REVISION GUIDE

The *cell*, the unit of life

Cell structure

Every living thing is made of cells, from a bacterium to a blue whale. Find out how we know, learn to measure a cell under the microscope, take apart a bacterium and an animal cell, compare plants, fungi and animals, name structures in electron micrographs, and at higher level see where mitochondria came from.

12 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-a2-2-cell-structure

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By the end you can

- [ ] State cell theory and use it to make a prediction about a newly discovered organism A2.2.1
- [ ] Make and stain a temporary mount, focus it, measure a cell with a graticule, and calculate actual size, magnification and a scale bar A2.2.2
- [ ] Outline the advantages of electron microscopy, freeze fracture, cryogenic electron microscopy and fluorescent stains A2.2.3
- [ ] Explain why every cell has DNA, a watery cytoplasm and a plasma membrane A2.2.4
- [ ] Draw and label a prokaryote cell: wall, membrane, cytoplasm, naked DNA in a loop and 70S ribosomes A2.2.5
- [ ] Describe the structures every eukaryote cell has, with the function of each A2.2.6
- [ ] Explain how a single-celled organism carries out all eight functions of life A2.2.7
- [ ] Compare the cells of animals, fungi and plants: walls, vacuoles, plastids, centrioles, cilia and flagella A2.2.8
- [ ] Use numbers of nuclei to describe four atypical eukaryote cells A2.2.9
- [ ] Identify cell types and structures in micrographs, and draw and annotate them from electron micrographs A2.2.10, A2.2.11
- [ ] Explain the endosymbiotic origin of mitochondria and chloroplasts and the evidence for it A2.2.12
- [ ] Explain differentiation as different patterns of gene expression, and why multicellularity evolved again and again A2.2.13, A2.2.14

Tick each one when you can do it without the book.

01 Every living thing is made of *cells*

A2.2.1 CELLS AS THE BASIC STRUCTURAL UNIT OF ALL LIVING ORGANISMS

In 1665 Robert Hooke looked at a thin slice of cork through a microscope and saw rows of empty boxes. He called them cells. They were only the walls of dead plant cells, but the name stuck. Over the next two hundred years, better microscopes and careful observers turned that word into one of the great ideas of biology.

Cell theory has three parts. All living things are made of one or more cells. The cell is the smallest unit that is alive. And cells only come from cells that were there before, by dividing. Nothing smaller than a cell, such as a mitochondrion or a ribosome taken out of a cell, can stay alive on its own.

A theory in science is not a guess. It is an explanation that fits a huge number of observations and has survived every attempt to prove it wrong. A strong theory also lets you **deduce** what you have not seen yet. If all living things are made of cells, then a new organism found tomorrow, in a deep-sea vent or under the Antarctic ice, will be made of cells too. That is a prediction you can test.

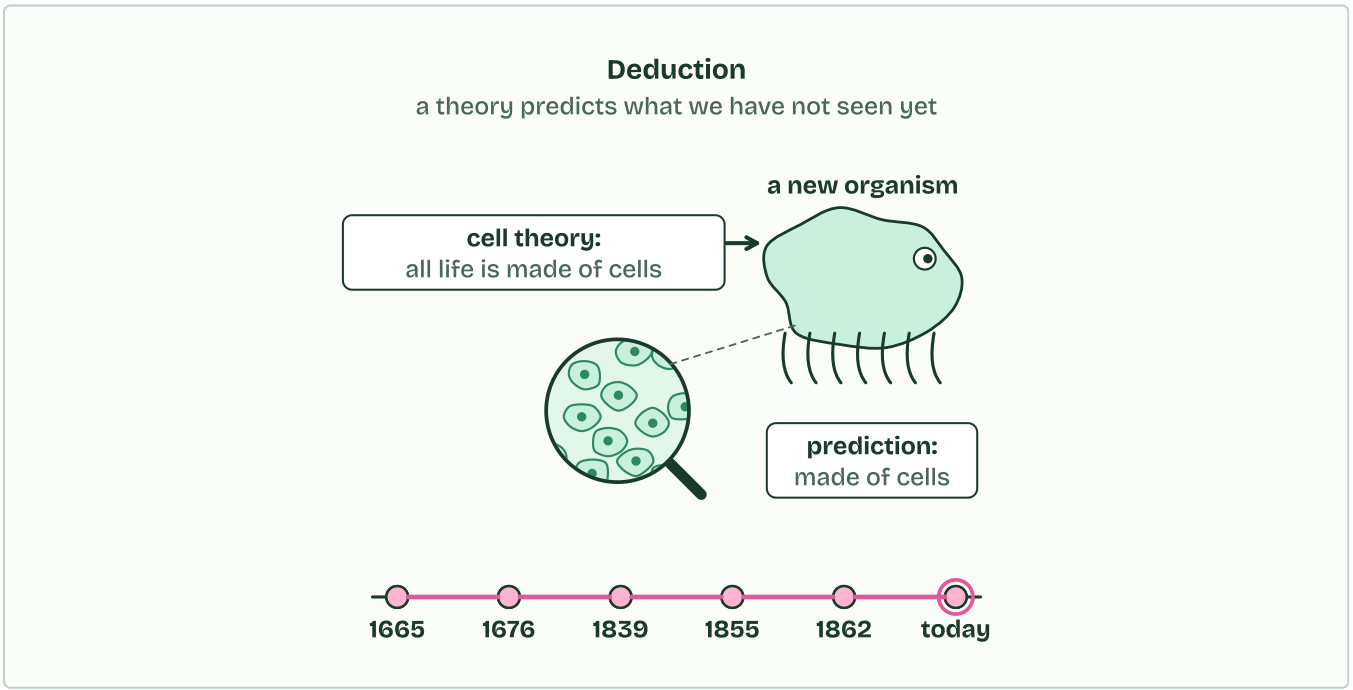
KEY POINTS

- All living things are made of cells, the cell is the smallest unit of life, and cells come only from cells.
- The theory was built from many observers' work with microscopes.
- A theory lets you predict: a newly discovered organism will be made of cells.

KEY TERMS

cell theory
The theory that all living things are made of cells, that the cell is the smallest unit of life, and that cells only come from cells that already exist.

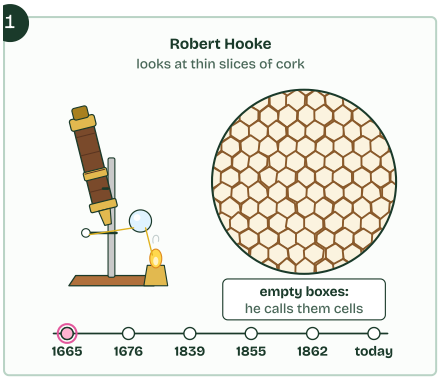
deduce
Reasoning from a general rule to a particular case: if every living thing is made of cells, then this new living thing will be too.



STEP BY STEP

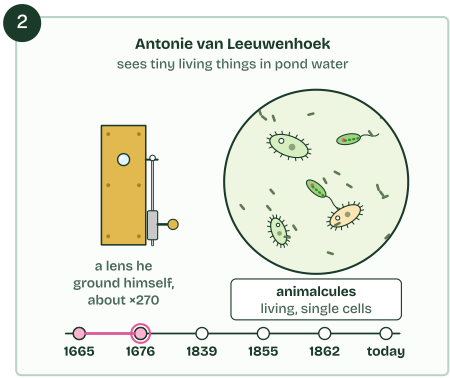
6 STEPS

1



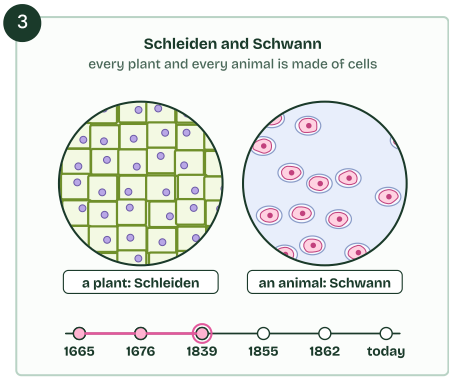
1665: Robert Hooke sees the walls of dead cells in cork, and names them **cells**.

2



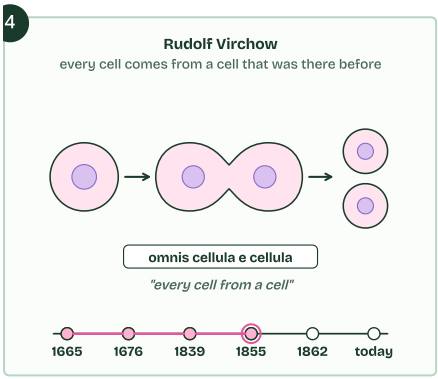
1670s: Antonie van Leeuwenhoek, with lenses he ground himself, sees **living single cells** in pond water.

3



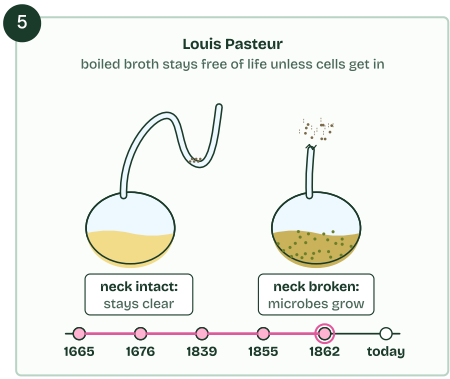
1838 and 1839: Schleiden finds that plants, and Schwann that animals, are **made of cells**.

4



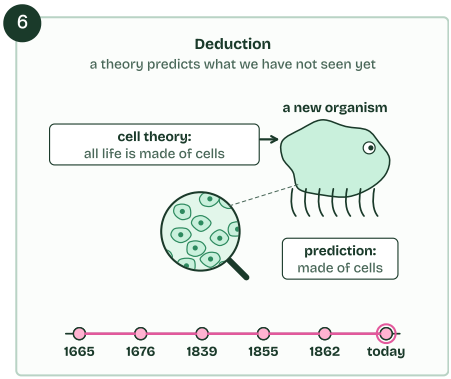
1855: Rudolf Virchow argues that **every cell comes from a cell**.

5



1860s: Louis Pasteur's swan-neck flasks: broth only grows microbes when **cells from outside** get in.

6



Today: the theory lets us **predict** that any new organism will be made of cells.

WATCH OUT

"Cells are the smallest living things" does not mean they are the smallest things in living things. Molecules and organelles are smaller, but none of them is alive on its own.

PREDICT

Biologists find a new kind of organism in a hot spring. Before they look at it under a microscope, what does cell theory let them predict?

(A) That it will be a bacterium, since only bacteria are able to live in water that hot

(B) That it will be made of one or more cells, each one made by another cell dividing

(C) Nothing, because a theory only explains the things that have already been observed

(D) That it will have a nucleus, a cell wall and mitochondria, as all cells do

Decide before you look. Answer on page 36.

02 Mount it, focus it, *measure* it

A2.2.2 MICROSCOPY SKILLS

Most cells are far too small to see. A light microscope shows them if the specimen is thin enough for light to pass through. A **temporary mount** is a thin layer of cells, such as onion skin or cells scraped from inside your cheek, in a drop of liquid on a slide, with a coverslip lowered at an angle so no air bubbles are trapped. A **stain** makes parts show up: iodine for plant cells, methylene blue for cheek cells.

Start with the lowest power objective and the coarse focus, then switch to a higher power and use only the fine focus. To measure, you need a scale. An **eyepiece graticule** is a scale in the eyepiece, but its units mean nothing until you line it up with a **stage micrometer**, a slide with a real scale on it. That is calibration, and it must be done again for each objective lens.

Measuring is a form of **quantitative observation**. Cells are measured in micrometres: 1 mm = 1000 µm, and 1 µm = 1000 nm. To find the **magnification** of a photograph or drawing, divide the image size by the actual size, in the same units. A **scale bar** does the same job and still works when the picture is enlarged.

