●●●●○ Level 4 · Science S4.1

Cells, photosynthesis and respiration

How cells are built, how they work, and how they get energy.

Look closely at animal, plant and bacterial cells, learn how to measure them under a microscope, and follow how substances move in and out. Then see how cells divide, how enzymes speed up reactions, and how photosynthesis and respiration pass energy through living things.

YOU ARE READY FOR THIS BOOK IF

You can draw a plant cell and an animal cell and label five parts.

One step up	S5.1 Molecules and cells
This book	**S4.1 Cells, photosynthesis and respiration**
One step down	S3.2 Ecosystems

Contents

S4.1.1 Cell structure in detail

S4.1.2 Microscopes and size

S4.1.3 Diffusion, osmosis and active transport

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S4.1.5 Enzymes

S4.1.6 Photosynthesis

S4.1.7 Testing photosynthesis

S4.1.8 Respiration

Key words, A to Z

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S4.1.1 CHAPTER 1

Cell structure in detail

> **A leaf and my skin are both made of cells. How can their cells be so different?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Plant cells have a cell wall and chloroplasts, and animal cells do not.
- ☐ **B** Plant cells have a nucleus and animal cells do not.
- ☐ **C** The two kinds of cell have the same parts. Only the size is different.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Cells, S3.1.3. It draws and labels the nucleus, cytoplasm, membrane, cell wall and chloroplast.
- Level 3, Cells, S3.1.4. It explains the jobs of the nucleus, membrane and cell wall.

BY THE END YOU CAN

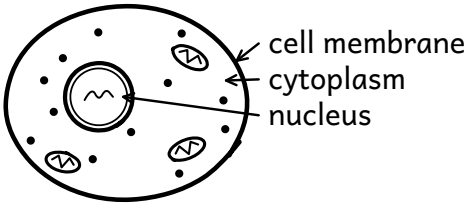
- Describe the jobs of mitochondria, ribosomes and the nucleus
- Compare plant, animal and bacterial cells

Your body is made of cells. So is a leaf, and so is the yeast in bread dough. Some living things are a single cell. You are made of tens of millions of millions of them.

In Level 3 you met the nucleus, the cytoplasm, the cell membrane, the cell wall and the chloroplast. This chapter adds three more parts. Then it puts three kinds of cell side by side: animal, plant and bacterial.

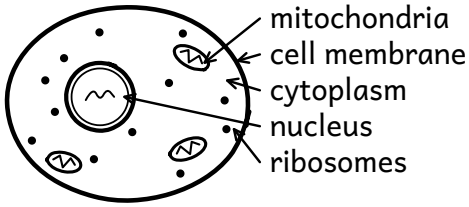
DRAW IT FIRST

Build an animal cell, then a plant cell

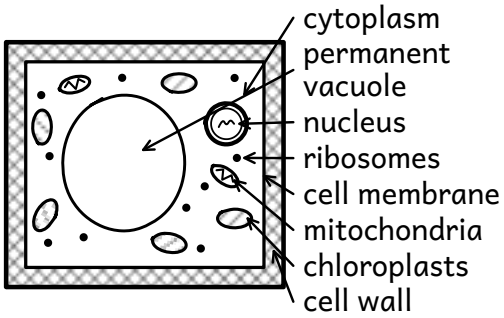


• ribosome

1 An animal cell has a cell membrane round it, cytoplasm inside, and a nucleus.



2 It also has mitochondria and ribosomes. The black dots are ribosomes.



3 A plant cell has all of these and three more: a cell wall, chloroplasts and a permanent vacuole.

The **nucleus** holds the genetic material, which is DNA. It controls what the cell does. Most animal and plant cells have one. A few lose it as they grow, such as the red blood cells of humans and other mammals.

Mitochondria are where aerobic respiration happens. This releases energy from glucose, using oxygen. Cells that use a lot of energy, such as muscle cells, have many mitochondria. Energy is not made here. It is released from food.

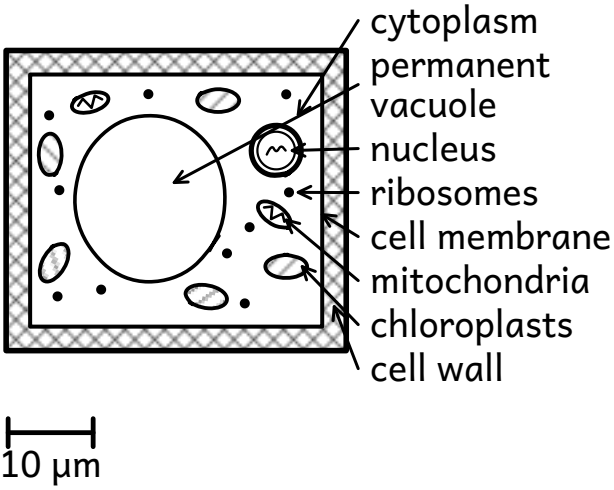
Ribosomes make proteins. They join small units called amino acids in the order the genetic material says. A cell uses proteins to build itself, and some proteins work as enzymes.

Part	Job
nucleus	holds DNA
mitochondria	respiration
ribosomes	make proteins
cytoplasm	reactions

Respiration in the mitochondria releases energy from glucose. Most reactions of the cell happen in the cytoplasm. The cell membrane controls what goes in and out.

Now the extra parts of a plant cell. The **cell wall** is made of cellulose. It is stiff and holds the cell in shape. The **permanent vacuole** is a large space filled with a watery liquid called cell sap. It helps keep the cell firm.

Chloroplasts contain a green substance called chlorophyll. They absorb light for photosynthesis. Not every plant cell has them. A root cell is underground, in the dark, and has none.

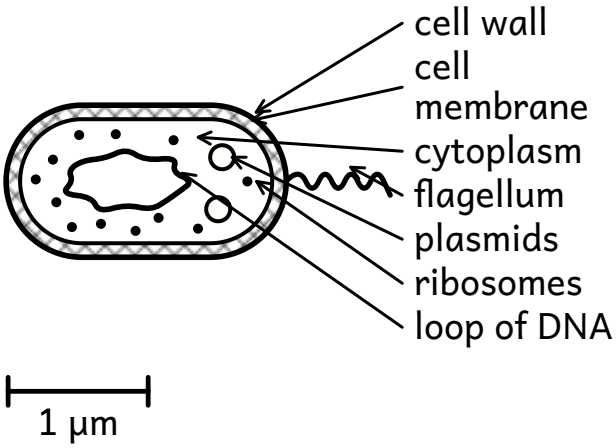


A leaf cell. The cell is about 40 µm wide. The bar shows 10 µm. Ribosomes are drawn much bigger than they are. Each is about 25 nm across, far too small to see at this scale.

Bacteria are cells too, but they are built differently. A bacterial cell has no nucleus. Its DNA is a single loop that lies free in the cytoplasm. It often has small extra rings

of DNA called **plasmids**.

A bacterium has a cell wall, but the wall is not made of cellulose. It has ribosomes, but they are smaller than the ones in plant and animal cells. It has no mitochondria. Some bacteria swim with a tail called a **flagellum**.



A bacterium. It is about 2 µm wide, and the bar shows 1 µm. There is no nucleus. Ribosomes are drawn much bigger than they are. Each is about 20 nm across, far too small to see at this scale.

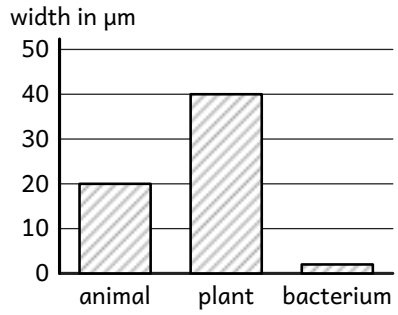
Part	Animal	Plant
nucleus	yes	yes
mitochondria	yes	yes
membrane	yes	yes
ribosomes	yes	yes
cell wall	no	yes
chloroplasts	no	some
vacuole	no	yes
DNA loop	no	no

Part	Bacterium
nucleus	no
mitochondria	no
membrane	yes
ribosomes	smaller
cell wall	yes
chloroplasts	no
vacuole	no
DNA loop	yes

The membrane is the cell membrane. The vacuole is the permanent vacuole. The DNA loop is the genetic material of a bacterium. Plant cells have chloroplasts only where there is light, so the table says some. A plant wall is cellulose. A bacterial wall is not.

SEE IT THREE WAYS

As a picture



In words

Real cells vary a lot. Animal cells are about 10 to 30 µm wide. Plant cells are about 10 to 100 µm. Bacteria are about 1 to 5 µm. The bars show one example of each. Take a plant cell 40 µm wide and a bacterium 2 µm wide. About 20 bacteria fit side by side across the plant cell.

In symbols

40 ÷ 2 = 20

WORKED EXAMPLE

A bacterium is 2 µm wide. A plant cell is 40 µm wide. How many bacteria fit side by side across the plant cell?

1. Both widths are in µm, so they can be divided.
2. Number across = width of the plant cell ÷ width of a bacterium.
3. 40 ÷ 2 = 20.

Answer: 20 bacteria

TRY IT

Build a model cell

You need: a clear plastic bag, water, a stone, two beans, a spoonful of small seeds or grains of rice, a cardboard box that the bag fits in, paper and a pencil for labels.

Be safe: Keep small seeds and stones away from young children. Do not eat or taste anything in the model. Do the water part over a tray or sink.

1. Half fill the bag with water. This is the cytoplasm. Hold it over a tray or a sink.
2. Put the stone in the bag. It stands for the nucleus. Add the two beans for mitochondria and drop in the seeds for ribosomes.
3. Tie the bag closed. The bag is the cell membrane.
4. Write a label for each part on paper and set it beside the model.
5. Now push the bag into the box. The box is a cell wall. The bag fills the box and the box holds it in shape. Take the bag out and the shape changes.

What you will see: The membrane holds the cell together but the bag sags. The box is stiff and keeps the shape. That is the job of the cell wall in a plant cell.

If you cannot try it, this is what happens.

Model	Real part
bag	cell membrane
water	cytoplasm
stone	nucleus
beans	mitochondria
seeds	ribosomes
box	cell wall

A WRONG IDEA MANY PEOPLE HAVE

~~Bacteria have no nucleus, so they have no DNA.~~

Why it feels right: In plant and animal cells the DNA is in the nucleus. No nucleus seems to mean no DNA.

The test that breaks it: A bacterium has to make proteins and copy itself, as all cells do. It needs the instructions in DNA to do that.

What is true: A bacterium has DNA. It is a loop in the cytoplasm, with plasmids beside it, not inside a nucleus.

KEY WORDS

nucleus
the part that holds the genetic material and controls the cell.

mitochondria
the parts where aerobic respiration releases energy from glucose.

ribosomes
tiny parts that make proteins.

cell wall
the stiff outer layer of a plant or bacterial cell.

chloroplasts
the parts of a plant cell that absorb light for photosynthesis.

permanent vacuole
a large space of cell sap in a plant cell.

plasmids
small rings of DNA in a bacterial cell.

flagellum
a tail that some bacteria use to swim.

BACK TO YOUR GUESS

The answer is A: Plant cells have a cell wall and chloroplasts, and animal cells do not.

Plant and animal cells both have a nucleus, mitochondria and ribosomes. A plant cell also has a cell wall, chloroplasts and a permanent vacuole.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which part of a cell makes proteins?

   A The nucleus

   B The ribosomes

   C The mitochondria

   Answer at the back of the book.

2. Where in a cell is energy released from glucose by aerobic respiration?

   A In the mitochondria

   B In the nucleus

   C In the chloroplasts

   Answer at the back of the book.

3. Which of these is found in a leaf cell but not in an animal cell?

   A Mitochondria

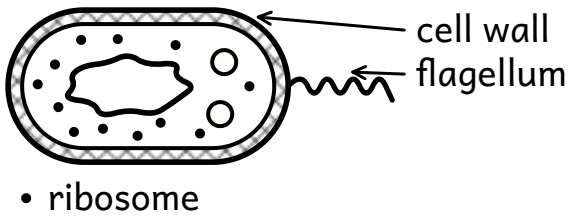
   B Ribosomes

   C Chloroplasts

   D A nucleus

   Answer at the back of the book.

4. Ana looks at the cell in the picture. She says it has no nucleus. Is she right?



A No. Every cell has a nucleus, even if it is hard to see.

B Yes. Its DNA is a loop that lies free in the cytoplasm.

C Yes. It has no DNA at all.

Answer at the back of the book.

5. Joseph says root cells of a plant have chloroplasts, because they are plant cells. What is true?

A He is wrong. Root cells are in the dark and have no chloroplasts.

B He is right. Every plant cell has chloroplasts.

C He is right, but root cells have fewer of them.

Answer at the back of the book.

6. Why does a muscle cell have many mitochondria?

A It makes a lot of protein.

B It needs to release a lot of energy to make the muscle move.

C It makes its own food from light.

D It needs a large nucleus.

Answer at the back of the book.

7. A plant cell is 60 µm wide. A bacterium is 3 µm wide. How many times wider is the plant cell?

Answer at the back of the book.

8. A row of bacteria, each 2 µm wide, lies side by side across an animal cell 30 µm wide. How many bacteria are in the row?

Answer at the back of the book.

9. A cell has a cell wall, a nucleus and chloroplasts. Is it an animal, plant or bacterial cell?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Nucleus: holds DNA, controls the cell. Mitochondria: aerobic respiration, releasing energy. Ribosomes: make proteins. Plant cells add a wall, chloroplasts and a vacuole. Bacteria: no nucleus, a DNA loop.

Draw: An animal cell and a plant cell side by side, with each part named.

S4.1.2 CHAPTER 2

Microscopes and size

A cell is too small to see. How do scientists know how big it really is?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** They multiply the size of the picture by the magnification.
- ☐ **B** They read the real size from the edge of the picture.
- ☐ **C** They divide the size of the picture by the magnification.

IF THIS FEELS HARD, READ THIS FIRST

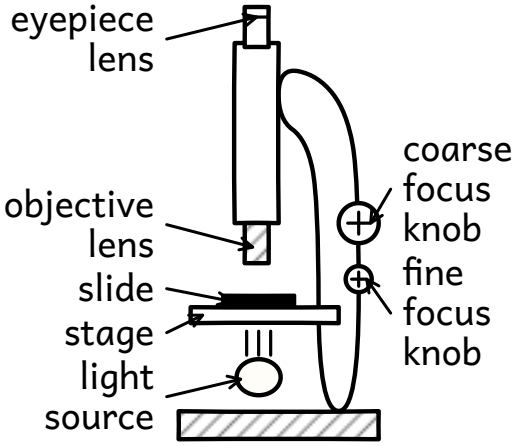
- Level 3, Cells, S3.1.2. It shows how a lens makes a small thing look bigger.
- Level 2, Measuring, M2.6.2. It teaches millimetres and how 1 000 of a small unit make a big one.
- Level 3, Fractions, decimals and percentages, M3.3.5. It shows how to multiply and divide by 1 000.

BY THE END YOU CAN

- Calculate magnification from image size and real size
- Convert between millimetres, micrometres and nanometres

The smallest thing you can see with your eyes alone is about a tenth of a millimetre across. Most cells are much smaller. We need a microscope to see them.

A light microscope shines light through a thin slide. Two lenses magnify what the light shows. The **objective lens** is close to the slide. The **eyepiece lens** is the one you look through.



Light from below passes through the slide. You turn the coarse knob first to find the picture, then the fine knob to make it sharp.

Each lens has its own magnification. The total magnification is the two multiplied together. An eyepiece of ×10 with an objective of ×40 gives ×400.

WORKED EXAMPLE

A microscope has an eyepiece lens of ×10 and an objective lens of ×40. What is the total magnification?

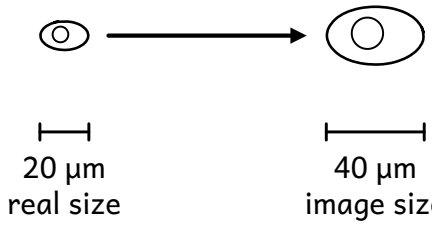
1. Total magnification = eyepiece magnification × objective magnification.
2. 10 × 40 = 400.

Answer: ×400

Magnification says how many times bigger the image is than the real object. The rule has three forms, and all of them need the two sizes in the same unit.

