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REVISE BTEC NATIONAL Applied Science REVISION GUIDE

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REVISE BTEC NATIONAL
Applied Science

REVISION GUIDE

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Introduction

Which units should you revise?

This Revision Guide has been designed to support you in preparing for the externally assessed units of your course. Remember that you won't necessarily be studying all the units included here – it will depend on the qualification you are taking.

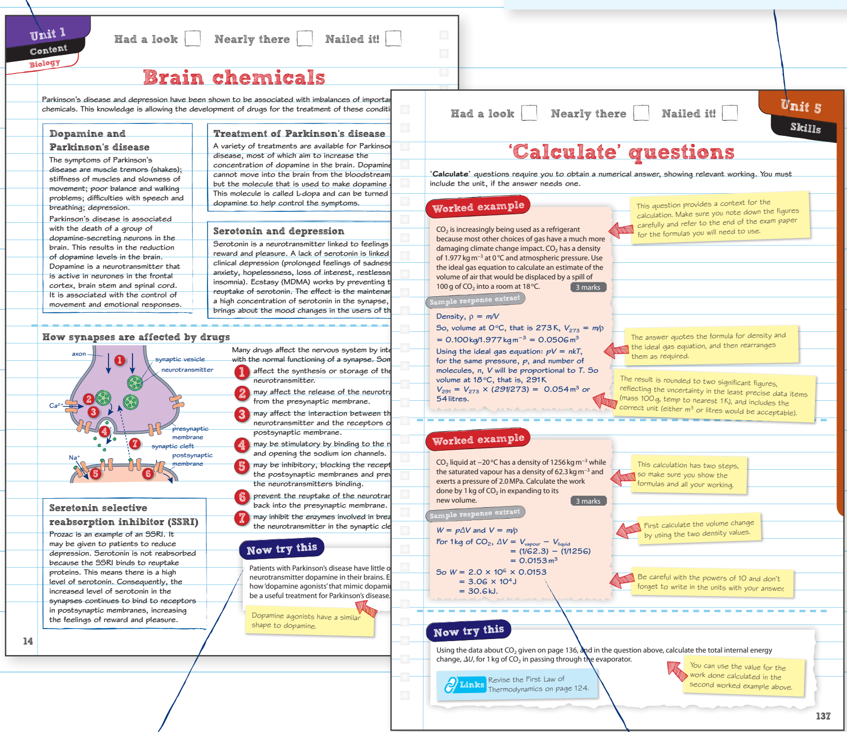
BTEC National Qualification	Externally assessed units
Certificate	1 Principles and Applications of Science I
For both: Extended certificate Foundation diploma	1 Principles and Applications of Science I 3 Science Investigation Skills
Diploma	1 Principles and Applications of Science I 3 Science Investigation Skills 5 Principles and Applications of Science II
Extended diploma	1 Principles and Applications of Science I 3 Science Investigation Skills 5 Principles and Applications of Science II 7 Contemporary Issues in Science

Your Revision Guide

Each unit in this Revision Guide contains two types of pages, shown below.

Content **pages** help you revise the essential content you need to know for each unit.

Skills **pages** help you prepare for your exam or assessed task. Skills pages have a coloured edge and are shaded in the table of contents.



Use the **Now try this** activities on every page to help you test your knowledge and practise the relevant skills.

Look out for the **sample response extracts** to revision questions or tasks on the skills pages. Post-its will explain their strengths and weaknesses.

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Contents

Workbook also available for externally assessed units ISBN 9781292150031

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Unit 7 Contemporary Issues in Science

A small bit of small print
Pearson publishes Sample Assessment Material (SAMs) and the Specification on its website. This is the official content and this book should be used in conjunction with it. The questions in *Now try this* have been written to help you test your knowledge and skills. Remember: the real assessment may not look like this.

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Cells and microscopy

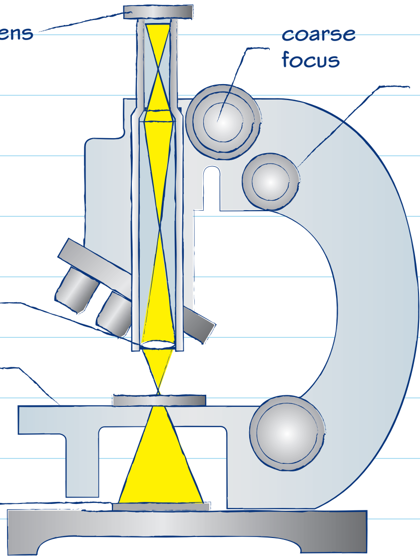
All living things are made of cells. Cells are the basic units of life and all cells come from other cells. **Microscopes** magnify images so it is easier to see cells and their structures more clearly.

The light microscope

Magnification is an important property of microscopes. The magnification is calculated as follows:

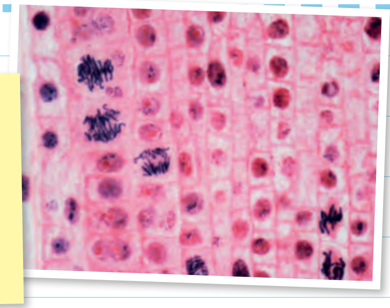
Total magnification = magnification of eyepiece lens × magnification of objective lens.

The eyepiece lens usually has a ×10 magnification and the greatest magnification of the objective lens is usually ×100. So the greatest total magnification is usually ×1000.



The specimen

The material to be viewed on the slide or specimen needs to be **thin**, so that light or an electron beam can pass through it. A **coverslip** is needed to protect the specimen and also the lens if they should touch. **Stains** can help to distinguish different features in the specimen.



Light micrograph of onion root tip cells, undergoing mitosis (nuclear division). Magnification ×300. Compare the detail of this image to the one below taken with an electron microscope.

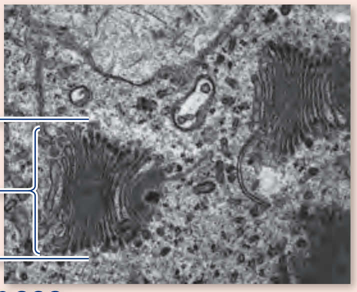
Electron microscopes

Electron microscopes were invented in the middle of the twentieth century and have a far greater magnification. However, you can only examine dead material with an electron microscope.

Worked example

The photograph shows an electron micrograph of part of a cell.

Calculate the width of P at its widest part (between A and B). **3 marks**



x16 000

Sample response extract

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

$$\text{so } 16\,000 = \frac{20\,\text{mm (1)}}{\text{size of real object}}$$

$$\text{rearrange, so width of P} = \frac{20\,\text{mm (1)}}{16\,000\text{mm (1)}}$$

$$= 0.001\,25\,\text{mm (1)}$$

Take care with the very small numbers. Remember $1\,\mu\text{m} = 0.000\,001\,\text{m} = 1 \times 10^{-6}\,\text{m} = 0.001\,\text{mm} = 1 \times 10^{-3}\,\text{mm}$. So the above answer is also $1.25\,\mu\text{m}$.

Now try this

A structure viewed under a light microscope with a magnification of ×400 is measured using a scale in the eyepiece. Each division in the scale is equal to 0.06 mm. The structure measures 7 divisions.

Calculate the real length of the structure.

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Cells

All living organisms are made of cells, which share some common features. They all contain **DNA**, **cytoplasm**, **ribosomes** and have **plasma**. However, some of these structures differ in prokaryote and eukaryote cells.

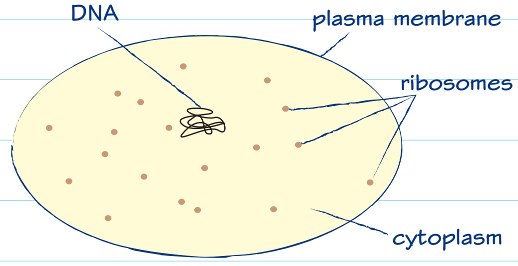
Cells are tiny!

It was not realised that living things are made from cells until Robert Hooke invented the microscope in 1665 and saw cells for the first time in tiny slivers of cork.

Light microscopes are very limited as to what they can allow us to see inside cells, because the wavelength of light is the limiting factor.

Electron beams have a much shorter wavelength than beams of light and allow much more detail to be seen through an electron microscope. However, electron microscopes can allow only dead material to be examined.

Structures seen with a light microscope



All cells have the four features shown, although they are not always the same, for example bacterial cells have 70S ribosomes, whilst plant and animal cells have 80S ribosomes.

