AP BIOLOGY · 2.1, 2.2

BIOLOGY BY BRADFORD

REVISION GUIDE

The parts of a cell, and why it *stays small*

Cell structure and size

A bacterium and a liver cell share four parts, and a eukaryotic cell divides the rest into rooms with jobs. Take both apart, compare a plant cell with an animal cell, read an electron micrograph, and find out why no cell grows the size of a grapefruit.

10 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ap-biology-unit-2-cell-structure-and-size

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By the end you can

- [ ] Name the four structures every cell has and compare prokaryotic and eukaryotic cells 2.1.A
- [ ] Describe ribosomes and explain why their presence in all life is evidence of common ancestry 2.1.A
- [ ] Describe the structure and function of the nucleus, rough and smooth ER, Golgi complex, lysosomes and vacuoles 2.1.A
- [ ] Explain how the folded inner membrane of a mitochondrion and the thylakoids of a chloroplast let a cell capture and use energy 2.1.A
- [ ] Compare plant and animal cells and identify cells and organelles in electron micrographs 2.1.A
- [ ] Calculate surface area-to-volume ratios and explain how they limit cell size and shape the exchange surfaces of cells and organisms 2.2.A

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

2.1.A CELL STRUCTURE AND FUNCTION

01 Every cell, the same *four* parts

Living things come in two kinds of cell. **Prokaryotes**, the bacteria and archaea, are small and simple inside. **Eukaryotes**, the cells of animals, plants, fungi and protists, are usually ten times wider and divided into compartments.

Strip any cell down and four things are left. A **plasma membrane** wraps it and controls what crosses. **Cytoplasm**, mostly water, fills it. **DNA** carries its instructions. And **ribosomes** read those instructions to make proteins. A cell missing any one of the four could not keep itself alive or copy itself.

That shared kit is evidence that all cells come from a common ancestor: the same membrane, the same genetic code, the same ribosomes, in a bacterium and in you.

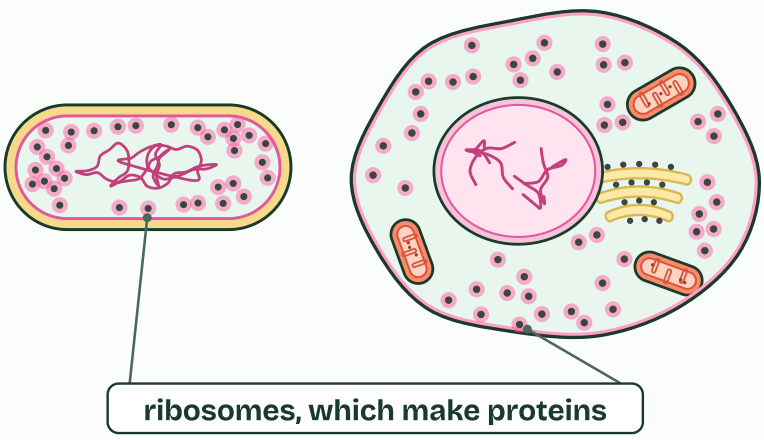
KEY POINTS

- Prokaryotes: bacteria and archaea. Eukaryotes: animals, plants, fungi, protists.
- Every cell has a plasma membrane, cytoplasm, DNA and ribosomes.
- The shared parts point to a common ancestor.

KEY TERMS

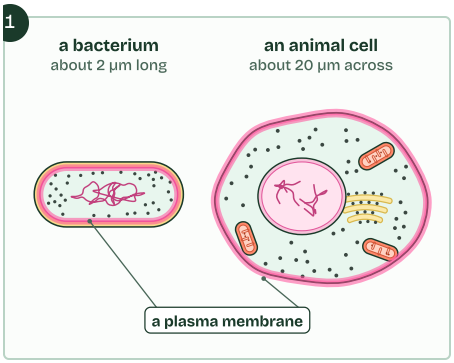
prokaryotes
A cell with no nucleus and no membrane-bound organelles: the bacteria and archaea.

eukaryotes
A cell whose DNA is held in a nucleus and which has membrane-bound organelles: the cells of animals, plants, fungi and protists.



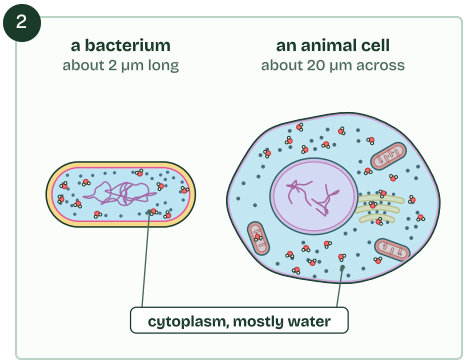
STEP BY STEP
4 STEPS

1



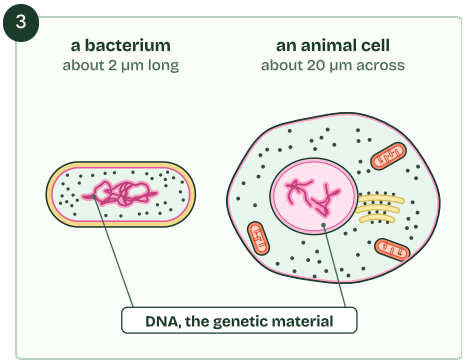
Both cells are wrapped in a **plasma membrane** made of lipids.

2



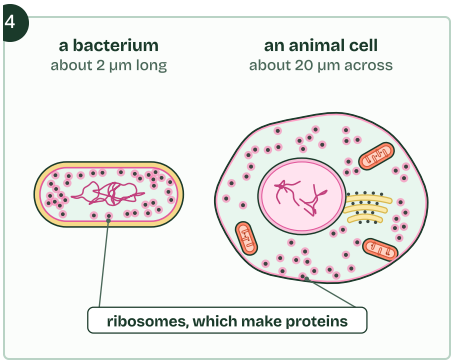
Both are filled with **cytoplasm**, which is mostly water.

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

"Prokaryotes have no DNA because they have no nucleus." They have DNA, usually one circular chromosome; it just lies in the cytoplasm with no membrane round it.

PREDICT

A new single-celled organism is found in a hot spring. Which of these must it have?

(A) A nucleus to hold its DNA, and mitochondria to make the ATP it needs to keep itself alive in the spring

(B) Ribosomes, DNA, cytoplasm and a plasma membrane, whatever kind of cell it turns out to be

(C) A cell wall of peptidoglycan to protect it from the heat, and a flagellum to move toward food

Decide before you look. Answer on page 28.

02 A cell with no *rooms*

2.1.A CELL STRUCTURE AND FUNCTION

A bacterium is one open space. Its DNA, a single loop, lies in a region of the cytoplasm called the **nucleoid**, with no membrane round it. Its ribosomes are free in the cytoplasm. There are no membrane-bound organelles: no nucleus, no mitochondria, no ER.

Outside the membrane most prokaryotes have a **cell wall**, which in bacteria is made of peptidoglycan. It holds the cell's shape and stops it bursting when water floods in. Many also have small extra loops of DNA, **plasmids**, and some have a flagellum to swim.

With no compartments, every reaction happens in the same space. That works because the cell is tiny: nothing is far from the membrane. Some prokaryotes do fold their plasma membrane inward to add surface for reactions, an idea you will meet again in chapter 5 and in Unit 2's last guide.