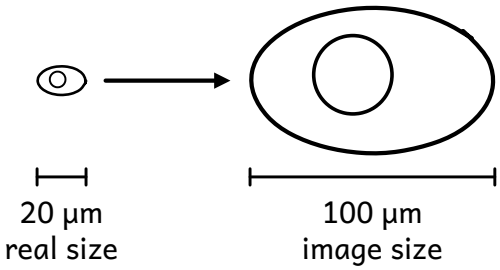
DRAW IT FIRST

The same cell at three magnifications



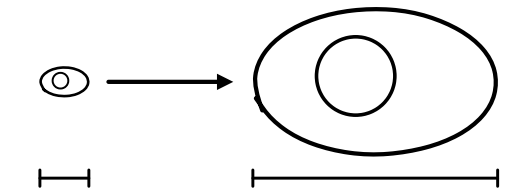
magnification ×2

1 At ×2 the image is 2 times the real size: 20 µm becomes 40 µm.



magnification ×5

2 At ×5 the image is 5 times as wide: 20 µm becomes 100 µm.

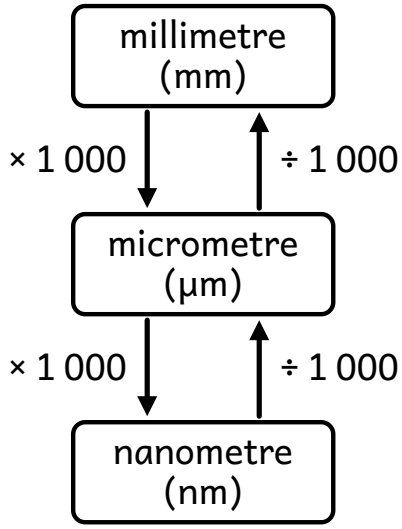


magnification ×50
not to scale

3 At ×50 the image is 1 000 µm, which is 1 mm. It is too big to draw to scale here.

Image size = real size × magnification. Turn it round and you get the other two forms. Magnification = image size ÷ real size. Real size = image size ÷ magnification.

Cells are measured in micrometres. One **micrometre**, written µm, is one thousandth of a millimetre. Things smaller than that, such as ribosomes, are measured in **nanometres**, written nm. One nanometre is one thousandth of a micrometre.



Down to *a* smaller unit, multiply by 1 000. Up to *a* bigger unit, divide by 1 000. Two steps down is × 1 000 000: 1 mm = 1 000 000 nm.

Thing	µm	nm
ribosome	0.025	25
bacterium	2	2 000
blood cell	7	7 000
plant cell	40	40 000

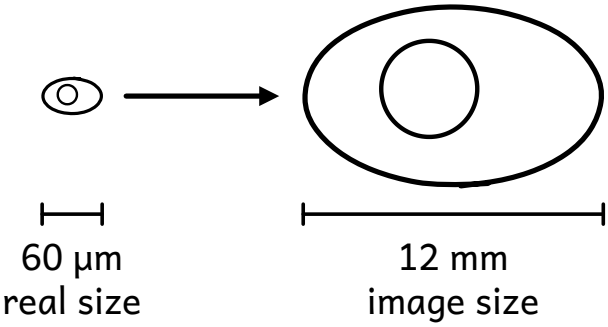
The same sizes in two units. A blood cell here is *a* red blood cell, *a*bout 7 µm *a*cross. These *a*re typical sizes.

WORKED EXAMPLE

A cell is 60 µm long. In *a* drawing it is 12 mm long. What is the magnification?

1. Change 12 mm to µm. 1 mm = 1 000 µm, so 12 mm = 12 000 µm.
2. Magnification = image size ÷ real size.
3. 12 000 ÷ 60 = 200.

Answer: ×200



The worked example as a picture. Both sizes must be in the same unit before you divide.

Now the limit. A light microscope can magnify up to about ×1 500. It cannot show things smaller than about 0.2 µm, so it cannot show ribosomes. An **electron microscope** uses a beam of electrons, not light. It magnifies far more and shows ribosomes and the inside of mitochondria.

The difference is **resolution**. This is how close two points can be and still be seen as two. An electron microscope has a much better resolution. A light microscope can look at living cells. An electron microscope looks at specimens that are no longer alive.

WORKED EXAMPLE

An electron micrograph shows a ribosome 5 mm across at a magnification of ×200 000. How many nm across is a ribosome?

1. Real size = image size ÷ magnification.
2. Change the image to nm. 1 mm = 1 000 000 nm, so 5 mm = 5 000 000 nm.
3. 5 000 000 ÷ 200 000 = 25.
4. A ribosome is 25 nm across.

Answer: 25 nm

Image	Times	Real
5 mm	×200 000	25 nm

The ribosome example as a table. A 5 mm image at this magnification shows a ribosome 25 nm across.

TRY IT

Find the magnification of your own drawing

You need: a grain of rice, a lentil or a small seed, a ruler with millimetres, paper and a pencil.

1. Measure the length of the grain in mm. This is the real size.
2. Draw the grain on the paper as large as you can, with the same shape.
3. Measure the length of your drawing in mm. This is the image size.
4. Divide the image size by the real size.

What you will see: A grain 6 mm long drawn 48 mm long gives 48 ÷ 6 = 8. The drawing is ×8. Scientists write the magnification beside every drawing they make.

If you cannot try it, this is what happens.

Real	Image	Magnification
6 mm	48 mm	×8

A WRONG IDEA MANY PEOPLE HAVE

~~A higher magnification always lets us see smaller things.~~

Why it feels right: If a lens makes things bigger, more of it should show smaller things.

The test that breaks it: Enlarge a photocopy of a printed letter again and again. The edges only get blurry. No new detail appears.

What is true: There is a limit called resolution. Past about ×1 500 a light microscope only makes a bigger blur. To see more detail you need a microscope with a better resolution, such as an electron microscope.

KEY WORDS

magnification
how many times bigger an image is than the real object.

eyepiece lens
the lens of a microscope that you look through.

objective lens
the lens of a microscope that is close to the slide.

micrometre
one thousandth of a millimetre, written µm.

nanometre
one thousandth of a micrometre, written nm.

resolution
how close two points can be and still be seen as two.

electron microscope
a microscope that uses a beam of electrons and shows much more detail.

BACK TO YOUR GUESS

The answer is C: They divide the size of the picture by the magnification.

The picture is bigger than the cell by the magnification. To get back to the real size, divide the size of the picture by the magnification.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. A cell is 25 µm long. In a drawing it is 5 mm long. What is the magnification?

   A ×200

   B ×125

   C ×0.2

   Answer at the back of the book.

2. A bacterium is 2 µm wide. How wide is that in nm?

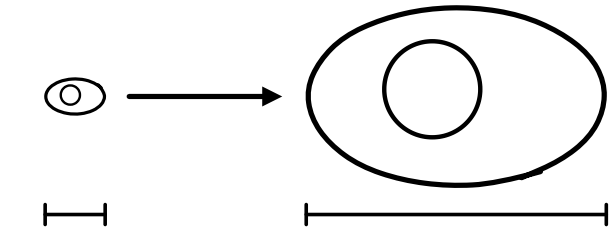
   A 0.002 nm

   B 200 nm

   C 2 000 nm

   Answer at the back of the book.

3. The image of a cell is 1 mm long at a magnification of ×40. How long is the cell?



magnification ×40
not to scale

   A 0.025 µm

   B 25 µm

   C 40 000 µm

   Answer at the back of the book.

4. Which of these is the smallest?

   A 0.002 mm

   B 500 nm

   C 1 μm

   Answer at the back of the book.

5. Why can an electron microscope show ribosomes when a light microscope cannot?

   A It has a better resolution, as well as a higher magnification.

   B It has more lenses, which add more light.

   C A light microscope could, if its magnification were turned up high enough.

   Answer at the back of the book.

6. Which rule gives the magnification of an image?

   A real size ÷ image size

   B image size × real size

   C image size ÷ real size

   Answer at the back of the book.

7. **From an earlier chapter**

   A cell has no nucleus and a cell wall that is not made of cellulose. What kind of cell is it?

   A A bacterial cell

   B A plant cell

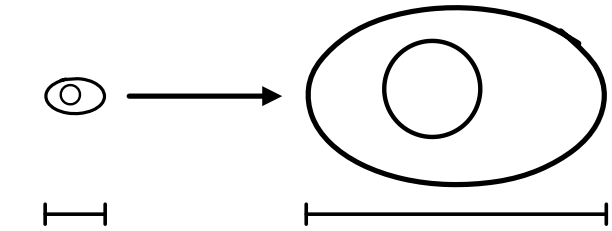
   C An animal cell

   Answer at the back of the book.

8. A cell is 40 μm long. In a drawing it is 20 mm long. What is the magnification?

   Answer at the back of the book.

9. A photograph of a cell is 18 mm long and the magnification is ×300. How long is the real cell in µm?



magnification ×300
not to scale

Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Magnification = image size ÷ real size, in the same unit. 1 mm = 1 000 µm. 1 µm = 1 000 nm. Light microscope: up to about ×1 500, cannot show ribosomes. Electron microscope: better resolution.

Draw: A cell and its drawing, with the real size, the image size and the magnification written beside them.

S4.1.3 CHAPTER 3

Diffusion, osmosis and active transport

> **A potato strip in plain water goes firm. In strong salt water it goes floppy. What is the water doing?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Salt moves into the potato and makes it soft.
- ☐ **B** Water moves into the potato in plain water and out of it in strong salt water.
- ☐ **C** The potato makes water when it is put into plain water.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Particles, S3.5.2. It shows how a smell spreads, which is diffusion.
- Level 3, Particles, S3.5.4. It shows why particles spread faster when they are warmer.
- Level 3, Cells, S3.1.4. It explains the cell membrane.
- Level 3, Fractions, decimals and percentages, M3.3.8. It teaches how to write one amount as a percentage of another.

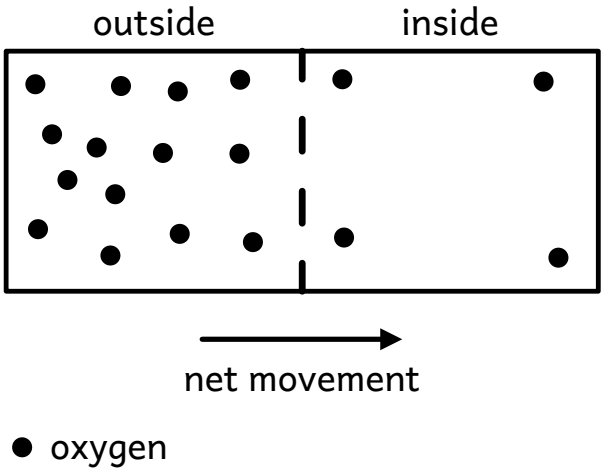
BY THE END YOU CAN

- Explain osmosis using potato pieces in salty and plain water
- Compare diffusion, osmosis and active transport

Everything a cell needs has to get in, and the waste has to get out. All of it crosses the cell membrane. This chapter is about the three ways it does.

A cell membrane is **partially permeable**. It lets some particles through and holds others back. Small particles such as water and oxygen get through. Many others, such as sugar, are held back.

The particles of a liquid or a gas are always moving and bumping about. In a crowded place more of them move out than move in. The result is a spread from a place with more of them to a place with fewer. This is **diffusion**.

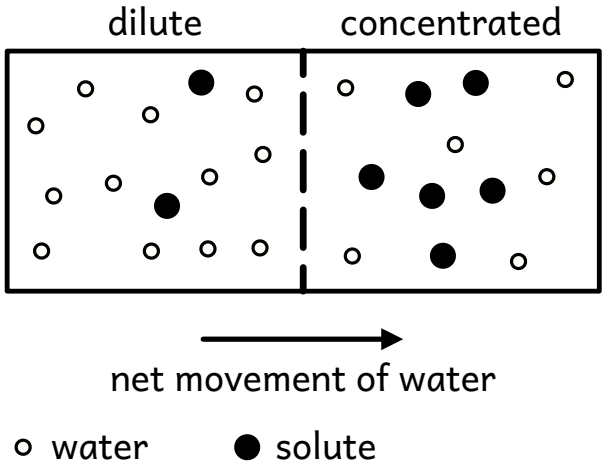


Particles move both ways through the gaps. More cross from the crowded side, so the net movement is from outside to inside.

Diffusion is the net movement of particles from a higher concentration to a lower concentration. The cell does not have to use energy for it. Oxygen diffuses into cells, and carbon dioxide diffuses out.

Water also moves across a membrane, in a way with its own name. **Osmosis** is the movement of water across a partially permeable membrane from a dilute solution to a more concentrated solution.

A dilute solution has a lot of water for each particle of solute. A concentrated solution has less. The solute particles, such as sugar or the ions of salt, cannot cross the membrane easily. The water particles can, and more of them cross towards the concentrated side.

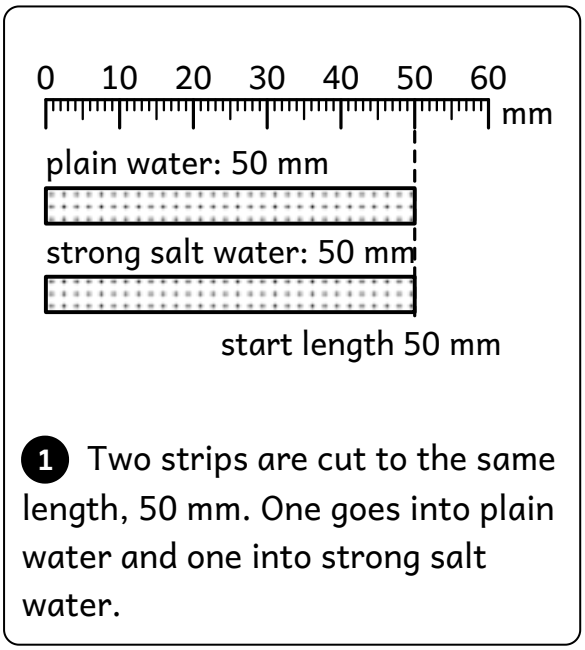


The gaps let water through but not the larger solute particles. Water moves to the concentrated side.

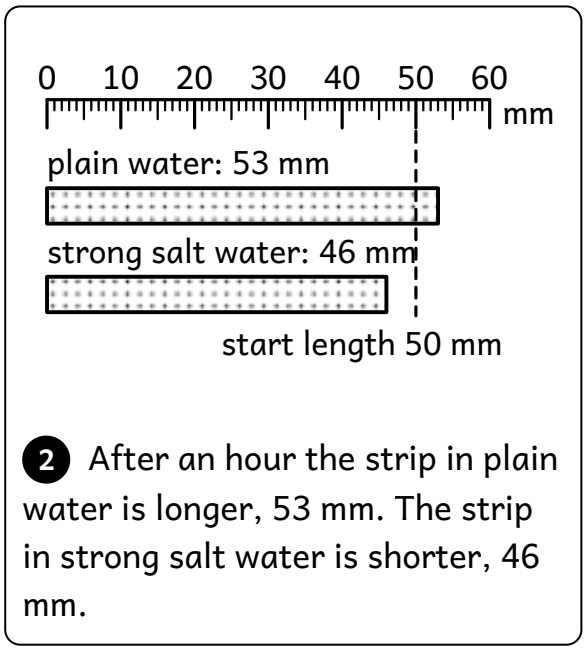
A potato is a good test of osmosis. Cut strips of the same length and put them in different solutions. Then measure them again.

DRAW IT FIRST

Potato strips in plain water and strong salt water



1 Two strips are cut to the same length, 50 mm. One goes into plain water and one into strong salt water.



2 After an hour the strip in plain water is longer, 53 mm. The strip in strong salt water is shorter, 46 mm.

In plain water the liquid outside the cells is more dilute than the liquid inside them. Water moves in by osmosis. The cells swell and press against their walls. The strip becomes longer and firm.

In strong salt water the liquid outside is more concentrated. Water moves out of the cells by osmosis. The cells shrink, and the strip becomes shorter and floppy. Its mass falls. The wall of a plant cell stops it bursting in plain water.

Scientists often compare the **percentage change**. Percentage change = (end value − start value) ÷ start value × 100. A gain gives a plus and a loss gives a minus.

WORKED EXAMPLE

A potato strip is 50 mm long. After an hour in plain water it is 53 mm long. What is the percentage change in length?

1. Change in length = 53 − 50 = 3 mm.
2. Percentage change = change ÷ start length × 100.
3. 3 ÷ 50 × 100 = 6, so the strip is 6% longer.

Answer: 6% longer

WORKED EXAMPLE

A potato piece has a mass of 10.0 g. After an hour in strong salt water it has a mass of 9.1 g. What is the percentage change in mass?

1. Change in mass = 9.1 − 10.0 = −0.9 g, a loss of 0.9 g.
2. Percentage change = change ÷ start mass × 100.
3. 0.9 ÷ 10.0 × 100 = 9.
4. The piece has lost 9% of its mass.