Structures seen with an electron microscope (ultrastructure)

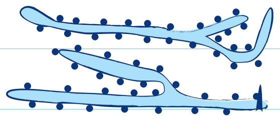
Eukaryotic cells contain **organelles**, which are structures in cells with specialised functions often bound by a membrane. Only the plasma membrane, nucleus and nucleolus are visible under the light microscope.

plasma membrane
- protects cell from its surroundings
- regulates movement of substances in and out of cells

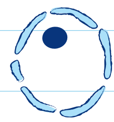
vesicle
- small, membrane-bound sac
- transports and stores substances in the cell

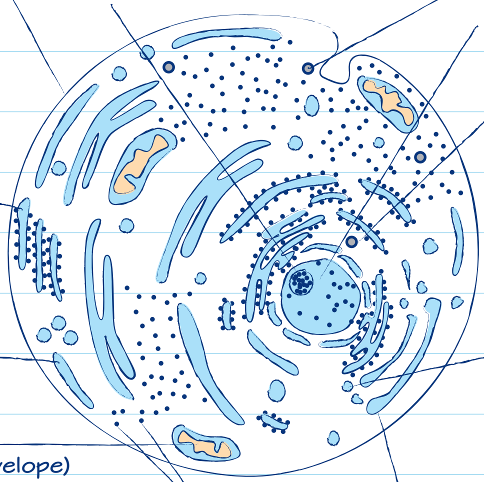
nucleolus
- region of dense DNA and protein
- makes ribosomes

rER (rough endoplasmic reticulum)
- a series of single, flattened sacs enclosed by a membrane
- has ribosomes on the surface
- proteins made here

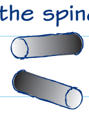


nucleus
- surrounded by a double membrane (envelope)
- pores (holes) in the nuclear envelope

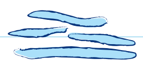




centrioles
- two hollow cylinders
- arranged at right-angles to each other
- makes the spindle in cell division



sER (smooth endoplasmic reticulum)
- a series of single, tubular sacs made of membrane
- lipids made here

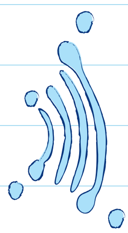


lysosome
- enclosed by a single membrane
- containing digestive enzymes
- destroys old organelles and pathogens

mitochondrion
- surrounded by a double membrane (envelope)
- inner membrane folded into finger-like projections called cristae (singular, crista)
- central area contains a jelly called the matrix
- containing 70S ribosomes and DNA
- site of respiration

80S ribosomes
site of protein synthesis, contrast with 70S in prokaryotes

Golgi apparatus
- a series of single, curved sacs enclosed by a membrane
- many vesicles cluster around the Golgi apparatus
- modifies proteins and packages them in vesicles for transport



cytoplasm
- fluid that fills a cell
- many molecules dissolved in solution (enzymes, sugars, amino acids, fatty acids)
- site of many metabolic processes

Now try this

Make a table listing animal cell organelles not surrounded by a membrane, those surrounded by a single membrane and those surrounded by a double membrane.

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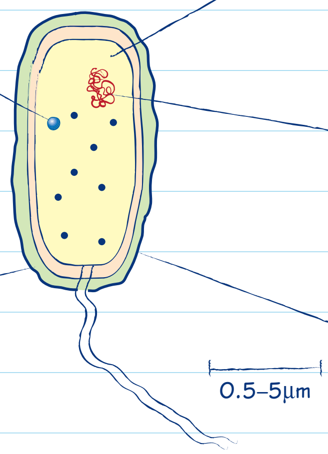
Prokaryotes

Bacteria are **prokaryotes**, made of a single cell with no membrane-bound organelles.

Bacteria cell structure

Plasmids
- ✓ double-stranded DNA in a circular structure
- ✓ often contain additional genes that aid the bacterium's survival, such as antibiotic resistance or toxin producing genes.

Ribosome
- ✓ makes proteins
- ✓ 70S (S is a Svedberg, a measure of size by rate of sedimentation)



Nucleoid
- ✓ region where single circular, length of DNA, is folded.
- ✓ DNA carries all essential information.

Capsule
- ✓ polysaccharide layer outside the cell wall
- ✓ protects cells from drying out, being engulfed by, for example, white blood cells
- ✓ helps cells to stick to surfaces.

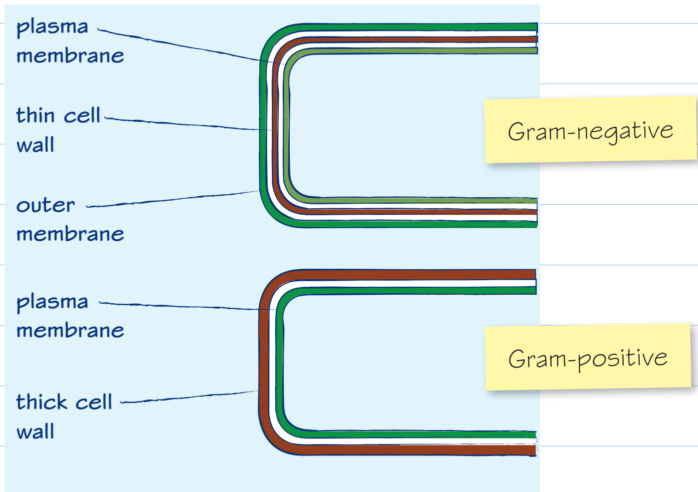
Cell wall
- ✓ made of long-chained molecule made up of a sugar and amino acids called peptidoglycan.

Gram-negative and gram-positive bacteria

Gram-negative bacteria **do not** retain the gram stain (crystal violet) when washed with acetone and absolute alcohol because their cell wall has an outer layer.

Gram-positive bacteria **do** retain the gram stain because the thick peptidoglycan wall absorbs the stain and they do not have an outer wall.

Gram-negative bacteria are more resistant to antibiotics than gram-positive bacteria. This is because gram-negative bacteria have a cell wall with an outer membrane, which protects them from the antibiotic.



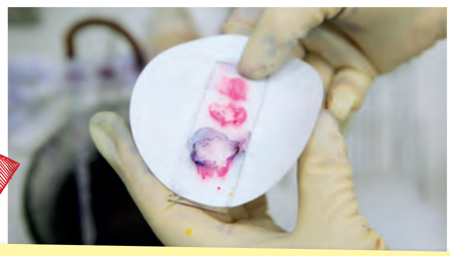
Now try this

The photograph shows a technician testing a swab from meat for bacteria.

1 Examine the photograph and state what the results show.

2 Explain why some bacteria stained purple.

Another stain, usually safranin, is also used at the same time. This stains the thin peptidoglycan cell wall red.



Most meat pathogens are gram-positive.

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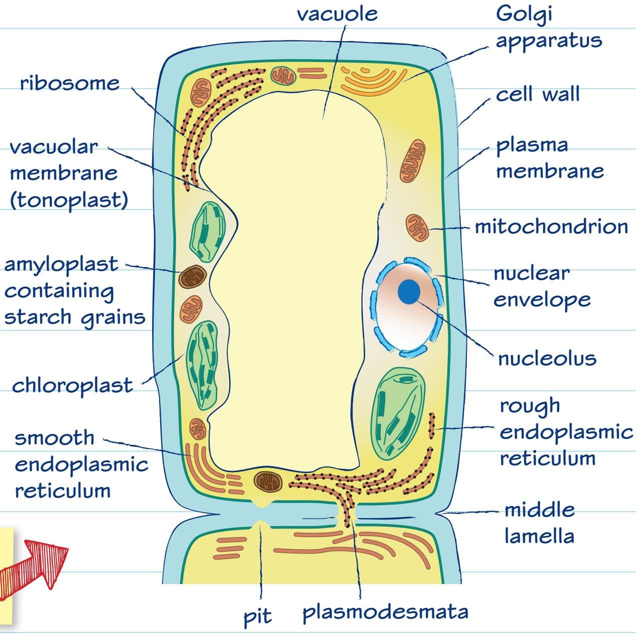
Plant cells

Plants are eukaryotes, but their cells differ from those of other eukaryotes, such as animals.

The more complex plant cell

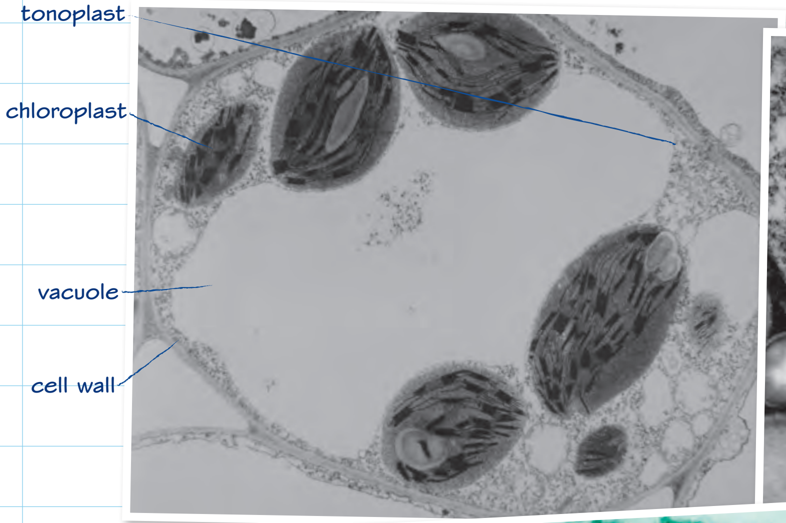
Plant cells include all the structures (except centrioles) that are in animal cells, **as well as**:

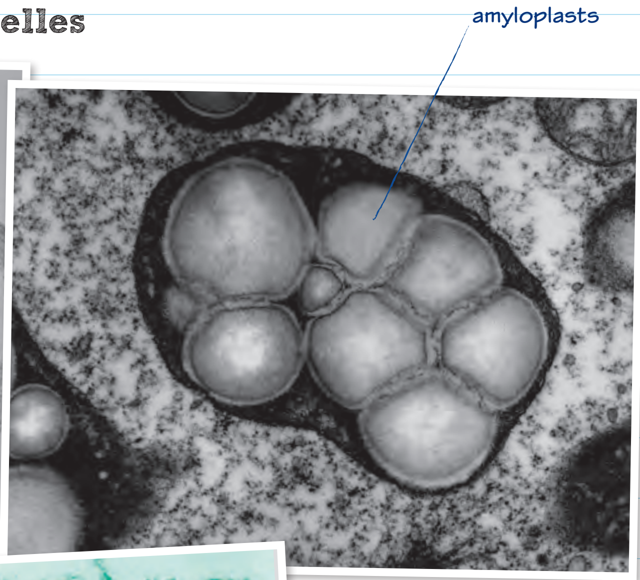
- **chloroplasts** (for photosynthesis)
- a **vacuole** stores water and other substances
- a **tonoplast membrane** controls movement of molecules into and out of the vacuole
- a **cell wall** (for support and protection)
- **amyloplasts** to store starch
- **middle lamella** to stick cells together
- **plasmodesmata** and **pits** to allow communication between one cell and another.

