**
Nucleus	Large compartment, double envelope; dense chromatin or chromosomes may be visible	Stores DNA and is a site of transcription
Mitochondrion	Double envelope and inner-membrane folds called cristae	Aerobic respiration and ATP production
Rough endoplasmic reticulum (ER)	Membrane sacs with attached ribosomes	Synthesis and processing of proteins entering the secretory pathway
Smooth ER	Tubular membranes without attached ribosomes	Lipid synthesis; other roles depend on cell type
Golgi apparatus	Stack of flattened sacs with associated vesicles	Modifies, sorts and packages cell products
Secretory vesicle	Small membrane-bound compartment	Carries material towards secretion by exocytosis
Lysosome	Membrane-bound compartment; identification needs context	Intracellular digestion using enzymes

Structure	Recognition clue in a suitable image	Function to annotate
Chloroplast	Double envelope and internal thylakoid membranes, often stacked	Photosynthesis
Sap vacuole	Large fluid-filled compartment bounded by the tonoplast	Storage and maintenance of turgor

The mitochondrial matrix is the region inside the inner membrane; it contains enzymes for some respiration reactions. In a chloroplast, the stroma surrounds the thylakoid membranes. Condensed chromosomes can appear as dense rods during division; their function is to carry DNA into daughter cells. Ribosomes appear as much smaller dense particles in suitable electron micrographs, beyond ordinary light-microscope resolution.

The cytoskeleton includes microtubules and microfilaments. It helps maintain organization and shape, moves materials and participates in cell division. A microvillus is an extension of the cell surface supported by microfilaments, increasing surface area for exchange. It is not a cilium. Cilia and eukaryotic flagella have microtubule-based internal structures and commonly move the cell or surrounding fluid.

A lysosome cannot always be identified confidently from a single round dark profile. Use several structural clues and the preparation context. A drawing's neat colours and labels may make identification much easier than it is in a real micrograph.

One cell can carry out the processes of life

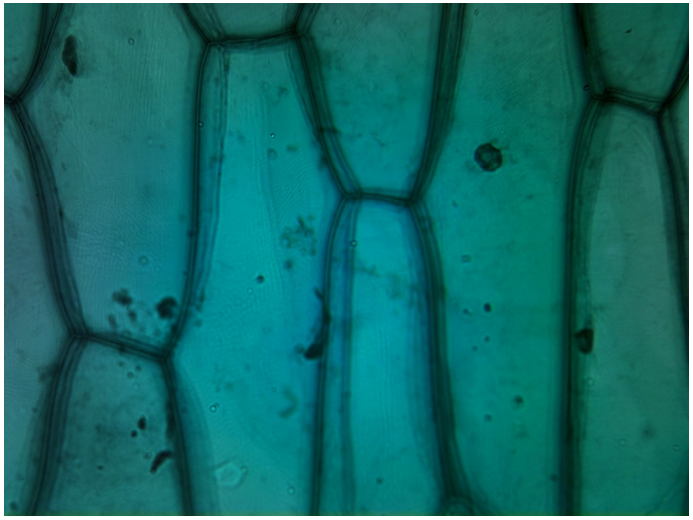
A freshwater *Paramecium* provides a connected example. Cilia move the cell and help bring food towards an oral region. Food enters food vacuoles, where digestion supplies nutrients. Enzyme-controlled metabolism uses these materials and releases energy. Waste products such as carbon dioxide leave across the cell surface; removal of metabolic waste is excretion, different from loss of undigested food.

Water tends to enter from the dilute surroundings. Contractile vacuoles collect and expel excess water, helping maintain internal conditions: an example of homeostasis. The organism responds to stimuli, grows by making cellular material, and reproduces by cell division. These functions happen in one cell; a contractile vacuole is not a miniature kidney and a food vacuole is not a multicellular stomach.

Compare animals, plants and fungi

Feature	Typical animal cell	Typical plant cell	Typical fungal cell
Plasma membrane	Present	Present inside the wall	Present inside the wall
Cell wall	Absent	Mainly cellulose	Chitin and other polysaccharides
Vacuoles	Usually smaller compartments; no single large sap vacuole	Often a large central sap vacuole	Vacuoles involved in storage and regulation
Chloroplasts/plastids	Absent	Chloroplasts in photosynthetic cells; other plastids also occur	No chloroplasts
Centrioles	Common in many animal cells	Absent from most higher-plant cells	Vary among fungal groups; not universal
Cilia/flagella	Present in some cell types, such as ciliated epithelia or sperm	Absent from most vegetative cells; some plant gametes are motile	Present in some groups or stages, absent from many familiar fungi

A plant root cell can lack chloroplasts and still be a plant cell. Onion bulb epidermis is useful for observing cell boundaries and nuclei, but is a poor choice for demonstrating chloroplasts. A fungal wall does not make a fungus a plant; wall composition and nutrition differ. Presence/absence statements should name the cell type rather than treating one textbook sketch as universal.



