

Cell structure

Revision notes • Cell theory, microscopy skills and techniques, prokaryote and eukaryote cells, atypical cells, micrographs and (HL) endosymbiosis and multicellularity.

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Cell structure Spec A2.2

Cell theory and structures common to all cells Spec A2.2.1, A2.2.4

Cell theory is one of the most important theories in biology. It states that:

- All living organisms are composed of one or more cells.
- Cells are the **basic structural unit of all living organisms**, and the smallest unit of life.
- Cells only arise from pre-existing cells.

Cell theory was built up from a very large number of observations made with microscopes. It can then be used to make predictions: a newly discovered organism can be predicted to consist of one or more cells.

Exam tip: Nature of science: deductive reasoning generates predictions from a theory. If an observation does not fit, such as cells with many nuclei or none, the theory may need refining.

Structures common to cells in all living organisms

What all typical cells have, and why	
Structure	Reason it is needed
DNA as genetic material	Stores the instructions for making proteins, including enzymes, and can be replicated so that copies pass to daughter cells
Cytoplasm composed mainly of water	Water is the solvent in which most metabolic reactions happen; enzymes and substrates dissolve and move in it
Plasma membrane composed of lipids	A hydrophobic barrier that encloses the cytoplasm, keeps its contents in and controls what enters and leaves

All cells also contain **ribosomes** for protein synthesis, although ribosomes in prokaryotes are smaller than those in the cytoplasm of eukaryotes.

Microscopy skills Spec A2.2.2

Making a temporary mount

1. Place a thin layer of tissue, such as onion epidermis or cells scraped from the inside of the cheek, on a clean slide in a drop of water or stain.
2. Stain to increase contrast: iodine solution for plant cells (stains starch and makes nuclei visible) or methylene blue for animal cells (stains the nucleus).
3. Lower a coverslip at an angle with a mounted needle to avoid trapping air bubbles.
4. Blot away excess liquid with filter paper.

Focusing

1. Start with the low-power objective lens.
2. Use the **coarse adjustment** to bring the specimen roughly into focus.
3. Centre the area you want, then rotate to a higher-power objective.
4. Use only the **fine adjustment** at high power, so the lens does not hit and crack the slide.

Measuring with an eyepiece graticule

An **eyepiece graticule** is a scale in the eyepiece marked in arbitrary units. It is calibrated against a stage micrometer, a slide with a ruled scale (often 1 mm divided into 100 divisions of 10 μm). Calibration is repeated for each objective lens, because the length of specimen covered by one eyepiece unit changes with magnification.

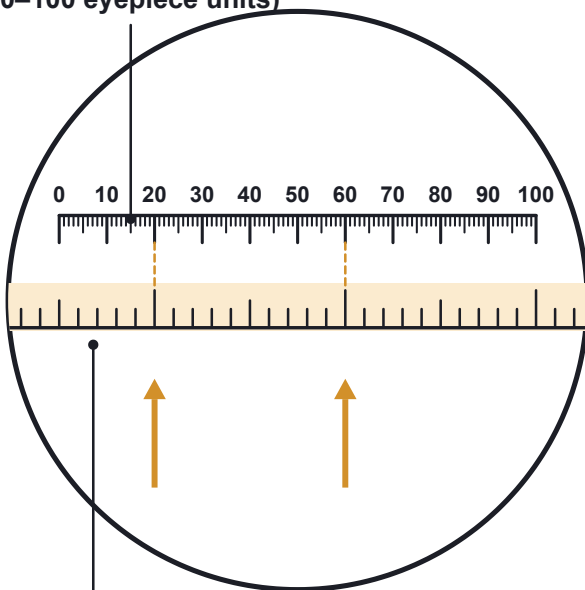
Calibrating a graticule

At $\times 400$, 40 eyepiece units line up with 10 divisions of a stage micrometer. Each division is 10 μm . A cheek cell is 24 eyepiece units across. Calculate its actual diameter.

1. 10 stage divisions = $10 \times 10 \mu\text{m} = 100 \mu\text{m}$
2. 40 eyepiece units = 100 μm , so 1 eyepiece unit = $100 \div 40 = 2.5 \mu\text{m}$
3. Cell diameter = $24 \times 2.5 \mu\text{m} = 60 \mu\text{m}$

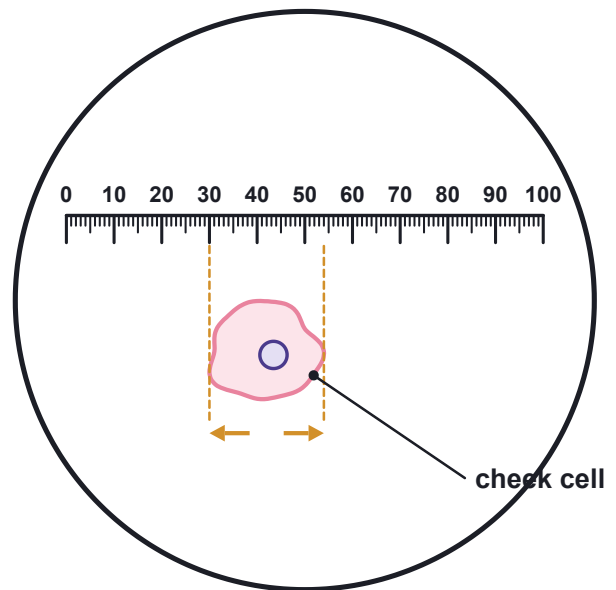
Answer: 60 μm

eyepiece graticule
(0–100 eyepiece units)



stage micrometer
(1 division = 10 μm)

40 eyepiece units = 10 divisions = 100 μm
so 1 eyepiece unit = $100 \div 40 = 2.5 \mu\text{m}$



cell = 24 eyepiece units across
diameter = $24 \times 2.5 \mu\text{m} = 60 \mu\text{m}$

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Calibrating the graticule: $40 \text{ eyepiece units} = 100 \mu\text{m}$, so a cell 24 units across is 60 μm in diameter.