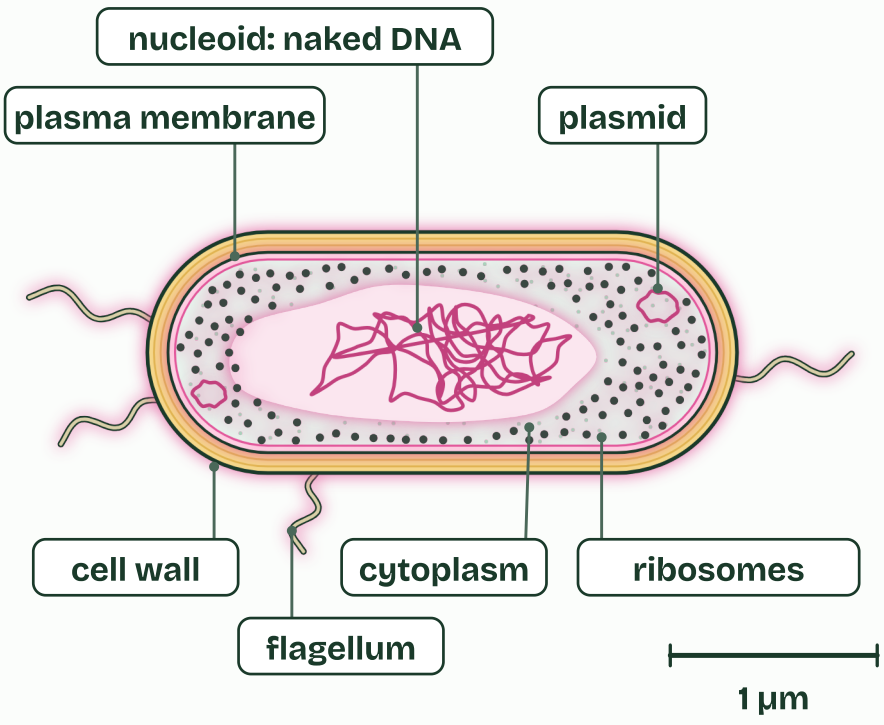
KEY POINTS

- DNA: one loop in the nucleoid, no nuclear membrane.
- Ribosomes, cytoplasm, plasma membrane and usually a cell wall.
- No membrane-bound organelles.

KEY TERMS

nucleoid
The region of a prokaryotic cell where its DNA lies. It has no membrane round it.

plasmids
A small circle of DNA in a prokaryote, separate from its chromosome, often carrying genes such as antibiotic resistance. It can pass from one cell to another.



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

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.

Ribosomes Smaller than the ribosomes of a eukaryote, but built the same way, of rRNA and protein. They make the cell's proteins.

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

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 cell wall is not the boundary that controls what enters. Water and small molecules pass through the wall freely; the plasma membrane inside it does the controlling.

PREDICT

A drug blocks the ribosomes of bacteria but not ours. Why could it still stop a bacterium growing, though bacteria have no organelles for it to target?

(A) Bacterial ribosomes sit inside a nucleus, and the drug crosses the nuclear membrane to reach and block them

(B) Every cell needs ribosomes to make its proteins, and bacteria have their own, built differently from ours

(C) Ribosomes are a membrane-bound organelle, so bacteria do have one organelle that the drug can attack

Decide before you look. Answer on page 28.

03 The one structure in *every* cell

2.1.A CELL STRUCTURE AND FUNCTION

A **ribosome** is made of **ribosomal RNA (rRNA)** and protein, in two subunits that clamp round a strand of messenger RNA. It reads the mRNA three bases at a time and joins amino acids into a chain in that order (Unit 6). It has no membrane, so it is not an organelle in the strict sense, but it is in every cell that has ever been found.

That is a clue. Ribosomes in bacteria, archaea and eukaryotes differ in detail, but their rRNA and the way they work are so alike that all three must have inherited them from one common ancestor.

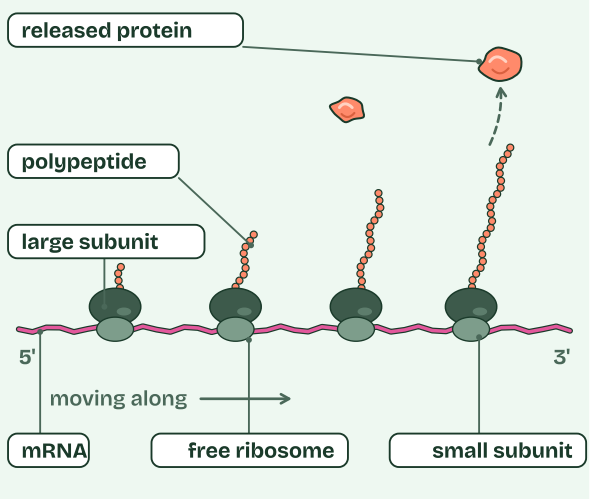
In a eukaryote, ribosomes work in two places. **Free ribosomes** in the cytoplasm make proteins that stay in the cytoplasm. **Bound ribosomes** on the rough ER make proteins that go into the ER: for the membrane, for lysosomes, or for export. The ribosomes are the same; the protein they are making decides where they sit.

KEY POINTS

- Ribosomes: rRNA and protein, no membrane; they make proteins.
- Found in all life: evidence of common ancestry.
- Free ribosomes: proteins for the cytoplasm. Bound: proteins for membranes, lysosomes and export.

KEY TERMS

ribosome
A particle of ribosomal RNA (rRNA) and protein that makes proteins by reading mRNA. It has no membrane.

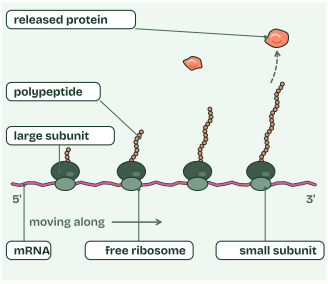


Free ribosomes: proteins for the cytosol.
Each releases its protein into the cytosol, for use in the cell, such as enzymes of glycolysis.

SWITCH IT

2 SETTINGS

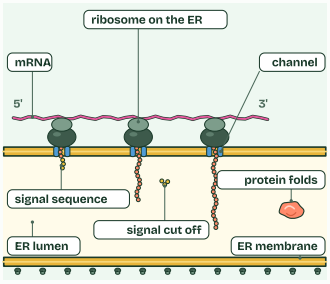
1



Free ribosomes: proteins for the cytosol.
Each releases its protein into the cytosol, for use in the cell, such as enzymes of glycolysis.

Free

2



Bound: proteins threaded into the ER lumen.
A signal sequence takes the ribosome to the ER. Made for export, for membranes or for lysosomes.

On the rough ER

WATCH OUT

"Ribosomes are made in the ER." They are assembled in the nucleus, at the nucleolus, and some then attach to the ER while they make a protein.

PREDICT

A cell secretes large amounts of a digestive enzyme. Where would you expect most of its ribosomes to be?

(A) Free in the cytoplasm, where the amino acids are, so the enzyme can be made quickly and leave by diffusion

(B) Inside the nucleus, close to the genes, so the enzyme can be made as soon as its gene has been read

(C) Bound to the rough ER, which takes the enzyme in as it is made and sends it on toward the membrane

Decide before you look. Answer on page 28.

04

2.1.A CELL STRUCTURE AND FUNCTION

A eukaryotic cell, *room by room*

A eukaryotic cell is divided by membranes into **organelles**, each with its own job. The **nucleus** holds the DNA behind a double membrane with pores. The **endoplasmic reticulum** runs through the cytoplasm: **rough ER**, studded with ribosomes, makes proteins and sends them on; **smooth ER** has no ribosomes and makes lipids and breaks down toxins.

The **Golgi complex** is a stack of flattened sacs. It folds and modifies proteins from the ER, adding sugar chains for example, and sorts them into **vesicles** for the membrane, for lysosomes or for export. **Lysosomes** are sacs of hydrolytic enzymes that break down worn-out parts and whatever the cell takes in. **Vacuoles** store water, food or waste.

Tap each part of the cell. The ER, Golgi, vesicles, lysosomes and the outer membrane of the nucleus pass membrane and cargo between them: together they are the **endomembrane system**, which Unit 2's last guide follows in more detail.

