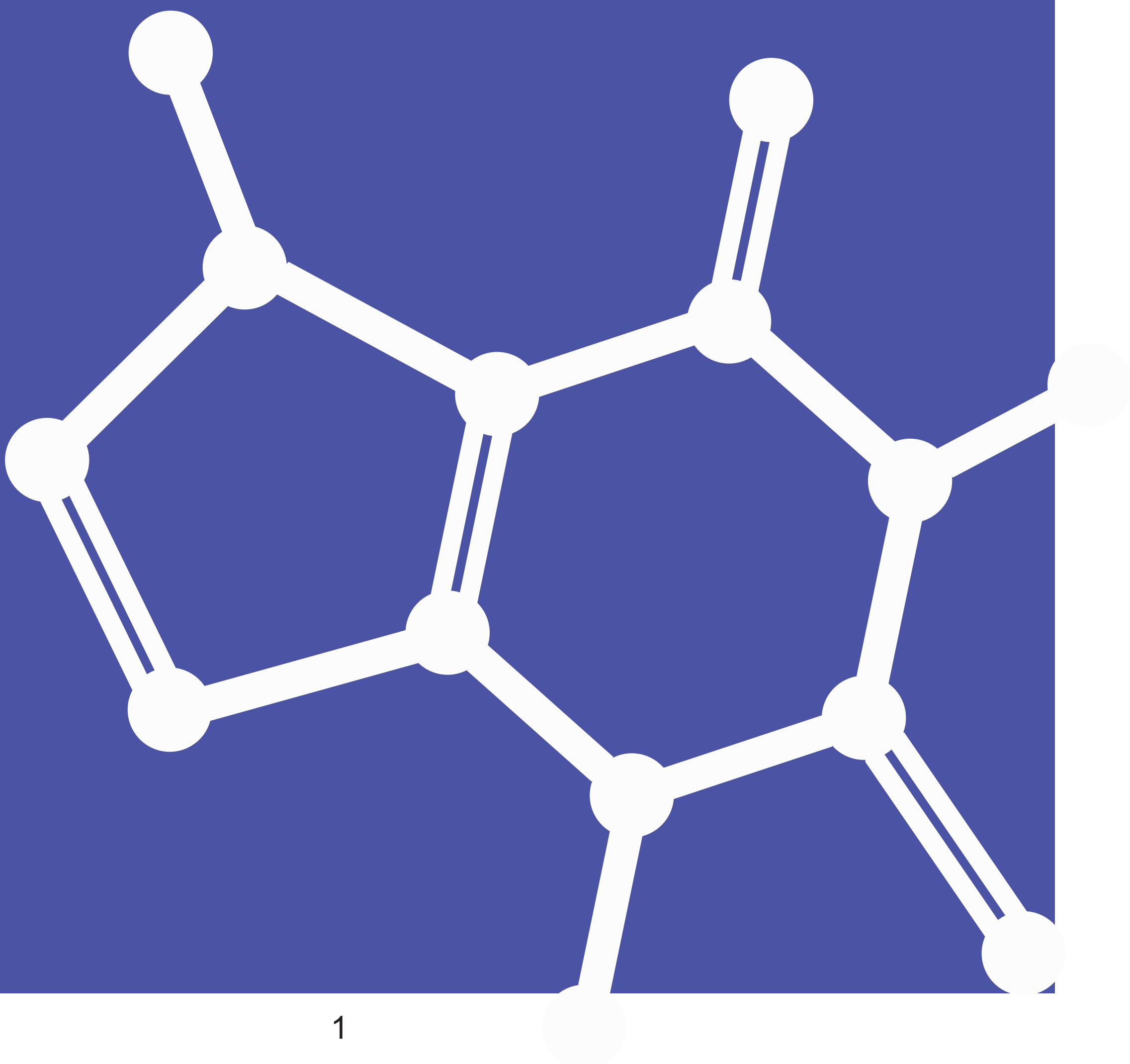
Food, materials and processes (Unit 3)

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)



Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

BONDING

What is the best material for the frame of a tennis racquet? Racquets were made of laminated wood up until the late 1960s when the first racquets using steel were introduced. In the mid-1970s steel was replaced with aluminium but these were in turn replaced by racquets made from graphite. Why the changes, and what advantages did the new materials give to tennis players using them?

Apart from sport, decisions need to be made about the best material to use for applications in every walk of life. What material is best for car bodies or aircraft fuselage? What properties make a material suitable for replacement hips or artificial veins? How do we select materials for safety equipment such as crash-helmets?

Material scientists need to understand how materials are held together if they are to develop new materials with properties that make them suitable for a purpose. This means they need to understand bonding.

Ionic and covalent bonding

Atoms bond together so that they can get a full outer shell of electrons. They can do this by:

either

transferring electrons from one atom (the metal) to another element (non metal).
This results in the formation of ions. The bonding that results is called ionic bonding.

or

sharing electrons between atoms so that they both get full shells.
This sort of bonding is called covalent bonding. It occurs between non-metals.

A summary of the two sorts of bonding is found in the following table.

Bonding	Type of elements	Description of bonding
ionic	metal and non-metal	**transfer** of electrons from a metal to a non-metal to form **ions** of opposite charge **strong electrostatic** attraction between oppositely charged ions holds the ions in a close, regular structure
covalent	non-metals only	pairs of electrons are **shared** between atoms to form **molecules** strong covalent bonds **in** the molecules weak forces **between** molecules

Ionic bonding

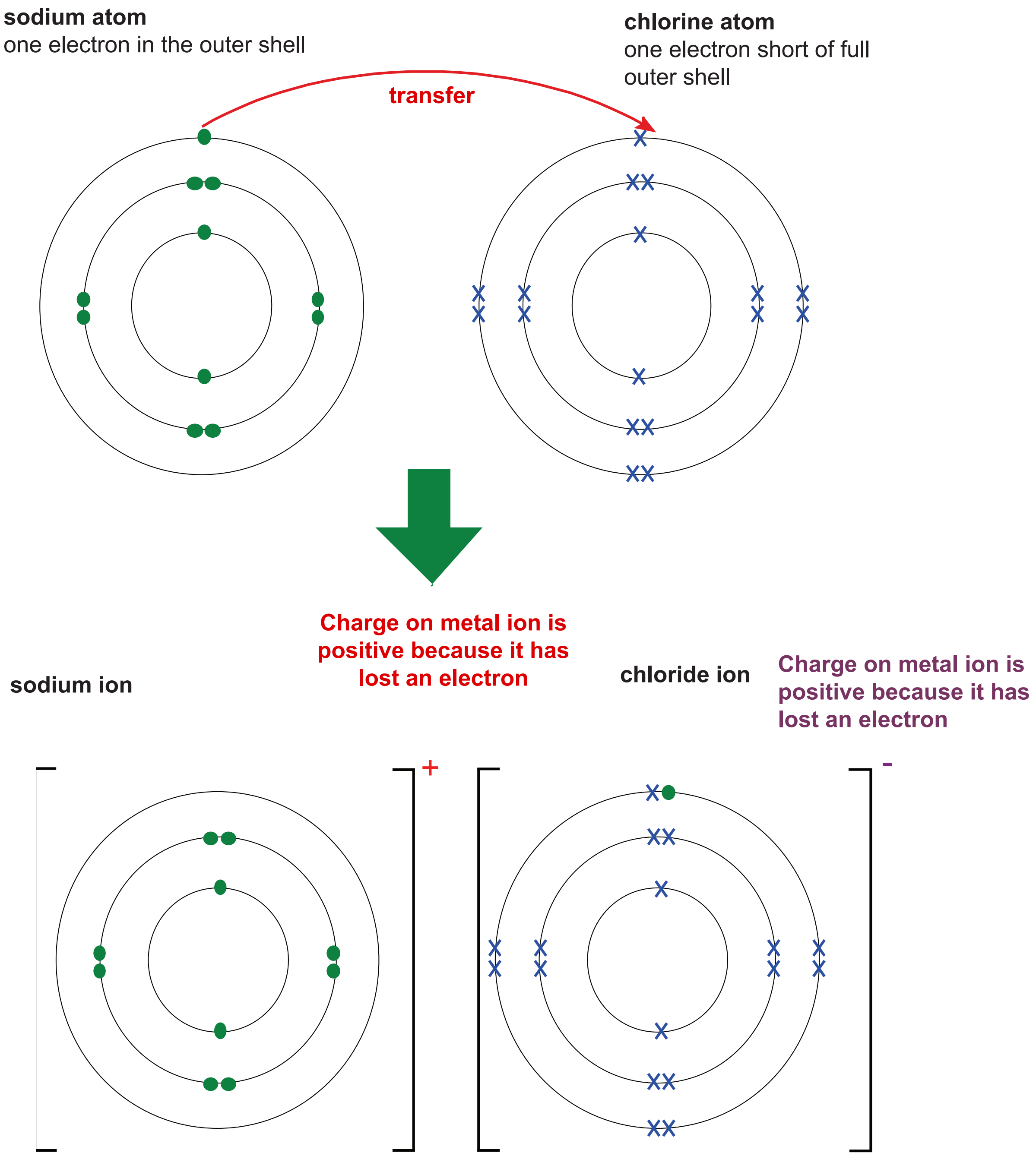
Ionic bonding occurs between a metal **and** non-metal.

It involves the **transfer** of electrons from the metal to the non-metal to form ions of opposite charge.

Electrostatic attraction between the oppositely charged ions holds them in a close regular structure.

Dot and cross diagrams

We represent bonding using dot and cross diagrams. The diagram below shows how an electron transfers from a sodium atom to a chlorine atom.



Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

In ionic bonding:

- metals will lose electrons to form positive ions (also called cations)
- non-metals gain electrons to form negative ions (also called anions)

You must be able to draw dot and cross diagrams for ionic compounds in an exam.

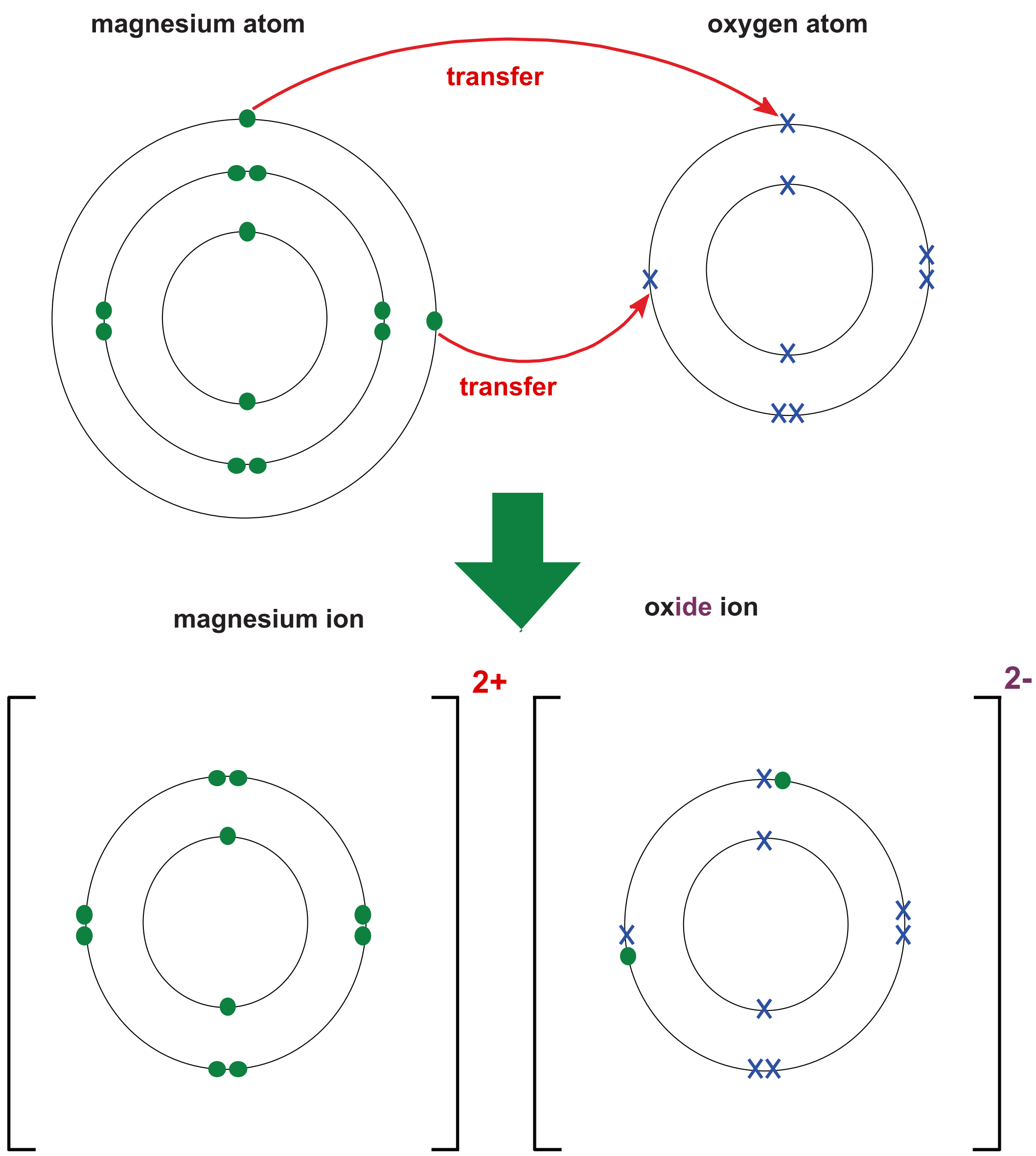
Remember:

- take electrons **off** the metal to empty the outer shell
- **add** electrons to the non-metal to fill the outer shell.

Examples

1. Draw diagrams to show the transfer of electrons and the formation of ions that occur as magnesium oxide is formed.

Answer

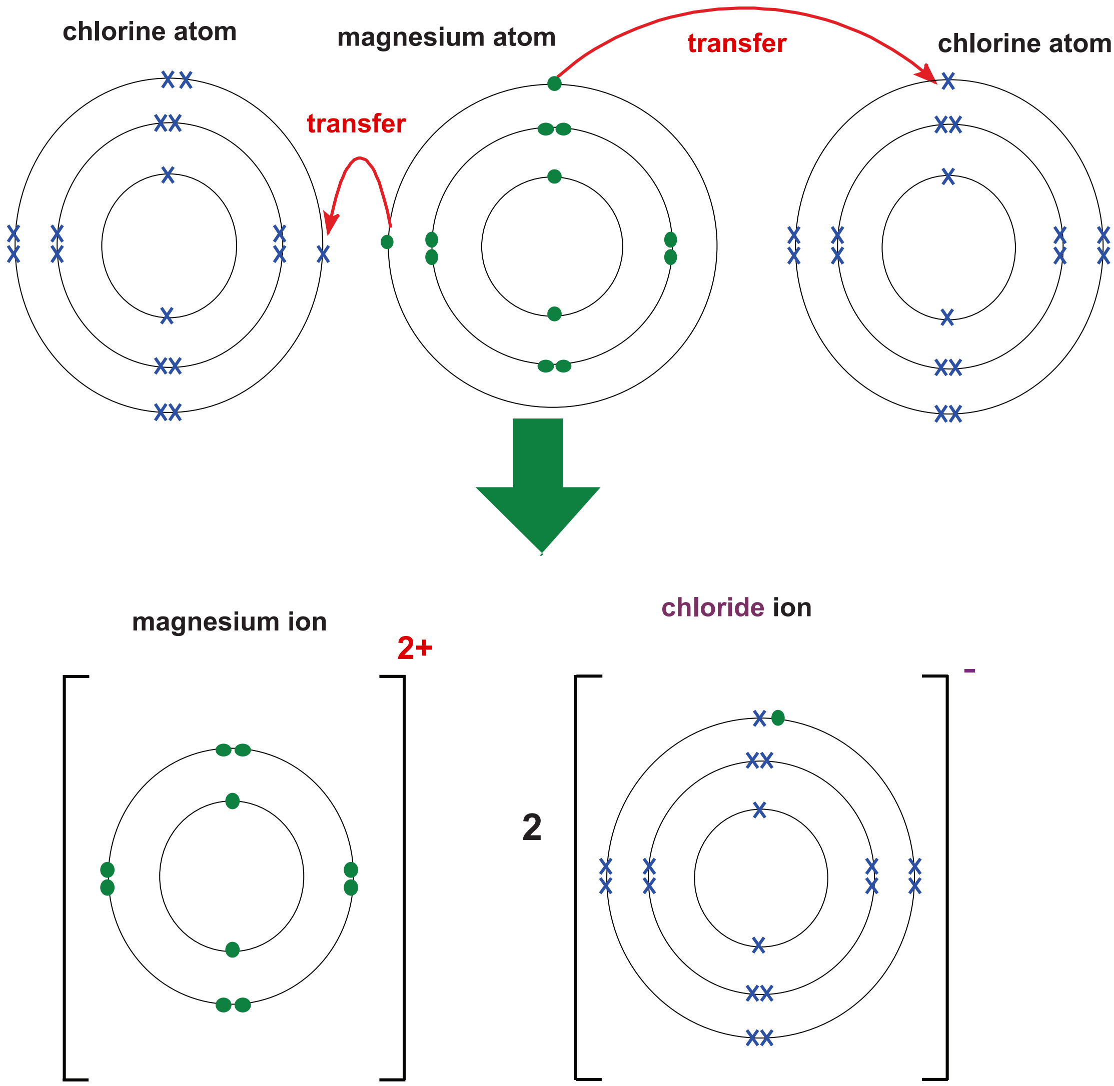


2. Draw diagrams to show the transfer of electrons and the formation of ions when magnesium chloride is formed from magnesium and chlorine atoms.

Answer

In this case each magnesium atom needs to lose two electrons and each chlorine atom only needs one electron to fill the outer shell.

We therefore need two chlorine atoms to make the bonding work.



Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Ionic charge and position in the periodic table

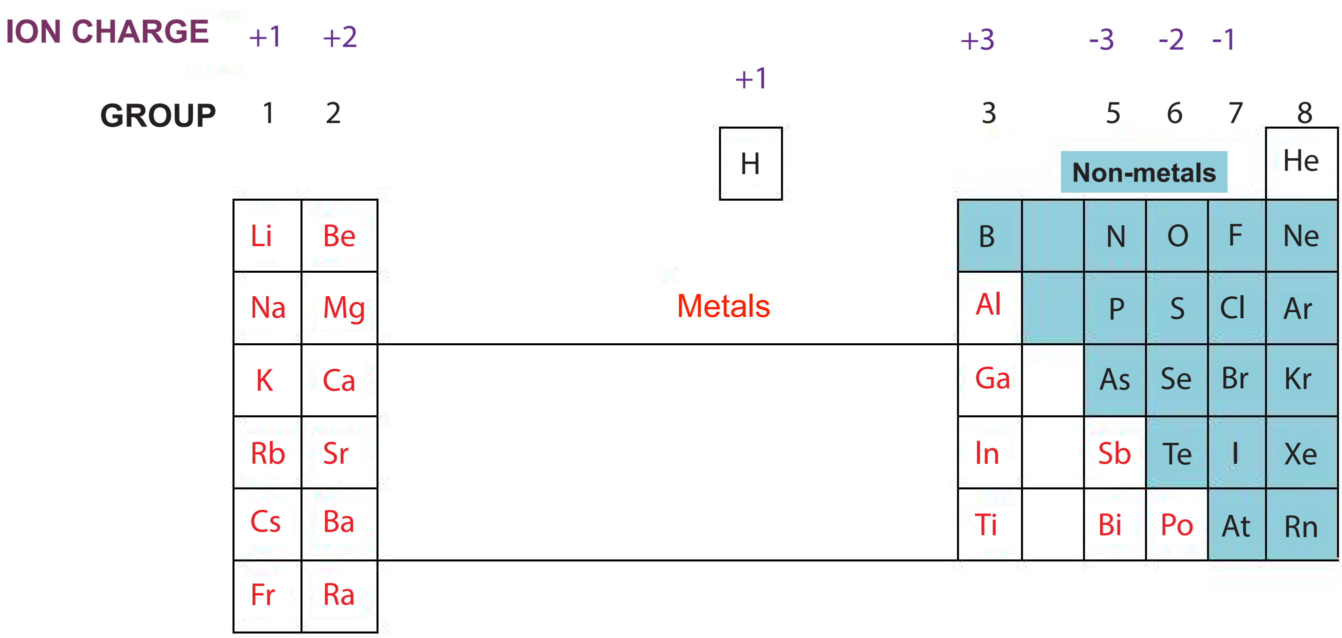
The charge that an atom gains depends upon:

- whether it is a metal or non-metal
  - metals get positive charges
  - non-metals get negative charges
- where it is in the periodic table

Group	Ion charge
- 1 metals	+1
- 2 metals	+2
- 3 metals	+3
- elements in group 4 do not tend to form ions	
- 5 non-metals	-3
- 6 non-metals	-2
- 7 non-metals	-1

HIGHER TIER

You need to know how the charge of an ion depends upon its position in the periodic table



Unit 3.1: Materials for a purpose

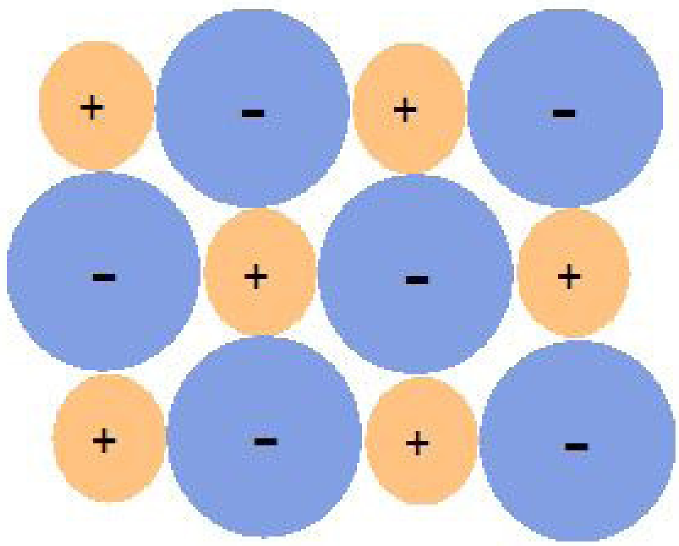
Materials for a purpose (specification 3.1)

Structure and properties of ionic compounds

Ionic compounds are giant structures made up of large numbers of ions. In the giant structure (lattice) each positive ion (cation) is surrounded by negative ions (anions) to which it is attracted by strong electrostatic forces. Every negative ion is surrounded by positive ions.

Structure of sodium chloride

Sodium chloride, NaCl, contains oppositely charged ions. The ions form a regular lattice (structure) in which the strong electrostatic forces between oppositely charged ions act in all directions.



Properties of ionic compounds

Property	Explanation
High melting and boiling points	Ionic bonding is very strong - a lot of energy is needed to break the electrostatic forces holding ions together
Conductive when liquid	Ions are charged particles which can move when the compound is dissolved in water or when it is molten. They decompose when they conduct electricity (see electrolysis – unit 1)
Non-conductors when solids	Ions cannot move in the solid as there are no free electrons to carry the current
Most (but not all) are soluble in water	

TEST YOURSELF

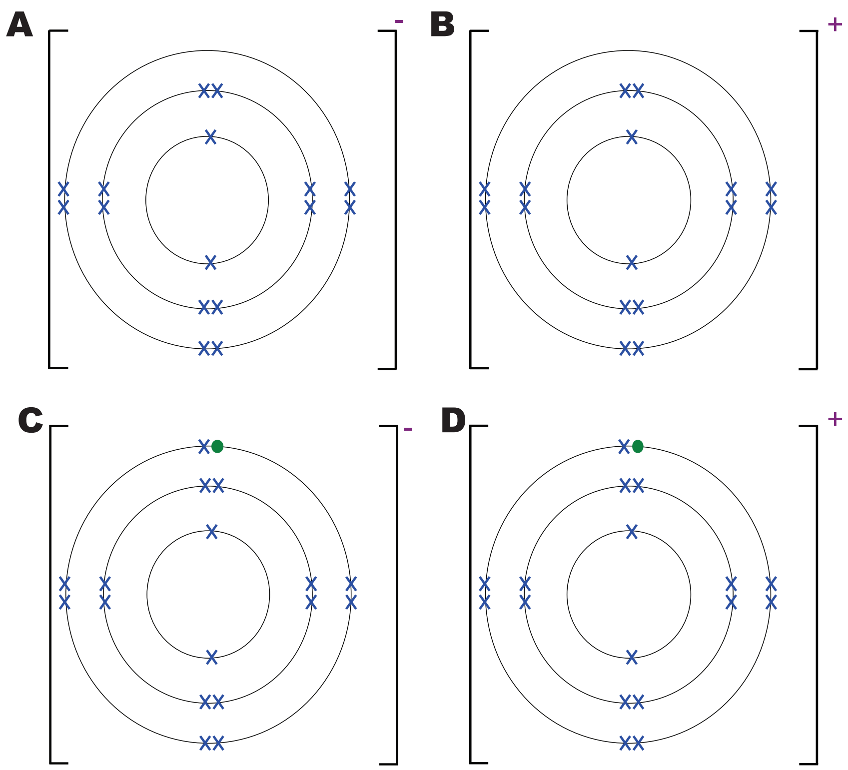
1. Ionic bonding occurs when the following types of elements bond to form a compound:

A metal & metal **B** metal & non-metal **C** non-metal & non-metal

2. When an ionic compound is formed, the metal atoms:

A gain electrons to form negatively charged ions
B lose electrons to form negatively charged ions
C gain electrons to form positively charged ions
D lose electrons to form positively charged ions

3. The chlorine atom has the electronic configuration 2,8,7.
The electronic structure of the chloride ion is:



4. State the electronic configuration of the **potassium ion** in potassium oxide.
The atomic number of potassium is 19.

- **A** 2,8,8,1
- **B** 2,8,8,8
- **C** 2,8,8

5. Ionic compounds:

- **A** have high melting points and are conductors of electricity when solids
- **B** have low melting points and are non-conductors of electricity when solids
- **C** have high melting points and are non-conductors of electricity when solids
- **D** have low melting points and are conductors of electricity when solids

6. Ions are held together in a regular structure by:

- **A** strong covalent bonds
- **B** weak electrostatic forces between ions of the same charge
- **C** strong electrostatic forces between ions of the opposite charge
- **D** weak covalent bonds

Higher tier only

7. Nitrogen (group 5) forms ions when it bonds to certain metals.
State the charge on the nitride ion in these compounds.

- **A** +5
- **B** -5
- **C** +3
- **D** -3

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Covalent bonding

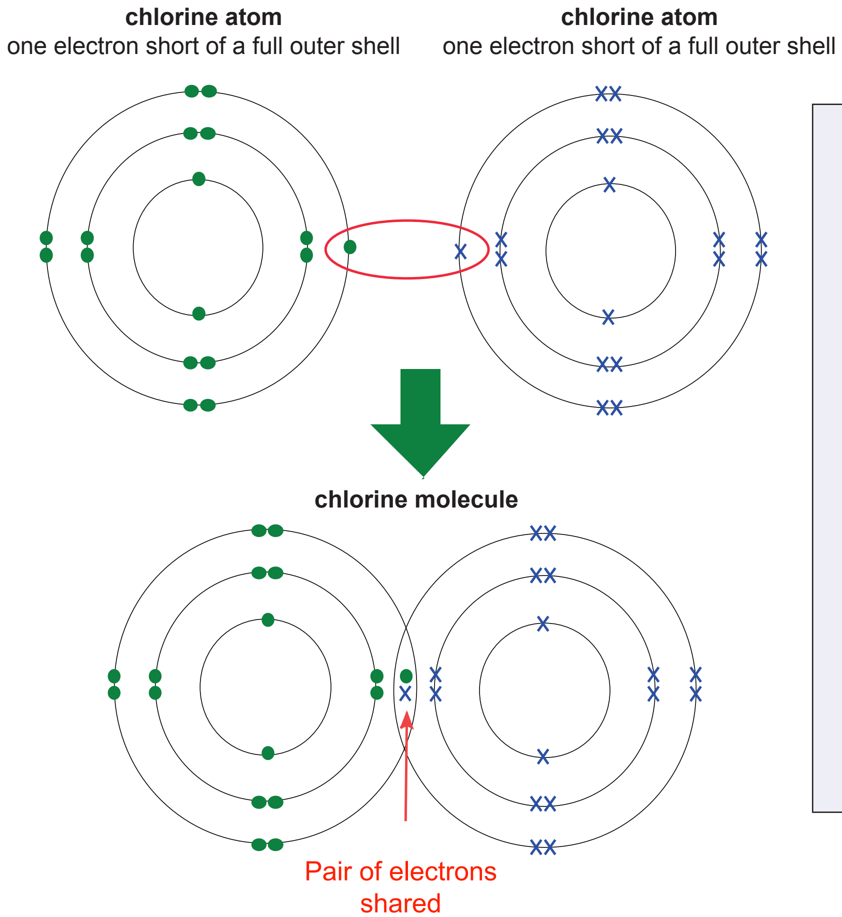
Atoms can also obtain full shells of electrons by sharing electrons. The bond formed is called a covalent bond. It occurs when non-metals bond together.

> A **covalent bond** occurs when **non-metals share a pair** of electrons.
> The atoms bond together to form **molecules**.

The covalent bonds **in** a molecule are **strong** but the forces **between** molecules are weak.

Dot and cross diagrams

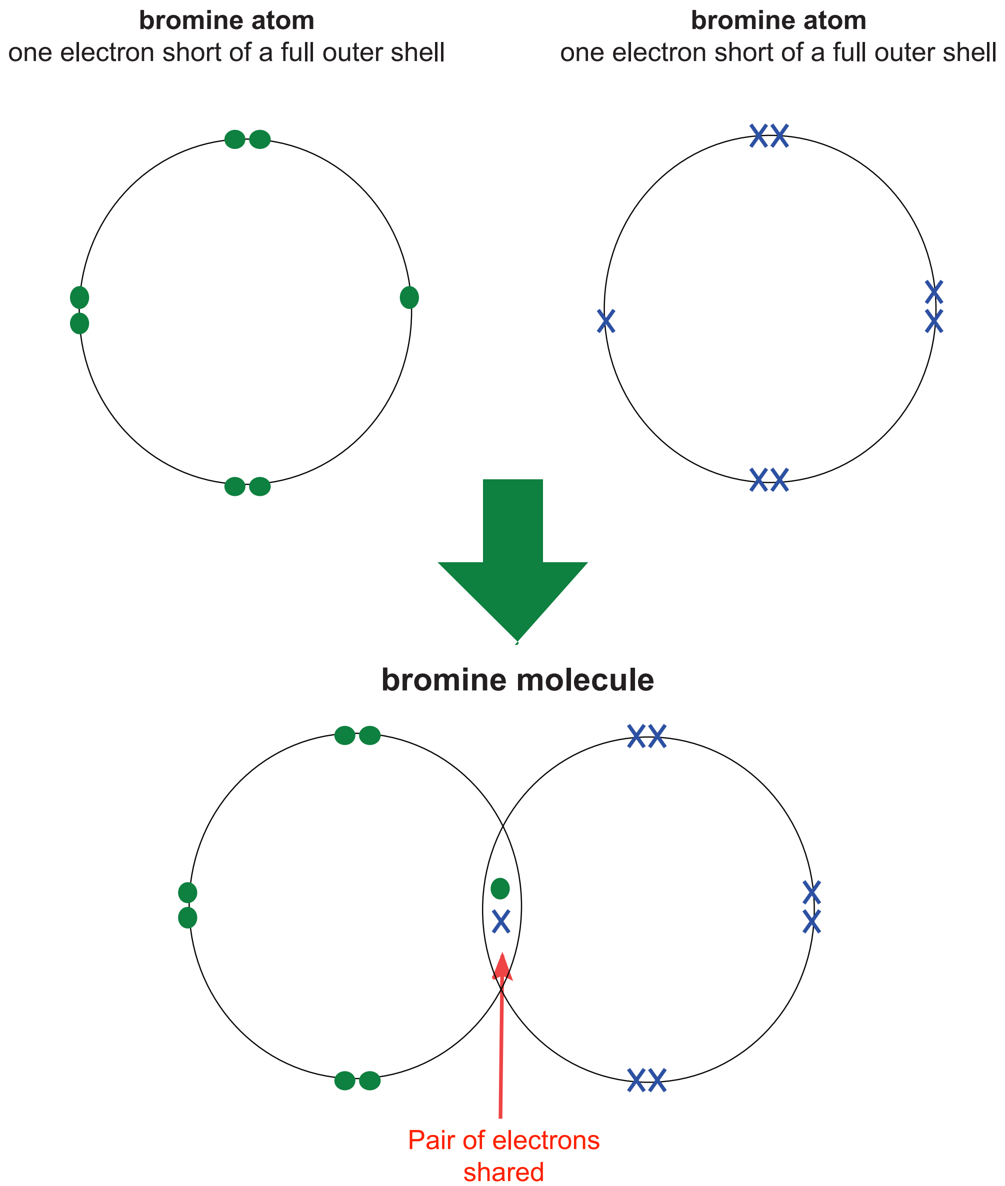
We can also represent covalent bonding using dot and cross diagrams. The diagram below shows how electrons are shared between two chlorine atoms.