Magnification, actual size and scale bars

magnification = size of image $\div$ actual size of specimen

Rearranged: actual size = size of image $\div$ magnification. Convert to the same units first: 1 mm = 1000 μm and 1 μm = 1000 nm.

Actual size from a micrograph

A *Staphylococcus* cell is 30 mm across on an electron micrograph with a magnification of $\times 30\,000$. Calculate its actual diameter in μm .

1. Convert the image size to μm : $30\text{ mm} \times 1000 = 30\,000\text{ }\mu\text{m}$
2. actual size = image size $\div$ magnification = $30\,000\text{ }\mu\text{m} \div 30\,000$
3. = 1 μm

Answer: 1 μm

Producing a scale bar

On the same micrograph ($\times 30\,000$), how long should a scale bar representing 0.5 μm be?

1. image size = actual size $\times$ magnification
2. = $0.5\text{ }\mu\text{m} \times 30\,000 = 15\,000\text{ }\mu\text{m}$
3. $15\,000\text{ }\mu\text{m} \div 1000 = 15\text{ mm}$

Answer: A line 15 mm long, labelled 0.5 μm

Maths skill: To find magnification from a scale bar, measure the bar with a ruler, convert it to the unit written on the bar, then divide the measured length by the value on the bar.

Practical skill: Photographs can be taken through the eyepiece with a camera or phone; add a scale bar so sizes can be measured later. Measurement with an instrument is quantitative observation, so record each reading with its uncertainty.

Developments in microscopy Spec A2.2.3

Resolution is the ability to distinguish two points that are close together as separate. Increasing magnification without increasing resolution only gives a bigger, blurred image.

Light and electron microscopes compared

Feature	Light microscope	Electron microscope
Radiation used	Light	A beam of electrons
Resolution	About 0.2 μm (200 nm)	About 1-2 nm for biological specimens
Useful magnification	Up to about $\times 1500$	Over $\times 100\,000$
Specimens	Living or dead; natural colour can be seen	Dead only, because the specimen is in a vacuum; images are black and white
What it shows	Cells, nuclei, chloroplasts	Ultrastructure: ribosomes, membranes and the inside of organelles

The **advantage of electron microscopy** is its much higher resolution, because electrons have a far shorter wavelength than light. Transmission electron microscopes pass electrons through thin sections to show internal structure. Scanning electron microscopes scan the surface to give 3D images.

Freeze fracture

A sample is frozen rapidly and then cracked with a blade. The fracture often runs along the middle of membranes, between the two layers of lipid. A thin metal replica of the fractured surface is examined

with an electron microscope. Freeze fracture revealed **proteins spanning the membrane**, which supported the fluid mosaic model.

Cryogenic electron microscopy (cryo-EM)

Samples are frozen so fast that water forms glass-like ice rather than crystals, which preserves molecules in their natural shape. Thousands of images of individual molecules are combined by computer to build a **3D model of a protein**, often at near-atomic resolution, without the need to crystallise it. Cryo-EM is used to find the structures of membrane proteins and virus capsids.

Fluorescence in light microscopy

- **Fluorescent stains** bind to specific structures, such as DNA, and emit visible light when illuminated with light of a particular wavelength (often ultraviolet). The stained structures glow against a dark background.
- **Immunofluorescence** uses antibodies carrying a fluorescent marker. Each antibody binds one specific protein (its antigen), so the glow shows exactly where that protein is in the cell. Several proteins can be labelled in different colours at once.

Exam tip: Give a specific advantage: 'higher resolution, so ribosomes and membranes can be seen' scores; 'a clearer picture' does not.

