Science to Support our Lifestyles (Unit 2)

Health, fitness and sport (Unit 2.1)

Factors affecting human health (specification 2.1.1)

Health, fitness and sport (Unit 2.1)

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Genes, inheritance and health

Some characteristics of living organisms are caused by the environment while others are inherited. This is true for humans as for all other organisms. Inheritance is governed by our chromosomes and the genes we carry.

Chromosomes, DNA and genes

Each body cell in the human body contains **23 pairs** of **chromosomes.**

One chromosome from each pair is inherited, one from the mother and the other from the father.

Chromosomes are long sections of DNA (deoxyribonucleic acid) found in the nucleus of body cells.
DNA is a large, complex molecule which carries the genetic code that determines the characteristics of living things.

A single strand of DNA is made from chemicals called bases. There are four different types of bases, A, T, C and G. The pattern of these bases forms the code which holds information in the gene.

In DNA, two strands coil together to form a structure known as double helix (see the diagram). You can think of DNA as a ladder-type structure with the weak bonds between bases forming the rungs of the ladder.

The bases A, T, C and G are **NOT** the same as bases we met in acid base theory. Don't confuse the two!

The two strands are held together by weak bonds between complementary base pairs. The weak bonds holding these strands together will only be formed between certain base pairs (called complementary pairs).
The complementary pairs between which bonds can form are:

- A and T
- C and G

DNA
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Chromosomes contain the genes that are inherited from both parents.

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Genes are short sections of DNA.
Each gene carries information which codes for a specific protein.

Since we inherit a chromosome from each parent, we will also have two copies of each gene; one from the father, the other from the mother.

Alleles, phenotypes and genotypes

Some genes may have different forms. These different forms are called alleles.

An **allele** is a variant form of a gene.

Some characteristics, such as eye colour, are controlled by a single gene. There is one allele (form of the gene) for blue eye colour and a different allele for brown eye colour.
For every characteristic we have two forms of one gene, one from the father and one from the mother. For some individuals the two genes are the same, for others they are different.
In other words, we either inherit **two** copies of the **same allele** or **two different alleles.**

The **genotype** describes the alleles present in an individual for a particular characteristic.
Individuals who are:

- **homozygous** for a certain gene carry two copies of the same allele
- **heterozygous** for a certain gene carry two different alleles

Alleles are either dominant or recessive.

This means that:
- the characteristic controlled by the **dominant allele** will develop if the allele is present on one **or** both chromosomes in the pair.
- the characteristic controlled by the **recessive allele will** develop only if the allele is present on **both** chromosomes in the pair.

Another important word which can be confused with genotype is phenotype.

Phenotype is the physical characteristic resulting from the inherited information.

Example

In the case of eye colour, one allele codes for blue eyes and one another codes for brown eyes. If someone has blue eyes we say they have the phenotype for blue eyes.

What happens if you inherit an allele for blue eyes and an allele that codes for brown eyes? The allele for brown eyes is dominant but the allele for blue eyes is recessive. You will have:

- brown eyes if you inherit either one or both alleles for brown eyes
- blue eyes only if you inherit two copies of the allele for blue eyes.

We represent the dominant allele with a capital letter.

The recessive allele is represented by the corresponding lower case letter.

We can represent the dominant allele for brown eyes with B. Since blue is a recessive genotype we will use a lower case letter to represent it, b.

The table below shows the possible genotypes and phenotypes that can arise from the combination of these two alleles.

Genotype	Phenotype
bb	blue eyes
Bb	brown eyes
BB	brown eyes

Genetic mutations

A genetic mutation occurs when DNA changes, altering the genetic instructions.

This may result in a genetic disorder or a change in characteristics. Mutations can happen spontaneously but they can also be caused by environmental factors such as radiation and certain chemicals (e.g. in cigarette smoke).

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Mutations may be harmless or occasionally beneficial. Generally mutations are harmful.
Some inherited medical conditions, such as cystic fibrosis or Huntington's disease, are directly caused by a mutation in a single gene.

Inherited disorders

An example of an inherited condition is Huntington's disease. The symptoms associated with Huntington's disease usually develop in middle age. They include tremors, clumsiness, mood changes and memory loss. Huntington's is caused by the presence of the **dominant** allele, **H**. A person who has the heterozygous genotype, **Hh**, will therefore suffer from the disease.

Not all genetic diseases are caused by a dominant allele.

In some cases, such as **cystic fibrosis,** the allele for the disease, **n**, is recessive. In this case, a person who has the heterozygous genotype, **Nn**, will **not** develop the disease themselves but since they have the recessive allele associated with the disease they are a carrier.

If they have children with another person who is a carrier there is a chance that some of their children will inherit both recessive genotypes and therefore suffer from the disease.

Inheritance is best explained using Punnett squares.

Punnett squares

Genetic diagrams, called Punnett Squares, are used to show the possible outcomes of inheriting different alleles. In these diagrams a dominant allele is shown by a capital letter and a recessive allele by a lower case letter.

Example problem - Huntington's disease

Huntington' is caused by the presence of the **dominant** allele, H. A father is a **heterozygous** carrier of Huntington's. The mother is **not** a Huntington's sufferer. What is the chance (probability) that one of their children will inherit the disorder?

Answer

The father is a **heterozygous** carrier. This means he carries both the dominant and recessive alleles. His genotype is **Hh**.

The mother is **not** a sufferer so she cannot carry the dominant allele. Her genotype must be **hh**.

		father	
		H	h
mother	h	Hh	hh
	h	Hh	hh

Whenever the dominant allele is present, the child will inherit the disease.
In this case the dominant allele is found in two of the four possible offspring.
This means the chance of a child suffering from the disease is 1 in 2 or 50%.