Answer: 9% lighter

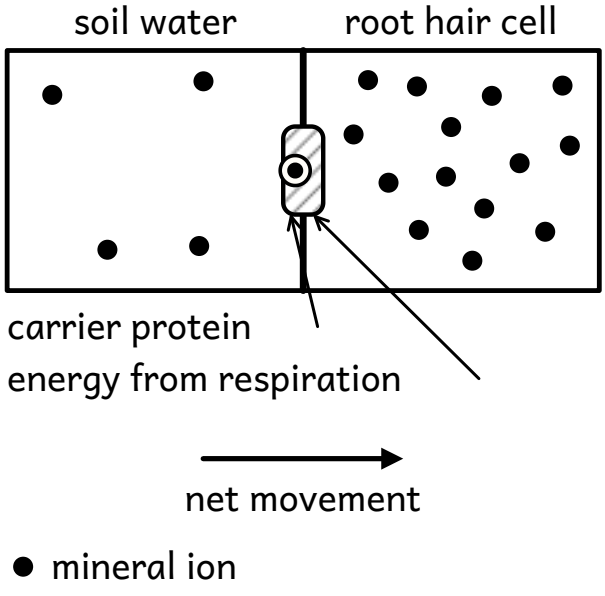
Try a range of salt concentrations. Each piece starts at 10.0 g. The percentage change goes from a gain, to nothing, to a loss. Where it is nothing, the liquid outside has the same concentration as the liquid inside the cells.

Salt	End mass	Change
0 g	11.0 g	+10%
0.5 g	10.5 g	+5%
1 g	9.9 g	−1%
1.5 g	9.5 g	−5%
2 g	9.1 g	−9%

Salt is in grams for every 100 mL of water. The mass changes from a gain to a loss as the salt goes up.

Diffusion and osmosis move things down the gradient. The third way goes the other way. **Active transport** moves particles from a place where they are at a lower concentration to a place where it is higher. This is against the **concentration gradient**.

That takes energy, which comes from respiration. A carrier protein in the membrane picks up the particle and carries it across. Root hair cells take up mineral ions from the soil in this way. The gut takes up glucose into the blood when there is more in the blood than in the gut.



The ions move from fewer to more, so the cell must use energy. Cells that do a lot of active transport have many mitochondria.

Kind	Goes	Energy
diffusion	down	no
osmosis	down	no
active	up	yes

Down is from a higher to a lower concentration. Up is from a lower to a higher one. Active is active transport. Osmosis is for water, and the other two are for any particles.

TRY IT

Potato strips in plain and salty water

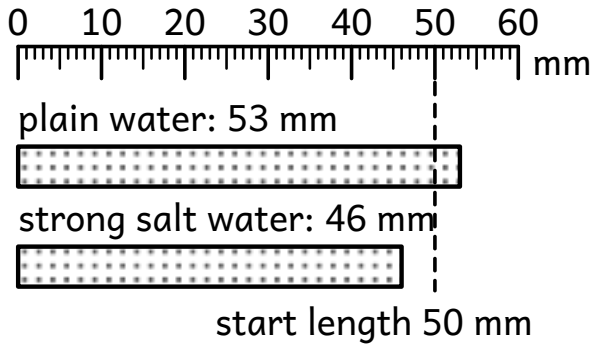
You need: a potato, two cups, water, 3 spoonfuls of salt, a ruler with millimetres, a table knife and a chopping board, paper towel, a clock.

Be safe: An adult cuts the potato. Or use a table knife on a board, with your other hand well away from the blade. Do not eat or taste the potato or the water afterwards.

1. Ask an adult to cut two strips from the potato, each 50 mm long and about as thick as a finger. Cut the strips from the same potato.
2. Fill one cup with plain water. Fill the other with water and stir in the salt until it is gone. This is strong salt water.
3. Put one strip in each cup. Wait one hour.
4. Take the strips out, dry them lightly on the paper towel and measure each one. Bend each strip gently.
5. Work out the percentage change in length of each strip.

What you will see: The strip in plain water is a little longer and firm. The strip in strong salt water is shorter and bends easily. The results of the strips in the picture were 53 mm and 46 mm.

If you cannot try it, this is what happens.



A WRONG IDEA MANY PEOPLE HAVE

~~Water moves to wherever there is more water.~~

Why it feels right: It sounds as if water should gather where it is plentiful, like a crowd moving towards a crowd.

The test that breaks it: Put a potato strip in strong salt water. The salt water has less water for each particle of solute than the potato cells do. The strip shrinks, so the water has left the potato.

What is true: Water moves from the more dilute solution, where there is more water, to the more concentrated one, where there is less.

KEY WORDS

partially permeable
letting some particles through and not others, as a cell membrane does.

diffusion
the net movement of particles from a higher to a lower concentration.

osmosis
the movement of water across a partially permeable membrane from a dilute to a more concentrated solution.

active transport
moving particles against a concentration gradient, using energy from respiration.

concentration gradient
the difference in concentration between two places.

percentage change
the change as a percentage of the start value.

BACK TO YOUR GUESS

The answer is B: Water moves into the potato in plain water and out of it in strong salt water.

Water moves across the membranes of the potato cells. In plain water it goes in, and the strip gains water and firmness. In strong salt water it goes out, and the strip loses water and goes floppy.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. A potato strip is put into strong salt water. What happens to it?

   A It gains water and gets longer.

   B It loses water and gets shorter and floppy.

   C It stays the same, because salt cannot get in.

   Answer at the back of the book.

2. Which statement describes osmosis?

   A Any particles move from a low to a high concentration.

   B Solute particles cross a membrane from a concentrated to a dilute solution.

   C Water crosses a partially permeable membrane from a dilute solution to a more concentrated solution.

   Answer at the back of the book.

3. Why does active transport need energy from respiration?

   A It moves particles against the concentration gradient.

   B It moves particles down the concentration gradient, which is hard.

   C It moves water through the membrane.

   Answer at the back of the book.

4. There are fewer mineral ions in the soil water than in a root hair cell. How do the ions get into the cell?

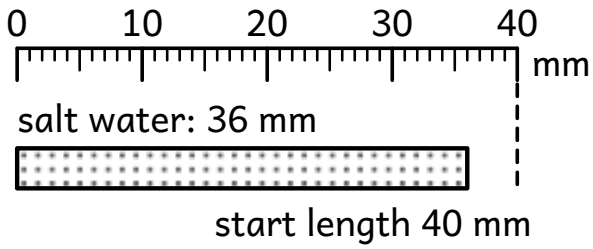
   A By osmosis

   B By active transport

   C By diffusion

   Answer at the back of the book.

5. A potato strip 40 mm long is 36 mm long after an hour in salt water. By what percentage did its length change?



   A 10% shorter

   B 4% shorter

   C 11% shorter

   Answer at the back of the book.

6. Which is an example of diffusion?

   A A potato strip losing water in strong salt water

   B A root hair cell taking up mineral ions from dilute soil water

   C The gut taking up glucose from a lower to a higher concentration

   D Carbon dioxide leaving a cell for the blood, where there is less of it

   Answer at the back of the book.

7. Every piece in the table started at 10.0 g. Between which two salt amounts does the mass stay about the same?

Salt	End mass	Change
0 g	11.0 g	+10%
0.5 g	10.5 g	+5%
1 g	9.9 g	−1%
1.5 g	9.5 g	−5%
2 g	9.1 g	−9%

   A Between 0 g and 0.5 g

   B Between 1.5 g and 2 g

   C Between 0.5 g and 1 g

   Answer at the back of the book.

8. **From an earlier chapter**

   A cell is 80 µm long. In a photograph it is 40 mm long. What is the magnification?

   A ×0.5

   B ×500

   C ×3 200

   Answer at the back of the book.

9. A potato strip is 40 mm long at the start and 44 mm long at the end. What is the percentage change in length?

   Answer at the back of the book.

10. A potato piece has a mass of 20 g at the start and 17 g at the end. What is the percentage change in mass?

    Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Diffusion: any particles, high to low, no energy. Osmosis: water, dilute to concentrated, through a partially permeable membrane. Active transport: low to high, uses energy from respiration. Percentage change = change ÷ start × 100.

Draw: Three boxes with a membrane in each, an arrow for the net movement, and the words energy on the third.

S4.1.4 CHAPTER 4

Cell division

When I cut my finger, it heals. Where do the new cells come from?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** The blood turns into new skin cells.
- ☐ **B** The cells in the wound grow bigger to fill the gap.
- ☐ **C** Cells next to the cut divide and make new cells like themselves.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Cells, S3.1.6. It shows how cells make up tissues and organs, which grow and repair.
- Level 3, Cells, S3.1.4. It explains the nucleus, which holds the genetic material.
- Level 3, Negative numbers, factors and powers, M3.1.7. It shows how repeated multiplying is written as a power, such as 2^5.

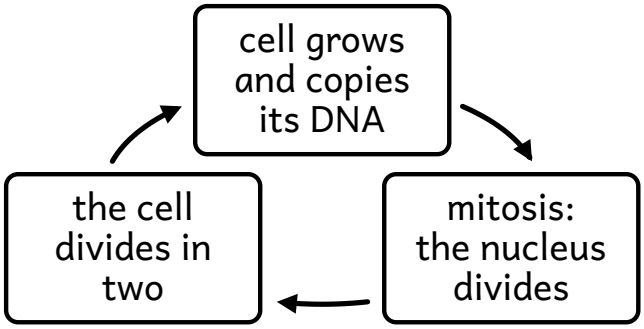
BY THE END YOU CAN

- Describe how mitosis makes two identical cells for growth and repair
- Explain what stem cells are and how they could treat disease

A baby grows into an adult. A cut on your finger heals. A worn skin cell is replaced. All of these need new cells, and new cells come from old cells dividing.

The nucleus holds the genetic material. In a human body cell the DNA is in 46 **chromosomes**. A chromosome is a long thread of DNA, coiled up so that it is short enough to fit in the nucleus.

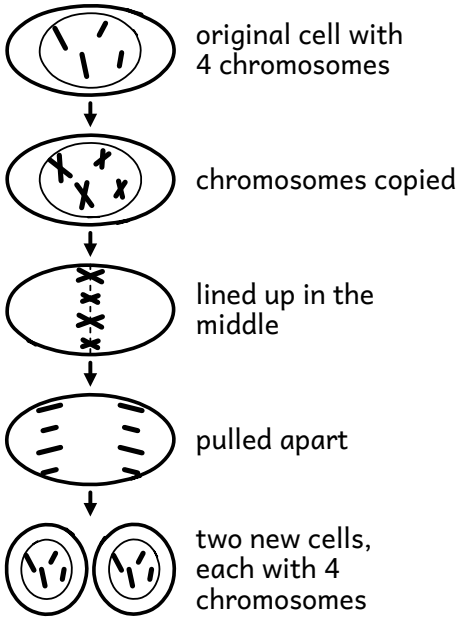
A cell that divides goes round the **cell cycle**. First the cell grows. It makes more of its parts, such as mitochondria and ribosomes, and it copies its DNA. Then the nucleus divides. Last the rest of the cell divides.



The cycle goes round and round. Each new cell can start the cycle again.

The part where the nucleus divides is **mitosis**. Before it starts, the cell has copied every chromosome. Each chromosome is now two identical copies joined together, like an X.

In mitosis the copied chromosomes line up across the middle of the cell. The two copies of each one are pulled to opposite ends. Then a new nucleus forms round each set. The cytoplasm and membrane divide, and there are two cells.



A human cell has 46 chromosomes. This model has 4, 2 long and 2 short, so the steps are clear to count. Each new cell gets one copy of every chromosome. The thin outline is the nucleus.

The two new cells have the same chromosomes as the first cell, and the same genes. They are genetically identical. The cell copies, and then splits the copies, so nothing is lost and nothing is new.

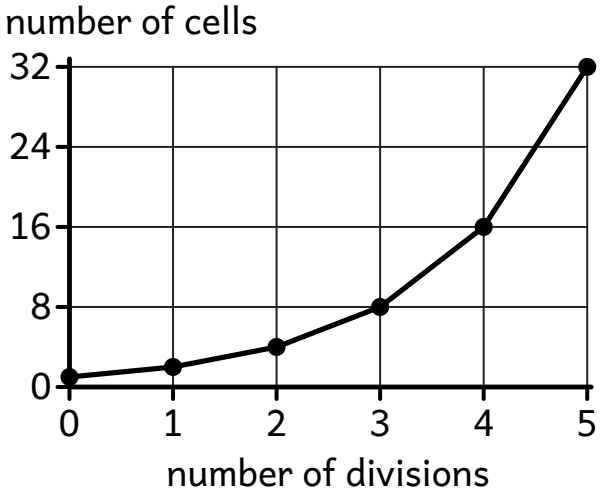
WORKED EXAMPLE

A human skin cell has 46 chromosomes. It divides by mitosis. How many chromosomes are in each new cell?

1. The cell copies every chromosome first. That makes 46 × 2 = 92 copies, joined in 46 X shapes.
2. The 92 copies are shared between two new cells.
3. 92 ÷ 2 = 46.

Answer: 46 chromosomes

Mitosis is how an organism grows and repairs itself. It is also how some living things make new individuals that are copies of themselves. One cell makes two, then four, then eight. The number doubles with every division.



The line gets steeper because each division doubles a bigger number.

WORKED EXAMPLE

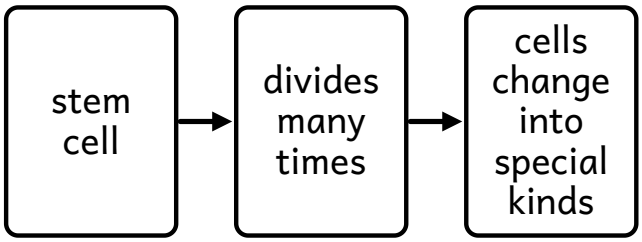
One cell divides by mitosis once every hour. How many cells are there after 5 hours?

1. Each division doubles the number of cells.
2. 1 cell becomes 2, then 4, then 8, then 16, then 32.
3. Five doublings: 2 × 2 × 2 × 2 × 2 = 32.

Answer: 32 cells

Now to the cells that make all the others. A **stem cell** is an unspecialised cell. It can divide again and again, and it can change into other kinds of cell. A cell that has changed into one kind, such as a nerve cell, is **specialised**.

Stem cells are found in several places. An embryo has stem cells that can become almost any kind of cell in the body. Bone marrow, the soft middle of some bones, has stem cells that make new blood cells all through your life. A plant has them in the tips of its shoots and roots, where it grows.



A stem cell is not yet a nerve cell, a blood cell or a muscle cell. An embryo's stem cells can become almost any of them. Stem cells in bone marrow make only blood cells.

Source	Can become
embryo	almost any cell
bone marrow	blood cells
shoot tip	any plant cell

Embryonic stem cells come from an embryo in its first few days.

One use is already established. A bone marrow transplant gives a patient healthy stem cells. These make new blood cells. Doctors use transplants to treat some blood

cancers. Gardeners also use plant stem cells to grow many identical plants from one cutting.

Other uses are being researched. Stem cells could one day replace damaged nerve cells after a spinal injury, or cells in a heart that has been harmed. These uses are not yet part of ordinary treatment.

There are concerns, and people weigh them differently. Some people object to using embryos, because they see an embryo as the start of a human life. Others point to the diseases the cells could help treat. Stem cells that keep dividing could also form a tumour, so they must be tested with great care.

TRY IT

Act out mitosis with paper strips

You need: a sheet of paper, a pencil, tape, a loop of string or a circle drawn on a big sheet.

Be safe: Tear the paper. If you cut it instead, use blunt scissors and cut away from yourself.

1. Tear the paper into 8 strips: 4 long and 4 short. Mark each strip with a pencil.
2. Put 2 long and 2 short strips inside the loop. This is the cell with 4 chromosomes.
3. Copy each chromosome: tape a matching strip across each one to make an X. You now have 4 X shapes.
4. Line the 4 X shapes up across the middle of the loop.
5. Pull each X apart. Put one strip of each X on the left and the other on the right.
6. Draw a line down the middle. Count and compare the two sides.

What you will see: Each side has 2 long and 2 short strips, the same as the cell had at the start. The two new cells are identical.

If you cannot try it, this is what happens.

Step	Strips
start	4
copied	8
pulled apart	4 and 4

A WRONG IDEA MANY PEOPLE HAVE

~~**A stem cell is a cell from the stem of a plant.**~~

Why it feels right: The word stem makes people think of the stem of a plant.

The test that breaks it: Bone marrow has stem cells, and a bone has no stem like a plant. The cells are called stem cells because other cells grow from them, as branches grow from a stem.

What is true: A stem cell is an unspecialised cell that can divide and become other kinds of cell. It can be in an animal or a plant.