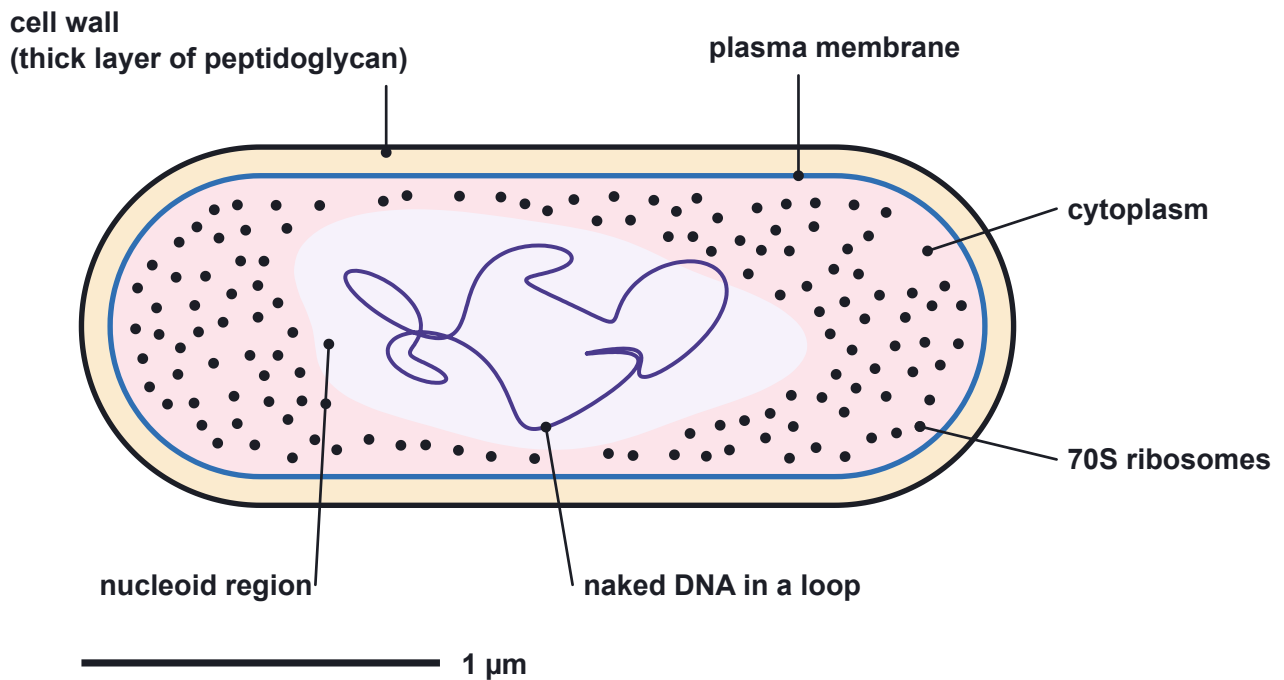
Prokaryote and eukaryote cell structure Spec A2.2.5, A2.2.6

Prokaryote cell structure

Prokaryotes have no nucleus. The structure you need is that of **Gram-positive eubacteria** such as *Bacillus* and *Staphylococcus*.

Components of a Gram-positive bacterium	
Component	Description and function
Cell wall	A thick layer of peptidoglycan outside the plasma membrane, with no outer membrane beyond it; protects the cell and stops it bursting when water enters by osmosis
Plasma membrane	Phospholipid bilayer with proteins; controls the entry and exit of substances
Cytoplasm	Mainly water; the site of metabolic reactions; not divided into compartments
Naked DNA in a loop	A single circular chromosome, not associated with histones, in a region called the nucleoid
70S ribosomes	Smaller ribosomes, free in the cytoplasm, that carry out protein synthesis

Prokaryote cell structure varies. Many prokaryotes also have plasmids, flagella, pili or a capsule, but the details of these variations are not required.



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A Gram-positive bacterium such as *Bacillus*: naked DNA in a loop in the nucleoid region, and 70S ribosomes.

Eukaryote cell structure

- A plasma membrane enclosing a compartmentalised cytoplasm with 80S ribosomes.
- A nucleus with chromosomes made of DNA bound to histones, contained in a double membrane with pores (the nuclear envelope).
- Membrane-bound cytoplasmic organelles: mitochondria, rough and smooth endoplasmic reticulum, the Golgi apparatus and a variety of vesicles or vacuoles, including lysosomes.
- A cytoskeleton of microtubules and microfilaments, which supports the cell, moves organelles and allows some cells to move.

Compartments let enzymes and substrates be concentrated where they are needed, keep potentially harmful enzymes (such as those in lysosomes) away from the rest of the cell, and allow different conditions, such as pH, in different organelles.

Prokaryotes and eukaryotes compared		
Feature	Prokaryote	Eukaryote
Nucleus	Absent; DNA in a nucleoid region	Present, with a double membrane and pores
DNA	Naked and circular	Linear chromosomes bound to histones
Ribosomes	70S	80S in the cytoplasm
Membrane-bound organelles	Absent	Present: mitochondria, ER, Golgi apparatus, lysosomes
Cytoplasm	Not compartmentalised	Compartmentalised
Typical size	About 0.5–5 μm	About 10–100 μm