Example problem - cystic fibrosis

The allele for cystic fibrosis is recessive. A person will therefore only experience the symptoms associated with the disease if they have inherited the recessive allele from both parents.
A mother and father are both **heterozygous** carriers of cystic fibrosis. What is the chance (probability) that one of their children will suffer with the disorder?

Answer

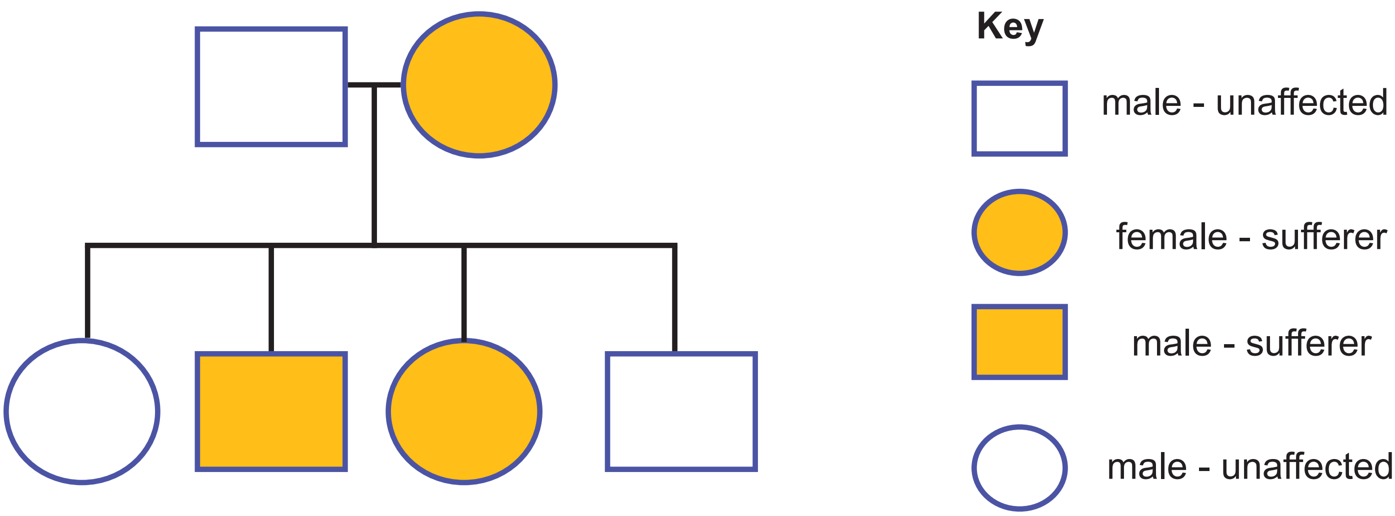
We will represent **recessive** allele by **n**. The parents are both **heterozygous**. This means they carry both the dominant and recessive alleles. Their genotype is **Nn**.

		father	
		N	n
mother	N	NN	Nn
	n	Nn	nn

In only one case does the child inherit both recessive alleles from their parents (genotype nn). This means the chance of a child suffering from the disease is 1 in 4 or 25%.

Example – Family information and Huntington's

Huntington's disease is caused by the dominant allele, H.



Examine the family tree shown in the diagram and state the genotype of:

(i) an unaffected child

(ii) the mother

Answer

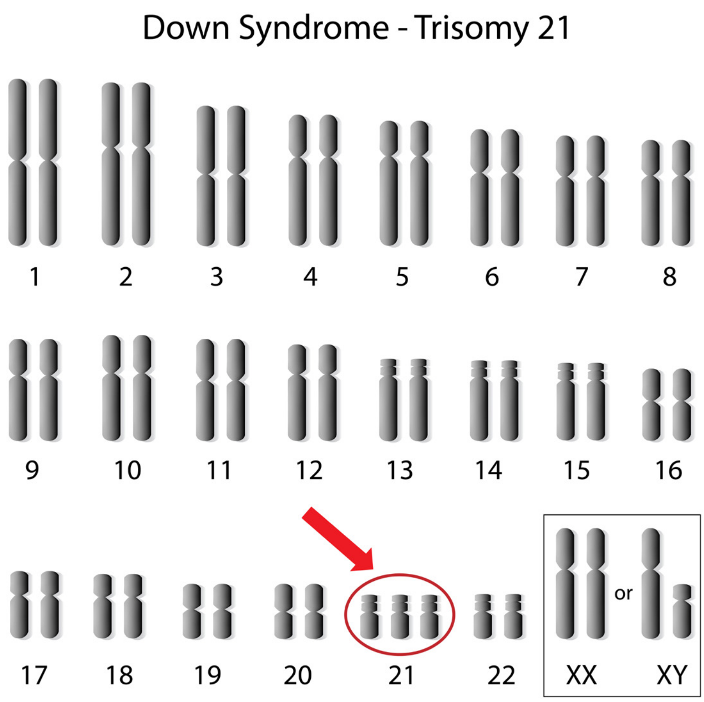
(i) An unaffected child can**not** carry the dominant allele at all.
The unaffected child must be hh.

(ii) Since some of the children are unaffected, the mother must carry the recessive allele as well as the dominant allele. (If she was a homozygous sufferer, all her children would carry the allele and so all would be sufferers).

Her genotype must be Hh.