KEY WORDS

chromosomes
long threads of DNA in the nucleus, which carry the genes.

cell cycle
the series of steps a cell goes through to grow and divide.

mitosis
the division of the nucleus that makes two identical nuclei.

stem cell
an unspecialised cell that can divide and change into other kinds of cell.

specialised
changed to do one job, such as a nerve cell does.

BACK TO YOUR GUESS

The answer is C: Cells next to the cut divide and make new cells like themselves.

Cells next to the cut divide by mitosis. Each division makes two new cells that are identical to the first, and they fill the gap.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. What does mitosis make?

    A Two cells with half the chromosomes each

    B Four cells that are all different

    C Two cells that are identical to the first cell

    Answer at the back of the book.

2. Which is a use of mitosis in the body?

    A Replacing skin cells that are lost from a cut

    B Releasing energy from glucose

    C Letting water into a root hair cell

    Answer at the back of the book.

3. A cell is about to divide by mitosis. What happens first?

    A The copied chromosomes are pulled apart.

    B The cell copies its chromosomes.

    C The cell splits into two.

    Answer at the back of the book.

4. What is a stem cell?

    A A cell from the stem of a plant

    B A cell that has changed to do one job, such as a nerve cell

    C A cell that can only make more copies of itself

    D An unspecialised cell that can divide and become other kinds of cell

    Answer at the back of the book.

5. Which use of stem cells is already established in medicine?

    A Growing a new heart from the cells of the patient

    B A bone marrow transplant to treat some blood cancers

    C Mending a broken spine with new nerve cells

    Answer at the back of the book.

6. Where are the stem cells of a plant?

   A Only in the seed

   B In every leaf cell, as they grow

   C In the tips of the shoots and roots

   Answer at the back of the book.

7. **From an earlier chapter**

   Which process moves mineral ions into a root hair cell against the concentration gradient?

   A Active transport

   B Osmosis

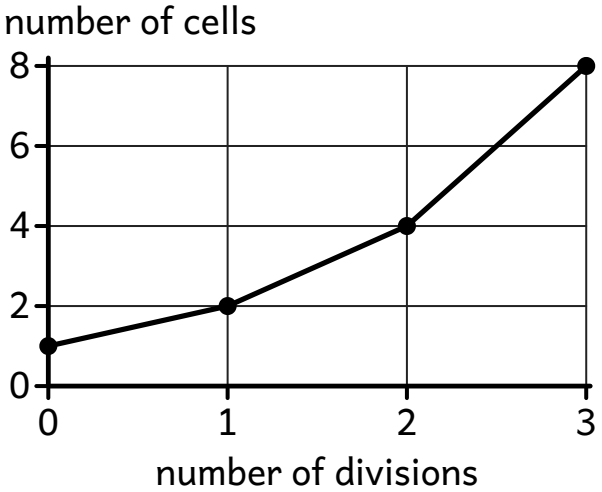
   C Diffusion

   Answer at the back of the book.

8. A cell with 78 chromosomes divides by mitosis. How many chromosomes are in each new cell?

   Answer at the back of the book.

9. One cell divides by mitosis every hour. Use the graph to say how many cells there are after 6 hours.



   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Mitosis: copy the chromosomes, line up, pull apart, split. Two identical cells, for growth and repair. Each division doubles the cells. Stem cells are unspecialised and can become other kinds. Bone marrow transplants are used now.

Draw: A cell with 4 chromosomes dividing into two cells, with the word copied beside the middle step.

S4.1.5 CHAPTER 5

Enzymes

> **Starch on a plate hardly changes in days. In your gut it breaks down in minutes. What speeds it up?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Enzymes, which are proteins that speed up the reaction.
- ☐ **B** The warmth of the body is enough on its own.
- ☐ **C** The food is burned up by the acid in the stomach.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Body systems, S3.3.2. It shows that food is broken into small pieces so the blood can take it up.
- Level 3, Elements, mixtures, reactions and acids, S3.6.4. It explains what a chemical reaction is.
- Level 3, Particles, S3.5.4. It shows why warmer particles move faster.
- Level 2, Tables and charts, M2.7.6. It teaches how to read a line graph.

BY THE END YOU CAN

- Explain how enzymes speed up reactions using the lock and key model
- Explain how temperature and pH change enzyme activity

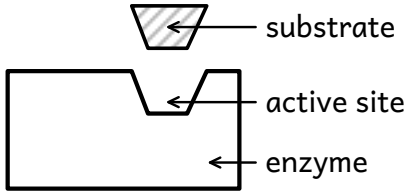
A living cell is full of reactions. Large molecules are built up and others are broken down. At body temperature most of these would be far too slow. Cells speed them up with **enzymes**.

An enzyme is a protein. It is a **catalyst**, which means it speeds up a reaction without being used up. The same enzyme can work again and again.

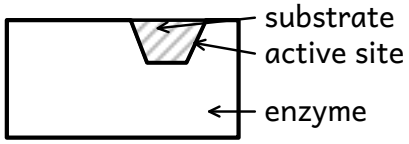
Each enzyme has a hollow of one shape called the **active site**. The molecule it works on is the **substrate**. The substrate has the right shape to fit into the active site, like a key in a lock.

DRAW IT FIRST

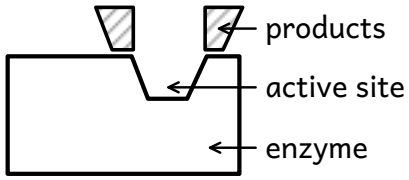
The lock and key model



1 The substrate comes to the enzyme. Its shape matches the active site.



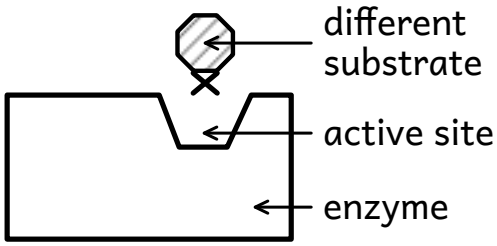
2 The substrate fits into the active site. The reaction happens.



3 The substrate has been split into products, which leave. The enzyme is unchanged and ready for the next substrate.

The lock and key is a model. Real active sites flex a little as the substrate arrives. The idea still holds: the shape of the active site and the shape of the substrate must match.

So each enzyme works on one kind of substrate only. A substrate with a different shape does not fit the active site, and nothing happens.



The round substrate does not fit the notch. This enzyme cannot work on it.

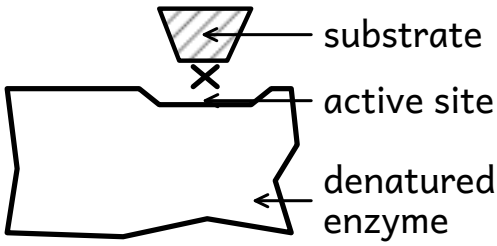
There are many enzymes, with different jobs. Amylase breaks starch into sugars. Protease breaks proteins into amino acids. Lipase breaks fats into fatty acids and glycerol. Cells also use enzymes to join small molecules into large ones.

Enzyme	Job
amylase	breaks starch
protease	breaks protein
lipase	breaks fat

The name of an enzyme often ends in ase. Starch breaks into sugars, proteins into amino acids, and fats into fatty acids and glycerol.

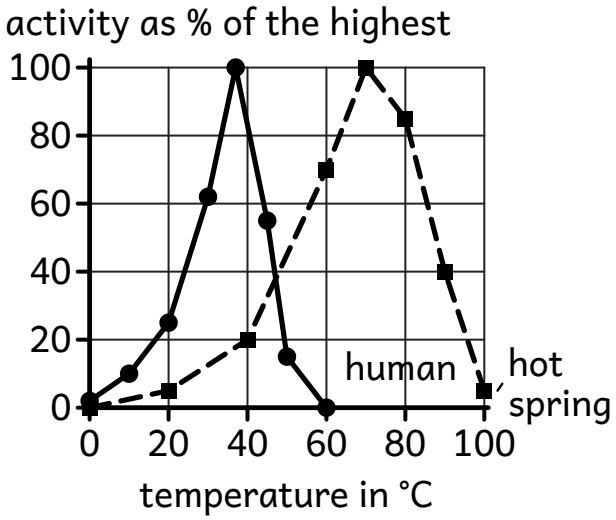
Temperature changes how fast an enzyme works. When it is warmer, the enzyme and substrate molecules move faster. They meet more often and with more energy, so the reaction speeds up.

But there is a limit. Past a certain temperature the enzyme loses its shape. The active site changes, and the substrate no longer fits. The enzyme is **denatured**. This does not reverse when it cools.



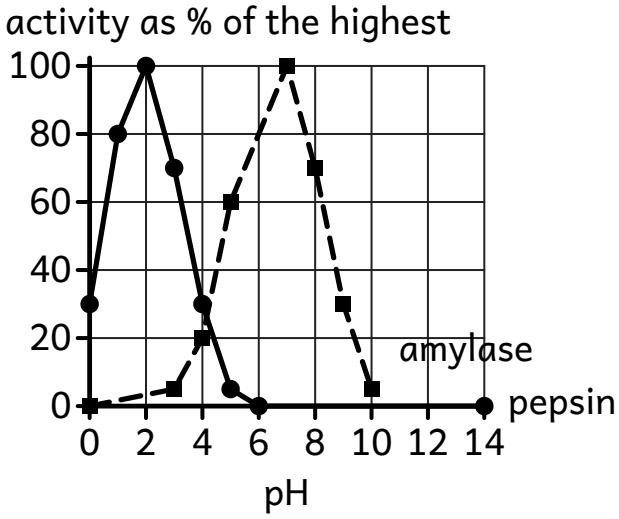
The active site is now shallow and wide. The substrate that fitted before does not fit it.

The graph shows two enzymes. The temperature where an enzyme works best is its **optimum**. For most enzymes in the human body it is about 37 °C. An enzyme from a bacterium that lives in a hot spring has a much higher optimum.



Both lines rise to a peak and then fall fast. The fall is where the enzyme is being denatured. The solid line with dots is the human enzyme. The dashed line with squares is the enzyme from a hot spring bacterium.

The acidity of the liquid also matters. Acidity is measured on the pH scale. Pepsin works in the stomach, where it is very acid, at about pH 2. Amylase of the saliva works best at about pH 7. Outside its optimum pH an enzyme works more slowly. Far outside it, the enzyme is denatured.



Each enzyme has its own best pH. Pepsin suits the stomach. Amylase does not work well there. The solid line with dots is pepsin. The dashed line with squares is amylase.

A test of an enzyme counts the time a reaction takes. A reaction that finishes in less time has a higher rate. The rate is 1 ÷ time. A reaction that takes half the time runs twice as fast.

Temperature	Time
20 °C	10 min
37 °C	4 min
60 °C	no change

Time for amylase to break down all the starch in a test. At 60 °C the enzyme was denatured.

WORKED EXAMPLE

Amylase breaks down all the starch in a test in 10 minutes at 20 °C and in 4 minutes at 37 °C. How many times faster is the reaction at 37 °C?

1. The rate is 1 ÷ time.
2. At 37 °C the rate is 1 ÷ 4 = 0.25 per minute. At 20 °C it is 1 ÷ 10 = 0.1 per minute.
3. 0.25 ÷ 0.1 = 2.5.

Answer: 2.5 times faster

TRY IT

Yeast in cold water and in warm water

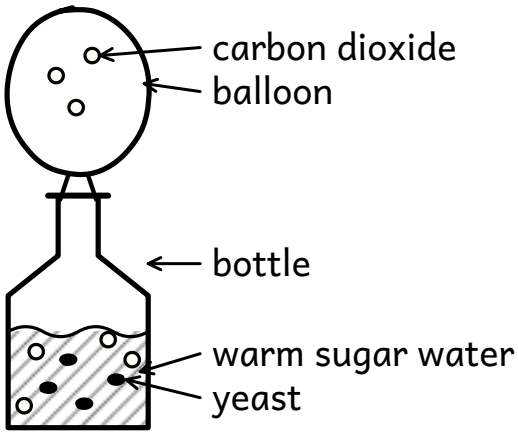
You need: two plastic bottles, two balloons, 2 spoonfuls of dried yeast, 4 spoonfuls of sugar, cold tap water, warm tap water that is comfortable to touch, a spoon, string and a ruler, a clock.

Be safe: Use warm tap water only, never hot, and keep an adult near. Do not boil water for this. Nothing is tasted or swallowed. Wash your hands after handling the yeast.

1. Put 1 spoonful of yeast and 2 spoonfuls of sugar into each bottle.
2. Pour cold tap water into one bottle, to about a third full. Pour the same amount of warm tap water into the other. Swirl both bottles.
3. Fit a balloon over the neck of each bottle. Do not seal the bottles in any other way.
4. Wait 20 minutes. Look at the balloons.
5. Measure round the widest part of each balloon with the string. Hold the string against the ruler.

What you will see: The balloon on the warm bottle fills much more than the balloon on the cold bottle. Yeast cells use enzymes to break down sugar. They make carbon dioxide, which fills the balloon. Warmth speeds the enzymes up.

If you cannot try it, this is what happens.



WORKED EXAMPLE

A balloon on a bottle of yeast grows 15 cm round in 20 minutes. What is the rate of growth in cm per minute?

1. Rate = change ÷ time.
2. The time is 20 minutes and the change is 15 cm.
3. 15 ÷ 20 = 0.75, so the balloon grows 0.75 cm each minute.

Answer: 0.75 cm per minute

A WRONG IDEA MANY PEOPLE HAVE

~~Heat kills an enzyme.~~

Why it feels right: Enzymes do their work inside living cells, and we say heat kills germs.

The test that breaks it: An enzyme is a protein molecule. A molecule is not alive, so it cannot be killed. What heat does is change the shape of the molecule.

What is true: Heat denatures an enzyme: it changes the shape of the active site, so the substrate does not fit. Cold does not denature an enzyme. It only slows the reaction.

KEY WORDS

enzymes
proteins that speed up reactions in living things.

catalyst
something that speeds up a reaction and is not used up.

active site
the hollow in an enzyme where the substrate fits.

substrate
the molecule that an enzyme works on.

denatured
with a changed shape, so the enzyme no longer works.

optimum
the best temperature or pH, where the enzyme works fastest.

BACK TO YOUR GUESS

The answer is A: Enzymes, which are proteins that speed up the reaction.

Enzymes are proteins that speed up reactions. Amylase in saliva and in the gut breaks starch into sugars. Warmth helps, but only with the right enzyme.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. What happens to an enzyme during a reaction?

   A It is used up.

   B It is unchanged and can work again.

   C It is turned into the products.

   Answer at the back of the book.

2. Why does one enzyme work on only one kind of substrate?

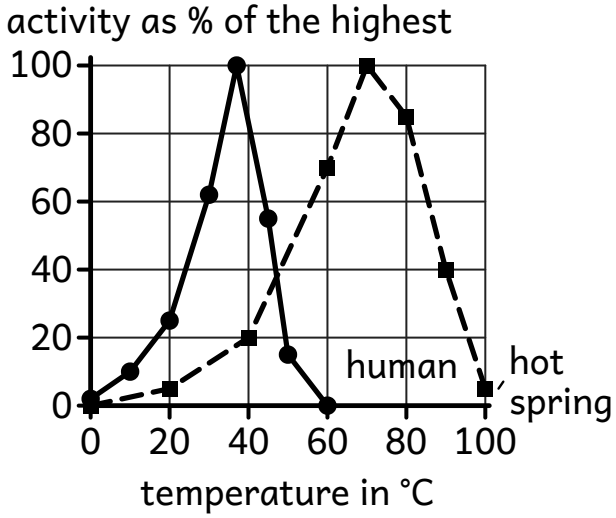
   A Only the shape of that substrate fits the active site.

   B Other substrates would use the enzyme up.

   C The cell makes only one kind of substrate.

   Answer at the back of the book.

3. At what temperature does the human enzyme in the graph work best?



A 30 °C

B 37 °C

C 45 °C

Answer at the back of the book.

4. Why does an enzyme stop working at 60 °C?

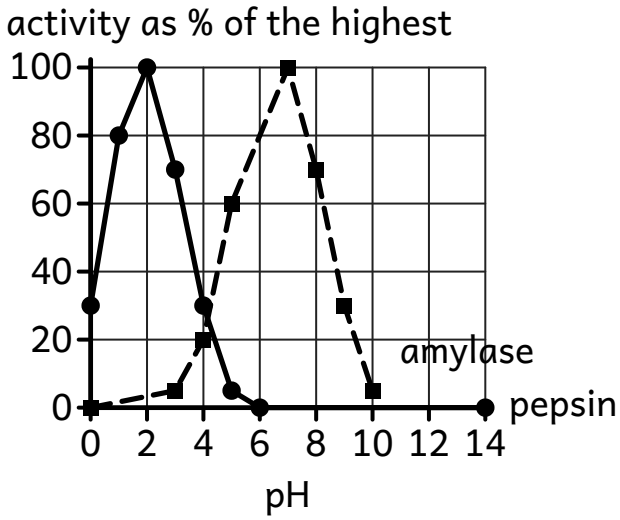
A The enzyme is killed.