KEY POINTS

- Nucleus: DNA, double membrane, pores.
- Rough ER: proteins. Smooth ER: lipids and detoxification.
- Golgi: modifies, sorts and packages proteins. Lysosomes: hydrolytic enzymes.

KEY TERMS

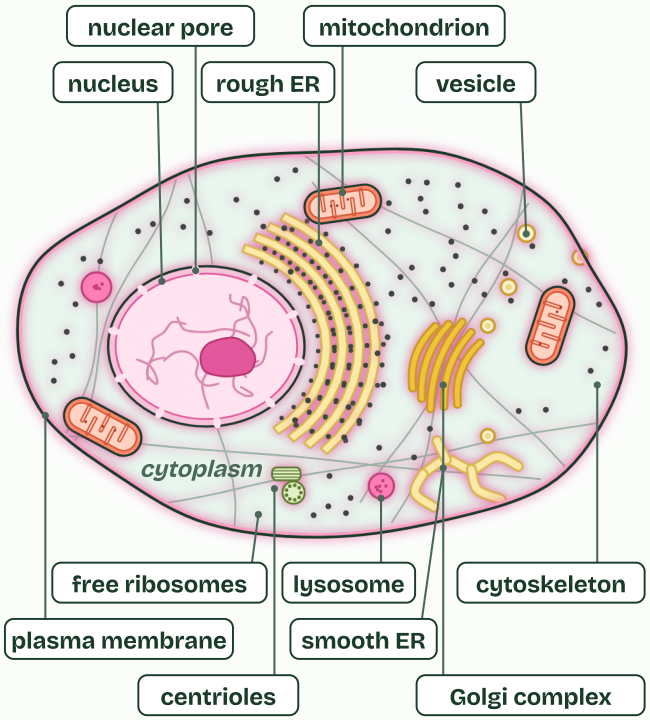
organelles
A structure inside a cell with a particular job, usually bounded by membrane.

endoplasmic reticulum
A network of membrane sacs and tubes through the cytoplasm. Rough ER has ribosomes on it and makes proteins; smooth ER has none and makes lipids and breaks down toxins.

Golgi complex
A stack of flattened membrane sacs that modifies, sorts and packages proteins from the rough ER into vesicles.

lysosomes
A membrane sac of hydrolytic enzymes that breaks down large molecules, worn-out organelles and anything the cell takes in.

vacuoles
A membrane sac that stores water, food or waste. Plant cells have one large central vacuole.



Cytoskeleton Microtubules and microfilaments, protein fibers 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 complex 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 organize 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 complex 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 complex to the plasma membrane.

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

WATCH OUT

The Golgi does not make proteins. Ribosomes make them; the Golgi changes and ships them.

PREDICT

Liver cells break down drugs and alcohol. Which organelle would you expect a liver cell to have a lot of?

(A) Golgi complexes, because they package the drug and the alcohol into vesicles and carry them out of the cell

(B) Smooth ER, whose enzymes break down toxins such as drugs and alcohol into forms the body can get rid of

(C) Rough ER, because its ribosomes make the antibodies that bind to the drug and carry it out of the liver

Decide before you look. Answer on page 28.

05 A folded membrane for *energy*

2.1.A CELL STRUCTURE AND FUNCTION

A **mitochondrion** has a **double membrane**. The outer one is smooth. The inner one is folded into **cristae**, and the fluid inside it is the **matrix**.

Each compartment has its own part of cellular respiration. The **Krebs cycle** runs in the matrix, where its enzymes and substrates are kept close together. The **electron transport chain and ATP synthase** sit in the inner membrane. The folds give that membrane a far bigger surface than a smooth one could, so more chains and more ATP synthase fit in, and the cell makes more ATP.

Cells that use a lot of energy, such as muscle and sperm, have many mitochondria, each with closely packed cristae. Unit 3 takes respiration step by step.

KEY POINTS

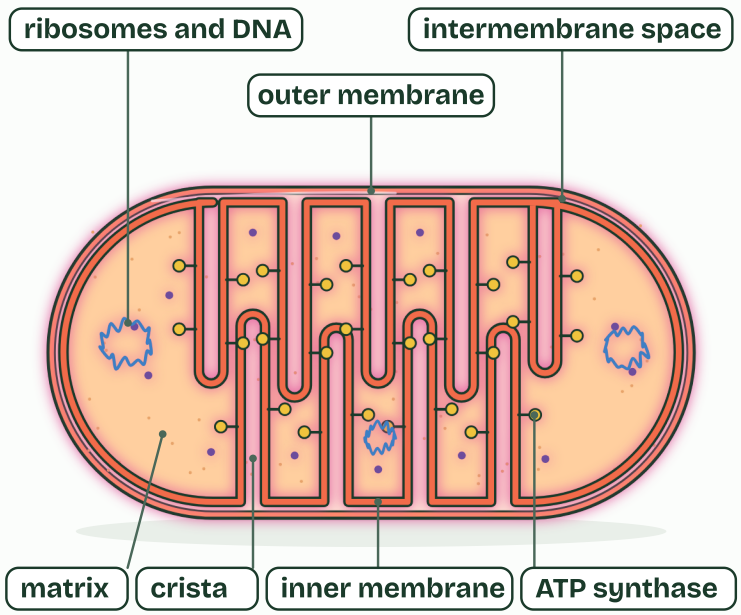
- Double membrane: smooth outer, folded inner (cristae).
- Matrix: the Krebs cycle.
- Inner membrane: electron transport and ATP synthesis; folding adds surface.

KEY TERMS

mitochondrion
The organelle where aerobic cellular respiration makes most of a eukaryotic cell's ATP. It has a double membrane, the inner one folded into cristae.

cristae
The folds of the inner membrane of a mitochondrion. They give a large surface for the electron transport chain and ATP synthase.

matrix
The fluid inside the inner membrane of a mitochondrion, where the Krebs cycle happens.



Outer membrane and the **intermembrane space** The outer membrane wraps the whole organelle. The space between it and the inner membrane is very small, so the protons pumped into it during respiration build up a steep gradient quickly.

Inner membrane , folded into **cristae** The folds give a very large surface for the electron transport chains and ATP synthase that make most of the cell's ATP.

Matrix The fluid inside the inner membrane. It holds the enzymes and substrates of pyruvate oxidation and the Krebs cycle together in one small compartment, so they meet often and the reactions run fast.

Ribosomes and a loop of **DNA** The mitochondrion makes a few of its own proteins: a trace of its bacterial past.

WATCH OUT

The cristae are folds of the inner membrane, not separate compartments or sacs inside the matrix.

PREDICT

Two cells have the same number of mitochondria. In one the inner membranes are much more folded. What follows?

(A) It makes more ATP, because the extra folding fits in more electron transport chains and ATP synthase

(B) It makes less ATP, because tight folds leave too little room in the matrix for the Krebs cycle to run

(C) Both make the same ATP, because the folding only holds the mitochondrion in shape and takes no part

Decide before you look. Answer on page 28.

06 Stacks of membrane that *catch light*

2.1.A CELL STRUCTURE AND FUNCTION

Chloroplasts are found in plants and photosynthetic algae. Like mitochondria they have a **double membrane**. Inside are flattened sacs of membrane, **thylakoids**, stacked like coins into **grana**, in a fluid called the **stroma**.

The thylakoid membranes hold the chlorophyll and the electron transport proteins of the photosystems, so the **light-dependent reactions** happen in the grana. The **Calvin cycle**, which fixes carbon dioxide into sugar, runs in the stroma. Stacking packs a large area of membrane into a small space, so the chloroplast catches more light.

Mitochondria and chloroplasts have more in common: each has its own small loop of DNA and its own ribosomes. Unit 2's last guide shows why.