Down’s syndrome

Down’s syndrome is caused by the presence of three copies of chromosome 21, rather than just the usual two copies. It happens when a sperm cell or egg cell forms abnormally.
The chromosomes below are found in pairs as expected except for chromosome 21 where there are three copies of the chromosone (and therefore the genes).



Down’s syndrome
Alila Medical Images / Alamy Stock Photo

TEST YOURSELF

1. Each body cell in the human body contains 23 pairs of:

A genes **B** DNA **C** chromosomes

2. This question is about cystic fibrosis. We will represent recessive allele for cystic fibrosis by **n**.

(a) A heterozygous carrier of the disease has the genotype:

A NN **B** Nn **C** nn

(b) A sufferer from cystic fibrosis has the genotype:

A NN **B** Nn **C** nn

3. Use the following Punnett square to determine the probability (chance) that a child will be a carrier for cystic fibrosis.

		father	
		N	n
mother	N	NN	Nn
	n	Nn	nn

A 0%
B 25%
C 50%
D 100%

Health, fitness and sport (Unit 2.1)

Factors affecting human health (specification 2.1.1)

Lifestyle plays a big role in human health. Factors which are all known to have a big impact on our health and life expectancy are:

- alcohol intake
- whether an individual smokes
- diet
- amount of exercise.

It can be difficult however to link health to specific lifestyle choices in certain cases. Only over time after a large amount of data is collected and analysed in an appropriate way can it be safe to draw conclusions about health and lifestyle choices.

Obesity

Figures for 2015 show around a quarter of adults in the UK were classed as obese and a further 40 % were overweight. The situation in Wales was worse with over half the population of Wales being overweight. Wales is facing an obesity crisis and the NHS struggles under increased demand. The NHS nationally already spends an estimated **£5.1billion a year** treating obesity. This is money that could otherwise have been spent on other problems.

Some experts believe obesity is responsible for more ill health than smoking. Being significantly overweight is linked to a wide range of health problems, including:

- diabetes
- heart disease
- high blood pressure
- some cancers (e.g. breast and prostate cancers)
- stress, anxiety, and depression.

Obesity
Ian Shaw / Alamy Stock Photo

When is a person said to be obese?

A person is considered **obese** if they are very overweight with a high degree of body fat.

Health, fitness and sport (Unit 2.1)

Factors affecting human health (specification 2.1.1)

The most common way to assess if a person is obese is to check their body mass index, BMI. A person is said to be obese if their BMI value is in the range 30 – 40 and very obese if it is over 40.

Body mass index

One way that is often used to assess our health is to measure our body mass index (BMI). BMI is an attempt to measure the amount of tissue mass (muscle, fat, and bone) in an individual, and then categorize that person as underweight, normal weight, overweight, or obese based on that value.

$$\text{BMI} = \frac{\text{mass}}{\text{height}^2}$$

mass is measured in **kilograms** and height is measured in **metres**

BMI value	Significance
less than 18.5	underweight
18.5 – 24.9	ideal weight
25-29.9	over weight
30-39.9	obese
over 40	very obese

$$\text{BMI} = \frac{\text{mass}}{\text{height}^2}$$

e.g. for a person who has a mass of 64 kg and a height of 1.82 m:

$$\text{BMI} = \frac{64}{1.82^2} = 19.8$$

The individual has an ideal weight for their height.

The BMI provides an easy way of measuring whether we are overweight, however it may not be particularly accurate.

Limitations of BMI

BMI has limitations, particularly when applied to:

- athletes – BMI does not distinguish between fat and muscle, which tends to be heavier and can tip more toned individuals such as athletes into overweight status, even if their fat levels are low.
- children - children are growing and may show significant variations in height, muscle tone etc. at different ages. BMI charts designed for adults should not be used for children.

Important contributors to obesity include poor diet and a lack of exercise.

Eating too little

Eating too little of one type of food substance can lead to deficiency diseases.
There are also times when some people do not eat enough food although food is available. This may be because of poor diet or poor self-image or a wrong view of themselves as fat when they are not. It may lead to illnesses such anorexia.

Diet

Reference intake (RI) and Guideline Daily Amount (GDA)

Energy and different types of nutrients in food have been given daily intake guideline values called reference intake (RIs). The **reference intake** is the amount regarded as suitable to maintain a healthy body.

An older term you may see is **guideline daily amounts** (GDAs). It means the same thing.
The new reference intake values (RIs) are values which have been set out in European law.

An individual's nutritional requirements can vary with gender, weight, activity and age.

This means that some people may need to eat more and others less. RIs (or GDAs, if you prefer) are guidelines for an average person of a healthy weight and level of activity.

The table below shows some typical reference intake values.

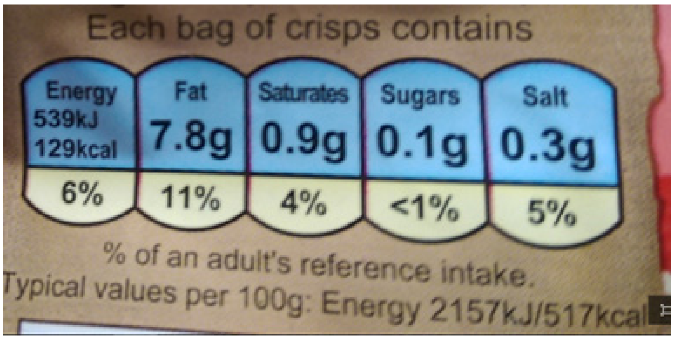
Typical values	Women	Men	Children (5-10 years)
energy (calories)	2 000	2 500	1 800
protein (g)	45	55	24
carbohydrate (g)	230	300	220
sugars (g)	90	120	85
fat (g)	70	95	70
saturated fat (g)	20	30	20
fibre (g)	24	24	15
salt (g)	6	6	4

A typical nutrition panel given on food packs usually gives information on the content of a product **per 100g** for calories and nutrients (protein, carbohydrate, sugars, fat, saturated fat, fibre and salt).