KEY POINTS

- Calibrate the graticule against a stage micrometer, separately for each objective.
- Magnification = image size ÷ actual size; convert to the same units first.
- A scale bar is labelled with the real length it stands for.

KEY TERMS

temporary mount
A specimen put on a glass slide in a drop of water or stain, with a thin coverslip on top, for looking at straight away.

stain
A dye that colours some parts of a cell more than others, so they show up. Iodine stains starch blue-black; methylene blue stains nuclei.

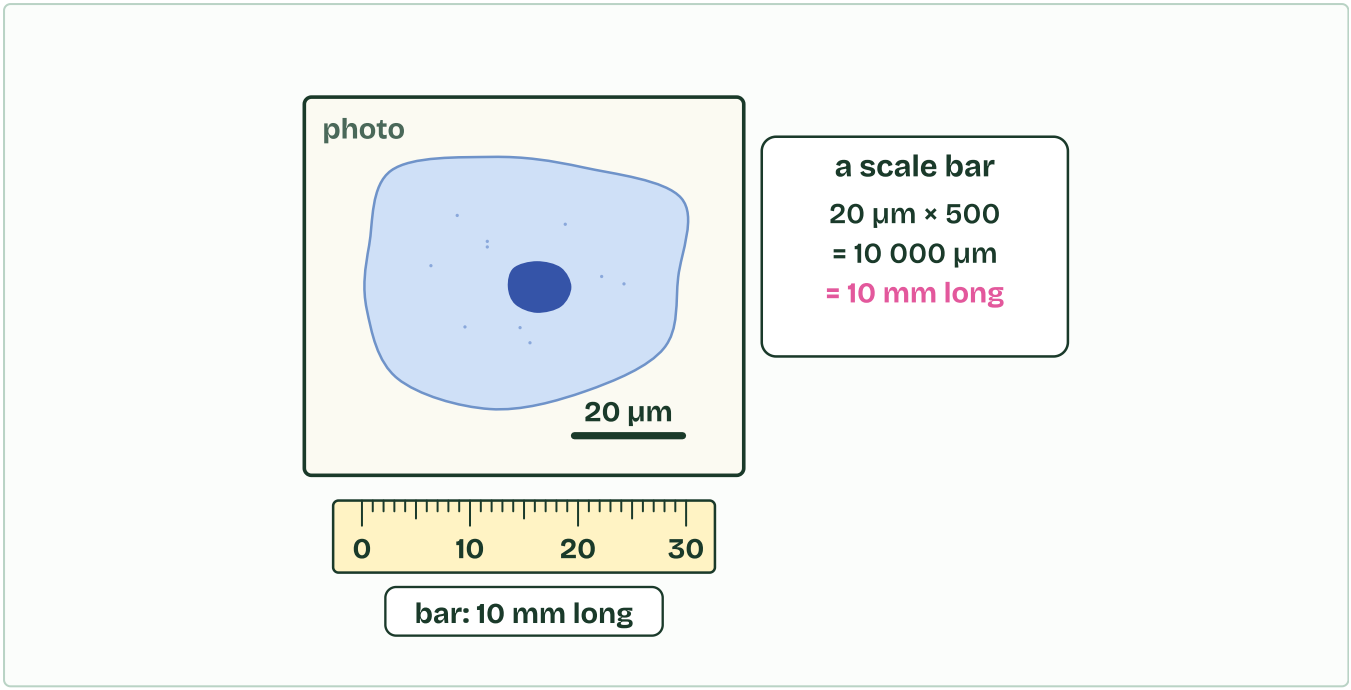
eyepiece graticule
A small scale fitted inside the eyepiece, seen over the specimen. Its units have no fixed size until it is calibrated.

stage micrometer
A slide with a tiny ruler engraved on it, usually 1 mm split into 100 divisions of 10 µm each.

quantitative observation
Observation that records an amount, with a number and a unit, rather than a description.

magnification
How many times bigger an image is than the real thing: image size divided by actual size, both in the same units.

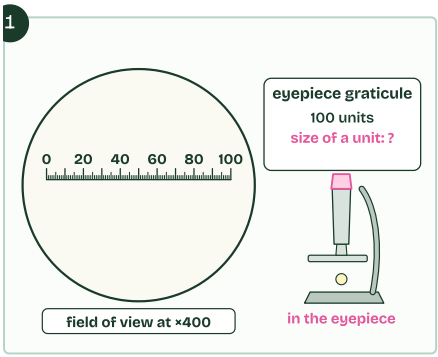
scale bar
A line on a micrograph or drawing labelled with the real length it stands for, so sizes can be read off at any enlargement.



STEP BY STEP

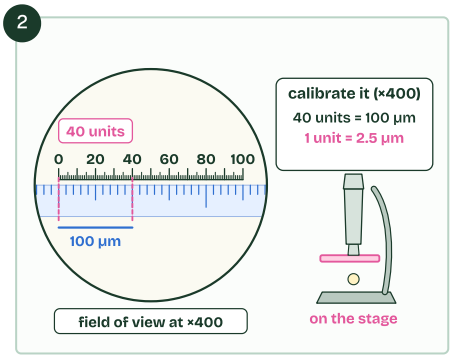
5 STEPS

1



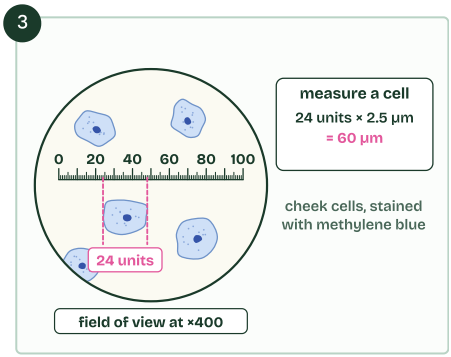
The **eyepiece graticule**: 100 units across the field, but how big is a unit?

2



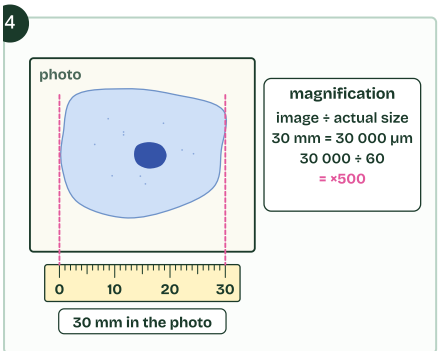
A **stage micrometer** underneath: 40 graticule units match 100 µm, so at ×400 **1 unit = 2.5 µm**.

3



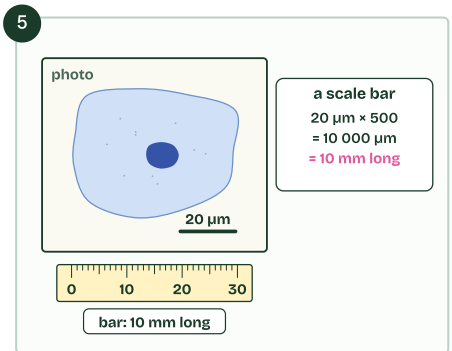
Swap in cheek cells. One is **24 units** across: 24 × 2.5 µm = **60 µm**.

4



In a photo the cell is 30 mm across. **Magnification = image ÷ actual** = 30 000 µm ÷ 60 µm = **×500**.

5



A **scale bar** for 20 µm on this photo is 20 × 500 = 10 000 µm, so **10 mm long**.

REMEMBER IT

Size and magnification

I	A	M
I	Am	Magnified
Image size what you measure on the picture	**Actual size** the real size: image ÷ magnification	**Magnification** image ÷ actual, same units

WATCH OUT

Most wrong answers to magnification questions are unit mistakes. Turn millimetres into micrometres (×1000) before you divide, and magnification has no units: it is "×500", not "500 µm".

PREDICT

A chloroplast is 5 µm long. In a photograph it is 25 mm long. What is the magnification?

(A) ×5, since 25 mm divided by 5 µm gives 5

(B) ×125, since 25 multiplied by 5 gives 125

(C) ×5000, since 25 000 µm divided by 5 µm gives 5000

(D) ×0.0002, since 5 µm divided by 25 000 µm is that

Decide before you look. Answer on page 36.

03 Seeing *smaller*: beyond the light microscope

A2.2.3 DEVELOPMENTS IN MICROSCOPY

Making an image bigger is easy. Making it sharper is the hard part. **Resolution** is how close two points can be and still be seen as separate. Light has a wavelength of about 0.5 µm, so no light microscope can separate points closer than about 0.2 µm. Magnify past about ×1500 and you just get a bigger blur.

An **electron microscope** uses a beam of electrons, whose wavelength is far shorter. Its resolution in a cell section is about 1 nm, a few hundred times better, so it shows the inside of organelles: the cristae of a mitochondrion, the ribosomes on the ER. The price: the specimen is dead, in a vacuum, cut very thin, and the image has no natural colour.

Three techniques pushed further. In **freeze fracture**, frozen cells are cracked open and the break runs through the middle of membranes, showing the proteins inside them. In **cryogenic electron microscopy**, thousands of copies of a protein are frozen in solution and imaged from every angle, and a computer combines them into a 3D model, without crystals. And back in light microscopy, **fluorescent stains** make one part of a living cell glow; in **immunofluorescence**, the dye rides on an antibody that binds a single protein.

KEY POINTS

- Light: living cells, colour, about 0.2 µm resolution.
- Electron: about 1 nm in a cell section; dead, thin specimens, no natural colour.
- Freeze fracture shows proteins inside membranes; cryo-EM gives protein structures; fluorescence picks out one part or one protein.

KEY TERMS

resolution
The smallest distance between two points that can still be seen as two separate points. The better the resolution, the finer the detail.

electron microscope
A microscope that uses a beam of electrons, with a far shorter wavelength than light, to form an image, giving much higher resolution.

freeze fracture
Freezing a specimen fast and cracking it, so the break often runs between the two layers of a membrane, showing the proteins embedded in it.

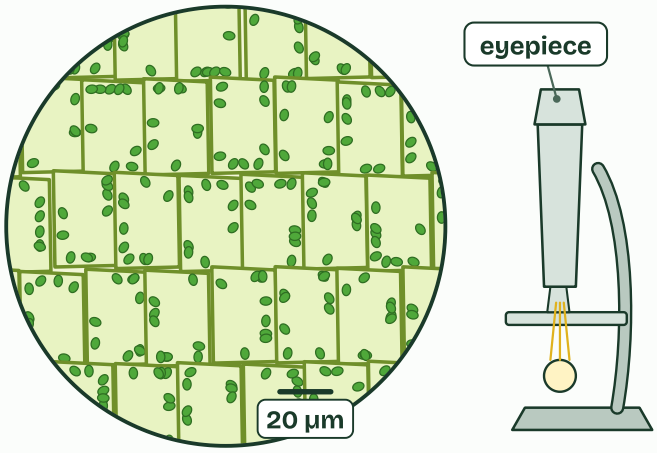
cryogenic electron microscopy
Electron microscopy of molecules frozen fast in a thin layer of water, imaged in many orientations and combined into a 3D structure.

fluorescent stains
A dye that glows a bright colour when lit by light of another wavelength, and binds to a particular part of the cell, such as DNA.

immunofluorescence
Using antibodies that bind one particular protein, each carrying a fluorescent dye, so that protein glows wherever it is in the cell.