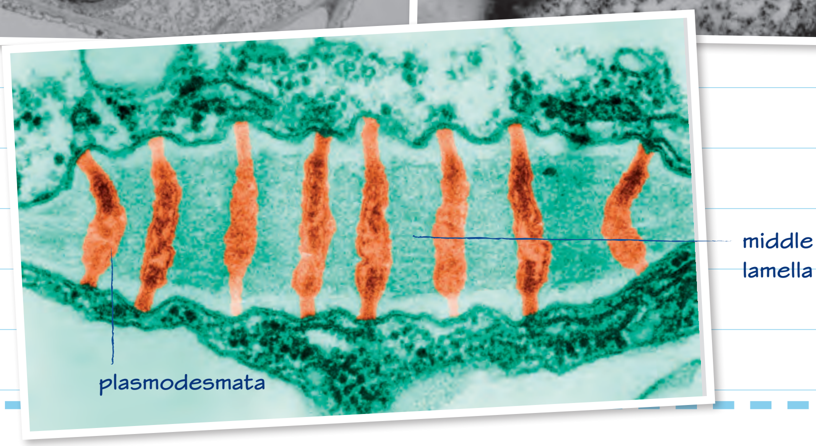


A generalised plant cell as seen through a low power electron microscope

Electron micrographs of the key organelles







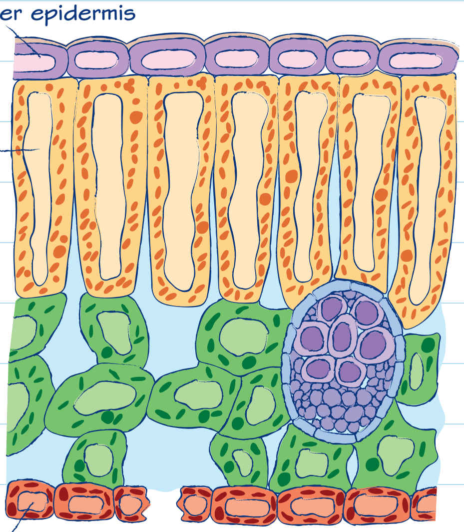
Now try this

Compare animal, plant and bacterial cells, making reference to cell wall, chloroplasts, nuclear membrane, cell membrane, ribosomes and centrioles.

A table would be a good way of doing this.

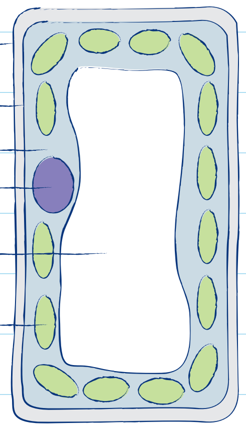
Specialised cells: Plant cells

The organs of the plant, for example, leaves and roots contain some cells that are specially **adapted** for their **function**.



Palisade cell

Palisade cells are **cylindrical shaped**, so they pack tightly in the upper part of a leaf.They contain many **chloroplasts** to capture as much energy from light as possible for photosynthesis. They have a **large vacuole**, which helps to keep the cell and leaf structure rigid.



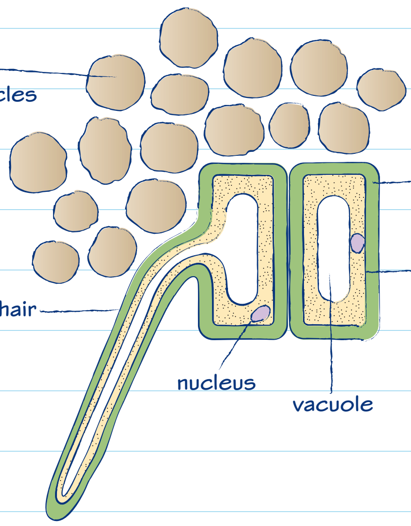
Root hair cell

Root hair cells are found in the **epithelium** (surface cells) near the root tip, where there is no thickening.

The hair is a fine protrusion from the cell out into the soil. This provides a **large surface area** to volume ratio to absorb water and dissolved minerals from the soil. The cells have a thin cell wall to make it easier for water absorption.

They contain many mitochondria to help supply energy for active transport of minerals from the soil into the cell.

Links See page 105 for information on active transport.



Now try this

1 Palisade mesophyll cells are found in leaf tissue. What is the main function of palisade mesophll cells?
- A To capture energy transferred by light
- B To provide water
- C To provide carbon dioxide
- D To make starch

2 Explain how root hair cells are adapted to their function.

In this question, you need to state the function and the adaptation, then link them.

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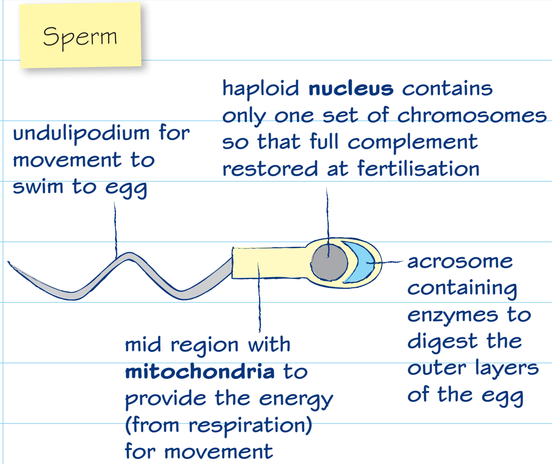
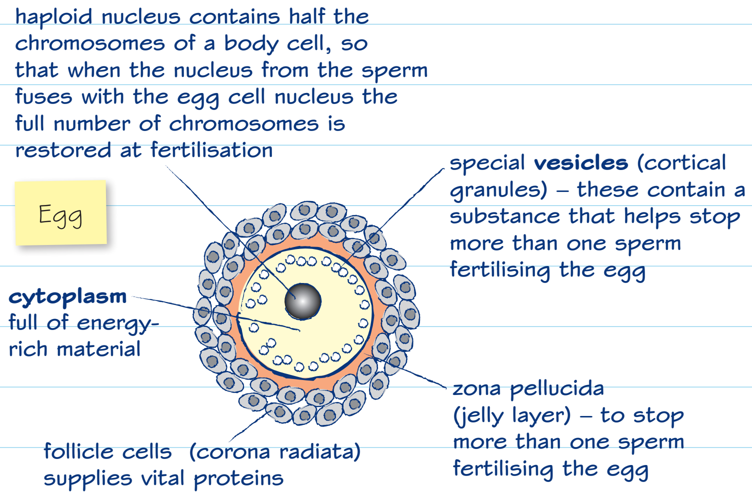
Had a look ☐ Nearly there ☐ Nailed it! ☐

Specialised cells: Animal cells

Mammalian **gametes** (the sperm and egg), and red and white **blood cells** are specialised for their functions.

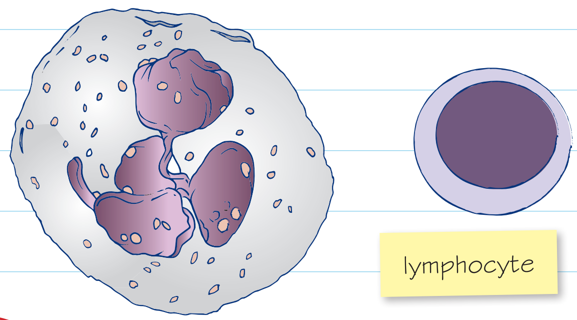
Structure and function in sperm and egg





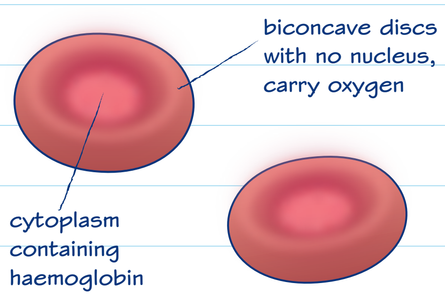
White blood cells

These blood cells have a large nucleus, often with protrusions, and are made in the bone marrow and lymph nodes. There are different types of white blood cell and their function is to fight pathogens. They can squeeze through capillary walls and are found in tissues as well as the blood. So they are able to move to sites of infection easily.



Phagocytes and lymphocytes are types of white blood cell.

Red blood cells



Mature red blood cells have no nucleus or other organelles, so there is room for more haemoglobin, which is the protein that carries oxygen.

They are small, round, biconcave discs. This optimises their **surface area to volume ratio**. This allows more oxygen and carbon dioxide to diffuse into the haemoglobin. Their size and shape also allow them to squeeze through narrow blood vessels.

Having no nucleus also means that they cannot divide, which is another difference between them and white blood cells. They are made in the bone marrow.

Now try this

Describe three structural differences between a human sperm cell and a human egg cell.