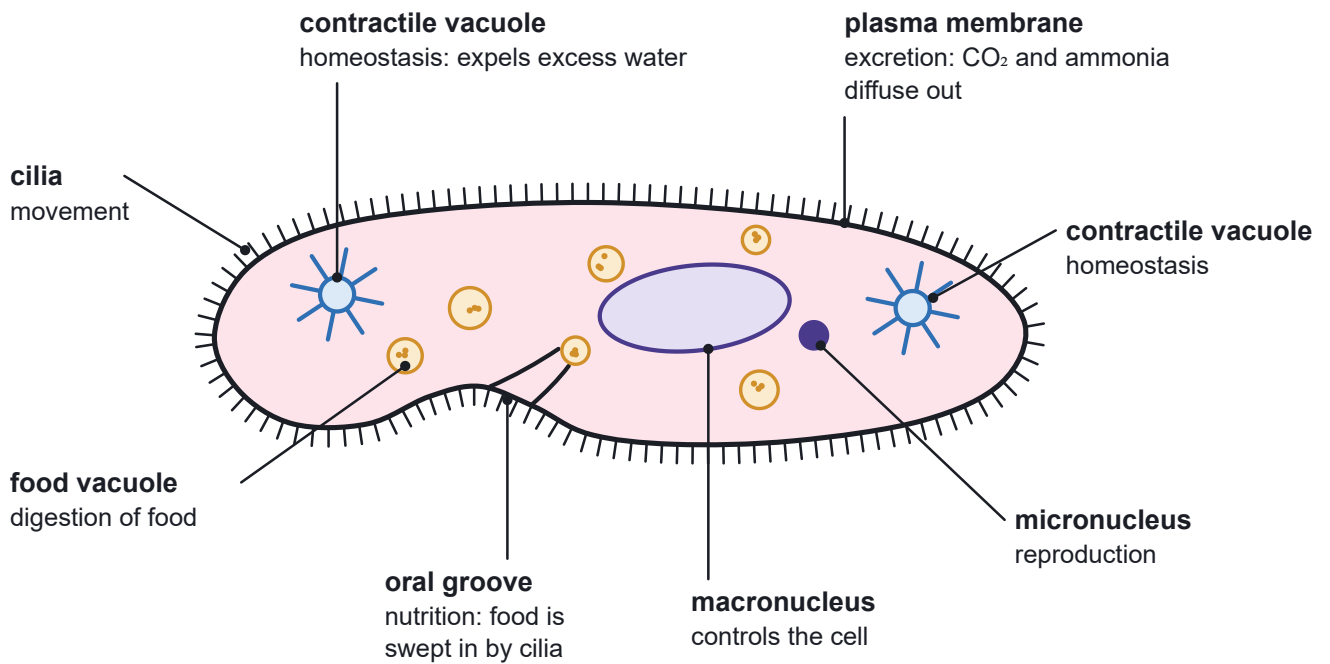
Common mistake: Do not write that prokaryotes have 'no DNA' or 'no chromosome'. They have DNA, as a single naked loop; what they lack is a nucleus.

Processes of life in unicellular organisms Spec A2.2.7

A unicellular organism consists of one cell, so that one cell must carry out **all the functions of life**.

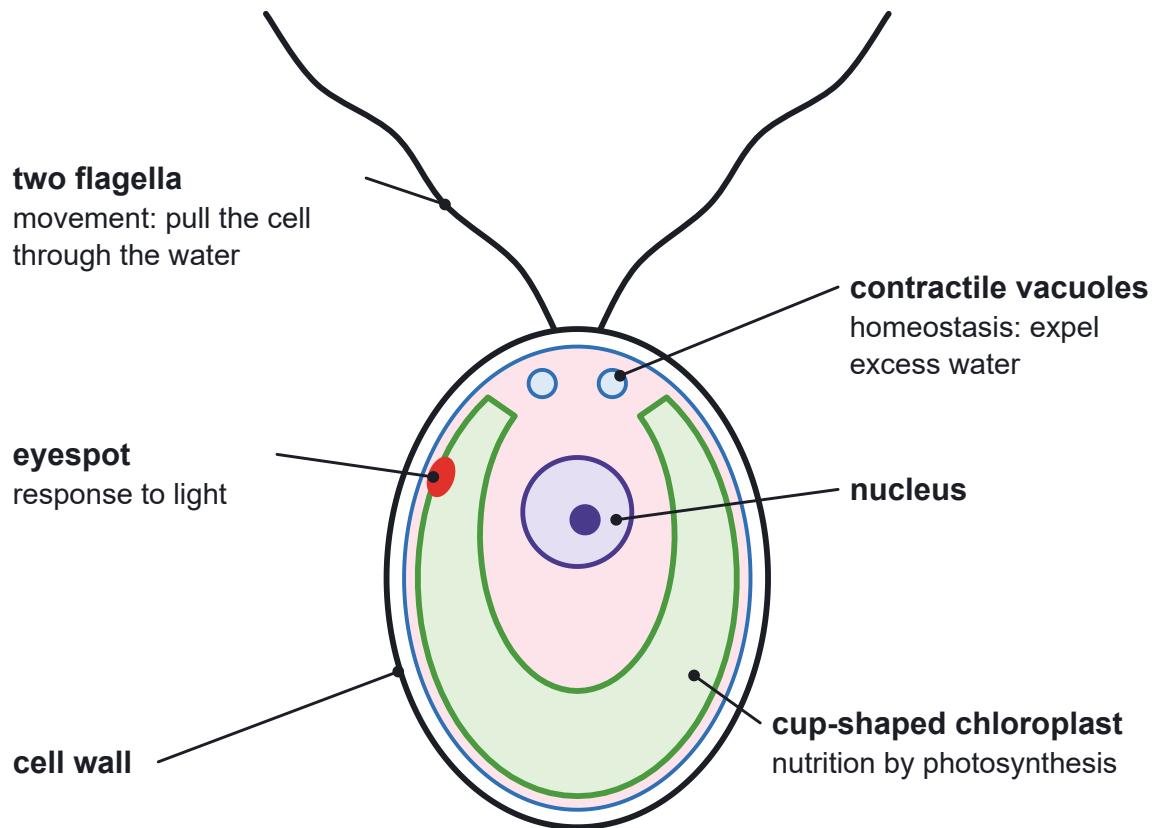
Homeostasis	Keeping internal conditions within narrow limits
Metabolism	All the enzyme-catalysed reactions in the cell
Excretion	Removal of the waste products of metabolism

