Cell structure

A2.2 · SL and AHL

An image needs a scale and an explanation

How can a bacterium look as large as a leaf cell?

Displayed size depends on magnification. Compare actual sizes using a calibrated image or scale bar.

Cell structure links internal organization to life processes. Microscopy supplies observations; models help explain them.

This unit covers A2.2. Numerical examples are invented; diagrams are models and photographs are attributed.

Cell theory generates a testable prediction

A theory connects organisms, units and division

Organisms consist of cells; cells are their basic structural and functional units; present-day cells arise from existing cells.

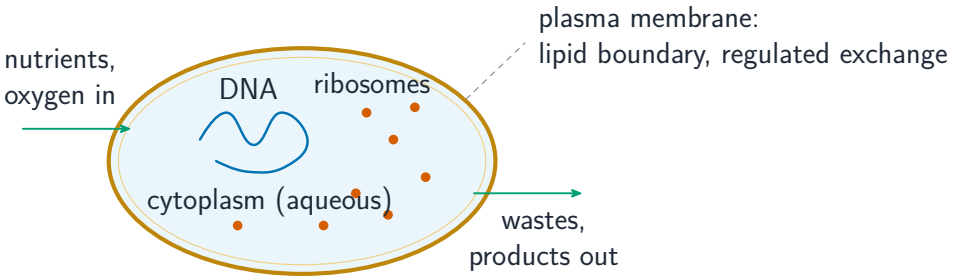
For a newly discovered organism, predict one or more cells. Then examine it at sufficient resolution.

A deduction guides observation; it does not replace it. Viruses depend on host cells and are not cellular organisms.

Shared structures solve shared problems

Feature	Functional connection
DNA	Carries heritable information
Aqueous cytoplasm	Medium for cellular reactions
Ribosomes	Synthesize proteins
Plasma membrane	Separates conditions while allowing regulated exchange

What every cell has



Nutrients and oxygen in, wastes out

Make a temporary mount that reveals one layer

Preparation changes what can be observed

Place thin tissue in a drop of water. Lower a coverslip at an angle to reduce bubbles; folded tissue creates overlapping images.

Approved stains improve contrast. A dark object is not automatically a nucleus; stains can alter or kill cells.

Handle slides and stains safely. Record preparation, objective and calibration with a photograph.

Focus safely before increasing power

Start low, centre, then use fine focus

Use the low-power objective to find and centre the specimen. Coarse focus is appropriate at low power.

After changing to high power, use fine focus and avoid driving the objective into the slide. Adjust illumination for contrast.

A $10\times$ eyepiece and $40\times$ objective give $400\times$ optical magnification. A larger display does not automatically resolve more detail.

Calculate magnification with matching units

1. **Invented image.** 30 mm represents a $50\,\mu\mathrm{m}$ cell.
2. **Convert.** $I = 30 \times 1000 = 30\,000\,\mu\mathrm{m}$.
3. **Ratio.** $M = I/A = 30\,000/50 = 600$.

Decision

Magnification has no unit. A length divided by a length is a ratio.

Calibrate arbitrary divisions before measuring

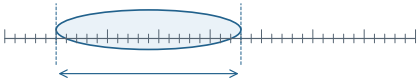
Calibrate at one objective



Stage micrometer:
100 µm

Eyepiece:
40 divisions

Measure with the same objective



Cell length:
18 × 2.5 = 45 µm

One division = 100 / 40 = 2.5 µm.
Recalibrate after changing the objective.

Calibrate: 40 divisions $=$ 100 μm. Then 18 divisions $=$ 45 μm.

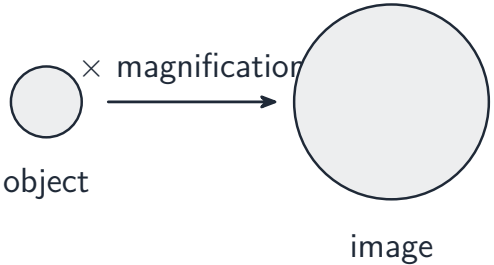
Use the scale belonging to this photograph

1. **Invented bar.** 10 mm represents $20\,\mu\text{m}$: $M = 10\,000/20 = 500$.
2. **Cell image.** 25 mm gives $A = 25\,000/500 = 50\,\mu\text{m}$.
3. **Resizing.** Enlarge image and bar together: their ratio stays valid; actual cell size is unchanged.