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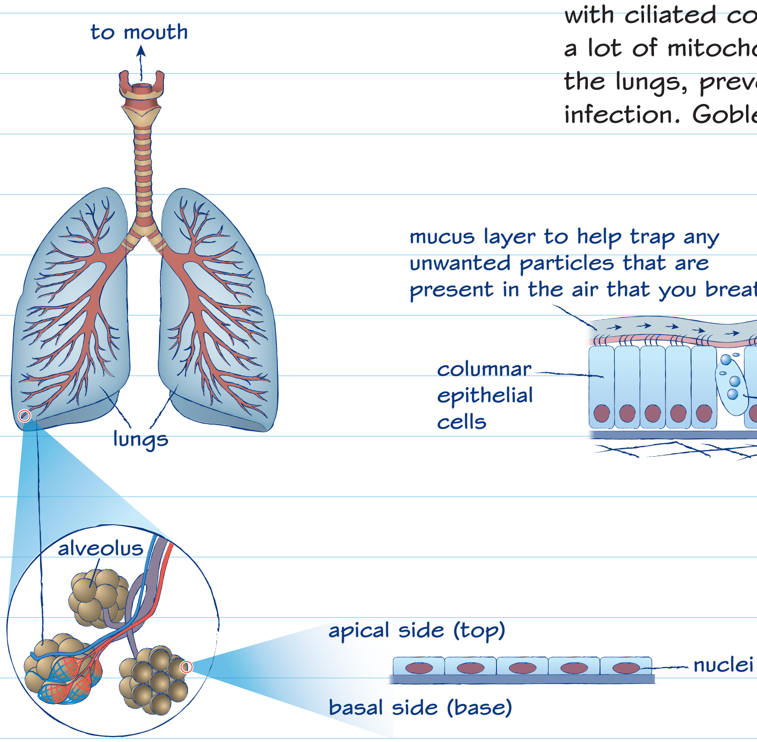
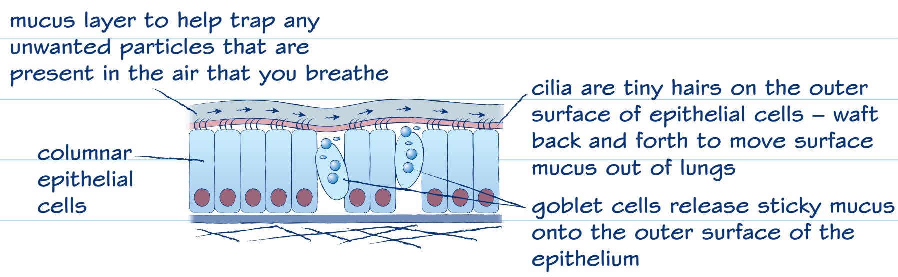
Epithelial tissue

Epithelial cells line any surface that is in contact with the external environment. They may also line the surface of internal organs, such as the lungs. In the lungs are two types of epithelial tissue: squamous epithelium and columnar epithelium.

Columnar epithelium

The upper airway (trachea and bronchi) is mainly lined with ciliated columnar epithelium cells. These cells have a lot of mitochondria. The cilia move mucus away from the lungs, preventing any inhaled particles causing infection. Goblet cells produce mucus.





Squamous epithelium

Very flat and thin with egg-shaped nuclei, often only one cell thick and very good for surfaces where diffusion occurs as in the lungs.

Chronic obstructive pulmonary disease (COPD)

COPD includes several conditions and is more common in smokers than non-smokers, because substances in smoke damage the lungs.

Cigarette smoke causes the cilia of columnar epithelium to slow and stop beating and eventually die off so mucus builds up. This clogs the airways and this causes more coughing that ruptures the thin alveolar epithelial cells (destroying them), reducing the surface area for gas exchange. This also provides a good environment for pathogens to grow.

Now try this

Explain why ciliated columnar cells contain many mitochondria.

Remind yourself about the function of mitochondria on page 3.

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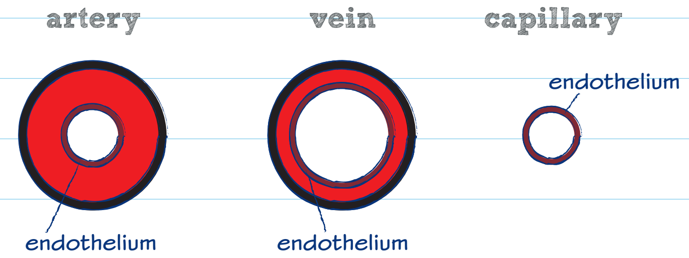
Blood vessels and atherosclerosis

Blood vessels are lined with **endothelial** tissue. Blood clots form when there is damage to tissue, if there is damage to an artery and a clot forms this can cause a number of health-related problems.

Endothelial tissue in blood vessels

Endothelial tissue lines the inside of blood vessels. It is made up of a single layer of flat, long cells, which are orientated lengthways in the direction of blood flow. Their function is to provide a smooth surface so that blood flows easily over them.

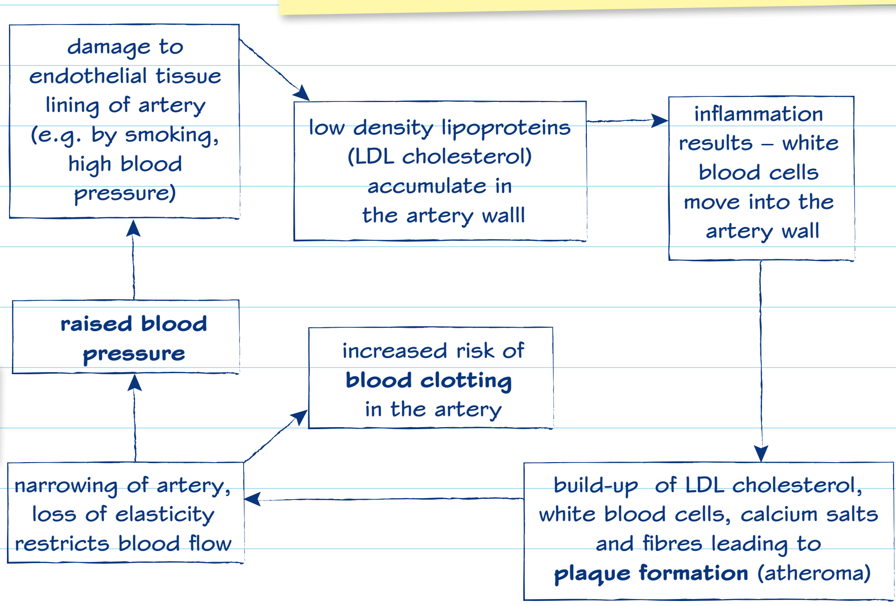


Arteries and veins are made of the same tissues but in different proportions. They both have an outer layer of connective and elastic tissue. This is thicker in veins to prevent collapse of the blood vessel. They also have a middle layer composed of smooth muscle, connective and elastic tissue. This is thicker in arteries to maintain blood pressure. The inner layer is made up of endothelial tissue. Capillaries only have an endothelium.

Atherosclerosis

Atherosclerosis is the disease process that leads to coronary disease and strokes (cardiovascular diseases). Fatty deposits (**atheroma**) can either block an artery directly or increase its chance of being blocked by a blood clot (**thrombosis**).

Development of atherosclerosis



Smoking and atherosclerosis

Cigarette smoke contains many toxic chemicals, which can lead to atherosclerosis. The thickness of the blood increases. The thick blood causes fatty deposits to build up on the walls of arteries and increases the risk of clotting. Smoking also increases blood pressure and heart rate, which can also cause damage to the endothelium.

Now try this

Describe endothelial tissue and explain how it is adapted to its function.

In this case, an annotated drawing would help to answer the question.

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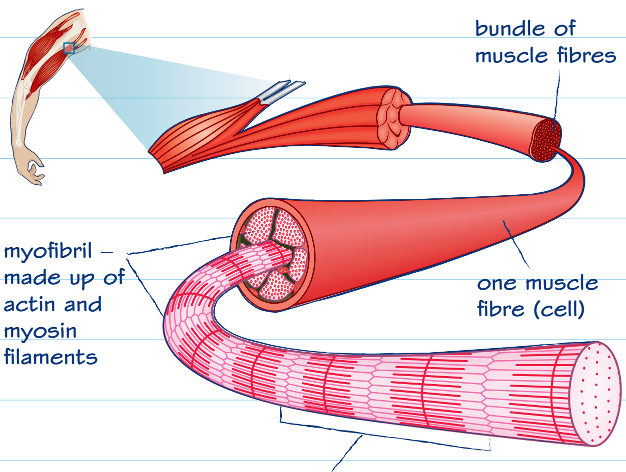
Fast and slow twitch muscle

Muscle is a soft tissue, which can contract to maintain a position in the body or produce movement.

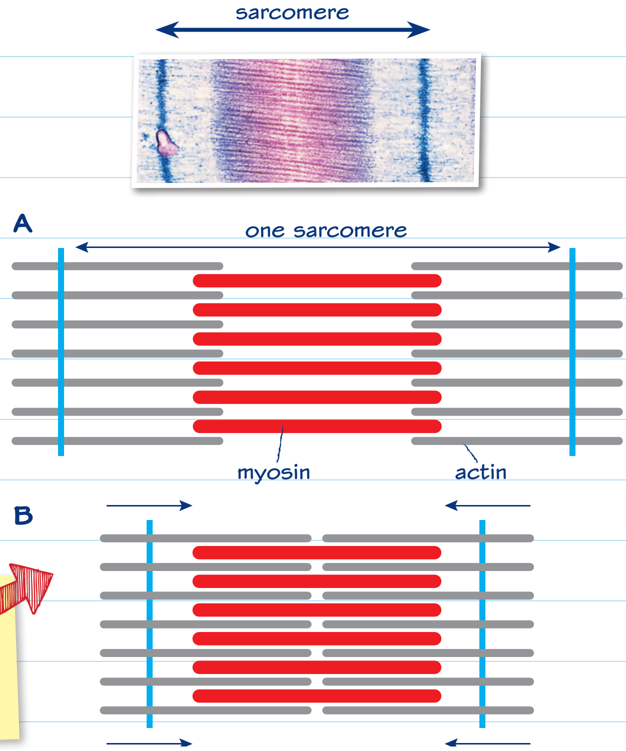
Muscle structure

Muscle is made up of bundles of cells called muscle fibres (cells). These muscle fibres are made up of myofibrils.



Muscle contraction

Muscles are made up of a thick protein filament composed of the protein myosin and a thin filament composed of actin. When muscle contracts, the thin actin filaments move between the thick myosin filaments, shortening the length of the sarcomere and the overall length of the muscle.