KEY POINTS

- Double membrane round the stroma.
- Thylakoids stacked in grana: chlorophyll and the light-dependent reactions.
- Stroma: the Calvin cycle.

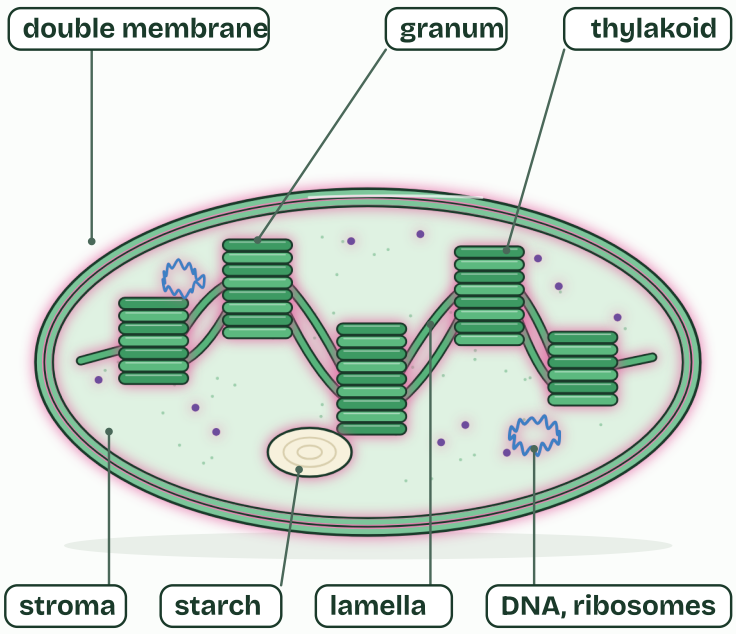
KEY TERMS

chloroplasts
The organelle of photosynthesis in plants and algae: a double membrane round the stroma, with stacks of thylakoids inside.

thylakoids
Flattened membrane sacs inside a chloroplast that hold chlorophyll and the proteins of the light-dependent reactions.

grana
Stacks of thylakoids in a chloroplast (one stack is a granum), where the light-dependent reactions happen.

stroma
The fluid inside a chloroplast's inner membrane and outside the thylakoids, where the Calvin cycle fixes carbon.



Stroma The fluid inside the inner membrane. It holds the enzymes and substrates of the Calvin cycle, Rubisco above all, together in one compartment.

Lamellae Single thylakoids joining one granum to the next, so the membrane system is all one.

Starch grain A store of the sugar made by photosynthesis.

Double membrane An outer and an inner membrane round the whole chloroplast, keeping the stroma's enzymes and substrates in.

Thylakoids , stacked in **grana** Flattened sacs whose membranes hold the photosystems and ATP synthase. Stacking gives a large surface for absorbing light. The space inside each thylakoid is tiny, so protons pumped in quickly build a steep gradient.

Ribosomes and a loop of **DNA** Like a mitochondrion, the chloroplast makes some of its own proteins.

WATCH OUT

"Plant cells have chloroplasts instead of mitochondria." They have both. Photosynthesis makes sugar; respiration in the mitochondria turns that sugar into ATP, day and night.

PREDICT

A chloroplast is broken open and its thylakoids separated from the stroma. Which part can still absorb light and pass on electrons?

(A) The stroma, because its enzymes carry the chlorophyll that is needed to absorb the light falling on it

(B) The thylakoids, because their membranes hold the chlorophyll and the electron transport proteins

(C) Neither, because light can only be absorbed while the double membrane round the chloroplast is whole

Decide before you look. Answer on page 28.

07 Plant cell, *animal* cell

2.1.A CELL STRUCTURE AND FUNCTION

Plant and animal cells are both eukaryotic, with a nucleus, ER, Golgi, mitochondria and ribosomes. Three structures set a plant cell apart. A **cell wall** of cellulose outside the membrane holds its shape. A large **central vacuole**, often most of the cell's volume, holds water and pushes the cytoplasm against the wall. And **chloroplasts** carry out photosynthesis, in the cells that photosynthesize.

Animal cells have no wall, so their shape is held by the cytoskeleton, and they often have many small vacuoles rather than one. **Lysosomes** are common in animal cells; plants do much of the same breaking down in the central vacuole. Animal cells also have **centrioles**, which plant cells lack.

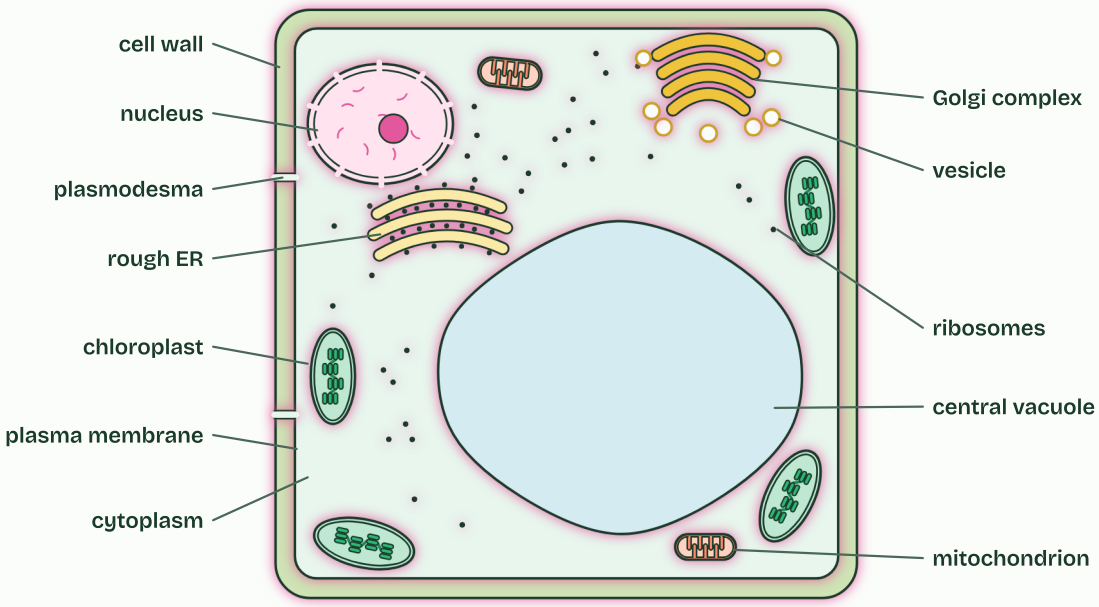
Tap each part of the plant cell, then compare it with the animal cell in chapter 4.

KEY POINTS

- Plant cells only: cell wall, large central vacuole, chloroplasts.
- Animal cells: no wall, small vacuoles, lysosomes, centrioles.
- Both: nucleus, ER, Golgi, mitochondria, ribosomes, plasma membrane.

KEY TERMS

central vacuole
The large membrane sac in a mature plant cell, holding water and dissolved substances. It keeps the cell firm and stores substances.



Cell wall A layer of cellulose fibers outside the plasma membrane. It is strong, so it holds the cell's shape and stops it bursting when water comes in. Water and most dissolved substances pass straight through it.

Plasmodesmata Narrow channels through the wall, lined with membrane, that join the cytoplasm of one plant cell to the next.

Ribosomes Small particles of rRNA and protein, free in the cytoplasm or on the rough ER. They make the cell's proteins, as they do in every cell.

Rough endoplasmic reticulum Flattened sacs with ribosomes on them. The proteins they make go into the sacs and on to the Golgi.

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

Chloroplast A double membrane round the stroma, with stacks of thylakoids inside. Photosynthesis here turns light energy into the chemical energy of sugar.

Chloroplast A double membrane round the stroma, with stacks of thylakoids inside. Photosynthesis here turns light energy into the chemical energy of sugar.