Light microscope: up to about ×1500

living cells, in colour;
detail down to about 0.2 µm

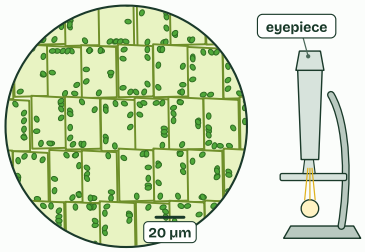


SWITCH IT

5 SETTINGS

1

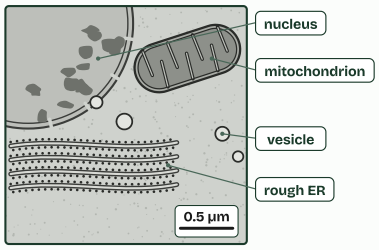
Light microscope: up to about ×1500
living cells, in colour;
detail down to about 0.2 µm



Light

2

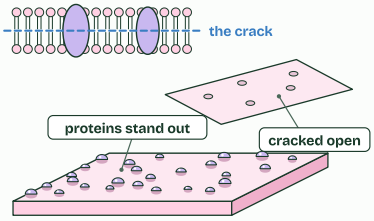
Electron microscope: up to ×1 000 000
far higher resolution, about 1 nm in a cell; dead, thin sections



Electron

3

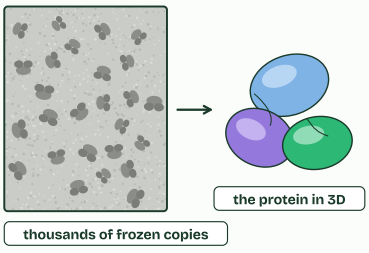
Freeze fracture
a frozen membrane splits between its two layers, showing the proteins inside it



Freeze fracture

4

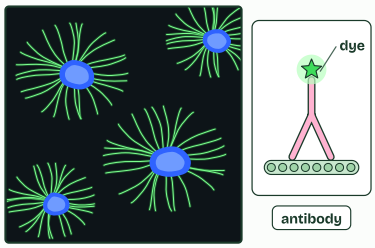
Cryogenic electron microscopy
proteins frozen in solution, imaged at many angles and combined



Cryo-EM

5

Fluorescent stains and immunofluorescence
a dye, or an antibody carrying one, lights up one part of the cell



Fluorescence

WATCH OUT

The electron microscope's main advantage is **resolution**, not magnification. A blurry picture made ten times bigger is still blurry.

PREDICT

A researcher wants to watch where one particular protein goes inside living cells over an hour. Which technique fits best?

(A) Transmission electron microscopy, because it has the highest resolution of all

(B) Freeze fracture, because it shows the proteins embedded inside membranes

(C) Immunofluorescence or a fluorescent tag, viewed with a light microscope

(D) Cryogenic electron microscopy, because it shows protein shapes in three dimensions

Decide before you look. Answer on page 36.

04 What *every* cell has

A2.2.4 STRUCTURES COMMON TO CELLS IN ALL LIVING ORGANISMS

Cells come in a huge range of shapes and sizes, but they all share a few parts, and each one is there for a reason.

DNA is the genetic material. It holds the instructions for making the cell's proteins, and it is copied each time the cell divides, so each new cell gets a set. **Cytoplasm** fills the cell. It is mostly water, which dissolves the substances the cell uses, so they can move about and react. Most of the cell's metabolism happens here, run by enzymes.

A **plasma membrane** encloses the cytoplasm. It is made of lipids, which do not dissolve in water, so it can hold a watery inside apart from a watery outside. That keeps the cell's contents together and lets it control what comes in and goes out. Nearly every cell also has **ribosomes** to make proteins, though the guide treats them with each type of cell.

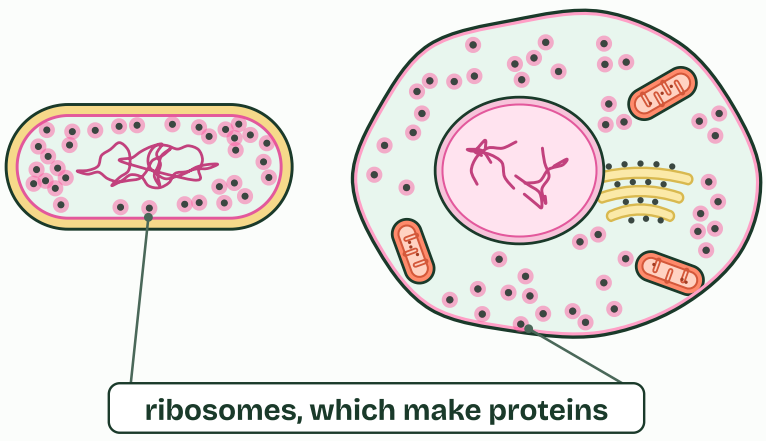
KEY POINTS

- DNA: the instructions, passed on when the cell divides.
- Cytoplasm, mostly water: the medium for the cell's reactions.
- Plasma membrane, made of lipids: a barrier that encloses the cell and controls what crosses.

KEY TERMS

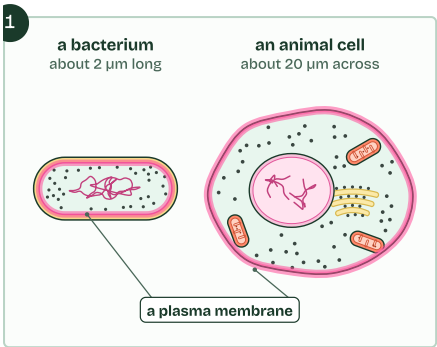
plasma membrane
The membrane round every cell, a double layer of phospholipids with proteins in it. It controls what enters and leaves.

ribosomes
Small structures made of RNA and protein that build proteins by joining amino acids in the order the mRNA codes for.



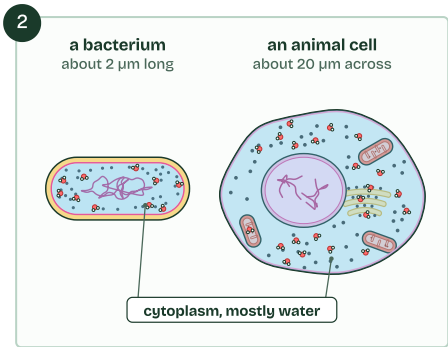
STEP BY STEP
4 STEPS

1



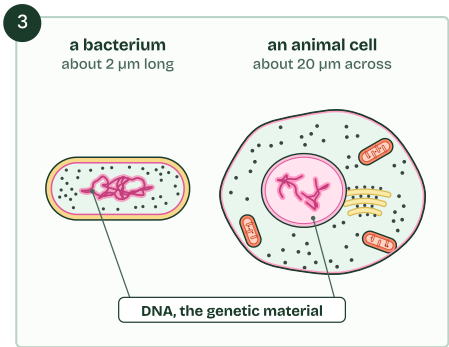
Both cells are wrapped in a **plasma membrane** made of lipids.

2



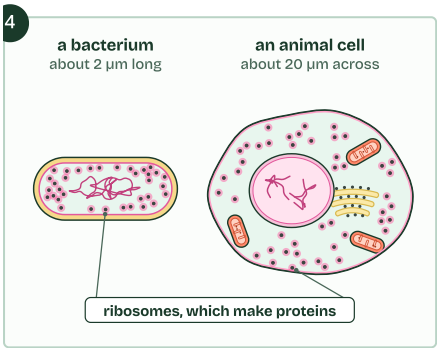
Both are filled with **cytoplasm**, which is mostly water.

3



Both have **DNA**: a loop in the bacterium, chromosomes in the animal cell's nucleus.

4



Both have **ribosomes** to make proteins, though of different sizes.

WATCH OUT

A cell wall is not on this list. Animal cells have none, so it is not common to all cells. Every cell has a plasma membrane, including those that also have a wall outside it.

PREDICT

Why is the plasma membrane made of lipids rather than proteins or carbohydrates?

(A) Lipids are the strongest molecules, so they protect the cell from being damaged

(B) Lipids do not dissolve in water, so a layer of them can keep two watery spaces apart

(C) Lipids store energy, so the membrane acts as a fuel supply for the rest of the cell

Decide before you look. Answer on page 36.

05 The prokaryote: small, and *no nucleus*

A2.2.5 PROKARYOTE CELL STRUCTURE

Prokaryotes are the bacteria and archaea. The name means "before the nucleus": their DNA is not inside a nucleus. Most are 1 to 5 µm long, and they divide by **binary fission**. The drawing is a Gram-positive bacterium such as *Bacillus* or *Staphylococcus*.

Outside is a **cell wall** of **peptidoglycan**, thick in Gram-positive bacteria. It keeps the cell's shape and stops it bursting when water comes in. Inside the wall is the **plasma membrane**, then the **cytoplasm**. The DNA is one loop, not wound round proteins, so it is called **naked DNA**. It sits in a region called the **nucleoid**, with no membrane round it. The cytoplasm is packed with **70S ribosomes**, smaller than those of eukaryotes.

Prokaryotes vary. Many have extra small loops of DNA called plasmids, or a flagellum, or hair-like pili, and a few have no wall at all. You do not need the details of these variations.

KEY POINTS

- Cell wall (peptidoglycan), plasma membrane, cytoplasm.
- Naked DNA in a loop, in the nucleoid: no nucleus.
- 70S ribosomes; no membrane-bound organelles.

KEY TERMS

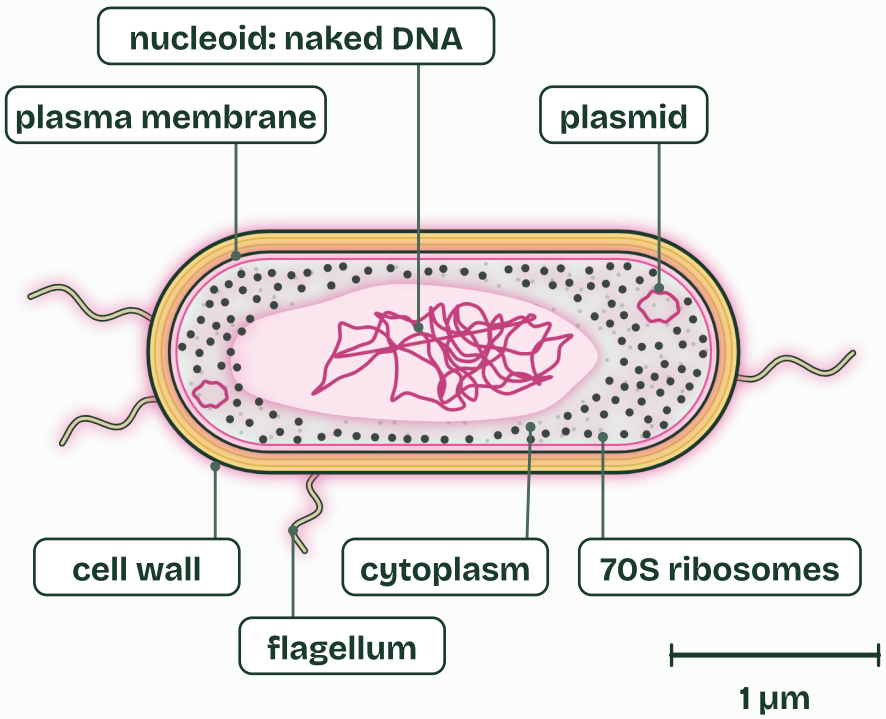
prokaryotes
Cells with no nucleus and no membrane-bound organelles: bacteria and archaea.

binary fission
How a prokaryote divides: its loop of DNA is copied, and the cell splits in two.

peptidoglycan
The material of bacterial cell walls: sugar chains cross-linked by short chains of amino acids. Gram-positive bacteria have a thick layer.

naked DNA
DNA that is not bound to histone proteins, as in prokaryotes and in mitochondria and chloroplasts.

nucleoid
The region of a prokaryote's cytoplasm where its DNA is. It has no membrane round it.



Flagellum A long protein whip that spins to drive the cell along. Bacillus has many; not every bacterium has one.

Cell wall A thick layer of peptidoglycan outside the membrane. It keeps the cell's shape and stops it bursting when water comes in.

Plasma membrane A phospholipid bilayer just inside the wall. It controls what enters and leaves the cytoplasm.

Nucleoid The region where the DNA is: one loop of naked DNA, not wound round histones, with no membrane round it.

70S ribosomes Smaller than the 80S ribosomes of a eukaryote. They make the cell's proteins.

Cytoplasm Mostly water, with enzymes, ribosomes and the DNA in it. Most of the cell's metabolism happens here.

Plasmid A small extra loop of DNA, found in many bacteria but not all. Plasmids can carry genes such as antibiotic resistance, and can pass from cell to cell.