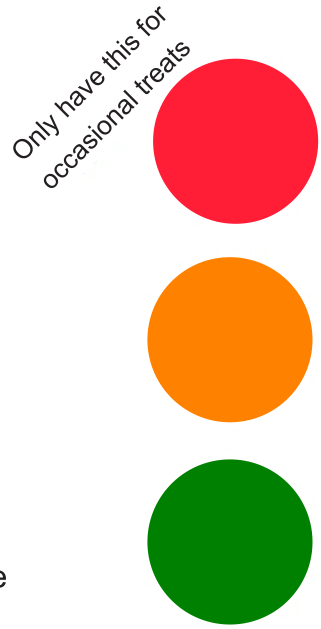
The RIs quoted on food packets are based on the requirements for an **average female**.

If the values for males and children were also quoted on a packet the information would appear confusing so just quoting the values for women makes it is easier to follow.

An example of the information shown on a crisp packet is shown below.



Traffic light system



means *high*
inicating the food is high in fats, sugars or salt

means *medium*
making it an ok choice

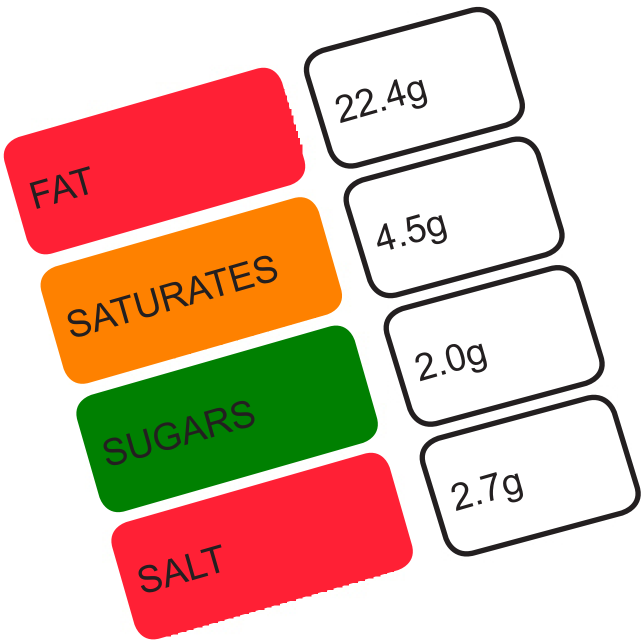
means *low*
making it the healthier choice

The Food Standards Agency has developed a traffic light label that gives independent expert advice to help individuals make healthier choices quickly and easily.

The green, amber or red coloured labels on the front of the pack give a quick indication of the balance of nutrients in the food.

These show you at a glance if the food you are thinking about buying has low, medium or high amounts of fat, saturated fat, sugars and salt, helping you get a better balance.

Question: What if the traffic light panel has all three colours?
Answer: For a healthier choice, try to pick the products with more greens and ambers and fewer reds.



Salt

Salt (sodium chloride) is found naturally in many kinds of food, but it is also added by food manufacturers. Processed foods often have a high proportion of salt. Salt is a necessary nutrient for correct functioning of our bodies. **Too little salt** is associated with:

- muscle cramps
- dizziness
- electrolyte disturbance

However **too much salt** in the diet can be harmful and can lead to:

- high blood pressure leading to an increased risk of heart disease and strokes

It is thought that a daily intake of 6 g of salt should be about right for the average adult. Obviously, if you are doing physical work or taking part in prolonged exercise then you may need to have a higher salt intake to balance the losses from sweating.

Alcohol and health

Alcoholic drinks such as wine, beer or spirits contain an alcohol called ethanol. Alcohol has a number of effects on the body, some of which are well known.

Short-term effects include	Long-term effects include damage to the:
• depressant • sleepiness • reduced reaction times and impaired judgment • impaired balance and muscle control (causing slurred speech and blurred vision) • reddening of the skin caused by increased flow of blood to the skin • poor sleep • a very high intake can also cause death	• damage to the liver • circulatory and heart diseases • damage to the brain

Action of alcohol

Alcohol interferes with chemical processes in the body and the signals between the nerves and brain. For this reason, reaction times are slowed down and judgement is impaired.
People, who regularly drink alcohol, become tolerant of it and need to drink more in order to experience the same effect. If they carry on drinking they can become addicted to alcohol.

Smoking

Cigarette smoke contains an addictive substance called nicotine which is responsible for smokers becoming dependant. It reaches the brain in about 10-20 seconds after being inhaled.

Cigarette smoke contains over 4 000 **chemicals**, including 43 known cancer-causing (carcinogenic) compounds and 400 other toxins. These include nicotine, tar, and carbon monoxide.

Harmful effects from cigarette smoke include:

Cigarette packet
Science Photo Library / Alamy Stock Photo

1. An increased risk of heart disease and strokes. Carbon monoxide reduces the ability of the blood to carry oxygen. This puts extra strain on the circulatory system which can lead to strokes and heart disease.
2. An increased risk of miscarriage and premature birth if mothers smoke while pregnant. This is caused by a reduction of the amount of oxygen being received by the growing foetus.
3. Emphysema which is a long-term, progressive disease of the lungs, that primarily causes shortness of breath. Cigarette smoke destroys lung tissue reducing the ability of the lungs to exchange gases.
4. An increase in the risk of lung cancer, mouth cancer and throat cancer. Tar in cigarette smoke contains many carcinogens.

