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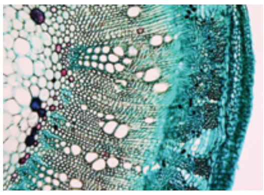
CELL LEVEL SYSTEMS

IDEAS YOU HAVE MET BEFORE:

ALL LIVING ORGANISMS ARE MADE OF CELLS.

- Cells are the building blocks of life.
- Cells contain specialised structures.
- Organisms such as bacteria are unicellular.
- Most plants and animals are multicellular.

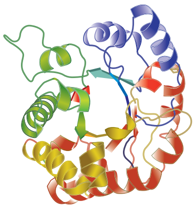


THE CELL CONTAINS GENETIC INFORMATION

- Genetic information is contained within genes on our chromosomes.
- Our chromosomes and genes are found in the nucleus of our cells.

ENZYMES ARE IMPORTANT FOR THE REACTIONS THAT OCCUR IN OUR BODY.

- Enzymes speed up reactions inside the body.
- Different enzymes are used to speed up different reactions.
- The digestive system uses enzymes to digest food.



ORGANISMS OBTAIN ENERGY BY THE PROCESS OF RESPIRATION.

- The energy that is released drives all the processes necessary for life.
- Most organisms respire by aerobic respiration, using oxygen.
- Some cells or organisms can survive without oxygen. They respire anaerobically.
- Energy is transferred between living organisms.

PLANT CELLS ARE ADAPTED TO CARRY OUT THEIR FUNCTIONS.

- Chloroplasts absorb energy from light for photosynthesis.
- Photosynthesis happens in the mesophyll cells in leaves.
- The amount of photosynthesis can be affected by a range of different factors.

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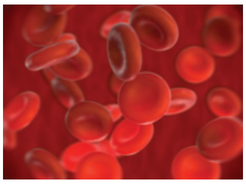
IN THIS CHAPTER YOU WILL FIND OUT ABOUT:

STUDYING CELL STRUCTURE AND FUNCTION

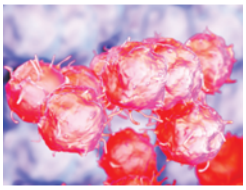


- The structures inside cells do different jobs within the cell.
- Cells can be studied using different types of microscopes.
- The cells of bacteria are different to the cells of plants and animals.

HOW DNA AND GENES WORK

- DNA is a polymer made up of units called nucleotides.
- A gene is a short section of DNA that codes for the production of a particular protein.
- The code for the synthesis of each protein is carried by a sequence of chemicals called bases.
- Chromosomes and genes are found in the nucleus of cells.

HOW ENZYMES WORK

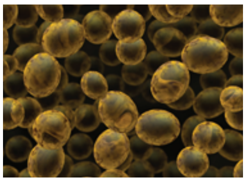


- All reactions in cells are controlled by enzymes.
- The lock-and-key and collision theories are used to explain enzyme function and specificity.
- There are specific enzymes in the digestive system; their action is affected by different factors.

HOW ORGANISMS OBTAIN THEIR ENERGY FROM FOOD

- Anaerobic respiration: when some organisms run out of oxygen, they can respire without it.
- Many microorganisms can respire anaerobically, as can the muscles of mammals for short periods.
- Energy is lost from each trophic level in a food chain.
- There is a maximum size to food chains.
- Pyramids of biomass show the mass of organisms in a food chain.

FACTORS WHICH AFFECT THE PHOTOSYNTHESIS REACTION



- Leaves are adapted to absorb the light energy needed for photosynthesis.
- Substances move in and out the leaf during photosynthesis.
- The useful products of photosynthesis are simple carbohydrates, for example glucose and sucrose.
- Different environmental factors interact to limit the rate of photosynthesis in different habitats at different times.

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The light microscope

Learning objectives:

- observe plant and animal cells with a light microscope
- understand the limitations of light microscopy.

KEY WORDS

magnification
resolving power
micrographs

The type of light microscope you have used in the school laboratory is called a compound microscope. Microscopes magnify the specimen you are looking at, making them look bigger than they are.

Figure 1.1 A light microscope

Magnification

The magnified image is produced by two lenses, an eyepiece and an objective lens. There is usually a choice of objective lenses.

Total magnification = magnification of eyepiece × magnification of objective lens

For instance, if the eyepiece has a **magnification** of ten, which is written ×10, and the objective lens has a magnification of ×40, the total magnification is ×400.

1. **Calculate is the total magnification with an eyepiece magnification of ×15 and an objective lens magnification of ×40?**
2. **What magnification would the objective lens need to be to give a total magnification of ×300 with an eyepiece of ×15?**

DID YOU KNOW?

British scientist Robert Hooke first used the term 'cell'. He recorded the first drawings of cells using a compound microscope in his book *Micrographia*, which was 350 years old in 2015.

You may also have heard of Hooke for his law of elasticity, Hooke's law, in physics.

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Magnification of images

The magnification described on the previous page is the magnification used to *view* an image. Microscope images, or **micrographs**, in books, scientific papers or exam papers must show the magnification to be meaningful.

$$\text{magnification of the image} = \frac{\text{size of the image}}{\text{size of real object}}$$

The cell in Figure 1.2 is 50 mm across on the page. In real life, it measures 40 μm.

To calculate the magnification, first convert the 50 mm into micrometres (or convert 40 μm to millimetres).

50 mm = 50 000 μm

The cell measures 40 μm

Therefore, the magnification of the image $= \frac{50\,000}{40} = \times 1250$.

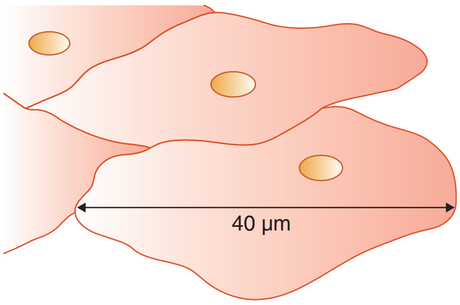

Figure 1.2 A drawing of a micrograph of a cell

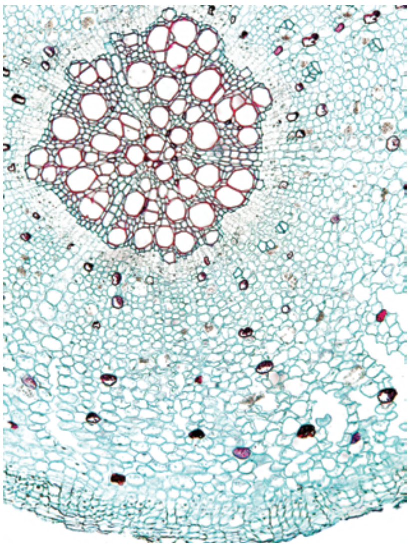

Figure 1.3 A micrograph of the cross section of a root. Magnification x100

3. **A micrograph of a plant cell in a book is 150 mm long. The plant cell measures 120 μm long. Calculate the magnification.**
4. **Why is it essential to state the magnification of an image of a cell in a book but of little value on a website?**

The limits of the light microscope

Very high magnifications are not possible with the light microscope. This is because of the light-gathering ability of the microscope and the short working distances of high-power lenses. The highest magnification possible is around ×1500.

Using higher magnification does not always mean that you can see greater detail in an image. This depends on the **resolving power**, or resolution. This is the ability to distinguish between two points. In other words, whether you see them as two points, or one.

The resolving power of a light microscope is around 0.2 μm, or 200 nm. This means that you could not separately pick out two points closer than 200 nm apart.

5. **What is the maximum resolving power of the light microscope?**
6. **What is the maximum magnification possible with a light microscope?**
7. **Make a table to show the pros and cons of using a light microscope.**

COMMON MISCONCEPTIONS

Do not confuse magnification, which is how much bigger we can make something appear, with resolving power, which is the level of detail we can see.

Think about a digital photo. You can make it as big as you like, but at a certain point you will not be able to see any more detail.

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Looking at cells

KEY WORDS

chloroplast
chlorophyll
chromosome
eukaryotic
order of magnitude

Learning objectives:

- describe the structure of eukaryotic cells
- explain how the main sub-cellular structures are related to their functions.

Cell biology helps us to understand how parts of the cell function and interact with each other. It also helps us to learn how we develop, and about our relationships with other organisms.
Biomedical scientists use cells to look for signs of disease and in new drug development.

Plant and animal cells

Almost all organisms are made up of cells. Cells are the fundamental units of living organisms. Plant and animal cells have a basic structure.

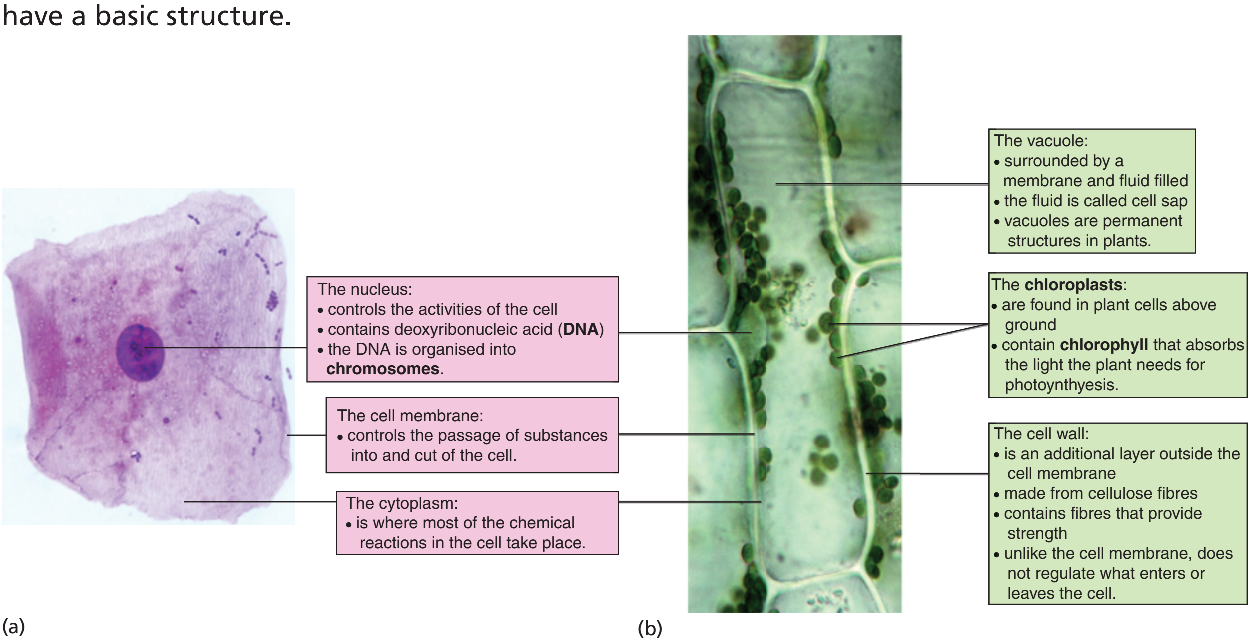

Figure 1.4 (a) A simple animal cell and (b) a plant leaf cell

This type of cell, containing a true nucleus in the cytoplasm, is called a **eukaryotic** cell.

1. **List the sub-cellular structures found in both plant and animal cells.**
2. **Which sub-cellular structures are found only in plant cells?**

   What is the function of:
   - **the nucleus**
   - **the cell membrane?**
3. **What structure gives strength to a plant cell?**

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Cell size

The smallest thing we can see is about 0.04 mm, so you can see some of the largest cells with the naked eye. For all cells, however, we need a microscope to see them in any detail.

Most animal and plant cells are 0.01–0.10 mm in size. The unit we use to measure most cells is the micrometre, μm. For some sub-cellular structures, or organisms such as viruses, it is best to use a smaller unit: the nanometre, nm.

1 millimetre (mm) = $\frac{1}{1000}$ m or 10^{-3} m

1 micrometre (μm) = $\frac{1}{1000}$ mm or 10^{-3} mm or 10^{-6} m

1 nanometre (nm) = $\frac{1}{1000}$ μm or 10^{-3} μm or 10^{-9} m

4 **What size is the smallest thing our eye can see, in mm?**

5 **What is the range in size of most animal and plant cells, in μm?**

Order of magnitude

Figure 1.5 shows the size of plant and animal cells compared with some other structures.

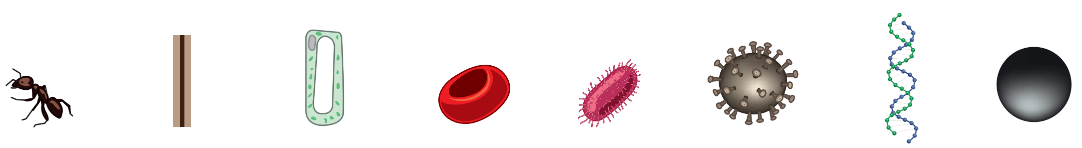

Figure 1.5 Size and scale

When comparing the sizes of cells, scientists often refer to differences in **order of magnitude**. That's the difference calculated in factors of 10.

So, the difference in order of magnitude for the HIV and the plant cell:

The plant cell in Figure 1.5b is 100 μm = 10^{-4} m

The human immunodeficiency virus (HIV) is 100 nm = 10^{-7} m

The difference in order of magnitude is 10^3, expressed as 3

6 **A cell membrane measures 7 nm across. Convert this to micrometres.**

7 **A white blood cell measures 1.2×10^{-5} m. An egg cell measures 1.2×10^{-4} m. Calculate the difference in order of magnitude.**

8 **Suggest what substances might pass in or out of a muscle cell and explain why.**

REMEMBER!

You'll notice that this system of units uses, and gives names to, multiples and sub-multiples of units at intervals of thousands (10^3) or thousandths (10^{-3}). A common exception is the centimetre, $\frac{1}{100}$ or 10^{-2} of a metre. But it is often convenient to use centimetres, particularly in everyday life.

