IB BIOLOGY · B2.3

BIOLOGY BY BRADFORD

REVISION GUIDE

One *zygote*, two hundred kinds of cell

Cell specialization

You began as one cell. Find out how its daughters came to be so different, what stem cells can do and where they hide, why cells stay small, and at higher level how lung, muscle, sperm and egg cells are shaped for their jobs.

10 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-b2-3-cell-specialization

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By the end you can

- [ ] Explain how a zygote's unspecialised daughter cells become specialised, and how gradients of signals switch on different genes B2.3.1
- [ ] State the two properties of stem cells: they divide again and again, and they can differentiate along different pathways B2.3.2
- [ ] Describe two stem cell niches in adults, bone marrow and the hair follicle, and what a niche does B2.3.3
- [ ] Distinguish totipotent, pluripotent and multipotent stem cells, with an example of each B2.3.4
- [ ] Compare the sizes of human cells, from red blood cells to neurons B2.3.5
- [ ] Calculate surface area to volume ratios and explain why they limit the size of cells B2.3.6
- [ ] Explain how flattening, microvilli and infolding increase the surface area to volume ratio of a cell B2.3.7
- [ ] Explain the adaptations of type I and type II pneumocytes B2.3.8
- [ ] Compare cardiac muscle cells with striated muscle fibres, and discuss whether a fibre is a cell B2.3.9
- [ ] Explain the adaptations of human sperm and egg cells B2.3.10

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

B2.3.1 PRODUCTION OF UNSPECIALIZED CELLS FOLLOWING FERTILIZATION AND THEIR DEVELOPMENT INTO SPECIALIZED CELLS BY DIFFERENTIATION

01 From one cell to *many kinds*

When a sperm fertilises an egg, the result is a single cell, the **zygote**. It divides by mitosis into two cells, then four, then eight. These first cells are all alike: none of them is specialised yet. After about five days the ball of cells has become a hollow **blastocyst**, with an outer layer that will help form the placenta and an inner cell mass that will form the body.

Every one of these cells has the same genes. They become different by **differentiation**: each cell switches on some of its genes and leaves others off. What decides which genes? Partly its position. Some cells release signal molecules that spread through the embryo, so there is a **gradient**: a high concentration near the source and a low one far away. A cell reads the concentration where it sits and switches on the genes that match. Neighbours in different places get different instructions.

KEY POINTS

- The zygote divides by mitosis into unspecialised cells, then a blastocyst.
- Every cell has the same genes; differentiation is switching on different ones.
- Gradients of signal molecules tell cells where they are, and so which genes to express.

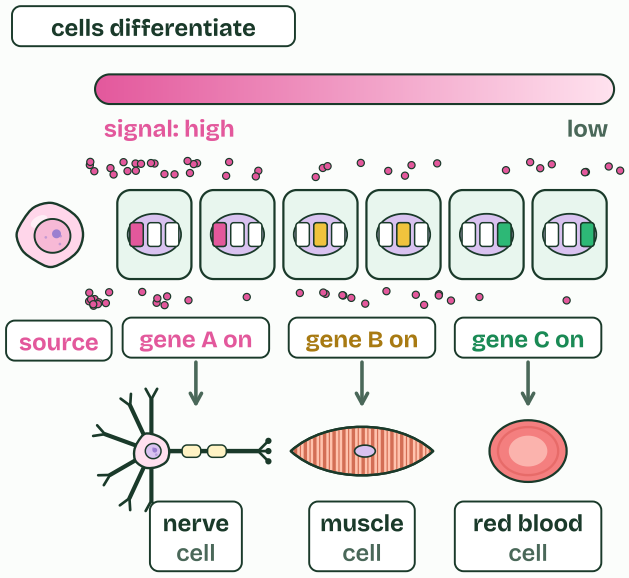
KEY TERMS

zygote
The single cell formed when a sperm and an egg fuse at fertilisation. It has a full set of chromosomes, one set from each parent.

blastocyst
An early embryo of a mammal, about five days after fertilisation: a hollow ball of cells with a cavity and a small inner cell mass that will form the body.

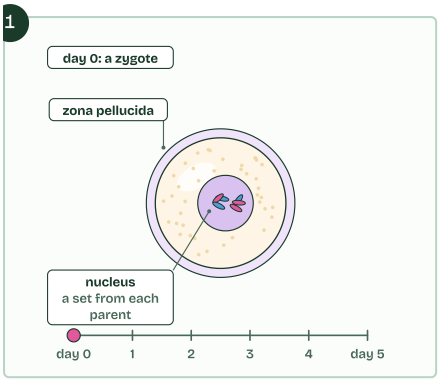
differentiation
The process by which an unspecialised cell becomes specialised for one job, by expressing some of its genes and not others.

gradient
A steady change in the concentration of a substance from one place to another, high near its source and low further away.



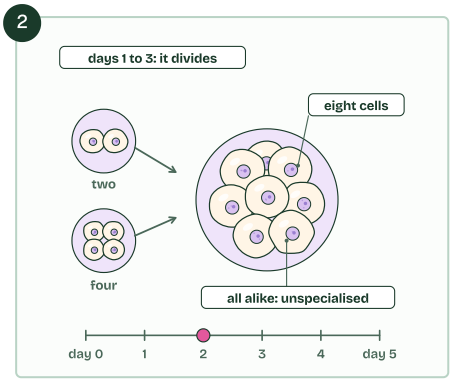
STEP BY STEP
5 STEPS

1



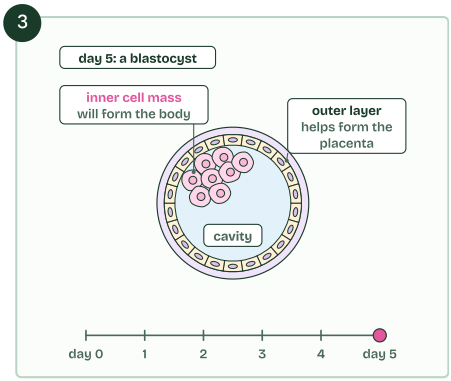
A **zygote**: one cell, with one set of chromosomes from each parent.

2



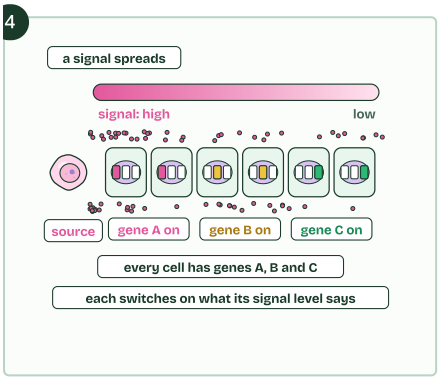
It divides by mitosis. The first cells are all alike: **unspecialised**.