Decision

A printed "500×" becomes wrong after resizing. A scale bar resized with the image still works.

Magnification



$$\text{magnification} = \frac{\text{image}}{\text{actual}}$$

Rearrange for actual size

Magnification and resolution answer different questions

Idea	Meaning and consequence
Magnification	How much larger the image is than the specimen
Resolution	Whether close details appear separate
Conventional light microscope	Roughly 0.2 μm resolution in favourable conditions
Digital enlargement	Cannot recover detail absent from the original image

Choose the image method for the question

Question	Useful approach and limit
Movement in a living cell	Light microscopy; balance contrast and cell condition
Internal membrane folds	TEM thin section; the cutting plane affects appearance
External surface form	SEM; not a direct view of internal organelles

A fluorescent signal needs a validated label

Locate a target rather than colouring every structure

A fluorophore emits light after excitation. A chosen label can highlight a particular component in light microscopy.

In immunofluorescence an antibody binds a target antigen; a fluorescent label reveals the binding location.

Check specificity and background with controls. An absent signal does not automatically prove that the target is absent.

Preparation can reveal new structures

Freeze fracture and cryogenic EM have different roles

Fracturing frozen material can split membranes. Replicas of fracture faces reveal aspects of membrane organization.

Cryogenic EM uses rapid freezing to preserve hydrated material without conventional chemical fixation and heavy-metal staining.

Neither is a direct film of an undisturbed living cell. Interpret preparation effects and, where used, reconstruction.

Resolution, not just magnification



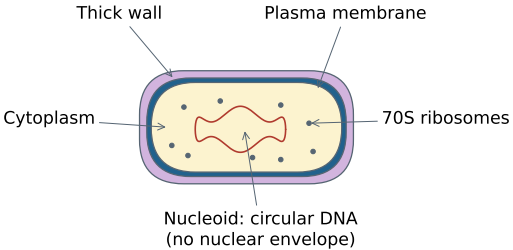
light microscope:
the two blur into **one**



electron microscope:
resolved as **two**

> Electrons have a much shorter wavelength

Distinguish wall, membrane and nucleoid



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

A wall lies outside the membrane; the nucleoid has no nuclear envelope.

No nucleus does not mean no DNA

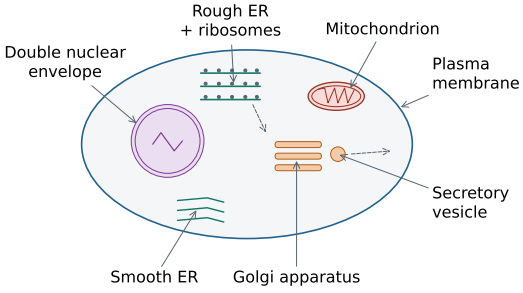
A typical Gram-positive bacterium is a living cell

Its circular chromosome carries information in the nucleoid. “Naked DNA” is a model contrast with eukaryotic histone packaging.

70S ribosomes synthesize proteins; cytoplasm supports reactions. The wall helps resist osmotic bursting and the membrane regulates exchange.

Plasmids, flagella and capsules are not compulsory in every bacterium. This Gram-positive model has no Gram-negative outer membrane.

Follow a secretory pathway through compartments



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

For secretion: rough ER $\rightarrow$ Golgi $\rightarrow$ vesicle $\rightarrow$ plasma membrane.

Trace a protein destined for secretion

1. **Synthesize and process.** A ribosome on rough ER makes a protein entering the secretory pathway; ER supports processing.
2. **Modify and sort.** Transport vesicles carry material to the Golgi apparatus.
3. **Release.** Secretory vesicles fuse with the plasma membrane, releasing contents by exocytosis.