WATCH OUT

The nucleoid is not a nucleus. It is just the part of the cytoplasm where the DNA lies, with no membrane round it.

PREDICT

An antibiotic stops 70S ribosomes working. Why does it harm bacteria much more than the human cells around them?

(A) Human cells have no ribosomes at all, so the antibiotic has nothing to act on

(B) Bacteria have no cell wall to protect their ribosomes from the antibiotic outside

(C) The ribosomes in human cytoplasm are the larger 80S kind, which it does not affect

Decide before you look. Answer on page 36.

06 The eukaryote: a cell of *compartments*

A2.2.6 EUKARYOTE CELL STRUCTURE

Eukaryotes are animals, plants, fungi and protists. Their cells are usually 10 to 100 µm across, and their cytoplasm is divided by membranes into **compartments**. Each compartment can hold its own enzymes and conditions, so reactions that would clash are kept apart.

The **nucleus** holds the chromosomes, each one long DNA molecule wound round proteins called **histones**. It is enclosed by a double membrane with pores. In the cytoplasm are **80S ribosomes** and membrane-bound organelles: **mitochondria** for respiration, the **endoplasmic reticulum** (rough, with ribosomes, and smooth), the **Golgi apparatus**, and many **vesicles** and vacuoles, including **lysosomes**. A **cytoskeleton** of microtubules and microfilaments holds the shape and moves things around. Tap each part to read what it does.

KEY TERMS

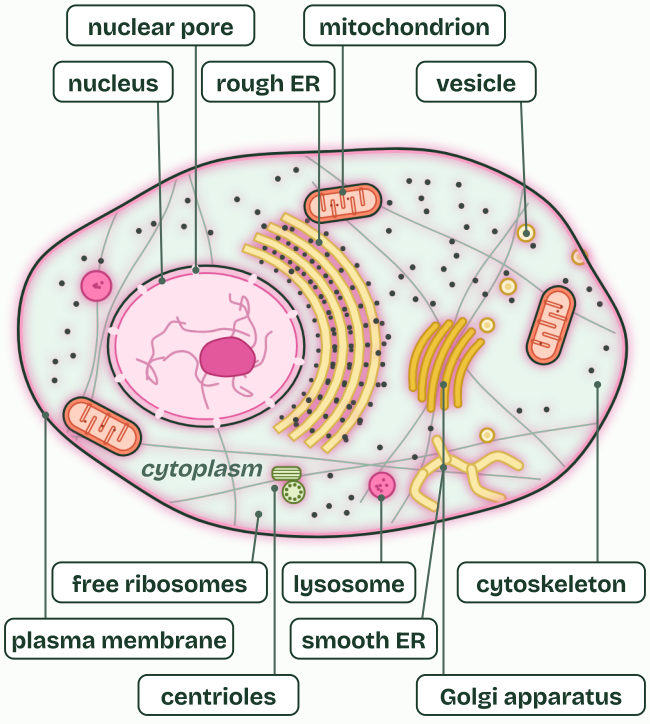
eukaryotes
Cells with a nucleus and membrane-bound organelles: the cells of animals, plants, fungi and protists.

compartments
Separate spaces inside a cell, each enclosed by a membrane, so different conditions and reactions can be kept apart.

histones
Proteins that DNA winds round in a eukaryote's chromosomes, packing it and controlling which genes can be used.

lysosomes
Vesicles full of digestive enzymes that break down worn-out organelles and material the cell has taken in.

cytoskeleton
A network of protein fibres, microtubules and microfilaments, that gives a eukaryotic cell its shape and moves things inside it.



Cytoskeleton Microtubules and microfilaments, protein fibres that hold the cell's shape and move things through it. (Drawn here as a few faint lines.)

Rough endoplasmic reticulum Flattened sacs studded with ribosomes. The proteins they make go into the sacs, to be sent to the Golgi apparatus and out of the cell.

Smooth endoplasmic reticulum Tubes with no ribosomes. It makes lipids, such as phospholipids and steroid hormones.

Lysosome A vesicle of digestive enzymes. It breaks down worn-out organelles and anything the cell takes in.

Centrioles Two short cylinders of microtubules at right angles. In an animal cell they organise the spindle that moves chromosomes when the cell divides.

Plasma membrane A bilayer of phospholipids with proteins in it. It encloses the cytoplasm and controls what enters and leaves the cell.

Nucleus Holds the chromosomes, each one DNA molecule wound round histone proteins. A double membrane, the nuclear envelope, surrounds it, with pores that let mRNA out.

Golgi apparatus A stack of curved sacs. It modifies proteins from the rough ER and packs them into vesicles.

Mitochondrion A double membrane, the inner one folded into cristae. Aerobic respiration here makes most of the cell's ATP.

Vesicle A small sac of membrane that carries substances around the cell, such as proteins from the Golgi apparatus to the plasma membrane.

Free ribosomes 80S ribosomes loose in the cytoplasm. They make proteins that stay and work in the cytoplasm.

REMEMBER IT

Prokaryote against eukaryote

N Never	R Ride	D Dragons	O Over	S Seas
Nucleus none against a nucleus	**Ribosomes** 70S against 80S	**DNA** naked loop against chromosomes with histones	**Organelles** none membrane-bound against many	**Size** 1 to 5 µm against 10 to 100 µm

WATCH OUT

"Prokaryotes have no organelles" is too strong: they have ribosomes. What they lack are **membrane-bound** organelles.

PREDICT

A cell is 40 µm across, has 80S ribosomes and a cytoskeleton, but in this electron micrograph no nucleus can be seen. Which is the best conclusion?

(A) It is a prokaryote, because a cell with no nucleus visible must be one

(B) It is a eukaryote; the section may have missed the nucleus, or it lost it

(C) It is a virus, because viruses are the only cells that never contain a nucleus

Decide before you look. Answer on page 36.

07 One cell, *every* job

A2.2.7 PROCESSES OF LIFE IN UNICELLULAR ORGANISMS

A single-celled organism is a whole living thing in one cell. Every function of life has to be carried out by that one cell. There are eight to know.

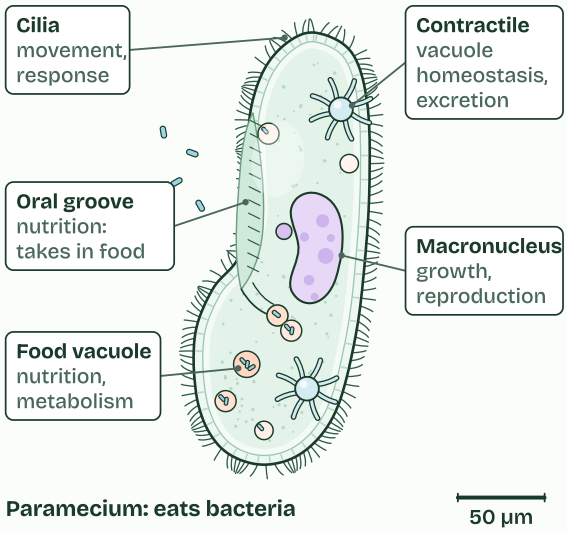
Metabolism: all the chemical reactions in it. **Nutrition**: getting food, by eating or by photosynthesis. **Growth**: getting bigger. **Reproduction**: making more of itself. **Movement**: getting from place to place. **Response**: reacting to changes around it. **Homeostasis**: keeping its inside steady. **Excretion**: getting rid of the waste of metabolism.

Paramecium lives in ponds and eats bacteria. Cilia beat to move it and sweep food into its oral groove, where food vacuoles form and digest it. Pond water keeps entering by osmosis, so contractile vacuoles pump the extra out: homeostasis. Carbon dioxide and ammonia diffuse out across the membrane. It reproduces by dividing in two. *Chlamydomonas* photosynthesises in its chloroplast and swims towards light, which it senses with an eyespot.

KEY TERMS

homeostasis
Keeping conditions inside an organism within limits, such as its water content or temperature.

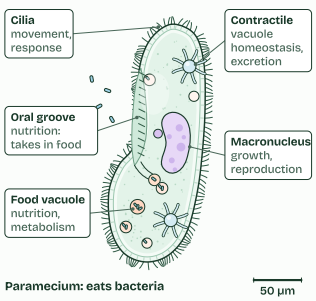
excretion
Getting rid of the waste products of metabolism, such as carbon dioxide or ammonia.



Paramecium: eats bacteria

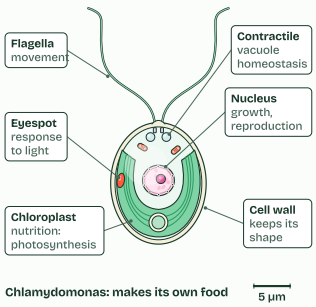
SWITCH IT 2 SETTINGS

1



Paramecium

2



Chlamydomonas

REMEMBER IT

The eight functions of life

M	H	N	M	E	G	R	R
Many	Hungry	Newts	Munch	Eggs	Grubs	Roots	Rice
Metabolism	**Homeostasi**	**Nutrition**	**Movement**	**Excretion**	**Growth**	**Response**	**Reproductic**
all its chemical reactions	keeping the inside steady	eating or photosynthesi	cilia or flagella	removing metabolic waste	getting bigger	reacting to its surroundings	making more of itself

WATCH OUT

Excretion is not egestion. Pushing out undigested food from a food vacuole is egestion; excretion removes waste made by the cell's own metabolism, such as carbon dioxide.

PREDICT

A *Paramecium* is moved from pond water into a salt solution as concentrated as its cytoplasm. What happens to its contractile vacuoles?

(A) They fill and empty faster, to pump out the salt that now diffuses into the cell

(B) They fill and empty far more slowly, as water stops flooding in by osmosis

(C) They stay the same, since contractile vacuoles are there to get rid of food waste

Decide before you look. Answer on page 36.

08 Plant, fungus, animal: *spot* the difference

A2.2.8 DIFFERENCES IN EUKARYOTIC CELL STRUCTURE BETWEEN ANIMALS, FUNGI AND PLANTS

All three are eukaryotes, with a nucleus, mitochondria, ER and Golgi. They differ in a few clear ways.

Cell walls. Plant cells have a wall of cellulose and fungal cells a wall of **chitin**. Animal cells have no wall. **Vacuoles.** A plant cell has one large, permanent **sap vacuole** that stores sugars and salts and keeps the cell firm. Fungal cells often have large vacuoles too. Animal cells have only small, temporary ones. **Plastids.** Only plants have **plastids**: chloroplasts in green tissue, and amyloplasts that store starch, as in a potato. Fungi have none: they feed on other organisms.

Centrioles, cilia and flagella. Animal cells have centrioles, and many have cilia (lining the airways) or a flagellum (a sperm). Flowering plants have none of these, and most fungi have none.

KEY POINTS

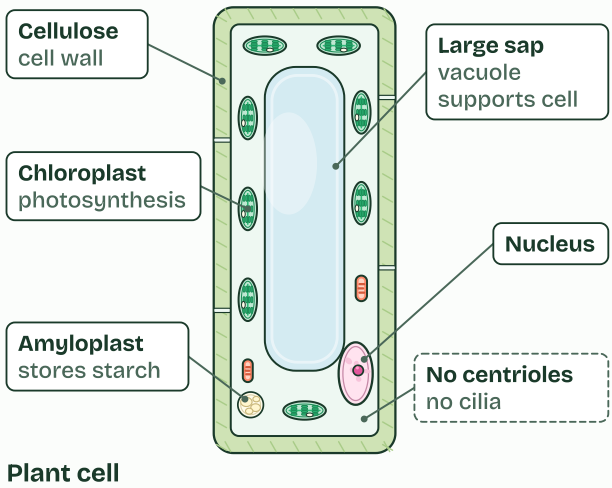
- Walls: cellulose in plants, chitin in fungi, none in animals.
- Vacuoles: large and permanent in plants, often large in fungi, small and temporary in animals.
- Plastids only in plants; centrioles, cilia and flagella mainly in animals.