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Primitive cells

Learning objectives:

- describe the differences between prokaryotic cells and eukaryotic cells
- explain how the main sub-cellular structures of prokaryotic and eukaryotic cells are related to their functions.

KEY WORDS

genome
nucleic acid
plasmid
prokaryotic
prokaryota
eukaryotic

The oldest fossil evidence of life on Earth comes from Australia. It confirms that there were bacteria living around 3.5 billion years ago.

The bacteria probably formed thin purple and green mats on shorelines. The bacteria would have photosynthesised, but produced sulfur as waste instead of oxygen.

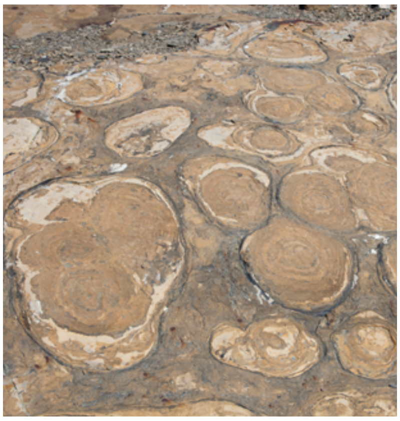

Figure 1.6 The organisms in this fossil are similar to purple bacteria that are living today

Prokaryotic cells

Bacteria are among the simplest of organisms. Along with bacteria-like organisms called Archaeans, they belong to a group of organisms called the **prokaryota**. These are single cells with a **prokaryotic cell** structure.

The cells of most types of organisms – such as all animals and plants – are **eukaryotic**. These have a cell membrane, cytoplasm containing sub-cellular structures called organelles and a nucleus containing DNA.

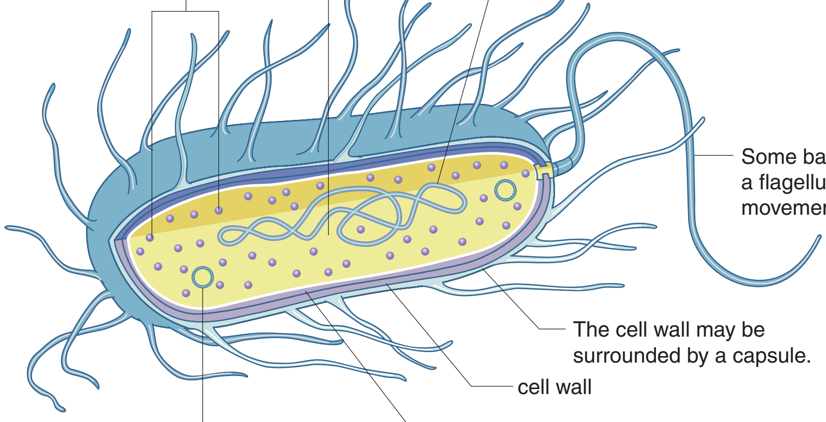

Figure 1.7 The structure of a prokaryotic cell

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Prokaryotic cells are much smaller than eukaryotic cells, around 1 μm across. Their DNA is not enclosed in a nucleus. It is found as a single molecule in a loop. They may also have one or more small rings of DNA called **plasmids**.

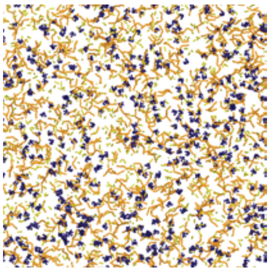
1. **List the differences between prokaryotic and eukaryotic cells.**
2. **Where is DNA found in prokaryotic cells?**

DID YOU KNOW?

A 'superfood' called Spirulina is the dried cells of a blue-green bacterium. The cells contain high concentrations of protein, and are rich in essential fatty acids, vitamins and minerals.

A new classification system

Traditionally, prokaryotic organisms have been grouped together, but now many scientists suggest that they should be divided into two sub-groups – the Bacteria and Archaea.



Many people think of bacteria as causing disease, but most are free-living. They live in all habitats on the planet.

Population explosions of blue-green bacteria sometimes cause 'blooms' in rivers, lakes and the sea.

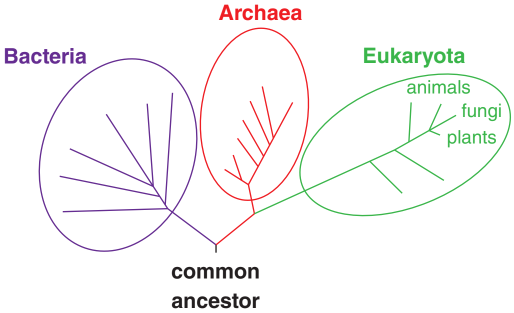


Figure 1.8 The three-domain classification system

3. **Which types of organism are prokaryotic?**
4. **Give three habitats where prokaryotic organisms live.**

Looking at cells in more detail

Learning objectives:

- identify the differences in the magnification and resolving power of light and electron microscopes
- explain how electron microscopy has increased our understanding of sub-cellular structures.

KEY WORDS

scanning electron microscope (SEM)
transmission electron microscope (TEM)

The *transmission electron microscope (TEM)* uses an electron beam instead of light rays.

Some of the electrons are scattered as they pass through the specimen. Those able to pass through it are focused in TEMs using electromagnetic coils instead of lenses.

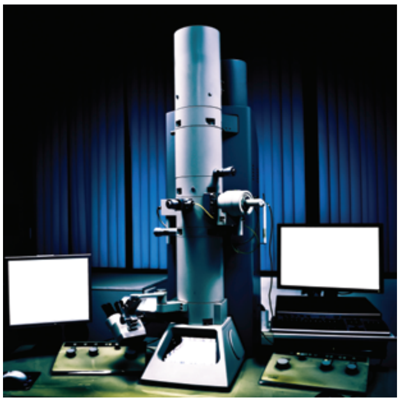


Figure 1.9 A transmission electron microscope. The electrons are displayed as an image on a fluorescent screen

Electron microscopes

TEMs are used for looking at extremely thin sections of cells. The highest magnification that can be obtained from a transmission electron microscope is around ×1 000 000, but images can also be enlarged photographically.

The limit of resolution of the transmission electron microscope is now less than 1 nm.

The **scanning electron microscope (SEM)** works by bouncing electrons off the surface of a specimen that has had an ultra-thin coating of a heavy metal, usually gold, applied. A narrow electron beam scans the specimen. Images are formed by these scattered electrons.

SEMs are used to reveal the surface shape of structures such as small organisms and cells. Because of this, resolution is lower and magnifications used are often lower than for TEM.

Electrons do not have a colour spectrum like the visible light used to illuminate a light microscope. They can only be 'viewed' in black and white. Here, false colours have been added.

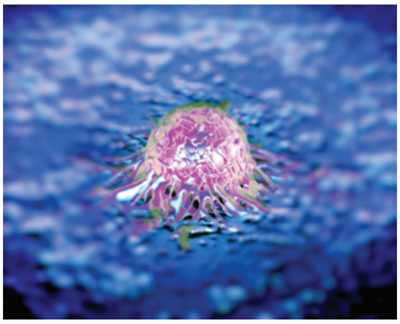


Figure 1.10 A scanning electron micrograph of a cancer cell

1. **What is the maximum resolution of an electron microscope?**
2. **What types of samples would a TEM and an SEM be used to view?**
3. **How has electron microscopy improved our understanding of cells?**

Cell ultrastructure

The TEM reveals tiny sub-cellular structures that are not visible with the light microscope. It also shows fine detail in those structures.

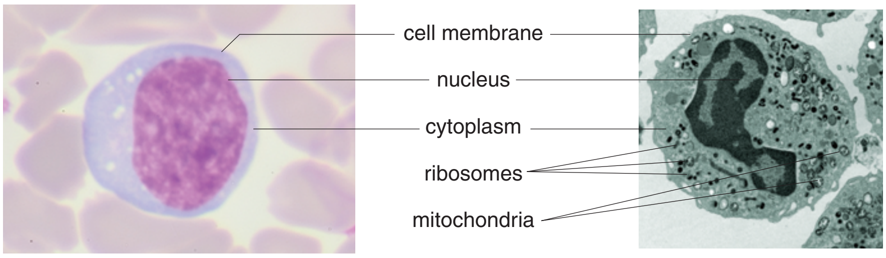


Figure 1.11 A white blood cell, as seen with a light microscope and a transmission electron microscope

We can see mitochondria and chloroplasts with the light microscope, but the electron microscope reveals their internal structure.

(a)
Mitochondria are where aerobic respiration takes place in the cell. A mitochondrion has a double membrane. The internal membrane is folded.

(b)
Chloroplasts are the structures in the plant cell where photosynthesis takes place. Like mitochondria, they also have a complex internal membrane structure.

(c)
Ribosomes are tiny structures where protein synthesis takes place. You can see them as dots in the micrograph. They can either lie free in the cytoplasm or may be attached to an internal network of channels within the cytoplasm.

Figure 1.12 Viewing (a) mitochondria, (b) chloroplasts and (c) ribosomes by transmission electron microscopy

The size of sub-cellular structures is important. Mitochondria and chloroplasts vary in size and shape. The complexity of a mitochondrion indicates how active a cell is. Chloroplast size varies from one species to another. Scientists sometimes investigate the ratio of the area of the cytoplasm to that of the nucleus in micrographs. A high ratio of cytoplasmic: nuclear volume can indicate that the cell is about to divide. A low one can be characteristic of a cancer cell.

4 **Name one structure visible to the electron microscope, but not the light microscope.**

5 **What process happens in ribosomes?**

6 **Which type of microscope would be best suited to viewing the 3D structure of a cell? Explain why.**

COMMON MISCONCEPTIONS

Don't assume that we always use electron microscopes in preference to light microscopes, or that electron microscopes are always used at high magnifications. Confocal microscopy is used in a lot of biomedical research. It can give high resolution images of live cells. And SEM is often used at low magnifications.

DID YOU KNOW?

Three scientists won the Nobel Prize in 2014 for the development of super-resolved fluorescence microscopy. It allows a much higher resolution than normal light microscopy. And, unlike electron microscopy, it has the advantage of allowing scientists to look at living cells.

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The structure of DNA

Learning objectives:

- describe the structure of DNA as repeating nucleotide units
- identify the four bases in DNA
- explain that the bases A and T, and C and G are complementary.

KEY WORDS

base
complementary
double helix
genetic code
nucleotide
polymer

In April 1953, Francis Crick and James Watson, working in the Cavendish Laboratory in Cambridge, produced the breakthrough scientific paper in which they revealed the structure of DNA.

Laboratories in Cambridge are still at the forefront of current work in genomics.

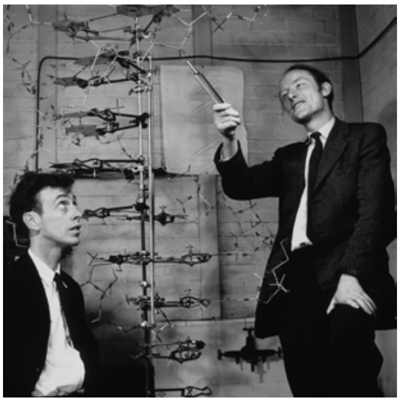

Figure 1.13 On 25 February 1953, Francis Crick walked into the Eagle pub in Cambridge and announced, 'We have found the secret of life'

The DNA double helix

A molecule of DNA has a structure like a ladder that has been twisted. The shape is called a **double helix**.

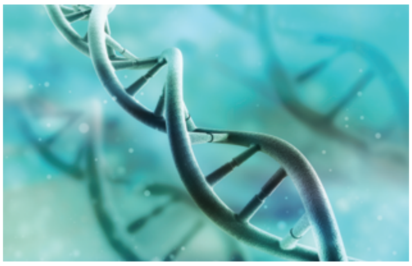

Figure 1.14 An illustration of DNA. The molecule consists of two strands and is like a ladder that has been gently twisted

1. **What is the name given to the structure of the DNA molecule?**
2. **Describe the shape of the DNA molecule.**

DNA is a polymer

The DNA molecule is a **polymer** made up of repeating units called **nucleotides**. 'Each nucleotide consists of a common sugar and phosphate group.' The two supports of the 'ladder' are alternating sugar molecules and phosphate groups. The 'rungs' of the ladder are made up of chemicals called **bases**. Each base is attached to the sugar molecule of the 'backbone' of the DNA.

There are four different bases in DNA:

- adenine (A)
- thymine (T)
- cytosine (C)
- guanine (G)

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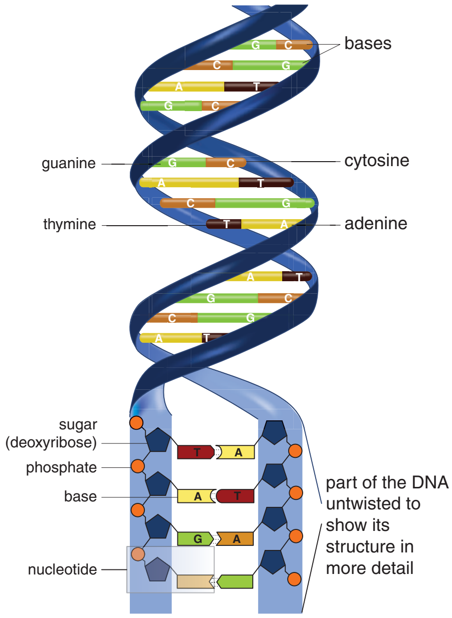

Figure 1.15 Each nucleotide consists of a sugar molecule, phosphate and a base

It is the bases of DNA that make up the **genetic code**. The Human Genome Project revealed that our genome contains approximately 3.3 billion base pairs. Human genes vary in size from a few hundred bases to more than 2 million.

3 **Name the four bases that make up the genetic code.**

4 **How many nucleotides are there?**

HIGHER TIER ONLY

The genetic code

Bases always pair up in the same way. The two strands that make up the DNA molecule are said to be **complementary**.

- An A on one side is linked to a T on the other side.
- A C on one side is linked to a G on the other side.