3



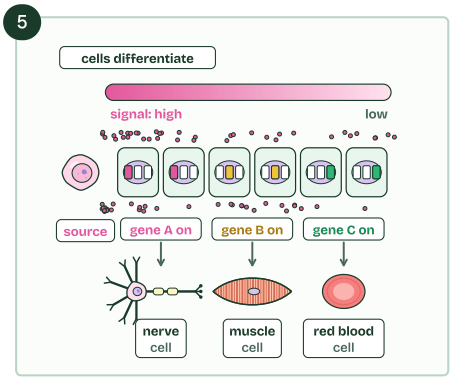
About five days on, a hollow **blastocyst**. Its inner cell mass will make the body.

4



A signal spreads from one end. Each cell reads its concentration and **switches on different genes**.

5



Different genes, different cells: they **differentiate** into nerve, muscle and blood cells.

WATCH OUT

Cells do not lose the genes they are not using. A skin cell still has the genes for haemoglobin; they are just switched off.

PREDICT

A signal molecule is made at one end of an early embryo. A cell near that end and a cell at the far end have exactly the same genes. Why do they end up different?

(A) The cell near the source gains extra genes from the signal molecule as it passes in

(B) They receive different concentrations of the signal, so they switch on different genes

(C) The cell at the far end loses the genes it will not need while it divides by mitosis

Decide before you look. Answer on page 27.

02 Cells that can *still choose*

B2.3.2 PROPERTIES OF STEM CELLS

Most specialised cells have a fixed job and some, such as nerve cells, rarely divide again. A **stem cell** is different in two ways. It can divide again and again, for as long as the body needs, and keep making stem cells: this is **self-renewal**. And its daughters can differentiate along different pathways into more than one kind of specialised cell.

Often a stem cell divides so that one daughter stays a stem cell and the other goes on to specialise. That keeps the number of stem cells steady while new specialised cells keep coming. It is why stem cells interest doctors: a supply of cells that could replace damaged tissue, in a burn, a failing pancreas or a damaged spinal cord.

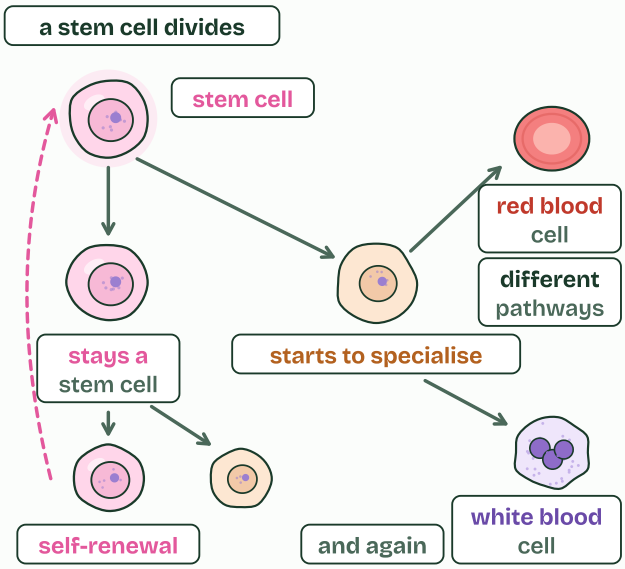
KEY POINTS

- Stem cells divide endlessly, making more stem cells.
- Their daughters can differentiate along different pathways.

KEY TERMS

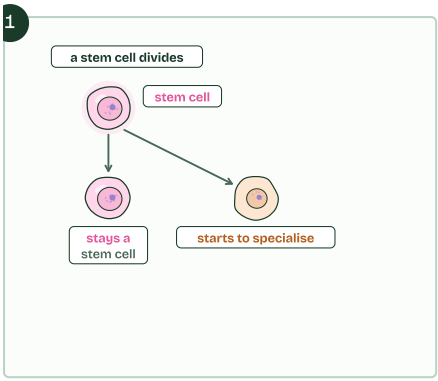
stem cell
An unspecialised cell that can divide again and again to make more stem cells, and whose daughters can differentiate into specialised cells.

self-renewal
A stem cell dividing to make a daughter that is still a stem cell, so the supply never runs out.

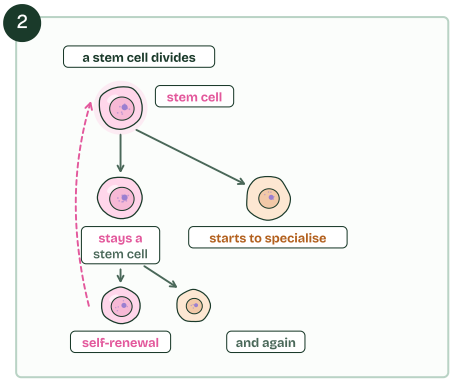


STEP BY STEP

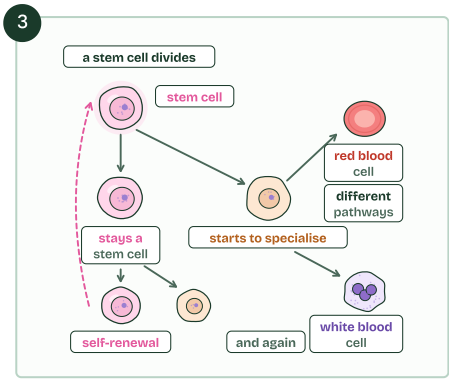
3 STEPS



A stem cell divides. One daughter **stays a stem cell**; the other starts to specialise.



The stem cell can do it **again and again**: self-renewal.



The other daughter's line can go down **different pathways**, here a red or a white blood cell.

WATCH OUT

Stem cells are not only in embryos. Adults have them too, in bone marrow, skin, the gut lining and elsewhere, replacing cells all through life.

PREDICT

A stem cell divides and both daughters differentiate into red blood cell precursors. If this happened every time, what would go wrong?

(A) Too many stem cells would build up, and the marrow would form a tumour

(B) The stem cells would run out, and no new blood cells could be made

(C) The red blood cells would keep their nuclei and divide in their turn

Decide before you look. Answer on page 27.