KEY TERMS

chitin
A tough polysaccharide that makes fungal cell walls and the outer skeletons of insects.

sap vacuole
A large vacuole in a plant cell, full of a watery solution of sugars and salts, that stores substances and keeps the cell firm by pressing out on the wall.

plastids
A family of double-membraned organelles in plants and algae: chloroplasts for photosynthesis, amyloplasts that store starch, and others that hold pigments.

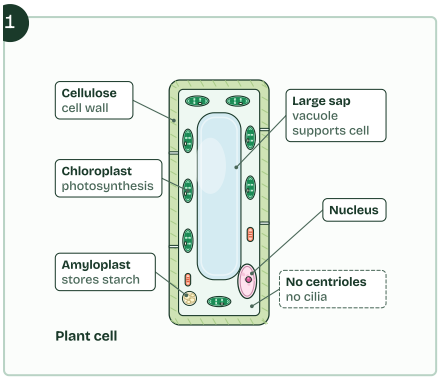


Plant cell

SWITCH IT

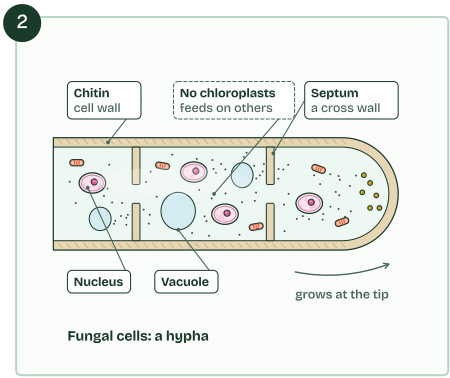
3 SETTINGS

1



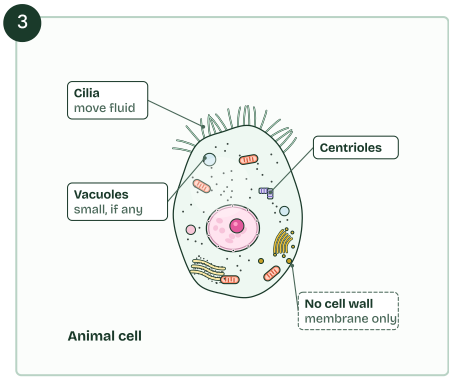
Plant

2



Fungus

3



Animal

WATCH OUT

Not every plant cell has chloroplasts. Root cells are underground and have none, but they still have a wall, a sap vacuole and other plastids such as amyloplasts.

PREDICT

A cell has a cell wall, a large vacuole and no chloroplasts. What could it be?

(A) Only an animal cell, since plant cells must all have their chloroplasts

(B) Only a fungal cell, as fungi are the only cells with walls and no chloroplasts

(C) A fungal cell, or a plant cell from a part with no light such as a root

Decide before you look. Answer on page 36.

09

A2.2.9 ATYPICAL CELL STRUCTURE IN EUKARYOTES

Cells that break the *rules*

A typical eukaryotic cell has one nucleus. Some do not, and counting their nuclei is a quick way to see how they differ from the textbook cell.

Many nuclei. Some fungi grow as **aseptate hyphae**: long tubes with no cross walls, so hundreds of nuclei share one stretch of cytoplasm. A **skeletal muscle fibre** forms when many cells fuse, so one fibre can be several centimetres long, with many nuclei pressed against its membrane.

No nucleus. A mammal's **red blood cell** loses its nucleus as it matures. That leaves more room for haemoglobin, but means it cannot divide or repair itself, and lasts only about 120 days. A **phloem sieve tube element** loses its nucleus and most organelles, leaving an open tube for sap to flow through. A **companion cell** beside it keeps it alive.

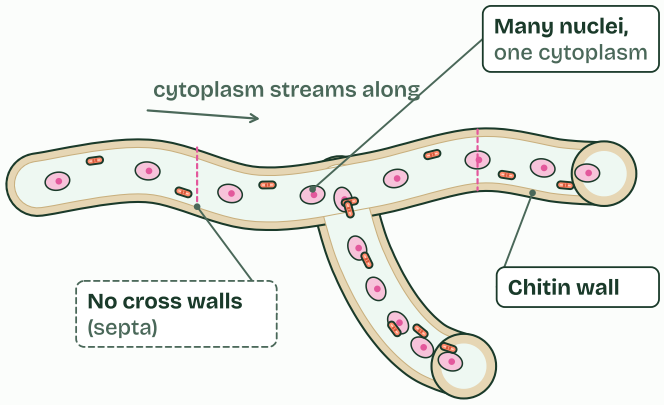
KEY POINTS

- Many nuclei: aseptate fungal hyphae and skeletal muscle fibres.
- No nucleus: red blood cells in mammals and phloem sieve tube elements.
- The unusual structure suits the cell's job.

KEY TERMS

aseptate hyphae
Fungal hyphae with no cross walls, so the cytoplasm and many nuclei run continuously along a long tube.

companion cell
A cell beside each phloem sieve tube element, with a nucleus and many mitochondria, that keeps the sieve tube alive and loads it with sugar.

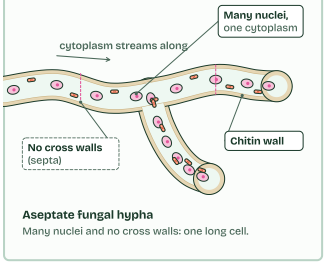


Aseptate fungal hypha
Many nuclei and no cross walls: one long cell.

SWITCH IT

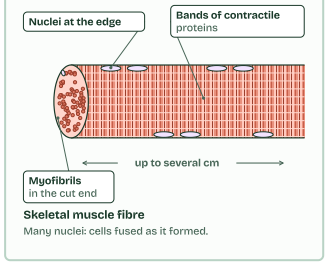
4 SETTINGS

1



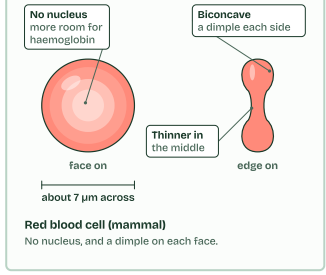
Hypha

2



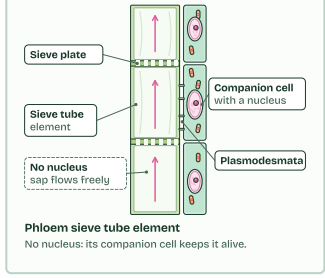
Muscle

3



Red blood cell

4



Phloem

WATCH OUT

Do these cells disprove cell theory? Not really. They are still made of cells and from cells; they show that "one cell, one nucleus" is a common pattern, not a law. A muscle fibre is the hardest case: is it one cell, or many fused?

PREDICT

A mature red blood cell cannot make new proteins. Why?

(A) It is full of haemoglobin, which blocks its ribosomes from reaching the amino acids

(B) It has no nucleus, so there is no DNA to copy into new mRNA for its ribosomes

(C) It has no mitochondria, so it has no energy left over to spend on making proteins

Decide before you look. Answer on page 37.

10 Reading a *micrograph*

A2.2.10 A2.2.11 MICROGRAPHS: IDENTIFYING, DRAWING AND ANNOTATING

A **micrograph** is a photograph through a microscope. To say what kind of cell it shows, look for a few clues. No nucleus, and small: a prokaryote. A wall, a large vacuole and perhaps chloroplasts: a plant. No wall and no large vacuole: an animal. Electron micrographs are in shades of grey, so you go by shape, not colour.

The structures to know by sight in an electron micrograph are the nucleoid and the prokaryotic cell wall, the nucleus, mitochondria, chloroplasts, the sap vacuole, the Golgi apparatus, rough and smooth ER, chromosomes, ribosomes, the cell wall, the plasma membrane and microvilli. Chromosomes only show as separate threads in a dividing cell. Switch between the three micrographs and name each numbered part before you tap it.

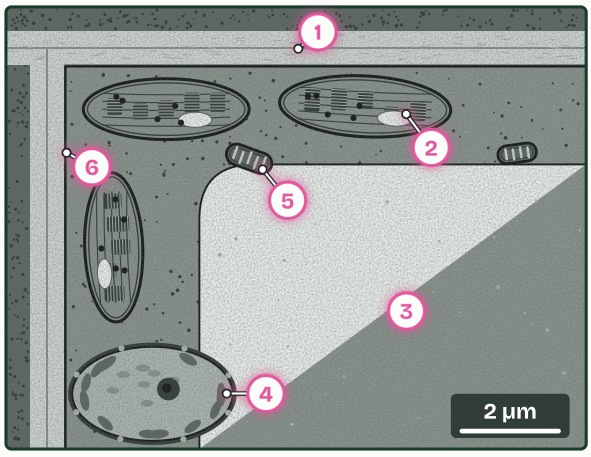
A drawing from a micrograph shows what is really there, simplified. Use a sharp pencil and clear, unbroken lines, with no shading. Draw each structure in proportion. Label with ruled lines that do not cross, and **annotate**: add the function of each part beside its name. Give a title, and a scale bar or the magnification.

KEY POINTS

- Identify the cell type from a few features: nucleus, wall, vacuole, chloroplasts.
- In electron micrographs, go by shape and membranes, not colour.
- Drawings: pencil, clean lines, no shading, ruled labels, functions in the annotations.

KEY TERMS

micrograph
A photograph taken through a microscope: a light micrograph or an electron micrograph.



Part of a leaf cell
drawn as seen in an electron microscope

1 Cell wall The thick, even band outside the membrane: plant cells and prokaryotes have one, animal cells do not.

2 Chloroplast An oval with a double membrane and stacks of thylakoid membranes (grana) inside.

3 Sap vacuole The big, pale, almost empty space in the middle, bounded by its own membrane.

5 Mitochondrion Smaller than a chloroplast, with a double membrane, the inner one folded into cristae.

1 Microvilli Rows of tiny fingers of plasma membrane: they increase the surface area for absorption.

3 Rough ER Flattened sacs in parallel, dotted with ribosomes on their outer surface.

5 Nucleus The large round body with a double membrane and pores.

7 Smooth ER Branching tubes with no ribosomes on them.

2 Plasma membrane The thin line just inside the wall.

4 Ribosomes The dark grains that fill the cytoplasm and make it look grainy.

4 Nucleus The largest structure: a double membrane with pores, darker patches of chromatin.

6 Plasma membrane The thin line pressed against the inside of the wall.

2 Mitochondrion A double membrane with the inner one folded into cristae.

4 Golgi apparatus A stack of curved, flattened sacs, with vesicles at the edges and no ribosomes.

6 Secretory vesicle A small round sac of membrane, often near the Golgi apparatus or the plasma membrane.

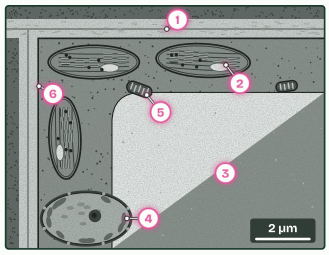
1 Cell wall The outer band round the whole cell.

3 Nucleoid A pale region with fine strands of DNA in it and no membrane round it.

SWITCH IT

3 SETTINGS

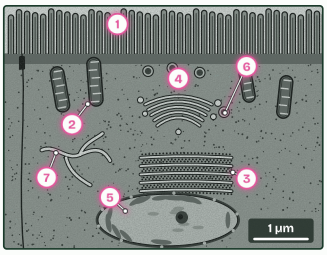
1



Part of a leaf cell
drawn as seen in an electron microscope

Leaf cell

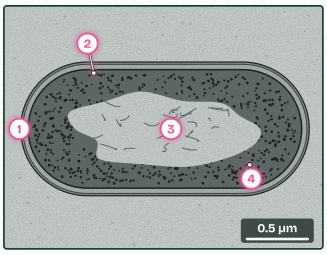
2



Part of a cell lining the gut
drawn as seen in an electron microscope

Gut cell

3



A bacterium
drawn as seen in an electron microscope

Bacterium

WATCH OUT

An annotation is more than a label. "Mitochondrion" is a label; "mitochondrion: aerobic respiration makes ATP" is an annotation.