B The enzyme is used up by the heat.

C The active site changes shape, so the substrate no longer fits.

Answer at the back of the book.

5. Pepsin works in the stomach. Use the graph to find its optimum pH.



A about pH 7

B about pH 10

C about pH 2

Answer at the back of the book.

6. An enzyme is cooled from 37 °C to 5 °C. What happens?

A The enzyme is denatured for ever.

B The reaction slows down, but the enzyme is not denatured.

C The reaction runs faster, because the enzyme is still.

Answer at the back of the book.

7. **From an earlier chapter**

Which part of a cell makes the proteins that include enzymes?

A The ribosomes

B The nucleus

C The mitochondria

Answer at the back of the book.

8. A reaction with an enzyme takes 10 minutes at 20 °C and 5 minutes at 30 °C. How many times faster is it at 30 °C?

Answer at the back of the book.

9. A balloon on a yeast bottle grows 12 cm round in 24 minutes. What is the rate of growth in cm per minute?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Enzyme: a protein that speeds up a reaction and is not used up. The substrate fits the active site. Warmer is faster up to the optimum, about 37 °C. Past it the enzyme is denatured. Each has an optimum pH.

Draw: A key fitting a lock labelled substrate and active site, and a curve of activity against temperature with its peak marked.

S4.1.6 CHAPTER 6

Photosynthesis

> **A tree grows from a seed to many tonnes of wood. Where does all that material come from?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Mostly from the soil, which the roots take up.
- ☐ **B** Mostly from carbon dioxide in the air and from water.
- ☐ **C** Mostly from the light of the Sun.

IF THIS FEELS HARD, READ THIS FIRST

- Level 2, How plants grow, S2.1.5. It says that green leaves use sunlight, air and water to make food.
- Level 3, Cells, S3.1.4. It explains why only green plant cells have chloroplasts.
- Level 3, Energy stores and transfers, S3.8.1. It names the chemical energy store, which is where the energy of light ends up.
- Level 4, Reactions, equations and amounts, S4.7.1. It shows how to count the atoms of each element in a formula.
- Level 4, Reactions, equations and amounts, S4.7.2. It shows how to balance a symbol equation.

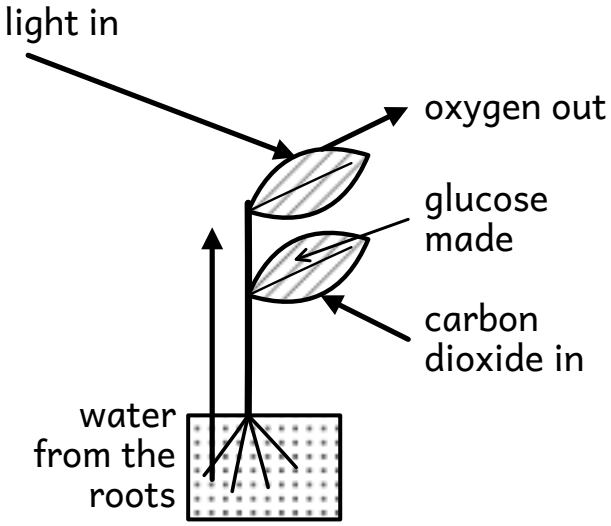
BY THE END YOU CAN

- Write the word and symbol equations for photosynthesis
- Explain how light, carbon dioxide and temperature limit the rate

In the 1600s Jan van Helmont grew a young willow tree in a pot of dried soil. He gave it only water. After five years the tree had gained about 74 kg. He weighed the dried soil again. It had lost only about 60 g.

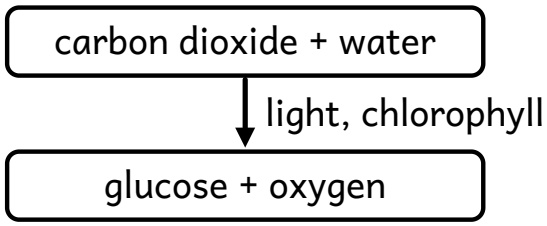
So the tree did not build itself from the soil. Van Helmont thought the water had become wood. He was partly right. About half of a living tree is water. Most of the rest, the dry mass, comes from carbon dioxide in the air, which the leaves take in. The process is **photosynthesis**.

Photosynthesis makes **glucose** from carbon dioxide and water, using the energy of light. It happens in the chloroplasts, which contain the green substance **chlorophyll**. Chlorophyll absorbs the light.



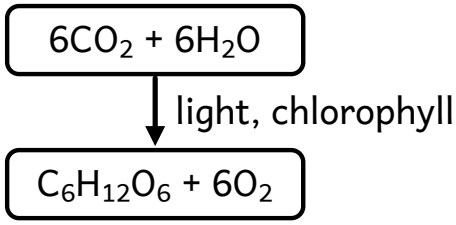
Light, carbon dioxide and water go in. Glucose is made in the leaf. Oxygen goes out. Carbon dioxide and oxygen pass through tiny holes in the leaf called stomata.

Photosynthesis takes in energy. The energy of light is stored as chemical energy in the glucose. This is why photosynthesis is the start of almost every food chain.



Read it from top to bottom. Light and chlorophyll are the conditions, so they are written beside the arrow. Light gives the energy. Chlorophyll is not used up.

The same equation in symbols uses the formulae. Carbon dioxide is CO_2, water is H_2O, glucose is $C_6H_{12}O_6$ and oxygen is O_2.



The numbers in front are how many molecules take part. A molecule of glucose needs 6 molecules of carbon dioxide and 6 of water.

The equation is balanced when each side has the same number of atoms of every element. Count them. The numbers in front multiply the whole formula.

Atom	Left	Right
carbon	6	6
hydrogen	12	12
oxygen	18	18

The two sides match for every element, so the equation is balanced. No atoms are lost or made. They are rearranged.

WORKED EXAMPLE

How many oxygen atoms are on the left of the equation $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$?

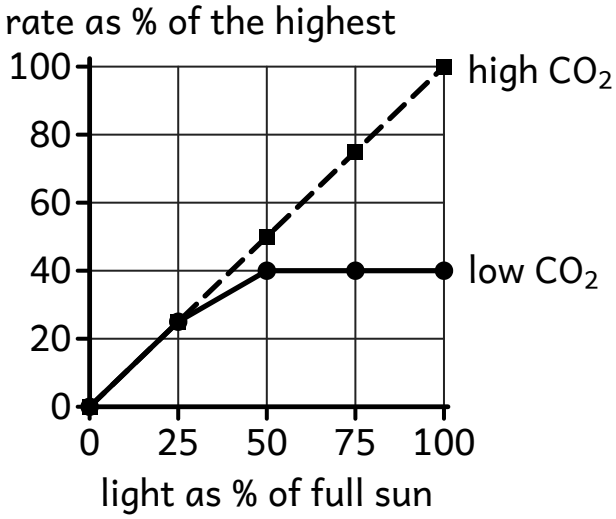
1. Count the oxygen in the carbon dioxide. $6CO_2$ is 6 molecules with 2 oxygen atoms each: 6 × 2 = 12.
2. Count the oxygen in the water. $6H_2O$ is 6 molecules with 1 oxygen atom each: 6 × 1 = 6.
3. Add them: 12 + 6 = 18.

Answer: 18 oxygen atoms

The plant uses the glucose in several ways. It releases energy from it by respiration. It stores some as starch. It makes cellulose for cell walls. With nitrates from the soil it makes proteins.

How fast does photosynthesis go? Its rate depends on three things: light, carbon dioxide and temperature. If one of these is in short supply, it limits the rate. It is called the **limiting factor**.

Light first. In dim light, more light gives a higher rate. But a plant with little carbon dioxide soon stops gaining. The line goes flat, because carbon dioxide has now become the limiting factor.



CO_2 is carbon dioxide. At low light both lines are the same, because light is the limiting factor. Then low CO_2 goes flat. High CO_2 keeps rising.

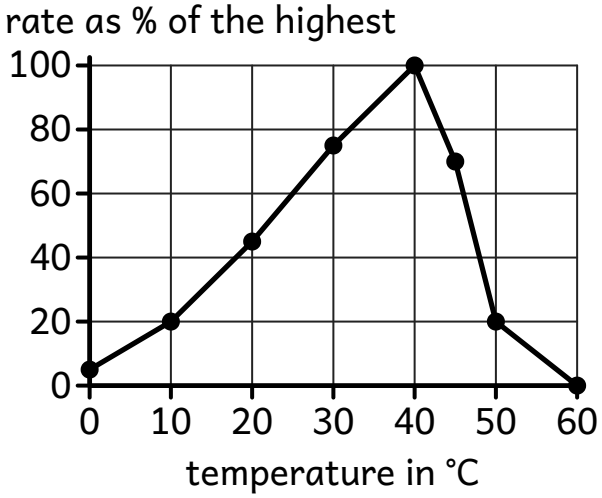
WORKED EXAMPLE

At 75% of full sun, how much higher is the rate with high carbon dioxide than with low carbon dioxide?

1. Read the high CO_2 line at 75. It is at 75% of the highest rate.
2. Read the low CO_2 line at 75. It is at 40% of the highest rate.
3. 75 − 40 = 35, so the rate is 35% of the highest rate higher.

Answer: 35% of the highest rate

Temperature acts in two ways. A warmer leaf has faster enzymes, so the rate rises. But above a certain temperature the enzymes begin to be denatured, and the rate falls fast. The best temperature differs from one plant to another.



The rate climbs to a peak near 40 °C for this plant, which grows in a hot place. Many plants work best between about 25 °C and 35 °C. Above the peak the enzymes start to be denatured.

Growers use this in a greenhouse. They can add light at dusk, raise the carbon dioxide, or keep the air warm. Only the factor that is in shortest supply helps. Adding more of another gives no gain.

TRY IT

Does a leaf need light?

You need: a living plant with soft leaves, growing in soil or a pot, a strip of dark paper, such as brown paper, a paper clip or tape, a pencil and paper.

1. Choose one leaf that gets light for most of the day. Draw it.
2. Cover a strip across the middle of the leaf with dark paper, front and back. Fix it with a paper clip or tape. Leave the rest of the leaf uncovered.
3. Leave the plant where it was for a week.
4. Take the paper off. Compare the covered strip with the part that was uncovered.

What you will see: The covered strip is usually paler, because a leaf needs light to keep making chlorophyll. In a lab, scientists test the leaf for starch with iodine. They find none in the covered strip, which shows it made no glucose there. That test uses hot alcohol and is not done at home. The effect is smaller on some plants, so a plant with soft leaves is best.

If you cannot try it, this is what happens.

Part of leaf	After a week
covered strip	pale
uncovered	green

A WRONG IDEA MANY PEOPLE HAVE

~~Plants get their food from the soil.~~

Why it feels right: We feed plants with manure and fertiliser, and we see roots going into the soil.

The test that breaks it: Van Helmont weighed his willow tree and the soil. The tree gained about 74 kg. The soil lost only about 60 g. The soil could not supply the mass.

What is true: A plant makes its own food by photosynthesis. The soil supplies water and a few minerals, such as nitrate. Most of the plant is built from carbon dioxide and water.

KEY WORDS

photosynthesis
the process in which a plant uses light to make glucose and oxygen from carbon dioxide and water.

chlorophyll
the green substance in chloroplasts that absorbs light.

glucose
a sugar that the plant makes and uses as food and as a building material.

limiting factor
the thing in shortest supply, which sets the rate.

stomata
tiny holes in a leaf that let gases in and out.

BACK TO YOUR GUESS

The answer is B: Mostly from carbon dioxide in the air and from water.

Most of the mass of a plant comes from carbon dioxide taken from the air, and from water. Photosynthesis uses light to join them into glucose, and the plant builds itself from glucose.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which is the word equation for photosynthesis?

   A glucose + oxygen → carbon dioxide + water

   B carbon dioxide + water → glucose + oxygen

   C carbon dioxide + oxygen → glucose + water

   Answer at the back of the book.

2. Where does most of the mass of a growing tree come from?

   A Carbon dioxide from the air, and water

   B The soil

   C The light of the Sun

   Answer at the back of the book.

3. Which equation for photosynthesis is balanced? Equation A is $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$. Equation B is $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 12O_2$. Equation C is $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$.

   A Equation A

   B Equation B

   C Equation C

   Answer at the back of the book.

4. A greenhouse has bright light and a warm temperature, but the air has little carbon dioxide. What helps the plants most?

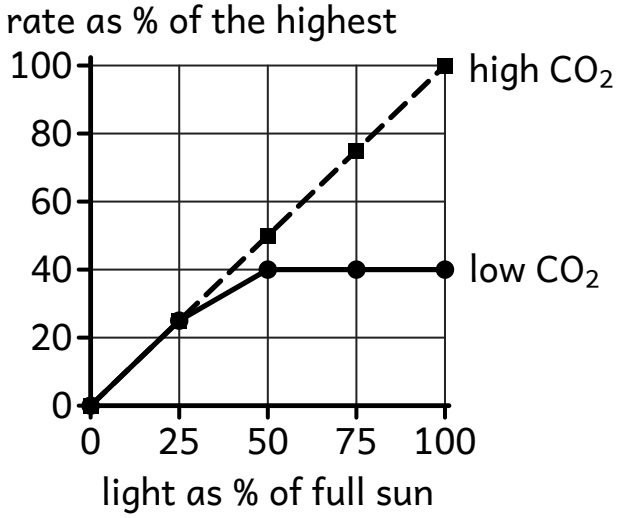
   A More light

   B More carbon dioxide

   C A higher temperature

   Answer at the back of the book.

5. Look at the graph. With low carbon dioxide, what limits the rate at 75% of full sun?



A Light

B Carbon dioxide

C Nothing, since the rate is at its highest

Answer at the back of the book.

6. Why does the rate of photosynthesis fall fast at 50 °C?

A There is no more light at that temperature.

B The carbon dioxide runs out.

C The extra heat gives the plant too much energy to use.

D The enzymes are denatured.

Answer at the back of the book.

7. **From an earlier chapter**

Carbon dioxide gets into leaf cells from the air, where there is more of it than inside the cells. How does it move?

A By diffusion

B By active transport

C By osmosis

Answer at the back of the book.

8. How many oxygen atoms are on the right side of the equation $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$?

   Answer at the back of the book.

9. In photosynthesis 6 molecules of carbon dioxide make 1 molecule of glucose. How many molecules of glucose can be made from 30 molecules of carbon dioxide?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Carbon dioxide + water → glucose + oxygen, using light and chlorophyll. $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$. The factor in shortest supply, light, carbon dioxide or temperature, limits the rate.

Draw: A leaf with arrows for light, carbon dioxide and water going in, and glucose and oxygen coming out.

S4.1.7 CHAPTER 7

Testing photosynthesis

How can you measure how fast a plant makes oxygen?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Weigh the plant before and after.
- ☐ **B** Measure how green its leaves are.
- ☐ **C** Count the bubbles of gas that a water plant gives off in a minute.

IF THIS FEELS HARD, READ THIS FIRST

- Level 2, How plants grow, S2.1.3. It shows how to plan a test that changes only one thing.
- Level 3, Statistics and chance, M3.7.3. It teaches how to find the mean of a set of numbers.
- Level 3, Statistics and chance, M3.7.5. It teaches how to draw and read a line graph.

BY THE END YOU CAN

- Count oxygen bubbles from a water plant at different distances from a lamp
- Plan a fair test of how light changes the bubble rate

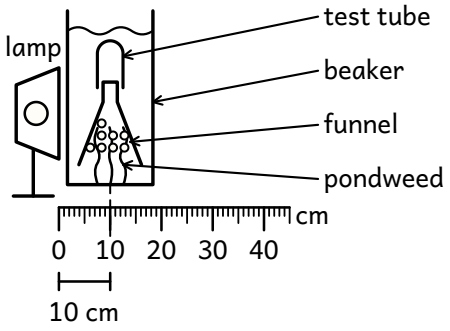
Photosynthesis gives off oxygen. A water plant in the light makes oxygen under the water, and the gas rises as small bubbles. If you count the bubbles in a minute, you have a number that stands for the rate.

Scientists ask how light changes the rate. They use a lamp and move it nearer to the plant and further away. A water plant that scientists often use is called Elodea. Any water plant from a pond or an aquarium can be used.