B2.3.3 LOCATION AND FUNCTION OF STEM CELL NICHES IN ADULT HUMANS

03 Where stem cells *live*

Adult stem cells are kept in special places called **niches**. A niche is the stem cells' surroundings: the neighbouring cells, the material between them and the signals they send. The niche can keep the stem cells as they are, resting and unspecialised, or it can tell them to divide and differentiate when more cells are needed.

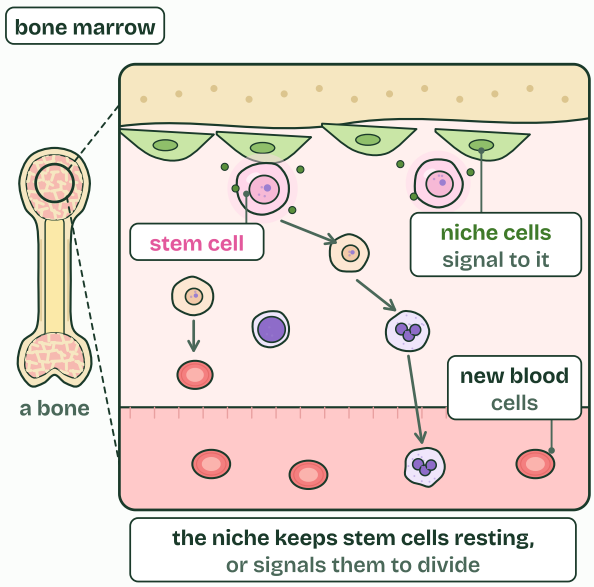
Bone marrow. In the spongy middle of some bones, stem cells sit against niche cells. They make every kind of blood cell, red and white, and platelets: hundreds of billions a day. After heavy bleeding or an infection, signals from the niche speed this up. **Hair follicles.** A bulge in the side of each follicle holds stem cells. They make the cells of a new hair in each growth cycle, and after a cut they move out to help rebuild the skin.

KEY POINTS

- A niche keeps its stem cells, or signals them to divide and differentiate.
- Bone marrow: stem cells that make all the blood cells.
- Hair follicle bulge: stem cells that make hair and help heal skin.

KEY TERMS

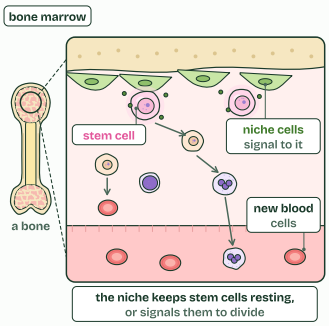
niches
The small region of a tissue where stem cells are kept, with the neighbouring cells and signals that keep them as stem cells or tell them when to divide and differentiate.



SWITCH IT

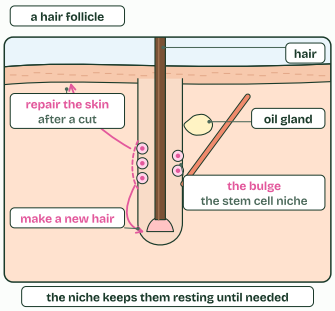
2 SETTINGS

1



Bone marrow

2



Hair follicle

WATCH OUT

A niche is not a kind of cell. It is the place, and everything around the stem cells there that controls them.

PREDICT

A patient loses a lot of blood in an accident. What happens in the bone marrow over the following days?

(A) Red blood cells left in the marrow divide by mitosis to replace the ones that were lost

(B) Signals in the niche make the stem cells divide faster, and more of their daughters become blood cells

(C) The niche cells themselves turn into red blood cells, which then move into the blood

Decide before you look. Answer on page 27.

04 How many *doors* are open?

B2.3.4 DIFFERENCES BETWEEN TOTIPOTENT, PLURIPOTENT AND MULTIPOTENT STEM CELLS

Stem cells differ in how many kinds of cell they can still become, their potency. The zygote and the cells of the first few divisions are **totipotent**: any one of them could make a whole organism, placenta included. Within days, the cells of the inner cell mass are **pluripotent**: they can become any cell of the body, but not the placenta.

Stem cells in adult tissue are **multipotent**. A bone marrow stem cell can make the several kinds of blood cell, but not nerve or skin cells. As cells go down a pathway, doors close, until a specialised cell has one job left.

KEY POINTS

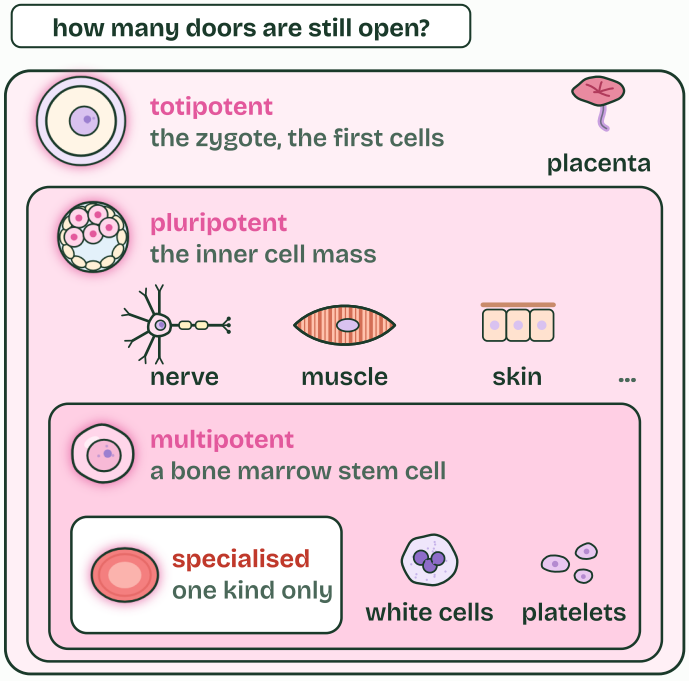
- Totipotent: the zygote and the first cells; any cell, placenta included.
- Pluripotent: the inner cell mass; any body cell.
- Multipotent: adult stem cells such as bone marrow; a few related cells.

KEY TERMS

totipotent
Able to become any kind of cell, including the cells of the placenta: the zygote and the first few cells it makes.

pluripotent
Able to become any cell of the body, but not the placenta: the cells of the inner cell mass, called embryonic stem cells.

multipotent
Able to become only a few, closely related kinds of cell, such as the different blood cells made by stem cells in bone marrow.



Zygote and the cells of the first few divisions: **totipotent**. Each could become any cell of the body, or of the placenta.

Inner cell mass of a blastocyst: **pluripotent**. These embryonic stem cells can become any cell of the body, but no longer the placenta.