Functions of life in two unicellular organisms		
Function	Paramecium (heterotroph)	Chlamydomonas (autotroph)
Homeostasis	Contractile vacuoles collect and expel excess water that enters by osmosis	Contractile vacuoles expel excess water
Metabolism	Enzyme-catalysed reactions in the cytoplasm and mitochondria, including respiration	Reactions in the cytoplasm, mitochondria and chloroplast, including photosynthesis and respiration
Nutrition	Ingests bacteria and other food into food vacuoles, where it is digested	Makes its own food by photosynthesis in a large cup-shaped chloroplast
Movement	Beating cilia over the cell surface	Two flagella pull the cell through the water
Excretion	Wastes such as carbon dioxide and ammonia diffuse out across the plasma membrane	Oxygen from photosynthesis and other wastes diffuse out
Growth	Increases in size and dry mass by making new molecules	Increases in size and dry mass by making new molecules
Response to stimuli	Reverses direction when it meets an obstacle or harmful chemical	An eyespot detects light, so it swims towards light
Reproduction	Asexually, by dividing in two (binary fission)	Asexually by mitosis, or sexually when gametes fuse



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Paramecium, a heterotroph, carries out all the functions of life in **one cell**



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Chlamydomonas, an autotroph, makes its food by **photosynthesis** in a cup-shaped chloroplast.

Exam tip: Learn the eight functions as a list: homeostasis, metabolism, nutrition, movement, excretion, growth, response to stimuli and reproduction. Questions often ask how a named organism carries out each one.

Animal, fungal and plant cells, and atypical cells Spec A2.2.8, A2.2.9

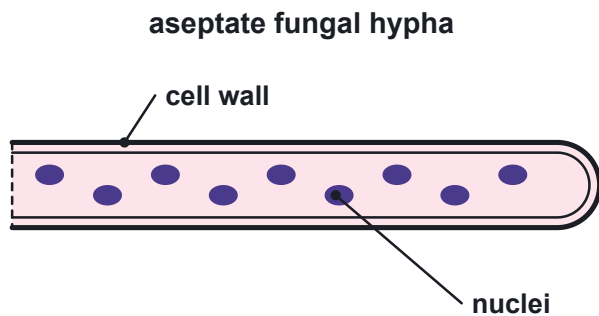
Differences in eukaryotic cell structure			
Feature	Animal cells	Fungal cells	Plant cells
Cell wall	Absent	Present, made of chitin	Present, made of cellulose
Vacuoles	Small and temporary, such as food vacuoles and vesicles	Present; can be large in older hyphae	A large permanent central vacuole of cell sap; maintains turgor and stores substances
Chloroplasts and other plastids	Absent	Absent	Chloroplasts in green tissues; other plastids, such as amyloplasts, store starch
Centrioles	Present	Absent in most fungi	Absent in flowering plants
Cilia and flagella	Present in some cells, such as ciliated epithelium and the sperm flagellum	Absent in most fungi; only some produce spores with flagella	Absent in flowering plants; mosses and ferns have sperm with flagella

Common mistake: Not every plant cell has chloroplasts: root cells have none. Write 'plant cells may have chloroplasts' when comparing cell types.

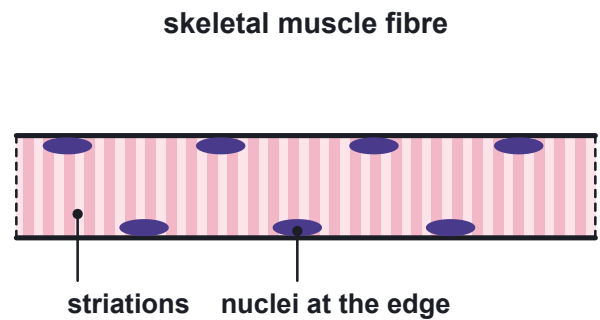
Atypical cell structure in eukaryotes

Cell theory pictures a cell as one unit with one nucleus. The **numbers of nuclei** show that some eukaryotic cells are atypical.

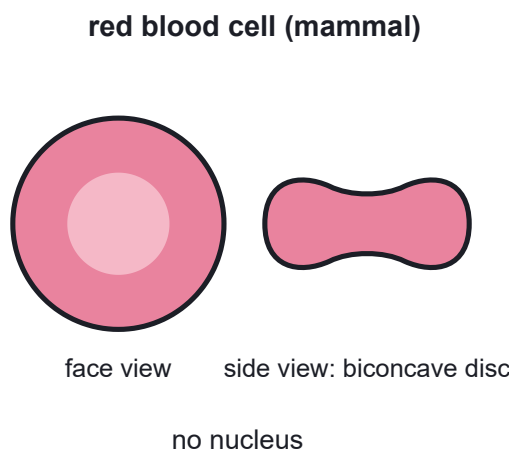
Atypical cells		
Cell	Number of nuclei	Explanation
Aseptate fungal hyphae	Many	The long hyphae have no cross walls (septa), so many nuclei share one continuous cytoplasm
Skeletal muscle fibres	Many	Each fibre forms when many embryonic muscle cells fuse, and it can be several centimetres long
Red blood cells (mammals)	None	The nucleus is lost as the cell matures, leaving more space for haemoglobin; the cell cannot divide and lives about 120 days
Phloem sieve tube elements	None	The nucleus and most organelles break down so sap can flow freely; a companion cell with a nucleus keeps each element alive