Mitochondrion A double membrane, the inner one folded. Plant cells have chloroplasts and mitochondria: respiration here makes ATP day and night.

Plasma membrane A phospholipid bilayer pressed against the inside of the wall. It, not the wall, controls what enters and leaves the cell.

Central vacuole A large sac of membrane full of water with salts, sugars and pigments dissolved in it. Pressing out against the wall, it keeps the cell firm, and it stores substances and breaks some down.

Nucleus Holds the cell's DNA in chromosomes. Pushed to one side by the vacuole, but still the control center: its genes are read here.

Golgi complex A stack of flattened sacs. It modifies proteins from the rough ER and packs them into vesicles: here, many carry the materials for the wall.

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

Chloroplast A double membrane round the stroma, with stacks of thylakoids inside. Photosynthesis here turns light energy into the chemical energy of sugar.

Chloroplast A double membrane round the stroma, with stacks of thylakoids inside. Photosynthesis here turns light energy into the chemical energy of sugar.

Mitochondrion A double membrane, the inner one folded. Plant cells have chloroplasts and mitochondria: respiration here makes ATP day and night.

WATCH OUT

Not every plant cell has chloroplasts. Root cells live in the dark and have none, but they still have a wall and a central vacuole.

PREDICT

A cell from an onion bulb has a wall and a large vacuole but no chloroplasts. What is it?

(A) An animal cell, because a cell without any chloroplasts in it cannot be a plant cell, whatever else it has

(B) A prokaryote, because it has a wall and a vacuole but none of the chloroplasts that eukaryotic cells all have

(C) A plant cell that grows out of the light, so it has the wall and central vacuole but makes no chloroplasts

Decide before you look. Answer on page 28.

08 Name it from a *micrograph*

2.1.A CELL STRUCTURE AND FUNCTION

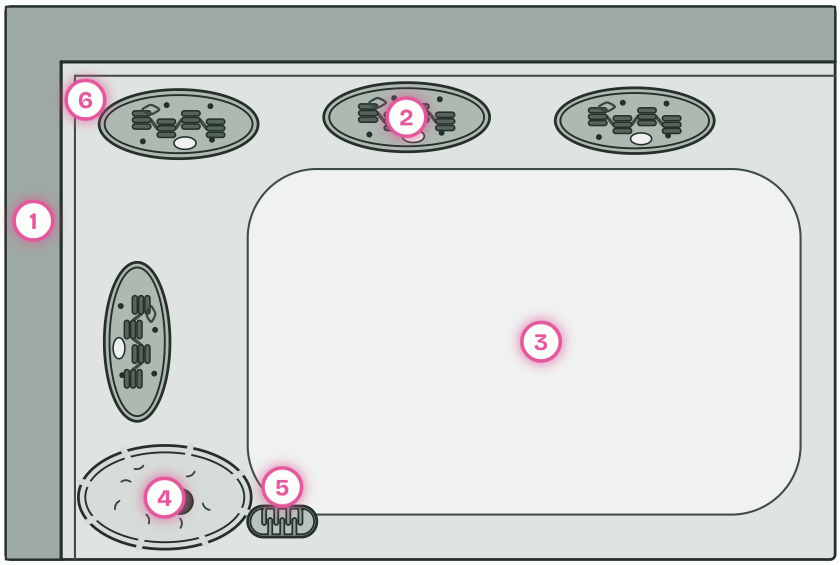
AP questions often show a cell as an electron microscope sees it: in shades of gray, with no labels. Each structure has a look you can learn. The nucleus is the biggest round body, with a double membrane and pores. A chloroplast is an oval with stacks of membrane inside. A mitochondrion is smaller, with a folded inner membrane. Rough ER is parallel sacs dotted with ribosomes; the Golgi is a curved stack with vesicles at its edges and no ribosomes.

Then ask what kind of cell it is. A wall and no nucleus: a prokaryote. A wall, a large vacuole and chloroplasts: a plant cell. No wall, many mitochondria and lots of rough ER and Golgi: an animal cell that makes and secretes protein.

Name each numbered part in the three drawn micrographs, then tap it to check.

KEY POINTS

- Nucleus: largest, double membrane, pores. Mitochondria: folded inner membrane.
- Rough ER: sacs with dots. Golgi: curved stack with vesicles.
- Wall and no nucleus: prokaryote. Wall, vacuole, chloroplasts: plant.



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

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.

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

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

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.

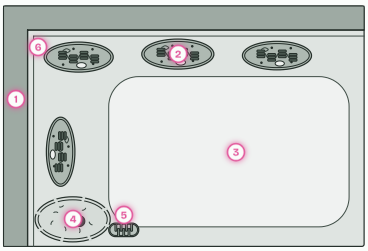
6 Secretory vesicle A small round sac of membrane, often near the Golgi complex or the plasma membrane.

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.

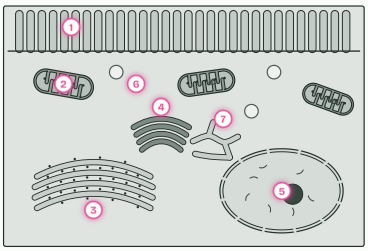
SWITCH IT 3 SETTINGS

1



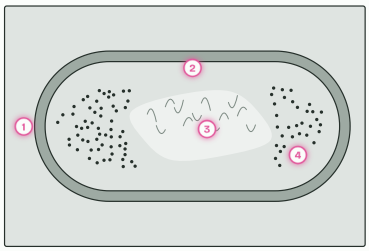
Leaf cell

2



Gut cell

3



Bacterium

WATCH OUT

Size on a micrograph depends on the magnification. Compare structures with each other in the same picture, not with what you remember of another one.

PREDICT

A micrograph of a gut cell shows rows of tiny fingers on one surface, many mitochondria and much rough ER. What is the cell specialized to do?

(A) Store fat, because the fingers of membrane hold fat droplets and the mitochondria break them down slowly

(B) Absorb food and make proteins: the fingers add surface, and mitochondria and rough ER power and make

(C) Divide quickly, because the fingers are spindle fibers and the mitochondria supply the energy to divide

Decide before you look. Answer on page 29.

09

2.2.A CELL SIZE

Why cells stay *small*

Everything a cell takes in or gets rid of crosses its plasma membrane, so its rate of exchange depends on its **surface area**. Its need for exchange depends on how much cytoplasm is using things up: its **volume**. As a cell grows, volume grows faster than surface area.

Model it with cubes. A cube of side 1 cm has a surface area of $6 \times 1^2 = 6$ cm^2 and a volume of $1^3 = 1$ cm^3: a **surface area-to-volume ratio** of 6. Double the side to 2 cm: area 24 cm^2, volume 8 cm^3, ratio 3. Area went up four times, volume eight times, so the ratio halved.

A large cell has too little membrane for its volume, and its middle is far from any surface, so it cannot take in what it needs or remove waste fast enough. That is why most cells are small, and why a cell divides rather than keep growing. The formulas for a sphere, a cylinder and a box are on the AP formula sheet, and the reasoning is the same for each.

KEY POINTS

- Exchange depends on surface area; demand depends on volume.
- Cube: SA = $6s^2$, V = s^3, so SA:V = $6 \div s$.
- Smaller cells have a higher ratio and exchange more efficiently.