Bone marrow stem cell in an adult: **multipotent**. It makes the kinds of blood cell, and not nerve or skin cells.

Red blood cell specialised. It has no nucleus left and cannot divide at all.

REMEMBER IT

Potency, widest first

T	P	M
Total	Plenty	Many
Totipotent	**Pluripotent**	**Multipotent**
any cell and the placenta	any cell of the body	a few related cells

WATCH OUT

"Pluripotent" does not mean "can become many cells" in the loose sense. It means any cell of the body; "multipotent" is the one that means a few.

PREDICT

Why would researchers who want to grow new nerve cells for a damaged spinal cord prefer pluripotent cells to bone marrow stem cells?

(A) Bone marrow stem cells divide far too slowly to make enough cells for any treatment

(B) Bone marrow stem cells are multipotent and make blood cells; pluripotent cells can make nerve cells

(C) Pluripotent cells are always taken from the patient's own body and so are never rejected

Decide before you look. Answer on page 27.

05 Small, large and *very long*

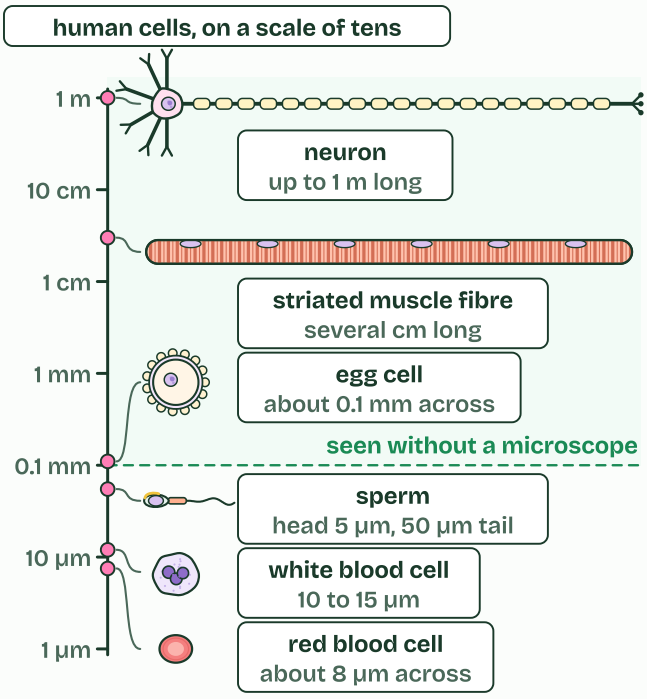
B2.3.5 CELL SIZE AS AN ASPECT OF SPECIALIZATION

Human cells differ in size by a factor of more than a hundred thousand, and the size suits the job. A **red blood cell**, about 8 µm across, is small enough to squeeze through the narrowest capillaries. A **white blood cell** is a little bigger, at 10 to 15 µm. A **sperm** has a head only about 5 µm long, small and light to swim, with a tail about ten times that. The **egg cell**, about 0.1 mm across, is one of the few human cells you can just see with the naked eye: it carries food for the embryo's first days.

Length can be extreme too. A **striated muscle fibre** can run several centimetres, the length of the muscle, so it contracts as one. And a **neuron** that runs from the base of your spine to your toe has a single fibre up to a metre long, carrying a signal the whole way without a break.

KEY POINTS

- Red blood cells about 8 µm; white blood cells 10 to 15 µm; egg about 0.1 mm.
- Sperm are small and light; eggs large, with stored food.
- Muscle fibres reach centimetres and neurons up to a metre in length.



Each step up the scale is ten times the last.

WATCH OUT

Long is not the same as big. A neuron is up to a metre long but only microns wide, so no part of it is far from its surface.

PREDICT

Why can a neuron be a metre long, when cells generally have to stay small?

(A) Its fibre is filled with fluid that moves food and oxygen along it very fast

(B) Its fibre is very thin, so no part of it is far from its surface

(C) Neurons need very little oxygen because they do almost no work

Decide before you look. Answer on page 27.

06 Why cells stay *small*

B2.3.6 SURFACE AREA-TO-VOLUME RATIOS AND CONSTRAINTS ON CELL SIZE

Everything a cell takes in or gets rid of crosses its plasma membrane: oxygen, glucose, carbon dioxide, waste. So the rate of exchange depends on the cell's **surface area**. But the need for exchange depends on how much cytoplasm is using it up: the **volume**. As a cell grows, its volume grows faster than its surface. Model it with cubes: a cube of side 1 cm has a surface area of 6 cm^2 and a volume of 1 cm^3, a **surface area to volume ratio** of 6 to 1. Double the side to 2 cm and the area is 24 cm^2, the volume 8 cm^3, the ratio only 3 to 1.

A big cell has too little membrane for all its volume, and its middle is far from any surface, so substances take too long to diffuse in. That is why cells divide rather than keep growing, and why most cells are tiny. Cubes are a **model**: real cells are not cubes, but the same scaling applies to any shape.

KEY POINTS

- Exchange depends on surface area; the need for it depends on volume.
- Double the side of a cube: area times 4, volume times 8, ratio halves.
- Large cells have a small ratio and a long way to their middle.

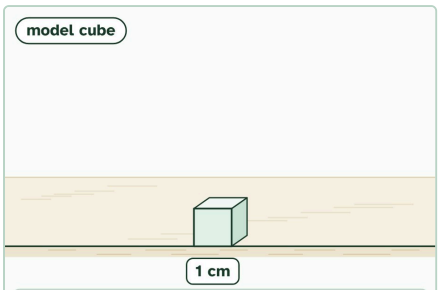
KEY TERMS

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

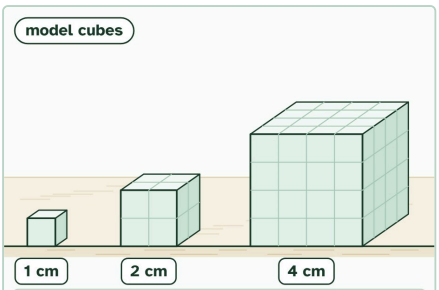
1 1 CM CUBE



side / cm	1	—	—
surface area / cm²	6	—	—
volume / cm³	1	—	—
surface area : volume	6 : 1	—	—
centre 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.

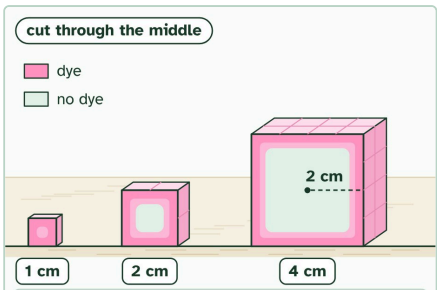
2 THREE CUBES



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
centre 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 centre of the 1 cm cube.