It is the sequence of base pairs in a gene that provides the code for the cell to build a protein.

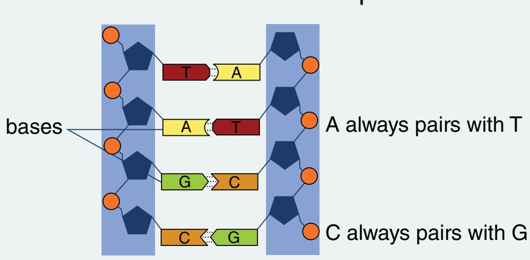

Figure 1.16 Complementary base pairs link the two strands together

5 **Create a diagram to show how the bases pair up.**

6 **How is the structure of a protein determined?**

REMEMBER!

You only need to know the *letters* of the four bases.

KEY INFORMATION

Remember that base pairs, and therefore opposite strands, are *complementary*. Remember to spell it correctly, with an 'e'.

DID YOU KNOW?

Other information helped Crick and Watson to work out the structure of DNA. Biochemist Erwin Chargaff discovered that the amount of adenine is usually similar to that of thymine, and the amount cytosine approximates to that of guanine.

The X-ray data of Rosalind Franklin and James Wilkins helped Crick and Watson deduce that DNA had a helical structure.

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Proteins

Learning objectives:

- describe how proteins are synthesised according to the DNA template of a gene
- explain that the genetic code of a gene specifies the protein to be made.

KEY WORDS

transcription
translation
amino acid
ribosome

We have several hundred thousand proteins in our bodies. Some of these are also found in other organisms. Our hair is the same chemical as feathers, hooves, horns and the shell of a tortoise.

Genes are needed to assemble proteins

Genes provide the code for the assembly of proteins.

Proteins are essential chemicals that are involved in nearly every task in the life of the cell.

Although proteins are very different in structure, they are all made up of the same 20 types of **amino acids**.

It is the number and combination of these amino acids, and the order in which they're arranged, that's important.

A gene provides the code for how a protein is assembled from its constituent amino acids.

The four bases (A, C, T and G) work in threes: there is a three-letter (or triplet) code for each amino acid.

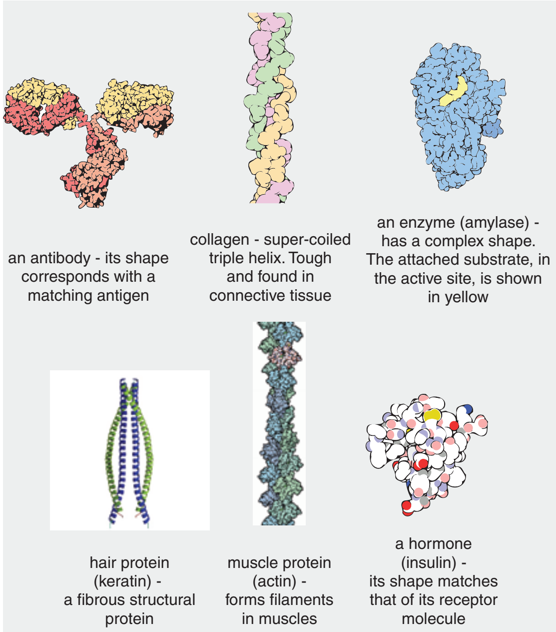

Figure 1.17 Proteins have a wide range of molecular shapes. It is its structure that enables a protein to do a particular job

1. **Name three types of protein.**
2. **How many different types of amino acids are found in proteins?**

HIGHER TIER ONLY

Protein synthesis

The sequence of bases in a gene acts as a template for a messenger molecule. The messenger molecule ensures that, as a protein is assembled on a **ribosome**, amino acids are linked together in the required order.

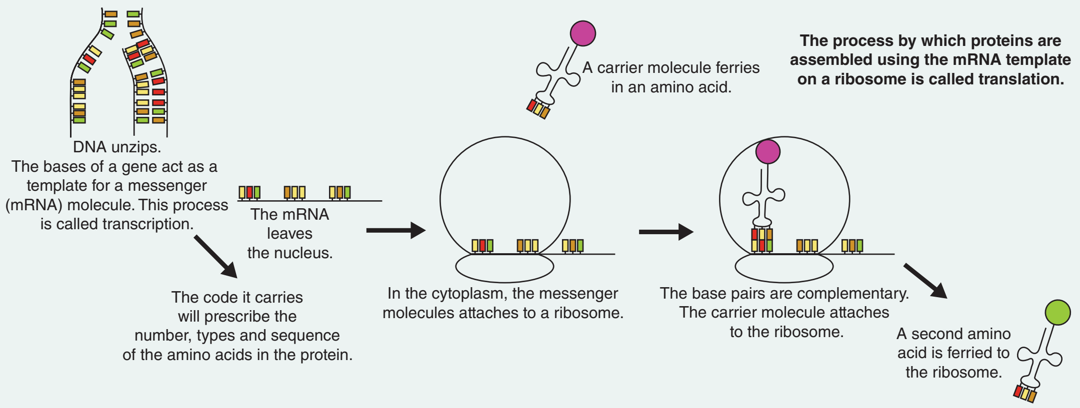

Figure 1.18a Protein synthesis

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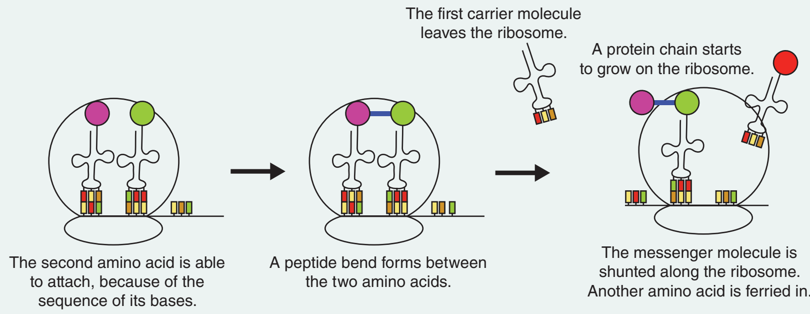

Figure 1.18b Protein synthesis continued

3 **How many base letters code for an amino acid?**

4 **Where are amino acids assembled into proteins?**

Proteins have a unique shape

The amino acid chain does not stay straight for very long. In less than a second, most proteins bend, twist and fold into a particular shape. This is because different amino acids in the chain are attracted to each other, while others repel.

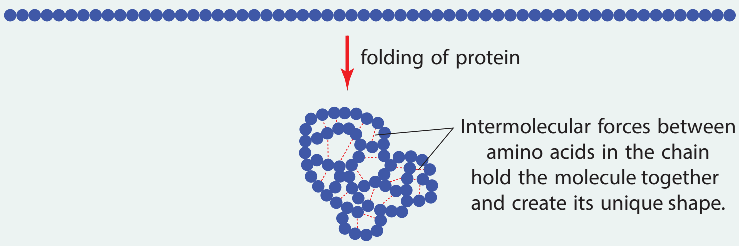

Figure 1.19 The protein folds into a unique shape

The sequence of amino acids in a protein is very important. If the sequence were changed, the protein would be a different shape. The complex shape is essential for the activity of physiological proteins such as enzymes, antibodies and hormones, and structural proteins such as collagen and keratin.

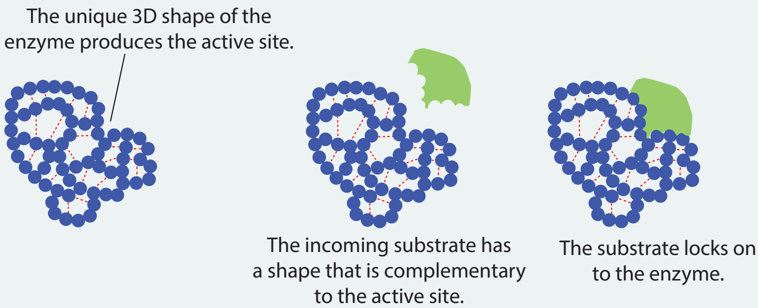

Figure 1.20 The enzyme and substrate have a complementary shape. Anything that disrupts the intermolecular forces holding the enzyme together will affect its activity

5 **Why does a protein chain fold immediately after synthesis?**

6 **What holds the protein structure together?**

7 **Construct a flow diagram to show how the structure of DNA affects the protein made.**

REMEMBER!

You do not need to know protein synthesis in *detail*, but you need to understand how the genetic code works.

DID YOU KNOW?

One of the smallest proteins in the human body is insulin, the hormone that helps to control our blood sugar. It contains 51 amino acids.

The largest is titin, with around 30 000. Titin helps to keep the muscle proteins that move when a muscle contracts in place.

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KEY CONCEPT

Investigating the need for transport systems

KEY WORDS

Surface area
Exchange surfaces

Learning objectives:

- describe the conditions needed for diffusion to occur
- calculate and compare surface area to volume ratios
- explain how materials pass in and out of cells

Many chemical reactions happen inside living cells. Substances must enter the cell to fuel these reactions and the waste products of the reactions need to be removed. Larger cells have greater chemical activity, so need more substances, for example, nutrients and oxygen, and more substances have to be removed, for example, carbon dioxide.

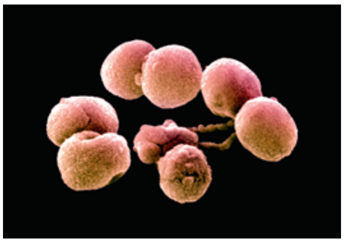

Figure 1.21 Which will have the faster diffusion rate?

Size matters

Most cells are no more than 1 mm in diameter. This is because in small cells nutrients, oxygen and waste substances can diffuse quickly in and out. As the volume of a cell increases, the distance increases between the cytoplasm at the centre of the cell and the cell membrane. In cells bigger than 1 mm diameter, the rate of exchange with the surrounding environment may be too slow for diffusion to meet the cell's needs. The cell would probably not survive.

1. **How does the size of a cell affect the chemical activity inside the cell?**
2. **Describe one chemical activity that takes place in cells.**

Looking at surface-area-to-volume ratio

The surface area of a cell affects the rate at which particles can enter and leave the cell. The volume of the cell affects the rate of chemical reactions within the cell (how quickly materials are used in reactions and how fast the waste products are made).

Look at the diagram. The cubes represent cells.

- cubes have 6 sides, so the surface area = length × width × 6
- the volume of a cube = length × width × height
- surface-area-to-volume ratio = surface area ÷ volume

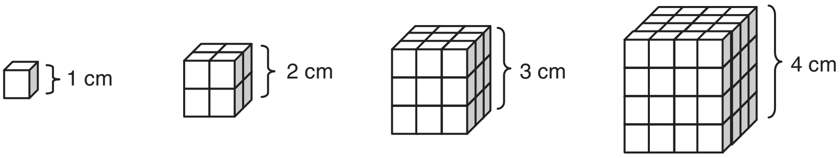

Figure 1.22 Cubes of increasing size

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Calculate the surface area, volume and surface-area-to-volume ratio (SA:V) for each of the cubes. Cube A has been done for you.

Cube	Number of internal cubes	Surface area (cm^2)	Volume (cm^3)	SA:V
A	1	6	1	6
B	8			
C	27			
D	64			

3 **What happens to the surface area and volume as the size increases?**

4 **What happens to the surface-area-to-volume ratio as the size increases?**

5 **What does a decrease in surface-area-to-volume ratio make it more difficult to do?**

Transport systems and exchange surfaces

With a small surface-area-to-volume ratio, multicellular organisms need surfaces and organ systems specialised for exchanging materials. Once an organism is multicellular and has several layers of cells, the oxygen and nutrients take longer to diffuse in and are all used up by the outer layers of cells. Exchange systems allow transport into and out of all cells for the organism's needs. As well as exchanging substances, cells also have to lose heat fast enough to prevent overheating.

To function efficiently, exchange surfaces need the following features:

- a large surface area to maximise exchange
- a thin membrane to provide a short diffusion path
- a method of transporting substances to and from the exchange site, for example, a blood supply to carry nutrients around the body, and lungs to take oxygen into the body.

6 **How are efficient exchange surfaces adapted to carry out their function?**

7 **Explain why large organisms need transport systems but small organisms do not.**

Organism		SA:V
bacterium		6000000
amoeba		60000
fly		600
dog		6
whale		0.06

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PRACTICAL

Investigate the effect of pH on the rate of reaction of amylase enzyme

Learning objectives:

- describe how safety is managed, apparatus is used and accurate measurements are made
- explain how representative samples are taken
- make and record accurate observations
- draw and interpret a graph from secondary data using knowledge and observations.

KEY WORDS

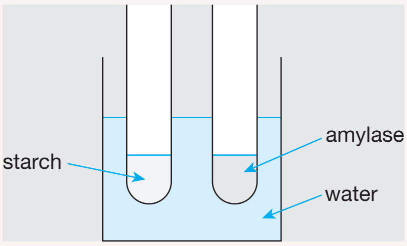
amylase
starch
iodine

Amylase is an enzyme that controls the breakdown of starch in our digestive systems. Starch turns a blue-black colour when iodine (an orange solution) is added.

These pages are designed to help you think about aspects of the investigation rather than to guide you through it step by step.

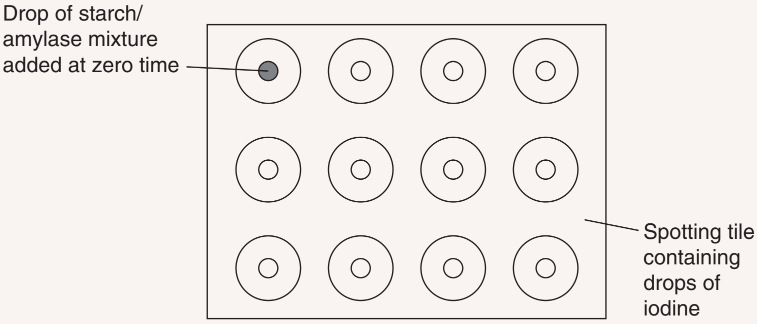
Making accurate measurements and working safely

In this investigation digestion is modelled, using solutions of starch and **amylase** in test tubes, to find the optimum pH required for the reaction. Amylase and **starch** solution are each added to a test tube and put in a water bath or a beaker of hot water at 25°C and left for 5 minutes. The pH buffer solution is added to the amylase, before adding the starch. To carry out this method small volumes of chemicals and enzymes (less than 10cm^3) must be accurately measured. To do this a 10cm^3 measuring cylinder or a 10cm^3 calibrated dropping pipette could be used.