PREDICT

In an electron micrograph you see a stack of curved, flattened sacs with small round vesicles at their edges and no dots on them. What is it?

(A) Rough endoplasmic reticulum, which is made of flattened sacs

(B) The Golgi apparatus, a stack of curved sacs that buds off vesicles

(C) A mitochondrion, whose inner membrane is folded into cristae

Decide before you look. Answer on page 37.

11

A2.2.12 HL ORIGIN OF EUKARYOTIC CELLS BY ENDOSYMBIOSIS

The cell that *swallowed* a bacterium

All eukaryotes seem to descend from one single-celled ancestor that already had a nucleus and reproduced sexually. Mitochondria came later. The theory of **endosymbiosis** says that this ancestor took in an aerobic bacterium by engulfing it, and did not digest it. The bacterium lived on inside, using food from its host and giving it plenty of ATP from aerobic respiration. Over many generations it became the mitochondrion.

Some of these cells later took in a photosynthetic bacterium, a cyanobacterium, in the same way. It became the chloroplast, which is why plants and algae have both organelles, and animals and fungi only mitochondria.

The evidence is that mitochondria and chloroplasts still look like bacteria. They have **70S ribosomes**, like prokaryotes, not the 80S ones in the cytoplasm around them. They have their own **naked, circular DNA**. They **divide on their own**: a cell cannot make one from scratch, only by splitting an existing one. They also have **two membranes**, the inner one their own and the outer one from the engulfing. A theory is strong when it explains many separate observations, and this one explains them all.

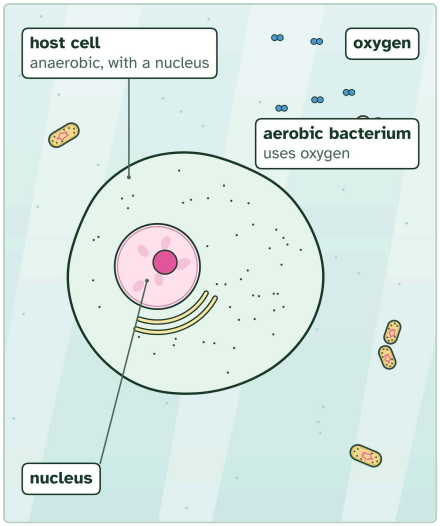
KEY TERMS

endosymbiosis
The theory that mitochondria and chloroplasts began as free-living prokaryotes that were taken into a larger cell and lived on inside it, to the benefit of both.

ANIMATION · TAKING IN A PARTNER

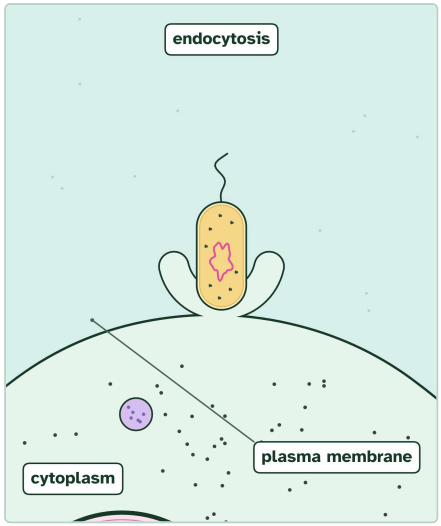
12 MOMENTS

1 THE ANCIENT SEA



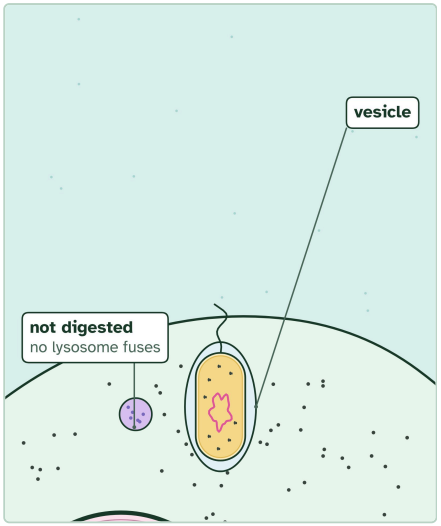
Long ago, a large **anaerobic** cell with a **nucleus** lives among small prokaryotes. Some are **aerobic bacteria**: they use oxygen to release far more energy from food.

2 ENDOCYTOSIS



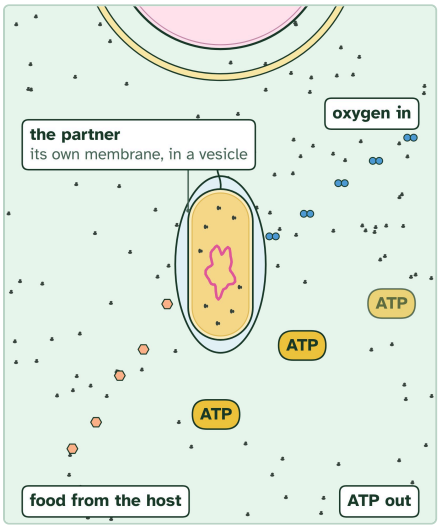
The host's plasma membrane flows round an aerobic bacterium: **endocytosis**.

3 INSIDE A VESICLE



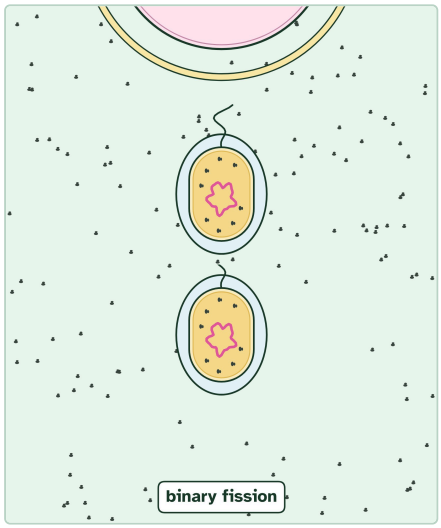
The membrane pinches off a **vesicle**. The bacterium is inside the cell, wrapped in the host's membrane, and it is **not digested**.

4 PARTNERS



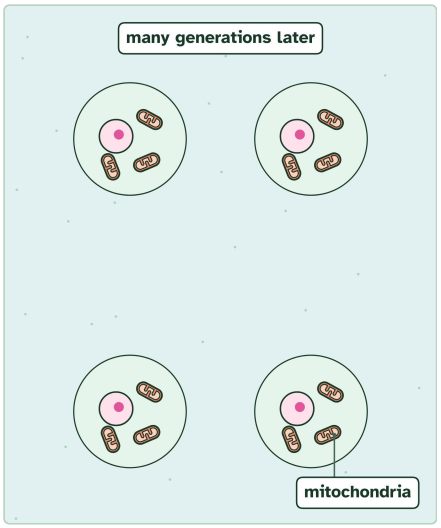
A **partnership**: the host supplies food, and the bacterium uses **oxygen** to make far more **ATP** than the host could alone.

5 BINARY FISSION



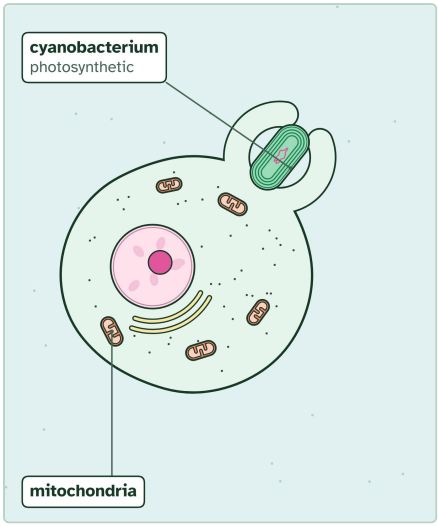
Inside its host the bacterium still **divides in two**, by binary fission.

6 MITOCHONDRION



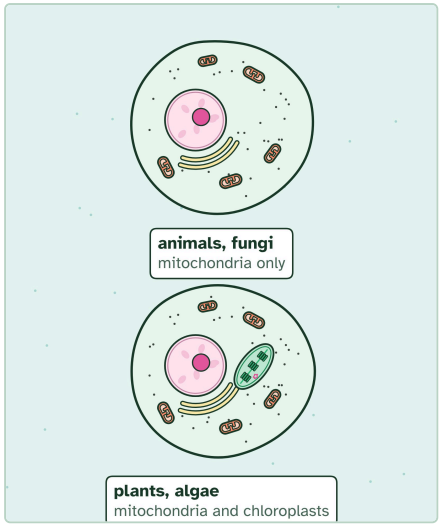
Each time the host divides, both daughters inherit partners. Over **many generations** neither can live without the other: the bacterium has become the **mitochondrion**.

7 A CYANOBACTERIUM



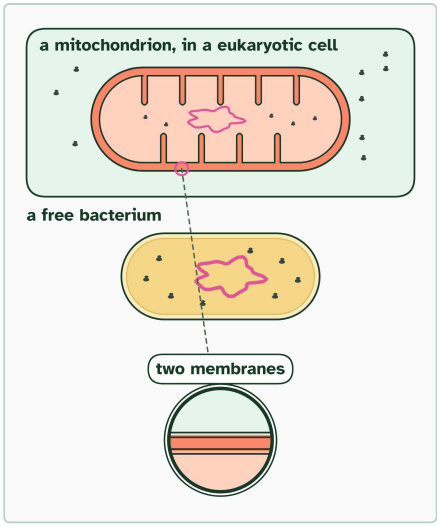
Later, **some** of these cells take in a **cyanobacterium**, which photosynthesises, in the same way.

8 CHLOROPLAST



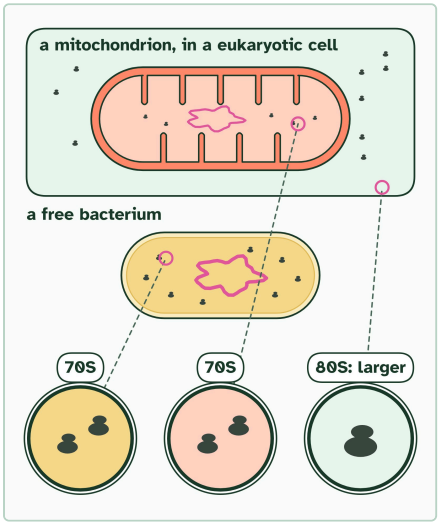
It becomes the **chloroplast**. So plants and algae have both organelles, while animals and fungi have only mitochondria.

9 TWO MEMBRANES



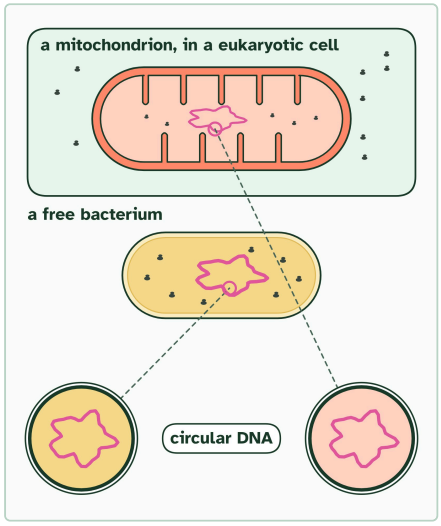
The evidence: a mitochondrion still looks like a bacterium. It has **two membranes**, the outer one from the vesicle it was taken in by.

10 70S RIBOSOMES



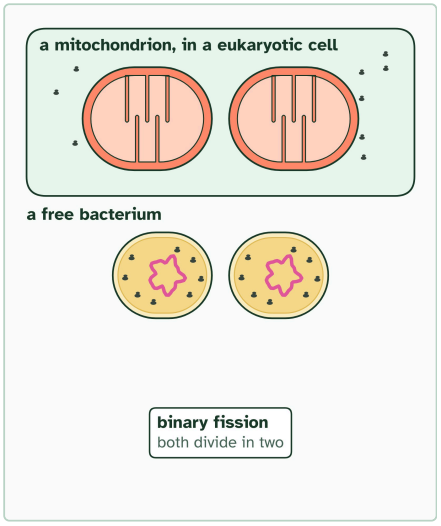
70S ribosomes, like a prokaryote's, not the larger 80S ribosomes of the cytoplasm around it.