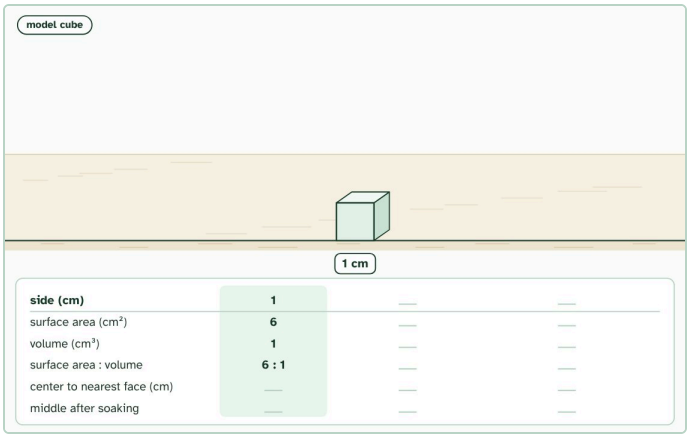
KEY TERMS

surface area-to-volume ratio
The surface area of an object divided by its volume. The larger the object, the smaller the ratio.

ANIMATION · BIGGER CELLS, SLOWER SUPPLY

4 MOMENTS

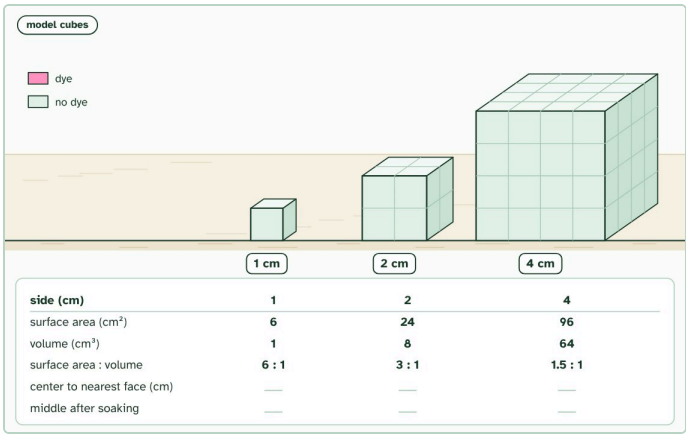
1 1 CM CUBE



side (cm)	1	—	—
surface area (cm²)	6	—	—
volume (cm³)	1	—	—
surface area : volume	6 : 1	—	—
center to nearest face (cm)	—	—	—
middle after soaking	—	—	—

A **model** cube, not a real cell: 1 cm on each side, with 6 cm² of surface around 1 cm³ of volume.

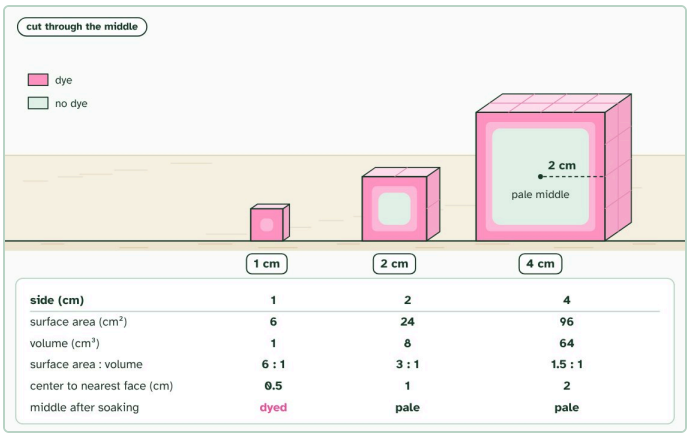
2 THREE CUBES



side (cm)	1	2	4
surface area (cm²)	6	24	96
volume (cm³)	1	8	64
surface area : volume	6 : 1	3 : 1	1.5 : 1
center to nearest face (cm)	—	—	—
middle after soaking	—	—	—

Three cubes **soak in a dye** for the same time: just long enough for it to reach the center of the 1 cm cube.

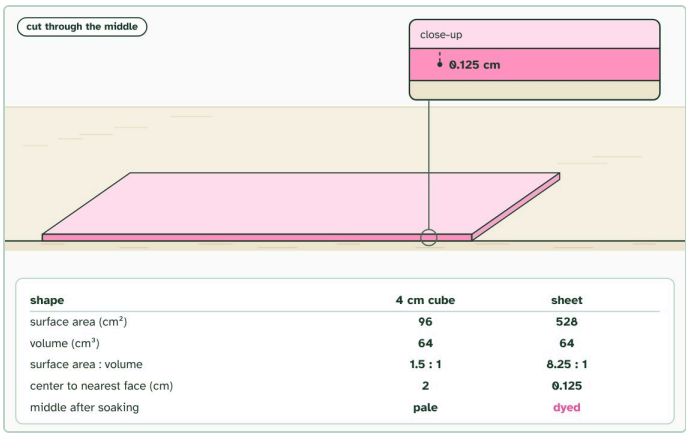
3 THREE CUBES



side (cm)	1	2	4
surface area (cm²)	6	24	96
volume (cm³)	1	8	64
surface area : volume	6 : 1	3 : 1	1.5 : 1
center to nearest face (cm)	0.5	1	2
middle after soaking	dyed	pale	pale

Cut open, the 1 cm cube is dyed right through. The 4 cm cube is still **pale** in the middle, 2 cm from the nearest face.

4 SHEET



shape	4 cm cube	sheet
surface area (cm²)	96	528
volume (cm³)	64	64
surface area : volume	1.5 : 1	8.25 : 1
center to nearest face (cm)	2	0.125
middle after soaking	pale	dyed

The 4 cm cube's 64 cm³ squashed into a sheet 0.25 cm thick: after the same soak it is dyed right through, as no part is more than 0.125 cm from a surface.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-2-cell-structure-and-size#cell-size

WATCH OUT

A bigger cell has more surface area, not less. It is the area for each unit of volume that falls.

PREDICT

Cube A has sides of 1 cm; cube B has sides of 3 cm. How do their surface area-to-volume ratios compare?

(A) B's ratio is 3 times A's, because B's sides are each 3 times as long as A's sides

(B) A's ratio is 6 and B's is 2, so A has 3 times as much surface for each cm

3

(C) They are the same, because both are cubes and so the ratio of a cube never depends on its size

Decide before you look. Answer on page 29.

10 Flatten it, fold it, *fringe* it

2.2.A CELL SIZE

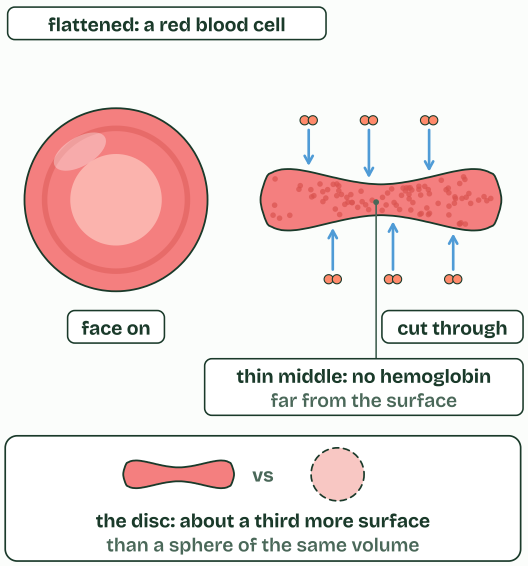
Some cells must exchange a lot and cannot simply be small. They raise their surface area instead. **Flattening:** a red blood cell is a disc thinner in the middle than at the rim, so no hemoglobin is far from the surface. **Microvilli:** cells lining the small intestine and kidney tubules carry thousands of tiny fingers of membrane, which multiply the area for absorption. **Folding:** the membrane at the base of a kidney cell folds inward, like the inner membrane of a mitochondrion.

Plants do the same. A **root hair cell** grows a long thin extension into the soil, adding surface for taking in water and minerals. Leaves are thin and flat, so gases reach every cell, and **guard cells** open and close the pores that let them in.

Whole organisms face the same scaling. A small animal has a large surface for its volume, so it loses heat fast: a mouse must eat a large share of its weight each day to stay warm, while an elephant's problem is losing heat, which its large thin ears help with. Large animals also need lungs, guts and blood to bring exchange surfaces close to every cell.