The investigation also involves taking samples from the mixture at timed intervals and adding them to **iodine** in a spotting tile. To do this a glass rod or a dropping pipette could be used. The time at which the solution no longer turns a blue-black colour with iodine solution (the iodine solution remains orange) is recorded.

The procedure is repeated for different values of pH buffer solution.



1 **Which piece of apparatus would you use to:**

a **measure small volumes accurately?**
b **add drops of solution to the iodine?**

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2 To calculate the time taken for the reaction to occur, the teacher has told the students to count up the drops of iodine used. Explain how this is an accurate measurement of the time taken.

3 Give two safety precautions that should be taken when doing the investigation.

Planning your sampling

Tom carries out a trial run of the procedure before starting his investigation. Tom found that at pH7 the colour change took 40 seconds to happen. He then decided when to take samples of the solution.

4 What colour will Tom see in the spotting tile when all the starch has been broken down by the amylase?

5 Explain why Tom will need to take continuous samples throughout his investigation.

6 Why did Tom carry out a trial before starting the investigation?

7 From the result of the trial run, suggest suitable time intervals for Tom to take the continuous samples in his investigation.

Using results to draw and interpret a graph

Tom completed the investigation. He sampled the test solutions every ten seconds. This is his data.

pH of solution	Time for colour change to occur (seconds)		
	Test 1	Test 2	Test 3
5	150	160	160
6	70	70	80
7	40	50	40
8	80	80	60
9	130	90	140

Tom decided to draw a graph of the data in his table to make it easier for him to see trends in the data.

8 Should Tom draw a bar chart or a line graph?

9 Tom repeated each pH test three times.

a Why did he repeat the tests?
b Tom thought he had an anomalous result. Which result do you think it was?
c What should Tom do with the anomalous result?

10 Calculate the mean time for the colour change to happen at each pH.

11 Plot the graph of Tom's data.

12 Use the graph to calculate the rate of reaction at each pH.

13 Use your knowledge of enzymes to help you identify patterns, make inferences and draw conclusions.

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Explaining enzymes

Learning objectives:

- describe what enzymes are and how they work
- explain the lock-and-key theory.

KEY WORDS

biological catalyst
denatured
lock and key
metabolism
optimum

Chemical reactions happen all the time. *Metabolism* describes all the reactions in a cell or the body. The energy transferred by respiration in cells is used for the continual enzyme-controlled processes of metabolism that synthesise new molecules.

A special catalyst

A catalyst is a chemical that speeds up a reaction without being used up itself. This means it can be reused. Different reactions need a different catalyst.

Enzymes are **biological catalysts.** Enzymes catalyse most chemical reactions that happen in cells, for example, respiration, protein synthesis and photosynthesis. Enzymes help to:

- break down large molecules into smaller ones
- build large molecules from smaller ones
- change one molecule into another molecule.

1. **What is an enzyme?**
2. **Explain what enzymes do in a living organism.**

How do enzymes work?

Enzymes are large protein molecules made from folded, coiled chains of amino acids. Each enzyme has a unique sequence of amino acids. The active site, the area that attaches to the substrate (reactant), has a very specific shape that fits its substrate exactly.

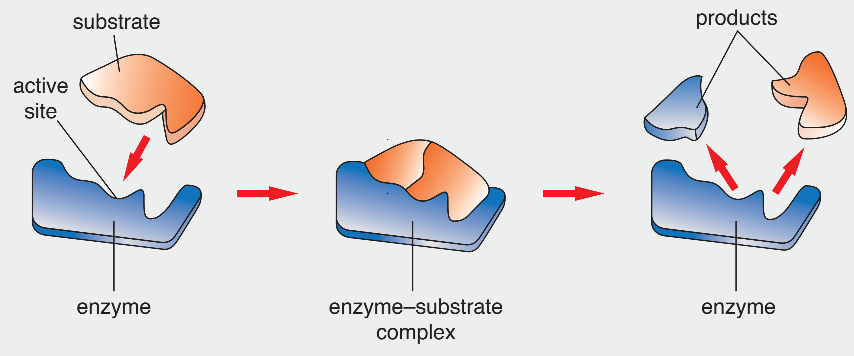

Figure 1.22 The **lock-and-key theory** is a simple explanation of how enzymes work

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Only one type of substrate can fit into the active site of an enzyme, like a key fits into a lock. Once the substrate is attached to the active site, it is changed into a product. Each enzyme catalyses one type of reaction This is called enzyme specificity.

If the shape of the active site changes, the enzyme is **denatured** and cannot catalyse the reaction. This is an irreversible change. The enzyme cannot work because the substrate cannot fit into the active site.

3 **What is an enzyme made from?**

4 **What happens when an enzyme is denatured?**

KEY INFORMATION

Enzymes are chemicals. They are not living and, therefore, cannot be killed. They are denatured.

Changing enzyme reactions

Enzyme-controlled reactions are affected by:

- pH
- temperature.
- substrate concentration
- enzyme concentration

Every enzyme has an **optimum** pH and an optimum temperature. Above or below these levels, the rate of reaction will slow down. Extremes of pH or temperature can denature an enzyme.

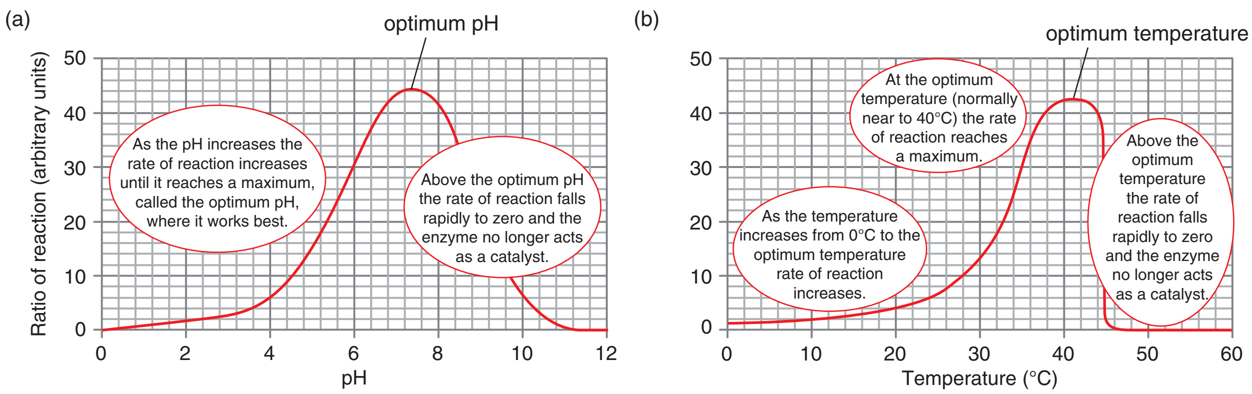

Figure 1.23 Graphs to show how (a) pH and (b) temperature affect the rate of an enzyme-catalysed reaction. What is the optimum pH for the reaction in (a)?

5 **Biological washing detergents contain enzymes. Explain why clothes washed at 60°C will not be as clean as those washed at 40°C.**

6 **How does the lock-and-key theory explain the specificity of enzymes?**

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Cells at work

Learning objectives:

- explain the need for energy
- describe aerobic respiration as an exothermic reaction.

KEY WORDS

respiration
aerobic respiration
exothermic

This runner is using energy to run a marathon. But we all need a continuous supply of energy – 24 hours a day – just to stay alive.

Figure 1.24 An average runner uses around 13 000 kJ of energy for a marathon

We need energy to live

Organisms need energy:

- to drive the chemical reactions needed to keep them alive, including building large molecules
- for movement.

Energy is needed to make our muscles contract and to keep our bodies warm. It's also needed to transport substances around the bodies of animals and plants.

In other sections of the book, you will also find out that energy is needed:

- for cell division
- to maintain a constant environment within our bodies
- for **active transport**. Plants use active transport to take up mineral ions from the soil, and to open and close their stomata
- to transmit nerve impulses.

1. **List four uses of energy in animals.**
2. **List four uses of energy in plants.**

Aerobic respiration

Respiration is the process used by all organisms to release the energy they need from food.

Respiration using oxygen is called **aerobic respiration**. This type of respiration takes place in animal and plant cells, and in many microorganisms.

Glucose is a simple sugar. It is the starting point of respiration in most organisms. The food that organisms take in is, therefore, converted into glucose.

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This chemical reaction is **exothermic**. A reaction is described as exothermic when it releases energy. Some of the energy transferred is released as heat.

The energy released during respiration is used to build a high energy compound called **adenosine triphosphate**, or **ATP**. ATP is an energy carrier; it carries energy to the part of the cell where it's needed. On reaching this, the ATP breaks down, releasing its stored energy.

Respiration is exothermic. A reaction is described as exothermic when it releases energy. Energy not transferred to ATP is released as heat.

Figure 1.25 Birds and mammals use heat energy to maintain a constant body temperature

3 **What is the purpose of respiration?**

4 **How do birds and mammals make use of the waste heat energy?**

Bioenergetics

This is the equation for aerobic respiration:

glucose	+	oxygen	→	carbon dioxide	+	water (energy released)
$C_6H_{12}O_6$		O_2		CO_2		H_2O

Figure 1.26 Insect flight muscles have huge numbers of well-developed mitochondria

This equation describes the overall change brought about through each of a series of chemical reactions. A small amount of energy is actually released at each stage in the series.

The first group of steps occurs in the cytoplasm of cells, but most of the energy is transferred by chemical reactions in mitochondria. A maximum of 38 molecules of ATP can be synthesised for each molecule of glucose.

DID YOU KNOW?

The muscle an insect uses to fly is the most active tissue found in nature.

5 **When and where does respiration occur?**

6 **Give one characteristic feature of actively respiring cells.**

7 **What is the maximum number of molecules of ATP that can be produced from one molecule of glucose.**

COMMON MISCONCEPTIONS

Don't forget that *all* organisms respire. The equation is the reverse of photosynthesis, but don't confuse the two. Photosynthesis is the way in which plants make their food.

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Living without oxygen

Learning objectives:

- describe the process of anaerobic respiration
- compare the processes of aerobic and anaerobic respiration.

KEY WORDS

anaerobic respiration
fermentation

Stewart is a brewer. He adds yeast to a mixture of malted barley and hops in water.

Figure 1.27 Yeast converts sugar into alcohol, or ethanol. The process is completed in around 3 days

Anaerobic respiration

The yeast respires using the sugary liquid. The yeast cells divide rapidly. After a few hours there are so many yeast cells that the oxygen runs out. The yeast is able to switch its respiration so that it can obtain energy *without* oxygen. Many microbes such as yeast can respire successfully without oxygen.

This is **anaerobic respiration** – respiration without oxygen.

Anaerobic respiration in yeast cells and certain other microorganisms is called **fermentation.**

Anaerobic respiration occurs in the cytoplasm of cells.

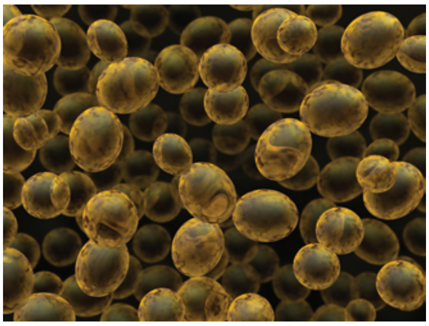

Figure 1.28 Yeast cells divide rapidly by mitosis. Many of the cells do not separate from each other

1. **What is meant by anaerobic respiration?**
2. **Why do yeast cells switch from aerobic to anaerobic respiration in the process of making ethanol?**

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Baking

Yeast is also used in baking bread. Yeast is mixed with flour and some sugar. The ingredients are mixed together thoroughly and the dough is left to rise before baking it.

3. **Explain why sugar is added to dough.**
4. **Why does the dough rise?**
5. **What happens to the alcohol made during bread production?**

Figure 1.29 Dough is kneaded to mix the ingredients

DID YOU KNOW?

Yeast is unable to use the starch in barley for respiration. Maltsters germinate the barley grains first to break down the starch into sugar.

The biochemistry of fermentation

The equation for fermentation is:

glucose → ethanol + carbon dioxide (energy released)

Anaerobic respiration is much less efficient than aerobic respiration. Only two molecules of ATP are produced per molecule of glucose that's respired. That's only a nineteenth as much energy as aerobic energy. But in situations where there's little oxygen, it means that cells can stay alive, and the amount of energy produced is still enough to keep single cells running.

Certain plant cells can also use alcoholic fermentation to obtain their energy. These include plants that grow in marshes, where oxygen is in short supply. Pollen grains can also respire anaerobically.

Without oxygen, we would die. But when actively contracting, our muscles run short of oxygen. They are able to respire anaerobically for short periods of time. Lactic acid, and not ethanol, is produced.

glucose → lactic acid (energy released)

6. **Explain why it is helpful for pollen grains to respire anaerobically.**
7. **Write down the equation for fermentation.**
8. **For anaerobic respiration in muscle:**
    - **write down the word equation**
    - **work out the symbol equation.**
9. **Compare the reactants, products and the amount of energy produced for anaerobic respiration to aerobic respiration.**

KEY SKILLS

You must be able to compare aerobic and anaerobic respiration: the need for oxygen, the products and the amount of energy transferred.