Decision

Ribosomes have no enclosing membrane; vesicles are not the sites that translate the protein.

Recognize internal membrane patterns

Structure	Observation and functional annotation
Nucleus	Double envelope, chromatin; stores DNA and supports transcription
Mitochondrion	Cristae inside envelope; respiration and ATP production
Chloroplast	Internal thylakoid stacks; photosynthesis
Sap vacuole	Large fluid-filled space; storage and turgor

Use context for smaller compartments

Structure	Clue and function
Rough versus smooth ER	Ribosomes distinguish rough ER; smooth ER includes lipid synthesis
Golgi apparatus	Stacked flattened sacs; modifies, sorts and packages
Lysosome	Digestive compartment; a round dark profile alone is insufficient
Vesicle	Membrane-bound transport/storage compartment

The cytoskeleton is more than scaffolding

Microtubules and microfilaments support organization

These components help shape cells, move materials and participate in division.

Microvilli are surface projections supported by microfilaments, increasing area for exchange.

Cilia and eukaryotic flagella have microtubule-based structures and commonly move cells or fluid. A microvillus is not a cilium.

Connect life processes within Paramecium

Process	Connected example
Movement and nutrition	Cilia move the cell and food; food vacuoles digest material
Homeostasis	Contractile vacuoles collect and expel excess water
Metabolism and excretion	Enzyme-controlled reactions; carbon dioxide leaves the cell
Growth, response, reproduction	Adds material, responds to stimuli and divides

Name the process rather than a miniature organ

One cell performs coordinated activities

A food vacuole digests material; a contractile vacuole manages excess water. Neither is a multicellular organ.

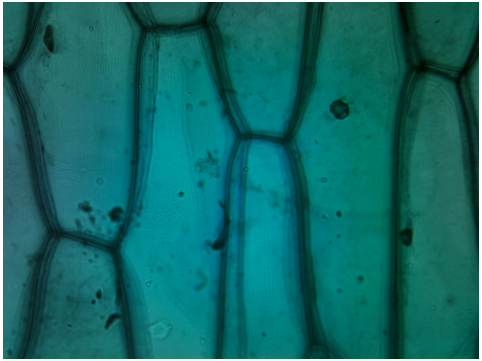
Excretion removes metabolic waste such as carbon dioxide. Undigested food is not a waste product made by metabolism.

The same organism must coordinate all essential life processes in one cell.

Cell walls and plastids separate typical models

Feature	Plant, fungal and animal comparisons
Cell wall	Plant: cellulose; fungal: chitin and other polysaccharides; animal: absent
Chloroplasts	Photosynthetic plant cells; absent from animal and fungal cells
Vacuoles	Plants often have a large sap vacuole; fungi also have vacuoles
Motile structures	Depend on the cell type and life stage; not universal in a group

Observe a plant cell without inventing chloroplasts



Onion epidermis shows adjoining cell boundaries and darker nuclei; this image has no calibrated scale bar.

A root cell can lack chloroplasts and still be plant

Qualify typical-cell comparisons

Chloroplasts occur in photosynthetic tissues. Other plastids also occur in plants; one non-photosynthetic cell need not contain chloroplasts.

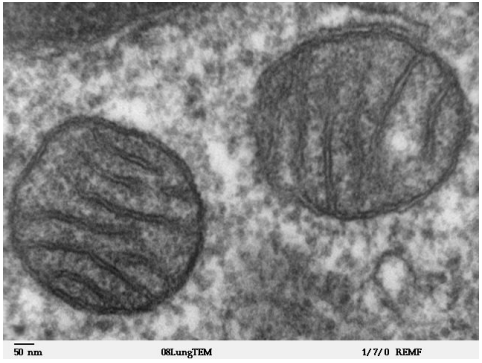
Animal centrioles are common, while most higher-plant cells lack them. Cilia and flagella occur in selected types or stages.

A fungal wall is not evidence that a fungus is a plant. Use several features and the cell's context.