> You must be able to draw dot and cross diagrams for covalent molecules in an exam.
> Remember:
>
> - share electrons in pairs
> - **the atoms should have full outer shells after they bond**
> - it is the outer shell that is important in bonding – so concentrate on that

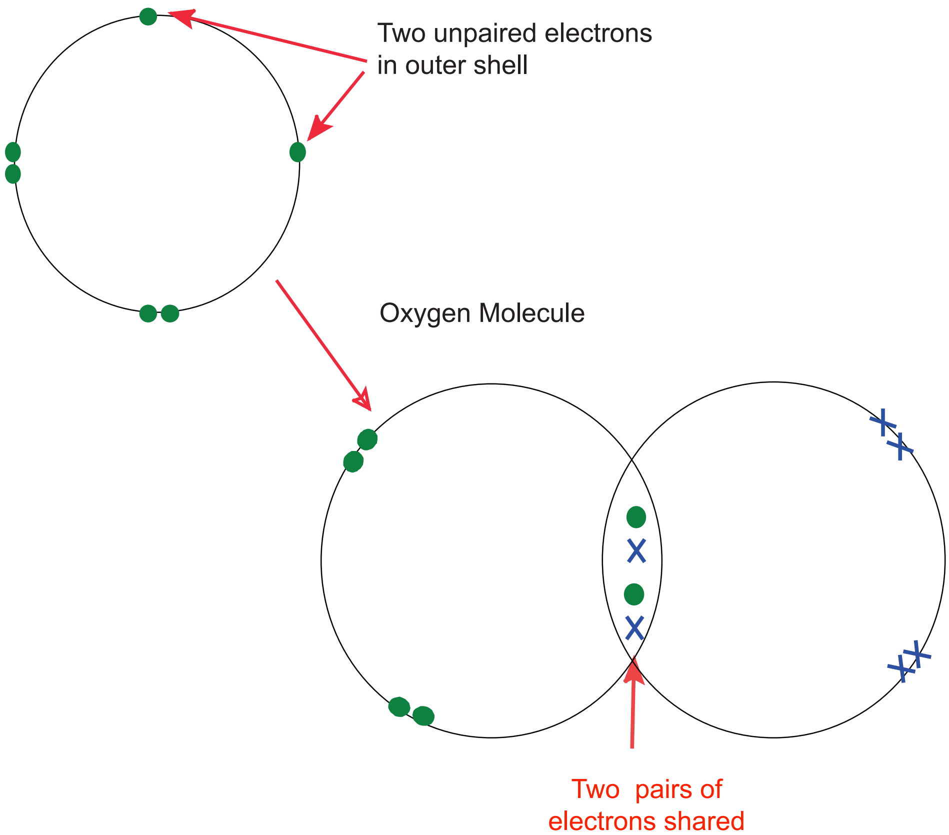
Examples

1. Bromine gas, Br_2, consists of bromine molecules. Draw a diagram to show the bonding in a bromine molecule.



2. Oxygen gas, O_2, consists of oxygen molecules. Draw a diagram to show the bonding in an oxygen molecule.

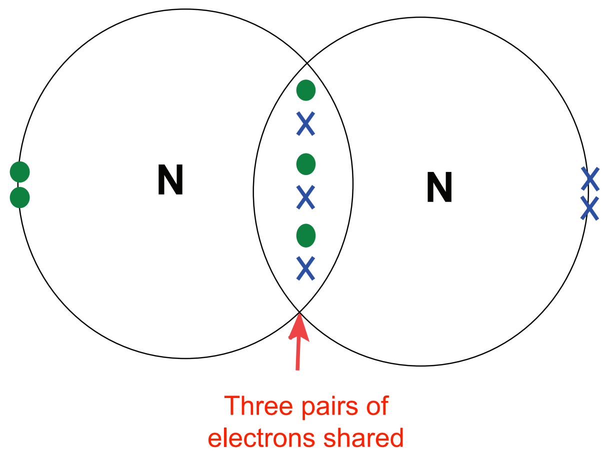
Oxygen atom
In this case we are **two electrons short** of a full shell.
Oxygen needs to share **two pairs** of electrons to complete its outer shell.



3. Nitrogen gas, N_2, consists of nitrogen molecules.
Draw a diagram to show the bonding in a nitrogen molecule.

Nitrogen atom
Electronic structure 2,5
In this case we are **three electrons short** of a full shell. Nitrogen needs to share three **pairs** of electrons to complete its outer shell.

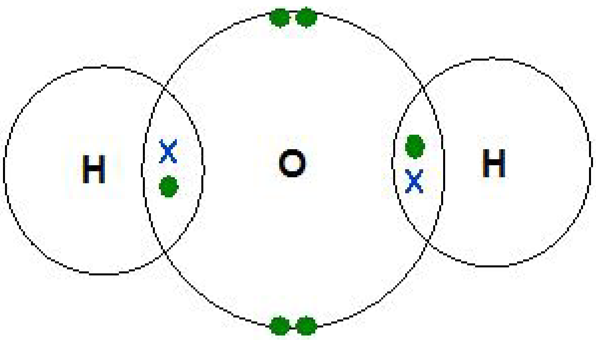
Nitrogen molecule



4. Water, H_2O, consists of oxygen and hydrogen atoms.
Draw a diagram to show the bonding in a water molecule.

Oxygen atom
Electronic structure 2,6
In this case we are **two electrons short** of a full shell.
Each oxygen atom will need to share **two pairs** of electrons to complete its outer shell.
Hydrogen atom
Electronic configuration: 1
Each hydrogen is **one electron** short of a full shell.
Each hydrogen atom will need to share **one pair** of electrons to complete its outer shell.

Water molecule



Strong electrostatic forces between the nuclei of the atoms and the shared pair of electrons means the **covalent bonds are strong.**

The forces **between** molecules tend to be weak which means that it is easy to separate molecules.

When a compound is made of small molecules (‘simple’ molecules) it will have a low melting/boiling point because we only need to break these weak forces between molecules and not covalent bonds.

TEST YOURSELF

1. Covalent bonding occurs when the following types of elements bond to form a compound:

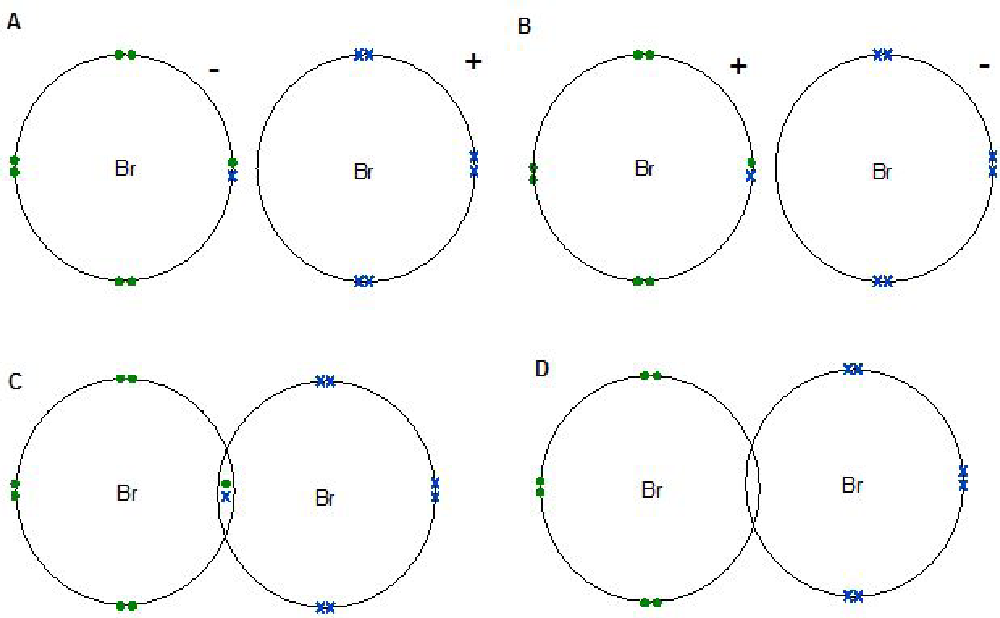
A Metal and a metal
B Metal and a non-metal
C non-metal and non-metal

2. Nitrogen can bond with another nitrogen atom to form a stable molecule (N_2). State how many electron pairs will be shared between the two nitrogen atoms.

Nitrogen is in group 5 and has the electronic configuration 2,5.

A 3
B 1
C 5

3. Bromine has seven electrons in its outer shell.
The diagram showing the bonding in bromine (Br_2) is:



Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Allotropes of carbon

The element carbon comes in different forms or ‘allotropes’. These include:

- graphene
- graphite
- carbon nanotubes
- fullerenes
- diamond (Higher tier only)

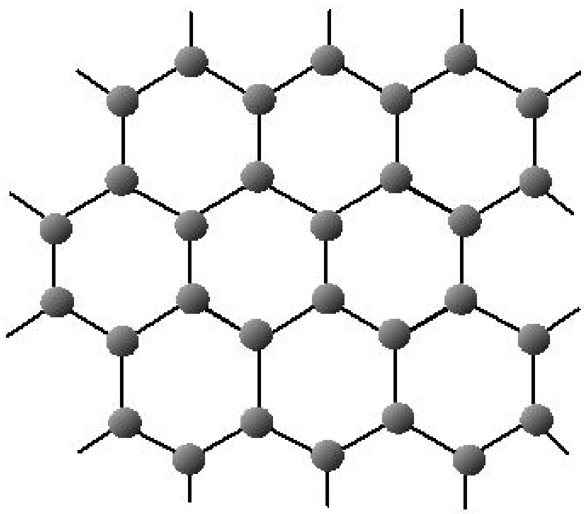
All these different forms are giant molecules in which very large numbers of carbon atoms are bonded together. In each allotrope there are differences in the way that the atoms are joined.

Graphene

Graphene is a **one-atom** thick (two-dimensional) sheet of carbon atoms bonded into a honey-combed lattice.

Each carbon atom is covalently bonded to **three** others forming hexagonal rings.

A small part of a sheet of graphene is shown below.



The carbon atoms are very strongly bonded in each layer. This means it is a **very** strong material.

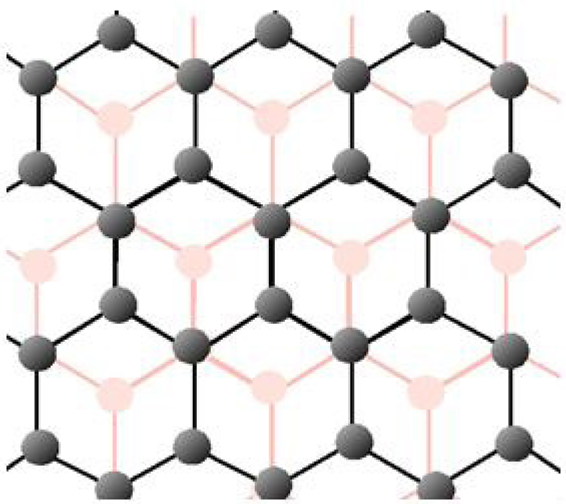
Currently, it is the strongest material yet made. It is about 200 times stronger than steel.

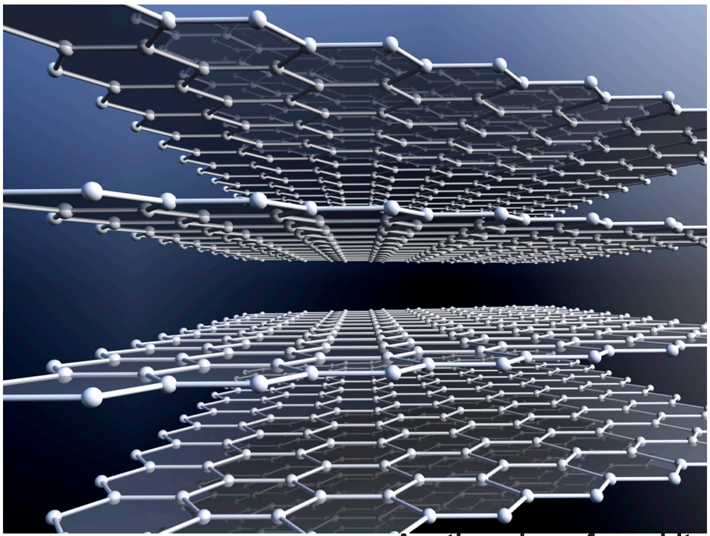
This means we will soon be able to make stronger, lighter and thinner materials than we use at the moment e.g. we could replace the metal in cars to make a much lighter and more economical car.

Graphite

Graphite is also a sheet structure. It is made of **many** layers of graphene stacked together on top of each other.

Diagram showing two layers of graphite, looking from above:





Another view of graphite
PASIEKA/SPL/gettyimages

The carbon atoms **in** each layer are strongly bonded together. This means that it is a strong material. Its strength has been used to make light sports equipment, for example tennis rackets.

The bonds **between** layers are very weak. This means layers can slide over one another, like sheets of paper.

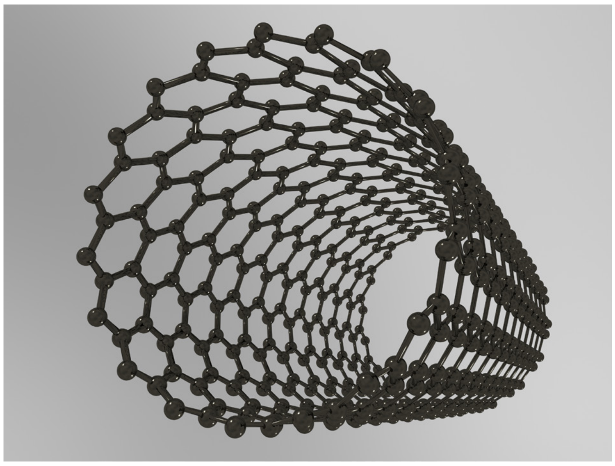
Graphite is therefore used in pencils (layers of atoms slide off to mark the paper) and as a lubricant.

Materials for a purpose (specification 3.1)

Carbon nanotubes

These are long molecular-scale tubes of carbon. Once again carbon is bonded to three neighbours in hexagonal rings. Think of a layer of graphite or graphene curled to form a cylinder.

Carbon nanotubes have already been constructed with lengths up to 132 000 000 times their diameter.



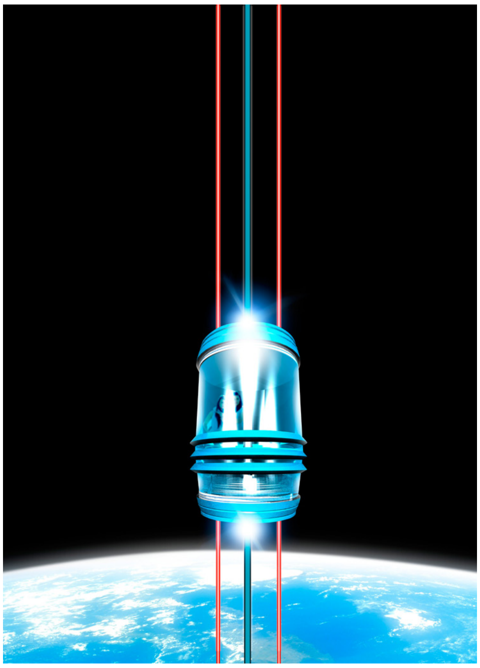
Carbon nanotube
Olga Reukova/gettyimages

This is also a **very** strong material because of the strong covalent bonding within each tube. Their strength gives them many possible applications, e.g. bullet proof vests, making lightweight and strong sports equipment.

An elevator into space

It has been suggested that an elevator could be made from Earth to a satellite in space. This would need to have cables made of a very light and strong material

Carbon nanotubes may be strong and light enough to do this.



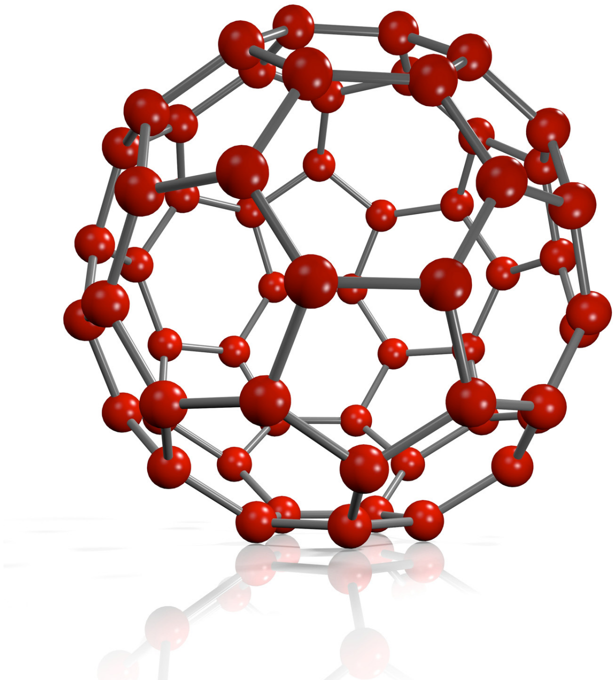
Space elevator
Science Photo Library / Alamy Stock Photo

Fullerenes

Fullerenes are a large class of allotropes of carbon and are made of balls and ‘cages’ of carbon atoms.

Buckminster fullerene is one type of fullerene. The molecule has 60 carbon atoms arranged in a hollow sphere. Each carbon is bonded to three neighbouring carbon atoms in rings of 5 or 6 carbon atoms.

Their structure allows them to be used for drug delivery into the body, as lubricants and as catalysts.



Buckyball
maggio07/gettimages

Electrical properties of graphene, graphite and carbon nanotubes

Carbon is in group four and is four electrons short of a full shell.

In each of the structures we looked at, carbon shares three of the four electrons to make strong covalent bonds.

The fourth electron of each carbon is a free electron (or delocalised electron). It can move throughout the layer.

All you need to know is that the electrical properties of these materials is due to the free (or delocalised) electrons.

Delocalised electrons are not fixed to a carbon atom but are free to move over the whole layer (or 'through' the tube).

This means each of these structures can conduct electricity. In some cases their electrical properties are unusual which means they may have useful applications in the future in electronics.

Some of the structures described have only been discovered very recently and there is still a lot of research going on into how we can make these allotropes for different uses.

A ***few*** examples of uses are given below.

Allotrope	Use based upon electrical properties
graphene	• low energy light bulbs • lightweight flexible display screens • solar cells
graphite	• electrodes in industrial processes
carbon nanotubes	• electronics industry

A graphene light bulb
Manchester University

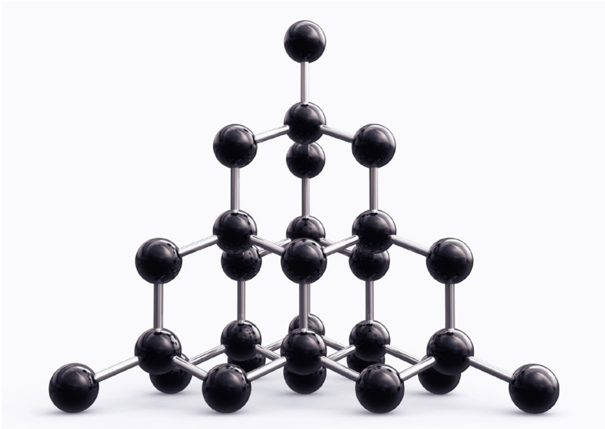
Foundation tier: You do **not** need to know about diamond.

Diamond

Diamond is also a giant molecular structure. Unlike the other allotropes of carbon we have examined, each carbon atom is covalently bonded to four other carbon atoms into a giant three-dimensional molecule.

Structure of diamond

- There are **no** free electrons or ions in diamond, so it does **not** conduct electricity
- Diamond is a hard material with a high melting and boiling point. A lot of energy is needed to separate the atoms in diamond. This is because covalent bonds are strong, and there are covalent bonds throughout diamond.



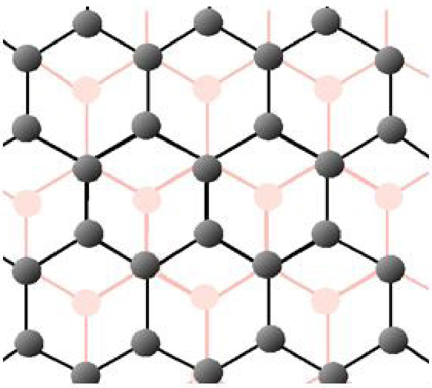
Diamond
goktugg/gettyimages

Uses of diamond

1. The hard structure of diamond means that it is used in drill bits which cut through rocks or other hard materials
2. It is used in cutting tools.
3. Diamond is used in jewellery because it will sparkle and reflect light when cut correctly.

TEST YOURSELF

1. The following structure represents:



A graphene
B graphite
C diamond

2. In each layer of graphite there are only:

A strong forces holding atoms together
B weak forces holding atoms together
C no forces acting

3. Graphene is an electrical conductor due to:

A free ions
B localised electrons
C delocalised electrons

4. Which of the following is best described as a cage structure?

A diamond
B graphite
C a fullerene

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

MAIN CLASSES OF MATERIALS

Summary

A summary of the main types of material you need to know about is given below.

Material	Summary	Examples
metals	Pure metals are made of one kind of atom and typically have high electrical and thermal conductivities, are hard and strong.	aluminium iron titanium
alloys	Mixture of two or more elements, one of which is a metal. Properties of alloys make them more useful than pure metals	stainless steel low carbon steel brass
polymers	Polymers are generally organic compounds based upon carbon and hydrogen. They are very large molecular structures. Usually they are low density and are not stable at high temperatures. Their strength, stiffness, and melting temperatures are generally much lower than those of metals and ceramics.	polyethene PVC
ceramics	Ceramics are inorganic solids that have been shaped and then hardened by heating to high temperatures. Hard brittle compounds with very high melting points, low thermal conductivity and high resistance to chemical attack.	pottery porcelain advanced ceramics

MAIN CLASSES OF MATERIALS

composite (composites)	Made when two or more materials with **different** properties are combined to produce a new material. Physical and chemical properties of each of the constituent materials remain distinct in the new material.	fibreglass carbon fibre composites

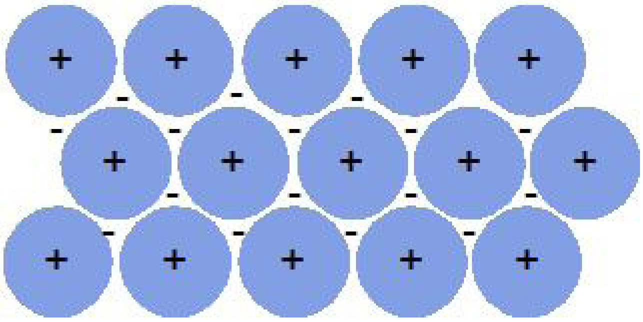
Metals and metallic bonding

FOUNDATION TIER

You do **not** need to be able to describe the bonding in a metal.

You **do** need to know the general properties of metals and that there are some important exceptions to these properties

The bonding between atoms in a metal is best described as closely packed positive metal ions in a 'sea' of delocalised (free) electrons.



The electrostatic attraction between the positive ions and the free (delocalised) electrons holds the metal together.

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

General properties of metals

The general properties of metals are described in the table below – but be warned there are exceptions!

Property	Explanation	Important exceptions
High thermal conductivity (good conductor of heat)	free (delocalised) electrons are able to move and carry energy with them	
High electrical conductivity (good conductor of electricity)	delocalised electrons are free to move throughout the metal	
Dense	atoms are closely packed together	sodium and potassium
High melting and boiling point	metallic bonding is strong – strong attraction between metal ions and delocalised electrons	mercury – a liquid at room temperature
Strong - High tensile strength		sodium and potassium
Hard	atoms are closely packed and held by strong bonds	lead is relatively soft
Malleable and ductile	layers of atoms are not held in rigid positions and can slide over each other	
Lustrous (shiny)		

NEW WORDS TO REMEMBER: Malleable: beaten into sheets
Ductile: pulled into wires

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

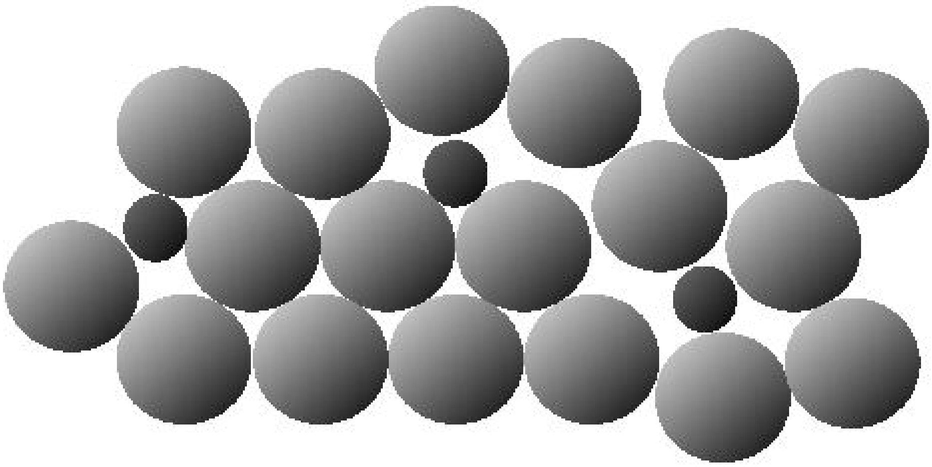
Alloys

Pure metals are rarely used in manufacturing because they are too soft. We can change the properties of metals by carefully adding other elements to the metal.

An **alloy** is a mixture of two or more elements, **one of which is a metal**.

Alloys are often harder and stronger than the pure metal.

When we make an alloy we mix together atoms of different sizes. This distorts the regular structure of the metal making it more difficult for layers to slide over each other.



Alloys are harder and less malleable than pure metals because it is more difficult for the layers to slide over each other.

You do **not** need to remember the details about different alloys but you must be able to interpret information on alloys.

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Steel

Steel is an example of an alloy. We can change the properties of steel by adding different elements.

Some examples of different types of steel are given in the table below.

Alloy	Iron mixed with	Properties	Uses - examples
low carbon steel	0.07-0.25% carbon	easily shaped	car bodies
high carbon steel	0.85-1.2% carbon	hard	railway lines cutting tools
stainless steel	>10.5% chromium carbon silicon manganese	resistant to corrosion	cutlery sinks exhaust systems surgical instruments

Alloys of aluminium and titanium

Metal/Alloy	Density (g/cm^3)	Tensile strength (MPa)	Corrosion resistance
aluminium	2.7	276	
Duralumin • aluminium • copper • magnesium	2.8	420-500	relatively good
titanium	4.4	434	
titanium alloys	4.3-4.9	950	good

Materials for a purpose (specification 3.1)

The density of steel is typically 7.7-8.1 g/cm^3 making both aluminium and titanium alloys much lighter than steel.

From the table, notice that:

- duralumin is much stronger than aluminium
- titanium alloys are much stronger than titanium

Since duralumin is a high strength and low weight alloy, it is used in aircraft.

Titanium is expensive, and is only used where its special properties of low density, hardness and resistance to corrosion cannot be reproduced by cheaper materials.

Titanium alloys are used in special parts of aircraft, nuclear reactors and hip joint replacements.

Polymers

Polymers are generally organic compounds based upon carbon and hydrogen.

Polymers are very large covalent molecules with atoms bonding to each other repeatedly in **one** direction.

The properties of polymers depend on the structure and bonding.

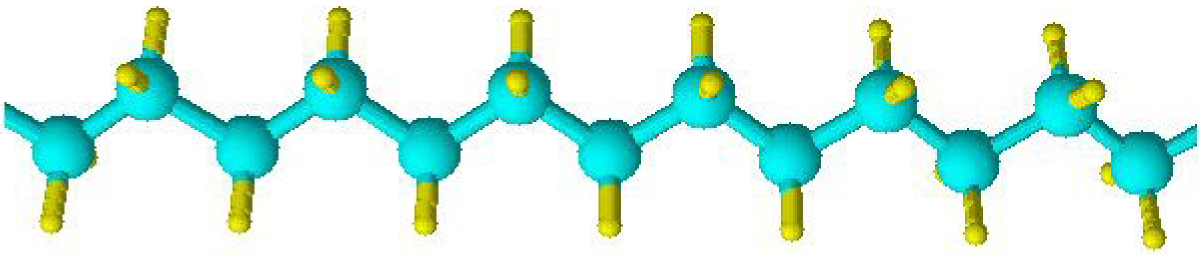
They can be formed into complex shapes. Their strength, stiffness, and melting temperatures are generally much lower than those of metals and ceramics.

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Polyethene

An example of a polymer is polyethene. A part of the long chain structure of polythene is shown here. There will be many thousands of atoms either side.



Blue represents carbon atoms while yellow represents hydrogen atoms.

The long molecules lie side by side. The forces in the chain are strong covalent bonds but **between** chains there are only weak forces. The weak forces between chains mean that the chains can slide past each other making the material flexible.

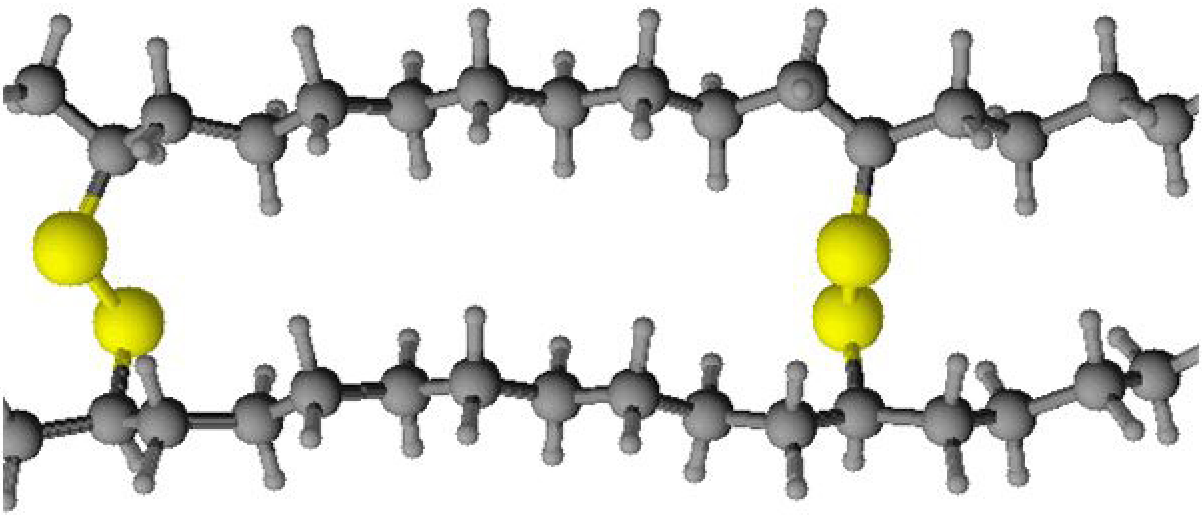
The melting point is relatively high since a lot of energy is needed to separate the long chains.