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Explaining digestion

KEY WORDS

carbohydrase
lipase
protease

Learning objectives:

- describe how physical digestion helps to increase the rate of chemical digestion
- name the sites of production and action of specific enzymes
- interpret data about digestive enzymes.

In 1822, Alexis St. Martin was shot. Dr William Beaumont saved his life, but the wound did not heal. Dr Beaumont used the hole to watch what happened in Alexis's stomach after he ate food!

Physical or chemical digestion?

In the mouth, teeth are used to cut and grind food into smaller pieces. This is physical digestion. It allows food to pass through the digestive system more easily. It increases the surface area of the foods to speed up chemical digestion.

Muscles in the stomach wall also help to physically digest food by squeezing it. Muscles in other parts of the digestive system also squeeze the food to keep it moving by peristalsis.

Even small pieces of food cannot pass into the blood. Enzymes are produced in some parts of the digestive system. Enzymes break down food into very small soluble molecules, so they can be absorbed by the blood. This is chemical digestion.

Figure 1.30 Pieces of meat in the stomach were much smaller after a few hours. What had happened?

1. **Why is physical digestion important?**
2. **How is chemical digestion different from physical digestion?**

Digestive enzymes

Enzymes breakdown fats, proteins and carbohydrates (polymers) into their constituent parts (monomers).

Most enzymes work inside cells, but the digestive enzymes work outside cells. They are produced by cells in glands and in the lining of the gut. The enzymes pass into the gut to mix with the food. There are three groups of enzymes in digestion:

- **Carbohydrases** break down carbohydrates into simple sugars. Amylase is a carbohydrase that breaks down starch.
- **Proteases** break down proteins into amino acids.
- **Lipases** break down fats into fatty acids and glycerol.

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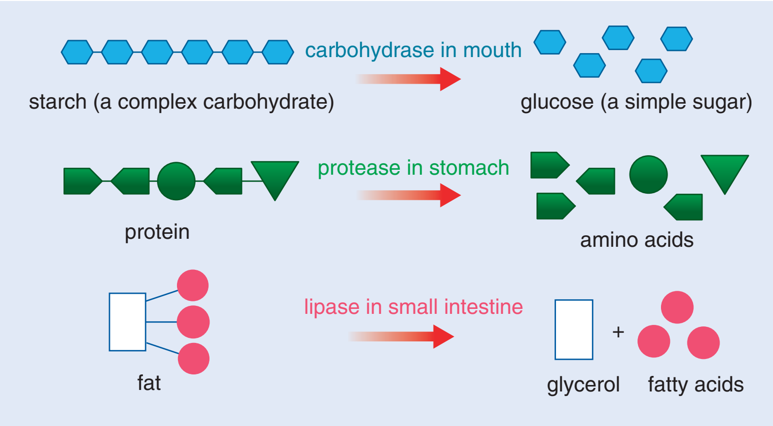

Figure 1.31 Why is chemical digestion important?

Different parts of the gut produce different enzymes, as shown in the table.

Enzyme	Site of production	Reaction
amylase	salivary glands, pancreas, small intestine	starch → sugars
protease	stomach, pancreas, small intestine	proteins → amino acids
lipase	pancreas, small intestine	lipids (fats) → fatty acids + glycerol

3 **Where are proteases produced and what reaction do they catalyse?**

4 **Suggest why digestive enzymes do not work inside cells.**

Speeding up digestion

Enzymes are affected by temperature and pH. Our body temperature is kept nearly constant at 37°C. That is the optimum temperature of enzymes in our body.

Enzymes also have an optimum pH. Salivary amylase in the mouth works best at pH 6·7–7·0 The protease enzyme in your stomach works best in acidic conditions, so the stomach produces hydrochloric acid. The stomach also produces mucus which coats the stomach wall to protect it from the acid and enzymes. Protease enzymes that are made in the pancreas and small intestine need alkaline conditions. Bile, made in the liver, neutralises the stomach acid so that these enzymes can work effectively.

5 **Look at Figure 1.32a. What does this graph tell you about pepsin and trypsin enzymes?**

6 **Explain Figure 1.32b using the collision theory.**

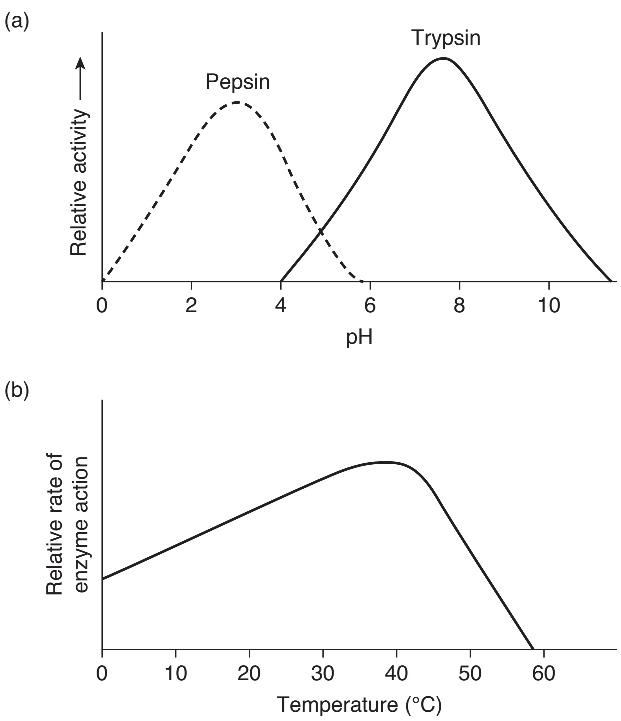

Figure 1.32

COMMON MISCONCEPTION

Bile is not an enzyme and it does not *digest* fat molecules. Bile *emulsifies* fat droplets to increase their surface area to speed up their digestion by lipase enzyme.

DID YOU KNOW?

Your stomach produces about 3 litres of hydrochloric acid a day.

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Investigating leaves

Learning objectives:

- identify the internal structures of a leaf
- explain how the structure of a leaf is adapted for photosynthesis
- recall that chloroplasts absorb energy from light for photosynthesis.

KEY WORDS

epidermal tissue
palisade mesophyll
spongy mesophyll
vascular bundle

Leaves work to manufacture glucose. Chloroplasts in leaves absorb the light needed for photosynthesis. How do the organelles inside the leaf work together to do this?

The structure of a leaf

Leaves of green plants are plant organs that are adapted to allow them to photosynthesise efficiently. Most leaves:

- are broad, with a large surface for light to be absorbed
- are thin, so that carbon dioxide has a short distance to diffuse
- have **vascular bundles** (veins). These support the leaf and transport
  - › water to the leaf
  - › glucose away from the leaf.

1. **How does the shape of a leaf help photosynthesis to happen?**
2. **What is the function of vascular bundles?**

Inside the leaf

The diagram shows the internal structure of a leaf. Each part has a specific function

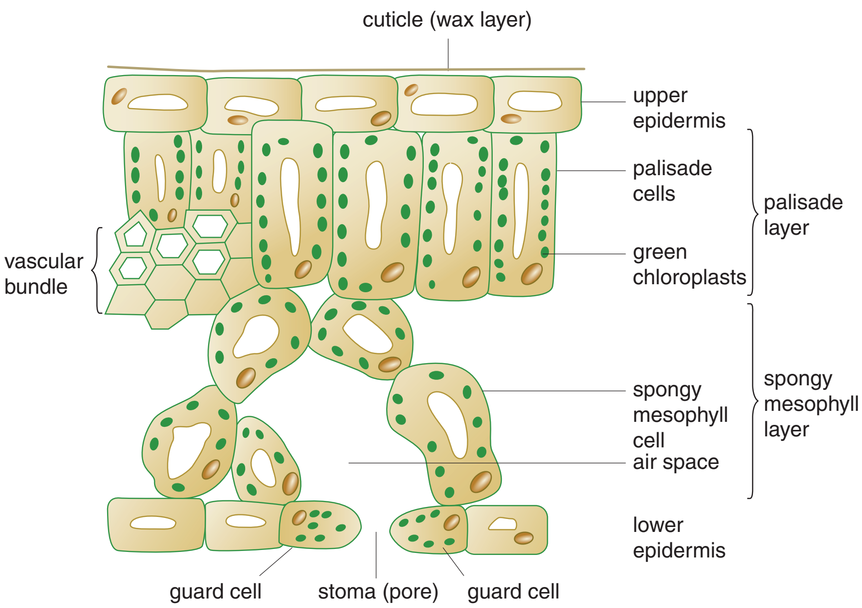

Figure 1.33 A diagram of a vertical section through a leaf

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The upper surface is covered by a cuticle to protect it. Under the cuticle are layers of different cells:

- **epidermal tissues** cover the leaf, letting light penetrate
- **palisade mesophyll** carry out photosynthesis, absorbing most of the light
- **spongy mesophyll** has air spaces for diffusion of gases
- lower epidermal tissue protects the underside of the leaf.

Chloroplasts in the mesophyll are where light is absorbed for photosynthesis.

The lower epidermis has small pores called stomata. Each stoma allows gases to diffuse in and out of the leaf.

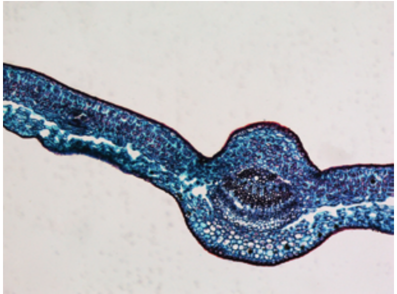

Figure 1.34 Compare what you can see here with Figure 1.33

3 **Describe the function of mesophyll cells**

4 **Why do leaf cells contain chloroplasts but root cells do not?**

5 **Why is the cuticle thin, transparent and waxy?**

DID YOU KNOW?

Meristem tissue is found at the growing tips of roots and shoots. It differentiates into different types of plant cells.

Adaptations for effective working

Using a microscope, look at a slide of a section through a leaf.

Identify the layers of cells. Calculate the magnification you used.

Each type of leaf cell has features that make it adapted for its function.

Layer	Adaptation	Function
upper epidermal tissue	thin and transparent waxy cuticle	allows light to pass to the mesophyll to protect the leaf and stop water loss
palisade mesophyll	regular-shaped cells, arranged end-on, near upper surface; most chloroplasts at the top of the cells	absorb the maximum amount of light possible
spongy mesophyll	irregular-shaped cells; many air spaces	increases surface area for CO_2 absorption; allows gases to diffuse
lower epidermal tissue	many stomata; surrounded by guard cells	allow gases to diffuse; guard cells open and close stomata
vascular bundles	contain xylem and phloem tubes	transport substances around the plant

6 **Suggest why stomata are found on the lower epidermal tissue.**

7 **Explain how the adaptations of the palisade mesophyll allow it to photosynthesise efficiently.**

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Looking at trophic levels

Learning objectives:
- explain trophic levels
- explain and construct pyramids of biomass
- explain the difficulties in constructing pyramids.

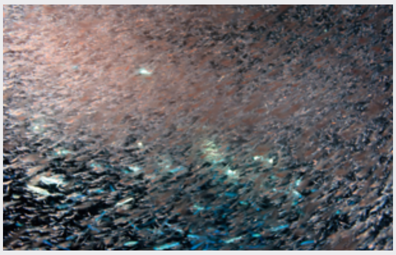
KEY WORDS

apex predator
biomass
decomposer
secrete
trophic level

Producers are photosynthetic organisms. They are the main producers of food (biomass) for all other living organisms on Earth. Consumers eat plants or other animals. Producers and consumers have a complex relationship.

Describing food chains

Trophic levels describe feeding positions in food chains. Energy is transferred from one trophic level to the next, along the food chain.

Level 1	Level 2	Level 3
 phytoplankton	 zooplankton	 herring
producer	primary consumer	secondary consumer

Level 4	Level 5
 mackerel	 tuna
tertiary consumer	quaternary consumer

Figure 1.35 Trophic levels in a food chain

Trophic levels in food chains are represented by numbers:

- Level 1: Plants and algae are producers.
- Level 2: Herbivores eat plants/algae.
- Level 3: Carnivores eat herbivores.
- Level 4: Carnivores eat other carnivores.

DID YOU KNOW?

Apex predators keep ecosystems stable. This is called trophic dynamics.

Phytoplankton are microscopic algae that float on the surface of the oceans'. Zooplankton are normally microscopic animals found near the surface of the sea'

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(In some food chains, as in Figure 1.35, there may be a further level of carnivores.) Carnivores in the top level, with no predators, are **apex predators**.

Decomposers break down dead plant and animal matter. They **secrete** enzymes onto food to digest it. The digested food molecules then diffuse into the microorganism. This is extracellular digestion.

1. **What are trophic levels?**
2. **What trophic level is**
   - **a mackerel**
   - **b zooplankton**
   - **c a producer?**

Using pyramids

The mass of organisms at different trophic levels in an area can be used to construct a pyramid of biomass. Level 1 is always at the bottom of the pyramid, Level 2 is above this, and so on (see Figure 1.36).

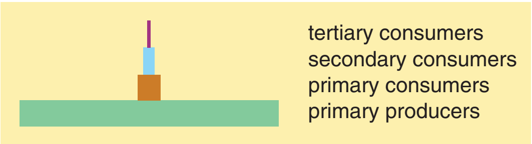

Figure 1.36 A simple pyramid of biomass

Pyramids of **biomass** use the dry mass of the organisms because 'wet' mass can vary. The biomass at each level in food chains is always less than the previous level.