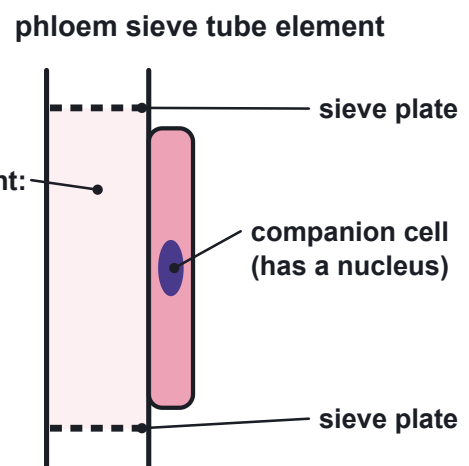
no septa (cross walls): multinucleate



multinucleate: formed by fusion of cells



sieve tube element:
no nucleus



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Atypical cells: two with many nuclei and two with none

Micrographs, drawing and annotation

Spec A2.2.10, A2.2.11

Identifying the cell type

Clues to cell type in micrographs	
Cell type	Look for
Prokaryote	Small (about 0.5–5 μm); nucleoid region with no nuclear membrane; cell wall; no membrane-bound organelles
Plant	Cell wall; large sap vacuole; chloroplasts in green tissue; often a regular, angular shape
Animal	No cell wall; no large vacuole; may have microvilli; often an irregular shape