Stopping people smoking

In order to encourage people to give up smoking the government has tried a number of different strategies including:

- stopping advertising
- making it illegal to sell cigarettes to people under 18
- placing high taxes on cigarettes
- printing warning messages on the front of cigarette packets
- banning smoking in public spaces.

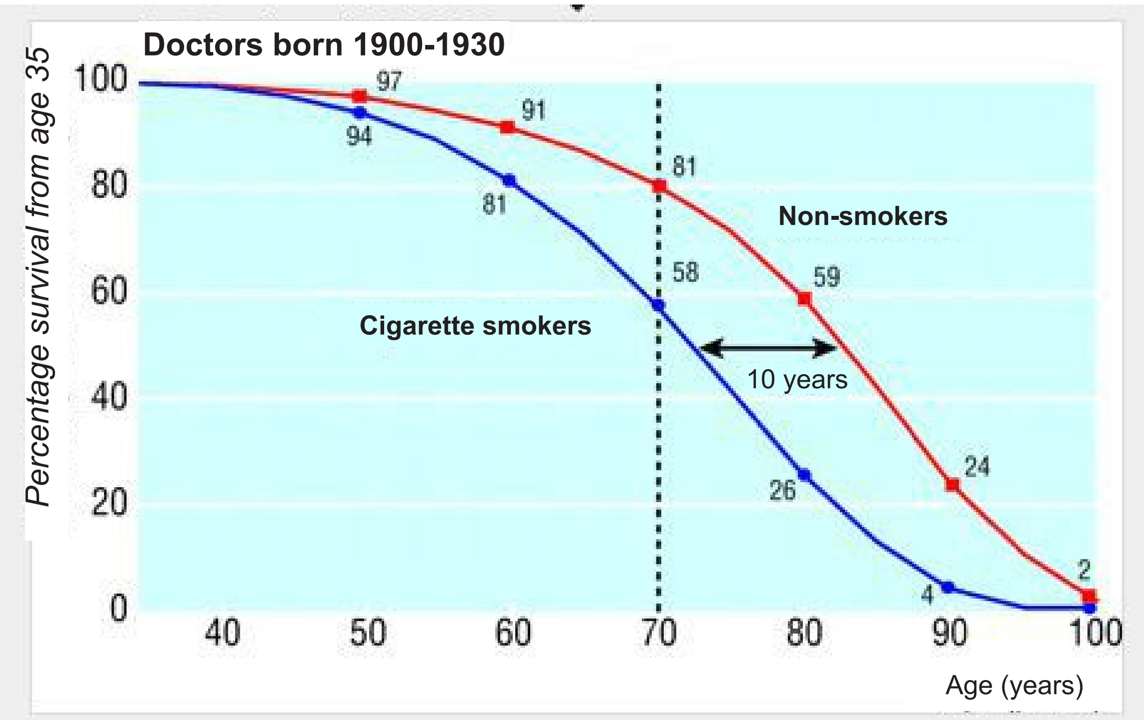
Epidemiological studies

Epidemiology is the study of factors that affect the health of populations.

Doctors and scientists carry out epidemiological studies to try to determine the lifestyle factors that could increase the chances of getting heart disease and other illnesses.

In a typical study, researchers examine two groups of people: for example those who smoke and those who do not smoke.

An example is of a study of doctors born between 1900 and 1930 that shows a difference in survival rates of those who were smokers and those who were non-smokers.



Reproduced from 'Mortality in relation to smoking: 50 years' observations on male British doctors', Richard Doll, Richard Peto, Jillian Boreham, Isabelle Sutherland, 328, 2004 with permission from BMJ Publishing Group Ltd

It is the work of the researcher to ensure that data from such studies is carefully analysed and checked to ensure that appropriate conclusions are drawn.

E-cigarettes

Are e-cigarettes safer than tobacco? Or are they a high-tech way to hook a new generation on a bad nicotine habit? The honest answer is nobody knows yet.

E-cigarettes contain addictive nicotine like tobacco cigarettes. This means if you stop using them, you can get withdrawal symptoms. This may include feeling irritable, depressed, and anxious. It can be dangerous for people with heart problems.

So far, evidence suggests that e-cigarettes may be safer than regular cigarettes. The biggest danger from tobacco is the smoke, and e-cigarettes don't burn tobacco. Tests show the levels of dangerous chemicals they give off are a fraction of what you'd get from cigarette smoke. However we really don't know the long term risks posed by e-cigarettes yet.

TEST YOURSELF

1. The formula for body mass index (BMI) is:

   A $\frac{\text{mass}}{\text{height}}$

   B $\frac{\text{mass}}{\text{height}^2}$

   C $\frac{\text{mass}^2}{\text{height}}$

2. Dave has a mass of 80 kg and height of 1.8 m. His BMI is:

   A 24.7 **B** 44.4 **C** 24.4

3. Too little salt in the diet is associated with:

   A muscle cramps
   B high blood pressure
   C heart disease

4. A packet of crisps has an energy content of 548 kJ. Joshua, aged 10, eats a packet of crisps every day. Calculate the percentage of his reference intake (guideline daily amount) to the nearest whole number that this represents.

   Energy: Daily reference intake for a child aged 5-10 = 7 530 kJ

   A 8% **B** 6% **C** 7%

Controlling blood glucose (sugar) levels.