Typical uses for polythene include plastic shopping bags and plastic bottles, while polystyrene is typically used for insulation and protective packaging.

Cross-linking chains

We can modify the properties of polymers by **cross-linking chains**.

Cross-linking involves linking different chains together with covalent bonds.



Polymer with cross-links between chains

The polymer molecules are no longer able to slide over each other so easily. This makes materials less flexible but tougher. It is also harder for it to be stretched. Cross-linking also gives materials high melting points.

Kevlar®

Body armour using Kevlar®
Murmakova/gettyimages

Kevlar® is the trade name for a high-strength, lightweight and flexible fibre. It can be woven into materials that are very light and strong.

It is strong and tough because its molecules are held together in sheets by strong chemical bonds and strong forces between chains.

Kevlar® has a low density but is not stable at high temperatures.

It is used in:

- bicycle tyres, racing sails and police bullet-proof vests because of its high strength-to-weight ratio.
- flexible body armour, i.e. it is a polymer designed for ‘heavy duty’ use!

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Ceramics

Ceramics are inorganic solids that have been shaped and then hardened by heating to high temperatures.

They include substances like clay and china.

Ceramics have giant structures with strong covalent bonds. This means they are hard, brittle compounds that have very high melting points, low thermal conductivity and are resistant to chemical attack.

The uses of ceramics:

There are a wide range of uses which include:

- electrical insulators
- wall and floor tiles
- pottery
- heat resistant tiles on space shuttle
- catalytic convertors in car exhausts
- toilets and wash basins

Discovery
David Coleman / Alamy Stock Photo

Ceramics in action
David R. Frazier Photolibrary, Inc. / Alamy Stock Photo

Bathroom
Arcaid Images / Alamy Stock Photo

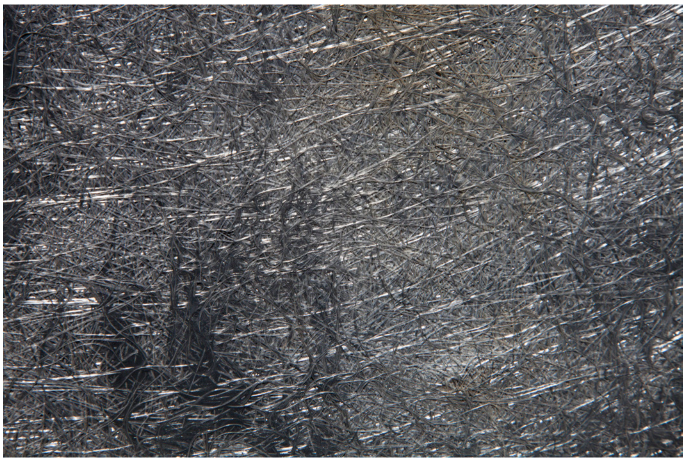
Composites

Composites are combinations of materials.

They are materials made from two or more materials which have different physical or chemical properties.

The individual materials making the composite remain separate and distinct within the finished structure. The new material may have a number of advantages compared to traditional materials. These materials may be:

- stronger
- lighter



Glass-fibre composite
hairballusa/gettyimages

The properties of the new material will be a combination of the best properties of the separate materials.

Typical engineered composite materials include:

- mortars and concrete
- carbon fibre composite (mixture of carbon fibres and polymer resin)
- glass-fibre (mixture of glass fibre and a polymer coating)

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Examples of uses

- buildings and bridges
- race car bodies
- baths
- sports equipment (e.g. bike frames, tennis rackets, shafts of golf clubs)

SOMETHING TO WATCH

Watch this clip about making car bodies.

http://www.bbc.co.uk/education/clips/zsx4d2p

Selecting a material for a purpose

In an exam you are likely to need to comment on why a material is needed for a particular purpose in light of its properties.

Think about the properties that are important if the material is to be used for a particular purpose.

- Does it need to be light (aircraft parts, car body)?
- Does it need to be resistant to corrosion or biologically inert (e.g. in replacement joints)?
- How important is strength?
- What about cost?

Very often you will need to consider a combination of properties that might make a material most suitable.

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Understanding the properties

Properties that you may need to consider are:

tensile strength	a measure of the force required to pull something such as wire, or beam to the point where it breaks
hardness	the resistance to scratching or wear
density	the mass per unit volume
durability	the ability to withstand wear, pressure, or damage
shock absorption	the ability to absorb mechanical shock
thermal conductivity	the ability of a material to allow the flow of heat
electrical conductivity	the degree to which a specified material conducts electricity
stress	the stress applied to a material is the force per unit area applied to the material. The maximum stress a material can stand before it breaks is called the breaking stress.

Measuring properties of materials

Measuring the density of a material

Density is the mass per unit volume.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Digital balance
Martin Shields / Alamy Stock Photo

To find the density of a material we need to find its mass and volume.

Mass

This can be found by weighing the object on a digital balance.

The mass needs to be measured accurately in grams.

Volume

There are a number of ways of finding the volume.

1. The best way is to immerse the object completely in water and measure the volume of water displaced.

   The volume of water displaced will equal the volume of the object.

2. If the object has a regular shape, e.g. a cube or sphere, you can use a digital calliper or micrometre to measure the length of each side or radius of a sphere.

Record the volume displaced in cubic centimetres.

Calculate the density in units of g/cm³ using the equation:

.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Micrometre
Image Source / Alamy Stock Photo

Digital calliper
Sergejs Nescereckis / Alamy Stock Photo

Unit 3.1: Materials for a purpose

Materials for a purpose (specification 3.1)

Measuring stress

The stress applied to a material is the force per unit area applied to the material. The maximum stress a material can stand before it breaks is called the breaking stress or ultimate tensile stress.

The equation below is used to calculate the stress.

$$\text{stress} = \frac{\text{force}}{\text{cross-section}}$$

Where:

stress is measured in Nm^{-2}
force in N (newtons)
cross-sectional area in m^2

Hooke's Law and the spring constant

If we stretch an elastic object like a spring then the increase in length is called the extension.

The extension of an elastic object is directly proportional to the force applied to it.
This is known as **Hooke's Law.**

It can be written as an equation:

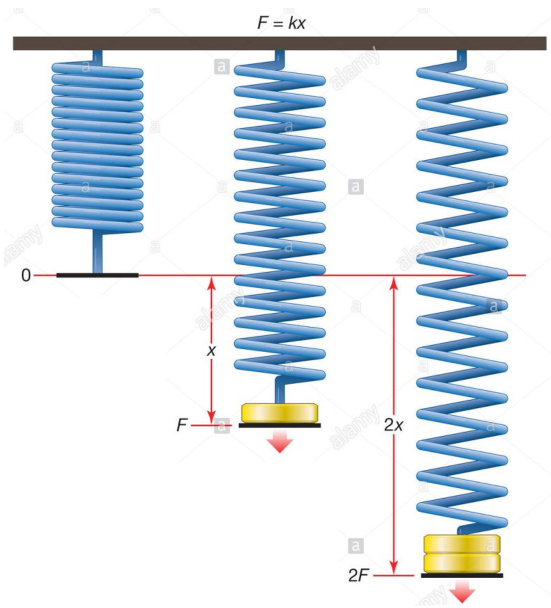
force (N) = constant (N/m) × extension (m)

$$F = k \times x$$

This equation works as long as the elastic limit is not exceeded.

If a spring is stretched too much (beyond its elastic limit), it will not return to its original length when the load is removed.

The stiffer the spring or the harder it is to stretch then the greater the value of the spring constant.



Hooke's law
Universal Images Group North America LLC / Alamy Stock Photo

Measuring the spring constant

The spring constant can be found by carrying out an experiment.

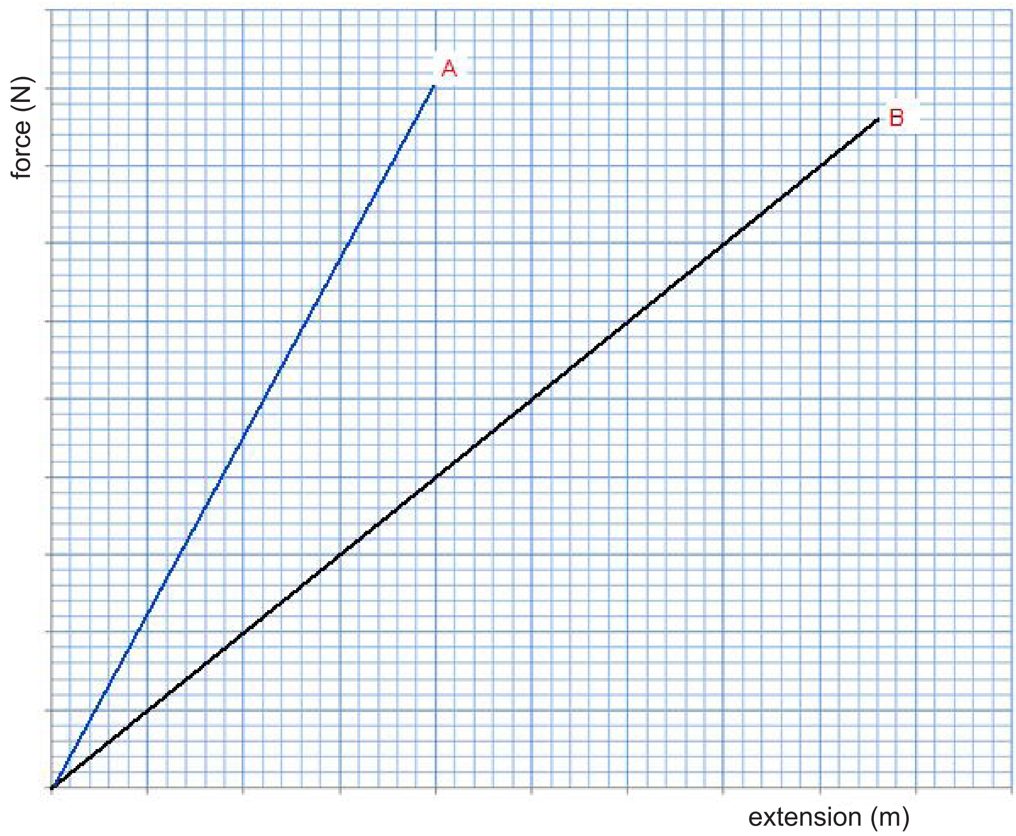
For example:

- measure the unloaded length of a spring
- add different numbers of slotted masses to the spring and measure its new length for each weight
- calculate the extension - the new length minus the unloaded length
- plot a graph of force against extension
- the gradient (slope) is the spring constant

The graph below shows a plot for two different springs.

The steeper the line the greater the spring constant:

spring constant of **A** > spring constant of **B**.



Materials for a purpose (specification 3.1)

TEST YOURSELF

1. Malleability describes the property of a substance when it is:

A pulled into wires
B beaten into sheets
C shattered into pieces

2. Density is given by:

A volume × mass
B volume/mass
C mass/volume

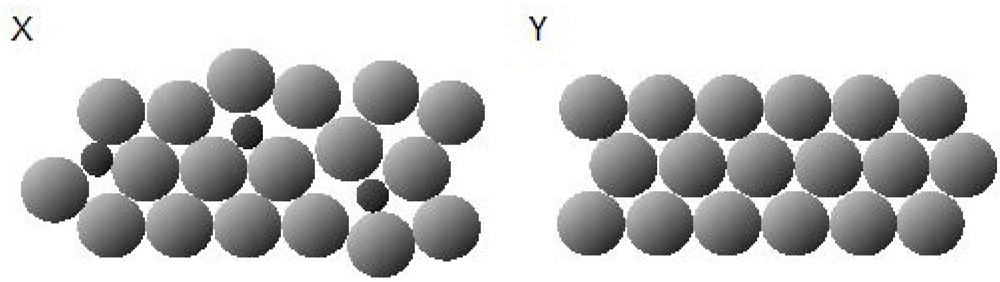
3. Examine the information below and explain why titanium is used in aircraft in preference to aluminium.

metal alloy	density (g/cm^3)	tensile strength (MPa)	tensile/density ratio (units)
aluminium alloy	2.8	420	150
titanium alloy	4.3	950	221

Titanium is used because of its:

A high density
B low density
C high tensile strength / density ratio
D low tensile strength / density ratio

4 Look at the two structures below and select which of A to E are true (It is possible that all statements are true, some statements are true or that no statements are true).



A X and Y are both alloys
B X is a metal and Y an alloy
C X is harder than Y
D X is an electrical conductor; Y is not an electrical conductor
E None of the statements A to D are true

Unit 3.1: Materials for a purpose

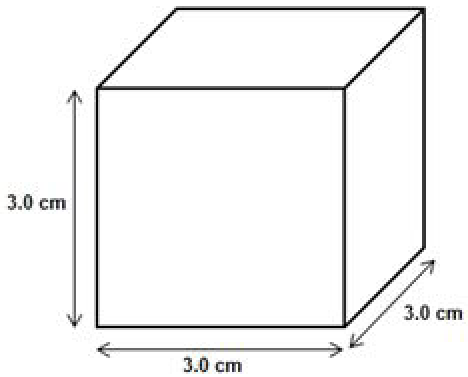
Materials for a purpose (specification 3.1)

PRACTICE QUESTIONS

1. The table below contains information on the density of metals.

Metal	Melting point (°C)	Density (g/cm^3)
lead	327	11.3
cobalt	1 495	8.9
aluminium	660	2.7
stainless steel	1 489	8.0

(a) A block of metal has been found in a laboratory. It has a mass of 72.0 g with three sides of the same length (3 cm).



(i) Calculate the volume of the metal block using the equation:

volume = width × depth × length [1]

..................cm^3

(ii) Identify the metal in the block. You will need to use your answer to part (i) and the equation below. [2]

$$\text{density} = \frac{\text{mass(g)}}{\text{volume(cm}^3\text{)}}$$

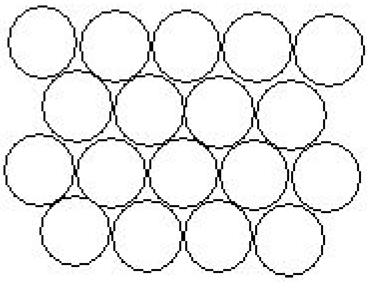
metal = ……………………………

(b) The table below shows some information about three alloys of iron.

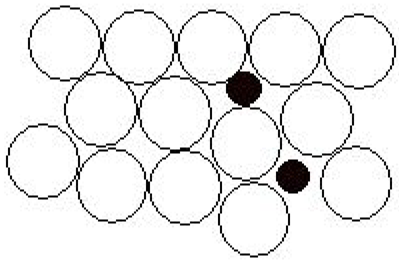
Alloy of iron	Composition	Properties
mild steel	99.8% iron 0.2% carbon	easily pressed into shape will rust
high carbon steel	98% iron 1.7% carbon 0.3% manganese	hard but brittle
stainless steel	74% iron 0.3% carbon ……% chromium 7.7% nickel	hard rust resistant

(i) State which diagram below represents the stainless steel.
Give **one** reason for your choice. [2]

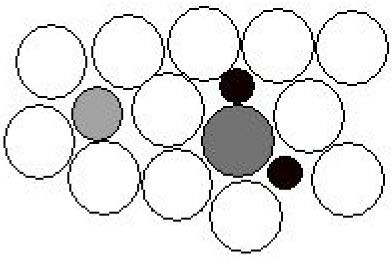
A



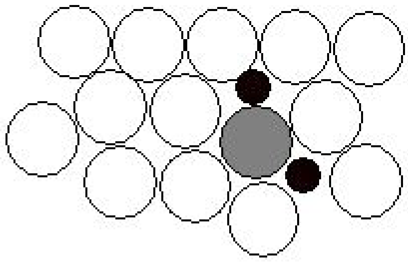
B



C



D



Stainless steel: ……………………….

Reason: …………………………………………………………………………….

………………………………………………………………………………………..

(ii) Calculate the percentage (%) chromium in stainless steel.
Use your answer to complete the table. [1]

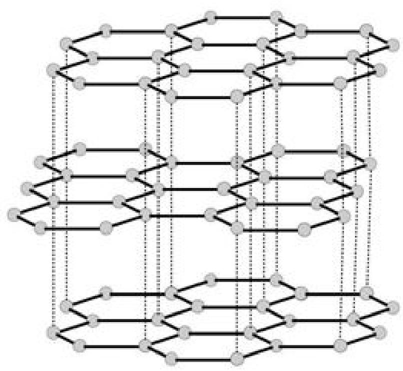
2 The correct choice of material can have a major effect on the success and performance of sporting equipment.

(a) Complete the table by adding one tick (✔) in each row to identify the properties of ionic and covalent compounds. [3]

Feature	Ionic bond	Covalent bond
sharing electrons		
strong electrostatic attraction		
found between non-metals		

(b) The diagrams below show two forms or allotropes of carbon.

(i) Identify each allotrope. [2]



1. .... **2.** ....

(ii) State the type of bond that is common to both allotropes. [1]

....

(c) Performance of cyclists in the Olympic Games can be improved by using the best materials available to build their bikes.

Bike
Sjoerd van der Wal/gettyimages

Information about materials that can be used in racing bikes is shown in the table below.

Material	Tensile strength (GPa)	Density (g/cm^3)	Melting point (°C)
carbon fibre	Density	1.75	3 500
steel	Melting point	7.90	2 750
aluminium	0.70	2.70	660
titanium	2.02	4.50	1 668

State which material is the most suitable for use in a racing bike, giving **two** reasons for your answer. [3]

....

....

TEST YOURSELF - ANSWERS FOR UNIT 3.1

Ionic bonding

1. B
2. D
3. C
4. C
5. C
6. C
7. D

Covalent bonding

1. C
2. A
3. C

Allotropes of carbon

1. B
2. A
3. C
4. C

Properties of metals and alloys

1. B
2. C
3. C
4. C only

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

GROWING CROPS

How can we produce enough high quality food economically for a growing population? How can we do this so that our environment is not damaged?

Bioscientists are continually looking at new ways of producing food as well as how we can improve existing farming methods.

In order to understand plant growth, it is vital we understand how plants grow and the requirements they need to maintain growth.

Field of maize
incamerastock / Alamy Stock Photo

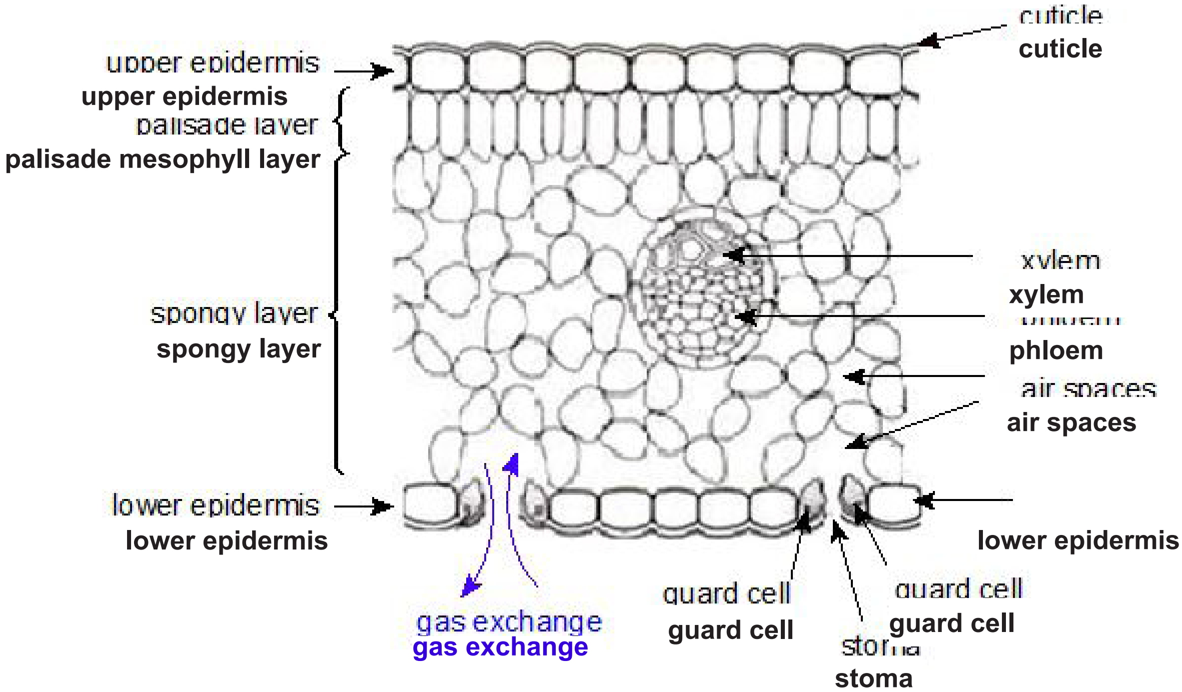
Materials for the life processes in a plant

A green plant needs certain materials and resources from its environment for the maintenance of life processes and healthy growth:

Resource	Comment
minerals	Four important minerals, nitrates, phosphates, potassium and magnesium are needed for healthy growth. These are absorbed from the soil by the roots.
water	This is absorbed by the plant's roots.
carbon dioxide	This is obtained from the air.
light	This is absorbed by chlorophyll in the leaves of green plants.

Structure of a leaf

Cells in the leaf contain chloroplasts which contain the chlorophyll and other enzymes needed for photosynthesis.



Make sure you can recognise and label the different structures in a leaf.

Key things to notice about the structure of a leaf:

- a leaf has a large surface area to maximise the light it can absorb for photosynthesis
- water travels to the leaf from the roots though the xylem by a process known as transpiration
- water vapour is lost to the atmosphere through the stomata (stomata is the plural of stoma) in the leaf
- gases can diffuse in and out of the leaf through the stomata
- at either side of the stomata are guard cells. These can open and close the stomata to control the rate of water loss
- the phloem moves food substances from leaves to the rest of the plant

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

The process of photosynthesis

Plants are called producers because they are able to make their own food. They convert simple materials found in the environment into sugar in a process known as photosynthesis.

The requirements for **photosynthesis** are:

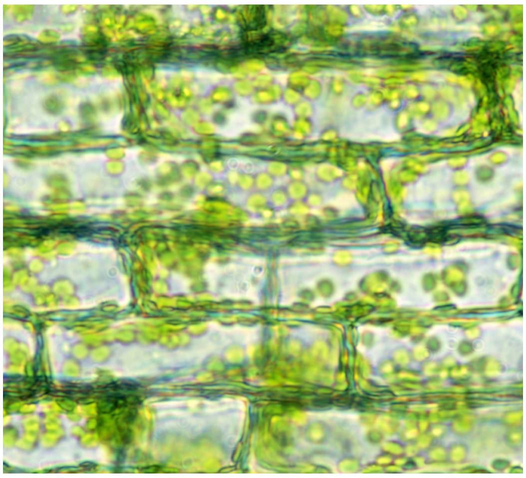
- carbon dioxide and water
- chlorophyll which absorbs light.

Chlorophyll (a green substance) is found in chloroplasts in the cells of plant leaves. Oxygen is also produced in this reaction as a by-product.

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

Enzymes are also needed but we don't need to know details of them for GCSE.

This photograph shows the chloroplasts in the leaf cells of a water plant.



Water weed
Grant Heilman Photography / Alamy Stock Photo

Factors affecting photosynthesis

If you want to grow a crop in a controlled environment, such as an industrial-size commercial greenhouse, then it is important to know how you can maximise the rate of photosynthesis.

There are **three** factors which can limit the rate of photosynthesis:

- light intensity (photosynthesis cannot occur without light)
- carbon dioxide concentration
- temperature (if it is cold photosynthesis will be slow)

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

Foundation tier: You do not need to know about limiting factors or the following graphs

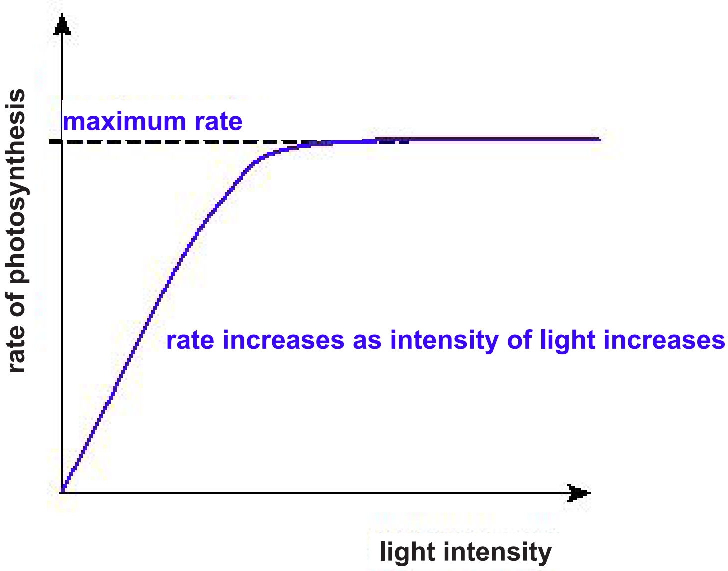
Limiting factors

A **limiting factor** is the factor that is controlling the rate of photosynthesis at a given time, and one that if increased will boost the rate.

In the winter, temperature may be a limiting factor. If the temperature is increased the rate of photosynthesis will increase. At night there is no light and so photosynthesis does not occur.

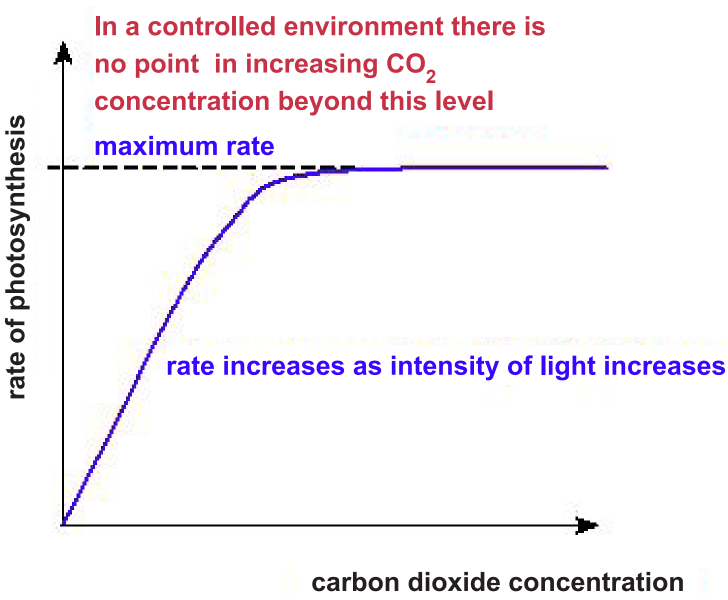
Light intensity

- without light a plant cannot photosynthesise
- increasing the light intensity increases the rate of photosynthesis
- eventually increasing light intensity has no effect on the rate of photosynthesis. Some other factor is limiting photosynthesis (e.g. concentration of carbon dioxide, temperature)



Carbon dioxide concentration

- without CO_2 a plant cannot photosynthesise
- as CO_2 concentration increases so does the rate of photosynthesis
- eventually increasing CO_2 concentration has no effect on the rate of photosynthesis. Some other factor is limiting photosynthesis (e.g. light intensity, temperature)

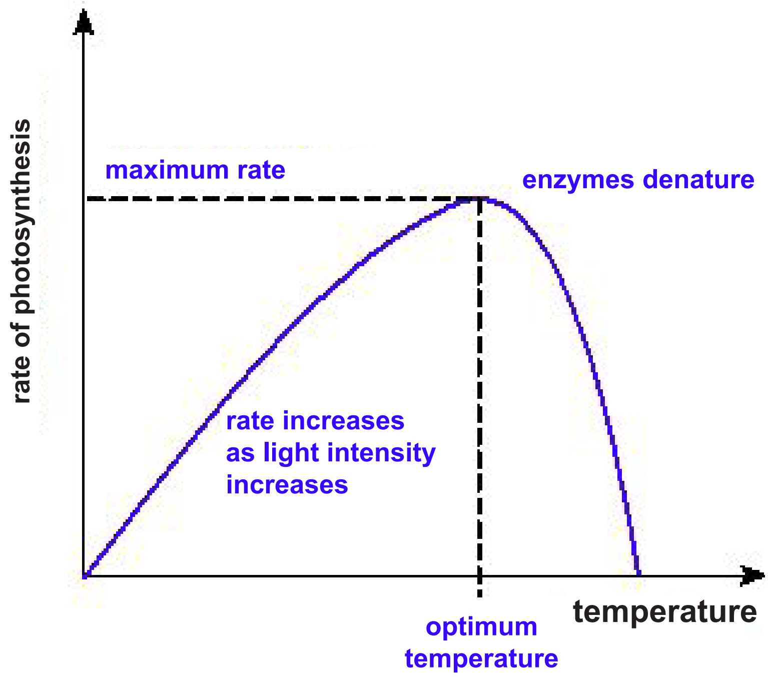


Unit 3.2: Food for the future

Producing food (specification 3.2.1)

Temperature

- if the temperature is too low the enzymes will not work effectively
- increasing temperature increases the rate of photosynthesis
- at higher temperatures the enzymes become denatured so the rate of photosynthesis decreases.



Applying our knowledge to crop production

The farmer can use this information to find the best growing conditions for the crop
They may use:

- artificial light to allow photosynthesis to occur at night
- artificial heating to keep the temperature near the optimum temperature for photosynthesis
- additional carbon dioxide released in the greenhouse to speed up photosynthesis

In each case, the cost of controlling a factor will need to be weighed against the increased productivity. Does the extra cost give a better return or not?

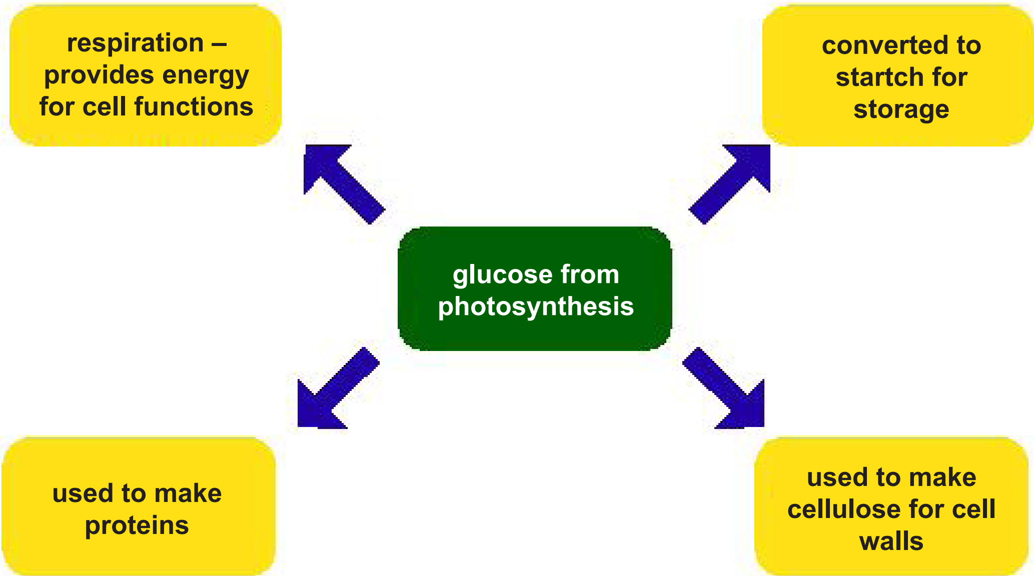
SOMETHING TO WATCH

Watch this clip about how commercial growers increase yield of crops:

http://www.saps.org.uk/secondary/teaching-resources/800-video-commercial-growers

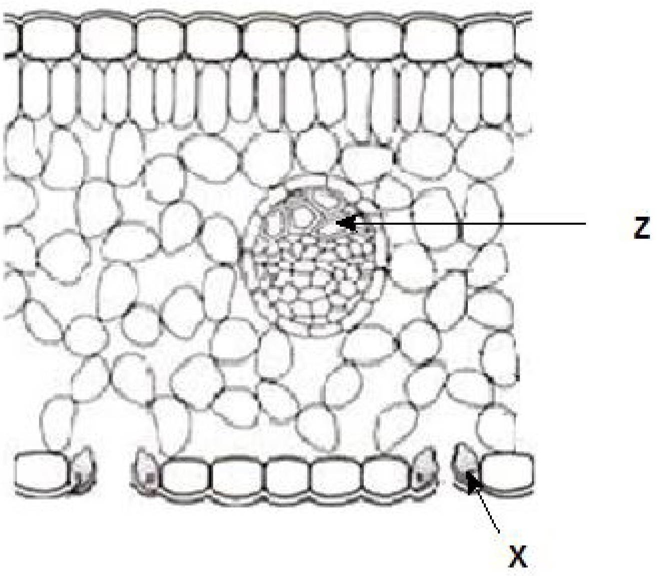
The fate of glucose produced in photosynthesis

What happens to the glucose made in photosynthesis? The fate of the glucose is summarised in the diagram below:



TEST YOURSELF

You need to look at the following diagram to answer questions 1 and 2.