Observe the repeated cell outlines and darker nuclei. This photograph has no calibrated scale bar: do not calculate cell size from the online display width.

Atypical cells refine a model

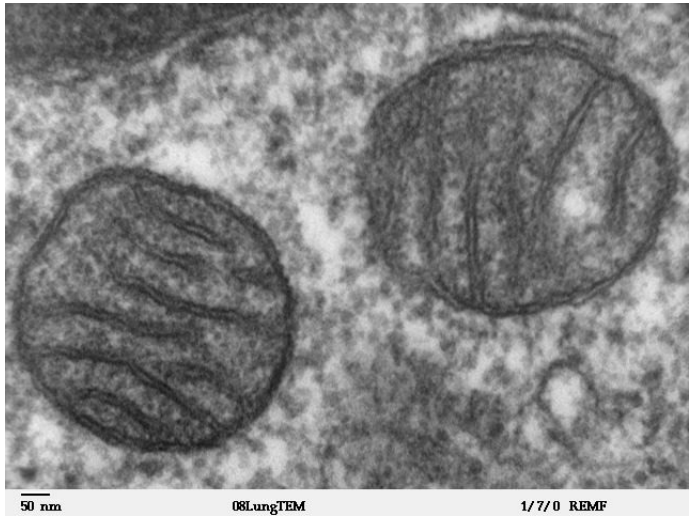
An aseptate fungal hypha is a long tube with many nuclei sharing cytoplasm, without cross walls dividing it into the usual sequence of separate compartments. A skeletal muscle fibre is also multinucleate: it forms through fusion of precursor cells. Neither is well represented by a tiny "one nucleus, one round cell" sketch.

A mature mammalian red blood cell has no nucleus and lacks mitochondria. Losing organelles leaves space for haemoglobin and supports its specialized transport role, but limits repair and prevents normal cell division. This is a mature mammalian example, not a statement that all vertebrate red blood cells lack nuclei.

A mature phloem sieve tube element also lacks a nucleus and loses many organelles. It remains living and depends on associated companion cells for support. It is not an empty dead tube like a mature xylem vessel element. These examples show why "every living cell now contains a nucleus and every organelle" is a poor rule.

Read micrographs and draw what is there

First identify the image method and scale, then examine boundaries, compartments and internal membranes. Plant identification is stronger when a wall, large vacuole and/or plastids agree. A nucleus with membrane-bound organelles supports a eukaryotic identification. A nucleoid and bacterial envelope support a prokaryotic identification. Shape alone is insufficient, and a missing feature may simply lie outside the section or below the instrument's resolution.



Follow the organelle boundaries and internal cristae. The scale bar, rather than the displayed pixel width, supports length estimates.

Make a large, clear line drawing with continuous outlines and no decorative shading. Preserve relative sizes and draw the structures actually visible, not every organelle recalled from a model. Use straight ruled label lines that end on the intended structure and do not cross. A drawing of a mitochondrion should show the outer boundary, inner membrane/folds and internal region when visible. A chloroplast drawing should distinguish its envelope, internal stacks and surrounding stroma; a nucleus should show envelope, pores or chromatin only where supported by the image.

Annotations add functions to labels: "cristae: increase inner-membrane area for ATP-producing processes" explains more than "cristae" alone. Label a cell wall outside the plasma membrane, a vacuole inside its tonoplast, and microvilli as projections of the surface. Give an accurate scale bar or magnification calculated for your drawing. Record image source and distinguish direct observations from functional interpretations.

Practice

All numerical data below are invented. Show conversions and state the evidence needed for identifications.

1. State three central ideas of cell theory. Use the theory to predict a property of a newly discovered organism, and explain why the prediction still needs observation.
2. Describe how to make a temporary mount, find a specimen at low power and change safely to high power. Explain what a stain changes and why an air bubble can mislead.
3. A cell image is 12 mm long and the actual cell is 40 micrometres long. Calculate magnification. Repeat for a 15 mm image of a 20 micrometre cell.