Homeostasis and the regulation of blood glucose levels

Conditions, such as temperature and the level of glucose in the blood, need to be controlled so that a constant internal environment in the body can be maintained.

This is called **homeostasis**.

Homeostasis control mechanisms in the body work by **negative feedback.** A negative feedback system is one in which the output is used to reduce the input.

Blood glucose levels will vary according to the amount of exercise we do and when (and what) we have eaten. It is important that the body maintains glucose levels over a narrow range. If blood glucose levels become:

- too low the cells will not have sufficient glucose for metabolism
- too high then glucose may start to be lost in urine.

Ultimately, if blood glucose levels become too high or too low then a person may go into a coma (loss of consciousness).

Blood glucose levels are controlled by the release or storage of glucose.

The body controls this by the **hormones** **insulin** and **glucagon.**

The **pancreas** produces both of these hormones.

1. If the glucose levels in the blood **are high,** insulin is released by the pancreas. The insulin acts on the liver, causing it to convert excess glucose into glycogen for storage.

   As blood glucose levels drop so less insulin is released by the pancreas.

2. If blood glucose levels **are too low** (e.g. after exercise) then the hormone glucagon is released by the pancreas which has the opposite effect to insulin on the liver, i.e. glycogen is converted back to glucose.

- Glucagon has the ability to raise blood glucose levels
- Insulin is capable of lowering blood glucose levels

SOMETHING TO WATCH

A short video explaining how blood glucose levels are controlled can be found at:

https://www.youtube.com/watch?v=e-3N7w2sWps

Diabetes

People who cannot control their blood glucose levels have a condition called **diabetes.**

If the blood glucose levels are not regulated then a person suffering with diabetes can go into a coma. When they go into a coma, they will need urgent medical attention.

There are two different types of diabetes.

Type 1 diabetes – The body does not produce sufficient insulin

Type 2 diabetes – Body cells do not correctly respond to the insulin that is produced

Type 1 diabetes

This accounts for about 5 to 10 out of every 100 people who have diabetes.
Without insulin, cells cannot absorb glucose, which they need to produce energy.

- **Treatment:** This can be treated by controlling the amount of sugar and carbohydrate in the diet **and regular insulin injections**. A pancreas transplant will also provide a new source of insulin.

Diabetes
Bill Cheyrou / Alamy Stock Photo

Type 2 diabetes

Type 2 diabetes accounts for the vast majority of people who have diabetes - 90 to 95 out of every 100 people. It generally occurs in more mature people who are often overweight, but type 2 diabetes is rising in children.

- **Treatment:** This is treated by controlling the amount of sugar and carbohydrate in the diet and taking medication which makes the liver respond to the insulin.

Diagnosing diabetes

A common symptom of diabetes is the presence of glucose in urine. We can test for blood glucose using Benedict's solution.

Benedict's solution is a blue solution that turns red when heated if glucose is present.

Health, fitness and sport (Unit 2.1)

Factors affecting human health (specification 2.1.1)

Pollutants and health

Our environment and the things we come in contact with can have a serious impact on our health.

Heavy metals

We have already shown that mercury caused Minamata disease in Japan after people ate sea food contaminated with high levels of mercury. Other heavy metals have also been associated with disease. One other well-known metal associated with poisoning is lead.
Lead poisoning is a serious and sometimes fatal condition. It occurs when lead builds up in the body over a period of time, perhaps many years. Lead is a highly toxic metal and a very strong poison. It is found in lead-based paints, including paint on the walls of old houses and toys. Water pipes were also once made of lead but these have now been largely removed.
Repeated exposure to lead can lead to

- aggressive behaviour
- loss of developmental skills in children
- loss of appetite
- memory loss
- anaemia

….. and many other problems.

Air pollution and health

A variety of air pollutants have known or suspected harmful effects on human health. These pollutants are often the products of combustion of fossil fuels, e.g. by motor vehicles. The level of these air pollutants can also depend upon weather conditions.

Pollutant	Health risk
nitrogen dioxide, sulfur dioxide, ozone	These gases irritate the airways of the lungs. They can increase the symptoms of those who suffer from asthma and lung disease.
particles	Very small particles can be carried deep into the lungs where they can cause inflammation and a worsening of asthma, heart and lung diseases. Diesel engines are linked to this type of pollution.
carbon monoxide	This gas prevents the uptake of oxygen by the blood. This can lead to a reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease.

TEST YOURSELF

1. Homeostatic control mechanisms work in the body by a:

- **A** positive feedback mechanism
- **B** reversed loop – positive feedback mechanism
- **C** negative feedback mechanism

2. Insulin and glucagon are made in the:

- **A** liver
- **B** gall bladder
- **C** pancreas

3. Match the correct hormone to the statement that follows.

glucagon	**A** causes the liver to convert glucose to glycogen
insulin	**B** causes the liver to convert glycogen to glucose

4. Which type of diabetes cannot be treated by regular insulin injections?

- **A** type 3 diabetes
- **B** type 2 diabetes
- **C** type 1 diabetes

5. Glucose in urine can be tested for using:

- **A** Starch solution
- **B** pH paper
- **C** Benedict's solution

6. Repeated exposure to lead can cause:

- **A** aggressive behaviour
- **B** heart disease
- **C** a stroke

PRACTICE QUESTIONS

1. Food energy is measured in kilojoules (kJ) and kilocalories (kcal). These units of measurement allow us to talk about how much energy a food contains and how much energy is used during exercise.