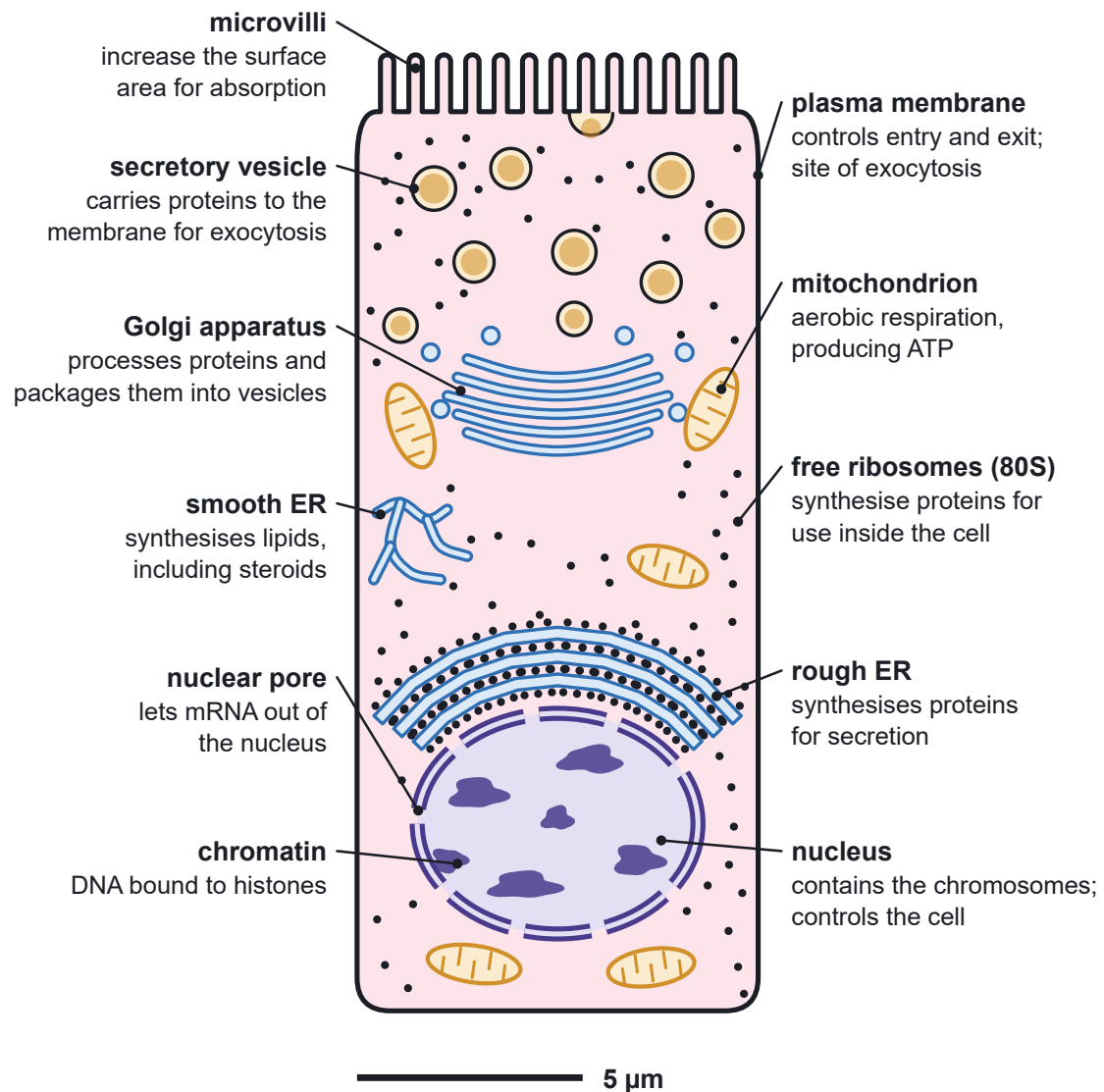
Structures in electron micrographs

Appearance and function of structures in electron micrographs		
Structure	Appearance	Function (for annotations)
Nucleoid region	Paler area of fine fibres in a prokaryote, with no membrane around it	Contains the loop of DNA
Prokaryotic cell wall	Dense layer just outside the plasma membrane	Protects the cell and prevents bursting
Nucleus	Large and round; double membrane with pores; dark patches of chromatin	Contains the chromosomes; controls the cell through gene expression
Chromosomes	Dark, condensed bodies, visible in dividing cells	Carry the genes; condensed so they can be separated in division
Mitochondrion	Oval; double membrane, with the inner membrane folded into cristae	Site of aerobic respiration, producing ATP
Chloroplast	Double membrane; stacks of thylakoids (grana); may contain starch grains	Site of photosynthesis
Sap vacuole	Large, pale area bounded by a single membrane	Stores cell sap; maintains turgor
Golgi apparatus	Stack of curved, flattened membrane sacs with vesicles at the edges	Processes proteins and packages them into vesicles
Rough endoplasmic reticulum	Flattened membrane sacs studded with ribosomes	Synthesises proteins for secretion or for membranes
Smooth endoplasmic reticulum	Branching tubular membranes without ribosomes	Synthesises lipids, including steroids
Ribosomes	Tiny dark granules, free in the cytoplasm or on rough ER	Protein synthesis
Cell wall (plant)	Thick layer outside the plasma membrane	Supports the cell and resists turgor pressure
Plasma membrane	Thin dark line at the edge of the cytoplasm	Controls the entry and exit of substances
Secretory vesicles	Small membrane-bound spheres near the Golgi apparatus or plasma membrane	Carry proteins to the plasma membrane for secretion by exocytosis
Microvilli	Finger-like projections of the plasma membrane	Increase the surface area for absorption

Drawing and annotating from an electron micrograph

- Use a sharp pencil and clear, continuous lines, with no shading or colouring.
- Draw only what is visible, with structures in the correct proportions and positions.
- Label with straight, ruled lines that do not cross and that end exactly on the structure.
- Annotate each labelled structure with its **function**; this is required, not optional.
- Add a title and a scale bar or magnification.

Exam tip: An annotation is more than a label. 'Mitochondrion: site of aerobic respiration, producing ATP' is an annotation; 'mitochondrion' alone is only a label.



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A secretory cell: proteins are made on **rough ER**, processed in the **Golgi apparatus** and secreted by exocytosis.

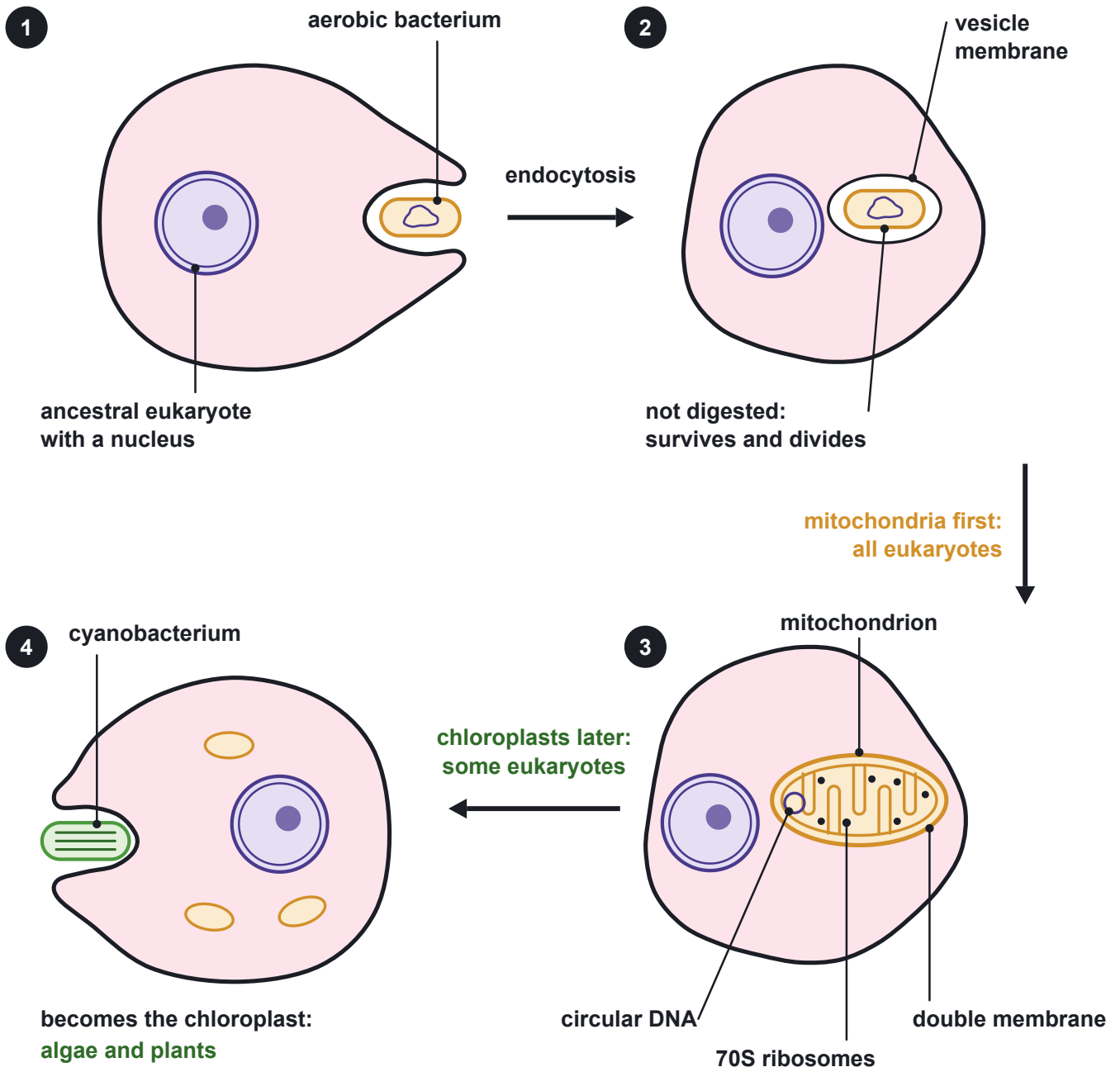
Origin of eukaryotic cells by endosymbiosis Spec A2.2.12 HL only