1. Feature **X** should be labelled:

   A stoma
   B guard cell
   C lower epidermis

2. Feature **Z** should be labelled:

   A air space
   B phloem
   C xylem

3. The word equation for photosynthesis is.

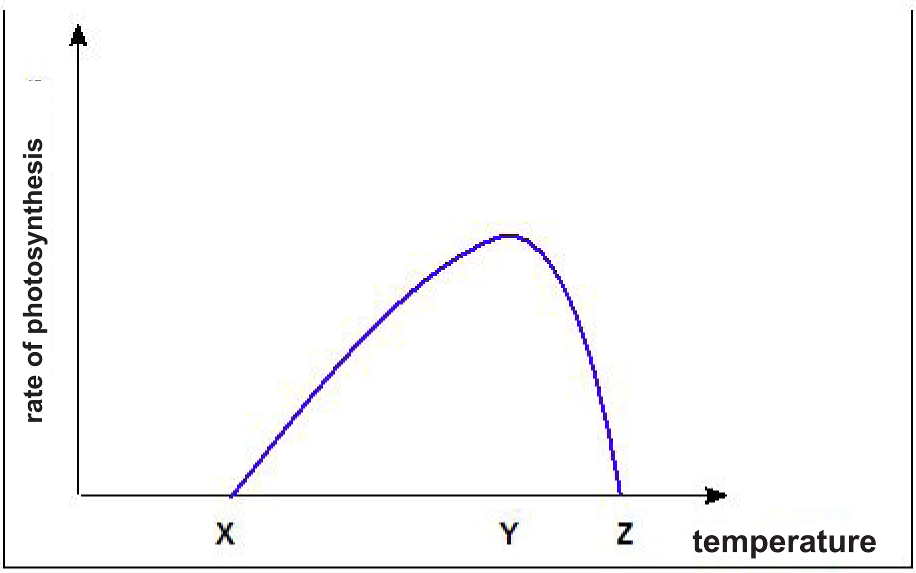
A **carbon dioxide + water** $\xrightarrow{\text{light energy}}$ **glucose + oxygen**

B **carbon dioxide + oxygen** $\xrightarrow{\text{light energy}}$ **glucose + water**

C **carbon dioxide + water** $\xrightarrow{\text{light energy}}$ **startch + water**

Higher tier only

4. Look at the graph showing how the rate of photosynthesis varies with temperature. State the optimum temperature (X, Y or Z) for photosynthesis.



A X
B Y
C Z

Plant nutrients and growth

Plants also need to obtain minerals from the soil in order to build the complex molecules to maintain their systems and for growth.

For healthy plant growth there are a number of key minerals that a plant needs. Some of the most important are recorded in the table below together with why they are important and what you will see if they are deficient.

Mineral	Use	Symptoms of deficiency
nitrates	producing amino acids and proteins	growth is stunted and leaves yellow
phosphates	part of plant DNA found in enzymes involved in photosynthesis	poor growth of roots discoloured leaves
potassium	needed for respiration and photosynthesis	discoloured leaves with dead areas around them

Maize plants showing nitrogen deficiency
Nigel Cattlin / Alamy Stock Photo

Phosphate deficiency in barley
Nigel Cattlin / Alamy Stock Photo

Potato leaf showing potassium deficiency
Nigel Cattlin / Alamy Stock Photo

Producing food (specification 3.2.1)

It is important to make sure that the soil has sufficient minerals and nutrients for the healthy growth of crops.

If plants exhibit symptoms of deficiencies then the farmer may test the soil to find out which mineral is deficient.

Often experience means that testing soils is unnecessary. A general fertiliser (an NPK fertiliser) can be added. An NPK fertiliser contains the elements nitrogen (N), phosphorus (P) and potassium (K) which are the minerals that plants need in the greatest quantities.

Application of NPK fertiliser to a wheat crop
Nemanja Otic / Alamy Stock Photo

Nutrients can also be added to the soil by adding manure or slurry.

Methods of food production

There are two contrasting approaches to producing food in UK farms:

- intensive farming
- organic farming

Manure being spread onto arable land
clynt Garnham Agriculture / Alamy Stock Photo

TEST YOURSELF

1. Nitrates are used by plants to produce:

A starch
B cellulose
C amino acids and proteins

2. The plants below are suffering from potassium deficiency.

Bean plants
Nigel Cattlin / Alamy Stock Photo

Potassium is needed for:

A chlorophyll
B producing amino acids
C photosynthesis

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

Intensive farming

Intensive farming is a type of farming which produces as much food as possible by making full use of the land. The aim is to maximize yields.

It includes:

- growing high yield crops
- using fertilisers and pesticides
- using highly efficient machinery

Harvesting wheat
Design Pics Inc / Alamy Stock Photo

Name of chemical used	Reason for use
artificial fertiliser	gives plants the essential nutrients for growth
herbicide	kills weeds which would otherwise complete for the same resources
pesticide	kills pests which way otherwise damage the crop
fungicide	kills fungi which may damage the crop

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

Animals and intensive farming

Intensively farmed animals can be kept indoors where their environment can be carefully controlled. The conditions are chosen so the animal grows quickly.

Barn kept hens
Tim Scrivener / Alamy Stock Photo

Factors that need to be controlled include:

• temperature	animals will use less energy if their environment is warm
• restrict movement	the more animals move, the more energy is wasted
• food	use high protein diet to promote growth
• security	animals need to be kept safe from predators
• antibiotics	to prevent the spread of disease

The main advantage of intensive farming is that it produces high yields of food relatively cheaply.

Problems with using chemicals in intensive farming

Intensive farming can have a negative impact on the environment.

- Fertilisers can cause eutrophication if they wash into water ways, i.e. the fertiliser causes algal blooms. When the algae die, decomposers use all the oxygen in the water leading to aquatic animals dying.

- Pesticides may also have unintended harmful effects on insects such as bees. The bee population is declining in the UK.

- The routine use of antibiotics in some forms of intensive farming is also feared to be helping the rise of antibiotic-resistant bacteria.

Organic farming

The Department for Agriculture and Rural affairs (DEFRA) states that:

> *'Organic food is the product of a farming system which avoids the use of man-made fertilisers, pesticides; growth regulators and livestock feed additives."*

It also says:

> *"This agricultural system relies on crop rotation, animal and plant manures, some hand weeding and biological pest control'.*

In summary organic farming:

- does **not** use artificial chemicals (fertilisers, pesticides etc.)
- uses crop rotation
- uses animal and plant manures
- uses hand weeding and biological pest control

Controlling pests without pesticides

All crop pests have natural predators. Farmers can make use of this to control pests that may otherwise damage their crops. This is called **biological pest control.**

For example, ladybirds eat aphids. These predators can be grown in large numbers and released onto a crop.

Ladybird eating aphids
Graphic Science / Alamy Stock Photo

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

Rearing animals organically

Organically reared animals are:

- allowed to move outside rather than kept indoors at all times. However they may be kept indoors overnight or when the weather is bad
- given organic food to eat
- not given artificial growth hormones or routinely given antibiotics

Free range chickens
Cultura Creative (RF) / Alamy Stock Photo

Pros and cons of farming different methods

The advantages and disadvantages of the two forms of farming have led to many debates.

Compared to food produced intensively, organic farming:

- takes longer to produce crops
- tends to have lower yields
- is often more expensive

However those who favour organic farming point to the:

- environmental advantages of not using pesticides and artificial fertilisers
- medical advantages of minimising the use of antibiotics (lower chance of creating antibiotic-resistant bacteria)
- animal welfare advantages of allowing animals to move in their environment

Producing food (specification 3.2.1)

Foundation tier: You do not need to know about Hydroponics

Hydroponics

Hydroponics is a method of growing plants in which the soil has been replaced with a mineral solution that is pumped around the plant roots.

Potato seedlings grown in a mineral solution
Sputnik / Science photo Library

Advantages

- plants can be grown anywhere
- no soil-borne pests or disease
- lower pesticide use
- uses less space for growing
- complete control over nutrient balance
- harvesting is easier
- no weeding

Disadvantages

- a hydroponic system is relatively expensive
- if water-based micro-organisms get into system, all plants will be affected
- growing a hydroponic crop requires technical expertise.

Unit 3.2: Food for the future

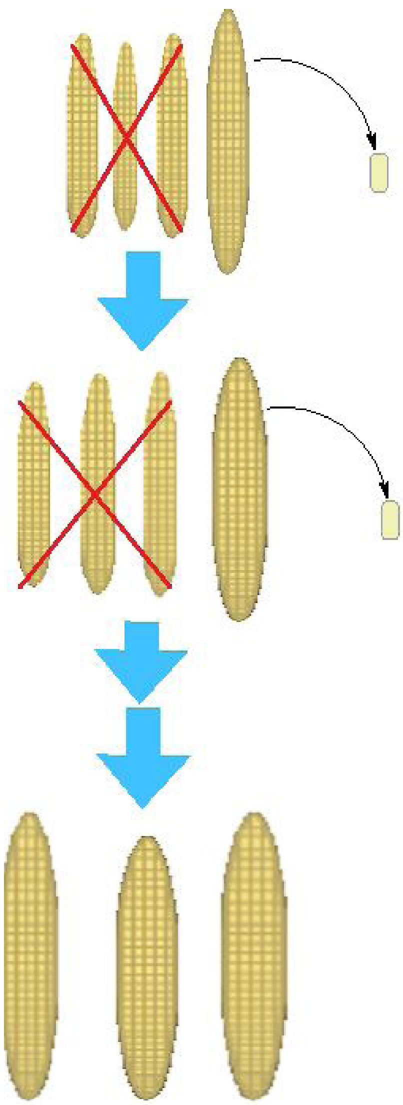
Producing food (specification 3.2.1)

Selective breeding in plants

Selective breeding (sometimes called artificial selection) involves selecting the plants with desirable traits, crossing them, selecting from their offspring and repeating the process over several generations.

All crops used today are a product of selective breeding.

In its most simple form, breeding consists of selecting the best plants in a given field, growing them to full seed and then using that seed to grow further generations.



Seed are selected from the plants with the most desireable traits. These are used to grow the next generation.

This process is repeated for a number of generations.

Over time the quality of the crop increases.

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

Selective breeding changes the genetic composition of the plants over time.
The most important factor for basic selective breeding is to select plants with the characteristic you want. A farmer who wants:

- to select a plant with resistance to an insect pest will watch for the plants that survive an insect attack.
- larger fruits will save seeds from plants yielding the biggest fruits in the field.

Wild wheat
Photo by Michael Palmer.
http://photorasa.com/

The wheat we use today for bread originated from wild wheat.

It is one of the most important crops in the world today.

Wild wheat blooms in April reaching a height of 70-100 cm.

It originally developed in the countries we now call Iraq, Egypt, and Israel.

As a result of breeding, most of the species we rely on for food are very different from their wild relatives.

Advantages of selective breeding

1. Crops give better yields
2. Resistance to pests and diseases
3. Crops may be bred to have more nutritional value
4. Harmful traits can be bred out

Disadvantages of selective breeding

1. Selective breeding can cause genetic variation to decrease. This may make mean one disease will affect many crops.
2. Some genes would be lost, making it more difficult to produce new varieties in the future.
3. There is an increased risk of genetic disease.

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

Genetic modification

Selective breeding to produce new crops takes a long time.

With a greater understanding of genetics, scientists are now able to alter a plant’s genes in a process known as **genetic modification** (or genetic engineering). This can be done in one generation.

What happens in genetic modification?

Genes from another organism (foreign genes) are put into plant cells at an early stage in their development. As the plant develops, it will display the characteristics of the foreign gene.

Why use genetic modification?

Genetic modification can be used to improve crops. e.g. higher yields or better resistance to disease.

Example: Genetically modifying a cabbage to limit pest damage. Cabbages are prone to attack from caterpillars.

Caterpillars feasting
Nigel Cattlin / Alamy Stock Photo

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

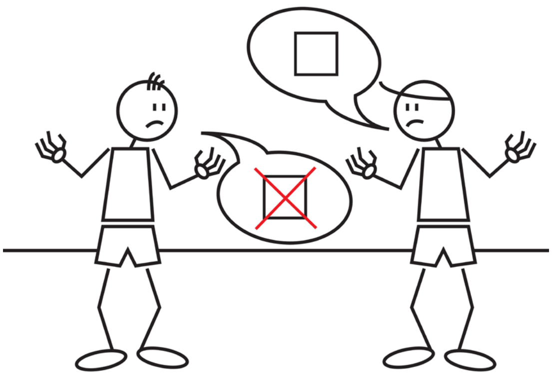
Scientists have recently taken the gene that produces poison in scorpion tails and transferred it into cabbage. The aim is to produce genetically modified cabbages that produce scorpion poison that kills caterpillars when they bite the leaves. The toxin produced by the cabbage is modified so it does not harm people.

There would be no need to add pesticides to this crop to control this particular pest.

The debate about genetic modification

The first genetically modified (GM) crops were sold in 1996 but the debate about their safety continues.

At present, GM crops are not grown in the UK but are grown in many other countries world-wide.



Debate
New Illustrations by Alfonsodetomas / Alamy Stock Vector

Those **in favour** of genetic modification point to a number of advantages:

- GM crops have a better yield.
- Resistance to pests, weeds and disease may be built into the crops.

This may also mean they are more environmentally friendly as less herbicide and pesticide will be required.

- Crops may be produced that stay ripe for longer so they can be shipped long distances.
- Crops may be produced that are more capable of thriving in regions with poor soil.

Critics make the following points:

- The claim of ending world hunger with GM crops is false.
- GM crops pose a risk to food diversity as the plants are much more dominant.
- It could give rise to super-weeds and super-pests.
- There may be undesirable consequences of changing a gene. Genes don't work in isolation, changing a few genes could cause unpredictable results.
- GM crops may cross-pollinate with nearby non-GM plants and this may create ecological problems.

Unit 3.2: Food for the future

Producing food (specification 3.2.1)

TEST YOURSELF

1. Fungicides are used by farmers to kill:

A weeds
B insects
C fungi

2. The sentences below explain how farmers may selectively breed their crops. You need to use the letters to put the sentences into the correct order (the first and last have been done for you).

A offspring grows
B These crops are then cross pollinated
C Farmer chooses the offspring with the best characteristics
D These are then bred and the process repeated for many generations
E Farmer chooses the crops with the best characteristics

Order:

E	....	....	....	**D**

3. An **advantage** of genetic modification of crops is claimed to be:

A GM crops may cross-pollinate with non-GM plants
B GM crops can be produced that don't produce grain that can germinate
C GM crops have high yields

PRACTICE QUESTIONS

1. (a) Photosynthesis takes place in the chloroplasts.

(i) Circle the correct answer in the following sentence. [1]

Chloroplasts are found in the **cytoplasm / vacuole / nucleus**

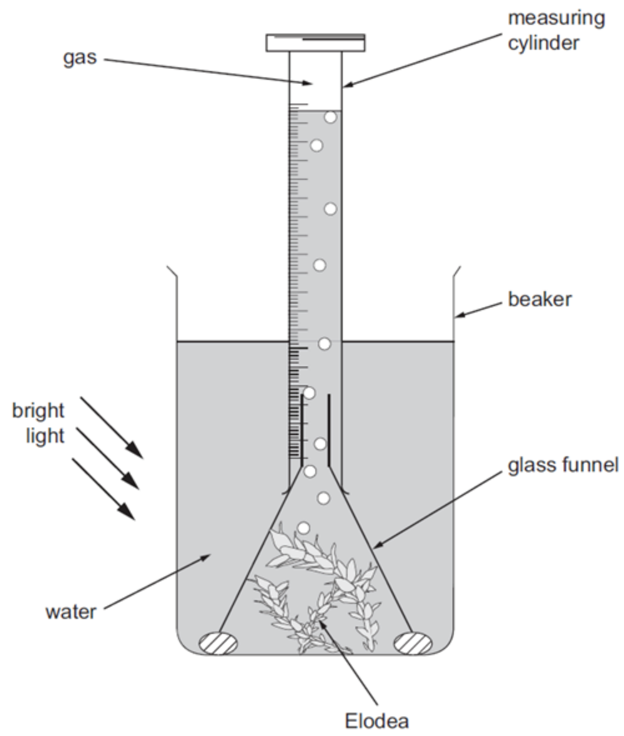
(ii) Chloroplasts contain chlorophyll.
State the function of chlorophyll. [1]

....

(iii) Complete the word equation for photosynthesis. [1]

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; + \; \text{water} \longrightarrow \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; + \; \text{oxygen}$$

(b) Bethan investigated the rate of photosynthesis in Canadian pondweed (*Elodea*) at three different temperatures using the apparatus shown below.



She counted the bubbles coming from the funnel every minute for ten minutes and recorded the results in the table below.

Temperature of water (°C)	Number of bubbles in each minute											
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Total number of bubbles in ten minutes	Mean number of bubbles per minute
5	1	2	1	2	2	1	1	1	2	2	15	1.5
15	2	3	2	3	4	3	3	3	3	3	……	……
25	3	6	3	6	7	7	8	8	6	6	……	……

(i) Calculate the total and mean number of bubbles per minute for *Elodea* in water at 15 °C and at 25 °C. **Write your answers in the table**. [1]

(ii) State the name of the gas in the bubbles. [1]

………………………………………………………………………………

(iii) What conclusions can you make about the effect of temperature on the rate of photosynthesis in this investigation? [2]

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

(iv) Instead of counting the number of bubbles, Bethan could have measured the volume of gas collected in the measuring cylinder. Explain which is the better method to use. [3]

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

FOOD PROCESSING

The food which comes to our homes needs to be processed for us.

Milk may be pasteurised or used to produce other dairy products such as yogurt, cheese or butter. The pasteurisation process is not just used by the dairy industry but also on products such as beer and fruit juice.

Food also needs to be safe for us to eat. It is important that harmful microorganisms do not enter the food chain.

This topic explores some of the science used in food processing.

Using microorganisms in food production

Microorganisms play an important role in processing our food.
Without using microorganisms we would not have alcoholic drinks such as beer and wine, yogurt and cheese or bread.

Two products that depend upon yeast

Bread
Brian Jackson / Alamy Stock Photo

Wine
incamerastock / Alamy Stock Photo

A summary of the role of yeast and bacteria in the production of some foods is shown in the table below.

Food	Microorganism	Role
bread	yeast	yeast fermentation produces carbon dioxide which makes dough rise
beer	yeast	yeast is used to ferment sugar (maltose) to make ethanol (alcohol)
wine	yeast	yeast is used to ferment sugars in grape juice to make ethanol (alcohol)
yogurt and cheese	bacteria	bacteria breaks down lactose (a sugar in milk) to form lactic acid

Fermentation

Fermentation is an example of anaerobic respiration – the yeast respires without oxygen.
Word equation for fermentation:

$$\textbf{glucose} \xrightarrow{\text{enzymes in yeast}} \textbf{ethanol + carbon dioxide}$$

Enzymes in yeast work best at a temperature between 15 °C and 25 °C when no oxygen is present.

Home made wine made by fermentation
Ian Simpson / Alamy Stock Photo

Making beer

The processes involve:

Malted barley grains are mixed with warm water

↓

Starch in the barely is converted into glucose

↓

Hops are added for flavour

↓

The liquid (called wort) is boiled

↓

The wort is cooled, and run into the 'mash tun'

↓

Yeast is added to the mixture

↓

Fermentation begins when the oxygen runs out

↓

Fermentation stops when all the maltose is uded up

↓

The beer is bottled or put into barrels

Hops
Charlie Newham / Alamy Stock Photo

Mash tun
Cephas Picture Library / Alamy Stock Photo

Barrels
Arterra Picture Library / Alamy Stock Photo

Making yogurt

The processes involved when making yogurt

Sterilise the equipment

↓

Pasteurise the milk by heating

↓

Add the bacterial culture to the cooled milk
Leave at 46 °C for about 4 hours

↓

Sample to see if the yogurt is ready

↓

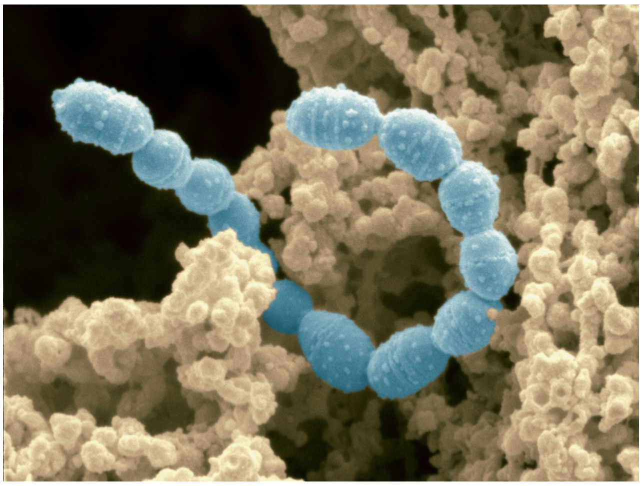
Add flavour and colouring

↓

Packaging of the yogurt

Pasteurisation kills harmfull microorganisms

Milk contains a sugar called **lactose**. The bacteria are able to break this to form **lactic acid**.
The lactic acid curdles the milk and lowers the pH of the yogurt which helps to preserve it.



Streptococcus thermophiles
Alamy Stock Photo

Making cheese

Cheese can be made from any type of milk. The flow chart shows the basic steps used in producing cheese.

The bacteria convert lactose into lactic acid.

Rennet contains the enzyme rennin which changes the milk protein into curd

Add bacteria and rennet to milk

↓

The milk curdles and separates into curds and whey

↓ **Drain off whey**

↓ **The curds (milk solids - fats and proteins) are pressed to make cheese solid**

↓

The cheese is left to mature to improve its flavour and consistency

Curds and whey in cheese making process
David Hall / Alamy Stock Photo

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

TEST YOURSELF

1. Select the correct statement about bread:

A Yeast fermentation produces carbon dioxide which makes dough rise
B Yeast fermentation produces oxygen which makes dough rise
C Yeast fermentation produces alcohol which makes dough rise

2. Select the missing substance for the word equation describing fermentation:

.... $\longrightarrow$ ethanol + carbon dioxide

A starch
B yeast
C glucose

3. The following sentences are to do with cheese production.

Select the correct words from inside the brackets to complete the sentences below.

(a) Bacteria is added to milk which convert (**glucose / lactose / lactic acid)** into **(carbon dioxide / lactose / lactic acid**).

(b) Rennet contains an enzyme which changes milk (**sugar / protein / whey**) into curd.

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

Harmful bacteria and food spoilage

Food can deteriorate rapidly if it is not stored properly. It may start smelling or appear unpleasant. The food is spoiled and is probably harmful to eat.

Food spoilage is due to bacterial and fungal action.

It is important to prevent food from being contaminated with microorganisms.

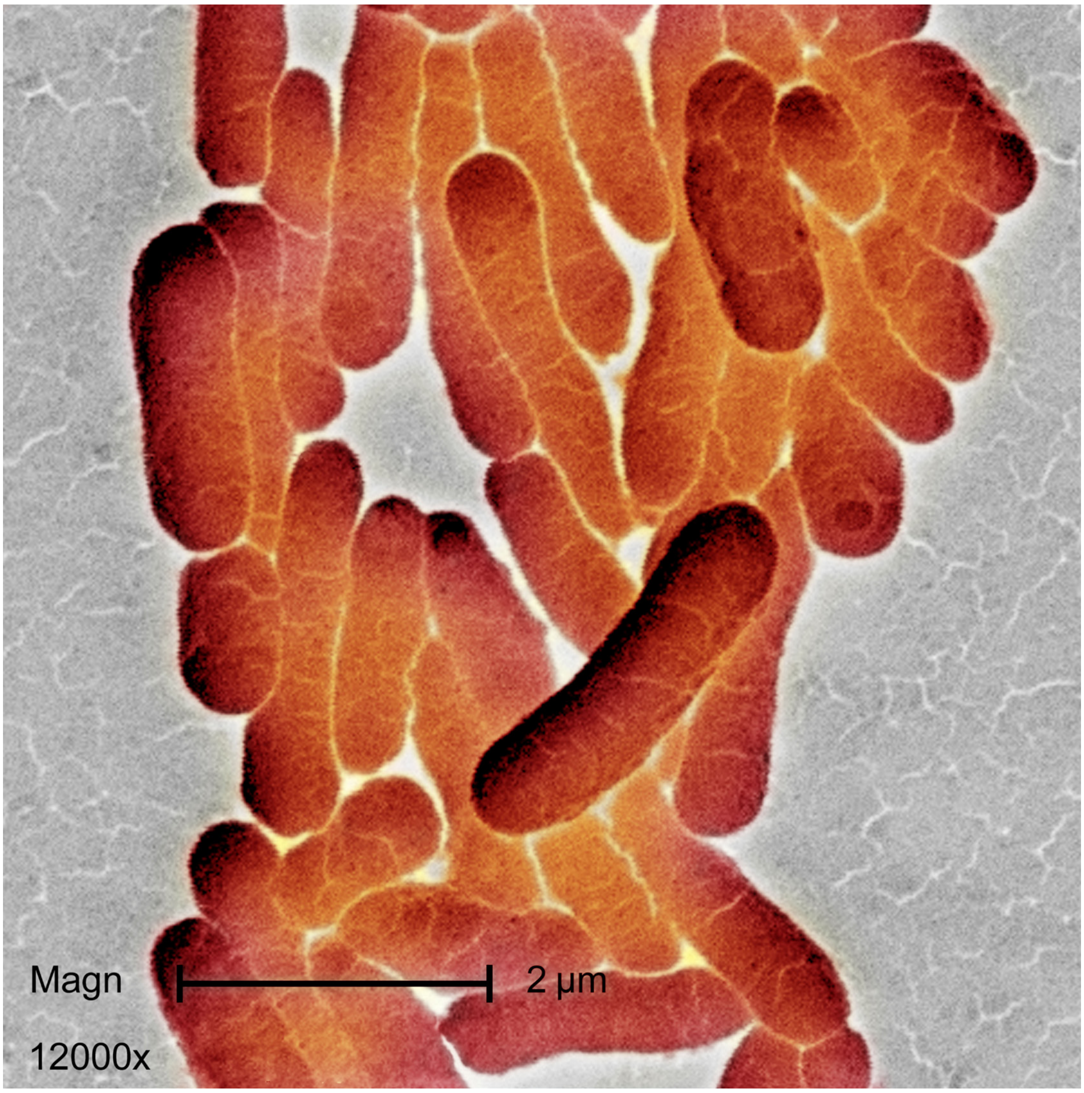
Food poisoning is also linked to the growth of microorganisms, usually bacteria on food, and the toxins they produce. Examples of bacteria associated with food poisoning are shown below:

Bacteria	Comment
campylobacter	In the UK, *campylobacter* bacteria are the most common cause of food poisoning.
Salmonella	*Salmonella* bacteria are often found in raw or undercooked meat, raw eggs, milk, and other dairy products.
E. coli	Most strains are harmless but some can cause serious illness. Most cases of *E. coli* food poisoning occur after eating undercooked beef or drinking unpasteurised milk.

Common cases of food poisoning will typically include at least three of the following symptoms:

- feeling sick (nausea)
- vomiting
- diarrhoea
- stomach cramps and abdominal pain
- a lack of energy and weakness
- loss of appetite
- a high temperature (fever)
- aching muscles

It is extremely important that food does not become contaminated with bacteria.
This is particularly important when processing food commercially but is also important in the home.



Salmonella bacteria
Scott Camazine / Alamy Stock Photo

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

Optimum conditions for bacterial growth

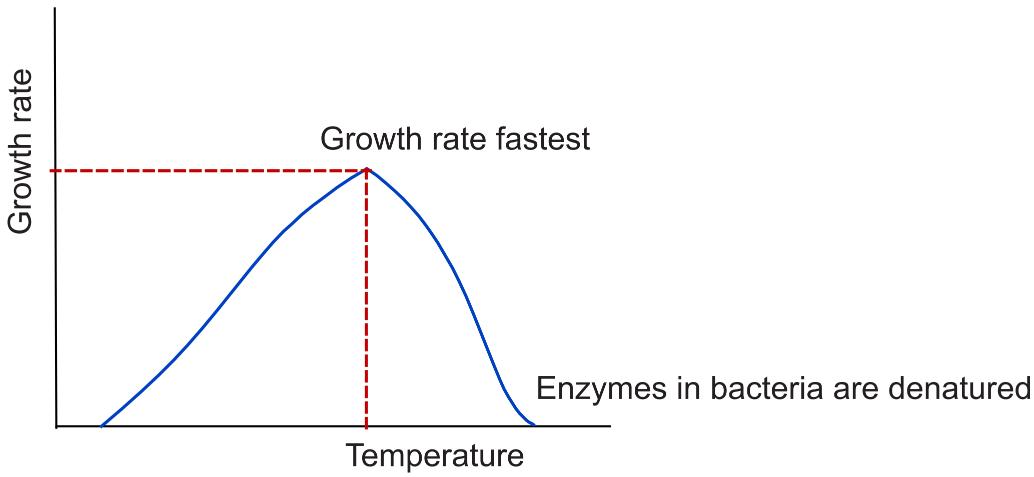
In the right conditions bacteria can multiply very quickly. These conditions include:

warm temperatures	Bacteria multiply rapidly in warm temperatures
moisture	Bacteria need water to grow Water in food provides an excellent environment for bacteria to grow
nutrients	Bacteria are able to survive on a large range of energy sources

Avoiding these conditions can prevent bacterial growth, bacterial infections and food poisoning.

Slowing bacterial growth in food

The graph shows how the growth rate of bacteria varies with temperature.



- At **low temperatures** the bacteria do not multiply or only grow very slowly. Food should be kept in the fridge or freezer to prevent bacterial growth. Low temperatures do **not** kill bacteria.
- Bacteria multiply rapidly in the **warm** especially near body temperature. Food must not be kept at this temperature.
- At **high temperatures** the bacteria are **killed**. It is important that food is cooked all the way through at a sufficiently high temperature to kill all bacteria.

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

Methods to preserve foods

Methods of preserving food and preventing bacterial growth are summarised below.