The energy value **per gram** of various food components includes:

- fat – 37 kJ
- carbohydrates – 16 kJ
- protein – 17 kJ
- dietary fibre – 13 kJ
- water – 0 kJ

When we regularly eat more energy than our body needs, the excess is stored inside fat cells.

(i) State one reason why foods high in fat should be eaten in moderation. [1]

…………………………………………………………………………………………………

…………………………………………………………………………………………………

(ii) State two medical problems linked to obesity. [2]

…………………………………………………………………………………………………

…………………………………………………………………………………………………

(iii) Calculate the energy content of 1 kg of fat. [1]

energy content = …………… kJ

(iv) An overweight person hopes to lose 1 kg of body fat in 30 days.
Calculate by how much they need to reduce their calorie intake each day. [2]

The conversion factors for joules and calories are:

1 kJ = 0.24 kcal

answer = ………… kcal /day

PRACTICE QUESTIONS

2. In a recent report by the National Obesity Forum high obesity rates were recorded in certain parts of the UK. The table below shows some of the 'best' and 'worst' areas of the country.

Best areas	Percentage registered with GP as obese (%)	Worst areas	Percentage registered with GP as obese (%)
Camden (London)	3.9	Merthyr Tydfil (Wales)	10.6
Westminster (London)	4.8	Barnsley (North England)	10.8
Lambeth (London)	5.6	Rhondda (Wales)	11.1
Dagenham (Kent)	9.3	Shetland (Scotland)	15.5

(a) All the 'best areas' are in the 'South of England'. Suggest why the 'South of England' may have less of an obesity problem than other parts of the UK. [2]

....

....

(b) There are approximately 22 000 people living in Shetland (Scotland).

(i) Use the equation below to calculate the actual number of people living in Shetland who are registered with their GP's as obese. [2]

$$\text{Number of obese people} = \frac{\text{\% of registered obese patients x population of Shetland}}{100}$$

Total number of people in Shetland who are registered obese = ...

(ii) State one assumption that has been made in your calculation of the number of obese people in Shetland. [1]

....

....

(iii) Suggest one method by which more accurate data for the number of obese people in the different regions could be obtained. [1]

....

Science to support our lifestyles (Unit 2)

Health, fitness and sport (Unit 2.1)

Diagnosis and treatment (specification 2.1.2)

Health, fitness and sport (Unit 2.1)

Diagnosis and treatment (specification 2.1.2)

INTRODUCTION

Medical scientists have developed and continue to develop methods to diagnose and treat disease. For example, scientists have found that some ionising radiations can be put to useful medical applications.

This topic explores some methods that medical scientists use to diagnose and treat diseases. We will start by explaining some important terms and concepts that medical scientists use.

Ionising radiation

Radiation is a broad term. It can be used to refer to:

- waves from the electromagnetic spectrum (e.g. radio waves, microwaves, gamma rays)
- particles emitted from a radioactive source (e.g. alpha or beta particles)

Ionising radiation is radiation that can cause electrons to be removed from atoms or molecules.

Examples of ionising radiation include:

- high energy electromagnetic radiation (UV, X-rays and gamma rays)
- alpha and beta particles emitted from radioisotopes

Radioisotopes and half-life

The nuclei of radioactive atoms are unstable. They break down and change into a completely different type of atom. This is called radioactive decay. An example of an unstable nucleus is iodine-131 which emits beta particles. Over a period of time the number of radioactive nuclei fall. Half-life is used to make predictions about how quickly the radioactivity takes to fall.

The **half-life** is the time taken for the number of radioactive nuclei (or the mass of radioactive nuclei) to reduce to half its initial value.

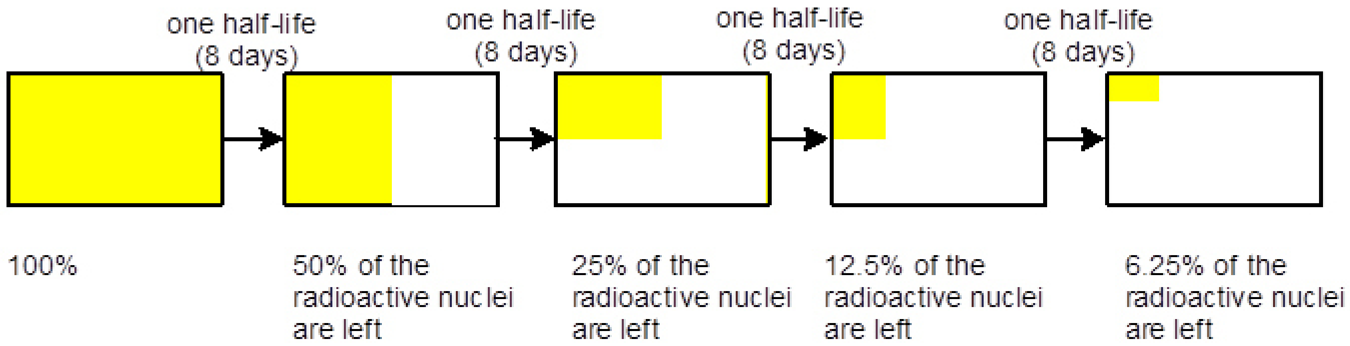
Another way of defining half-life
The half-life is the time taken for the activity (count rate of the sample) to reduce to half of the initial value.

Each radioactive isotope has its own half-life. Half-lives can be very different.

Examples

Radioactive isotope used in medicine	half-life
iodine-131	8 days
cobalt-60	5.2 years
caesium-137	30.2 years

In the diagram below, the number of radioactive **iodine-131** nuclei in a sample is represented by the yellow shaded area.