11 CIRCULAR DNA



Its own **naked, circular DNA**, like a bacterium's, not the linear chromosomes of the nucleus.

12 DIVIDES IN TWO



And it can only **divide in two**, as a bacterium does: a cell cannot make one from scratch. Chloroplasts show all the same evidence.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-a2-2-cell-structure#endosymbiosis

REMEMBER IT

The evidence for endosymbiosis

D Dad's	R Rusty	D Diesel	D Delivers
Double membrane the outer one from the engulfing	**Ribosomes** 70S, like a prokaryote's	**DNA** naked and circular	**Divides** only from existing ones

WATCH OUT

Endosymbiosis does not explain where the nucleus came from. The ancestor already had a nucleus before it took in the bacterium that became the mitochondrion.

PREDICT

If a cell lost all its mitochondria, could it make new ones from its own nuclear genes and membranes?

(A) Yes, because the instructions for every organelle are held in the DNA of the nucleus

(B) No, because new mitochondria only ever form when an existing one divides

(C) Yes, as long as the cell still has its endoplasmic reticulum to build membranes

Decide before you look. Answer on page 37.

12 Same genes, *different* cells

A2.2.13 HL A2.2.14 HL CELL DIFFERENTIATION AND THE EVOLUTION OF MULTICELLULARITY

Every cell in your body came from one fertilised egg, and nearly all of them carry the same genes. Yet a nerve cell and a muscle cell look and work nothing alike. The difference is in which genes are used. **Differentiation** happens because different cells have different patterns of **gene expression**: some genes switched on, the rest off. What switches them is often a change in the cell's surroundings, such as a signal from neighbouring cells. The proteins made then give the cell its shape and its job, and similar cells together form a tissue.

Being multicellular has two big advantages. An organism can grow far larger than any single cell. And its cells can **specialise**, each doing one job well, while others do the rest.

Multicellularity did not evolve just once. It arose separately in animals, in plants, in red algae, in brown algae and several times in fungi. Many fungi and algae and all plants and animals are multicellular; most other eukaryotes, and all prokaryotes, are single cells.

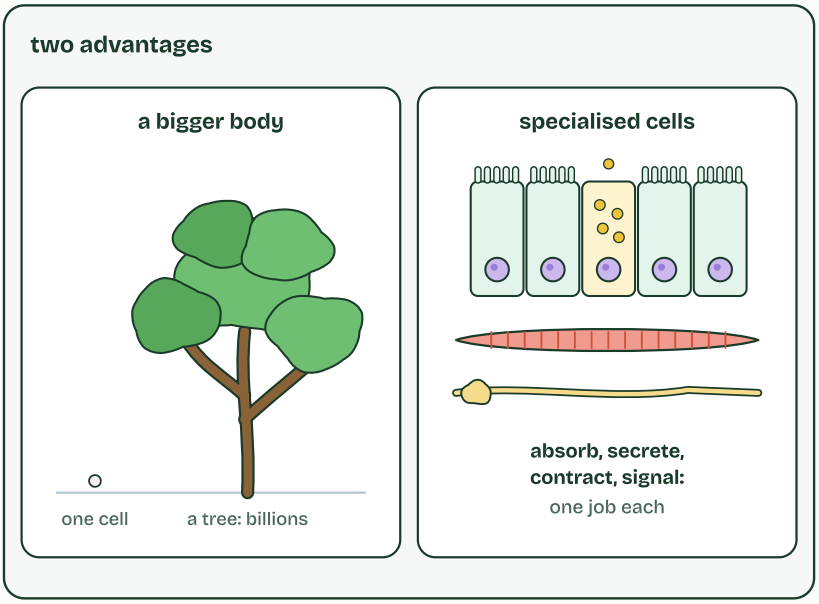
KEY POINTS

- Differentiation: the same genes, different ones expressed, often triggered by the cell's environment.
- Multicellularity allows a large body and specialised cells.
- It evolved many times, independently.

KEY TERMS

differentiation
The process by which a cell becomes specialised for one job, by switching on some genes and leaving others off.

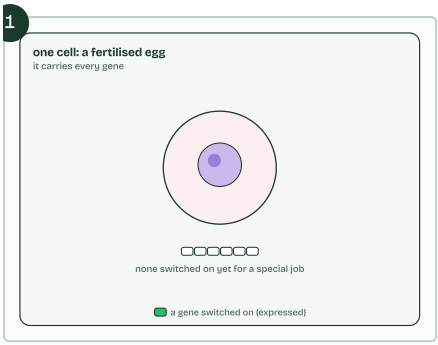
gene expression
Using a gene to make its product, usually a protein: the gene is transcribed to mRNA, which is translated.



STEP BY STEP

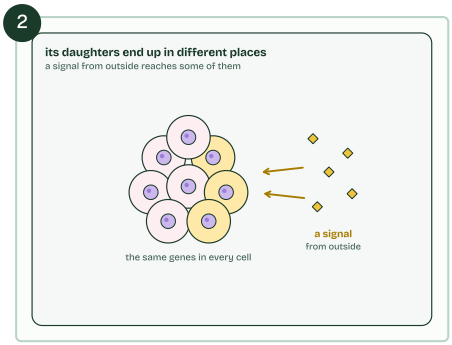
5 STEPS

1



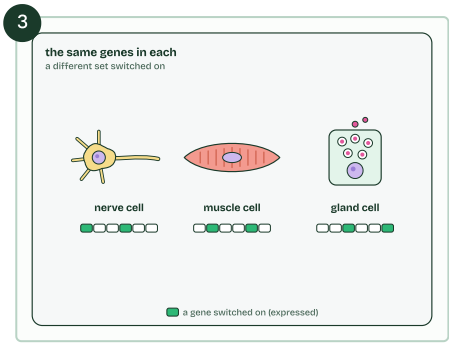
A cell carries **every gene**, none of them yet switched on for a special job.

2



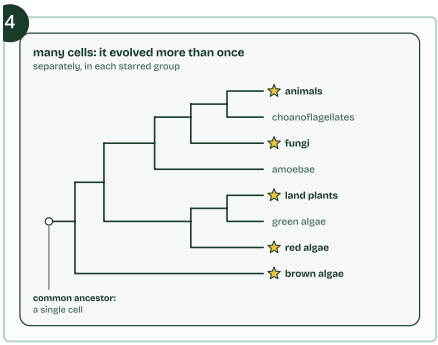
Its daughters end up in different places, and a **signal** from outside reaches some of them.

3



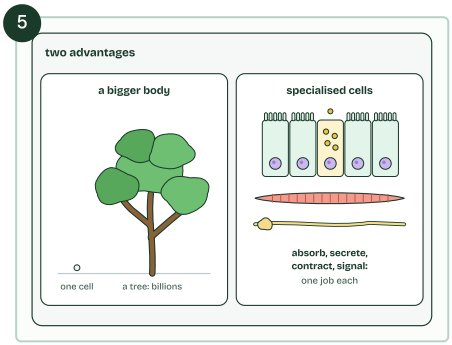
Each switches on a **different set of genes**, and becomes a nerve, muscle or gland cell.

4



Multicellularity **evolved separately** in each starred group, from single-celled ancestors.

5



Two advantages: a **bigger body**, and **specialised cells**.

WATCH OUT

A muscle cell has not lost the genes for being a nerve cell. It still carries them; they are just not expressed.

PREDICT

Plants and animals are both multicellular. Does that mean their last common ancestor was multicellular?

(A) Yes, because a feature shared by two groups always comes from their shared ancestor

(B) No; it was single-celled, and each group became multicellular separately

(C) Yes, but the plants later lost multicellularity and then evolved it a second time

Decide before you look. Answer on page 37.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

aseptate hyphae 09
Fungal hyphae with no cross walls, so the cytoplasm and many nuclei run continuously along a long tube.

binary fission 05
How a prokaryote divides: its loop of DNA is copied, and the cell splits in two.

cell theory 01
The theory that all living things are made of cells, that the cell is the smallest unit of life, and that cells only come from cells that already exist.

chitin 08
A tough polysaccharide that makes fungal cell walls and the outer skeletons of insects.

companion cell 09
A cell beside each phloem sieve tube element, with a nucleus and many mitochondria, that keeps the sieve tube alive and loads it with sugar.

compartments 06
Separate spaces inside a cell, each enclosed by a membrane, so different conditions and reactions can be kept apart.

cryogenic electron microscopy 03
Electron microscopy of molecules frozen fast in a thin layer of water, imaged in many orientations and combined into a 3D structure.

cytoskeleton 06
A network of protein fibres, microtubules and microfilaments, that gives a eukaryotic cell its shape and moves things inside it.

deduce 01
Reasoning from a general rule to a particular case: if every living thing is made of cells, then this new living thing will be too.

differentiation 12
The process by which a cell becomes specialised for one job, by switching on some genes and leaving others off.

electron microscope 03
A microscope that uses a beam of electrons, with a far shorter wavelength than light, to form an image, giving much higher resolution.

endosymbiosis 11
The theory that mitochondria and chloroplasts began as free-living prokaryotes that were taken into a larger cell and lived on inside it, to the benefit of both.

eukaryotes 06
Cells with a nucleus and membrane-bound organelles: the cells of animals, plants, fungi and protists.

excretion 07
Getting rid of the waste products of metabolism, such as carbon dioxide or ammonia.

eyepiece graticule 02
A small scale fitted inside the eyepiece, seen over the specimen. Its units have no fixed size until it is calibrated.

fluorescent stains 03
A dye that glows a bright colour when lit by light of another wavelength, and binds to a particular part of the cell, such as DNA.

freeze fracture 03
Freezing a specimen fast and cracking it, so the break often runs between the two layers of a membrane, showing the proteins embedded in it.

gene expression 12
Using a gene to make its product, usually a protein: the gene is transcribed to mRNA, which is translated.

histones 06
Proteins that DNA winds round in a eukaryote's chromosomes, packing it and controlling which genes can be used.

homeostasis 07
Keeping conditions inside an organism within limits, such as its water content or temperature.

immunofluorescence 03

Using antibodies that bind one particular protein, each carrying a fluorescent dye, so that protein glows wherever it is in the cell.

lysosomes 06

Vesicles full of digestive enzymes that break down worn-out organelles and material the cell has taken in.

magnification 02

How many times bigger an image is than the real thing: image size divided by actual size, both in the same units.

micrograph 10

A photograph taken through a microscope: a light micrograph or an electron micrograph.

naked DNA 05

DNA that is not bound to histone proteins, as in prokaryotes and in mitochondria and chloroplasts.

nucleoid 05

The region of a prokaryote's cytoplasm where its DNA is. It has no membrane round it.

peptidoglycan 05

The material of bacterial cell walls: sugar chains cross-linked by short chains of amino acids. Gram-positive bacteria have a thick layer.

plasma membrane 04

The membrane round every cell, a double layer of phospholipids with proteins in it. It controls what enters and leaves.

plastids 08

A family of double-membraned organelles in plants and algae: chloroplasts for photosynthesis, amyloplasts that store starch, and others that hold pigments.

prokaryotes 05

Cells with no nucleus and no membrane-bound organelles: bacteria and archaea.

quantitative observation 02

Observation that records an amount, with a number and a unit, rather than a description.

resolution 03

The smallest distance between two points that can still be seen as two separate points. The better the resolution, the finer the detail.

ribosomes 04

Small structures made of RNA and protein that build proteins by joining amino acids in the order the mRNA codes for.

sap vacuole 08

A large vacuole in a plant cell, full of a watery solution of sugars and salts, that stores substances and keeps the cell firm by pressing out on the wall.

scale bar 02

A line on a micrograph or drawing labelled with the real length it stands for, so sizes can be read off at any enlargement.