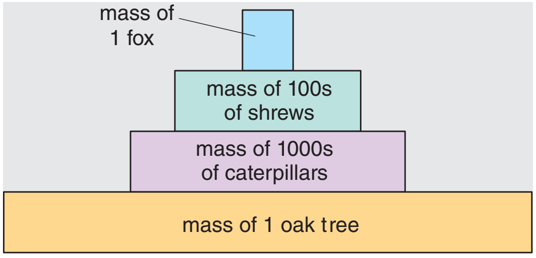

Figure 1.37 A woodland pyramid of biomass

3. **Why is dry biomass used for pyramids of biomass?**
4. **Draw a pyramid of biomass for this food chain (parasitic wasps lay eggs in ladybird pupae):**

   rose → aphid → ladybird → parasitic wasp

Difficult pyramids

- Pyramids of biomass show the amount of energy in a trophic level more accurately than pyramids of number. But they do have some disadvantages, which are:
- Organisms need to be collected and killed to measure dry mass.
- It is difficult to catch and weigh the organisms.
- Biomass varies. A tree in summer has more biomass than it does in winter.
- Some organisms are omnivores and feed at more than one trophic level.

To avoid killing living organisms, estimates of biomass are often used.

5. **Use graph paper to draw pyramids of biomass (to scale) for this food chain:**

   pondweed (2500 g) → insects (50 g) → frogs (25 g) → trout (10 g)

6. **Why would scientists find it difficult to measure the biomass in this food chain?**

   phytoplankton → krill → whale → human

KEY SKILL

Practise drawing pyramids of biomass for different food chains.

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Increasing food production

KEY WORDS

hydroponics
yield

Learning objectives:

- identify factors that increase food production
- explain how these factors can be controlled
- evaluate the benefits of manipulating the environment to increase food production.

In the past, farms were small and produce was only available during the growing season. Farmers now use their knowledge of the limiting factors of photosynthesis to increase crop *yields*. How can this be done? How do they change the factors?

Why use a greenhouse?

Growing plants in a greenhouse keeps them warmer, and increases the rate of photosynthesis and plant growth. If seeds are planted outside, they germinate and grow very slowly.

1. **Explain why plants grow faster in the summer.**
2. **Why do plants grow faster in a greenhouse in February or March than they do outside?**

Figure 1.38 Why are dull cold days in winter not good for growing plants?

Greenhouses

Growing crops in greenhouses gives a large yield for a given area. This is intensive farming. Conditions in the greenhouse can be controlled to optimise the rate of photosynthesis. Greenhouses protect plants from weather conditions and from being damaged or eaten by animals.

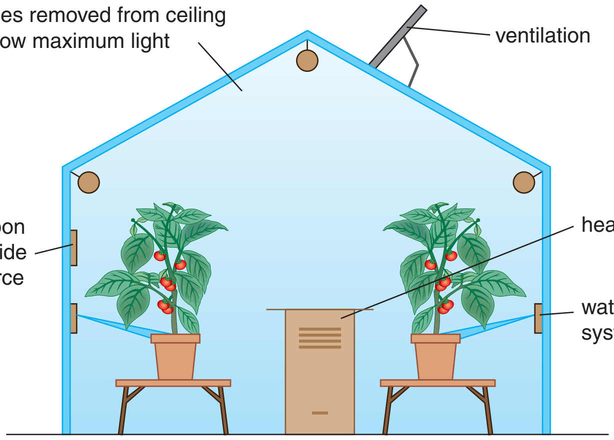

Figure 1.39 A greenhouse system

- Greenhouses trap heat from the Sun.
- A carbon dioxide source can be used to increase the concentration of the gas.
- Paraffin heaters are used in greenhouses. As they burn they produce carbon dioxide. They can also be used to increase the temperature on cooler days and nights.
- Watering systems deliver a regular supply of water.
- Blinds can be used to control the amount of light.
- Humidifiers are used to add moisture to the air.

3 **Why do many greenhouses have vents in the roof?**

4 **Explain why paraffin heaters are used in greenhouses.**

5 **How do greenhouses increase yield?**

Figure 1.40 Hydroponics is growing plants in mineral nutrient solutions, without soil

Optimising conditions

Farmers need to grow large fruits and vegetables without excessive leaf or root production. Using technology, commercial greenhouses increase yields by over twenty times, compared to traditional farming.

Plants are grown using **hydroponics**. Their roots are grown in rock wool (basalt-based medium) and nutrient-rich water.

Computer systems control conditions.

- Nutrients are monitored and concentrations adjusted as needed.
- Temperature is controlled by sensors to within 0.1°C
- Weather detection systems monitor external conditions and adjust vents and blinds to suit.
- Floors are covered in white plastic to reflect light.
- The glass used has a low iron content to ensure maximum light levels and even the metal supports are as thin as possible.
- Special lights are used to increase the hours of light. These are switched off for about 7 hours, allowing plants to transport the glucose that has been made.

6 **What are the benefits and drawbacks of changing conditions inside a greenhouse?**

7 **Suggest why large greenhouses have been built in Abu Dhabi and Spain.**

8 **'Light is a limiting factor for photosynthesis so it is not a good idea for commercial greenhouses to have blinds.' Do you agree with this statement? Give reasons for your answer.**

KEY INFORMATION

Remember that greenhouses optimise carbon dioxide concentrations, light levels, water levels, temperature and nutrient availability.

DID YOU KNOW?

The biggest threats to crops in commercial greenhouses are viruses. Workers wear protective clothing to prevent contamination of plants

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Looking at photosynthesis

Learning objectives:

- explain the importance of photosynthesis
- explain how plants use the glucose they produce.

KEY WORDS

endothermic
veins

Plants make carbohydrates (for example, sucrose and glucose) and oxygen when they photosynthesise. The plants release the oxygen that they do not need.

Learning about photosynthesis

Photosynthesis is a series of reactions that require energy. Reactions that need energy are called **endothermic** reactions. You will learn more about endothermic reactions in chemistry. In photosynthesis, energy is transferred from the environment to the chloroplast by light.

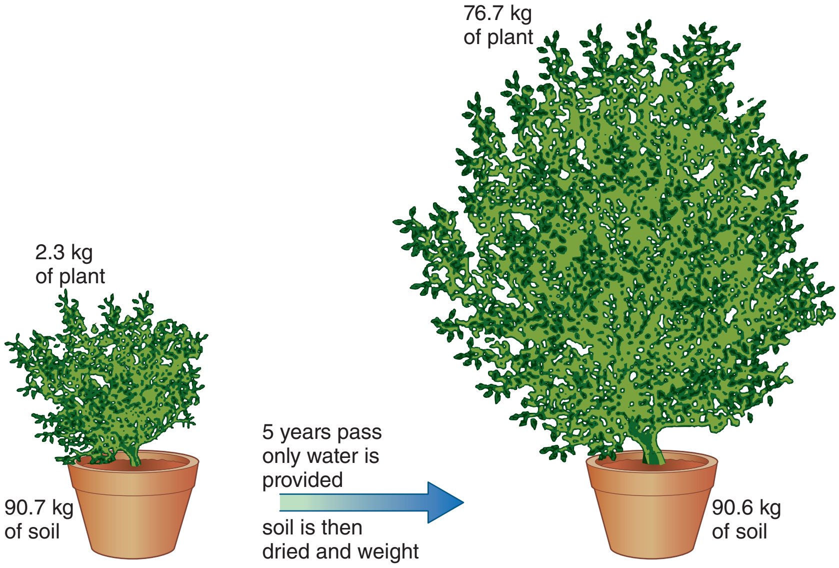

Figure 1.41 What do the results of Van Helmont's investigation show?

Early scientists thought that plants grew just by using minerals in the soil.

In 1600, Jan Baptist van Helmont showed that the increase in the mass of a willow tree was not just due to the soil minerals.

In 1771, Joseph Priestley put a plant in a glass container with a lit candle (to use up the oxygen). He then left the investigation for 27 days. Priestley found the candle then burned again. This showed that oxygen was present again.

COMMON MISCONCEPTION

Leaves look green because they only reflect the green light. They do not absorb green light for photosynthesis.

1. **What did Van Helmont's investigation show?**
2. **How could you investigate whether plants need light to photosynthesise?**

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Using sugars

Glucose and sucrose molecules produced by photosynthesis are used in a number of ways. Sugars are soluble molecules that dissolve to be transported to wherever they are needed. **Veins** transport glucose to parts of plants shown in Figure 1.42 that do not photosynthesise.

Glucose is used by cells for respiration. Plants cannot make glucose at night so it is converted into insoluble starch for when it is needed. Starch is the main energy store in plants. It is found in every cell, where it is used for respiration in low light levels or the dark.

Plant cells respire sugars to provide energy, and produce carbon dioxide and water. The energy released is used for chemical reactions in cells, for example:

- building glucose into starch for storage
- building sugars into cellulose for cell walls
- combining sugars with nitrate ions and other minerals to make amino acids for protein synthesis
- building fats and oils for storage.

3 **When and why do plants respire?**

4 **List five ways that plants use glucose.**

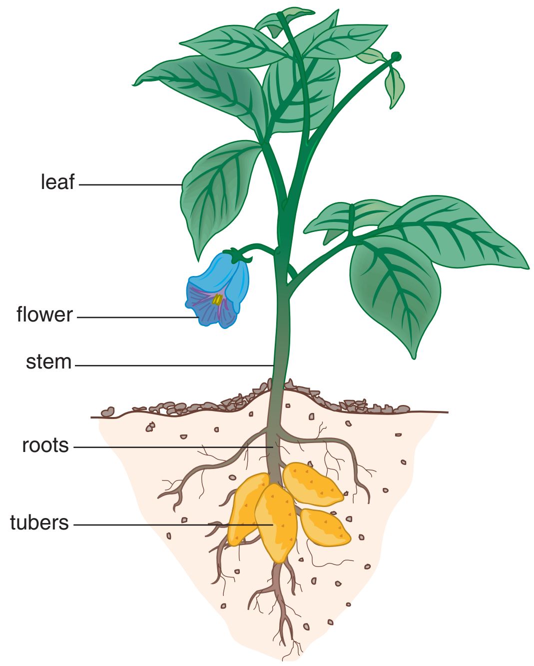

Figure 1.42 Why do plant organs need glucose?

Oxygen is a waste product of photosynthesis. When plant cells respire they use some of this oxygen. Plants respire continually because they need a constant supply of energy to keep them alive.

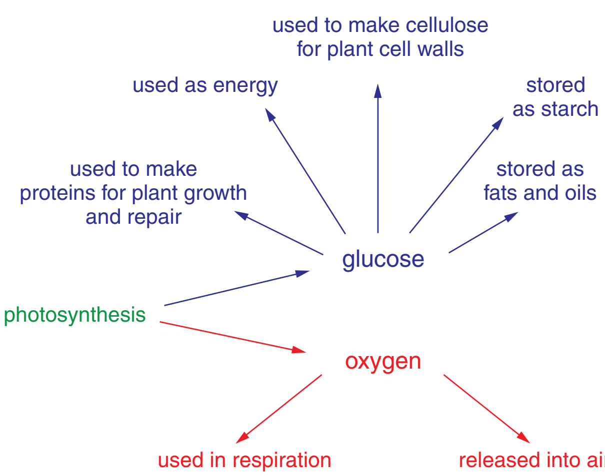

Figure 1.44 How plants use the products of photosynthesis

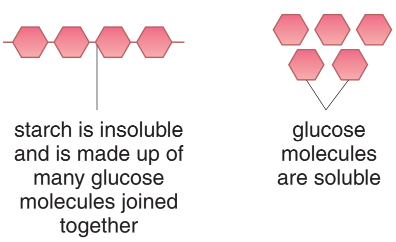

Figure 1.43 Starch is a large molecule and glucose is a small molecule

The rest of the oxygen is released through the stomata, back into the air.

DID YOU KNOW?

Some sea slugs eat algae but do not digest it fully. The algae photosynthesise inside the slugs to give them more food and energy.

5 **Explain the relationship between photosynthesis and respiration in leaves.**

6 **Explain what is incorrect about the statement 'plants make oxygen for us to breathe'?**

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Explaining photosynthesis

Learning objectives:

- identify the reactants and products of photosynthesis
- describe photosynthesis by an equation
- explain gaseous exchange in leaves.

KEY WORDS

chlorophyll
carbohydrate

Plants and algae are amazing organisms. They transfer energy from outer space into chemical energy in glucose. Without plants, there would be no life! How do plants harness this energy?

Describing the process

Photosynthesis is the chemical reaction that plants use to produce glucose, so essentially they are able to make their own food. Photosynthesis needs two raw materials. These reactants are:

- carbon dioxide (absorbed through leaves)
- water (absorbed through roots and transported to leaves).

The reaction also needs light and **chlorophyll** in the leaves. The equation is:

$$\text{carbon dioxide} + \text{water} \xrightarrow{\text{light + chlorophyll}} \text{glucose} + \text{oxygen}$$

$$CO_2 \quad H_2O \quad \rightarrow \quad C_6H_{12}O_6 \quad O_2$$

This is an endothermic reaction. It requires energy in the form of light.

The products of photosynthesis are **carbohydrates**, for example glucose and starch. When iodine is added to a leaf, it will turn blue/black if starch is present. If starch is present, it shows that photosynthesis has happened.

DID YOU KNOW?

Some leaves have green parts and yellow/white parts. They are called variegated leaves. Variegated leaves only photosynthesise in the green parts where the chlorophyll is found.