4. In another photograph a 10 mm bar represents 20 micrometres. A cell is 24 mm long on the same print. Calculate actual cell length. The whole photograph is enlarged twofold: state the new image length, bar length and actual cell length.
5. At one objective, 50 graticule divisions correspond to 125 micrometres. A cell spans 22 divisions. Find its length. At a second objective, 50 divisions correspond to 50 micrometres; the same cell spans 55 divisions. Explain whether the measurements agree.
6. Distinguish magnification from resolution. Select a method for observing a living cell's movement, internal mitochondrial membranes and the location of a particular protein. Give a limitation for the last method.
7. Describe five structures in the Gram-positive bacterial model and link each to its function. Explain why "no nucleus" does not mean "no DNA" or "no protein synthesis".
8. Trace a protein destined for secretion through a eukaryotic cell. Distinguish the roles of ribosomes, rough ER, Golgi apparatus, vesicles and plasma membrane. Name two cytoskeletal components.
9. Link four processes of life to structures or activities in *Paramecium*. Distinguish excretion from removal of undigested food.
10. An image shows a wall, a large vacuole and a nucleus but no chloroplast. Explain why this does not rule out a plant cell. Compare plant and fungal walls, and explain two atypical examples that challenge a one-nucleus-per-cell sketch.
11. Explain how to identify and draw a mitochondrion from a suitable TEM image. Give two functional annotations and explain why drawing every memorized organelle would weaken the observation record.

■ Worked answers

1. Organisms consist of one or more cells; cells are their basic structural/functional units; present-day cells come from existing cells. Predict that the organism has at least one cell. Examine it at suitable resolution: deduction generates a testable expectation, not an observation.
2. Put thin tissue in water on a slide and lower the coverslip at an angle. Start with low power, centre and focus, then use fine focus at high power without driving the lens into the slide. Stain increases contrast and can alter or kill the sample. A bubble can imitate a circular boundary but is not a cell.
3. $M = 12\,000/40 = 300$; $M = 15\,000/20 = 750$. Both are dimensionless ratios, with image and actual lengths in micrometres.
4. $M = 10\,000/20 = 500$; actual length $= 24\,000/500 = 48\,\mu$m. After enlargement, cell image = 48 mm and bar = 20 mm. Actual cell length remains $48\,\mu$m; the magnification becomes 1000.
5. First calibration $= 125/50 = 2.5\,\mu$m per division, so length $= 22(2.5) = 55\,\mu$m. Second calibration $= 50/50 = 1\,\mu$m per division, giving $55\,\mu$m. The readings agree after using the correct calibration.
6. Magnification enlarges an image; resolution separates close details. Use light microscopy for movement, TEM for internal membranes, and validated fluorescence/immunofluorescence for a protein. Antibody non-specificity or background can mislead; include controls. A larger blurry image need not reveal more detail.
7. Wall: support/resistance to osmotic bursting; membrane: regulated exchange; cytoplasm: reaction medium; circular chromosomal DNA in a nucleoid: heritable information; 70S ribosomes: protein synthesis. The nucleoid has no nuclear envelope, but DNA and ribosomes are present.
8. A ribosome on rough ER synthesizes the protein into the secretory pathway; ER processes it; transport vesicles carry it to the Golgi for modification/sorting; secretory vesicles fuse with the plasma membrane to release it. Microtubules and microfilaments contribute to organization and movement. Ribosomes are not membrane-bound organelles.
9. Any four connected examples: cilia produce movement; food uptake/digestion supplies nutrition; enzyme-controlled reactions provide metabolism; contractile vacuoles support water balance/homeostasis; growth adds cellular material; cell division reproduces; altered activity responds to stimuli. Excretion removes metabolic waste, such as carbon dioxide; undigested food was not produced as a metabolic waste.
10. Non-photosynthetic plant cells can lack chloroplasts; the combined features fit a plant cell, though identification needs context. Plant walls contain cellulose; fungal walls contain chitin. Aseptate fungal hyphae and skeletal muscle fibres have many nuclei in shared cytoplasm. Mature mammalian red cells and sieve tube elements instead lack nuclei; sieve elements depend on companion cells.
11. Look for a double envelope and folded inner membrane in a suitable thin section. Draw the observed outlines and folds in proportion, add straight non-crossing labels and a scale. Annotate cristae as increasing inner-membrane area for ATP-producing processes, and the matrix as containing enzymes for some respiration reactions. Invented extra organelles would mix recall with observation.

Exam tips

Use matching length units; distinguish magnification from resolution and recalibrate after changing objective. Identify cells from several features, allowing for sectioning and resolution limits. Draw observed structures with a scale, source and clear labels; annotate functions separately. Qualify typical-cell models: not every plant cell has chloroplasts, and specialized mature cells can lose nuclei or organelles.

References: IB Biology guide, A2.2; image credits recorded with figures.