DRAW IT FIRST

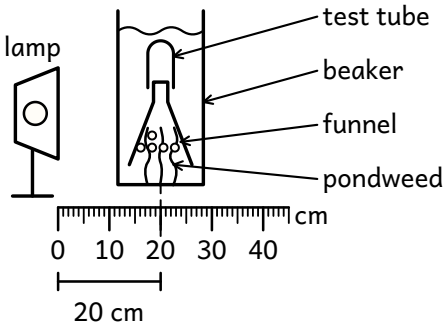
The pondweed at three distances from the lamp

8 bubbles per minute



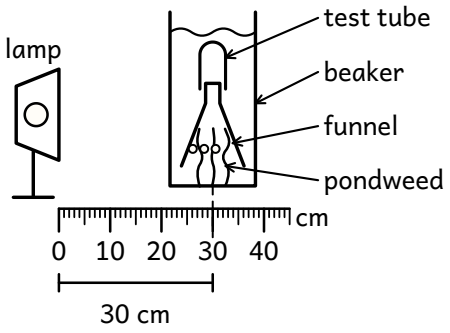
1 The lamp is 10 cm from the pondweed. Bubbles rise fast: 8 in a minute.

5 bubbles per minute



2 At 20 cm the plant gets less light. There are 5 bubbles in a minute.

3 bubbles per minute



3 At 30 cm there is less light again, and only 3 bubbles in a minute.

The plant is cut at its stem and placed upside down in the funnel, so the gas collects in the tube. The bubbles are mostly oxygen from photosynthesis. A pinch of baking soda in the water gives the plant plenty of carbon dioxide. So carbon dioxide is less likely to limit the rate.

Now think about a **fair test**. In a fair test you change one thing only, and keep everything else the same. The thing you change is the **independent variable**. The

thing you measure is the **dependent variable**. The things you keep the same are **control variables**.

Role	Item
change	lamp distance
measure	bubbles per min
keep same	plant and lamp
keep same	time counted
keep same	temperature
keep same	baking soda

The lamp distance is the independent variable. The bubble count is the dependent variable. The rest are control variables.

One thing needs care. A lamp gives out heat as well as light. Heat would warm the water, and warmth also speeds up photosynthesis. Then the test would not change only the light. Use a cool LED lamp, or put a beaker of water between the lamp and the plant to take up the heat.

Counting bubbles is not exact. You may miss one, or count a little more at times. So you count three times at each distance, and take the **mean**. Wait a few minutes after each move, so that the plant adjusts to the new light.

Distance	Per min	Mean
10 cm	8, 7, 9	8
20 cm	5, 6, 4	5
30 cm	3, 2, 4	3
40 cm	1, 2, 0	1

Bubbles counted in one minute, three times at each distance. The last column is the mean of the three.

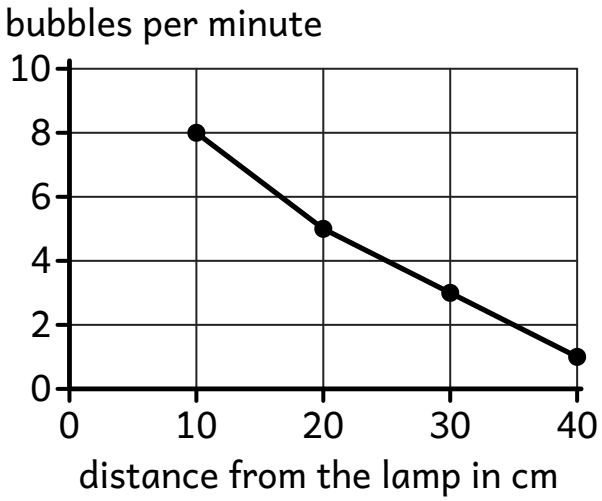
WORKED EXAMPLE

At 20 cm the three counts are 5, 6 and 4 bubbles per minute. What is the mean?

1. Mean = total ÷ number of counts.
2. Total = 5 + 6 + 4 = 15.
3. 15 ÷ 3 = 5.

Answer: 5 bubbles per minute

Now draw a graph of the means. Put the distance, which you changed, along the bottom. Put the bubbles per minute, which you measured, up the side.



The further the lamp is, the fewer the bubbles. The line falls, but not in a straight line.

For a small bare bulb that shines in all directions, light does not fall in step with distance. It falls much faster. At twice the distance the light spreads over four times the area, so the plant gets a quarter of the light. A torch with a reflector does not follow this rule closely, so use it only as a guide.

WORKED EXAMPLE

The lamp is moved from 10 cm to 20 cm away. What percentage of the light reaches the plant now?

1. For a small bare bulb, the light on the plant = (old distance ÷ new distance) squared.
2. 10 ÷ 20 = 0.5.
3. 0.5 × 0.5 = 0.25.
4. 0.25 is 25%, so the plant gets 25% as much light.

Answer: 25% as much light

Distance	Light
10 cm	100%
20 cm	25%
30 cm	11%
40 cm	6%

The light on the plant as a percentage of the light at 10 cm. The bubbles fall more slowly than the light. In bright light something other than light, such as the temperature, starts to limit the rate. The percentages are rounded to the nearest whole number.

Sometimes one count is far from the others, such as 14 when the rest are 8 and 7. It may be a miscount. A result like this is ***anomalous***. It is best to repeat that count. If you cannot, leave it out and say so.

WORKED EXAMPLE

At 10 cm the counts are 8, 7 and 14 bubbles per minute. The 14 is probably a miscount, so it is left out. What is the mean of the other two?

1. 14 is much higher than 8 and 7, so it is anomalous. Leave it out.
2. Total of the other two = 8 + 7 = 15.
3. 15 ÷ 2 = 7.5.
4. The mean is 7.5 bubbles per minute.

Answer: 7.5 bubbles per minute

A water plant may be hard to find. If you have none, there are two ways to see the same idea. Put a fresh green leaf under water in a glass with a pinch of baking soda. Stand the glass in bright sunlight, and look for small bubbles on the leaf. Then move it into shade and compare.

If you have a small syringe, without a needle, you can use leaf discs. Cut small circles from a leaf with the end of a clean drinking straw. Draw the air out of them with the syringe in baking soda water, and they sink. In the light they make oxygen and float. The less time they take to float, the faster the photosynthesis.

TRY IT

Count the bubbles

You need: a water plant from a pond or an aquarium, or a fresh leaf, a clear glass or jar, water and a pinch of baking soda, a battery lamp or LED torch, a ruler, a clock with a second hand, two more glasses of water.

Be safe: Keep mains electricity away from water. Use a battery torch or an LED lamp with a dry cable on a dry shelf. A hot lamp can burn you, so do not touch it. Do not drink the water. Return the water plant to its pond or aquarium afterwards. Wash your hands after touching pond water or the plant.

1. Put water and a pinch of baking soda in the glass. Stir it. Put in the plant, or the leaf. Fill one more glass the same way, with no plant in it. Stand it beside the first glass, the same distance from the torch. Bubbles in both glasses are air from the warming water. Only extra bubbles on the plant come from photosynthesis.
2. Put the torch 10 cm from the glass. Put the last glass of plain water between them. Wait three minutes.
3. Count the bubbles that rise from the plant in one minute. Do this three times.
4. Move the torch to 20 cm, and then 30 cm. Wait three minutes each time and count three times.
5. Work out the mean at each distance. Plot the means on a graph.

What you will see: The bubbles are fewer when the torch is further away. The numbers in the picture are from a test like this. Your numbers will not match, but the pattern will.

If you cannot try it, this is what happens.

Distance	Mean per min
10 cm	8
20 cm	5
30 cm	3

A WRONG IDEA MANY PEOPLE HAVE

~~The bubbles in the test are carbon dioxide.~~

Why it feels right: Gas bubbles are often carbon dioxide, and carbon dioxide is the gas plants are known for taking in.

The test that breaks it: Scientists collect the gas in the test tube and put a glowing splint into it. The splint bursts into flame, which is the test for oxygen. Carbon dioxide would put it out. This is done in a lab with a flame, not at home.

What is true: The bubbles are mostly oxygen, made by photosynthesis. The plant takes in carbon dioxide.

KEY WORDS

fair test
a test where only one thing changes and everything else is kept the same.

independent variable
the thing you change.

dependent variable
the thing you measure.

control variables
the things you keep the same.

mean
the total of the counts divided by how many counts there are.

anomalous
far from the other results, probably because of a mistake.

BACK TO YOUR GUESS

The answer is C: Count the bubbles of gas that a water plant gives off in a minute.

A water plant in bright light gives off small bubbles of oxygen. Counting the bubbles in a set time is a way to measure the rate of photosynthesis.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. In the bubble test the lamp is moved to different distances. What is the independent variable?

   A The number of bubbles

   B The distance of the lamp

   C The temperature of the water

   Answer at the back of the book.

2. A lamp heats the water, which could change the result. Which choice keeps the test fair?

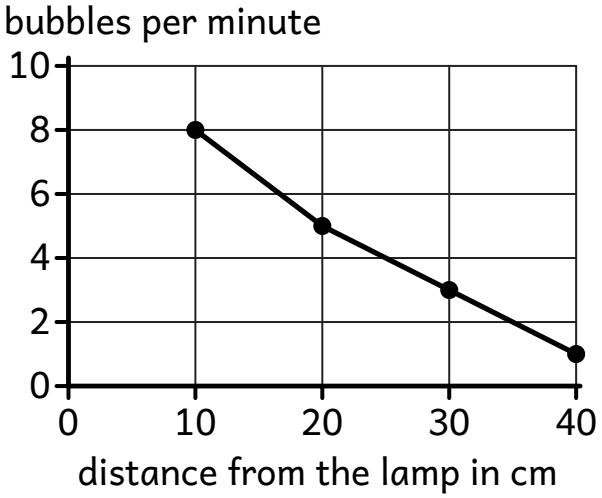
   A Put a beaker of water between the lamp and the plant, or use a cool LED lamp.

   B Ignore the heat, because heat can only help the plant.

   C Put the lamp as close as possible every time.

   Answer at the back of the book.

3. Use the graph. About how many bubbles per minute are there at 30 cm?



   A 8 bubbles per minute

   B 5 bubbles per minute

   C 3 bubbles per minute

   Answer at the back of the book.

4. Why do you count three times at each distance and take the mean?

   A To make the plant give off more bubbles

   B To give the plant more light

   C To lessen the effect of miscounts and chance

   Answer at the back of the book.

5. The lamp is moved from 20 cm to 40 cm from the plant. What percentage of the light does the plant get now?

   A 25% of the light

   B 50% of the light

   C 100% of the light

   Answer at the back of the book.

6. What gas are the bubbles from the pondweed?

   A Carbon dioxide

   B Nitrogen

   C Water vapour

   D Oxygen

   Answer at the back of the book.

7. **From an earlier chapter**

   A pondweed stops giving off bubbles when the water is heated to 55 °C. Why?

   A The plant has used up all its carbon dioxide.

   B The enzymes of the plant are denatured.

   C There is too much light in a hot beaker.

   Answer at the back of the book.

8. At 15 cm the three counts are 3, 6 and 6 bubbles per minute. What is the mean?

   Answer at the back of the book.

9. The lamp is moved from 10 cm to 40 cm from the plant. What percentage of the light reaches the plant now?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Count the bubbles per minute at several lamp distances. Change only the distance. Keep the plant, water, time and heat the same. Count three times and take the mean. Closer lamp, more light, more bubbles.

Draw: A lamp, a ruler and a beaker of pondweed with bubbles. Then a graph of distance against bubbles per minute.

S4.1.8 CHAPTER 8

Respiration

After I run, I keep breathing hard even though I have stopped. Why?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** My lungs are tired and cannot slow down at once.
- ☐ **B** My muscles made lactic acid, and oxygen is needed to break it down.
- ☐ **C** My body is making more lactic acid after I stop.

IF THIS FEELS HARD, READ THIS FIRST

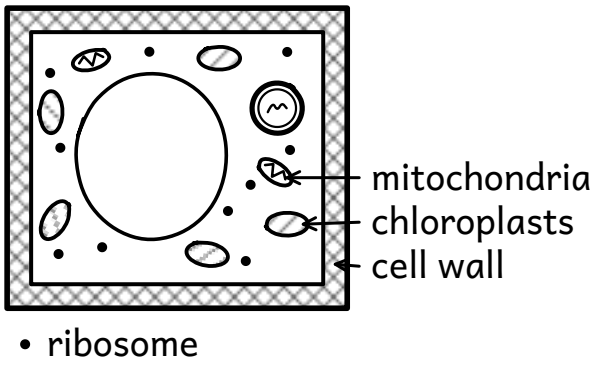
- Level 3, Body systems, S3.3.4. It shows how the ribs and diaphragm move air in and out.
- Level 3, Body systems, S3.3.5. It shows how oxygen enters the blood and carbon dioxide leaves it.
- Level 3, Elements, mixtures, reactions and acids, S3.6.6. It gives the word equation for burning a fuel, which is like respiration.
- Level 2, Bones, muscles, teeth and food, S2.3.7. It shows how to count the pulse before and after running.
- Level 4, Reactions, equations and amounts, S4.7.2. It shows how to check that the two sides of an equation balance.

BY THE END YOU CAN

- Compare aerobic and anaerobic respiration in animals, plants and yeast
- Explain why we breathe hard for a while after exercise

Breathing and respiration are not the same. **Breathing** moves air in and out of your lungs. **Respiration** is a reaction inside cells. It releases energy from glucose. Breathing brings the oxygen that most respiration needs.

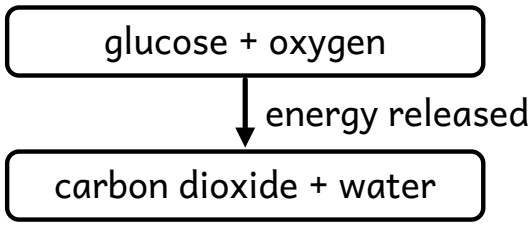
Every living cell respires, all the time, whether you are running or asleep. A plant cell respires too. A plant cell has chloroplasts for photosynthesis and mitochondria for respiration.



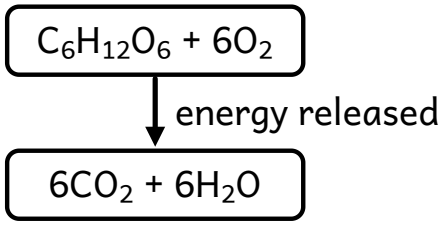
Chloroplasts make glucose. Mitochondria release the energy from glucose. A leaf cell does both.

Cells use the energy to move, to keep warm, to build large molecules and for active transport. The energy is not made. It is released from the chemical energy stored in glucose.

When there is plenty of oxygen, a cell uses **aerobic respiration**. Glucose reacts with oxygen. The products are carbon dioxide and water. Most of the energy in glucose is released. This happens mostly in the mitochondria.



Photosynthesis goes the other way. It takes in carbon dioxide and water and makes glucose and oxygen.



The sides are balanced. Each has 6 carbon, 12 hydrogen and 18 oxygen atoms.

WORKED EXAMPLE

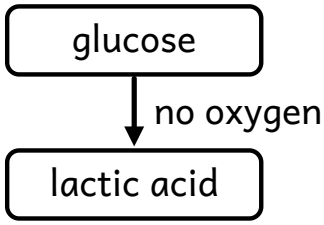
How many molecules of oxygen are needed to respire 4 molecules of glucose?

1. In the equation, 1 molecule of glucose reacts with 6 molecules of oxygen.
2. 4 × 6 = 24.

Answer: 24 molecules

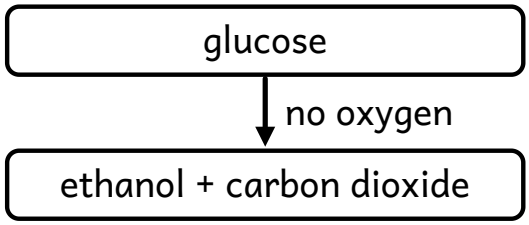
What if the cell runs short of oxygen? It can still release some energy, with no oxygen. This is ***anaerobic respiration***. The glucose is only partly broken down, so much less energy is released.

In your muscles, anaerobic respiration makes **lactic acid**. During hard exercise the blood cannot bring oxygen as fast as the muscles use it. The muscles then use both kinds of respiration. Lactic acid builds up, and the muscles tire.



Anaerobic respiration in muscles makes lactic acid and releases little energy. No carbon dioxide is made.

Yeast and plant cells do it differently. Without oxygen they make ethanol and carbon dioxide. This is **fermentation**. A plant root in waterlogged soil, where there is little oxygen, may do this.



Yeast uses this reaction to make bread dough rise. The carbon dioxide forms bubbles in the dough. The ethanol goes off as the bread bakes. The same reaction makes the ethanol in some drinks.