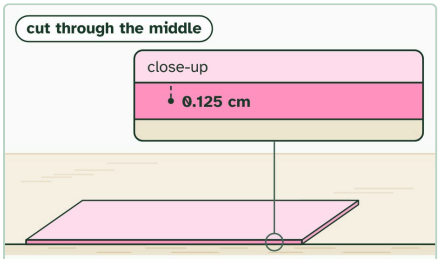
3 THREE CUBES



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
centre 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	cube	sheet
surface area / cm²	96	528
volume / cm³	64	64
surface area : volume	1.5 : 1	8.25 : 1
centre 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/ib-biology-b2-3-cell-specialization#sav

WATCH OUT

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

PREDICT

A cube of side 4 cm. What is its surface area to volume ratio?

(A) 4 to 1, because each face has a side of 4 cm

(B) 3 to 1, the same as the 2 cm cube

(C) 1.5 to 1: 96 cm² of surface for 64 cm³ of volume

Decide before you look. Answer on page 27.

07 Flatten it, fold it, *fringe* it

B2.3.7 HL ADAPTATIONS TO INCREASE SURFACE AREA-TO-VOLUME RATIOS OF CELLS

Cells that exchange a lot have shapes that raise their ratio without making them smaller. **Flattening.** A red blood cell is a disc that is thinner in the middle than at the rim, a **biconcave** shape. No haemoglobin is far from the surface, so oxygen loads and unloads quickly. The very thin type I cells lining the lungs (next chapter) do the same.

Microvilli. The cells lining the **proximal convoluted tubule** of the kidney have thousands of tiny finger-like projections of membrane facing the fluid in the tubule: a brush border that reabsorbs glucose, amino acids and salts. **Infolding.** On their other side, facing the blood, the membrane is folded deeply inwards, an **invagination**, with mitochondria packed between the folds to power active transport.

KEY POINTS

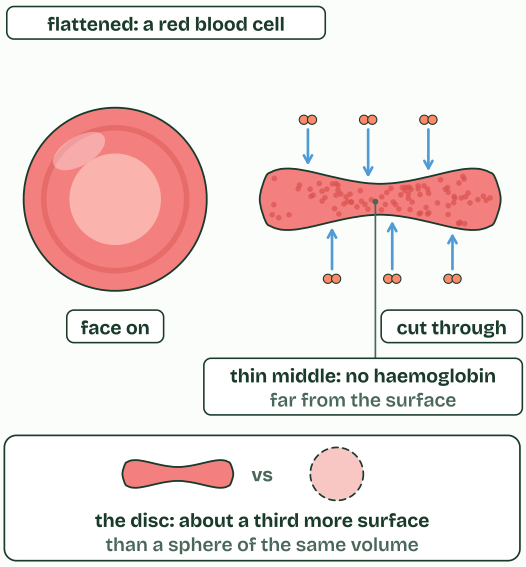
- Flattening: red blood cells, biconcave; type I pneumocytes, very thin.
- Microvilli: the brush border of kidney tubule cells.
- Infolding: the base of the same cells, with many mitochondria.

KEY TERMS

biconcave
Curved inwards on both faces, like a disc pressed in at the centre: the shape of a mammalian red blood cell.

proximal convoluted tubule
The first coiled part of the tubule of a nephron in the kidney, where most of the useful substances in the filtrate are reabsorbed into the blood.

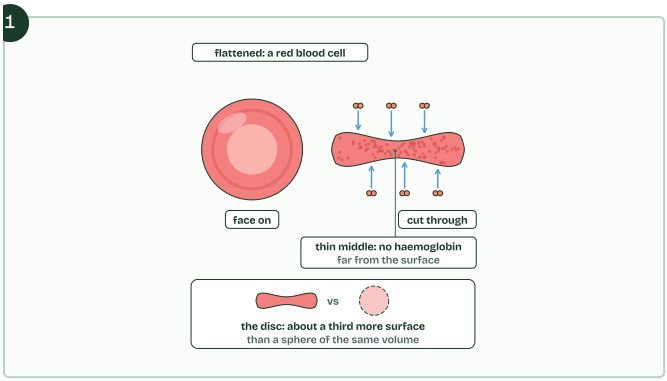
invagination
A fold of the plasma membrane into the cell, which adds membrane area without adding much volume.



SWITCH IT

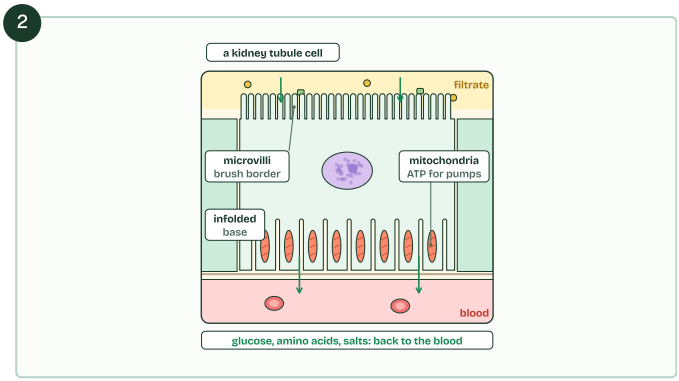
2 SETTINGS

1



Flattened

2



Microvilli and folds

WATCH OUT

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

PREDICT

Why are the folds at the base of a kidney tubule cell packed with mitochondria?

(A) The mitochondria hold the folds open so that the fluid can flow freely between them

(B) Pumping substances across the folded membrane is active transport, which needs ATP

(C) The mitochondria store the glucose that the cell has taken back from the filtrate

Decide before you look. Answer on page 27.

08 Two cells, one *wall*

B2.3.8 HL ADAPTATIONS OF TYPE I AND TYPE II PNEUMOCYTES IN ALVEOLI

The wall of each alveolus in the lungs is lined by two kinds of cell, the **pneumocytes**. **Type I pneumocytes** cover most of the surface. They are extremely thin, about 0.1 µm where they lie over a capillary, so oxygen and carbon dioxide diffuse only a very short distance between the air and the blood.

Type II pneumocytes are fewer and thicker. Their cytoplasm is full of **lamellar bodies**, vesicles of **surfactant** that they release onto the lining. Surfactant lowers the surface tension of the moist film, so the alveoli do not stick shut when you breathe out. The wall is a tissue made of more than one kind of cell, because it has more than one job.