One nucleus per cell is an incomplete rule

Example	How it differs from a typical sketch
Aseptate fungal hypha	Many nuclei in shared cytoplasm without cross walls
Skeletal muscle fibre	Multinucleate after fusion of precursor cells
Mature mammalian red cell	No nucleus or mitochondria; no normal division
Mature sieve tube element	No nucleus; living and supported by companion cells

Read internal folds in a real TEM section



Use the original 50 nm scale bar; identify boundaries and cristae before adding functional annotations.

Identify with several observations

Missing from the section is not necessarily absent

A wall, large vacuole and plastids jointly support plant identification. A nucleus and membrane-bound organelles support a eukaryote.

A nucleoid and bacterial envelope support a prokaryote. Shape alone or a blurred missing nucleus is weak evidence.

Sections cut through only part of a cell. Preparation and resolution limit what can be seen.

Make an observation drawing, then annotate

Preserve visible shapes, proportions and evidence

Draw large continuous outlines without decorative shading. Do not insert every organelle remembered from a model.

Use straight non-crossing labels ending on the structure. Add functions as annotations: cristae increase inner-membrane area for ATP-producing processes.

Include an accurate scale and image source. Distinguish direct observations from functional interpretations.

AHL: combine evidence for organelle ancestry

Observation	Why it supports the model
Organelle DNA	Retains genetic information with bacterial ancestry
Bacterial-type ribosomes	Supports connection to bacterial protein-synthesis systems
Replication within cells	Fits descent from formerly reproducing cellular lineages
Molecular comparisons	Several consistent relationships strengthen ancestry inference

AHL: replication is not complete independence

The model concerns mitochondria and chloroplasts

An ancestral endosymbiotic association produced mitochondria; a later photosynthetic association produced chloroplasts in some lineages.

Many required proteins are nuclear-encoded and imported. Organelle replication therefore does not mean full autonomy.

The course uses a circular-DNA/70S model; actual mitochondrial structures vary. The evidence does not imply that every organelle was once a bacterium.

AHL: different expression can produce different cells

Specialization usually retains a shared genome

A muscle cell and a nerve cell generally retain the same genome but express different subsets of genes.

Different proteins and amounts of proteins lead to specialized structures and functions. Signals and environmental conditions can trigger changes.

Differentiation does not normally require deleting every unused gene. Mature cells can depend on other cell types.

AHL: multicellularity brings benefits and demands

It evolved repeatedly, with coordinated cells

Larger body size and division of labour can be advantageous. Many fungi and eukaryotic algae, and all plants and animals, are multicellular.

Adhesion, communication and coordinated resource supply maintain organization. Deep tissues cannot all exchange rapidly with the external surroundings by diffusion.

A multicellular organism is more than a loose crowd of independent cells; specialization can reduce a cell's autonomy.

Try a scale-bar and calibration problem

Calculate before revealing the answer

Invented print: a 10 mm scale bar represents 20 μm. A cell image is 24 mm long. Find actual cell length.

Enlarge the entire image twofold. State new bar length, cell image length and actual cell length.

Separately, 50 graticule divisions represent 125 μm. A cell spans 22 divisions. Find its length.

Reveal: preserve the scale ratio

1. **Scale bar.** $M = 10\,000/20 = 500$; $A = 24\,000/500 = 48\,\mu\text{m}$.
2. **Enlargement.** Bar $= 20$ mm; cell image $= 48$ mm; actual cell $= 48\,\mu\text{m}$.
3. **Graticule.** $125/50 = 2.5\,\mu\text{m}$ per division; length $= 22(2.5) = 55\,\mu\text{m}$.

Decision

Recalibrate at a changed objective; a division is not a fixed biological distance.

Check yourself

Scale, structure and evidence

Use matching length units, distinguish magnification from resolution and use the correct calibration.

Identify cells from several features and qualify typical-cell models. A missing feature in one section is not automatically absent.

Draw observed structures, keep label lines clear and add functional annotations with an accurate scale and source.