KEY POINTS

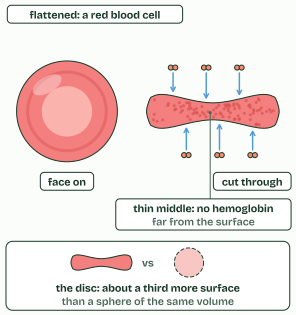
- Flattening: red blood cells. Microvilli: intestine and kidney. Folding: membranes.
- Root hairs add surface for water and minerals.
- SA:V also sets how fast an organism gains or loses heat.



SWITCH IT

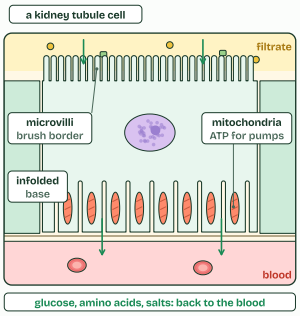
2 SETTINGS

1



Flattened

2



Microvilli and folds

WATCH OUT

Microvilli are not cilia. They are smaller, have no motor inside and do not beat: they only add surface.

PREDICT

Which change would most increase the rate at which a cell absorbs glucose from the gut?

(A) Growing larger, so the cell holds more cytoplasm and more of the enzymes that use the absorbed glucose up

(B) Growing microvilli on the surface facing the gut, so it has more membrane and more carriers for glucose

(C) Becoming a sphere, so it has the largest volume for its surface and can store the glucose it takes in

Decide before you look. Answer on page 29.

Key terms

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

central vacuole 07
The large membrane sac in a mature plant cell, holding water and dissolved substances. It keeps the cell firm and stores substances.

chloroplasts 06
The organelle of photosynthesis in plants and algae: a double membrane round the stroma, with stacks of thylakoids inside.

cristae 05
The folds of the inner membrane of a mitochondrion. They give a large surface for the electron transport chain and ATP synthase.

endoplasmic reticulum 04
A network of membrane sacs and tubes through the cytoplasm. Rough ER has ribosomes on it and makes proteins; smooth ER has none and makes lipids and breaks down toxins.

eukaryotes 01
A cell whose DNA is held in a nucleus and which has membrane-bound organelles: the cells of animals, plants, fungi and protists.

Golgi complex 04
A stack of flattened membrane sacs that modifies, sorts and packages proteins from the rough ER into vesicles.

grana 06
Stacks of thylakoids in a chloroplast (one stack is a granum), where the light-dependent reactions happen.

lysosomes 04
A membrane sac of hydrolytic enzymes that breaks down large molecules, worn-out organelles and anything the cell takes in.

matrix 05
The fluid inside the inner membrane of a mitochondrion, where the Krebs cycle happens.

mitochondrion 05
The organelle where aerobic cellular respiration makes most of a eukaryotic cell's ATP. It has a double membrane, the inner one folded into cristae.

nucleoid 02
The region of a prokaryotic cell where its DNA lies. It has no membrane round it.

organelles 04
A structure inside a cell with a particular job, usually bounded by membrane.

plasmids 02
A small circle of DNA in a prokaryote, separate from its chromosome, often carrying genes such as antibiotic resistance. It can pass from one cell to another.

prokaryotes 01
A cell with no nucleus and no membrane-bound organelles: the bacteria and archaea.

ribosome 03
A particle of ribosomal RNA (rRNA) and protein that makes proteins by reading mRNA. It has no membrane.

stroma 06
The fluid inside a chloroplast's inner membrane and outside the thylakoids, where the Calvin cycle fixes carbon.

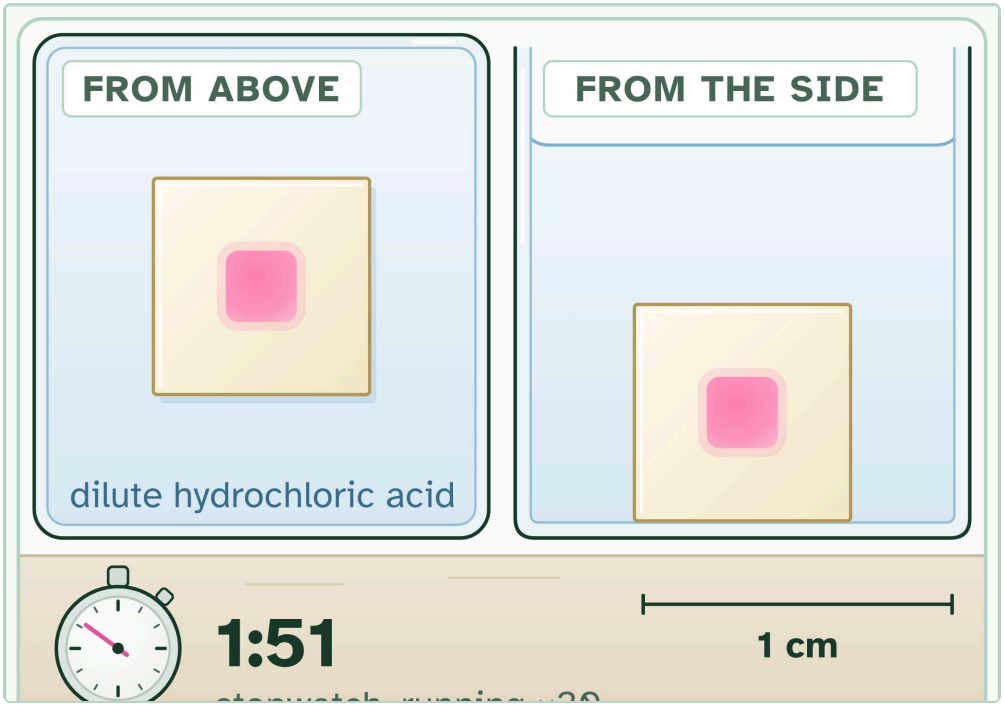
surface area-to-volume ratio 09
The surface area of an object divided by its volume. The larger the object, the smaller the ratio.

thylakoids 06
Flattened membrane sacs inside a chloroplast that hold chlorophyll and the proteins of the light-dependent reactions.

vacuoles 04
A membrane sac that stores water, food or waste. Plant cells have one large central vacuole.

Dry lab: *Pink cubes, clear cubes*

Cubes of agar stained pink with an indicator, dropped into acid. The acid diffuses in and the pink fades from the outside. Time how long each cube takes to lose its color, and find out how size and shape decide it.



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

Your question

How does the surface area to volume ratio of a block of agar affect the time acid takes to reach its middle? Predict before you start: will a cube twice as wide take twice as long?

What you can change

The side of the cube, from 0.3 to 1.0 cm, or the shape: a cube, a long rod or a thin slab, each with a volume of 1 cm^3. Each go drops one fresh block into the acid, so three goes are three repeats.

What to record

For each block: its size, its surface area, volume and ratio, and the time for the last of the pink to go. Then the mean time for each size, and a graph of time against the ratio. The times are modeled on real class results, with real scatter.

Find out

- **Size first.** Time three of each cube, from 0.3 to 1.0 cm. Does a cube twice as wide take twice as long to clear, or more?
- **Work out the ratio.** For each cube, find the surface area, the volume and the surface area to volume ratio before you look at the panel. Which grows faster as the cube gets bigger, the area or the volume?
- **Same volume, new shape.** Time the rod and the slab, each 1 cm³ like the big cube. Which clears first, and is the ratio the whole story?
- **Back to cells.** A cell that took as long to supply its middle as the 1.0 cm cube would starve. What does this tell you about why cells are small, and why some are flat or thin?