KEY POINTS

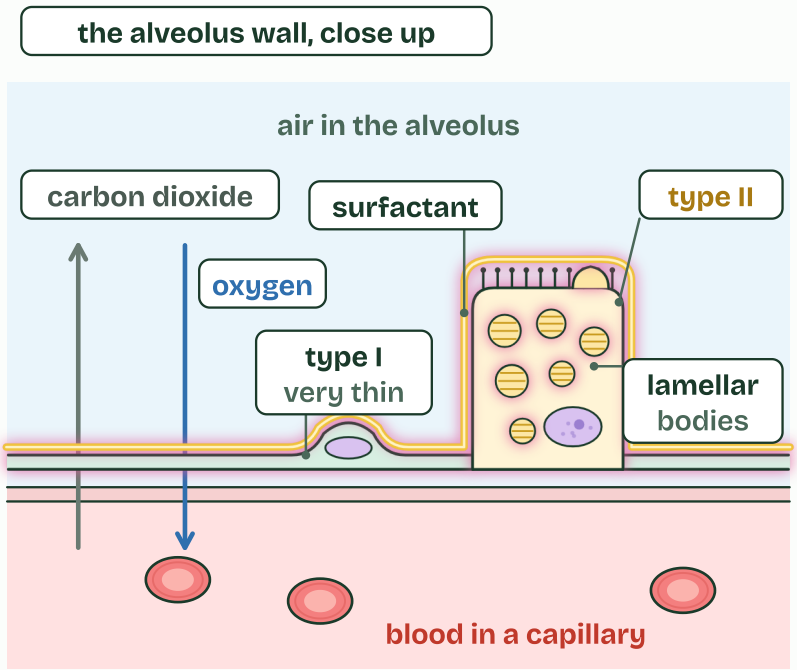
- Type I: extremely thin, short diffusion distance, most of the surface.
- Type II: many lamellar bodies, secrete surfactant.
- One tissue, two cell types, two jobs.

KEY TERMS

pneumocytes
The cells lining the alveoli of the lungs: type I cells for gas exchange and type II cells that secrete surfactant.

lamellar bodies
Secretory vesicles in type II pneumocytes, made of stacked layers of phospholipid, that release surfactant into the alveolus.

surfactant
A mix of phospholipids and proteins that coats the moist lining of the alveoli and lowers surface tension, so they do not collapse.



Type I pneumocyte Extremely thin, about 0.1 µm where it lies over the capillary, so oxygen and carbon dioxide diffuse only a short way. It covers most of the surface of the alveolus.

Lamellar bodies Secretory vesicles of surfactant, stacked in layers. They fuse with the membrane and release it by exocytosis.

Type II pneumocyte A taller cell among the type I cells. It is full of lamellar bodies and secretes surfactant into the alveolus.

Surfactant A thin film of phospholipids and proteins on the moist lining. It lowers the surface tension, so the alveoli do not stick shut when you breathe out.

WATCH OUT

Type II cells do not do the gas exchange. They are too thick for it; their job is the surfactant.

PREDICT

Babies born very early often have trouble breathing. Which cell is most likely not yet working properly?

(A) Type I pneumocytes, because they are not yet thin enough for any gas to diffuse across

(B) Type II pneumocytes, because they have not yet made enough surfactant

(C) Red blood cells, because they cannot yet carry any oxygen at all

Decide before you look. Answer on page 27.

09 Is a muscle fibre a *cell*?

B2.3.9 HL ADAPTATIONS OF CARDIAC MUSCLE CELLS AND STRIATED MUSCLE FIBRES

Both kinds of muscle are packed with **myofibrils**, bundles of the proteins that contract, giving both a striped look. Beyond that they differ. A **striated muscle fibre** in a skeletal muscle is a single long cylinder, often several centimetres, with no branches and hundreds of nuclei just under its membrane. It forms when many cells fuse. Being long lets it contract along its whole length at once.

Cardiac muscle is made of shorter cells, each with one nucleus (sometimes two), that branch and join end to end at **intercalated discs**. The branches make a network, so the signal to contract spreads through the whole heart wall and it squeezes as one. So is a skeletal fibre a cell? It has one continuous membrane, like a cell, but many nuclei, unlike the usual cell. It was made from many cells. Whether to call it a cell depends on which rule of cell theory you weigh more.

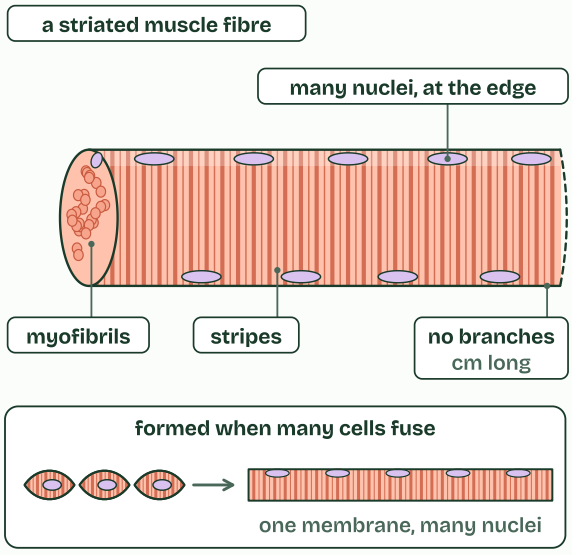
KEY POINTS

- Both: contractile myofibrils.
- Striated fibre: unbranched, very long, many nuclei, formed by fusion.
- Cardiac: branched cells, one nucleus each, joined by intercalated discs.

KEY TERMS

myofibrils
Long protein threads running the length of a muscle cell or fibre, made of repeating units that shorten to make it contract. Their bands give muscle its striped look.

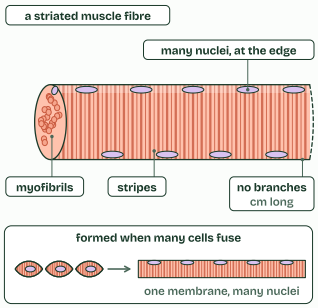
intercalated discs
Special junctions where cardiac muscle cells meet end to end, which hold them together and let the signal to contract pass straight from one cell to the next.