stage micrometer 02

A slide with a tiny ruler engraved on it, usually 1 mm split into 100 divisions of 10 µm each.

stain 02

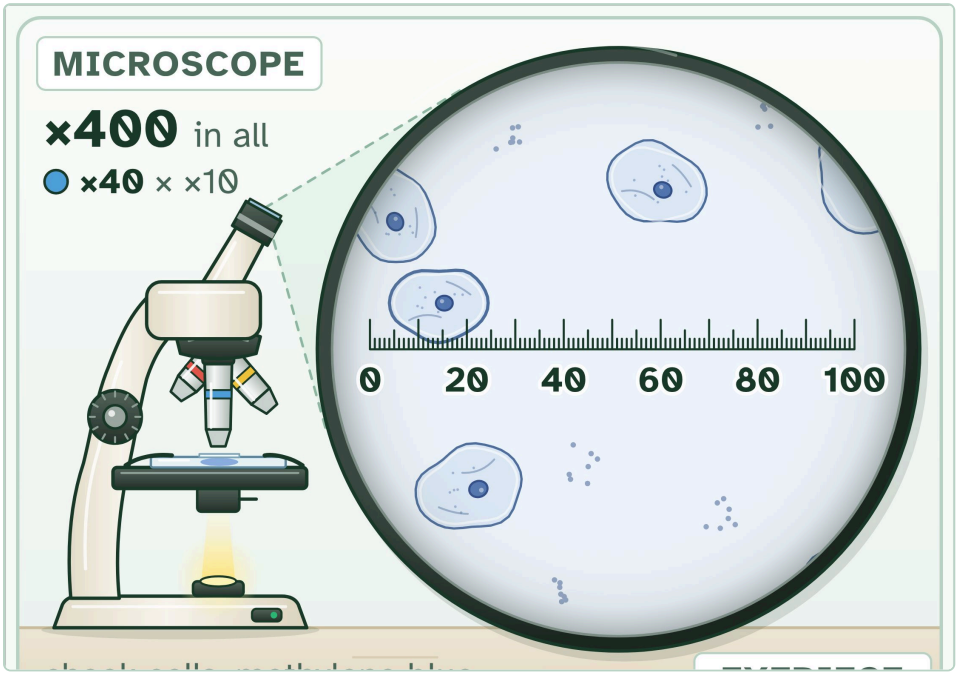
A dye that colours some parts of a cell more than others, so they show up. Iodine stains starch blue-black; methylene blue stains nuclei.

temporary mount 02

A specimen put on a glass slide in a drop of water or stain, with a thin coverslip on top, for looking at straight away.

Dry lab: *Measure the cells*

A microscope with an eyepiece graticule and a stage micrometer. Calibrate the graticule at each objective, then measure cheek cells, onion cells and guard cells, ten of each, and find out how big each kind of cell is.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. `biologybybradford.com/guides/ib-biology-a2-2-cell-structure#lab`

Your question

How long is a typical cheek cell, onion epidermis cell and guard cell? Predict the order, biggest to smallest, before you measure.

What you can change

The slide and the objective lens. Each objective needs its own calibration: line the graticule up against the stage micrometer and work out what one graticule unit is worth. Next cell moves to a new cell on the same slide, so ten cells are ten repeats.

What to record

For each cell: the slide, the objective, the length in graticule units, and the length in micrometres. Then the mean for each kind of cell, and the range. The cells are drawn and their sizes set close to real ones, with real scatter.

Find out

- **Calibrate first.** With the stage micrometer on, work out what one graticule unit is worth at each of the three objectives. Why does the answer change, and by how much each time?
- **Biggest to smallest.** Measure ten cheek cells, ten onion epidermis cells and ten guard cells. Was your predicted order right?
- **Choose the power.** Try a guard cell at ×4 and an onion cell at ×40. What goes wrong each time, and which objective suits each kind of cell?
- **From size to magnification.** Take the mean length of a cheek cell. If it is drawn 30 mm long in your notebook, what is the magnification of your drawing? Draw a 20 µm scale bar for it.

Record

- A calibration line for each objective: the micrometer length, the graticule units it covers, and the micrometres per unit.
- For each cell: the slide, the objective, its length in graticule units and in micrometres, to one decimal place.
- The mean and the range for each kind of cell. The graph shows each cell as a point and the mean as a bar.
- The uncertainty of one reading: half a graticule unit, in micrometres, at the objective you used. Download the CSV to keep your table.

Your question How long is a typical cheek cell, onion epidermis cell and guard cell? Predict the order, biggest to smallest, before you measure.**What you can change**The slide and the objective lens. Each objective needs its own calibration: line the graticule up against the stage micrometer and work out what one graticule unit is worth. Next cell moves to a new cell on the same slide, so ten cells are ten repeats.**What to record**For each cell: the slide, the objective, the length in graticule units, and the length in micrometres. Then the mean for each kind of cell, and the range. The cells are drawn and their sizes set close to real ones, with real scatter.

Back to cells

Your onion cells were the longest and your guard cells the shortest, yet both are plant cells. Is a plant cell always the bigger one, and what lets an onion cell grow so long?

QUESTIONS ON THE LAB

QUESTION 1

At ×10, one graticule unit is worth 10 µm. Switch to the ×40 objective. What is one graticule unit worth now?

(A) 40 µm, because the magnification has gone up four times

(B) 2.5 µm, because the specimen looks four times bigger behind the same scale

(C) 10 µm still, because the graticule is in the eyepiece and has not changed

Answer on page 37.

QUESTION 2

A guard cell measured at ×4 covers 1.5 graticule units, and the same cell at ×40 covers 15.5. Which reading gives the better estimate of its length, and why?

(A) At ×4, because more of the leaf is in view at once

(B) At ×40, because a misreading of half a unit is a far smaller share of the length

(C) Both are equally good, as they are converted with the right calibration

Answer on page 37.

QUESTION 3

Ten cheek cells range from 48 to 70 µm. Why measure ten, not one?

(A) Because one cell could be measured wrongly, and ten will be measured correctly

(B) Because cells of one kind vary in size, and a mean of many is a better estimate of a typical cell

(C) Because the graticule needs to be calibrated again for every cell measured

Answer on page 37.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on A2.2 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?topics=A2.2&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 Biologists find a new kind of organism in a hot spring. Before they look at it under a microscope, what does cell theory let them predict?

B **That it will be made of one or more cells, each one made by another cell dividing**

It will be made of cells, and those cells came from other cells. That is deduction: from a general theory to a particular case. The theory says nothing about which kind of cell, or which parts it will have. If the organism turned out not to be made of cells, the theory would need changing.

02 A chloroplast is 5 µm long. In a photograph it is 25 mm long. What is the magnification?

C **×5000, since 25 000 µm divided by 5 µm gives 5000**

×5000. First make the units the same: 25 mm is 25 000 µm. Then image ÷ actual: 25 000 ÷ 5 = 5000. Dividing 25 by 5 without converting gives an answer a thousand times too small.

03 A researcher wants to watch where one particular protein goes inside living cells over an hour. Which technique fits best?

C **Immunofluorescence or a fluorescent tag, viewed with a light microscope**

A fluorescent label on that one protein, seen with a light microscope. Light microscopy works on living cells and fluorescence picks out a single protein. Every electron microscopy technique needs dead, fixed or frozen specimens, so none can follow a protein over time.

04 Why is the plasma membrane made of lipids rather than proteins or carbohydrates?

B **Lipids do not dissolve in water, so a layer of them can keep two watery spaces apart**

Because lipids are hydrophobic: they do not mix with water. A layer of them separates the watery cytoplasm from the watery world outside. Most carbohydrates and many proteins dissolve in water, so a layer of them would not hold the two apart.

05 An antibiotic stops 70S ribosomes working. Why does it harm bacteria much more than the human cells around them?

C **The ribosomes in human cytoplasm are the larger 80S kind, which it does not affect**

The ribosomes in the cytoplasm of human cells are 80S, a different size and shape, so the antibiotic leaves them alone while bacteria cannot make proteins. Bacteria do have walls, and human cells do have ribosomes.

06 A cell is 40 µm across, has 80S ribosomes and a cytoskeleton, but in this electron micrograph no nucleus can be seen. Which is the best conclusion?

B **It is a eukaryote; the section may have missed the nucleus, or it lost it**

A eukaryote. Its size, 80S ribosomes and cytoskeleton are all eukaryotic features. A thin section can miss the nucleus, and a few eukaryotic cells, such as red blood cells, lose theirs. Viruses are not cells at all.

07 A *Paramecium* is moved from pond water into a salt solution as concentrated as its cytoplasm. What happens to its contractile vacuoles?

B **They fill and empty far more slowly, as water stops flooding in by osmosis**

They slow right down. In pond water, water floods in by osmosis and the vacuoles must keep pumping it out. In a solution as concentrated as the cytoplasm there is no net flow of water in, so there is little to remove. That is homeostasis: the vacuoles keep the water content steady.

08 A cell has a cell wall, a large vacuole and no chloroplasts. What could it be?

C **A fungal cell, or a plant cell from a part with no light such as a root**

Either a fungal cell or a plant cell from a root. Animal cells have no wall, so not those. To tell the two apart you would test the wall: cellulose means a plant, chitin a fungus. Amyloplasts full of starch would also point to a plant.

09 A mature red blood cell cannot make new proteins. Why?

B **It has no nucleus, so there is no DNA to copy into new mRNA for its ribosomes**

With no nucleus there is no DNA, so no new mRNA can be made, and without mRNA no new proteins. That is why a red blood cell cannot repair itself and is replaced after about four months. (It does lack mitochondria too, but it still makes ATP by anaerobic respiration.)

10 In an electron micrograph you see a stack of curved, flattened sacs with small round vesicles at their edges and no dots on them. What is it?

B **The Golgi apparatus, a stack of curved sacs that buds off vesicles**

The Golgi apparatus. Rough ER is also flattened sacs, but it is dotted with ribosomes; the Golgi has none, its sacs are curved and stacked, and vesicles bud from their edges. Cristae sit inside a mitochondrion's double membrane.

11 If a cell lost all its mitochondria, could it make new ones from its own nuclear genes and membranes?

B **No, because new mitochondria only ever form when an existing one divides**

No. Mitochondria arise only from other mitochondria, which grow and split as a bacterium does, and part of what they need is coded in their own DNA. That is one of the strongest clues that they were once free-living bacteria.

12 Plants and animals are both multicellular. Does that mean their last common ancestor was multicellular?

B **No; it was single-celled, and each group became multicellular separately**

No. Their last common ancestor was single-celled, and many single-celled groups branch off between them. Plants and animals each evolved multicellularity on their own. A shared feature can come from a shared ancestor, or from evolving more than once.

QUESTIONS ON THE DRY LAB

Q1 At ×10, one graticule unit is worth 10 µm. Switch to the ×40 objective. What is one graticule unit worth now?

B **2.5 µm, because the specimen looks four times bigger behind the same scale**

The graticule sits in the eyepiece, so it looks the same at every power, but the specimen behind it is magnified four times more. Each unit now covers a quarter as much of the specimen: 10 ÷ 4 = 2.5 µm. That is why every objective needs its own calibration.

Q2 A guard cell measured at ×4 covers 1.5 graticule units, and the same cell at ×40 covers 15.5. Which reading gives the better estimate of its length, and why?

B **At ×40, because a misreading of half a unit is a far smaller share of the length**

Each reading is uncertain by about half a unit. At ×4 that is 12.5 µm on a 38 µm cell, a third of its length. At ×40 it is 1.25 µm, about 3 percent. Use the highest power at which the whole cell fits on the scale.

Q3 Ten cheek cells range from 48 to 70 µm. Why measure ten, not one?

B **Because cells of one kind vary in size, and a mean of many is a better estimate of a typical cell**

Cells of the same kind are not all the same size, so any one cell may be large or small. The mean of ten is a fairer figure for a typical cell, and the range shows how much they vary. Two kinds of cell can only be called different in size if their ranges barely overlap.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.