Temperature	**refrigeration**	growth slows down but does not stop
Temperature	**freezing**	stops bacteria multiplying but does not kill them
Temperature	**heating**	kills bacteria if the cooking temperature is high enough and food cooked all the way through. Heating milk to kill bacteria is called **pasterisation**.
Moisture	**drying**	removes water so bacteria cannot digest and absorb the food source
Moisture	**salting**	bacteria lose water from the cells so they dehydrate and cannot reproduce
	pickling	the enzymes in vinegar lowers pH and inactivates microorganisms

Pickling is a method of preserving food
MBI / Alamy Stock Photo

Dried beef - for long term storage
Victor Nikitin / Alamy Stock Photo

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

Pasteurisation and milk

Pasteurisation is a process that kills harmful bacteria by heating **milk**.

Pasteurisation is also used to treat other foods including beer and fruit juice.

It was first developed by Louis Pasteur in 1864 and is widely used within the food and drink industry, and it is the most common form of heat treatment used on milk within the UK. Pasteurisation makes milk safe to drink by killing any bacteria. Pasteurisation also helps to prolong its shelf life.

Milk
Home Bird / Alamy Stock Photo

The process of pasteurisation

Pasteurisation involves heating milk to 72°C for at least 15 seconds. Once the milk has been heated, it is then cooled very quickly to less than 3°C and packaged for selling.

Homogenisation

Commercial milk is also usually **homogenized.**

This is done by pumping milk at high pressures through narrow tubes. This breaks the fat globules into smaller droplets so that they stay suspended in the ***milk*** rather than separating out and floating to the top.

Sometimes the amount of fat is reduced before the milk is homogenized. This is done by skimming fat off the milk. Depending upon how much fat is removed, we get:

- **semi-skimmed milk** (some of the fat is removed) or
- **skimmed milk** (most of the fat is removed).

Milk is normally pasteurised after it is homogenized.

SOMETHING TO WATCH

Watch a video that explains how milk is homogenised and pasteurised.
http://www.bbc.co.uk/education/clips/z7bxpv4

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

Reducing the chances of contaminating food

Food contaminated with bacteria can cause food poisoning.

The four ‘C’s below are used to help remind people how they can stop food poisoning.

	Reason	Action to take
Cross-contamination	Cross-contamination occurs when bacteria is spread between food, surfaces or equipment.	Do not allow raw food to come in contact with cooked food. Store raw and cooked food separately. Use different equipment for raw food and cooked food. Use appropriate protective clothing to prevent contamination.
Cleaning	Effective cleaning gets rid of bacteria on hands, equipment and surfaces. It helps to stop harmful bacteria from spreading onto food.	Wash and dry hands thoroughly before handling food. Clean using detergents and disinfect surfaces and equipment. Dispose of waste immediately and correctly.
Chilling	Chilling food properly helps to slow the growth of harmful bacteria.	Keep chilled food out of the fridge for the shortest time possible during preparation.
Cooking	Cooking kills harmful bacteria in food.	Cook food all the way through.

Pests, such as mice and insects, which can carry bacteria and contaminate surfaces and food also need to be controlled.

SOMETHING TO WATCH

Watch a video about bacterial growth on hands.
https://youtu.be/1xuEowtB7qg

The impact of food contamination

Research about food poisoning shows:

- There are more than 500 000 cases of food poisoning a year from known pathogens. This figure would more than double if it included food poisoning cases from unknown pathogens.
- *Campylobacter* was the most common food-borne pathogen, with about 280 000 cases every year.
- *Salmonella* is the pathogen that causes the most hospital admissions – about 2 500 each year.
- Poultry meat was the food linked to the most cases of food poisoning, with an estimated 244 000 cases every year.

Source:
Food Standards Agency https://www.food.gov.uk/news-updates/news/2014/6097/foodpoisoning 13/06/2016

Food poisoning costs the NHS and the UK economy
Paul Thompson Still Life / Alamy Stock Photo

It is estimated that there are 500 deaths a year with costs each year to the UK of £1.5 billion.

Unit 3.2: Food for the future

Food processing and spoilage (specification 3.2.2)

Culturing microorganisms

The conditions for growth of bacteria can be investigated using cultures of microorganisms. It is important that the cultures are uncontaminated by other microorganisms.

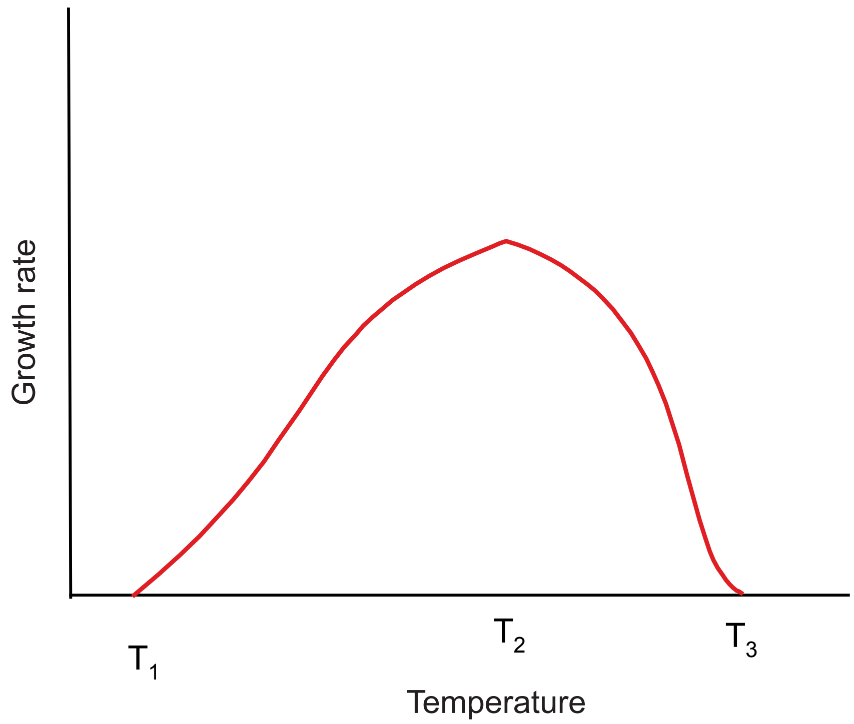
This means that sterile conditions must be used:

- the Petri dishes, nutrient agar and other culture media must be sterilised before use
- the inoculating loops used to transfer microorganisms must be sterilised by heating in a Bunsen flame
- the lid of the Petri dish is sealed with adhesive tape to stop microorganisms from the air getting in and contaminating the culture.

Scientist checking a Petri dish
Cultura Creative (RF) / Alamy Stock Photo

TEST YOURSELF

1. The graph shows how the growth rate of bacteria varies with temperature.



(a) The growth rate is greatest at temperature:

A T_1

B T_2

C T_3

(b) Bacteria are destroyed at:

A between T_1 and T_2

B below T_1

C At temperatures above T_3

2. Freezing food:

   A stops bacterial growth
   B kills some bacteria
   C slows bacterial growth

3. Refrigerating food:

   A kills some bacteria
   B stops bacterial growth
   C slows bacterial growth

4. Three methods of preserving food are:

   A pickling, drying and homogenizing
   B salting, pasteurising and pickling
   C pickling, freezing and by removing fat

PRACTICE QUESTIONS

1. Recent food poisoning studies have found that there are more than 500 000 cases of food poisoning per year from known pathogens in the UK. This figure would more than double if it included food poisoning cases from unknown pathogens.

The Food Standards Agency carried out a survey to explain why there has been an increase of food poisoning. One of the findings from the survey was that one in five (21%) of us don't wash our hands with soap after handling raw meat.

Explain the actions that staff working in a restaurant kitchen should take to reduce the risk of causing food poisoning (other than personal hygiene).

[6 QER]

....

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....

TEST YOURSELF - ANSWERS FOR UNIT 3.2

Growing crops

1. B
2. C
3. A
4. B

Producing food

1. C
2. C

Genetic modification

1. C
2. E B A C D
3. C

Food processing

1. A
2. C
3. (a) lactose, lactic acid (b) curd

Preserving food

1. (a) B (b) C
2. A
3. C
4. B

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

THE WORK OF ANALYTICAL SCIENTISTS

Analytical scientists answer questions such as: How can we know the water we drink is safe and not contaminated with harmful chemicals or how clean is the air we breathe? How can athletes be checked for the use of drugs that enhance performance? How can DNA evidence be used to connect a suspect to a crime scene? How much flavouring is present in a particular brand of chewing gum? Analytical scientists also make contributions in museums, art galleries and archaeological expeditions.

Forensic scientists use analytical procedures
Maurice Crooks / Alamy Stock Photo

Collecting a sample from a polluted site for chemical analysis
Francesco Mou / Alamy Stock Photo

Sampling

The first job of an analytical scientist is to collect a sample for testing. If a technician collects a water sample from a stream then it is important that the sample gives a true picture of the water in the stream.

> A sample that gives a true picture is said to be representative.
> To do this the technician will follow special procedures (called standard procedures).

The procedures may vary according to the type of analysis that will be done in the laboratory.

Examples of sampling procedures

Sampling water from a stream

If water is collected from a small stream, the following rules should be followed:

- take the water sample from parts of the stream where the water is moving well
- if possible, take the sample when standing on the bank of the stream
- collect the water sample one or two centimetres below the surface
- fill a sample bottle to the top and stopper
- give the sample bottle a sample number written with indelible ink
- write down the details of the sample e.g. where the sample was taken from, the time it was taken, the weather conditions etc.

Environmental Science student sampling water from a stream
Wikimedia CC, http://bit.ly/2e1yYJU

Sampling from water taps

Even if a water sample needs to be taken from a **customer's tap** there are procedures to be followed:

- remove all attachments from the tap
- give the sample bottles a sample number with indelible ink
- if the sample is to be taken for metal analysis (e.g. lead), fill a sample bottle immediately on opening the tap
- take another water sample 2 minutes after the tap is switched on to remove water that has stood in the water pipes of the house
- the details of both samples must be recorded against the bottle sample number (e.g. date, when the sample was taken, house address).

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

How do we carry out an analysis?

You have been asked to carry out an investigation but how do you proceed? What kind of method should you use to carry out your investigation?
It helps to start by asking some simple questions.

- Are you required to **identify** the chemicals that are present?
- Do you need to find **how much** of a chemical is present?
- If you want to find how much is present, how accurate does your value need to be? Does it need to be as exact as possible or will an approximate figure be enough?

Depending how you answer these questions helps you decide the type of analysis.
It is helpful to think of **three** different ways of doing chemical analysis:

1. **Qualitative analysis** - identifies whether a particular substance is present.

   It does not say how much is present.

2. **Quantitative analysis** - gives the concentration of a substance that is present.

3. **Semi-quantitative analysis** - gives a rough idea of how much of a substance is present. It is not as exact as quantitative analysis.

Qualitative tests

The following are examples of tests you may do to find out what is in your sample.

Qualitative

flame tests
test with sodium hydroxide sollution

These are used to test for metal (positive) ions

test for sulfates
test for carbonates
test for chlorides

These are used to test for negative ions

test for carbon dioxide using limewater

This is test for a gas

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

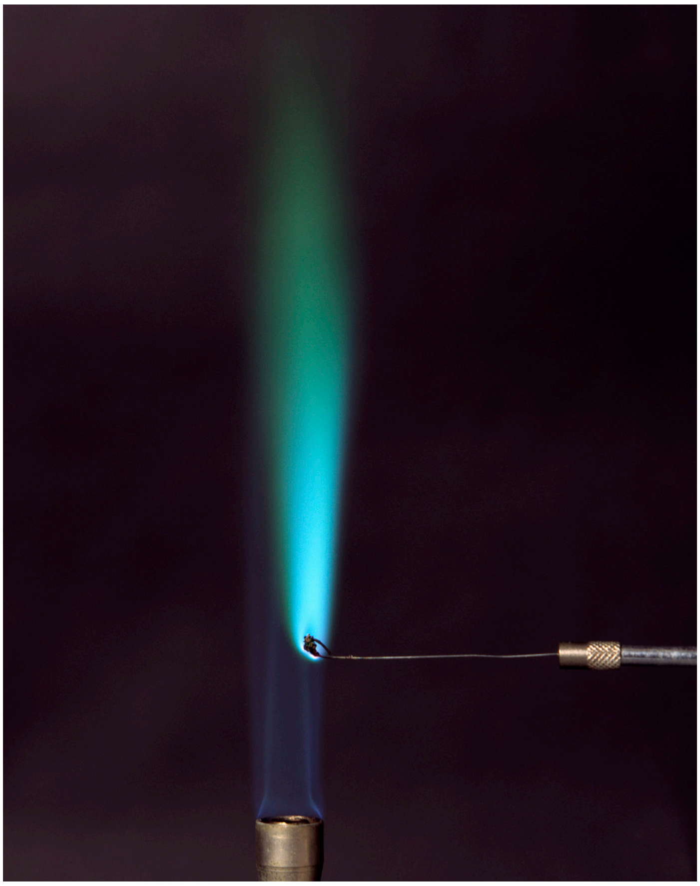
Flame tests

Some metal ions, when put into a Bunsen flame, give a coloured flame.
A particular metal ion will always colour the flame in the same way. We can use this to test for the presence of metal ions.

To carry out a flame test you do the following:

- Clean a wire loop in dilute hydrochloric acid
- Dip the metal loop into the solution or solid to be tested
- Hold the loop in the edge of a Bunsen burner flame.

You can then check the colour flame against that expected from different metals.
For example, if a sample of a salt containing copper is placed in a Bunsen flame, the flame is coloured blue-green.



Copper salts colour a Bunsen flame green-blue
David Taylor / Science Photo Library

Some other examples of metals which colour flames are:

Metal	Flame test colour
sodium	orange
potassium	lilac
barium	apple green
calcium	brick-red
copper	green-blue

Testing for metals using sodium hydroxide solution

Many, but not all, metal ions form precipitates with sodium hydroxide solution.
The kind of precipitate and its colour will tell us about the metal ions in our test sample.

Metal ion	Precipitate
Ca^{2+}	white precipitate which does **NOT** redissolve when sodium hydroxide solution is added to excess
Pb^{2+}	white precipitate which redissolves when sodium hydroxide solution is added to excess
Fe^{2+} (iron(II) ions)	green precipitate (slowly turns brown on standing)
Fe^{3+} (iron(III) ions)	rust brown precipitate
Cu^{2+} (copper(II) ions)	blue precipitate

Precipitates of copper(II), iron(II) and iron(III) hydroxides
Martyn F. Chillmaid / Science Photo Library

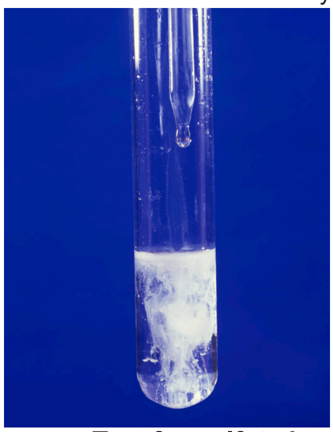
Scientific detection (specification 3.3)

Tests for negative ions

To test for **carbonates**, add dilute hydrochloric acid to the solid or a solution of the solid.
Positive result (carbonate present): You will see bubbling. **A colourless gas** (carbon dioxide) is given off.
Limewater can be used to confirm that the gas is carbon dioxide.
Limewater turns from clear to milky if carbon dioxide is bubbled through.

Test for carbonate ion
Martyn F. Chillmaid / Science Photo Library

To test for **sulfates** add a few drops of dilute hydrochloric acid followed by a few drops of dilute barium chloride solution.
Positive result (sulfate present): A white precipitate is observed. The white precipitate is barium sulfate.



Test for sulfate ion
Andrew Lambert Photography / Science Photo Library

To test for **chlorides** add a few drops of dilute nitric acid followed by a few drops of dilute silver nitrate solution.
Positive result (chloride present): A white precipitate is observed. The white precipitate is silver chloride.

Test for chloride ion
GIPhotoSctock / Science Photo Library

In an exam you will be required to interpret information from analytical investigations. The ions recorded above are the ones mentioned in the specification.
In an exam you may be given the tests that are expected with other ions and asked to use the information to interpret chemical tests.

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

TEST YOURSELF

1. If a water sample is taken from a stream, the water should be sampled:

   A as close to the bottom of the stream as possible
   B one or two centimetres from the surface of the stream
   C as close to the edge of the stream as possible

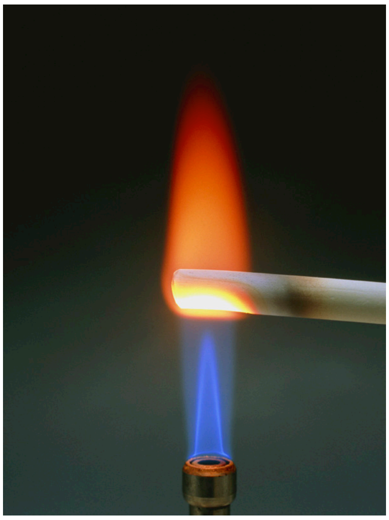
2. Qualitative analysis:

   A gives us an approximate idea of how much of a substance is present
   B gives an accurate value for how much of a substance is present
   C identifies the substances present

3. Flame tests are examples of a:

   A qualitative method
   B quantitative method
   C semi-quantitative method

4. A sample is tested using a flame test. The flame colour is shown below



Brick red flame
Jerry Mason / Science Photo Library

Metal	Flame test colour
sodium	orange
potassium	lilac
barium	apple green
calcium	brick-red
copper	green-blue

Identify the element present.

A calcium
B sodium
C copper

5. Sodium hydroxide solution is added to a clear solution in a test-tube.
The following result is seen.
The sample contains

A copper(II) ions
B iron(II) ions
C iron(III) ions

Rust-brown precipitate
Martyn F. Chillmaid / Science Photo Library

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

Chromatography

Chromatography is a method which allows us to **separate** the components in a mixture and **identify** what is present.

There are a number of different forms of chromatography, some of which are able to separate even very small amounts of a complex mixture.

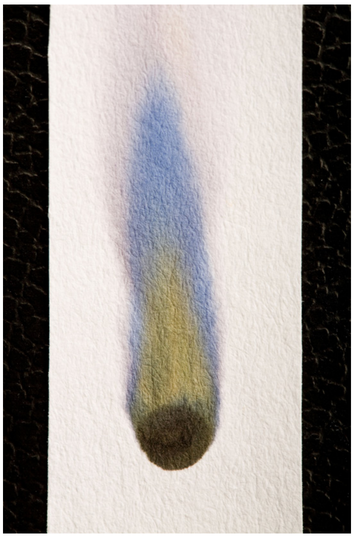
There include:

- paper chromatography
- thin layer chromatography (TLC)
- gas liquid chromatography (GLC)
- high performance liquid chromatography (HPLC)

There are a wide range of important applications, particularly of gas liquid chromatography and high performance liquid chromatography. A few are listed below.

Chromatography	Examples of uses
paper chromatography	• separate and identify colourings in food dyes and lipstick
thin layer chromatography	• analysis of pollutants in the environment • separation of colourings in plants (e.g. grass)
gas liquid chromatography	• analyse air pollutants
high performance liquid chromatography	• monitoring athletes for drug use by examining drugs in hair or blood samples

Scientific detection (specification 3.3)



Paper chromatography
SelectPhoto / Alamy Stock Photo

Gas liquid chromatography instrument used in a forensic lab
Mikael Karlsson / Alamy Stock Photo

Even though there appear to be big differences when we look at different methods of chromatography they all work according to similar principles.

All forms of chromatography have a stationary phase and mobile phase.

In paper chromatography, the stationary phase is the paper and the mobile phase is a solvent.

Higher tier only

Separation occurs since the substances in the mixture will move at different speeds with the mobile phase over the stationary phase.

Molecules which are strongly attracted to the stationary phase will move relatively slowly while molecules that are more strongly attracted to the mobile phase move more quickly.

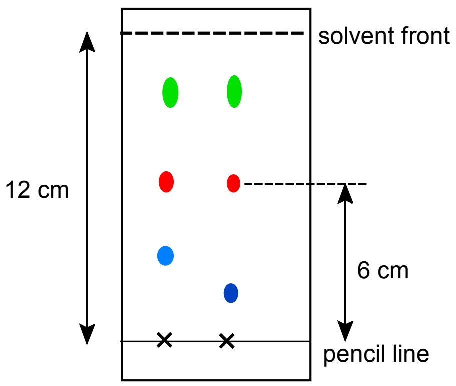
Scientific detection (specification 3.3)

Paper chromatography

Paper chromatography is the simplest form of chromatography which is useful for separating the chemicals in coloured samples (e.g. food dyes, inks).

Example

Two different dyes were spotted onto chromatography paper.
The diagram shows the pencil line where the dyes were spotted, the position each colour in the dye travelled to, and how far the solvent moved to (the solvent front).



The two dyes are not the same.
They both have the same red and green colourings.
The blue colours have moved different distances and so they cannot be the same.

R_f values

The R_f value is given by:

$$R_f = \frac{\text{distance travelled by substance}}{\text{distance travelled by solvent}}$$

In the example above, the R_f value of the red dye =6/12 =0.5.
As long as we carry out the experiment under exactly the **same conditions** i.e. with the same type of paper, with the same solvent and at the same temperature then the **R_f** will **stay the same**. If we change any of these conditions then we will change the R_f value.

Thin layer chromatography

Thin layer chromatography is similar to paper chromatography. The main difference is that we have changed the stationary phase for a solid stuck to a glass plate.
You can treat the results from thin-layer chromatography in the same way to those of paper chromatography. It tends to give more reproducible results than paper chromatography.

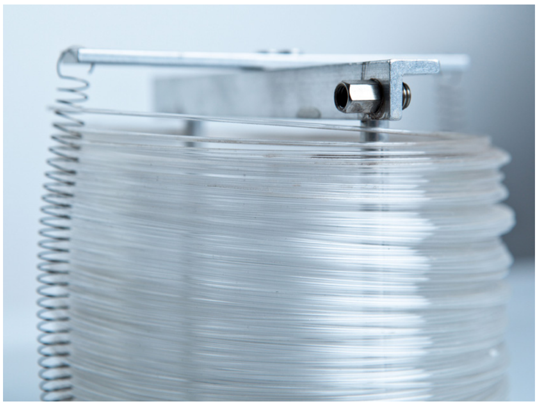
High performance and gas liquid chromatography

These two methods of chromatography look quite different to both paper and thin layer chromatography. They both use machines to help separate very small amounts of a mixture.

In **gas liquid chromatography, the stationary phase** is a liquid and the **mobile phase** is a gas.

The photograph shows a large coil of glass tubing.

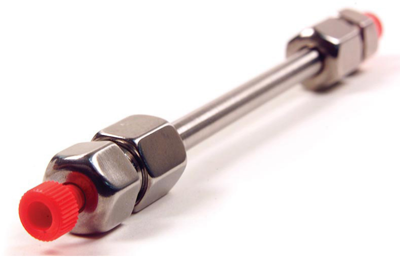
In gas chromatography the liquid is coated to the walls of the tube and a gas passes through the tube.



Gas chromatography
Viktor Cap / Alamy Stock Photo

In high performance liquid chromatography, the stationary phase is a liquid fixed on beads packed in a short metal tube.

Another liquid is pumped through the column. This is the mobile phase.



HPLC column
Unable to trace copyright. Please contact us if you are the copyright holder.

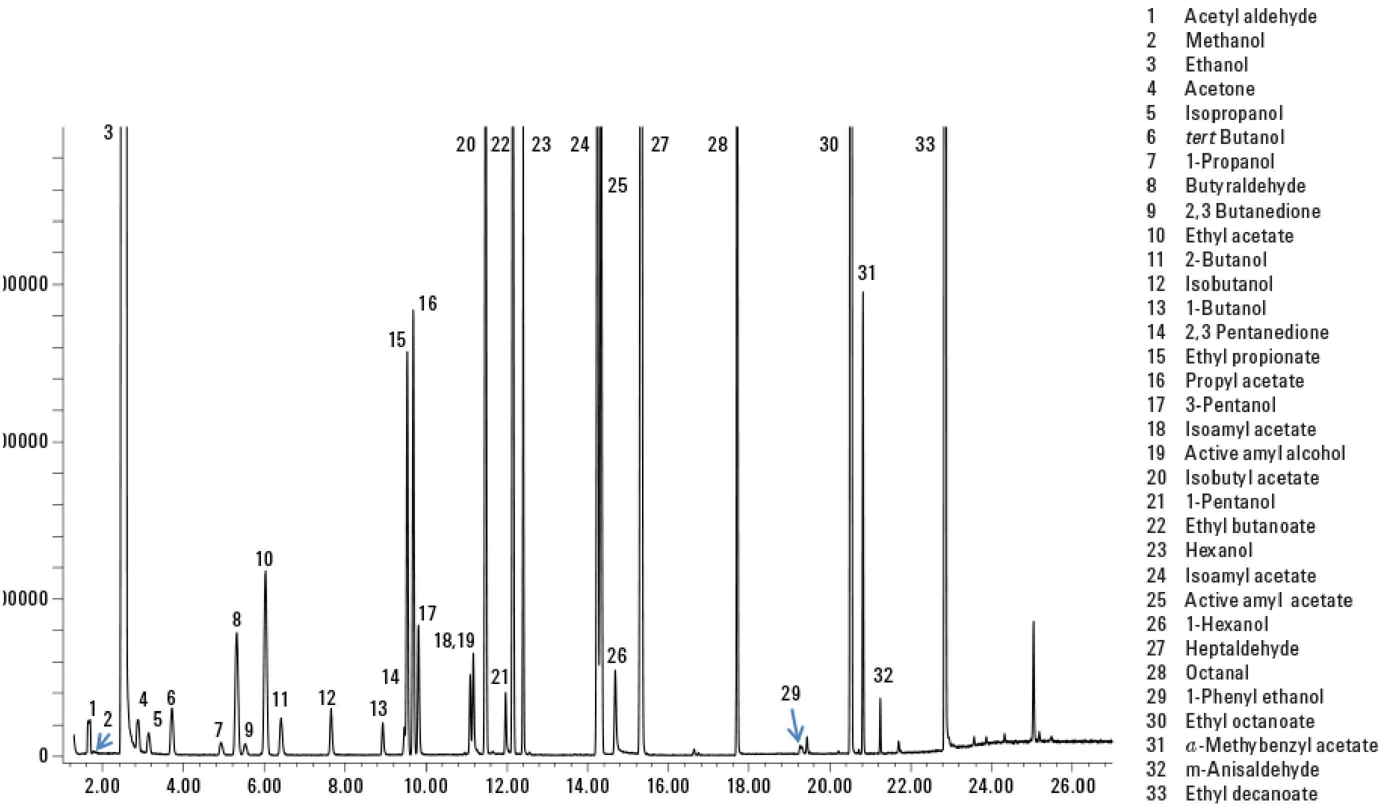
The photograph is of a HPLC column. A stationary phase is coated on small beads in the column. Another liquid is pumped through the column.

Both GLC and HPLC are very sensitive methods of analysis and can detect very low concentrations (e.g. parts per billion and even parts per trillion).

Special detectors are used to record how long it takes for substances to move through the column. The results are shown on a **chromatogram**.

GLC and HPLC are able to separate complex mixtures.

The chromatogram shows the results of analysing a beer. It shows 33 different substances in the beer.



A chromatogram of beer

Retention time

Scientists record the time for the different substances to move through the column.

> The retention **time** (t_R) is the **time taken** for a substance to travel through a column.

The retention time depends upon:

- temperature
- the stationary phase
- the mobile phase
- how fast the mobile phase flows

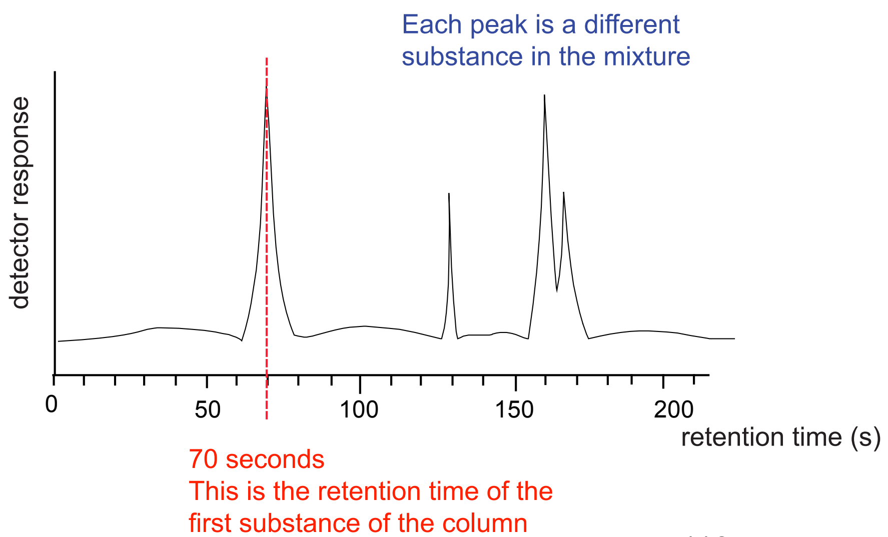
> If we keep the factors above the same then a particular component will always have the **same** retention time.

Analysing mixtures

We can use both HPLC and GLC to analyse mixtures and identify the substances present.

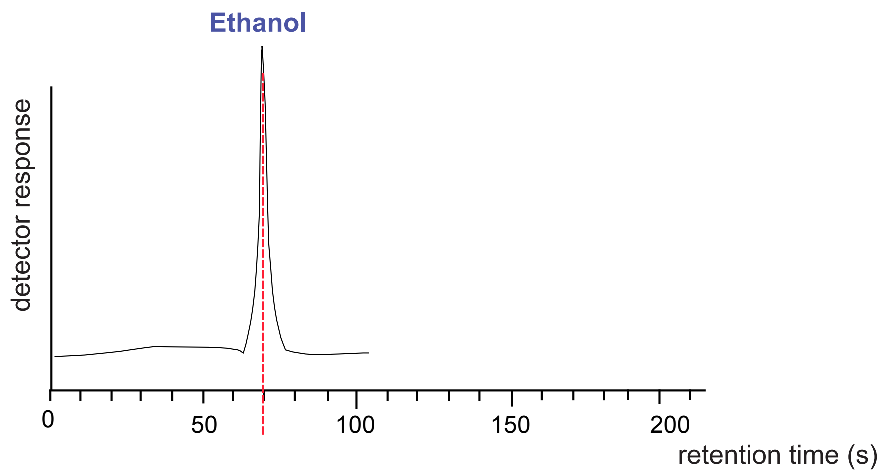
Example

The chromatogram below was obtained from a mixture using GLC.



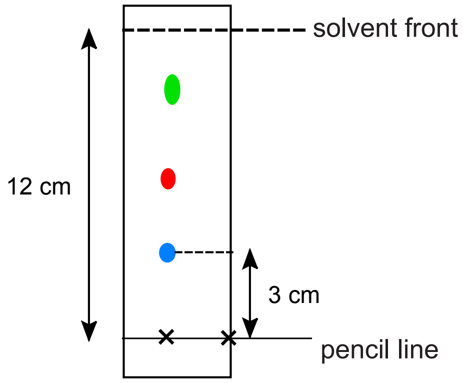
The retention times can be used to identify the substances in a column.
When only ethanol is injected into the column under exactly the same conditions it has a retention time of 70 seconds.

One of the substances in the mixture is probably ethanol (there is a chance that something else may have exactly same retention time).