SWITCH IT

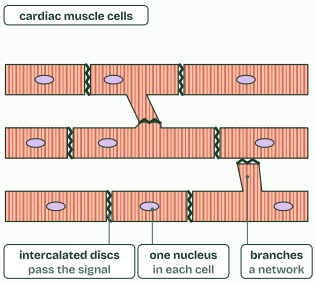
2 SETTINGS

1



Striated fibre

2



Cardiac muscle

WATCH OUT

"Fibre" in muscle does not mean a thread between cells, as in dietary fibre. A muscle fibre is the long, many-nucleated unit itself.

PREDICT

Why might branching suit heart muscle better than skeletal muscle?

(A) Branching lets each heart cell be far longer than any skeletal muscle fibre could be

(B) The heart wall must contract as one; branches spread the signal in every direction

(C) Branches give the heart cells more nuclei, so they can make more of the contractile proteins

Decide before you look. Answer on page 28.

10 Small and fast, big and *stocked*

B2.3.10 HL ADAPTATIONS OF SPERM AND EGG CELLS

The two human gametes are both haploid, with one set of chromosomes, but are built for opposite jobs. A **sperm** must swim and fuse. Its head holds a haploid nucleus, tightly packed, and a cap, the **acrosome**, full of enzymes that digest a way through the layers round the egg. Its midpiece is packed with mitochondria that make ATP for a long **flagellum** that beats to drive it along. It carries almost no cytoplasm: small and light.

The **egg cell** is huge by comparison and does not move. Its cytoplasm is rich in food, droplets of lipid and protein, for the embryo's first days. It is surrounded by a jelly-like layer, the **zona pellucida**, and a layer of follicle cells. Just under its membrane are **cortical granules**, which release their contents as soon as one sperm enters, so that no other can follow.

KEY POINTS

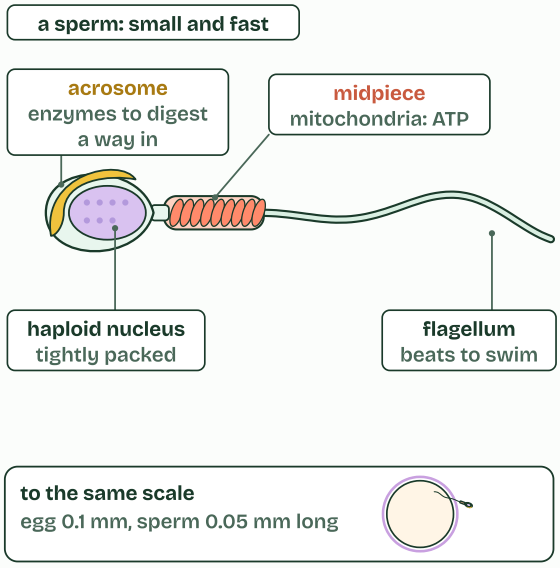
- Sperm: acrosome, haploid nucleus, mitochondria, flagellum; little cytoplasm.
- Egg: large, food stores, haploid nucleus, zona pellucida, cortical granules.
- Both haploid; millions of sperm, few eggs.

KEY TERMS

acrosome
A sac of digestive enzymes over the head of a sperm. Its enzymes digest a path through the layers round the egg.

zona pellucida
A layer of glycoprotein round the egg cell that sperm must bind to and digest through, and that hardens after fertilisation.

cortical granules
Vesicles just under the egg's membrane that release their contents when a sperm enters, hardening the zona pellucida so no other sperm can get in.

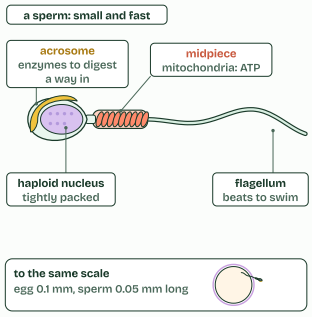


Not to the same scale: the egg is about twenty times as wide as a sperm's head.

SWITCH IT

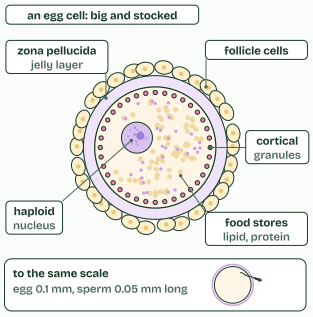
2 SETTINGS

1



Sperm

2



Egg cell

WATCH OUT

The egg is not passive in fertilisation. Its cortical granules and zona pellucida decide that only one sperm gets in.

PREDICT

A man's sperm have normal heads and tails but few mitochondria in the midpiece. What problem would you expect?

(A) The sperm could not digest a path through the zona pellucida round the egg

(B) The sperm would swim weakly, for lack of ATP to drive the flagellum

(C) The sperm would carry two sets of chromosomes into the egg instead of one

Decide before you look. Answer on page 28.

Key terms

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

acrosome 10
A sac of digestive enzymes over the head of a sperm. Its enzymes digest a path through the layers round the egg.

biconcave 07
Curved inwards on both faces, like a disc pressed in at the centre: the shape of a mammalian red blood cell.

blastocyst 01
An early embryo of a mammal, about five days after fertilisation: a hollow ball of cells with a cavity and a small inner cell mass that will form the body.

cortical granules 10
Vesicles just under the egg's membrane that release their contents when a sperm enters, hardening the zona pellucida so no other sperm can get in.

differentiation 01
The process by which an unspecialised cell becomes specialised for one job, by expressing some of its genes and not others.

gradient 01
A steady change in the concentration of a substance from one place to another, high near its source and low further away.

intercalated discs 09
Special junctions where cardiac muscle cells meet end to end, which hold them together and let the signal to contract pass straight from one cell to the next.

invagination 07
A fold of the plasma membrane into the cell, which adds membrane area without adding much volume.

lamellar bodies 08
Secretory vesicles in type II pneumocytes, made of stacked layers of phospholipid, that release surfactant into the alveolus.

multipotent 04
Able to become only a few, closely related kinds of cell, such as the different blood cells made by stem cells in bone marrow.

myofibrils 09
Long protein threads running the length of a muscle cell or fibre, made of repeating units that shorten to make it contract. Their bands give muscle its striped look.

niches 03
The small region of a tissue where stem cells are kept, with the neighbouring cells and signals that keep them as stem cells or tell them when to divide and differentiate.

pluripotent 04
Able to become any cell of the body, but not the placenta: the cells of the inner cell mass, called embryonic stem cells.

pneumocytes 08
The cells lining the alveoli of the lungs: type I cells for gas exchange and type II cells that secrete surfactant.

proximal convoluted tubule 07
The first coiled part of the tubule of a nephron in the kidney, where most of the useful substances in the filtrate are reabsorbed into the blood.