Record

- For each block: its dimensions, surface area in cm², volume in cm³ and the ratio, worked out by you and checked against the panel.
- The time for each go, to the nearest second, and the mean and range of the three goes for each block.
- The graph plots each go as a point and the mean as a bar, against the ratio. Sketch the curve through the cubes.
- One source of uncertainty in judging when the pink has gone, and how you would reduce it. Download the CSV to keep your table.

Your question How does the surface area to volume ratio of a block of agar affect the time acid takes to reach its middle? Predict before you start: will a cube twice as wide take twice as long?**What you can change**The side of the cube, from 0.3 to 1.0 cm, or the shape: a cube, a long rod or a thin slab, each with a volume of 1 cm³. Each go drops one fresh block into the acid, so three goes are three repeats.**What to record**For each block: its size, its surface area, volume and ratio, and the time for the last of the pink to go. Then the mean time for each size, and a graph of time against the ratio. The times are modeled on real class results, with real scatter.

Back to cells

A cell that took as long to supply its middle as the 1.0 cm cube would starve. What does this tell you about why cells are small, and why some are flat or thin?

QUESTIONS ON THE LAB

QUESTION 1

A 1 cm cube takes about 9 minutes to clear. How long will a 0.5 cm cube take?

(A) About 4.5 minutes, because it is half as wide as the big cube

(B) About 2 minutes, because the acid has half as far to go and time grows faster than distance

(C) About 1 minute, because it has an eighth of the volume of the big cube

Answer on page 29.

QUESTION 2

The 1 cm cube, the rod (4 × 0.5 × 0.5 cm) and the slab (2 × 2 × 0.25 cm) each have a volume of 1 cm³. Which clears first?

(A) The cube, because it is the most compact shape and has no long sides for acid to cross

(B) The rod, because it is the longest shape and so has the most surface for the acid

(C) The slab, because its middle is only 0.125 cm from a face, closer than in the other two

Answer on page 29.

QUESTION 3

The rod has a ratio of 8.5 and the 0.7 cm cube a ratio of 8.6, almost the same. Yet the rod clears in about 3 minutes and the cube in about 4.5. Why?

(A) Because the rod has a larger volume, so it can hold more acid at the same time

(B) Because the rod's middle is 0.25 cm from a face and the cube's is 0.35 cm away

(C) Because the rod has more corners and edges, where acid enters fastest of all

Answer on page 29.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on 2.1, 2.2 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?program=ap&units=U2&ced=2.1,2.2&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 A new single-celled organism is found in a hot spring. Which of these must it have?

B **Ribosomes, DNA, cytoplasm and a plasma membrane, whatever kind of cell it turns out to be**

Every cell has those four. Whether it has a nucleus, mitochondria, a wall or a flagellum depends on what kind of cell it is, and you would need a microscope to tell.

02 A drug blocks the ribosomes of bacteria but not ours. Why could it still stop a bacterium growing, though bacteria have no organelles for it to target?

B **Every cell needs ribosomes to make its proteins, and bacteria have their own, built differently from ours**

Ribosomes are not membrane-bound, so even a bacterium has them, and without them it cannot make any protein. Bacterial ribosomes are a little smaller than ours and differ in shape, which is how antibiotics such as streptomycin block theirs and leave ours alone.

03 A cell secretes large amounts of a digestive enzyme. Where would you expect most of its ribosomes to be?

C **Bound to the rough ER, which takes the enzyme in as it is made and sends it on toward the membrane**

Proteins for export are made on ribosomes bound to the rough ER. The chain is threaded into the ER as it grows, then travels on to the Golgi and out in vesicles. Cells that secrete a lot, such as those of the pancreas, are packed with rough ER.

04 Liver cells break down drugs and alcohol. Which organelle would you expect a liver cell to have a lot of?

B **Smooth ER, whose enzymes break down toxins such as drugs and alcohol into forms the body can get rid of**

Smooth ER carries the enzymes that detoxify drugs and alcohol, and liver cells have a great deal of it. Regular drinking makes them build even more, which is one reason tolerance grows.

05 Two cells have the same number of mitochondria. In one the inner membranes are much more folded. What follows?

A **It makes more ATP, because the extra folding fits in more electron transport chains and ATP synthase**

Folding increases the surface area of the inner membrane, and that membrane holds the electron transport chain and ATP synthase. More surface, more of both, more ATP. This is SYI-1.F in the course: structure that lets a cell capture and use energy.

06 A chloroplast is broken open and its thylakoids separated from the stroma. Which part can still absorb light and pass on electrons?

B **The thylakoids, because their membranes hold the chlorophyll and the electron transport proteins**

Chlorophyll and the photosystems are in the thylakoid membranes, so the thylakoids still capture light and move electrons. The stroma holds the Calvin cycle enzymes, which need the ATP and NADPH the thylakoids make.

07 A cell from an onion bulb has a wall and a large vacuole but no chloroplasts. What is it?

C **A plant cell that grows out of the light, so it has the wall and central vacuole but makes no chloroplasts**

The wall and the large central vacuole make it a plant cell. A bulb grows underground, where chloroplasts would be no use, so its cells do not make them. Onion skin is a classic first microscope slide for that reason: clear cells with easy walls.

08 A micrograph of a gut cell shows rows of tiny fingers on one surface, many mitochondria and much rough ER. What is the cell specialized to do?

B **Absorb food and make proteins: the fingers add surface, and mitochondria and rough ER power and make**

The fingers are microvilli, which add surface area for absorption (chapter 10). Mitochondria supply ATP for active transport, and rough ER makes proteins such as digestive enzymes for secretion.

09 Cube A has sides of 1 cm; cube B has sides of 3 cm. How do their surface area-to-volume ratios compare?

B **A's ratio is 6 and B's is 2, so A has 3 times as much surface for each cm^3**

A: 6 cm^2 ÷ 1 cm^3 = 6. B: 6 × 9 = 54 cm^2, divided by 27 cm^3 = 2. The smaller cube has three times as much surface for each unit of volume, so it would exchange materials three times as fast for its size.

10 Which change would most increase the rate at which a cell absorbs glucose from the gut?

B **Growing microvilli on the surface facing the gut, so it has more membrane and more carriers for glucose**

Absorption happens across the membrane, so more membrane facing the gut means more carrier proteins and more glucose taken in at once. Growing larger or rounder lowers the ratio, the opposite of what an absorbing cell needs.

QUESTIONS ON THE DRY LAB

Q1 A 1 cm cube takes about 9 minutes to clear. How long will a 0.5 cm cube take?

B **About 2 minutes, because the acid has half as far to go and time grows faster than distance**

Diffusion slows the further it goes: twice the distance takes about four times as long. The middle of a 0.5 cm cube is 0.25 cm from a face, half as far as in the 1 cm cube, so it clears in about a quarter of the time, a little over 2 minutes.

Q2 The 1 cm cube, the rod (4 × 0.5 × 0.5 cm) and the slab (2 × 2 × 0.25 cm) each have a volume of 1 cm^3. Which clears first?

C **The slab, because its middle is only 0.125 cm from a face, closer than in the other two**

The slab has the largest surface for its volume, 10 cm^2 to 1 cm^3, and its thinnest side is only 0.25 cm, so no part is more than 0.125 cm from the acid. The rod is next (ratio 8.5) and the cube is last (ratio 6). Flattening a cell does the same thing.

Q3 The rod has a ratio of 8.5 and the 0.7 cm cube a ratio of 8.6, almost the same. Yet the rod clears in about 3 minutes and the cube in about 4.5. Why?

B **Because the rod's middle is 0.25 cm from a face and the cube's is 0.35 cm away**

The time depends most on the distance from the surface to the middle. The ratio usually tracks that distance, which is why it is such a good guide, but two shapes with the same ratio can still differ. A cell's thinnest dimension is what keeps its middle supplied.

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.