Look at the vertical blue lines to see the shortening of the sarcomere that has happened between A and B.

Fast and slow twitch muscles

There are two types of muscle fibres.

Slow twitch	Fast twitch
slow, sustained contraction for long periods of exercise	rapid intense contractions in short bursts
many mitochondria supply energy from aerobic respiration (requires oxygen)	few mitochondria – energy for contraction from anaerobic respiration (needs no oxygen)
lots of capillaries	few capillaries
does not tire easily	tires easily
large oxygen and glucose stores	little stored oxygen and glucose

The properties of fast twitch muscle fibres suit short bursts of activity such as sprinting.

Which sport?

Humans have differences in the proportions of slow and fast twitch muscles. People who have a higher proportion of fast twitch muscles can move quickly in short bursts, for example sprinters. This is because the muscles contract rapidly and strongly in short bursts using energy from anaerobic respiration. People who have a higher proportion of slow twitch muscles are better at endurance events like the marathon, as they use aerobic respiration and can work for a long time without getting tired.

Now try this

State the type of muscle cells that are an advantage to marathon runners and explain why.

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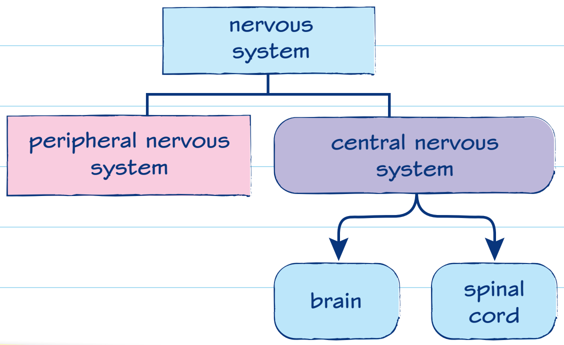
Nerve tissue

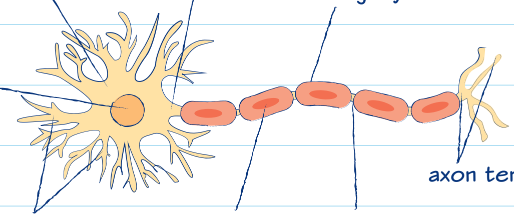
Nerves are made up of cells called **neurones**. Neurones carry messages in the form of electric signals, from one part of the body to another. These messages are also known as **nerve impulses**.

Structure of the nervous system



The nervous system of a mammal is divided into the **central nervous system** (CNS) and the **peripheral nervous system**. The CNS is made up of the brain and the spinal cord.

Structure of a neurone



Myelin sheaths

Most nerve cells are myelinated. Those that are not are small diameter nerves usually responsible for transmitting pain such as aches and soreness rather than sharp pain. They also detect temperature changes.

This table compares non-myelinated nerve cells with myelinated nerve cells. It is a useful way of displaying the answer to a compare and contrast question.

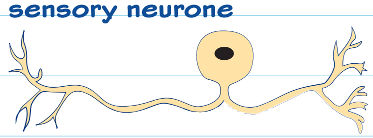
Comparing non-myelinated and myelinated nerve cells

Non-myelinated	Myelinated
do not have a myelin sheath	have a myelin sheath
grey	white
transmit impulses slower	transmit impulses very fast
do not have nodes of Ranvier	do have nodes of Ranvier

Types of neurone

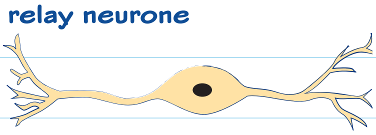
The mammalian nervous system is made up of cells called **neurones**. There are several types of neurone. The three most common types are shown here.

sensory neurone



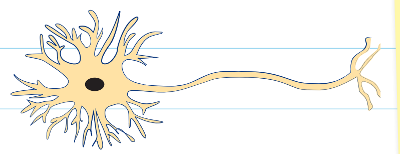
Connects sensory receptors to the central nervous systems

relay neurone



Found in the central nervous system

motor neurone



Communicates from central nervous system to effectors

Now try this

'Progressive' means 'increases over time' and 'de' before a word means 'removal of'.

Multiple sclerosis is known as a 'progressive de-myelinating disease' that affects the nervous system.

Suggest what 'progressive de-myelinating' means and how MS affects the transmission of nervous impulses.

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Nerve impulse

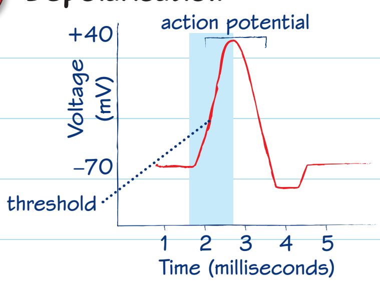
Neurons send electric impulses. These are generated by changes in the concentrations of ions inside and outside the nerve cell causing a potential difference (PD), called an **action potential**, which transmits an electrical signal between nerve cells.

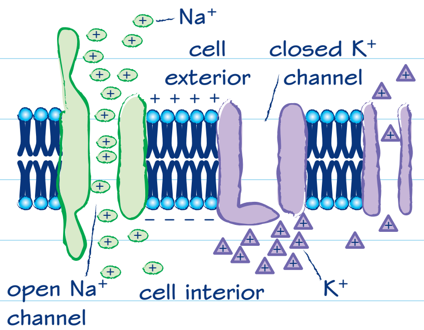
Changes in polarity

The **action potential** is triggered by the **depolarisation** of the nearby membrane changing the PD to the **threshold potential**. If the threshold potential is not reached, nothing happens.

A new action potential cannot be generated in the same section of membrane for about 5 milliseconds, which makes sure that the impulse travels in one direction along a nerve fibre. Between the action potentials the cell is at **resting potential** (between −60 and −70 mV, depending on the nerve cell).

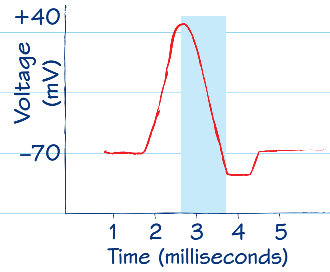
1 Depolarisation

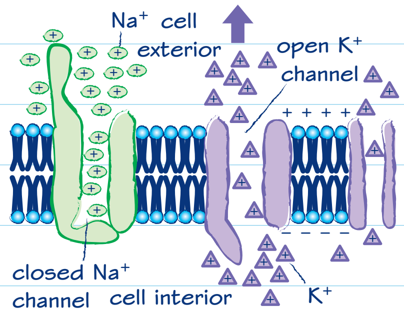




- Na^+ gates open.
- Na^+ diffuses into the cell carrying positive charge.
- Na^+ gates close.

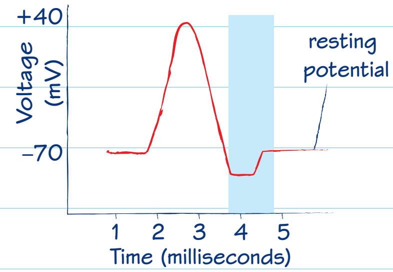
2 Repolarisation

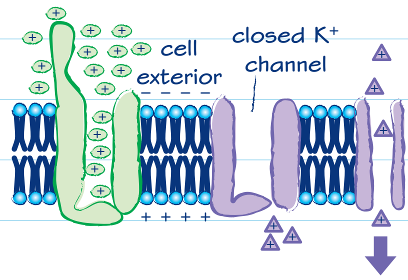




- K^+ gates open.
- K^+ diffuses out of the cell taking positive charge with it.
- K^+ gates close.

3 Recovery





- K^+ moves back into cell through non-voltage gated channels.
- Attracted by negative charge as **hyperpolarised** (that is, more negative than −60 to −70 mV).
- **Resting potential** equilibrium restored.

Saltatory (jumping) conduction

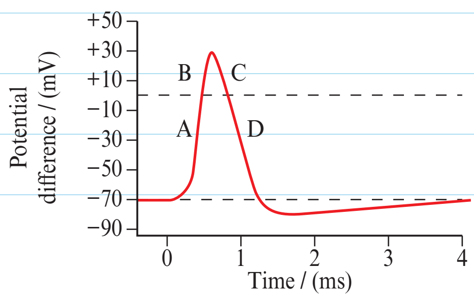
The only region of a myelinated nerve fibre that can depolarise is at the nodes of Ranvier where there is no myelin.

This means that nerve impulses can travel a much longer distance. They can also travel faster than without myelin, and the impulse 'jumps' from one node to the next.

Now try this

Describe and explain the movement of ions at point C in the diagram.

There are two different forces causing ions to move at this point.



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Electroencephalogram (EEG)

Neurons in the cerebral cortex of the brain send and receive nerve impulses all the time, so there is always electrical activity. This electrical activity is recorded in an EEG.

Links For more information on nerve impulses, see pages 10–11.

EEG

Electrodes are placed on the head at specific positions. Different electrodes record activity from different known areas of the brain. Each electrode has a number (odd numbers on the left of the head and even numbers on the right). They also have a letter, which shows where the electrode is placed, for example, F for frontal lobe.

There are usually 21 electrodes.

Brain waves

Each type of electrical activity has a normal pattern. Four simple periodic rhythms recorded in the EEG are alpha, beta, delta and theta.

Rhythm	Freq (Hz)	Amp (μV)	Presentation
alpha	8–13	20–200	when awake with eyes closed
beta	13–30	5–10	when awake
delta	1–5	20–200	during sleep
theta	4–8	10	young children and adults in deep sleep

In the EEG the potential difference between two electrodes is recorded.

What are EEGs used for?

EEGs are mainly used to diagnose and investigate epilepsy. They are also used to investigate such problems as sleep disorders, dementia, head injuries and encephalitis (inflammation of the brain).