Evidence suggests that **all eukaryotes evolved from a common unicellular ancestor** that had a nucleus and reproduced sexually. Mitochondria and chloroplasts then arose by **endosymbiosis**.

1. An ancestral eukaryotic cell took in an aerobic prokaryote by endocytosis, but did not digest it.
2. The prokaryote survived and divided inside the host. The host gained ATP from the prokaryote's aerobic respiration, and the prokaryote gained protection and a supply of carbon compounds.
3. Over many generations the two became dependent on each other, and the prokaryote evolved into the mitochondrion. All eukaryotes are descended from this cell.
4. Later, in some eukaryotes only, a photosynthetic prokaryote (a cyanobacterium) was taken in the same way and became the chloroplast, giving rise to algae and plants.

Evidence that mitochondria and chloroplasts were once prokaryotes

Evidence	What it shows
70S ribosomes	The same size as prokaryote ribosomes, not the 80S ribosomes of the eukaryotic cytoplasm
Naked circular DNA	Like a prokaryote chromosome, not linear chromosomes bound to histones
Ability to replicate	They divide by a process like binary fission; a cell cannot make them from scratch
Double membrane	Consistent with a prokaryote being taken in by a host cell; the inner membrane resembles a prokaryote plasma membrane
Gene base sequences	Most similar to those of aerobic bacteria (mitochondria) and cyanobacteria (chloroplasts)



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Endosymbiosis: **mitochondria first**, in the ancestor of all eukaryotes, then **chloroplasts later** in some lineages.

Exam tip: Nature of science: a theory is strong when it explains many observations. Endosymbiosis accounts for the ribosomes, DNA, membranes, division and gene sequences of both organelles.

Cell differentiation and the evolution of multicellularity

Spec A2.2.13, A2.2.14

HL only

In a multicellular organism nearly all cells contain the same genome. **Cell differentiation** is the process by which cells develop into specialised types, forming tissues.

The basis of differentiation is **different patterns of gene expression**. In each cell type some genes are switched on (transcribed) and others are switched off. Changes in gene expression are often triggered by changes in the cell's environment, such as signal molecules from neighbouring cells or the cell's position in the embryo.

For example, only developing red blood cells express the genes for haemoglobin, and only certain cells in the pancreas express the insulin gene, although almost every body cell carries both genes.

Common mistake: Differentiation does not remove genes. A specialised cell keeps the full genome; it expresses only some of its genes.

Evolution of multicellularity

Multicellularity has evolved repeatedly, separately in different lineages. Many fungi and eukaryotic algae, and all plants and animals, are multicellular.

- Larger body size: an organism is not limited to the size of one cell, which is restricted by its surface area to volume ratio.
- Cell specialisation: different cells carry out different functions (division of labour), so each function can be carried out more efficiently.

Quick check

1. State the three parts of cell theory.
2. Why must an eyepiece graticule be calibrated for each objective lens?
3. What size of ribosome do prokaryotes have?
4. Which substance makes up fungal cell walls?
5. **HL only** Give two pieces of evidence for the endosymbiotic origin of mitochondria.

Quick check answers

Cell structure

- 1 . All organisms consist of one or more cells; cells are the basic structural unit of life; cells only arise from pre-existing cells.
- 2 . The length of specimen covered by one eyepiece unit changes with magnification.
- 3 . 70S.
- 4 . Chitin.
- 5 . They have 70S ribosomes and naked circular DNA (and can replicate by division).