TEST YOURSELF

1. A food colouring is separated using paper chromatography



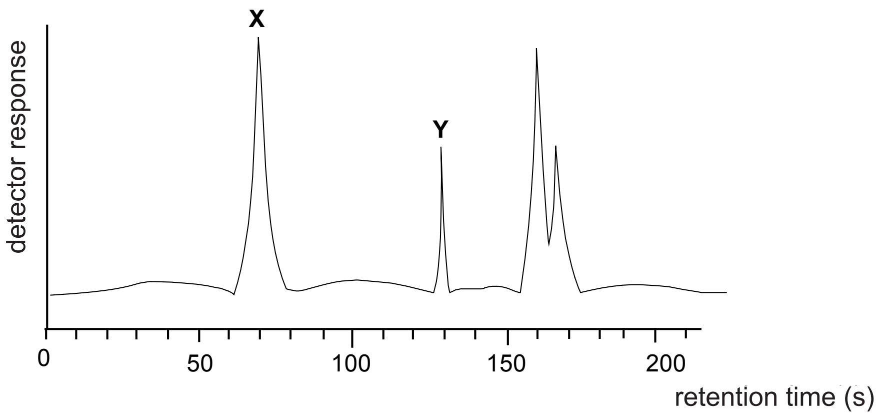
The R_f value for the blue dye below is:

A 4
B 36
C 0.25

2. In high performance liquid chromatography,

A the stationary phase is a liquid and the mobile phase a liquid
B the stationary phase is a liquid and the mobile phase a gas
C the stationary phase is a solid and the mobile phase a gas

3. The chromatogram below was obtained from the analysis of a clear liquid



The retention time of Y (in seconds) is:

A 70 seconds **B** 130 seconds **C** 150 seconds

Unit 3.3: Scientific detection

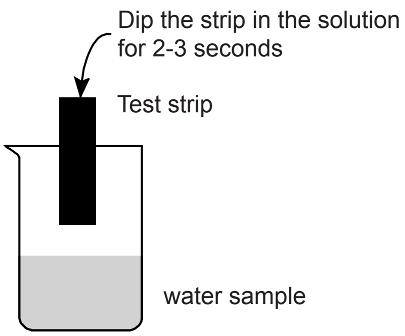
Scientific detection (specification 3.3)

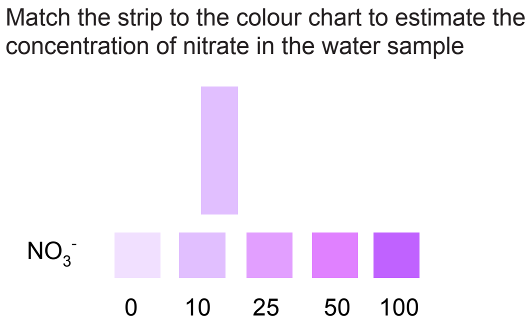
Semi-quantitative analysis

Semi quantitative analysis gives a rough idea of a concentration or amount present.

You should know that pH paper is used to estimate the pH of a solution. This is an example of semi-quantitative analysis.
By matching the pH colour of the paper to a colour chart you estimate the pH of a solution.
You can do something similar for many other analysis, e.g. to measure the concentration of nitrates in water.

Example of semi-quantitative analysis





The colour best matches 10 mg/dm^3

The concentration of nitrate is approximately 10mg/dm^3

Unit 3.3: Scientific detection

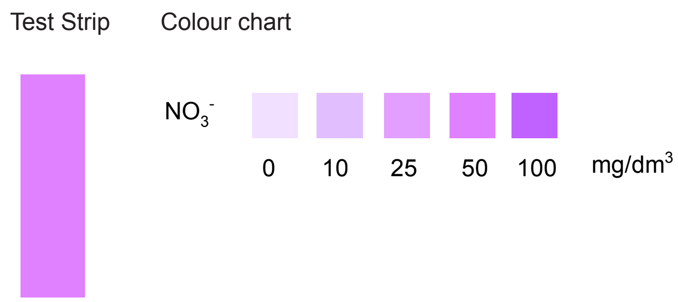
Scientific detection (specification 3.3)

TEST YOURSELF

1. Semi-quantitative analysis is used to:

A identify what is present in a sample
B give a rough idea of a concentration or amount of a substance
C give an exact value for a concentration or amount of a substance

2. The results of testing a water sample using nitrate paper is shown below



Select the statement below that is **not** consistent with this result.

A the concentration of nitrate is about 50 mg/dm^3
B the concentration of nitrate is between 25 and 100 mg/dm^3
C the concentration of the nitrate is exactly 50 mg/dm^3

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

Quantitative analysis

Quantitative analysis – gives the concentration of the substance that is present.

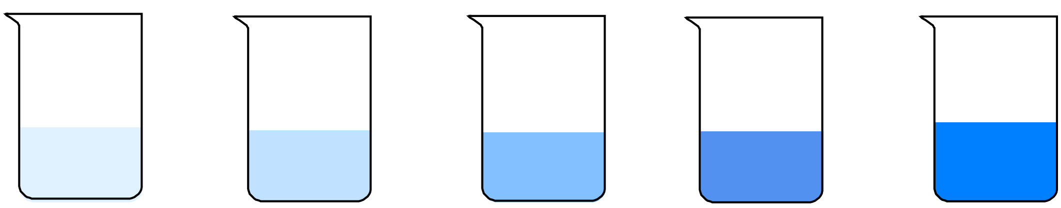
You need to be aware of two forms of quantitative analysis:

Method	What it does	Some examples of uses
colorimetry	measures the concentrations of coloured ions or substances in solutions	• measuring haemoglobin levels in blood • measuring the nitrate concentration in river water
acid-base titrations	measures the concentration of an acid using simple acid-base titration	• finding the carbonate concentration in river water • finding the concentration ethanoic acid in vinegar (food standards) • quality control laboratories

Colorimetry

Some substances are coloured. The colour of a solution tells us how dilute or concentrated the substance is. Colorimetry uses this idea to help us find the concentration.
An instrument called a colorimeter is used to measure the absorbance of the solutions.

Solutions of copper(II) ions



dilute solution

concentrated solution

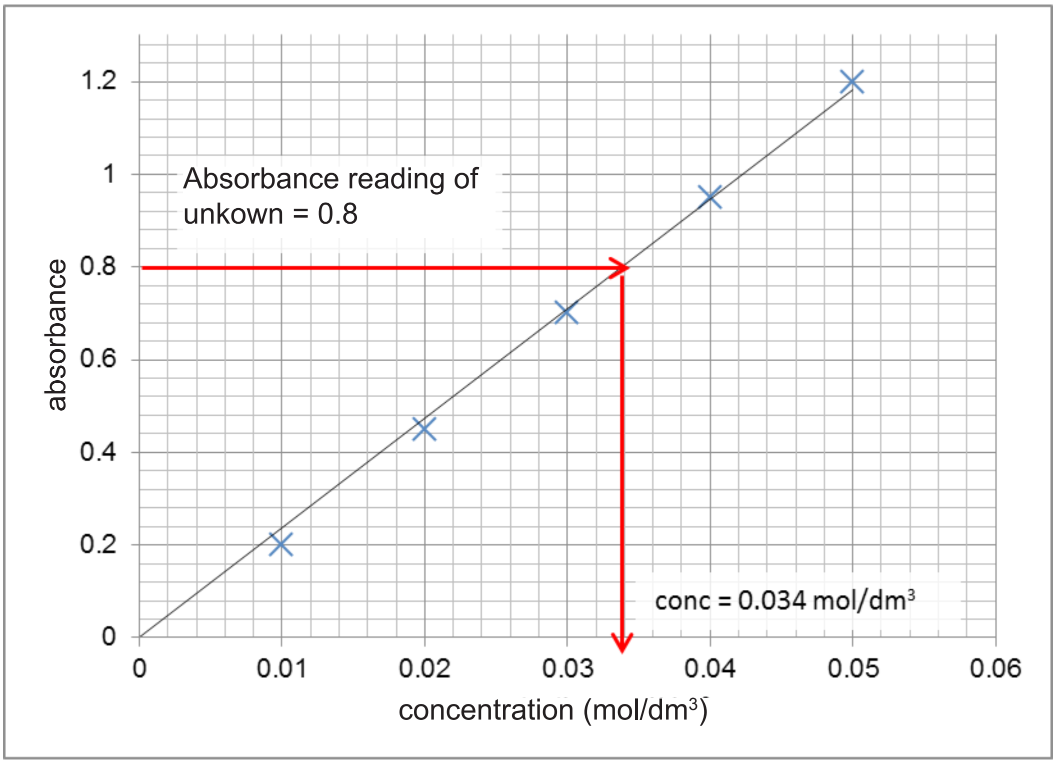
Steps in colorimetric analysis

1. Measure the absorbance for five solutions of different concentrations.
2. Plot the concentration against the absorbance for each solution to form a calibration curve.
3. Measure the absorbance of the unknown solution and use the calibration curve to find its concentration.

Scientific detection (specification 3.3)

Calibration curve

A calibration curve is drawn below for copper(II) ions.
The absorbance values of five different solutions were measured and plotted on the graph. The absorbance value of the unknown was then measured by the colorimeter.
This value (0.80) was used to find the concentration of the unknown solution.



The concentration of the unknown = 0.034 mol/dm^3.

> Make sure you can plot calibration curves for the exam and use them to find the concentration of an unknown solution.

Unit 3.3: Scientific detection

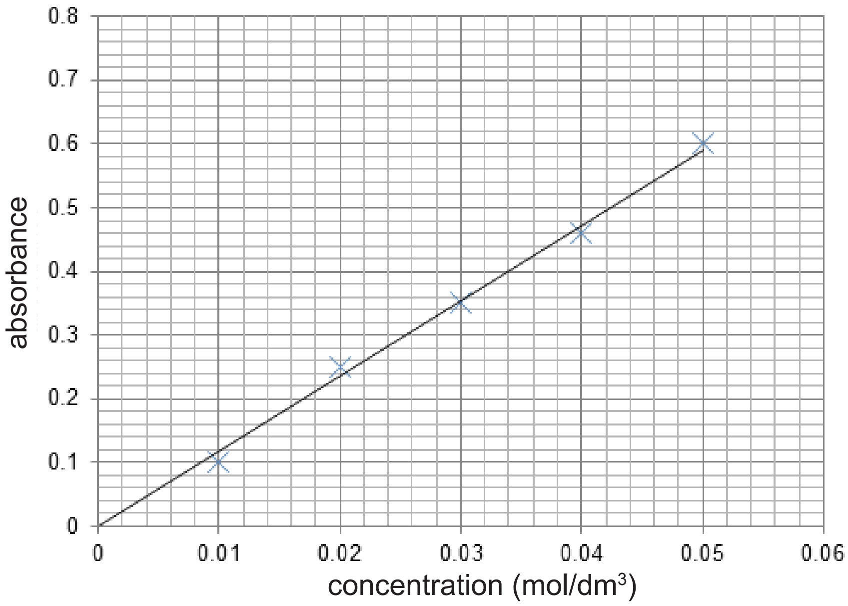
Scientific detection (specification 3.3)

TEST YOURSELF

1. Quantitative analysis:

A identifies what is present in a mixture
B gives a rough idea of the amount or concentration of a substance
C gives the amount or concentration of a substance.

2. A sample containing copper(II) ions was tested using colorimetry.
A calibration curve for the method is given below:

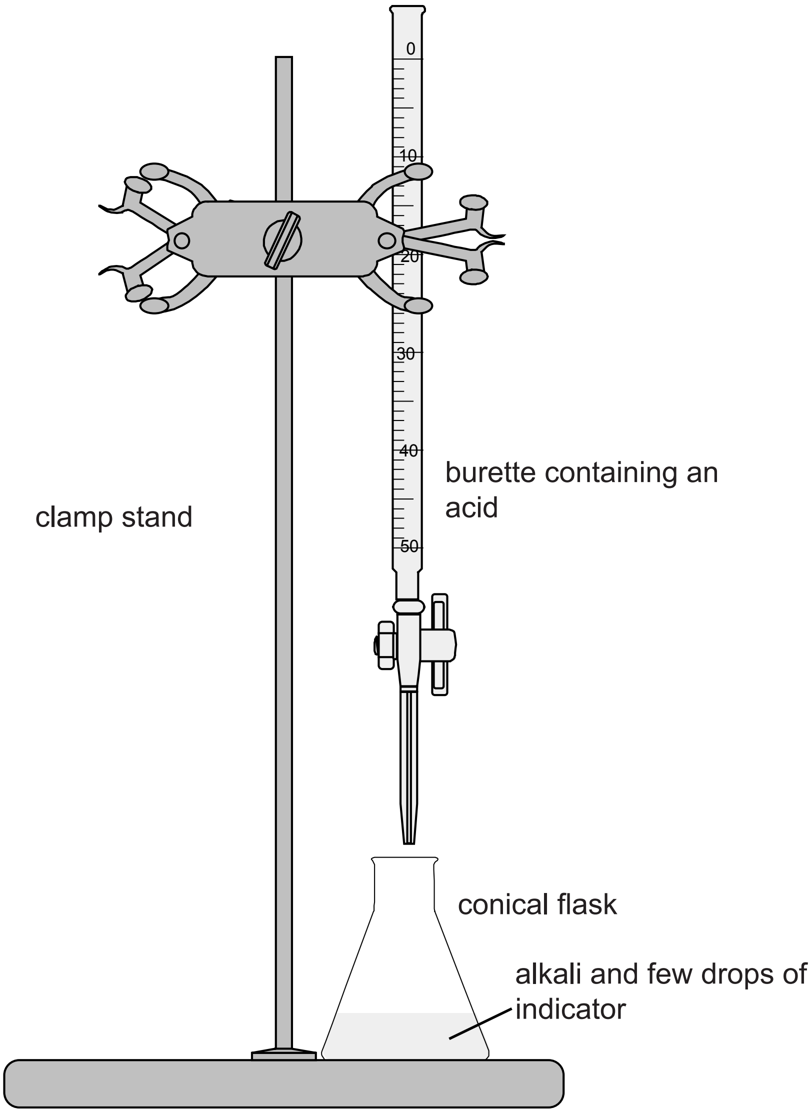


The sample gave an absorbance of 0.4.
The concentration of the copper(II) ion in the sample is:

A 0.4
B 0.034 mol/dm^3
C 0.034
D 0.4 mol/dm^3

Acid-base titrations

The concentration of an acid or alkali can be found using a titration.
The apparatus needed is shown below:



- The pipette is used to accurately measure a known volume of acid or alkali (e.g. 25 cm^3)
- The burette accurately transfers small volumes of alkali (or acid) until the indicator changes colour in the conical flask.

Unit 3.3: Scientific detection

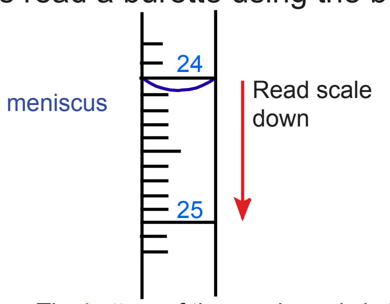
Scientific detection (specification 3.3)

Method

1. Add 25 cm^3 of alkali to a clean conical flask using a pipette.
2. Add a few drops of indicator and put the conical flask on a white tile.
3. Fill the burette with acid and note the starting volume.
4. Add the acid from the burette to the alkali in the conical flask, swirling to mix.
5. Stop adding the acid when the indicator changes colour (the end point). Note the final volume reading.
6. Repeat steps 1 to 5 until you get consistent readings.
7. Work out the titre for each titration you did.

Reading a burette

Always read a burette using the bottom of the meniscus:



If the bottom of the meniscus is level with a division we extimate the second place as ‘0’

If the bottom of the menisus is between two divisions we extimate the second decimal place to be ‘5’

The bottom of the meniscus is in line with the first division after 24.
Therefore the burette reading is 24.10 cm^3

Typical results

	Rough	First	Second	Third
Final burette reading (cm^3)	25.70	24.40	24.30	23.30
Initial burette reading (cm^3)	1.00	0.90	0.90	0.00
Titre (cm^3)	24.70	23.50	23.40	23.30

The titre is the final burette reading minus the initial burette reading. It is the volume of acid used each time.

The first reading is often ignored when we work out the mean. This is because it is difficult to get it right the first time you do a titration.

Ignore the rough value and use the other three to work out the mean titre.
mean titre = (23.50 + 23.40 + 23.30)/3 **= 23.40 cm^3**

Scientific detection (specification 3.3)

Sources of error in titrations

No matter how careful you are doing the work there will be errors in any titration.
Some reasons for errors include:

- not reading the meniscus on the burette from the bottom.
- adding the solution from the burette too quickly near the endpoint. One drop should be enough to change the colour of the indicator at the endpoint.
- not swirling the conical flask when you add the solution from the burette.
- knowing when the indicator has changed colour. It is more difficult to see the colour change for some indicators than others.
- using the wrong indicator. You must use the right indicator to find the endpoint.

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

TEST YOURSELF

1. The results from a titration are shown in the table below:

	Rough	First	Second	Third
Final burette reading (cm^3)	25.70	24.40	24.30	23.30
Initial burette reading (cm^3)	1.00	0.90	0.90	0.00
Titre (cm^3)	24.70	23.50	....	23.30

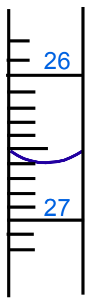
(a) The value of the second titre is:

A 23.40 **B** 24.10 **C** 22.30

(b) The mean titre is:

A 22.85 **B** 22.45 **C** 23.40

2. The reading on the burette scale is



A 26.60 cm^3

B 27.60 cm^3

C 27.40 cm^3

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

Foundation tier : You do **not** need to know about the mole or how to calculate it from the mass of a substance in an examination

Mass and moles

The **mole** is the unit for the amount of substance. One mole of atoms contains a certain number of particles (e.g. atoms or molecules), 6×10^{23} particles.

This is a very large number: it is 6 with 23 zeros after it. It is known as **Avogadro's number.**

For example:

- one mole of carbon contains 6×10^{23} atoms
- one mole of water contains 6×10^{23} molecules
- one mole of oxygen contains 6×10^{23} molecules

We count the number of particles (e.g. atoms or molecules) by weighing.

For example to measure one mole of:

- carbon atoms (i.e. 6×10^{23} atoms) you need to weigh out 12 g of carbon
- water molecules (i.e. 6×10^{23} molecules) you need to weigh out 18 g of water

Relative atomic mass (A_r)

All atoms have different masses. The table on page 123 tells us a carbon atom is 12 times the mass of a hydrogen atom.

You do not need to learn relative atomic masses. They will always be given to you in an exam.

Examples

Element	Relative atomic mass	Element	Relative atomic mass
H	1	O	16
C	12	Na	23
N	14	Cl	35.5

We need the relative atomic mass to find the mass of one mole of an element.

The mass of one mole of hydrogen atoms weighs 1 g.

The mass of one mole of nitrogen is 14 g.

The mass of one mole of sodium is 23 g.

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

Relative formula mass (M_r)

To find the relative formula mass (relative molecular mass) of a substance, you need to add together the relative atomic mass for all the atoms shown in its chemical formula.

Examples of calculations

Find the relative molecular mass (M_r) of (a) H_2, (b) HCl, (c) Na_2CO_3

(a) H_2 Relative atomic mass of hydrogen atoms (H) = 1.
The molecule (H_2) will therefore have a relative formula mass of 2.
The mass of one mole of hydrogen molecules is 2 g.

(b) HCl $M_r = 1 + 35.5 = 36.5$
The mass of one mole of hydrogen chloride molecules is 36.5 g.

(c) Na_2CO_3 $M_r = (2 \times 23) + 12 + (3 \times 16) = 106$
We multiplied 23 by 2 because there are 2 sodium atoms and 16 by 3 because there are 3 oxygen atoms

The mass of one mole of sodium carbonate is 106 g.

Molar mass

It is sometime useful to talk about the molar mass. This is simply the relative molecular mass expressed in grams.

Example:

The molar mass of hydrogen gas (H_2) is 2 g/mol (2 grams per mole).
The molar mass of sodium carbonate (Na_2CO_3) is 106 g/mol (106 grams per mole).

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

Finding moles from mass

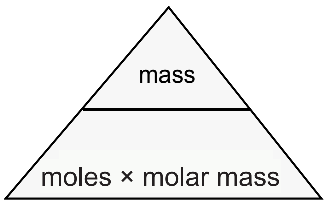
You can find the number of moles of a substance using the formula:

number of moles = mass ÷ molar mass

You can also rearrange this formula to find:

- the mass if the number of moles and the molar mass is known
- molar mass if you know the mass and number of moles

Use the formula triangle below to help you remember.

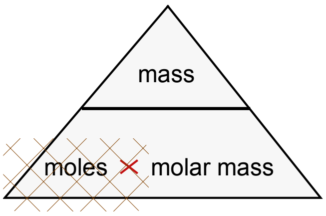


Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

Examples

1. How many moles are there in 1.06 g of sodium carbonate?
molar mass of sodium carbonate = 106 g/mol



Cover up 'moles'

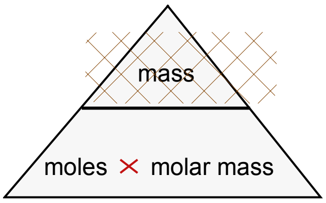
$$\text{moles} = \frac{\text{mass}}{\text{molar mass}}$$

$$\text{number of moles} = \frac{\text{mass}}{\text{molar mass}}$$

$$= \frac{1.06}{106}$$

$$= \mathbf{0.0100\ moles}$$

2. What is the mass of 0.10 moles of sodium chloride?
(Relative atomic mass Na = 23, Cl = 35.5)



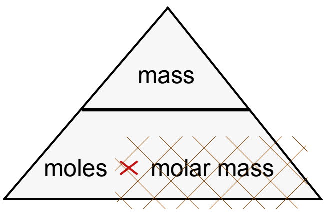
Cover up 'mass'

mass = moles × molar mass

Relative formula mass NaCl = 23 + 35.5 = 58.5
Molar mass NaCl = 58.5 g/mol

mass = moles × molar mas
mass = 0.10 × 58.5
= 5.85 moles

3. What is the molar mass of Na_2CO_3 if 2.00×10^{-2} moles has a mass of 2.12 g?



Cover up 'molar mass'

$$\text{molar mass} = \frac{\text{mass}}{\text{moles}}$$

2.00×10^{-2} moles = 0.0200 moles

$$\text{molar mass} = \frac{\text{mass}}{\text{moles}}$$

$$\text{molar mass} = \frac{2.12}{0.02}$$

$$= \mathbf{106\ g/mol}$$

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

TEST YOURSELF

Higher tier only

1. Use the following information to answer the question.

$A_r(Na) = 23$; $A_r(H) = 1$; $A_r(C) = 12$; $A_r(O) = 16$

The molar mass of sodium hydrogencarbonate ($NaHCO_3$) is:

A 36 g/mol **B** 84 g/mol **C** 72 g/mol

2. The molar mass of sodium chloride is 78.6 g/mol.

Use the equation:

$$\text{number of moles} = \frac{\text{mass}}{\text{molar mass}}$$

to find the number of moles in 7.86 g of sodium chloride.

A 0.1 moles **B** 7.86 moles **C** 10 moles **D** 0.786 moles

3. The molar mass of sodium carbonate (Na_2CO_3) = 106 g/mol.

Use **mass = moles × molar mass** to find the mass of 0.02 moles of sodium carbonate.

A 1.06 g **B** 10.6 g **C** 2.12 g **D** 21.2g

Unit 3.3: Scientific detection

Scientific detection (specification 3.3)

Genetic profiling

DNA is the complex chemical that carries genetic information. DNA is found in chromosomes, which are found in the nucleus of most cells. DNA is unique to each individual, **except for identical twins.**

Forensic scientists make use of this in a procedure known as **genetic profiling** (also called DNA profiling or DNA fingerprinting) to identify individuals from DNA left at a crime scene.

Forensic scientists extract DNA from any human cells left at a crime scene (e.g. blood or semen). The DNA is cut into pieces using enzymes and the fragments separated. The results are displayed as a series of bands.

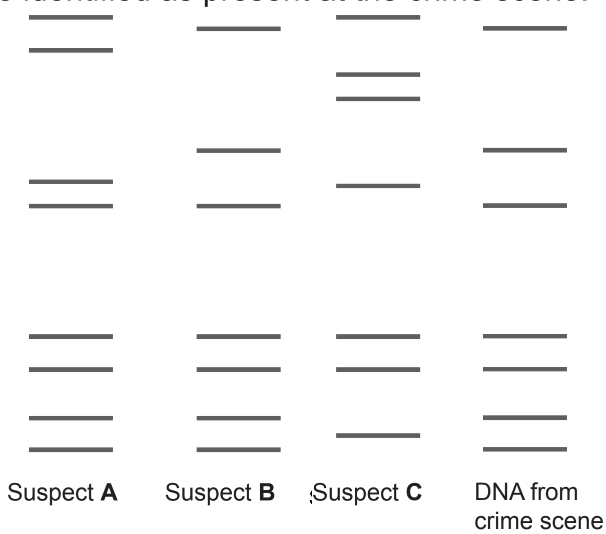
These bands are unique to each individual (except identical twins).

By comparing the bands of DNA from a crime scene with the bands obtained from a suspect's DNA, it is possible to work out if a suspect was at the crime scene.

Example

The DNA left at a crime scene and the DNA of three suspects was compared using genetic profiling. The results are shown below.

By comparing the set of bands we can see that the DNA at the crime scene is the same as suspect **B**. Suspect **B** can be identified as present at the crime scene.



DNA profiling also has many other applications which include:

- establishing the parents of a child in a paternity case
- diagnosing inherited diseases such as Huntington's disease.

TEST YOURSELF

1. Identify the suspect at the crime scene from the results below.

A Suspect AC
B Suspect BD
C Suspect TC
D none of the above

PRACTICE QUESTIONS

1. **DNA profiling** is a forensic technique used to identify individuals by characteristics of their DNA. A **DNA profile** is a small set of DNA variations that is very likely to be different in all unrelated individuals. DNA profiling can be used in paternity disputes.
The image below shows the DNA profile from such a paternity dispute.

(a) Explain how the DNA profiles above show that **male 1** is the father of the child. [2]

………………………………………………………………………………………………

………………………………………………………………………………………………

(b) State **two** other important uses of genetic profiling. [2]

………………………………………………………………………………………………

………………………………………………………………………………………………

(c) **(i)** Describe the principle upon which the use of genetic profiling for identification of individuals depends. [1]

………………………………………………………………………………………………

………………………………………………………………………………………………

(ii) Give **one** example when this principle will not be valid. [1]

………………………………………………………………………………………………

(d) '23andMe' is a home DNA testing kit which is on sale in the UK. Give **two** reasons why there is concern about the widespread use of this type of DNA testing. [2]

……

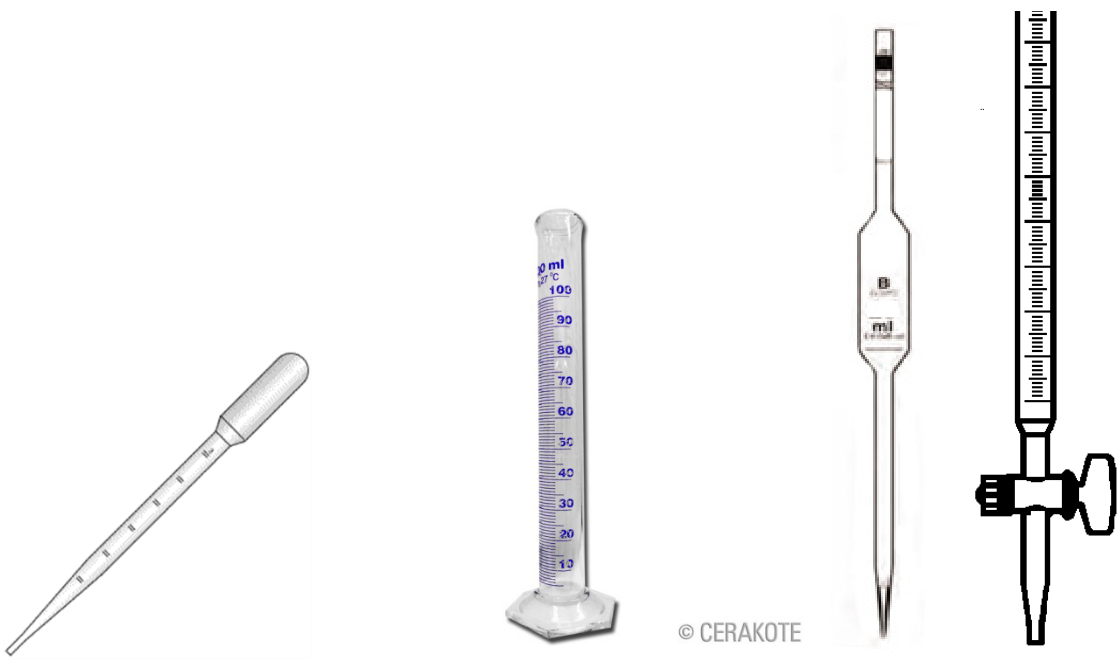
……

2. Vinegar contains a weak acid called ethanoic acid. The concentration of ethanoic acid in vinegar can be found using a titration with sodium hydroxide.

(a) Complete the word equation for the reaction. [2]

ethanoic acid + sodium hydroxide → ………………. ethanoate + …………………….

(b) A laboratory technician is checking the concentration of ethanoic acid in vinegar which is to be sold in a local supermarket.
He measures exactly 25.00 cm^3 of sodium hydroxide solution into a conical flask.
State the letter of the instrument that he should use to measure this volume. [1]



A B C D

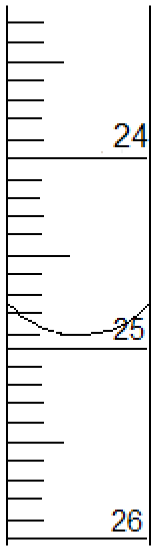
answer: ………….

(c) The technician carries out the titration by adding ethanoic acid to the sodium hydroxide using a 50.0 cm^3 burette. He records his results in the table below.

	Rough titration	Titration 1	Titration 2	Titration 3
Final volume (…………)	…………..	24.30	24.30	24.50
Start Volume (…………)	0.05	0.20	0.25	0.50
Titre (…………)	…………..	24.10	24.05	24.00

(i) The technician has not added the units used in the titration to his table. Add the units to the table. [1]

(ii) The first burette reading is shown in the diagram below. Add this volume to the table and use it to find the missing titre. [2]



(iii) Calculate the mean titre. [3]

mean titre ……………..…… cm^3

(iv) The vinegar should have a concentration between 0.780 and 0.860 mol/dm^3. If it does not the technician must report the vinegar as ‘out of range’.

The concentration of the ethanoic acid in vinegar can be found by multiplying the mean titre by 0.0327. Explain whether the technician should report the vinegar as ‘out of range’. [2]

....

....

TEST YOURSELF - ANSWERS FOR UNIT 3.3

Carrying out analysis

1. B
2. C
3. A
4. A
5. C

Chromatography

1. C
2. A
3. B

Semi-quantitative analysis

1. B
2. C

Quantitative analysis

1. C
2. B

Acid-base titrations

1. (a) A (b) C
2. A

Mass and moles

1. B
2. A
3. C

Genetic profiling

1. D

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

THE NEED TO CONTROL CHEMICAL REACTIONS

The chemical industry provides many of the chemicals that we need for modern life. To do this safely, scientists need to understand the energy changes involved in chemical reactions and how the rate of chemical processes depends upon the conditions for the reaction.

Failure to control chemical reactions can lead to runaway reactions which have caused a number of serious accidents.

Energy and chemical change

There is almost always a change in energy associated with a chemical reaction and as a result there is often a temperature change. Energy may be given out in a chemical reaction or it may be taken in during the reaction.

An **exothermic** reaction is one in which energy is **given out** to the surroundings.

This will cause the temperature of the surroundings to **increase**.