Sudden changes in electrical activity may show that normal brain activity is suddenly interrupted and changed, such as in an epileptic seizure.

A general change in how normal electrical activity looks on an EEG may show that there is a problem with the brain. For example, abnormal height (amplitude or frequency) or a brain wave that shows up when it shouldn't such as a delta wave occurring in an adult, who is awake.

EEGs only show that there is a problem in an area of brain activity and can give a clue about what might be wrong, but they do not give a conclusive diagnosis.

Now try this

1. Describe what an EEG shows.
2. Explain **two** factors that can affect brain activity.

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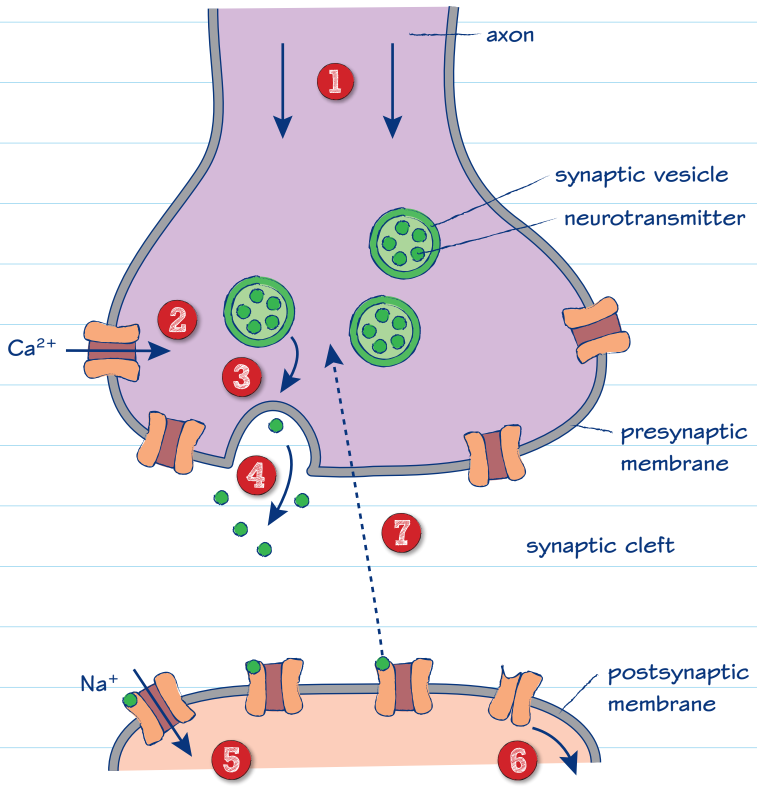
Synapses

Synapses are gaps between nerve cells. Action potentials cannot pass between nerve cells across the synapse, so transmitter substances are used.

Structure of a synapse

A synapse is the junction between two neurons. The **presynaptic membrane** (before the gap) allows the release of chemicals (**neurotransmitters**) when impulses are arriving to stimulate impulses in the cell after the gap (**postsynaptic cell**).

A typical synapse has a presynaptic knob containing vesicles filled with neurotransmitter. Receptor molecules on the postsynaptic membrane bind with neurotransmitter.



1. An action potential arrives.
2. The membrane depolarises. Calcium ion channels open. Calcium ions enter the neuron.
3. Calcium ions cause synaptic vesicles containing neurotransmitter to fuse with presynaptic membrane.
4. Neurotransmitter is released into the synaptic cleft.
5. Neurotransmitter binds with receptors on the postsynaptic membrane. Sodium channels open. Sodium ions flow through the channels.
6. The membrane depolarises and initiates an action potential.
7. When released, the neurotransmitter will be taken up across the presynaptic membrane (whole or after being broken down), or it can diffuse away and be broken down.

Acetylcholine

Acetylcholine was the first neurotransmitter to be discovered and has many functions, including the stimulation of muscles. It is largely made in the brain.

Acetylcholine is broken down in the synaptic cleft by acetylcholinesterase.

Now try this

Botulism toxin paralyses respiratory muscles, causing suffocation and death.

(a) State whether botulism toxin prevents or stimulates the release of acetylcholine.
(b) Explain the effect of botulism toxin.

Think about what acetylcholine does.

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Brain chemicals

Parkinson's disease and depression have been shown to be associated with imbalances of important brain chemicals. This knowledge is allowing the development of drugs for the treatment of these conditions.

Dopamine and Parkinson's disease

The symptoms of Parkinson's disease are muscle tremors (shakes); stiffness of muscles and slowness of movement; poor balance and walking problems; difficulties with speech and breathing; depression.

Parkinson's disease is associated with the death of a group of dopamine-secreting neurons in the brain. This results in the reduction of dopamine levels in the brain. Dopamine is a neurotransmitter that is active in neurones in the frontal cortex, brain stem and spinal cord. It is associated with the control of movement and emotional responses.

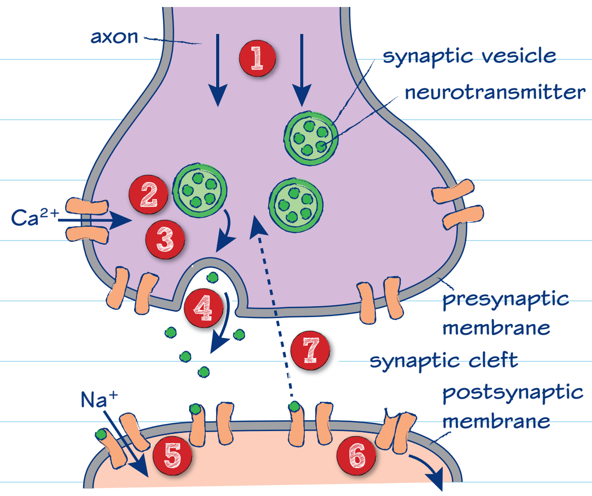
Treatment of Parkinson's disease

A variety of treatments are available for Parkinson's disease, most of which aim to increase the concentration of dopamine in the brain. Dopamine cannot move into the brain from the bloodstream, but the molecule that is used to make dopamine can. This molecule is called L-dopa and can be turned into dopamine to help control the symptoms.

Serotonin and depression

Serotonin is a neurotransmitter linked to feelings of reward and pleasure. A lack of serotonin is linked to clinical depression (prolonged feelings of sadness, anxiety, hopelessness, loss of interest, restlessness, insomnia). Ecstasy (MDMA) works by preventing the reuptake of serotonin. The effect is the maintenance of a high concentration of serotonin in the synapse, which brings about the mood changes in the users of the drug.

How synapses are affected by drugs



Many drugs affect the nervous system by interfering with the normal functioning of a synapse. Some drugs:

1. affect the synthesis or storage of the neurotransmitter.
2. may affect the release of the neurotransmitter from the presynaptic membrane.
3. may affect the interaction between the neurotransmitter and the receptors on the postsynaptic membrane.
4. may be stimulatory by binding to the receptors and opening the sodium ion channels.
5. may be inhibitory, blocking the receptors on the postsynaptic membranes and preventing the neurotransmitters binding.
6. prevent the reuptake of the neurotransmitter back into the presynaptic membrane.
7. may inhibit the enzymes involved in breaking down the neurotransmitter in the synaptic cleft.

Seretonin selective reabsorption inhibitor (SSRI)

Prozac is an example of an SSRI. It may be given to patients to reduce depression. Serotonin is not reabsorbed because the SSRI binds to reuptake proteins. This means there is a high level of serotonin. Consequently, the increased level of serotonin in the synapses continues to bind to receptors in postsynaptic membranes, increasing the feelings of reward and pleasure.

Now try this

Patients with Parkinson's disease have little of the neurotransmitter dopamine in their brains. Explain how 'dopamine agonists' that mimic dopamine might be a useful treatment for Parkinson's disease.

Dopamine agonists have a similar shape to dopamine.

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Writing formulae and equations

Scientists use formulae and equations to summarise the changes that occur in reactions.

Formulae

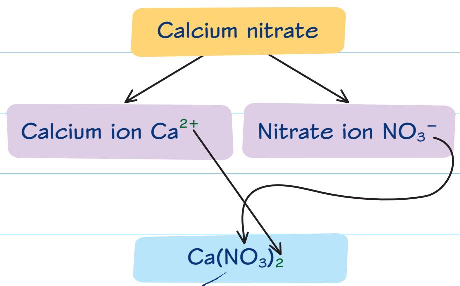
There are some ions that it is helpful to remember to help you write chemical formulae.

Ion	Formula
nitrate	NO_3^-
carbonate	CO_3^{2-}
sulfate	SO_4^{2-}
hydroxide	OH^-
ammonium	NH_4^+
zinc	Zn^{2+}
silver	Ag^+

Learn these by covering, recalling them, uncovering to check until you are consistently getting them correct.

Working out formulae

You can deduce the formula of an ionic compound using the formulae and charges of the ions involved. For example, working out the formula of calcium nitrate:



Brackets are used whenever you have more than one ion that consists of two or more types of atom, in this case, NO_3^-

If a molecule is covalent, a quick way to find out how many bonds each atom will form is to work out 8 minus its group number. So carbon dioxide contains C, which forms $8 - 4 = 4$ bonds, and O which forms $8 - 6 = 2$ bonds. Hence its formula must be CO_2.

Predicting charges on ions

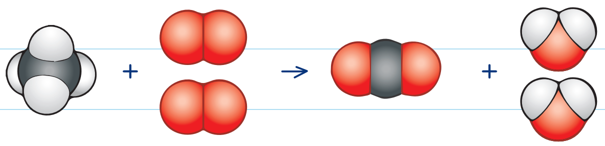
You should be able to predict the charge on some ions based on their position in the periodic table by following some simple rules. For example:

metals in groups 1, 2 and 3 form 1+, 2+ and 3+ ions, respectively

non-metals in groups 5, 6 and 7 can form 3−, 2− and 1− ions, respectively.