self-renewal 02
A stem cell dividing to make a daughter that is still a stem cell, so the supply never runs out.

stem cell 02
An unspecialised cell that can divide again and again to make more stem cells, and whose daughters can differentiate into specialised cells.

surface area to volume ratio 06
The surface area of an object divided by its volume. The larger the object, the smaller the ratio.

surfactant 08
A mix of phospholipids and proteins that coats the moist lining of the alveoli and lowers surface tension, so they do not collapse.

totipotent 04
Able to become any kind of cell, including the cells of the placenta: the zygote and the first few cells it makes.

zona pellucida 10

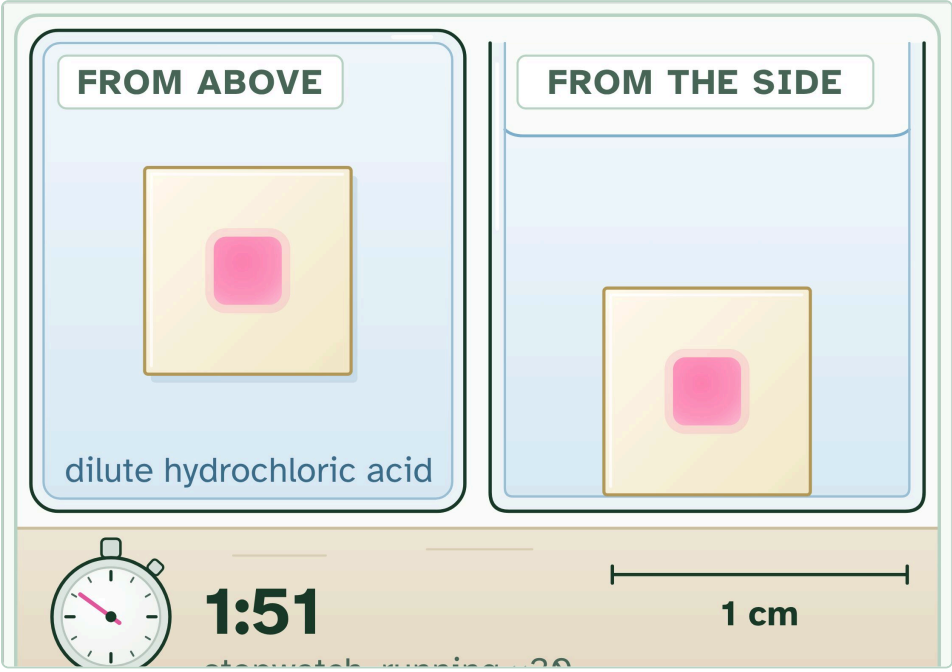
A layer of glycoprotein round the egg cell that sperm must bind to and digest through, and that hardens after fertilisation.

zygote 01

The single cell formed when a sperm and an egg fuse at fertilisation. It has a full set of chromosomes, one set from each parent.

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 colour, 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/ib-biology-b2-3-cell-specialization#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 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 modelled 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 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 modelled 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 28.

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 cm^3. 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 28.

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 28.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on B2.3 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=B2.3&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 A signal molecule is made at one end of an early embryo. A cell near that end and a cell at the far end have exactly the same genes. Why do they end up different?

B **They receive different concentrations of the signal, so they switch on different genes**

The signal is concentrated near its source and dilute far away. Each cell responds to the concentration it meets by expressing a different set of genes. Both keep every gene; they use different ones.

02 A stem cell divides and both daughters differentiate into red blood cell precursors. If this happened every time, what would go wrong?

B **The stem cells would run out, and no new blood cells could be made**

Without self-renewal, each division would use up a stem cell. Soon there would be none left. Keeping one daughter as a stem cell is what lets the supply last a lifetime.

03 A patient loses a lot of blood in an accident. What happens in the bone marrow over the following days?

B **Signals in the niche make the stem cells divide faster, and more of their daughters become blood cells**

Red blood cells have no nucleus and cannot divide. The niche responds to the loss with signals that step up stem cell division and differentiation, so the count recovers over days to weeks.

04 Why would researchers who want to grow new nerve cells for a damaged spinal cord prefer pluripotent cells to bone marrow stem cells?

B **Bone marrow stem cells are multipotent and make blood cells; pluripotent cells can make nerve cells**

A bone marrow stem cell is multipotent: its doors are open only to blood cells. A pluripotent cell can still become any body cell, nerve cells included. The catch is where pluripotent cells come from, which is why their use raises ethical questions.

05 Why can a neuron be a metre long, when cells generally have to stay small?

B **Its fibre is very thin, so no part of it is far from its surface**

What limits a cell is the distance from its surface to its middle. A neuron's fibre is only a few micrometres wide, so every part of it is close to the membrane, whatever its length.

06 A cube of side 4 cm. What is its surface area to volume ratio?

C **1.5 to 1: 96 cm² of surface for 64 cm³ of volume**

Area: 6 faces of 4 × 4 = 96 cm². Volume: 4 × 4 × 4 = 64 cm³. Ratio 96 ÷ 64 = 1.5 to 1. For any cube the ratio is 6 divided by the side, so it halves each time the side doubles.

07 Why are the folds at the base of a kidney tubule cell packed with mitochondria?

B **Pumping substances across the folded membrane is active transport, which needs ATP**

The tubule cells pump salts and other substances out into the blood against their gradients. That is active transport, and it uses ATP from the mitochondria close beside the membrane that does the pumping.

08 Babies born very early often have trouble breathing. Which cell is most likely not yet working properly?

B **Type II pneumocytes, because they have not yet made enough surfactant**

Type II cells start making enough surfactant only late in pregnancy. Without it, the alveoli collapse with each breath out and are hard to reinflate. Premature babies are often given surfactant into the lungs.

09 Why might branching suit heart muscle better than skeletal muscle?

B **The heart wall must contract as one; branches spread the signal in every direction**

A heart chamber squeezes blood by contracting all round at once. Branched cells joined by intercalated discs form a network that carries the signal through the wall in every direction. A skeletal muscle only needs to pull in one direction, along its length.

10 A man's sperm have normal heads and tails but few mitochondria in the midpiece. What problem would you expect?

B **The sperm would swim weakly, for lack of ATP to drive the flagellum**

The mitochondria of the midpiece make the ATP the flagellum uses to beat. With few of them, the sperm move slowly and few reach the egg. The acrosome and nucleus would be unaffected.

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 cm³. 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 cm² to 1 cm³, 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.