Kind	Oxygen	Energy
aerobic	yes	much
anaerobic	no	little

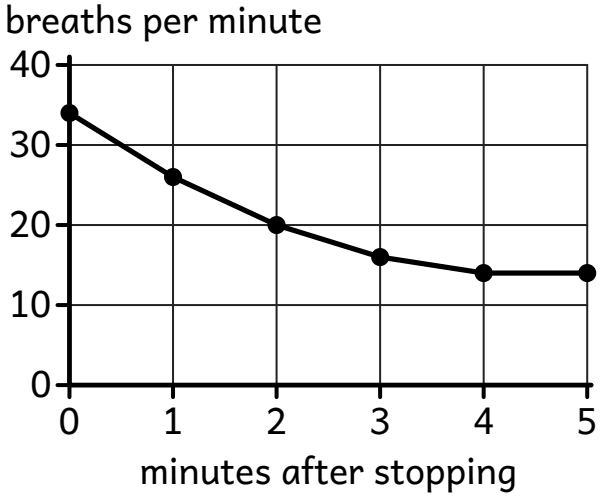
Much and little describe the energy released from each glucose. Aerobic respiration releases far more.

Where	Makes
muscle	lactic acid
yeast	ethanol and CO_2
plant	ethanol and CO_2

What anaerobic respiration makes, by where it happens. CO_2 is carbon dioxide.

Now, why do you keep breathing hard after exercise? During hard exercise the muscles built up lactic acid. Oxygen is needed to break down the lactic acid, which the blood carries to the liver. The oxygen needed is called the **oxygen debt**.

You pay the debt back after you stop. Breathing and the heart stay fast for a while. The extra oxygen refills the blood and muscles. It also starts to break down the lactic acid. The fast breathing removes extra carbon dioxide. Most of the lactic acid is gone within an hour.



Breathing is fast just after exercise and falls back to the resting rate of 14 breaths per minute.

WORKED EXAMPLE

At rest Ana takes 14 breaths per minute. Just after exercise she takes 34 breaths per minute. What is the percentage increase, to the nearest whole number?

1. Change = 34 − 14 = 20.
2. Percentage increase = change ÷ start × 100.
3. 20 ÷ 14 × 100 = 142.9, which is 143 to the nearest whole number.

Answer: 143%

WORKED EXAMPLE

Use the graph. At rest Ana takes 14 breaths per minute. How many extra breaths does she take in the first four readings, at 0, 1, 2 and 3 minutes?

1. Take the resting rate, 14, from each reading.
2. At 0 minutes: 34 − 14 = 20. At 1: 26 − 14 = 12. At 2: 20 − 14 = 6. At 3: 16 − 14 = 2.
3. Add the extras: 20 + 12 + 6 + 2 = 40.
4. She takes 40 extra breaths while she pays back the oxygen debt.

Answer: 40 extra breaths

TRY IT

Breathing before and after exercise

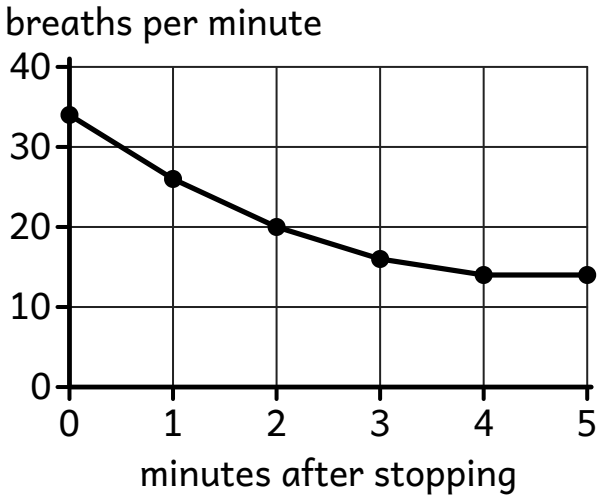
You need: a clock with a second hand, or a phone timer, paper and a pencil, a friend to count, or a way to count your own breaths.

Be safe: Do this only if you are well and have no heart or breathing problem. Run gently on flat ground and stop at once if you feel dizzy or have pain. An adult should be near the first time.

1. Sit still for two minutes. Count your breaths for one minute. This is your resting rate. One breath is one in and one out.
2. Stand and run on the spot, gently, for one minute.
3. Sit down at once. Count your breaths for one minute and write the number.
4. Keep counting one minute at a time and writing each number, until it is back to your resting rate.
5. Draw a graph of the numbers against the minutes since you stopped.

What you will see: Your breathing is fast just after the run, then it slows in steps back to the resting rate. The graph in the picture is an example. Your numbers will differ.

If you cannot try it, this is what happens.



A WRONG IDEA MANY PEOPLE HAVE

~~Plants photosynthesise, so they do not respire.~~

Why it feels right: We say animals breathe and plants make food, so it seems each does one thing.

The test that breaks it: In the dark a plant gives out carbon dioxide and takes in oxygen, as an animal does. A plant cell has mitochondria, where respiration happens.

What is true: Plants respire all the time, in the light and in the dark. In bright light they photosynthesise faster than they respire, so there is a net gain of oxygen.

KEY WORDS

respiration
the reaction in cells that releases energy from glucose.

aerobic respiration
respiration with oxygen. Glucose and oxygen make carbon dioxide and water.

anaerobic respiration
respiration without oxygen. It releases much less energy.

lactic acid
what muscles make in anaerobic respiration.

fermentation
anaerobic respiration in yeast and plants, making ethanol and carbon dioxide.

oxygen debt
the oxygen needed after exercise to break down lactic acid.

BACK TO YOUR GUESS

The answer is B: My muscles made lactic acid, and oxygen is needed to break it down.

In hard exercise the muscles run short of oxygen and make lactic acid. Afterwards extra oxygen is needed to break the lactic acid down, so you keep

breathing hard.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which statement about respiration is true?

   A It happens in every living cell, all the time.

   B It is the same as breathing.

   C It happens only when we exercise.

   Answer at the back of the book.

2. Which word equation is aerobic respiration?

   A carbon dioxide + water → glucose + oxygen

   B glucose → lactic acid

   C glucose + oxygen → carbon dioxide + water

   Answer at the back of the book.

3. What do muscles make in anaerobic respiration?

   A Ethanol and carbon dioxide

   B Lactic acid

   C Carbon dioxide and water

   Answer at the back of the book.

4. Why does bread dough rise?

   A The yeast makes oxygen, which fills the bubbles.

   B The yeast makes lactic acid, which is a gas.

   C The yeast gives off water vapour, which puffs up the dough.

   D The yeast makes carbon dioxide, which forms bubbles in the dough.

   Answer at the back of the book.

5. Why do you keep breathing hard for a while after exercise?

   A Your lungs are tired and cannot slow down at once.

   B Oxygen is needed to break down the lactic acid that built up in the muscles.

   C Your muscles go on making more lactic acid after you stop.

   Answer at the back of the book.

6. How does the energy released from one glucose compare in aerobic and anaerobic respiration?

   A Aerobic respiration releases much more.

   B They release about the same.

   C Anaerobic respiration releases more, because it is faster.

   Answer at the back of the book.

7. **From an earlier chapter**

   Which process in a leaf takes in carbon dioxide and gives out oxygen?

   A Respiration

   B Photosynthesis

   C Osmosis

   Answer at the back of the book.

8. How many molecules of oxygen are needed to respire 5 molecules of glucose?

   Answer at the back of the book.

9. At rest a boy takes 16 breaths per minute. After running he takes 40. What is the percentage increase?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Respiration is in every cell and releases energy from glucose. Aerobic: glucose + oxygen → carbon dioxide + water. Anaerobic: muscles make lactic acid. Yeast and plants make ethanol and carbon dioxide. Breathing hard repays the oxygen debt.

Draw: The three equations for respiration in three boxes, with the amount of energy released written beside each.

Key words, A to Z

Every key word in this book, what it means, and the chapter that teaches it.

active site
the hollow in an enzyme where the substrate fits. S4.1.5

active transport
moving particles against a concentration gradient, using energy from respiration. S4.1.3

aerobic respiration
respiration with oxygen. Glucose and oxygen make carbon dioxide and water. S4.1.8

anaerobic respiration
respiration without oxygen. It releases much less energy. S4.1.8

anomalous
far from the other results, probably because of a mistake. S4.1.7

catalyst
something that speeds up a reaction and is not used up. S4.1.5

cell cycle
the series of steps a cell goes through to grow and divide. S4.1.4

cell wall
the stiff outer layer of a plant or bacterial cell. S4.1.1

chlorophyll
the green substance in chloroplasts that absorbs light. S4.1.6

chloroplasts
the parts of a plant cell that absorb light for photosynthesis. S4.1.1

chromosomes
long threads of DNA in the nucleus, which carry the genes. S4.1.4

concentration gradient
the difference in concentration between two places. S4.1.3

control variables
the things you keep the same. S4.1.7

denatured
with a changed shape, so the enzyme no longer works. S4.1.5

dependent variable
the thing you measure. S4.1.7

diffusion
the net movement of particles from a higher to a lower concentration. S4.1.3

electron microscope
a microscope that uses a beam of electrons and shows much more detail. S4.1.2

enzymes
proteins that speed up reactions in living things. S4.1.5

eyepiece lens
the lens of a microscope that you look through. S4.1.2

fair test
a test where only one thing changes and everything else is kept the same. S4.1.7

fermentation
anaerobic respiration in yeast and plants, making ethanol and carbon dioxide. S4.1.8

flagellum
a tail that some bacteria use to swim. S4.1.1

glucose
a sugar that the plant makes and uses as food and as a building material. S4.1.6

independent variable
the thing you change. S4.1.7

lactic acid
what muscles make in anaerobic respiration. S4.1.8

limiting factor
the thing in shortest supply, which sets the rate. S4.1.6

magnification
how many times bigger an image is than the real object. S4.1.2

mean
the total of the counts divided by how many counts there are. S4.1.7

micrometre
one thousandth of a millimetre, written µm. S4.1.2

mitochondria
the parts where aerobic respiration releases energy from glucose. S4.1.1

mitosis

the division of the nucleus that makes two identical nuclei. S4.1.4

nanometre
one thousandth of a micrometre, written nm. S4.1.2

nucleus
the part that holds the genetic material and controls the cell. S4.1.1

objective lens
the lens of a microscope that is close to the slide. S4.1.2

optimum
the best temperature or pH, where the enzyme works fastest. S4.1.5

osmosis
the movement of water across a partially permeable membrane from a dilute to a more concentrated solution. S4.1.3

oxygen debt
the oxygen needed after exercise to break down lactic acid. S4.1.8

partially permeable
letting some particles through and not others, as a cell membrane does. S4.1.3

percentage change
the change as a percentage of the start value. S4.1.3

permanent vacuole
a large space of cell sap in a plant cell. S4.1.1

photosynthesis
the process in which a plant uses light to make glucose and oxygen from carbon dioxide and water. S4.1.6

plasmids
small rings of DNA in a bacterial cell. S4.1.1

resolution
how close two points can be and still be seen as two. S4.1.2

respiration
the reaction in cells that releases energy from glucose. S4.1.8

ribosomes
tiny parts that make proteins. S4.1.1

specialised
changed to do one job, such as a nerve cell does. S4.1.4

stem cell

an unspecialised cell that can divide and change into other kinds of cell. S4.1.4

stomata
tiny holes in a leaf that let gases in and out. S4.1.6

substrate
the molecule that an enzyme works on. S4.1.5

Answers

S4.1.1. Cell structure in detail

1. **The ribosomes**

   Ribosomes join amino acids into proteins, following the genetic material.

   - **If you chose A:** The nucleus holds the instructions for proteins, but it does not make them. Ribosomes read the instructions and build the proteins. Go to S3.1.4.
   - **If you chose C:** Mitochondria release energy from glucose. They do not make proteins.

2. **In the mitochondria**

   Aerobic respiration takes place in the mitochondria. It releases energy from glucose using oxygen.

   - **If you chose B:** The nucleus controls the cell, but it is not where energy is released.
   - **If you chose C:** Chloroplasts absorb light for photosynthesis, which stores energy in glucose. Aerobic respiration is in the mitochondria.

3. **Chloroplasts**

   Chloroplasts are found in plant cells and algae, and not in animal cells. A leaf cell has them to absorb light.

   - **If you chose A:** Plant cells and animal cells both have mitochondria. Plants respire too.
   - **If you chose B:** All cells have ribosomes, because all cells make proteins.
   - **If you chose D:** Both plant and animal cells have a nucleus. Go to S3.1.3.

4. **Yes. Its DNA is a loop that lies free in the cytoplasm.**

   A bacterium has no nucleus. Its DNA is a loop in the cytoplasm, sometimes with small plasmids.

   - **If you chose A:** Bacterial cells have no nucleus. They are built differently from plant and animal cells.
   - **If you chose C:** It has DNA. The DNA is a loop in the cytoplasm, not inside a nucleus.

5. **He is wrong. Root cells are in the dark and have no chloroplasts.**

   Chloroplasts are for photosynthesis, which needs light. Root cells are underground, so they have none.

   - **If you chose B:** Chloroplasts need light. Cells in the root are underground and have none.
   - **If you chose C:** Root cells have no chloroplasts at all, since they get no light.

6. **It needs to release a lot of energy to make the muscle move.**

   Moving needs energy. Mitochondria release it, so a busy cell has many.

   - **If you chose A:** Making protein is the job of ribosomes. Mitochondria release energy.
   - **If you chose C:** Animal cells cannot make food from light. Only cells with chloroplasts can. Go to S3.1.4.
   - **If you chose D:** The number of mitochondria is about energy, not about the nucleus.

7. **20 times wider**

   60 ÷ 3 = 20. Both widths are in µm.

8. **15 bacteria**

   30 ÷ 2 = 15.

9. **A plant cell**

   Of these three, only a plant cell has chloroplasts. A nucleus rules out a bacterium, and a cell wall rules out an animal cell.

S4.1.2. Microscopes and size

1. **×200**

   5 mm = 5 000 µm. 5 000 ÷ 25 = 200.

   - **If you chose B:** You multiplied 5 and 25. Magnification is image size divided by real size.
   - **If you chose C:** You divided 5 by 25 without changing the units. The mm must become µm first: 5 mm = 5 000 µm.

2. **2 000 nm**

   1 µm = 1 000 nm, so 2 µm = 2 × 1 000 = 2 000 nm.

   - **If you chose A:** You divided by 1 000. Going to a smaller unit makes the number bigger, so multiply.
   - **If you chose B:** There are 1 000 nm in 1 µm, not 100.

3. **25 µm**

   Real size = image size ÷ magnification. 1 mm = 1 000 µm, and 1 000 ÷ 40 = 25.

   - **If you chose A:** 1 ÷ 40 = 0.025, but that answer is in mm, not µm. 0.025 mm is 25 µm. Change the image to µm first: 1 000 ÷ 40 = 25.
   - **If you chose C:** You multiplied by the magnification. The cell is smaller than its image, so divide.

4. **500 nm**

   In nm the three sizes are 2 000, 500 and 1 000. The smallest is 500 nm.

   - **If you chose A:** 0.002 mm is 2 µm, which is 2 000 nm. It is the largest of the three.
   - **If you chose C:** 1 µm is 1 000 nm, which is twice 500 nm.

5. **It has a better resolution, as well as a higher magnification.**

   Ribosomes are about 25 nm, much smaller than the 0.2 µm a light microscope can separate. An electron beam can separate points far closer.

   - **If you chose B:** The limit is not the amount of light. It is the resolution, which an electron beam improves.
   - **If you chose C:** Past its limit a light microscope only gives a bigger blur. Resolution, not magnification, is the limit.

6. **image size ÷ real size**

   Magnification says how many times bigger the image is than the real object, so divide the image by the real size.

   - **If you chose A:** That turns the rule upside down. It gives a number below 1 for a magnified image.
   - **If you chose B:** Multiplying the two sizes does not give a magnification. Magnification compares them by dividing.

7. **A bacterial cell**

   A bacterium has no nucleus, and its cell wall is not cellulose.

   - **If you chose B:** A plant cell has a nucleus and a wall of cellulose. Go to S4.1.1.
   - **If you chose C:** An animal cell has a nucleus and no cell wall. Go to S4.1.1.

8. **×500**

   20 mm = 20 000 µm. 20 000 ÷ 40 = 500.

9. **60 µm**

   18 mm = 18 000 µm. 18 000 ÷ 300 = 60 µm.

S4.1.3. Diffusion, osmosis and active transport

1. **It loses water and gets shorter and floppy.**

   The salt water is more concentrated than the liquid in the cells. Water moves out of the cells by osmosis.