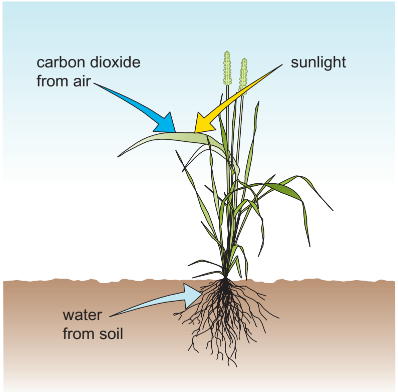

Figure 1.44 A plant needs light, water and carbon dioxide for photosynthesis

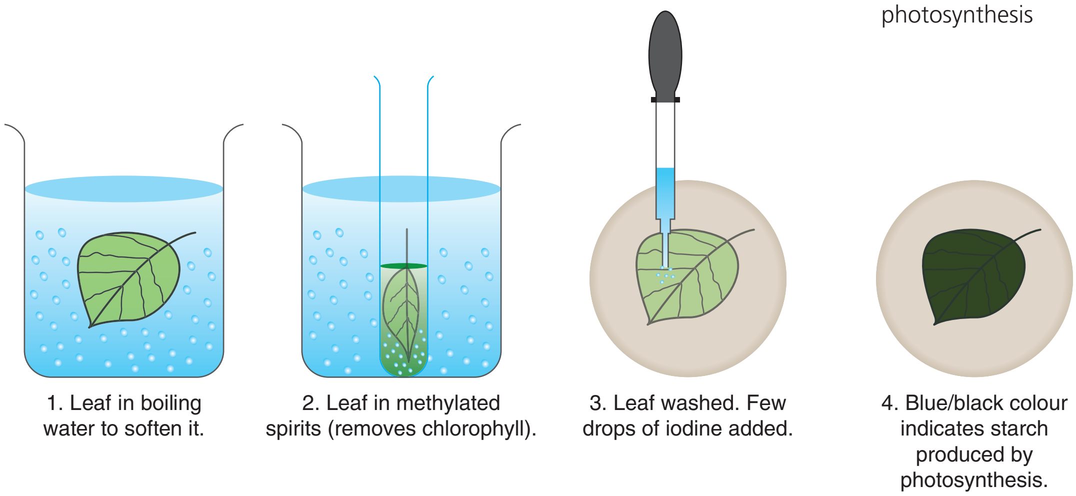

Figure 1.45 Testing a leaf for starch

Oxygen is made during photosynthesis and released into the air. It is a waste product on which animals depend.

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1 **Which raw materials (or reactants) are used in photosynthesis and what are the products of the reaction?**

2 **A leaf was tested for starch. The iodine stayed orange.**

a **What does this tell you about the leaf?**
b **What conditions was it kept in?**

Gaseous exchange in leaves

Leaves take in carbon dioxide from the air and release oxygen when they photosynthesise. This is called gaseous exchange.

Some students investigated gaseous exchange in leaves. They used the same size leaf in Tubes 1 and 2 and left them in a rack in bright light for an hour. Look at their method in the table.

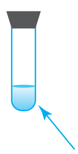
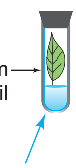
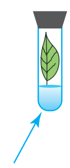
Tube	Control	Tube 1	Tube 2
Set up			
	2 cm^3 hydrogencarbonate indicator		
Results	no change in colour	turns yellow	turns red

Figure 1.46 Investigating gaseous exchange in leaves.

Hydrogencarbonate indicator is an orange solution.

- In more acidic conditions it turns yellow.
- In less acidic conditions it turns red.

Carbon dioxide dissolves in water to form an acidic solution.

3 **Describe the results of the investigation and explain why a control was used.**

4 **Explain what the results tell you.**

5 **Why are light and chlorophyll needed for photosynthesis?**

6 **Predict what would happen to the hydrogencarbonate indicator if you removed the aluminium foil? Explain your answer.**

REMEMBER!

Light does not make food, but light is needed for the reactions to occur.

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PRACTICAL

Investigate the effect of light intensity on the rate of photosynthesis using an aquatic organism such as pondweed

KEY WORDS

photosynthesis
hypothesis
chloroplasts
mesophyll cells

Learning objectives:

- use scientific ideas to develop a hypothesis
- use the correct sampling techniques to ensure that readings are representative
- present results in a graph.

Photosynthesis is the process by which green plants produce food. When plants photosynthesise they absorb light energy to power the reaction. The word equation for photosynthesis is:

$$\text{Carbon dioxide + water} \xrightarrow{\text{light energy}} \text{glucose + oxygen}$$

These pages are designed to help you think about aspects of the investigation rather than to guide you through it step by step.

Developing a hypothesis

Laura and Amy are investigating how light intensity affects the rate of **photosynthesis** in pondweed. They will measure how much gas is released by the pondweed in 1 minute when they put a lamp at 10cm, 15cm, 20cm, 25cm and 30cm away from the beaker containing the pondweed.

Before they begin the investigation they are going to make a **hypothesis**. Hypotheses are developed using previous knowledge or observations. Laura and Amy know that:

- photosynthesis produces glucose and oxygen
- the oxygen will be released as bubbles of gas in the water
- light energy is absorbed by chlorophyll found in the **chloroplasts** in the **mesophyll cells**
- photosynthesis can be limited by different factors.

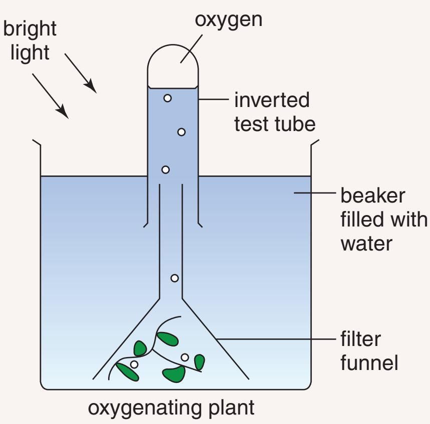

Figure 1.47 An oxygenating plant photosynthesising

1. **When will the light intensity be greatest?**
2. **How will increasing the light intensity affect the rate of photosynthesis?**
3. **When the rate of photosynthesis increases what will happen to the amount of oxygen produced?**

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4 **Could any other variable affect this investigation?**

5 **Suggest a hypothesis for the investigation that Laura and Amy are going to do.**

Planning your sampling

Amy and Laura decided that they would make their sampling representative by taking repeat readings at each light intensity. Look at their results.

Distance of lamp from pondweed (cm)	Number of bubbles per minute		
	Test 1	Test 2	Test 3
10	102	114	116
15	95	91	90
20	88	80	78
25	74	70	73
30	66	56	55

6 **What do you notice about the results in Test 1 compared to the results in tests 2 and 3?**

7 **Suggest why this happened.**

8 **Suggest what Laura and Amy should do with the Test 1 results.**

9 **Why is it important to take repeat readings when carrying out investigations?**

Presenting results

Amy and Laura used a table to record their results because it was quick and the results were organised, but they found it hard to analyse them in this form. Their teacher said that they should think of a better way to present their results to help them. Laura thought that using a bar chart would be the best method but Amy disagreed. She presented her results as a line graph.

10 **Which would be the best way to present these results? Explain why.**

11 **Plot the graph of Amy and Laura's results using only Test 2 and 3 data.**

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Increasing photosynthesis

Learning objectives:

- identify factors that affect the rate of photosynthesis
- interpret data about the rate of photosynthesis
- explain the interaction of factors in limiting the rate of photosynthesis.

KEY WORDS

limiting factor
tundra

Plants grow faster in summer than in winter. This means that they must produce more food to allow them to grow in summer. Some factors can increase the rate of photosynthesis.

Plants in different habitats

Plants are found in every ecosystem, but their size, appearance and adaptations mean that they look very different. Tropical rainforests have dense plant life. In contrast, few plant species grow in **tundra** (Arctic regions with permanently frozen subsoil) and desert regions.

Figure 1.48 What are the environmental conditions of these habitats?

1. **How would you describe environmental conditions in tropical forest, tundra and desert ecosystems?**
2. **Suggest how the conditions you have described affect photosynthesis in each habitat.**

Limiting factors

Some students investigated the effect of light on the rate of photosynthesis. Look at their results (Figure 1.49). The students found that:

- Between A and B, the rate of photosynthesis increases as the light intensity increases. Because the rate depends on the light intensity, light intensity is called the **limiting factor**.
- Between B and C, increasing the light intensity has no effect on the rate of photosynthesis. Another factor is now the limiting factor.

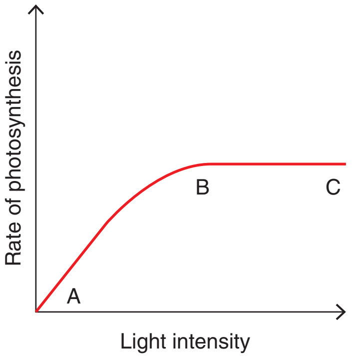

Figure 1.49 Can you explain the shape of the graph between B and C?

KEY INFORMATION

Remember that enzymes denature at temperatures greater than 40°C.

3 **What other factors might limit the rate of photosynthesis between B and C?**

Plants need carbon dioxide to photosynthesise but there is only 0.04% in the atmosphere. It is often the limiting factor controlling the rate of photosynthesis.

Carbon dioxide levels around plants rise when there is no light. This is because the plants are respiring but not photosynthesising. As light levels increase the plants use the carbon dioxide up.

Interacting limiting factors

Over one day, light, temperature and carbon dioxide levels change. Carbon dioxide may be the limiting factor when plants are crowded on a sunny day. Temperature may be the limiting factor in cooler months. Light may be the limiting factor at dawn.

Plants living in continual shade can adapt. They have a higher ratio of leaves to roots than other plants. The leaves are thinner, have a larger surface area and contain more chlorophyll to absorb light. A shortage of chlorophyll can limit the rate of photosynthesis.

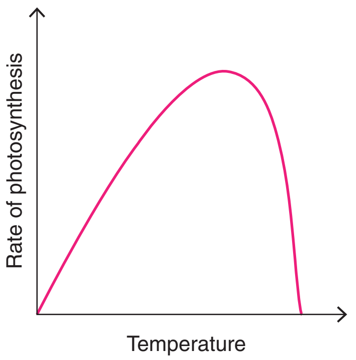

Figure 1.50 Explain what this graph shows

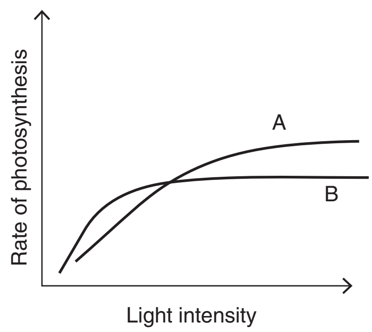

Figure 1.51 Photosynthesis in normal (A) and shade-adapted (B) leaves

The graph shows that shade-adapted leaves (B) are more efficient at absorbing low intensity light than normal leaves (A).

4 **Suggest the limiting factors for photosynthesis over one complete warm summer's day.**

5 **Describe and explain adaptations for photosynthesis shown by some shade-tolerant plants.**

6 **Suggest an advantage of a tree having needles rather than flat, broad leaves.**

DID YOU KNOW?

Pine trees grow in a cone shape to expose more needles to the sun, increasing the rate of photosynthesis.

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MATHS SKILLS

Surface area to volume ratio

Learning objectives:

- be able to calculate surface area and volume
- be able to calculate surface area to volume ratio
- know how to apply ideas about surface area and volume.

KEY WORDS

ratio
sphere

In science, we use mathematical skills to help us understand what is happening. Surface area to volume ratio is very important in living things.

Finding the area of a surface

Alveoli provide a large surface area for gas exchange between the air and the bloodstream. If our lungs were smooth on the inside, like balloons, the surface area would be much less and materials would not be exchanged fast enough.

We can calculate surface area in different ways. For a rectangular shape, we multiply the length by the width. For example, an area of skin 4 cm long and 7 cm wide has a surface area of (4 × 7) = 28 cm^2.

Living things are not generally made up of regular shapes, such as rectangles, so we have to use other ways of finding the area. One way is to use squared paper and to count how many squares are covered (or are largely covered) by the specimen.

Figure 2.35 Elephants have wrinkled skin to increase their surface area.

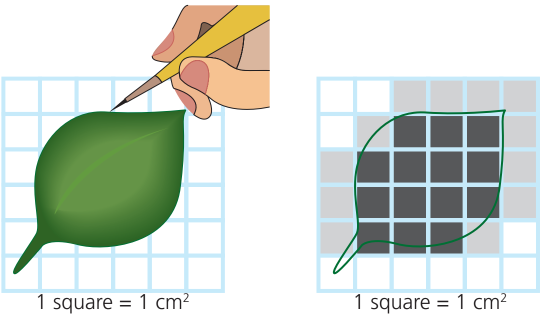

Figure 2.36 Counting squares that are largely covered is (approximately) balanced by not counting squares that are slightly covered.

KEY INFORMATION

Note that both the length and the width have to be measured in the same units and that the answer is in those units, squared.

1. **Estimate the surface area of the leaf in Figure 2.37.**
2. **Calculate the surface area of:**
   a) a piece of tree bark that is 30 cm long and 3 cm wide
   b) a razor shell that is 50 mm long and 8 mm wide.

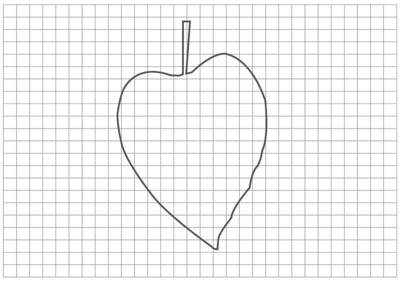

Figure 2.37 One square is 1 cm^2.

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Working out the volume

It is easier for warm-blooded animals to keep warm on cold days if their volume is large, but then it is harder for these same animals to lose heat on a hot day. We calculate the volume of a cube by multiplying length by width by height. A die with a side of 2 cm has a volume of (2 cm × 2 cm × 2 cm) = 8 cm^3. Again, all the distances need to be in the same units and the volume is also in those units, cubed.

3 What is the volume of:
a) a science laboratory 10 m wide, 15 m long and 3 m high?
b) a block of wood 2 cm wide, 3 cm long and 4 cm high?

4 Finding the volume of a tree branch is tricky, but one way is to immerse the branch in a tank full of water. Suggest how the volume is measured.

Surface area to volume ratio

In science it is useful to compare the surface area with the volume. We do this by finding the ratio of one compared with the other. To find the ratio, divide the surface area by the volume. For example, for a cube with sides 2 cm long:

surface area = 2 × 2 × 6 = 24 cm^2;
volume = 2 × 2 × 2 = 8 cm^3;
surface area to volume ratio = 24:8 = 3:1

The shape of an organism also affects its surface area to volume ratio. Spheres have the smallest surface area compared with their volumes. Many small mammals have a shape that is almost spherical – for example, a mouse – and puppies and kittens curl up into a ball to sleep. As small animals, they want to minimise their surface area to volume ratio so as to minimise heat loss.