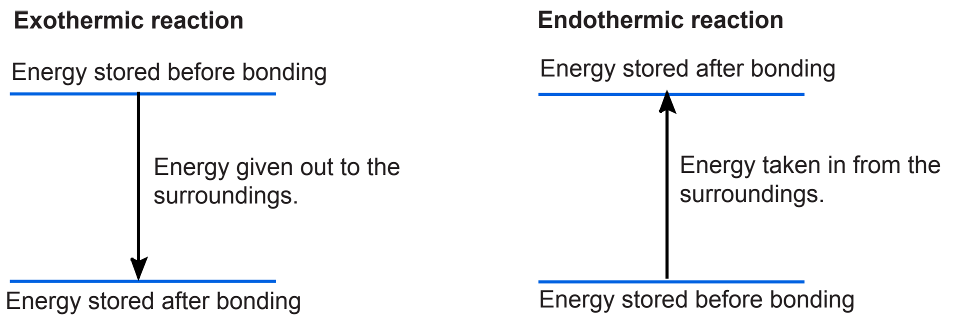
An **endothermic** reaction is one in which energy is **taken** in from the surroundings.

This will cause the temperature of the surroundings to **decrease**.

Energy is stored up within a compound in the chemical bonds. When a chemical reaction occurs, the way in which elements are bonded together changes.

If **less** energy is stored in the bonds after the reaction, then energy is **given out** to the surroundings.

If **more** energy is stored in the bonds after then reaction, then energy is **taken in** from the surroundings.



Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

The rate of a chemical reaction

Some chemical reactions are extremely fast whilst others are slow. The rate of reaction tells us how fast or slow a reaction is.

The rate of reaction is equal to either:

- the amount of reactant used, divided by the time taken
- the amount of product formed, divided by the time taken

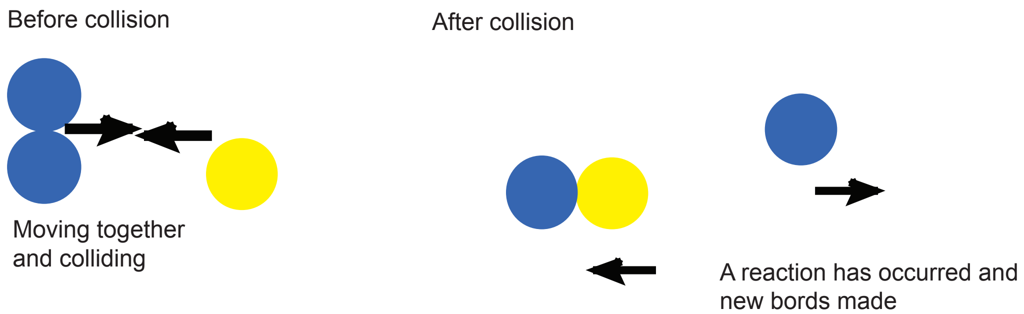
The **rate** of a chemical reaction can be **increased** in several different ways:

- increasing the concentration of the reactants (if it is a reaction involving gases increasing the pressure has the same effect)
- increasing the temperature
- increasing the surface area of a reactant (this only works if one of the reactants is a solid)
- adding a catalyst.

Collision theory

In order to understand why changing any of these things changes the rate, we need to understand how a reaction occurs.

In order for a reaction to occur the reactants need to collide with each other. This is called **collision theory**.



The rate of a reaction depends on the chance of successful collisions.

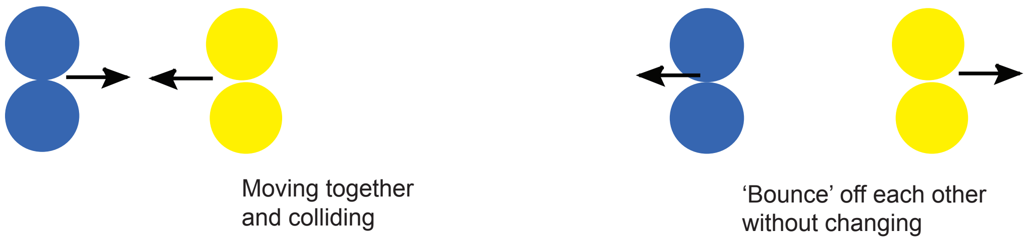
The greater the chance of successful collisions, the faster the reaction will be.

Controlling chemical reactions (specification 3.4.1)

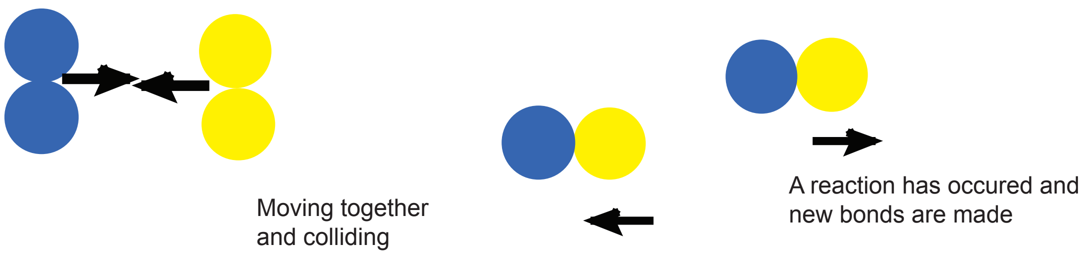
Do all collisions result in a chemical change?

Not all collisions have enough energy to break the bonds when a collision occurs. If the energy of collision is low, the particles will bounce off one another without reacting. There must be enough energy in the collision to break the bonds if a reaction will occur.

Low energy collison



A successful collision - High energy collison



There must be sufficient energy in the collision to break the bonds.

> The minimum amount of energy required for a reaction to occur when particles collide is called the **activation energy**.

The effect of increasing the temperature

Increasing the temperature increases the rate of reaction because:

- the reactant particles move more quickly at higher temperatures
- the particles will collide more often
- there will be more successful collisions because more particles have the minimum amount of energy (the **activation energy**) to react when they collide.

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

The effect of concentration (and pressure)

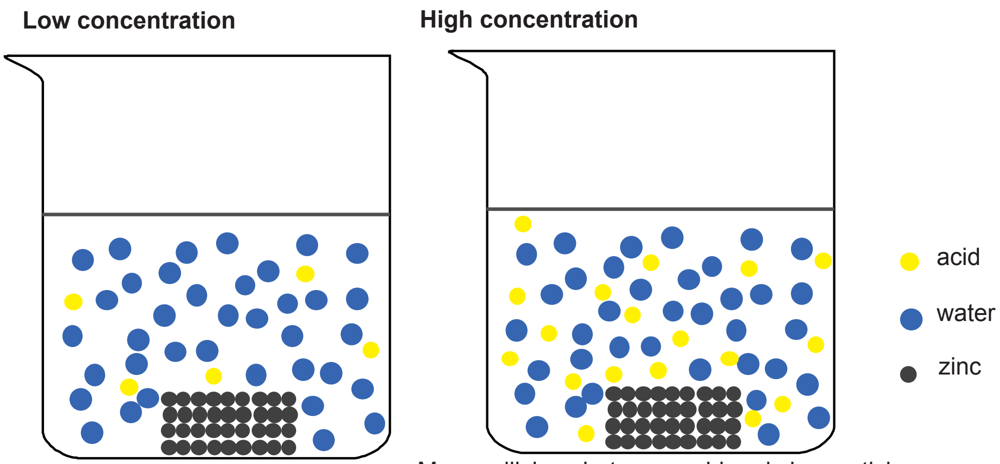
Increasing the concentration of the reactants means there are more reactant particles in the solution and therefore a greater chance of successful collision.

Since collisions occur more often, the reaction is faster.

Example

zinc + hydrochloric acid → zinc chloride + hydrogen

The diagram below shows that the higher the concentration the greater the chance of a collision between the acid (red) and zinc (grey) particles.



More collisions between acid and zinc particles

Increasing the pressure in a reaction involving gases also increases the rate of the reaction **for the same reason**.

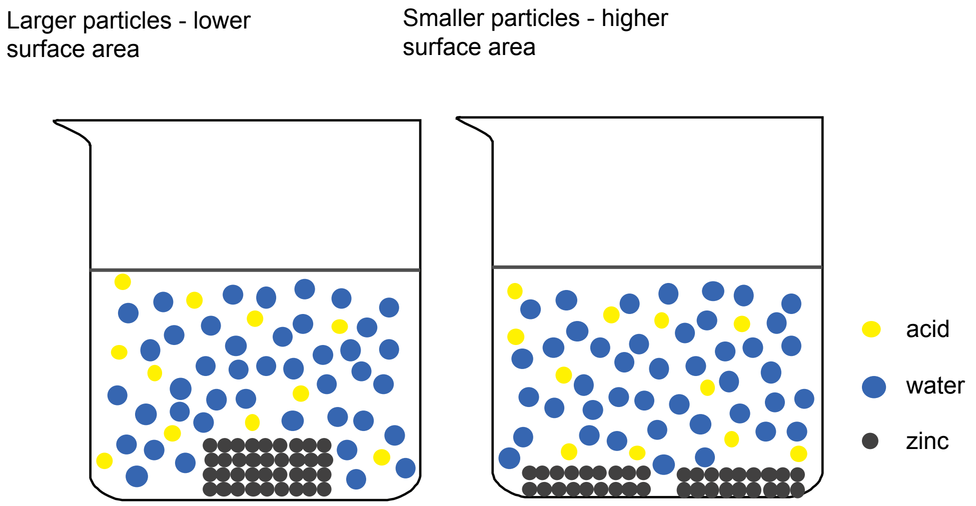
- At low pressure there is only a small chance particles will collide.
- Increasing the pressure increases the chances of collisions.
- Since collisions occur more often, the reaction is faster.

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

The effect of surface area

This only applies if one of the reactants is a solid.
Increasing the surface area means more particles in the solid are exposed to collisions. Therefore more successful collisions will occur and so the reaction is faster.



More collisions between acid and zinc particles

We increase the surface area by breaking a solid into smaller pieces or grinding it into a powder.

Adding a catalyst

> A **catalyst** is a substance that can increase the rate of a reaction but remains unchanged at the end of the reaction it catalyses.

How does a catalyst work?

- A catalyst **reduces** the energy required for a reaction to occur (the **activation energy**) when the reactants collide.
- This means there is a greater chance of a successful collision between particles. The rate of reaction therefore increases.

Only a very small amount of catalyst is needed to increase the rate of reaction between large amounts of reactants.

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

TEST YOURSELF

1. An endothermic reaction is one in which:

A energy is released
B energy is absorbed
C temperature increases

2. The rate of reaction is equal to:

A amount of a product formed divided by the time taken
B the time taken for a product to form
C the time taken for a reactant to form

3. The rate of a chemical reaction can be decreased by:

A increasing the temperature
B adding a catalyst
C decreasing the temperature

4. A catalyst works by:

A making the particles collide faster
B reducing the activation energy for a reaction
C increasing the energy available for reactants to react

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

Industrial processes and catalysts

Industry needs to find ways to carry out chemical reactions safely, cheaply and in a way that does little harm to the environment. This can be very difficult.

Catalysts need to be carefully chosen for the reaction they catalyse. Different catalysts are needed for different reactions.

An case study: The most important invention of the 20th century

Ammonia is an important compound. Without the mass production of ammonia, it is estimated that as many as a third of us would not be alive today.

One of the main uses of ammonia is to make fertilisers which helps give high crop yields to feed the growing population.

Ammonia can be made from two readily available elements: hydrogen and nitrogen.

Spreading an ammonia based fertiliser
Grant Heilman Photography / Alamy Stock Photo

The word equation for the process is:

nitrogen + hydrogen $\leftrightharpoons$ ammonia

The problem with the reaction is that nitrogen is very unreactive. There is a strong bond between the nitrogen atoms which is difficult to break. Mixing nitrogen and hydrogen together results in no change. The molecules bounce off each other without reacting.

Increasing the temperature and pressure alone does not help in this case.

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

The Haber Process

Just over 100 years ago a catalyst was found that means that we can make ammonia from nitrogen and hydrogen. The industrial process to make ammonia is called the Haber process and is often called the most important invention of the 20th century.

Industrial plant that makes ammonia
Vsevolod Chuvanov / Alamy Stock Photo

In the Haber process, ammonia is made by mixing nitrogen and hydrogen in the presence of an iron catalyst. However a high temperature (450°C) and a pressure 200 times atmospheric pressure is still needed. This needs a lot of energy and therefore is expensive. It is estimated that this chemical process uses 2% of the world's energy each year.

Although the catalyst is not used up in reaction, it does need replacing from time to time. This is because it can be poisoned by impurities in the reaction mixture.

The Haber process is very important but it could be cheaper!

You do not need to know the details of any industrial processes (including the Haber process) for an examination but you should be able to recognise the economic and environmental importance of developing new and better catalysts.
Better catalysts may mean:

- lower energy costs
- more environmentally friendly processes
- lower demands on raw products
- better yields

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

Finding a better catalyst

The aim of researchers is to find a better catalyst. If we could produce a catalyst that allows us to make ammonia at room temperature and pressure, then we would:

- reduce the energy used to make ammonia. This in turn reduces the amount of carbon dioxide (a greenhouse gas) and other pollutants that are produced
- make the process safer (no longer will we need to contain such high pressures)
- make fertilisers cheaper in turn reducing the cost of producing food.

Nitrogen fixing bacteria, using enzymes (biological catalysts) are able to do at 'ordinary' temperatures and 1 atmosphere pressure. Perhaps we can learn from bacteria to design new catalysts in the future?

Measuring the rate of reaction

The rate of a reaction can be measured by the rate at which a reactant is used up, or the rate at which a product is formed.

There are **two** ways to measure the rate of a reaction:

- measure the rate at which a reactant is used up
- measure the rate at which a product is formed.

The method chosen depends on the reaction being studied.
Sometimes it is easier to measure the change in the amount of a reactant that has been used up; other times it is easier to measure the change in the amount of product that has been produced.

How can we measure rate?

Two methods we could use to measure the rate of a reaction are:

1. Use an electronic balance to measure the mass of a substance against time.
2. Use a gas syringe, or an upside down measuring cylinder, to measure the volume of a gas against time.

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

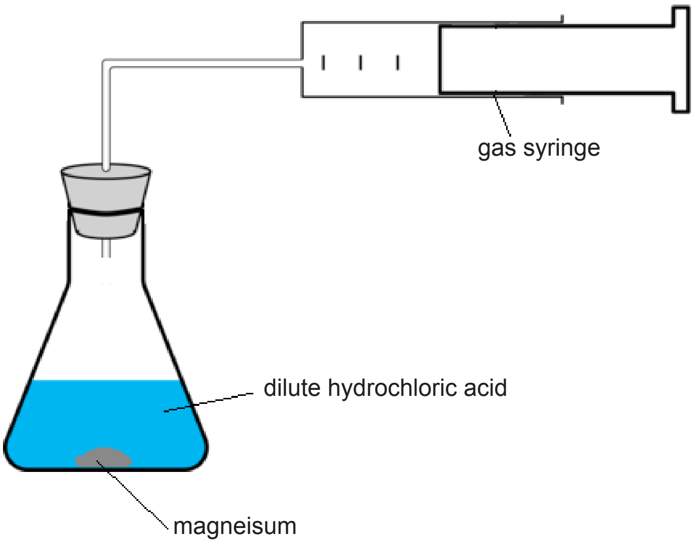
The rate of reaction between magnesium and hydrochloric acid

Magnesium reacts with hydrochloric acid to form magnesium chloride and hydrogen gas.

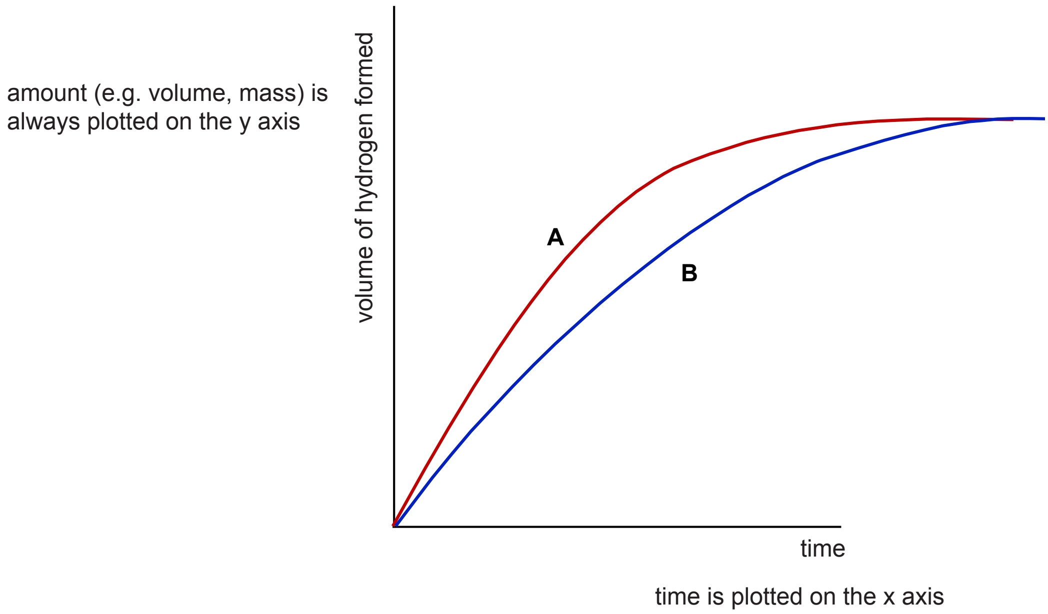
We could measure the rate of this reaction by:

- the volume of hydrogen gas formed **against time** using a gas syringe
- the mass of hydrogen formed by placing the reaction vessel on an electronic balance and watching the mass change **against time**.

Apparatus to measure using a gas syringe.



An example of the results obtained, plotted as a graph, when magnesium reacted with hydrochloric acid is shown below.



Notice:

- both reactions were carried out with the same amount of reactants.
- a reaction is finished when the plot levels out – reaction **A** levels out first.
- reaction **A** is faster than reaction **B** because the curve is steeper and it levels out sooner.

The rate of reaction between sodium thiosulfate and dilute hydrochloric acid

Word equation:

hydrochloric acid + sodium thiosulfate → sodium chloride + sulfur dioxide + sulfur + water

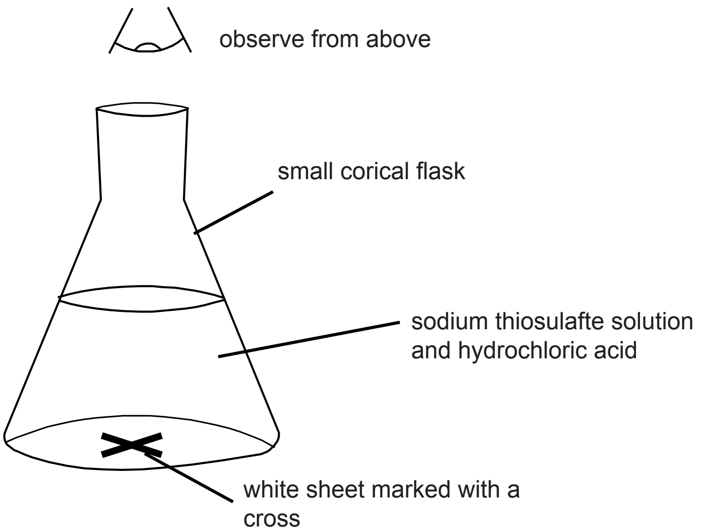
Symbol equation:

$$2HCl(aq) + Na_2S_2O_3(aq) \rightarrow 2NaCl(aq) + SO2(g) + S(s) + H_2O(l)$$

The rate of this reaction can be measured by looking at the rate at which the product solid sulfur (S(s)) is formed. The solid sulfur makes the colourless solution go cloudy.

This reaction is usually carried out in a flask placed on a piece of white paper. The white paper has a black cross on it.

At the beginning of the reaction, the cross can easily be seen through the solution in the flask. As the solution in the flask becomes cloudier, the cross gets harder to see.



You can measure the time from the start of the reaction until the cross can no longer be seen. This is a way of measuring the rate of formation of sulfur.

Results of an experiment showing the effect of temperature on reaction rate

The rate of reaction is measured for different temperatures using the apparatus shown on the previous page. The results are shown below.

Temperature (°C)	Time for cross to disappear (seconds)	Rate (1/time) (/s)
22	61	0.016
36	24	0.042
28	20	0.05
44	17	0.058
54	9	0.11

Notice that:

- as temperature increases, the time for the cross to vanish gets less – this is because the reaction is getting quicker
- the rate of reaction is measured 'per second' so a way of working out rate in this case is to do the calculation '1÷ time'

Improving the experiment

Measuring the time taken for the cross to disappear can be difficult to measure exactly. In order to improve the results you could take several readings at each temperature and use a mean value to find the rate.

> An alternative way of doing this experiment is to use a light sensor linked to a data logger to follow the precipitation of sulfur. This will give more reproducible results.

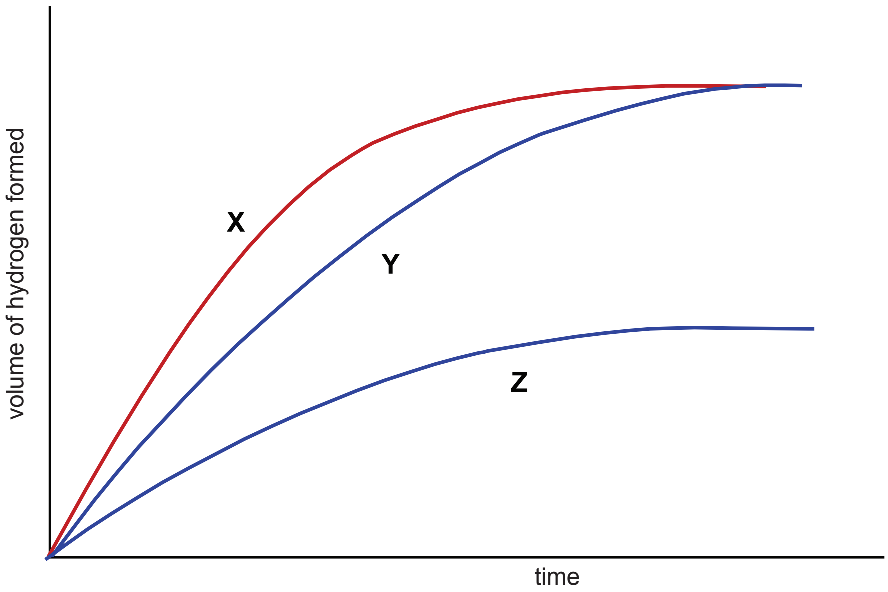
Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

TEST YOURSELF

1. Zinc metal was reacted with hydrochloric acid in three different reactions. In each case the same volume of hydrochloric acid was used.

The results of three different experiments are shown below.



A Reaction **X** is a slower reaction than **Y**
B Reaction **Z** is a faster reaction than **Y**
C Less zinc was used in reaction **Z** than the other two reactions
D Reaction **Y** is faster than **X**
E None of the above statements are true

2. The word equation for the reaction between hydrochloric acid and sodium thiosulfate is:

hydrochloric acid + sodium thiosulfate → sodium chloride + sulfur dioxide + sulfur + water

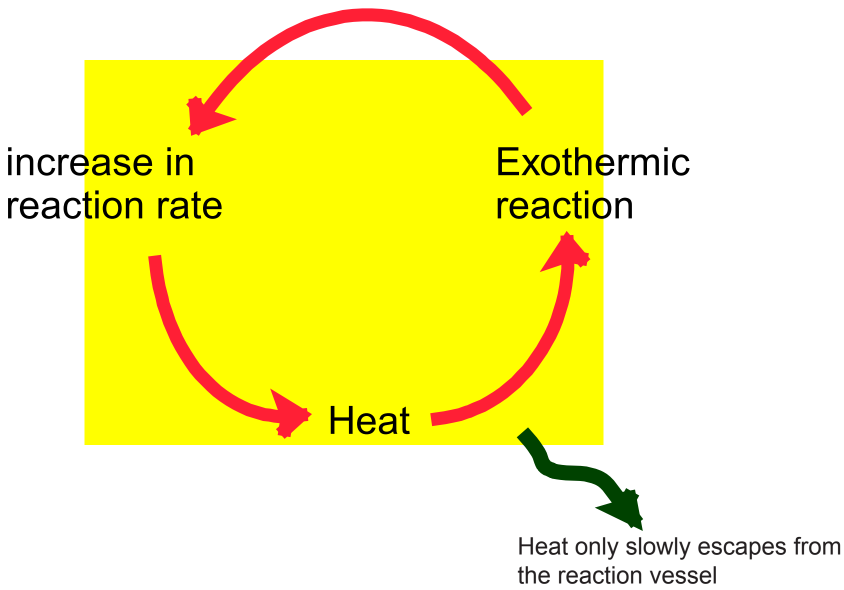
We can measure the rate of the reaction between hydrochloric acid and sodium thiosulfate by:

A measuring the volume of water formed
B using a light sensor to measure the amount of sulfur formed
C measuring the mass of sodium chloride formed

Thermal runaway chemical reactions

It is important that industrial reactions are carefully controlled to prevent them getting out of control. If the reaction being controlled is **exothermic** (energy is released), there is the danger that the heat released does not escape from the reaction vessel and the temperature of the reaction increases. This in turn can increase the rate of reaction leading to a **thermal runaway**.

The danger of a thermal runaway reaction can be summed up in the diagram below.



> **Thermal runaway** refers to a situation where an increase in temperature increases the speed of an exothermic process. In turn, this increases the temperature further increasing the rate of reaction. This can lead to destructive consequences such as an explosion.

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

Losing control of reactions

In order to prevent thermal runaway reactions it is important to carefully monitor and control reactions so that the temperature in a reaction vessel remains stable and does not start increasing in an uncontrolled way.

There have been a number of cases where thermal runaway reactions have occurred with disastrous consequences.

1. Texas City disaster (1947) in which 581 people died.
   This was caused by a thermal runaway reaction involving ammonium nitrate stored in a ship.

An image from the Texas City disaster
Moore Memorial Public Library

SOMETHING TO WATCH

Watch the following clips about Texas City disaster:
Texas City disaster https://youtu.be/TworcINhDhQ

2. Bhopal disaster (1984). The official immediate death toll was 2 259. More have died since from the toxic after effect of the chemicals released by the explosion.

   A thermal runaway reaction occurred when water got into a reaction vessel. The resultant explosion released toxic chemicals into the area.

Some of the victims of the Bhopal disaster
Dinodia Photos / Alamy Stock Photo

SOMETHING TO WATCH

Watch the following clips about the Bhopal disaster

http://www.bbc.co.uk/news/magazine-29833548

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

TEST YOURSELF

1. A thermal runaway reaction can only occur if:

A the chemical reaction is exothermic
B the chemical reaction is endothermic
C heat is allowed to escape from the reaction vessel

Unit 3.4: Controlling processes

Controlling chemical reactions (specification 3.4.1)

PRACTICE QUESTIONS

1. Students are investigating how effective the catalyst copper (II) oxide works is in decomposition of hydrogen peroxide. The students performed two experiments.

   In both experiments 5 g of copper(II) oxide was added to a flask containing 100 cm^3 of hydrogen peroxide solution. The balanced symbol equation for the reaction is given below.

$$2H_2O_2 \xrightarrow{CuO} 2H_2O + O_2$$

   The gas, oxygen was released.

   In **Procedure 1** the students counted the number of bubbles of gas given off every 10 seconds.

   In **Procedure 2** the students measured the volume of gas given off with a burette.

   The results of the students' experiments are given below.

Time (s)	**Procedure 1** Number of bubbles of oxygen	**Procedure 2** Total volume of gas given off (cm^3)
10	> 25	15
20	18	27
30	15	37
40	10	45
50	4	50
60	2	51
70	1	51
80	0	51
90	0	51

(a) Explain which method of measuring gas gives the most valid results. [2]

....

....

....

....

(b) Describe how the rate of the reaction changes during this experiment. [2]

....

....

....

....

(c) Use data from the table to calculate the maximum rate of reaction. [2]

rate = ... cm^3/min

(d) Explain what is meant by the term 'catalyst'. [2]

....

....

(e) State how much copper(II) oxide would be left in the flask at the end of the reaction. [1]

............g

(f) State two ways that the students could speed up the rate of this reaction. [2]

1 ....

2 ....

Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

NUCLEAR FISSION AND FUSION

Nuclear reactions have great potential to release vast amounts of energy and can be used to generate electricity. The use of nuclear power is not without controversy however. There are fears that nuclear reactions could have a devastating impact on human populations and the environment. A few accidents have helped fuel this concern.

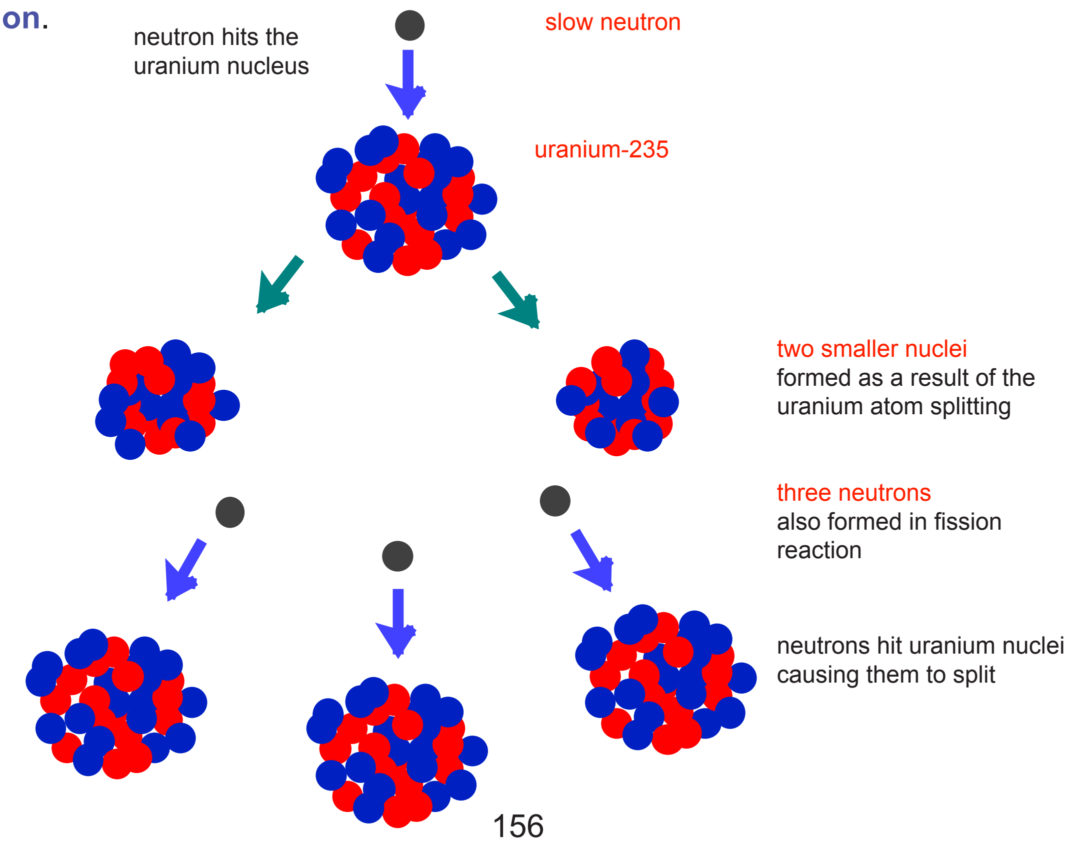
Nuclear fission reactions

Nuclear **fission** means **splitting** a nucleus of an atom into smaller nuclei with the release of energy.

It is easier to split relatively large nuclei such as those of uranium-235 or plutonium-239. Uranium-235 means uranium with a mass number of 235. It is particular isotope of uranium. When a uranium-235 or plutonium-239 nucleus is hit by a neutron, the following happens:

1. the nucleus splits into two smaller nuclei
2. two or three more neutrons are released
3. energy is released

The additional neutrons released may also hit other uranium or plutonium nuclei and cause them to split. Even more neutrons are then released, which in turn can split more nuclei. This is called a **chain reaction**.



Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

SOMETHING TO WATCH

Watch the following animation of a nuclear fission reaction

https://www.youtube.com/watch?feature=player_embedded&v=tQa4LONy9XM

Writing equations for nuclear fission reactions

The symbols of different nuclei are written using the system:

$^{A}_{Z}X$ where A is the mass number and Z the atomic number

Example

The uranium-235 isotope is written: $^{235}_{92}U$

mass number $\rightarrow$ 235

atomic number $\rightarrow$ 92

$^{235}_{92}U$

You may be asked to complete nuclear fission equations in an examination.

Examples of nuclear equations

Remember in such cases that:

- the sum of the atomic numbers on the left hand side equals the sum of the atomic numbers on the right hand side
- the sum of the mass numbers on the left hand side equals the sum of the mass numbers on the right hand side

mass number = 235 +1 = 236 mass number = 145 + 88 + (3 × 1) = 236

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{145}_{57}La + ^{88}_{35}Br + 3\,^{1}_{0}n \quad (+ \text{ energy})$$

atomic number = 92 + 0 = 92 atomic number = 57 + 35 + 0 = 92

Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

Example question

Find the missing numbers, x and y, in the following nuclear equation:

$$ {}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{x}_{y}\mathrm{Ba} + {}^{91}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n} $$

Answer:

mass number LHS = 235 + 1 = **236**

atomic number LHS = 92 + 0 = **92**

mass number RHS = x + 91 + (3 × 1) = 236
x + 94 = 236
x = 236 - 94 = **142**

atomic number RHS = y + 36 + 0 = 92
y = 92 -36
y = **56**

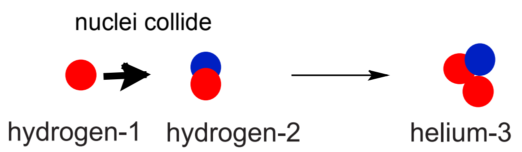
Nuclear fusion reactions

Nuclear **fusion** involves two atomic nuclei **joining** to make a large nucleus.

Energy is released when this happens.

The Sun and other stars use nuclear **fusion** to release energy.

In the Sun two hydrogen nuclei **join** to form a helium nucleus.



Expressed as a nuclear equation:

mass number LHS = 1+2 = 3

mass number RHS = 3

$$ {}^{1}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + \text{energy} $$

atomic number RHS = 1+1 = **2**

atomic number RHS = **2**

Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

TEST YOURSELF

1. Nuclear fission involves:

A joining together the nuclei of atoms
B joining together the atoms
C splitting the nuclei of atoms
D splitting apart atoms

2. The symbol for uranium-235 is ${}^{235}_{92}U$.

A the atomic number is 92 and mass number 235
B the atomic number is 235 and mass number 92
C the atomic number is 235 and mass number = 235 – 92 = 143

3. Find the number, x in the nuclear equation below.

$${}^{1}_{1}H + {}^{x}_{1}H \longrightarrow {}^{3}_{2}He + \text{energy}$$

A 1
B 2
C 3

Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

Nuclear power

When we split the nucleus of an uranium atom, a large amount of energy is released, much more than from a chemical reaction.

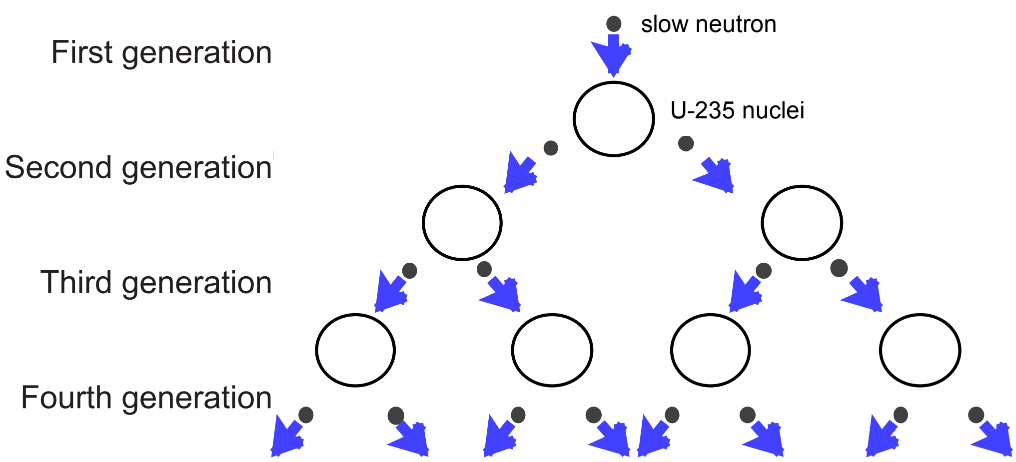
In the nuclear reaction, a small amount of mass has been lost and changed into a large amount of energy. Nuclear power stations use this energy to produce electricity.

Most nuclear power stations use uranium-235 as a fuel although some may use plutonium-239.

Controlling the chain reaction

Nuclear power stations attempt to control the fission chain reaction so that energy can be released in a controlled way.

The reaction below shows the start of a chain reaction in which two neutrons are formed when each nucleus is split. With each generation, the number of neutrons available to collide with more nuclei is doubling. If this continues, the reaction is out of control and an explosion can occur.



Fission reactions will need to be controlled in a nuclear reactor so this does not occur.

In order to **control the chain reaction** we need to:

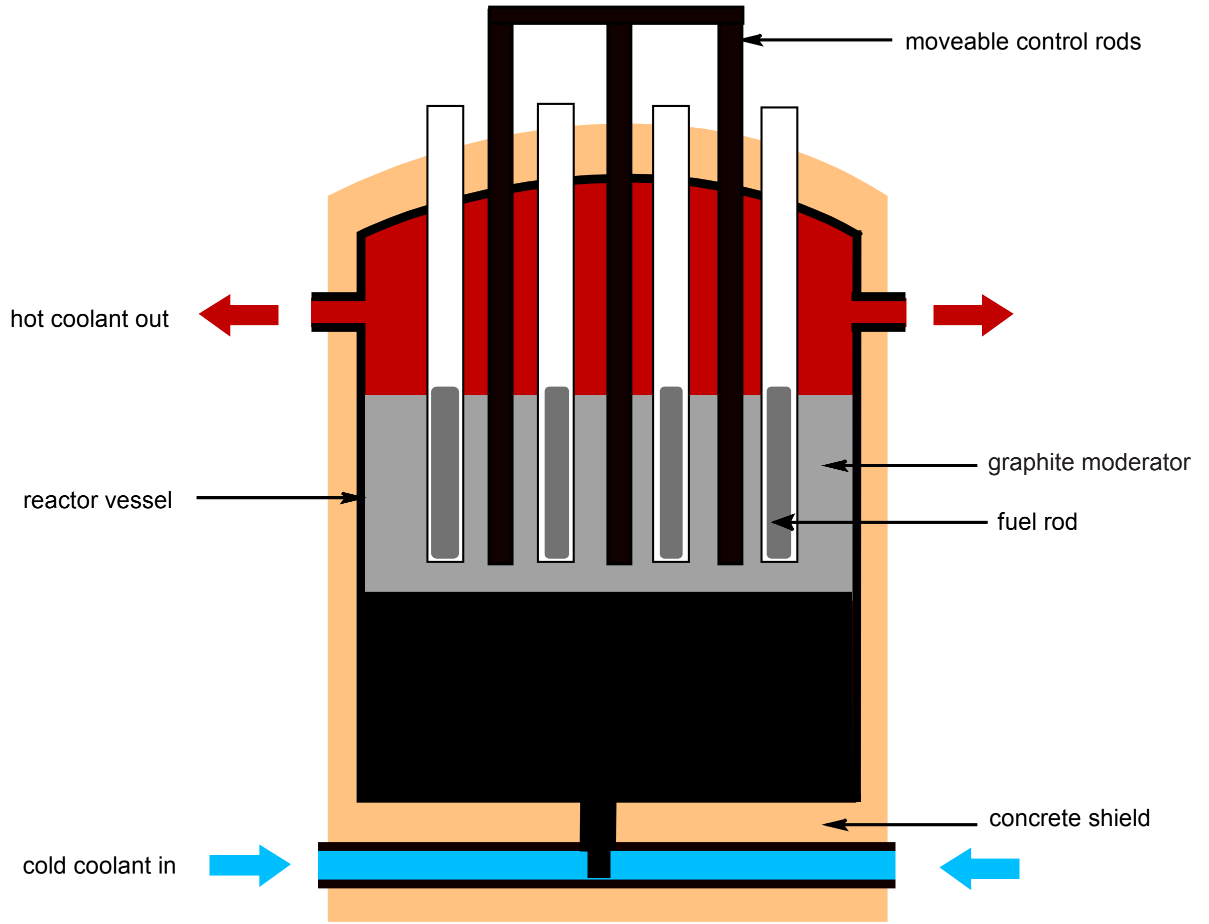
- control the speed of the neutrons (only **slow** neutrons will split nuclei)
- control the number of neutrons available to split nuclei

Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

The nuclear reactor

A nuclear reactor is designed to control the chain reaction to safely use the energy released to generate electricity.



Design features:

- **The fuel rods** are made of uranium-235 or plutonium-239.
- The **moderator** slows down neutrons so they can be absorbed and cause further nuclei to split.
- The **control rods** absorb neutrons. They help control the speed of the chain reaction by controlling the number of neutrons in the reactor.
- The **coolant** is circulated to remove heat from the reactor. The hot coolant is used to heat up steam to drive turbines to make electricity.
- The **concrete shield** absorbs neutrons and ionising radiation. This is often up to 5-6 m thick. It is to protect workers from the dangerous radiation.

Make sure that you can label a diagram of a nuclear reactor and explain the purpose of each part.

Unit 3.4: Controlling processes

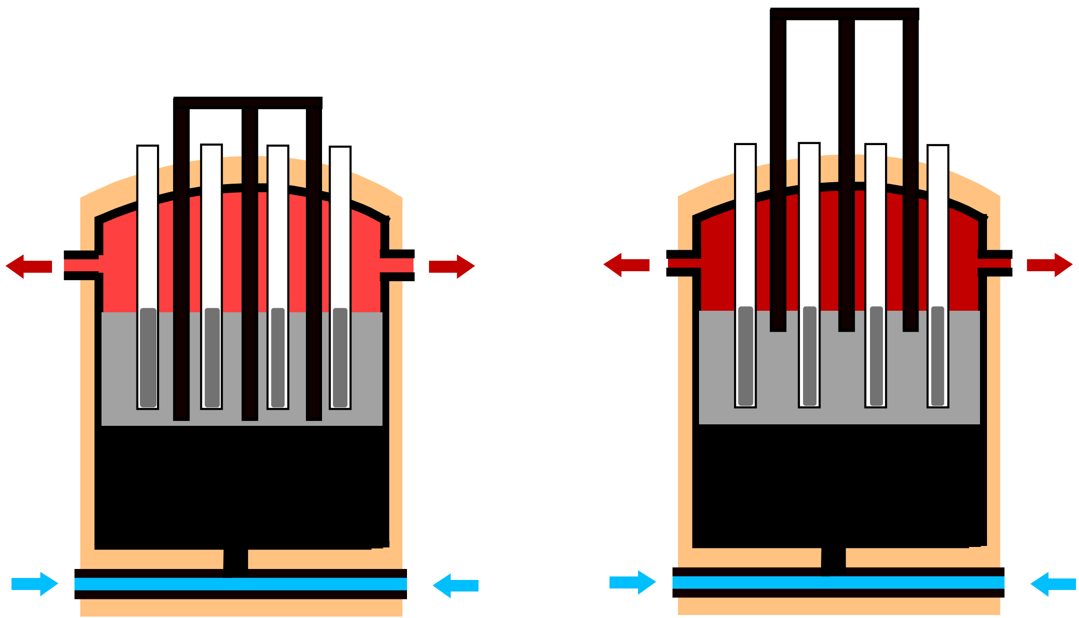
Controlling nuclear reactions (specification 3.4.2)

Control rods and the chain reaction

Control rods control the chain reaction by absorbing neutrons. They can be moved up and down into the reactor core.

Control rods are fully in
All neutrons are absorbed
Reactor closed down

Control rods are partially removed
Only some neutrons are absorbed
Chain reaction is faster
Reactor temperature increases



Radiation and isotopes

Radioactive isotopes are produced in the reactor. Some of these have long half-lives. For this reason, radioactive waste from the reactor will have to be kept secure for a **very long time** after the reactor has been decommissioned. It needs to be stored in such a way that it and cannot leak into the environment.

How long? Half-life and radioisotopes

How long radioisotopes in the waste from nuclear reactors remain a problem depends upon their half-life.

The **half-life** is the **time taken** for the number of radioactive nuclei (or the activity of a radioactive source) to reduce to one half of the initial value.

Alternative definition

The **half-life** is the **time taken** for the activity of a radioactive source to reduce to one half of the initial value.

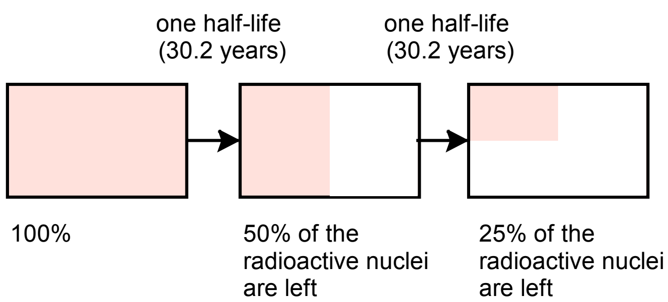
There is a large variation in the lifetime of different radioactive isotopes in nuclear waste.

Radioactive isotope in nuclear waste	Half-life
iodine-131	8 days
strontium-90	29 years
caesium-137	30.2 years
caesium-135	2 300 000 years
palladium-107	6 500 000 years

The long half-life of isotopes, such as caesium-135 and palladium-107, means that radioactive waste will need to be kept secure for millions of years.

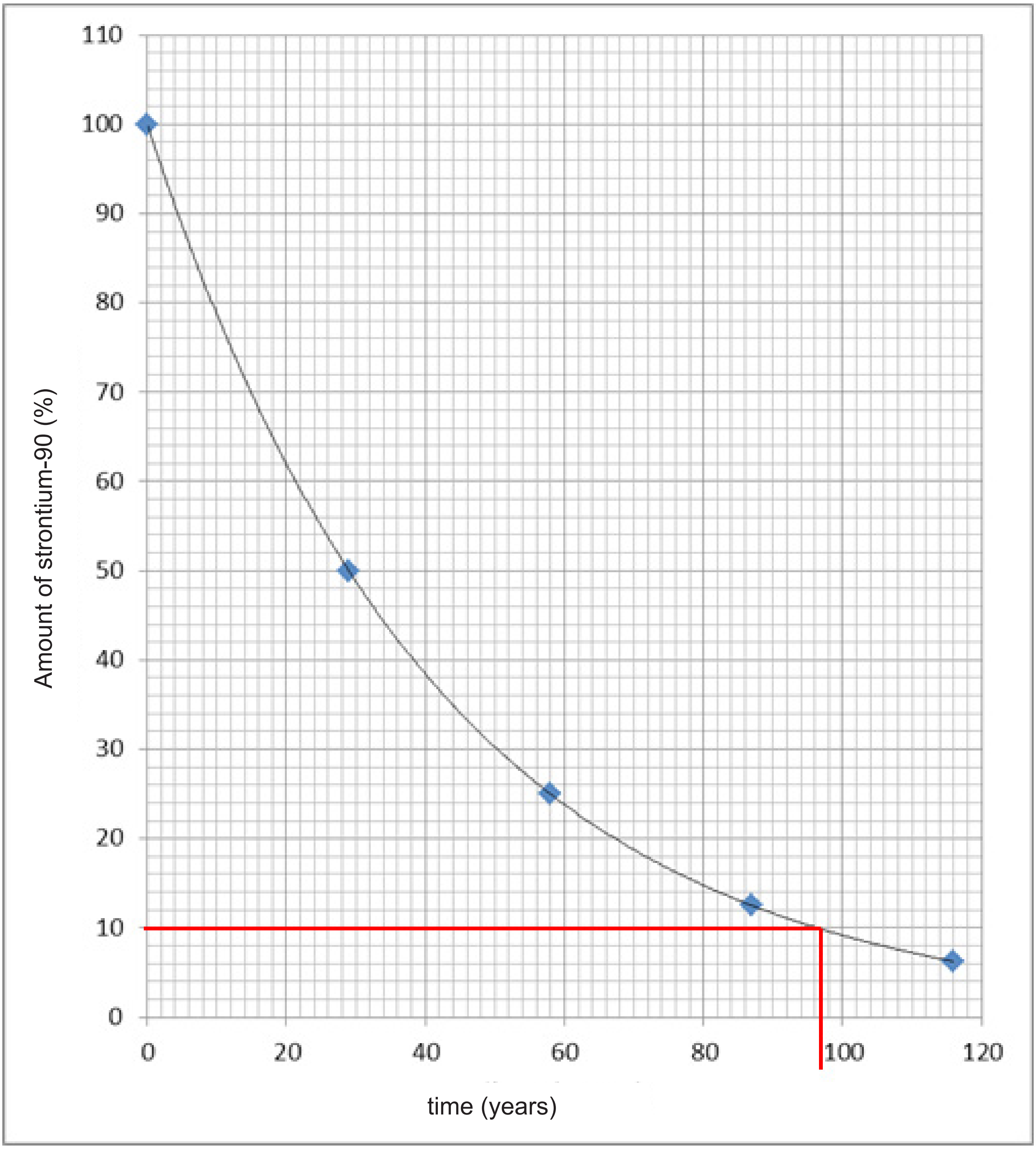
Examples of half-life problems

1. How long will it take for the number of caesium-137 nuclei to fall to 25% of the original value?



Time taken = 2 half-lives = 2 × 30.2 = 60.4 years

2. Use the plot below to calculate how long it will take for the amount of strontium-90 to fall to 10% of the original value.



The time taken for the amount of strontium-90 to fall to 10% of its original value = 97 years

Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

Nuclear reactors and safety

Nuclear reactors have the capacity to produce large amounts of electricity without producing greenhouse gases. They therefore could be an important source of energy as countries seek to reduce their carbon footprint. However there are concerns about the safety of nuclear power. There have been a number of high profile accidents.

Some of the most notable were:

- Three mile Island, USA (1979)
- Chernobyl, Ukraine (1986)
- Fukushima, Japan (2011)

Case Study - Chernobyl, Ukraine (1986)

The Chernobyl disaster is the **only** accident in the history of commercial nuclear power where radiation-related fatalities have occurred.

Chernobyl - Reactor number 4
Associated Press / PA

There were **two** reasons for the accident:

- the reactor was badly designed
- poorly trained personnel operating the plant broke safety rules when carrying out routine tests on the reactor by shutting down automatic safety mechanisms.

This led to an explosion that released at least 5% of the radioactive reactor core into the atmosphere. Two Chernobyl plant workers died on the night of the accident, and a further 28 people died within a few weeks as a result of acute radiation poisoning.

Most of the radiation released from the failed nuclear reactor was from iodine-131, caesium-134 and caesium-137. Iodine-131 has a relatively short half-life of eight days. Caesium isotopes have much longer half-lives and were a concern for years after their release into the environment.

The radioactive fall-out did not just affect the Ukraine but also countries far away. Up until 2012 restrictions were put in place on the sale of sheep from hills in Wales because of fears of contamination from the radioactive fall-out from Chernobyl.

The town of Pripyat where Chernobyl was situated has now been abandoned.

Chernobyl 2011
Anna Voitenko / Le Pictorium / Alamy Stock Photo

In 2011 Chernobyl was officially declared a tourist attraction.

UNSCEAR says that apart from increased thyroid cancers, “there is no evidence of a major public health impact attributable to radiation exposure 20 years after the accident.”

SOMETHING TO WATCH

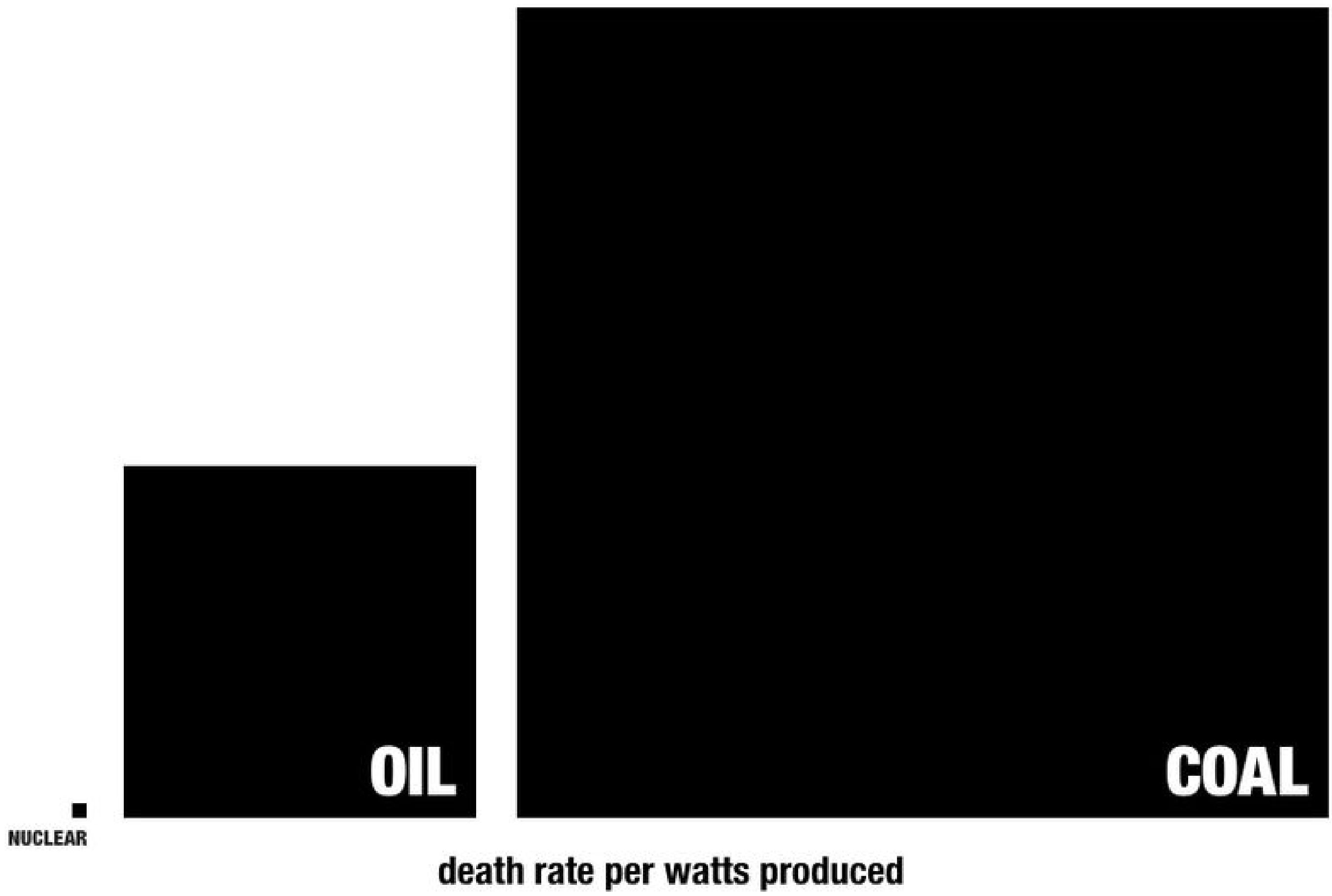
Watch a short clip on the Chernobyl disaster
http://www.bbc.co.uk/news/magazine-36129318

Watch a BBC docudrama on the Chernobyl disaster.
https://youtu.be/kADC2hBKX00 (59 minutes)

Relative risks of power generation

There are risks to the environment and human safety from nuclear power, but there are risks associated with all forms of power generation. People have died in obtaining fossil fuels for use as well.

One graphic suggests that the number of deaths from different forms of power generation look as follows:



You may be asked for your opinion of the relative safety of nuclear power. You may give your opinion but make sure that you back it up with good reasons.
You may consider that the future risks of storing the radioactive waste securely for millions of years outweigh everything that has happened up to this time. That would be a valid opinion.

Unit 3.4: Controlling processes

Controlling nuclear reactions (specification 3.4.2)

TEST YOURSELF

1. In a nuclear reactor the control rods:

A slow down neutrons
B release neutrons
C absorb neutrons

2. Iodine-131 has a half-life of 8 days. How much iodine-131 is left after 24 days?

A 12.5%
B 25%
C 50%

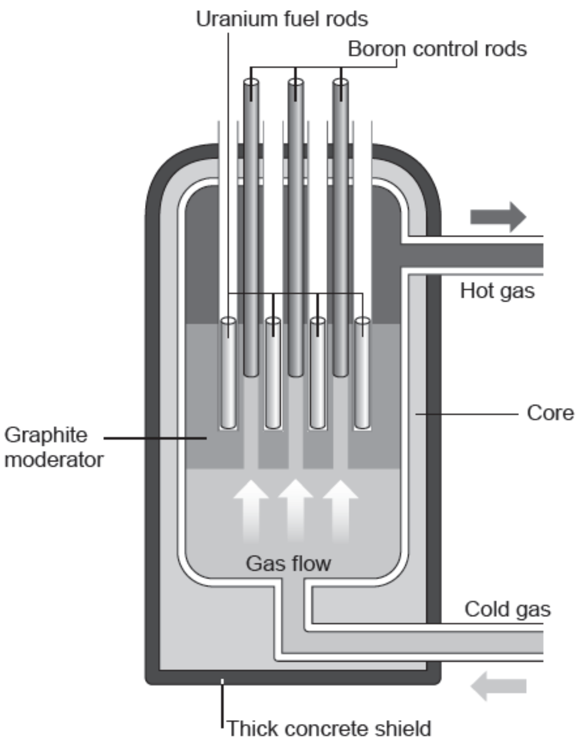
3. In the Chernobyl accident iodine-131 (half-life = 8 days), caesium-134 (half-life = 2 years) and caesium-137 (half-life = 30.2 years) were released into the atmosphere. Which of these poses the longest term threat to the environment?

A caesium-137
B caesium-134
C iodine-131

PRACTICE QUESTIONS

1. In a nuclear reactor, energy is released by fission and is the result of a controlled chain reaction. Fuel rods are made of uranium. The graphite moderator surrounds the fuel rods. The boron control rods can be raised and lowered.

The diagram shows the important parts in the core of a gas-cooled nuclear reactor.



(a) In the Chernobyl disaster the reactor nearly melted down due to mistakes made by the engineers. Which of the following statements could **cause** a meltdown in a reactor? Place a tick (✓) in the box next to the correct statements.

[2]

Adding more moderator	☐
Pouring sand over the reactor	☐
Removing the fuel rods	☐
Withdrawing the control rods	☐
Switching off the coolant	☐

(b) Explain the risks caused by damaging the thick concrete shield. [2]

....

....

(c) The table below shows different isotopes of uranium (U)

Isotope	Nuclear symbol
U-230	${}^{230}_{92}U$
U-234	${}^{234}_{92}U$
U-235	${}^{235}_{92}U$
U-238	${}^{238}_{92}U$

Use the table to complete the sentences. [3]

All the isotopes have a nucleus that contains ....protons.

The isotope that contains 143 neutrons in its nuclei is ....

The isotope containing the fewest neutrons is ....

(d) Complete the following nuclear equations which show the decay of two of these uranium isotopes listed in the table above. [2]

$${}^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{\dots\dots}_{90}Th$$

$${}^{\dots\dots}_{\dots\dots}U \rightarrow {}^{4}_{2}He + {}^{230}_{90}Th$$

TEST YOURSELF - ANSWERS FOR UNIT 3.4

The need to control chemical reactions

1. B
2. A
3. C
4. B

Measuring the rate of a reaction

1. C
2. B

Losing control of reactions

1. C
2. B

Nuclear fission reactions

1. C
2. A
3. B

Nuclear reactors and safety

1. C
2. A
3. A

Materials for purpose

1. (a) (i) 27 cm^3 (1)

(ii) (1)

$\frac{72}{27} = 2.7\ cm^3$

metal = aluminium

(b) (i) C (1)

Mixture of four elements

(ii) 18% (1)

2. (a) (3)

Feature	Ionic Bond	Covalent bond
sharing electrons		✓
strong electrostatic attraction	✓	
found between non-metals		✓

(b) (i) 1. fullerene

2. graphite

(ii) covalent

(c) carbon fibre (1)

lightest/least dense material (1)

strongest material/ material with highest tensile strength (1)

Food for the future

1. (a) (i) Cytoplasm

(ii) Absorb light

(iii) Carbon dioxide, glucose

(b) (i) 30, 3 and 60, 6

(ii) Oxygen

(iii)	Simple answer relating temperature to rate, e.g. the higher the temperature, the faster the rate	(1)
	Quantitative answer relating temperature to rate, e.g.rate doubles for every 10 °C rise	(2)
(iv)	Volume of gas (1) it is more accurate (1) the volume of bubbles varies (1)	(1) (1) (1)

Harmful bacteria and food spoilage

1. **Indicative content** (6)

- Food poisoning is caused by bacteria
- Bacteria on raw food
- Transferred by dirty hands/ to knife / other food preparation materials
- Use same knife – transferred to cooked food
- Uncooked food contains bacteria – transferred to human
- Use different/clean knife/cook food – reduce the transfer of bacteria

5 – 6 marks
Detailed explanation of actions that should be taken to reduce food poisoning. There is a sustained line of reasoning which is coherent, relevant, substantiated and logically structured. The candidate uses appropriate scientific terminology and accurate spelling, punctuation and grammar.

3 – 4 marks
Detailed explanation of some actions that should be taken to reduce food poisoning
There is a line of reasoning which is partially coherent, largely relevant, supported by some evidence and with some structure. The candidate uses mainly appropriate scientific terminology and some accurate spelling, punctuation and grammar.

1-2 marks
A basic explanation of some actions that should be taken to reduce food poisoning
There is a basic line of reasoning which is not coherent, largely irrelevant, supported by limited evidence and with very little structure. The candidate used limited scientific terminology and inaccuracies in spelling, punctuation and grammar.

Scientific detection

1.	(a)		All bands in child profile that do not match mothers	(1)
	(b)		Forensic investigation Criminal investigations	(2)
	(c)	(i)	DNA is unique to the individual	(1)
		(ii)	In twins/clones	(1)
	(d)		Lack of understanding of the information Results of the test may be inappropriately used	(2)
2.	(a)		sodium water	(2)
	(b)		C	(1)
	(c)	(i)	cm^3 added three times	(1)
			cm^3 added once or twice only (0)	(0)
		(ii)	24.90 24.85 (do not accept 24)	(2)
		(iii)	Use final three titres 24.10+24.05+24.00 =24.05	(3)
		(iv)	The concentrated vinegar = 24.05 × 0.0327 = 0.80115 (mol/dm^3) which means that it is within the acceptable range/ technician does **not** report it out of tolerance The candidate's conclusion should be consistent with the calculated concentration.	(2)

Controlling processes

1.	(a)	Volume of gas evolved since all gas is captured in the burette where it is relatively easy to measure the volume / it is difficult to count bubbles accurately / easy miss a bubble when counting in other method	(2)
	(b)	High rate at the start Rate drops	(2)
	(c)	15 x 6 = 90 (1) cm^3/min	(2)
	(d)	Substance that increases the rate remaining chemically unchanged	(2)
	(e)	5 g	(1)
	(f)	**Any 2 × (1) from:** • Increase temperature • add more CuO • Stir • increase conc of H_2O_2 (do not accept the term amount)	(2)

Controlling nuclear reactions

1.	(a)	Tick in boxes 4 and 5	(2)
	(b)	Escape of radioactive material into the environment Which may damage human health/cause cancer	(2)
	(c)	DNA is unique to the individual 92 U-235 U-230	(3)
	(d)	234 $^{234}_{92}U$	(2)