   - **If you chose A:** That happens in plain water. In strong salt water the liquid outside is more concentrated, so water leaves the cells.
   - **If you chose C:** Salt cannot cross easily, but water can. Water moves out by osmosis, so the strip changes.

2. **Water crosses a partially permeable membrane from a dilute solution to a more concentrated solution.**

   Osmosis is the movement of water, across a partially permeable membrane, from a dilute to a more concentrated solution.

   - **If you chose A:** That describes active transport, which needs energy.
   - **If you chose B:** In osmosis it is the water that crosses. The solute particles stay behind.

3. **It moves particles against the concentration gradient.**

   Particles do not move from a lower to a higher concentration by themselves. The cell uses energy from respiration to carry them.

   - **If you chose B:** Moving down the gradient is what diffusion does, and it needs no energy.
   - **If you chose C:** Moving water is osmosis, which needs no energy.

4. **By active transport**

   The ions go from a lower to a higher concentration, so the cell uses energy to carry them in. A root hair cell has many mitochondria for this.

   - **If you chose A:** Osmosis is the movement of water, not of mineral ions.
   - **If you chose C:** Diffusion would move the ions out of the cell, down the gradient. They would never build up inside.

5. **10% shorter**

   Change = 40 − 36 = 4 mm. 4 ÷ 40 × 100 = 10, so the strip is 10% shorter.

   - **If you chose B:** The strip is 4 mm shorter, but that is 4 mm, not 4%. Divide the change by the start length, then multiply by 100.
   - **If you chose C:** You divided by the end length, 36. Divide by the start length, 40.

6. **Carbon dioxide leaving a cell for the blood, where there is less of it**

   The carbon dioxide goes from a higher to a lower concentration, with no energy needed. That is diffusion.

   - **If you chose A:** That is osmosis, which is the movement of water across a membrane.
   - **If you chose B:** The ions go from a lower to a higher concentration. That is active transport.
   - **If you chose C:** Against the gradient means active transport, not diffusion. Go to S3.3.2.

7. **Between 0.5 g and 1 g**

   The change is +5% at 0.5 g and −1% at 1 g. It goes through 0 between them, where the liquid outside matches the liquid in the cells.

   - **If you chose A:** There the pieces still gain 10% and 5%. The change is not yet near 0.
   - **If you chose B:** There the pieces lose 5% and 9%. The change is not near 0 any more.

8. **×500**

   40 mm = 40 000 µm. 40 000 ÷ 80 = 500.

   - **If you chose A:** You divided 40 by 80 without changing the units. Turn mm into µm first. Go to S4.1.2.
   - **If you chose C:** You multiplied 40 by 80. Magnification is image size divided by real size. Go to S4.1.2.

9. **10% longer**

   44 − 40 = 4 mm. 4 ÷ 40 × 100 = 10, so the strip is 10% longer.

10. **15% lighter**

    20 − 17 = 3 g. 3 ÷ 20 × 100 = 15, so the piece is 15% lighter.

S4.1.4. Cell division

1. **Two cells that are identical to the first cell**

   The cell copies its chromosomes and then shares them equally. Each new cell has the same genetic material.

   - **If you chose A:** Halving the chromosomes happens when sex cells are made. In mitosis each new cell gets the full set.
   - **If you chose B:** Mitosis makes two cells, and they are identical to each other and to the first cell.

2. **Replacing skin cells that are lost from a cut**

   Mitosis makes new cells for growth and repair. Respiration and osmosis are different processes.

   - **If you chose B:** That is aerobic respiration, which happens in the mitochondria. Go to S4.1.1.
   - **If you chose C:** That is osmosis, which moves water across the membrane. It does not make new cells. Go to S4.1.3.

3. **The cell copies its chromosomes.**

   The cell copies its DNA while it grows, so each chromosome is two copies joined. Then they line up, are pulled apart, and the cell splits.

   - **If you chose A:** That comes later. The chromosomes must be copied before they can be pulled apart.
   - **If you chose C:** That is the last step. The nucleus divides before the rest of the cell.

4. **An unspecialised cell that can divide and become other kinds of cell**

   Stem cells are unspecialised. They can divide and change into other cells, such as blood cells.

   - **If you chose A:** The name is not about stems. Stem cells are in animals and in plants.
   - **If you chose B:** That is a specialised cell. A stem cell has not yet changed to one job.
   - **If you chose C:** A stem cell can also change into other kinds of cell.

5. **A bone marrow transplant to treat some blood cancers**

   Bone marrow has stem cells that make blood cells. Doctors already use transplants to treat some blood cancers.

   - **If you chose A:** Scientists are working on this. It could one day be possible, but it is not an ordinary treatment now.
   - **If you chose C:** This is being researched. It could help in future, but it is not an ordinary treatment now.

6. **In the tips of the shoots and roots**

   A plant grows at its tips, and the stem cells there divide and then specialise.

   - **If you chose A:** A seed has them, but a plant keeps them as it grows, in the tips of the shoots and roots.
   - **If you chose B:** Cells in a leaf are specialised. The cells that keep dividing are at the shoot and root tips.

7. **Active transport**

   The ions go from a lower to a higher concentration. That needs energy from respiration, so it is active transport.

   - **If you chose B:** Osmosis moves water, not ions. Go to S4.1.3.
   - **If you chose C:** Diffusion moves particles down the gradient. Here they go up it. Go to S4.1.3.

8. **78 chromosomes**

   The cell copies its chromosomes to make 156. They are shared between two cells, so each has 78.

9. **64 cells**

   The number doubles with each division: 8 after 3, then 16, 32 and 64. After 6 divisions it is 2 × 2 × 2 × 2 × 2 × 2 = 64.

S4.1.5. Enzymes

1. **It is unchanged and can work again.**

   An enzyme speeds up the reaction and is not used up, so one enzyme molecule can work on many substrate molecules.

   - **If you chose A:** An enzyme is a catalyst. It is not used up and can work again.
   - **If you chose C:** The substrate is turned into the products. The enzyme comes out as it went in.

2. **Only the shape of that substrate fits the active site.**

   In the lock and key model the substrate must fit the active site, like a key in a lock. A different shape does not fit.

   - **If you chose B:** An enzyme is not used up. The reason is the shape of the active site.
   - **If you chose C:** A cell has many substrates. Most of them do not fit this active site.

3. **37 °C**

   The line for the human enzyme is highest at 37 °C. This is its optimum temperature.

   - **If you chose A:** At 30 °C the activity is still rising. The peak is a little higher.
   - **If you chose C:** At 45 °C the activity has fallen. The enzyme is starting to be denatured.

4. **The active site changes shape, so the substrate no longer fits.**

   The enzyme is denatured. Its shape changes, and a substrate that fitted before no longer fits.

   - **If you chose A:** An enzyme is not alive, so it is not killed. High temperature changes its shape.
   - **If you chose B:** An enzyme is never used up. The heat changes its shape instead.

5. **about pH 2**

   The pepsin line peaks at pH 2. This suits the acid in the stomach.

   - **If you chose A:** That is the best pH for amylase, not pepsin. Pepsin has almost no activity at pH 7.
   - **If you chose B:** At pH 10 pepsin has no activity at all. The peak is at the acid end.

6. **The reaction slows down, but the enzyme is not denatured.**

   Cold slows the molecules, so they meet less often. The shape of the enzyme does not change, so it works again when it warms up.

   - **If you chose A:** Cold does not change the shape of the active site. Warm it up again and it works as before.
   - **If you chose C:** At a lower temperature the molecules meet less often, so the reaction is slower.

7. **The ribosomes**

   An enzyme is a protein, and ribosomes make proteins.

   - **If you chose B:** The nucleus holds the instructions for proteins, but ribosomes build them. Go to S4.1.1.
   - **If you chose C:** Mitochondria release energy from glucose. They do not make proteins. Go to S4.1.1.

8. **2 times faster**

   The rate is 1 ÷ time. 1 ÷ 5 = 0.2 and 1 ÷ 10 = 0.1. 0.2 ÷ 0.1 = 2.

9. **0.5 cm per minute**

   Rate = change ÷ time = 12 ÷ 24 = 0.5.

S4.1.6. Photosynthesis

1. **carbon dioxide + water → glucose + oxygen**

   A plant takes in carbon dioxide and water. It makes glucose and gives out oxygen.

   - **If you chose A:** That is the equation for respiration. It goes the other way round. Go to S3.6.6.
   - **If you chose C:** Oxygen is made in photosynthesis, not used. Glucose and oxygen are the products.

2. **Carbon dioxide from the air, and water**

   Photosynthesis joins carbon dioxide and water into glucose. The plant builds itself from glucose.

   - **If you chose B:** Van Helmont showed the soil lost only about 60 g while the tree gained about 74 kg. Go to S2.1.5.
   - **If you chose C:** Light gives the energy, but light is not material. The mass comes from carbon dioxide and water.

3. **Equation C**

   Equation C has 6 carbon, 12 hydrogen and 18 oxygen atoms on each side.

   - **If you chose A:** Equation A has 1 carbon on the left and 6 on the right. The numbers in front are missing. Go to S4.7.2.
   - **If you chose B:** Equation B has 18 oxygen atoms on the left and 30 on the right. Too many. Go to S4.7.2.

4. **More carbon dioxide**

   The factor in shortest supply sets the rate. Here it is carbon dioxide, so adding it raises the rate.

   - **If you chose A:** Light is not the limiting factor here. Carbon dioxide is in shortest supply, so more light gives no gain.
   - **If you chose C:** The temperature is already good, and a much higher one could denature the enzymes.

5. **Carbon dioxide**

   The low CO_2 line is flat. Adding light gives no gain, but the high CO_2 line shows that more carbon dioxide would raise the rate.

   - **If you chose A:** The line is flat from 50 to 100. More light does not raise the rate, so light is not the limit.
   - **If you chose C:** The high CO_2 line reaches 75 at this light, but the low CO_2 line stays at 40. It is limited.

6. **The enzymes are denatured.**

   The reactions of photosynthesis need enzymes. High temperature changes their shape, so they stop working.

   - **If you chose A:** Temperature does not change the light. The enzymes are what change.
   - **If you chose B:** Heat does not use up carbon dioxide in the air. The enzymes are what change.
   - **If you chose C:** The problem is not too much energy. Heat changes the shape of the enzymes.

7. **By diffusion**

   Carbon dioxide moves from a higher concentration outside to a lower one inside, so it diffuses. No energy is needed.

   - **If you chose B:** Active transport moves particles from a lower to a higher concentration. Here the carbon dioxide goes down the gradient. Go to S4.1.3.
   - **If you chose C:** Osmosis is the movement of water, not carbon dioxide. Go to S4.1.3.

8. **18 oxygen atoms**

   $C_6H_{12}O_6$ has 6 oxygen atoms. $6O_2$ is 6 × 2 = 12. 6 + 12 = 18, the same as on the left.

9. **5 molecules**

   30 ÷ 6 = 5, and each 6 molecules of carbon dioxide make 1 molecule of glucose.

S4.1.7. Testing photosynthesis

1. **The distance of the lamp**

   The independent variable is the thing you change on purpose. Here it is the distance from the lamp.

   - **If you chose A:** That is what you measure, so it is the dependent variable.
   - **If you chose C:** That should be kept the same, so it is a control variable.

2. **Put a beaker of water between the lamp and the plant, or use a cool LED lamp.**

   The test must change only the light. The water takes up the heat, and a cool LED gives very little heat.

   - **If you chose B:** Heat does speed up photosynthesis. That is the problem: it would change the rate for a reason other than the light.
   - **If you chose C:** The distance is what you must change. A close lamp heats the water most.

3. **3 bubbles per minute**

   The point at 30 cm is at 3 on the side axis.

   - **If you chose A:** That is the mean at 10 cm. Read the line at 30 on the bottom axis.
   - **If you chose B:** That is the mean at 20 cm. Read the line at 30 on the bottom axis.

4. **To lessen the effect of miscounts and chance**

   A single count may be a little high or low. The mean of three smooths out small mistakes.

   - **If you chose A:** Counting does not change the plant. The mean makes the result more trustworthy.
   - **If you chose B:** Repeating a count does not change the light.

5. **25% of the light**

   For a small bare bulb the light falls with the square of the distance. (20 ÷ 40) × (20 ÷ 40) = 0.25, which is 25%.

   - **If you chose B:** Light does not fall in step with distance. Twice as far gives a quarter, not a half.
   - **If you chose C:** The light on the plant falls as the lamp moves away. It is not the same.

6. **Oxygen**

   Photosynthesis makes glucose and oxygen. The oxygen is the gas that rises as bubbles.

   - **If you chose A:** The plant takes in carbon dioxide. It makes oxygen. Go to S4.1.6.
   - **If you chose B:** Photosynthesis does not make nitrogen. It makes glucose and oxygen. Go to S4.1.6.
   - **If you chose C:** The bubbles are under the water, and photosynthesis makes oxygen. Go to S4.1.6.

7. **The enzymes of the plant are denatured.**

   Photosynthesis depends on enzymes. At 55 °C their shape changes, so the plant cannot photosynthesise.

   - **If you chose A:** It would stop at any temperature if that were so. The key is the enzymes of the plant. Go to S4.1.5.
   - **If you chose C:** Heat does not change the amount of light. It changes the shape of the enzymes. Go to S4.1.5.

8. **5 bubbles per minute**

   3 + 6 + 6 = 15. 15 ÷ 3 = 5.

9. **6.25% as much light**

   10 ÷ 40 = 0.25. 0.25 × 0.25 = 0.0625, which is 6.25%.

S4.1.8. Respiration

1. **It happens in every living cell, all the time.**

   All living cells need energy all the time, so all of them respire. This includes plant cells.

   - **If you chose B:** Breathing moves air in and out of the lungs. Respiration is the reaction in cells that releases energy. Go to S3.3.4.
   - **If you chose C:** Cells respire all the time. Exercise only makes them respire faster.

2. **glucose + oxygen → carbon dioxide + water**

   Aerobic respiration uses oxygen to break down glucose. The products are carbon dioxide and water.

   - **If you chose A:** That is photosynthesis. Respiration goes the other way. Go to S4.1.6.
   - **If you chose B:** That is anaerobic respiration in muscle, with no oxygen.

3. **Lactic acid**

   In anaerobic respiration glucose is only partly broken down. In muscles it becomes lactic acid.

   - **If you chose A:** Yeast and plants make these. Muscles make lactic acid.
   - **If you chose C:** Those are made by aerobic respiration, which uses oxygen.

4. **The yeast makes carbon dioxide, which forms bubbles in the dough.**

   Yeast ferments the sugar in the dough. This makes ethanol and carbon dioxide. The gas forms bubbles that raise the dough.

   - **If you chose A:** Yeast cannot make oxygen. It makes carbon dioxide.
   - **If you chose B:** Lactic acid is made in muscles. It is a liquid, not a gas.
   - **If you chose C:** Respiration makes water, but the gas that raises the dough is carbon dioxide.

5. **Oxygen is needed to break down the lactic acid that built up in the muscles.**

   The oxygen debt is paid back after exercise. The extra oxygen breaks down the lactic acid, which the blood carries to the liver.

   - **If you chose A:** The lungs are not tired in that way. Your body needs extra oxygen.
   - **If you chose C:** The lactic acid was made during the exercise. Afterwards it is broken down.

6. **Aerobic respiration releases much more.**

   With oxygen the glucose is broken down fully, and far more energy is released than when it is only partly broken down.

   - **If you chose B:** Without oxygen the glucose is only partly broken down, so much less energy is released.
   - **If you chose C:** Anaerobic respiration can start fast, but it releases much less from each glucose.

7. **Photosynthesis**

   In light, photosynthesis uses carbon dioxide and water and makes glucose and oxygen.

   - **If you chose A:** Respiration does the opposite. It uses oxygen and gives out carbon dioxide.
   - **If you chose C:** Osmosis is the movement of water across a membrane. It does not make oxygen.

8. **30 molecules**

   Each molecule of glucose needs 6 molecules of oxygen. 5 × 6 = 30.

9. **150%**

   40 − 16 = 24. 24 ÷ 16 × 100 = 150.

About this book

For learners who can follow a written argument and have met cells, plants and the body in earlier books. In many schools this fits learners of about 14 to 16, and older learners can use it as a reference. Each chapter takes two or three short sessions. A learner can work alone: every exercise has its answer and the reason for it. The Try it activities use water, salt, a potato, yeast and sugar, balloons and household bottles. Nothing is

tasted. An adult should cut the potato, or the learner uses a table knife on a board, and an adult should be near for anything that uses warm water. Experiments that need a microscope, a lamp and special equipment are described as things scientists do, with a household version where one exists.

Written and drawn by attnom. Edition 1.0, 2026-11-12.

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