Writing a balanced equation

You cannot simply create or destroy atoms in chemical reactions, so the numbers of each atom on both sides of an equation have to balance, even if you rearrange the atoms into new compounds. Look at the equation for the combustion of methane.



One methane molecule		Two oxygen molecules		One carbon dioxide molecule		Two water molecules
CH_4	+	$2O_2$	→	CO_2	+	$2H_2O$
1C 4H		4O		1C 2O		2O 4H

Remember the large numbers before a formula tell you how many of that molecule take part or form in the reaction, in this case two oxygen molecules and two water molecules. Once you have practised lots of examples, balancing most equations becomes quite easy, especially if you learn the charges on ions to help you write the correct formulae.

Now try this

The biofuel ethanol, C_2H_5OH, reacts with oxygen to form carbon dioxide and water.

Write an equation for the reaction.

Leave elemental reactants, for example, O_2, until last when balancing.

Practising writing equations

✓ Write the **correct formula** for all reactants and products, for example:

$Na_2CO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$

✓ Check the numbers of each atom **balance**. If not, use numbers in front of reactants or products to balance atoms. In this equation, there are 2 Na atoms on the left but only one on the right, so '2' is placed before NaCl:

$Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$

✓ Add **state symbols** if required, (s) = solid, (l) = liquid, (g) = gas, (aq) = aqueous solution:

$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + CO_2(g) + H_2O(l)$

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Electronic structure of atoms

Bohr's model describes the shapes in space where electrons can be found in atoms.

Main energy levels or shells

Electrons orbit the nucleus in **shells**. The further the shell, or main energy level, is from the nucleus, the higher its energy. Each shell can hold a fixed number of electrons.

n	Shell	Number of electrons
1	1st shell	2
2	2nd shell	8
3	3rd shell	18
4	4th shell	32

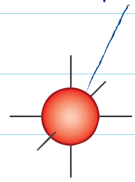
You can find the total number of electrons in an atom by using the **atomic number**. This is defined as the **number of protons** in an atom, but for a neutral atom also equals the number of electrons.

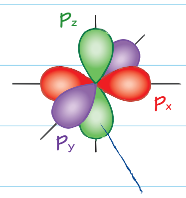
Atomic orbitals

Each shell consists of **atomic orbitals**. These are regions in space where electrons may be found. The larger the main energy level, the more orbitals it is made up from. The first four types of are called s, p, d and f orbitals.

Shapes of orbitals

An s-orbital is spherical in shape and holds up to 2 electrons.





Each p-orbital is dumb-bell shaped and holds up to 2 electrons. Each p sub-shell has 3 p-orbitals, p_x, p_y and p_z.

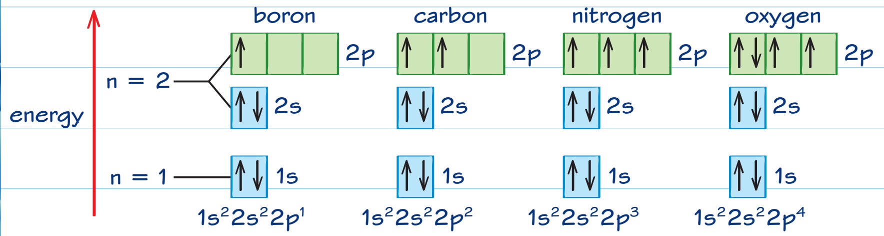
Writing electron configurations

Electron configurations are the arrangement of the electrons in atoms or ions. Bohr's model recognises that the main shells are split into **sub-shells** and electron configurations should reflect that.

Element	Electron configuration
B	$1s^2 2s^2 2p^1$
C	$1s^2 2s^2 2p^2$
N	$1s^2 2s^2 2p^3$
O	$1s^2 2s^2 2p^4$

Electrons 'in boxes'

In these diagrams each 'box' represents an orbital. The arrows represent electrons in the orbitals.



A third main energy level consists of one s-orbital, 3 p-orbitals and 5 d-orbitals.

The direction of the arrows shows the **spin of each electron**. A pair always spin in opposite directions to reduce repulsion.

Orbitals can be confused with sub-shells. Any orbital, regardless of the sub-shell it is in, can hold up to two electrons.

Rules for arranging electrons

1. Start at the lowest shell and add electrons one at a time to build up the configuration.
2. Fill each sub-level before starting on the next.
3. Fill each orbital singly in a sub-level before pairing electrons.
4. Paired electrons have opposite spins, so they are shown as arrows pointing in opposite directions.

The 4s orbital is lower in energy than the 3d when empty, but higher in energy when occupied.

The idea, shown by rules 1 and 2, that electrons fill lower shells before the higher shells, is called the **Aufbau principle**.

Now try this

Write the electron configuration of the following particles. The number of electrons is given in brackets.

(a) Na atom (11) (b) O^{2-} ion (10)
(c) Ti atom (22) (d) V^{3+} ion (20)

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Ionic bonding

Ionic bonds are strong **electrostatic attractions** between positive and negative ions. The ions in ionic bonds can be shown using **electron configuration diagrams**.

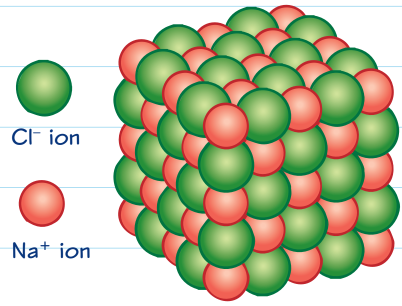
Ionic compounds and giant ionic structures

Ionic compounds have giant structures.

In a giant ionic structure, the ions are arranged in a regular, three-dimensional pattern called a **lattice**. The electrostatic forces between the ions act in all directions and keep the structure together. The large number of these strong electrostatic attractions gives ionic compounds **high melting points**.

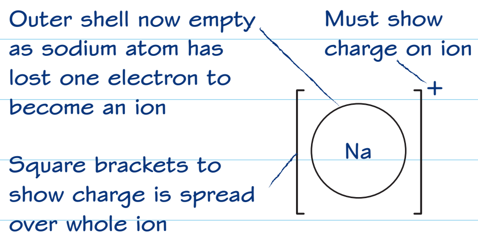
Sodium chloride lattice

In the sodium chloride lattice each sodium ion is surrounded by six chloride ions and each chloride ion is surrounded by six sodium ions. This repeating pattern continues for a vast number of ions.



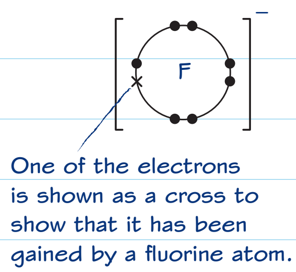
Positive ions:

- are generally formed by **metal atoms** losing electrons
- have a **positive** charge equal to the group number if formed from a group 1, 2 or 3 element
- have different charges if formed from a transition metal (for example, Fe^{2+}, Fe^{3+})
- can be represented in an electron configuration diagram, for example a Na^{+} ion
- are known as **cations**.



Negative ions:

- are generally formed by non-metal atoms gaining electrons from metal ions
- have a negative charge equal to 8 minus the group number of the element
- sometimes exist as polyatomic ions, such as CO_3^{2-}, SO_4^{2-}, NO_3^{-} and OH^{-}, whose charges should be learnt
- can be represented in an electron configuration diagram, for example an F^{-} ion.
- are known as **anions**.



Strength of ionic bonds

To compare the relative strength of ionic bonds, the **ionic charge** and **ionic radius** have to be considered, sometimes called the charge/size ratio. For instance, the ionic bonding in MgF_2 is much stronger than the ionic bonding in NaF. This is because the magnesium ion is smaller than the sodium ion and also has a greater charge. These factors increase the **electrostatic attraction** between the ions.

Now try this

Sodium chloride (NaCl) and potassium chloride (KCl) are both important in maintaining normal blood pressure.

Explain which compound has the strongest ionic bond.

Think about the size of each ion and their charges.

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Covalent bonds

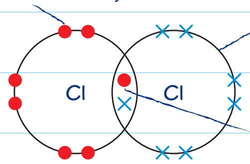
A covalent bond is an **electrostatic attraction** between a shared pair of electrons and the nuclei of the bonded atoms.

How do atoms form covalent bonds?

A covalent bond forms when atoms **share** a pair of electrons. Generally, each atom in the bond contributes one electron to the pair, but a covalent bond consisting of an electron pair derived from one of the atoms is called a **dative covalent (coordinate)** bond.

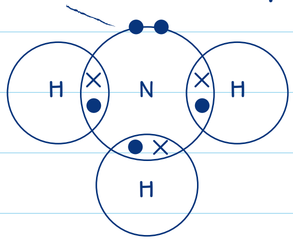
Dot and cross diagrams

These are a way of showing the bonding between atoms, for instance in a chlorine molecule.



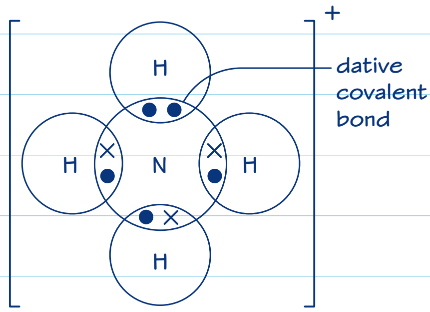
More dot and cross diagrams

Ammonia consists of 3 hydrogen atoms bonded to a nitrogen atom. Each hydrogen atom has only 1 unpaired electron ($1s^1$), so can form a single bond. The nitrogen atoms has 3 unpaired electrons in its outer shell, so can form 3 bonds.