5 Compare how surface area, volume, and surface area to volume ratio change as the size of a cube increases. Use cubes with sides of 1, 2, 3, 4, 6 and 8 cm.

6 Imagine the shapes below are animals. Look at A, B and C in Figure 2.38.

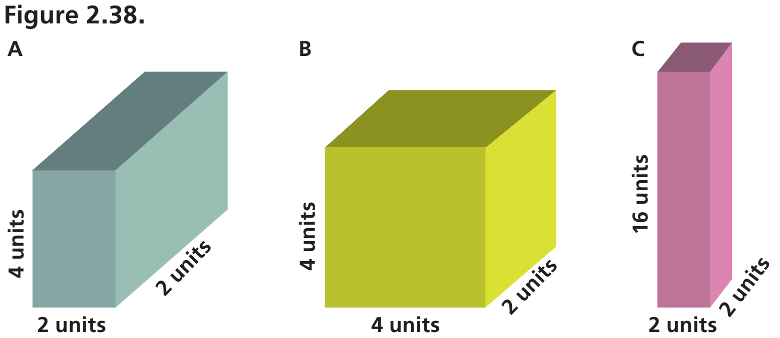

Figure 2.38 What do you notice about the surface area to volume ratios of these 'animals'?

Which animal will have problems keeping:
a) cool? Explain your answer.
b) warm? Explain your answer.

7 Devise a method to measure the volume of the air you breathe out in one breath.

DID YOU KNOW?

Arctic foxes have much smaller ears than desert-dwelling fennec foxes. Arctic foxes must reduce heat loss but fennec foxes must increase heat loss to their environment.

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Check your progress

You should be able to:

calculate magnification used by a light microscope using eyepiece and objective lens magnifications →	calculate the magnification of a light or electron micrograph →	explain limitations of light microscopy and advantages of electron microscopy
describe the structure of a prokaryotic cell →	describe the differences between eukaryotic and prokaryotic cells →	explain why scientists have now separated organisms into three domains using evidence from chemical analysis
describe the structure of DNA as repeating units called nucleotides arranged in a double helix →	describe the structure of nucleotides as a sugar molecule, phosphate groups and bases →	explain that strands of DNA are complementary
identify how a gene works in coding for the production of a protein →	describe how a gene controls the order of amino acids in a protein →	describe in outline how a protein is synthesised
know that enzymes catalyse reactions in cells →	describe how pH and temperature affect enzymes →	explain how pH and temperature affect enzyme activity
understand that substrate molecules fit into active sites of enzymes →	describe the lock and key theory →	use collision theory to explain enzyme action
recall that organisms can respire with oxygen (aerobic respiration) or without oxygen (anaerobic respiration) →	use word equations to describe the processes of aerobic and anaerobic respiration →	use symbol equations for aerobic and anaerobic respiration and be able to compare the two processes
use the word equation to describe photosynthesis →	recall and use the symbol equation for photosynthesis →	recall and use the balanced symbol equation for photosynthesis
know that chloroplasts absorb light and convert it to chemical energy →	describe the use of light and chloroplasts in photosynthesis →	explain that chloroplasts absorb energy to drive chemical reactions
name the factors that affect photosynthesis →	describe how the rate of photosynthesis can be increased →	explain the effects of limiting factors on photosynthesis
identify the parts of a leaf and their function →	describe how leaves are adapted for efficient photosynthesis →	explain how the leaf's structure is adapted for photosynthesis
explain what a trophic level is →	construct food chains →	construct accurate pyramids of biomass

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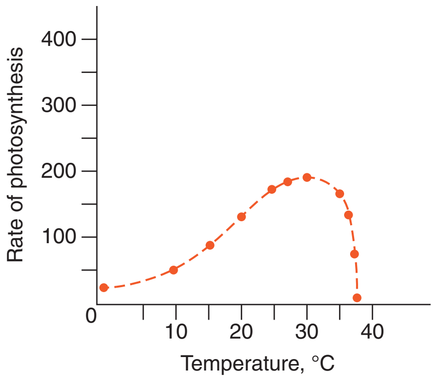
Worked example

Laura is growing tomatoes in her greenhouse.

Laura knows that to increase her crop of tomatoes, she must increase photosynthesis.

1 **Laura heats her greenhouse. She wants to know the best temperature to grow the tomatoes in. Look at the graph.**



Explain what the graph shows

The rate increases from 5-30°C and then decreases to 0 at 37°C because the enzymes denature

2 **What is the best temperature for Laura to grow the tomatoes?**

30°C

How does water for photosynthesis get to the leaves?

Through the xylem by osmosis.

3 **Laura notices that when she turns the heaters up, she needs to water the plants more often. Explain why.**

More water evaporates

4 **Complete the equation for photosynthesis**

$6CO_2 + H_2O \rightarrow C_6H_{12}O_6 + H_2O$

The pattern has been given (increases and then decreases) and the explanation for the decrease in rate is correct.

A better answer would be to explain that the rate increases from 5–30°C as the enzymes gain more energy or collide more often.

Correct answer given.

One correct answer is given (xylem).

A better answer would be '…by transpiration'.

One correct answer is given

A better answer would be: Transpiration increases because more water evaporates through the stomata.

More detailed responses would give a higher mark.

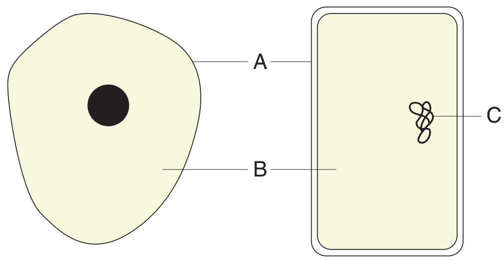
Water (H_2O) has been correctly identified as a reactant, but has also been given as the product. The equation has not been balanced. The correct answer is:

$6CO_2 + H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

End of chapter questions

Getting started

1 **The diagrams below show an animal cell and a bacterial cell.**



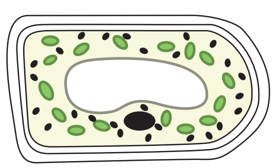
i **Parts of the cell A and B are found in both animal cells and bacterial cells. Name cell parts A and B.** — 1 Mark

a cell membrane
b cell wall
c cytoplasm
d nucleus
e vacuole

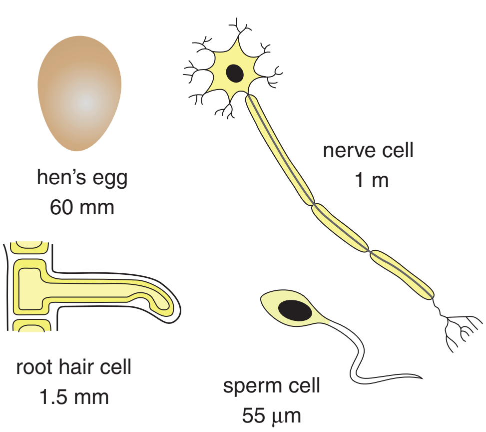
ii **What is the name of chemical C?** — 1 Mark

a cellulose
b chlorophyll
c DNA
d protein

2 **Explain how you know that the cell shown is a plant cell.** — 2 Marks



3 **The diagrams below show some different cells. The length of each is included on the diagram. Arrange them in order of size.** — 1 Mark

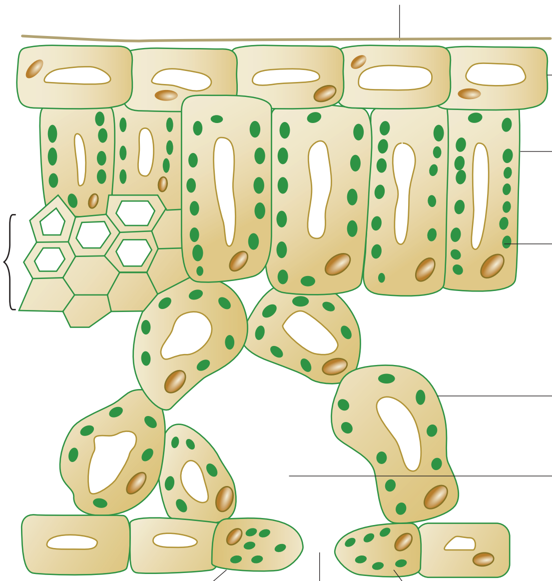


4 **a** **Why do plants photosynthesise?** — 1 Mark

b **What structures inside plant cells absorb energy from light?** — 1 Mark

c **What is the name of the solution used to test leaves for starch?** — 1 Mark

d **A palisade cell measures 60 micrometers in width. What is this in millimeters?** 1 Mark



5 **The table below shows energy released by respiration. Calculate how much energy would be released from 30 grams of glucose during aerobic respiration.** 1 Mark

Type of respiration	Energy released (KJ) per gram of glucose
aerobic	16.1
anaerobic	0.8

Going further

6 **Draw lines to match the two cell structures with their function.** 1 Mark

Cell structure	**Function**
Mitochondrion	Controls what enters and leaves cells
Ribosome	Respiration
	Protein synthesis

7 **Use words from the box to complete the word equation for aerobic respiration.** 1 Mark

alcohol	carbon dioxide	glucose	lactic acid

……………... + oxygen → ……………... + water (+energy)

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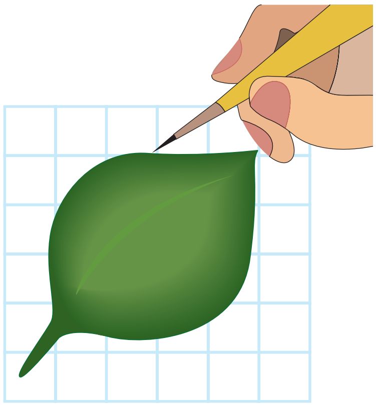
Draft specification subject to Ofqual feedback and accreditation

8 Jenna is investigating the effect of light on leaf growth. To do this she needs to calculate the surface area of each leaf.

a Estimate the surface area of this leaf: 1 Mark



1 square = 1 cm^2

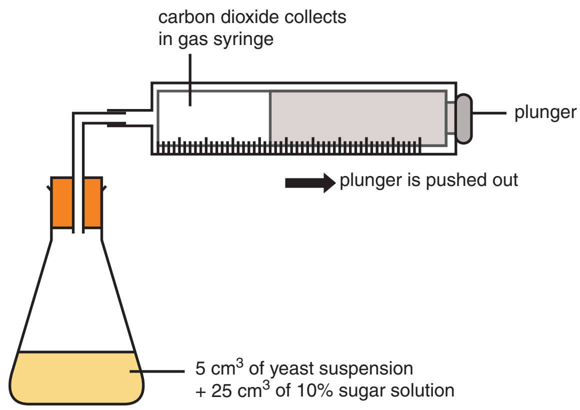
Jenna's results are shown below:

Leaf	South facing tree (most sun)	North facing tree (most shade)
	Area (cm^3)	
1	14.0	29.0
2	18.0	19.5
3	13.5	28.0
4	21.5	29.5
5	15.5	23.0
Mean	16.5	

b Calculate the mean area for the north facing tree 1 Mark

c Explain the difference in the results 2 Marks

9 A scientist is investigating the effect of different sugars on the anaerobic respiration of yeast.
She measures the volume of carbon dioxide produced over a 2-hour period.
She investigates two types of sugar, sucrose and lactose.



a Suggest ways in which she can be sure that the readings she takes are the result of using the two different types of sugar and not from other factors. 2 Marks b Her results are shown below. 2 Marks

Type of sugar	Volume of carbon dioxide produced (cm^3)						
	Time (min)						
	0	20	40	60	80	100	120
sucrose	0	0.2	1.8	5.6	7.6	7.9	7.9
lactose	0	0	0	0	0	0	0

Suggest reasons for the scientist's results.

10 What is a trophic level? 1 Mark

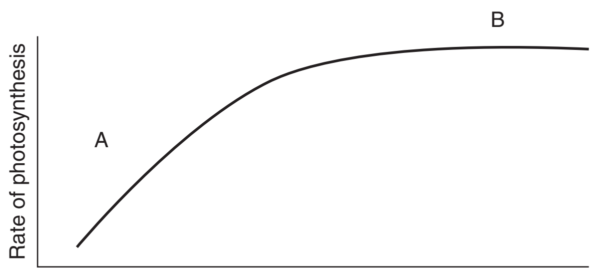
More challenging

11 Some students investigated how light intensity affects the rate of photosynthesis. The graph shows their results.

a Describe the pattern show by the graph 2 Marks

b Explain what is happening at A and B 2 Marks

c Predict what would happen if the temperature was increased from 25°C to 35°C. Give reasons for your prediction. 2 Marks



d Describe how you could measure the effect of light intensity on the rate of photosynthesis in pondweed. Draw a diagram to show what equipment you would need and how you would set it up. 4 Marks

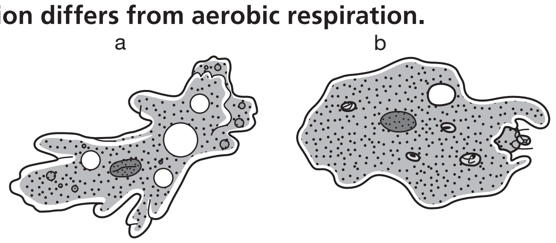
Most demanding

e Carbon dioxide, needed for photosynthesis moves into the leaf by diffusion. Suggest and explain 2 ways in which the structure of the leaf allows carbon dioxide to diffuse to the cells that require it 4 Marks

12 Explain how anaerobic respiration differs from aerobic respiration. 2 Marks

13 Which organism can absorb nutrients quicker?

Explain your answer. 2 Marks



14 What is the disadvantage of having a large volume compared to surface area? 2 Marks

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