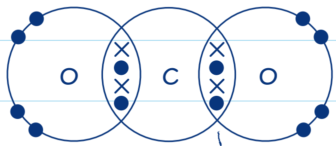


The **ammonium ion** forms from ammonia, NH_3 and a hydrogen ion, H^+.

The hydrogen ion has no electrons in its vacant orbital to form a bond, but the nitrogen atom in ammonia has a lone pair not involved in bonding. It uses this pair to bond to the hydrogen ion, forming a **dative covalent** (coordinate) bond.

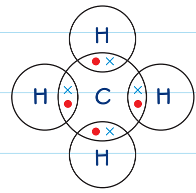


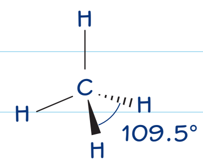
In **carbon dioxide**, each oxygen atom shares 2 pairs of electrons with the carbon atom.



Each oxygen forms a **double bond** to the carbon.

Methane consists of 1 carbon atom bonded to 4 hydrogen atoms. The orbitals containing the electron pairs repel as far away as possible, forming a **tetrahedral** shape, common around carbon atoms in organic chemistry.





Strength of covalent bonds

Bond length and bond strength in covalent bonds are **inversely related**. This means that the shorter the covalent bond length, the greater the covalent bond strength.

Now try this

Boron trifluoride, BF_3, is used in the manufacture of semi-conductors. It reacts with ammonia, NH_3, to form the compound $BF_3.NH_3$.

Draw a dot and cross diagram of $BF_3.NH_3$, labelling any dative covalent bonds clearly.

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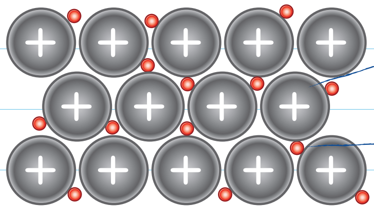
Metallic bonding

You will need to be able to describe the model of metallic bonding and use it to explain properties such as **melting points**.

Metallic bonding



Delocalised electrons are the electrons from the outer shell of the metal atoms, but are not fixed to a particular atom, so can move freely throughout the structure.

The metallic bond is a strong **electrostatic** attraction between the positive metal ions and the delocalised electrons.

The positive ions are layered in three dimensions – a giant **lattice** structure.

Properties of metals

The key properties of metals due to the bonding are:

- **electrical and thermal conductivity** due to the delocalised electrons, which are free to move
- **high melting and boiling points** due to strong electrostatic attractions between positive ions and electrons
- **malleability** – can be shaped, as layers of positive ions slide over each other and the delocalised electrons move with the layers, so strong metallic bonds remain intact
- **ductility** – can be pulled into wires as positive ions roll over each other and the delocalised electrons move with the positive ions, so strong metallic bonds remain intact.

Trends in melting points

These tables show the melting points of some different group 1 and group 2 metals:

Group 1 metal	Melting point (°C)
lithium	181
sodium	98
potassium	63
rubidium	39
caesium	28

Group 2 metal	Melting point (°C)
beryllium	1278
magnesium	649
calcium	839
strontium	769
barium	729

The melting points decrease as the atoms get larger. Larger metals have more electrons and more electron shells. This means they have more shielding between the nucleus and delocalised electrons, so the electrostatic attraction force between them is weakened. This produces a **weaker metallic bond**, so less energy is required to break these bonds.

Each group 2 metal has a higher melting point than the group 1 metal **in the same period**. This is because the group 2 metal has **two** delocalised electrons per positive ion, rather than one. This gives it a greater electron density around the positive ions. This, alongside the +2 charge, produces a stronger electrostatic attraction between the nucleus and the delocalised electrons, and so a stronger metallic bond.

Now try this

Metals are often used in manufacturing because they are hard-wearing and can be shaped easily.

Use the metallic bonding model to explain why most metals can be hammered into thin sheets without easily splitting.

A diagram to show the model may help you explain this property.

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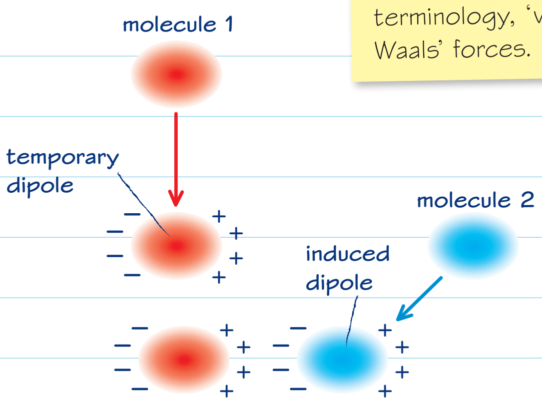
Had a look ☐ Nearly there ☐ Nailed it! ☐

Intermolecular forces

Intermolecular forces are interactions between molecules caused by either **permanent** or **induced dipoles**.

London forces

Instead of 'London' forces, you may still see the older terminology, 'van der Waals' forces.

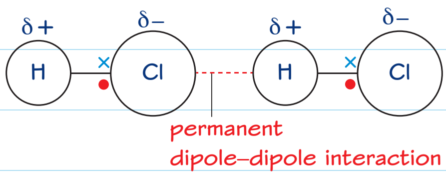


Electrons are moving randomly within the shells of a molecule or atom.

This can cause an uneven distribution in the molecule, resulting in an **instantaneous**, **temporary dipole**. This can **induce a temporary dipole** in a nearby molecule. This results in a weak attraction, called a **London force**. The more electrons a molecule has, the more likely this process occurs, so the stronger the London force.

Dipole–dipole interactions

Polar molecules such as HCl have permanent dipoles due to the much greater electronegativity of the chlorine atom and the fact that the molecule is not symmetrical. Hence the oppositely charged ends of two molecules are attracted to each other. This weak attractive force is called a **permanent dipole–dipole interaction**.

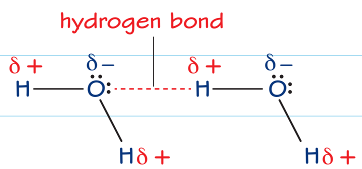


Hydrogen bonds

This type of intermolecular force is the attraction between an **electron-deficient hydrogen** atom (δ+) and a lone pair on oxygen, nitrogen or fluorine atoms. O, N and F are the only atoms that can form hydrogen bonds as they are small and highly electronegative, which means they pull pairs of electrons towards them.

Water molecules can form hydrogen bonds between each other.

Hydrogen bonds are an especially strong intermolecular force.



Only electron-deficient hydrogen atoms can form hydrogen bonds, so hydrogen atoms attached directly to a carbon cannot form hydrogen bonds, as the **electronegativities** of carbon and hydrogen are similar. This means hydrogen atoms attached to carbon atoms in hydrocarbons **do not** form hydrogen bonds.

Links For more information on electronegativity, see page 26.

Remember when drawing diagrams to show hydrogen bonds between molecules:

- Show the dipole charges on relevant atoms.
- Show the lone pairs of electrons on O, N or F.
- Indicate the hydrogen bond clearly, e.g. using a dashed line.
- The OHO bond angle should be 180°.

Now try this

The compound HF is used in the manufacture of polymers such as Teflon™. It is a liquid at 10°C but HCl, even though it has more electrons, is a gas.

Explain this observation in terms of intermolecular forces.

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Relative masses

As atoms are so small, scientists use the idea of **relative masses** to compare the mass of atoms, elements and compounds.

Relative atomic mass

The atoms in a sample of an element may have slightly different masses, so **relative atomic mass** is often useful as a way of comparing the masses of different elements. It is defined as:

Mean mass of atoms of the element (in a sample) compared with $\frac{1}{12}$**th of the mass of a carbon-12 atom**.

These values are found on the periodic table in your exam paper, so can be looked up when required.

Relative molecular mass

This term is used when comparing the mass of molecules with simple covalent structures. It is the sum of the relative atomic masses of all the atoms present in the substance.

Relative formula mass

This term is used when referring to substances with giant structures. It is the sum of the relative atomic masses of all the atoms in the formula of the substance.

Using relative atomic masses

Relative atomic masses can be used to calculate the relative molecular masses of molecules, for example, ethanol, C_2H_5OH.

Ethanol contains 2 C atoms = 2 × 12.0 = 24.0
and 6 H atoms = 6 × 1.0 = 6.0
and 1 O atom = 1 × 16.0 = 16.0
so relative molecular mass = 46.0

You don't have to include all the stages of working out shown here, but you may find it helpful when practising such examples, especially with more complex compounds. Notice the values used from the periodic table are given to one decimal place.

They are also used to calculate the relative formula mass of more complex substances, for example, hydrated copper sulfate, $CuSO_4.5H_2O$

$CuSO_4.5H_2O$ contains 1 Cu atom = 1 × 63.5 = 63.5
and 1 S atom = 1 × 32.1 = 32.1
and 4 O atoms = 4 × 16.0 = 64.0
and 5 H_2O molecules = 5 × 18.0 = 90.0
so relative molecular mass = 249.6

The '**.5H_2O**' in the formula means 5 water molecules are attached to the copper sulfate crystals – such crystals are said to be **hydrated**.

Always use the more precise value from the periodic table, rather than any values you may have remembered. For instance, 32 is often recalled for sulfur, but its precise value is 32.1, as used here.

Units of relative masses

As relative masses are effectively a ratio of the mass of atoms in an element, compared to $\frac{1}{12}$ of the mass of an atom of carbon-12, they **do not have units.**

Now try this

Mohr's salt, $(NH_4)_2Fe(SO_4)_2{\cdot}6H_2O$, is used in experiments to measure an absorbed dose of gamma radiation.

Calculate the relative formula mass of Mohr's salt.