Notice that the number of radioactive nuclei halves over 8 days no matter how much iodine-131 you start with.

The time to go from:

- 100 to 50 % is one half-life (8 days)
- 50 to 25 % is one half-life (8 days)
- 25 to 12.5 % is one half-life (8 days)
- 2.5 to 6.25 % is one half-life (8 days)

After another 8 days 6.25 % of the radioactive nuclei will halve to 3.125 %

Question

How long does it take for the iodine-131 to go from 100 % to 25 %?

Answer

The total time to go from 100 % to 25 %

= 2 × half-life = 2 × 8 = 16 days

Question

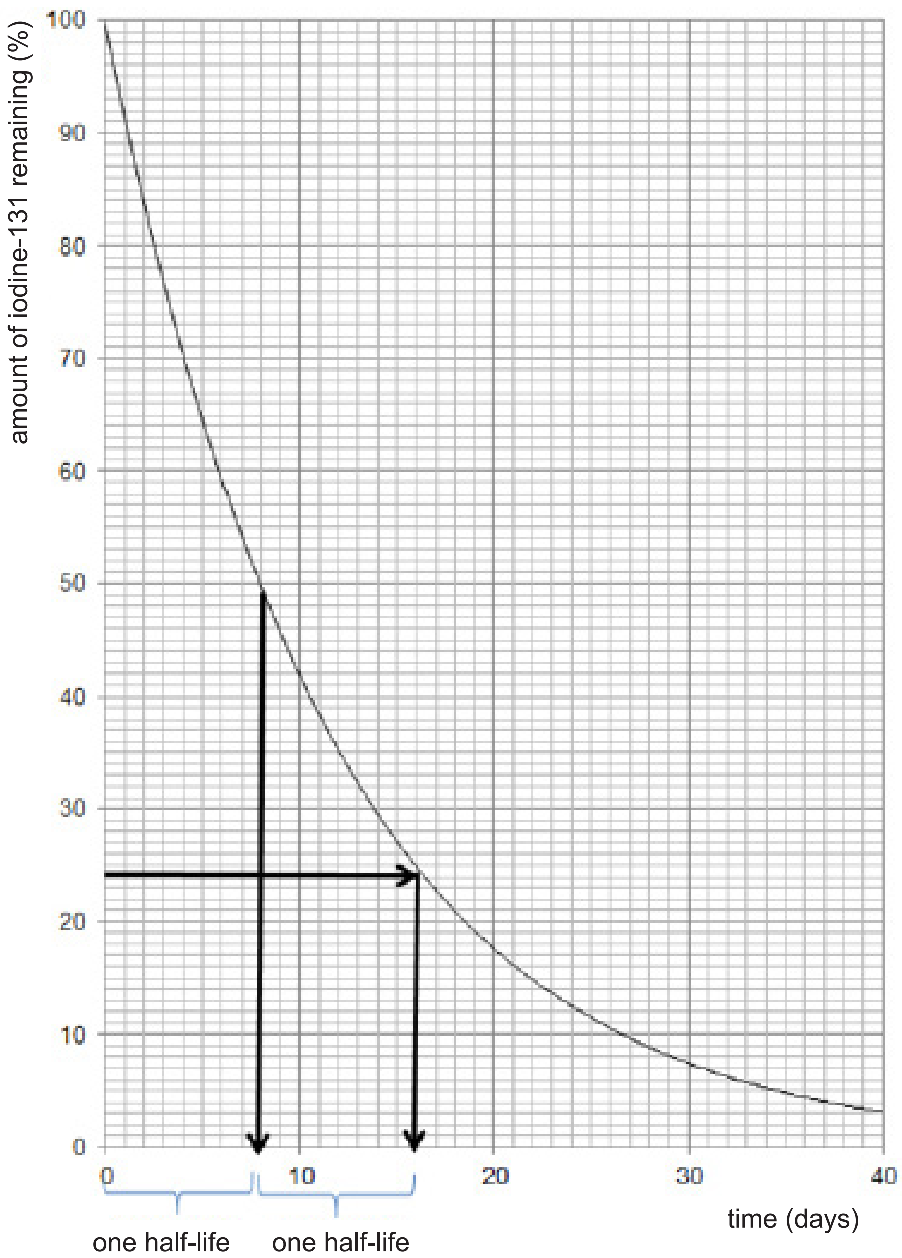
How long does it take for the iodine-131 to go from 100 % to 12.5 %?

Answer

The time to go down from 100 % to 12.5 %
= 3 × half-life = 3 × 8 = 24 days

The graph below shows the same information.

Notice it will always take 8 days to half the amount of iodine remaining. It does not matter where you start!



Alpha, beta and gamma radiation

Alpha radiation

Alpha radiation consists of alpha particles.

An **alpha particle** is the same as the **nucleus** of a helium atom

i.e. two protons and two neutrons

It is a common **mistake** to say an alpha particle is the same as a helium **atom** or helium **ion**.

It is not! There are **no** electrons in an alpha particle.

It is the same as a helium **nucleus**.

Beta radiation

A beta particle is a **high** velocity electron which comes out of the **nucleus** of an atom.

These electrons do **not** come from the electron shells around the nucleus.
They form when a neutron splits into a proton and an electron. The electron then shoots out of the nucleus at high speed.

Gamma radiation

Gamma radiation is high energy (high frequency) electromagnetic radiation.

Penetrating properties of radiation

Radiation can be absorbed by substances in its path. Different types of radiation have different penetrating power.

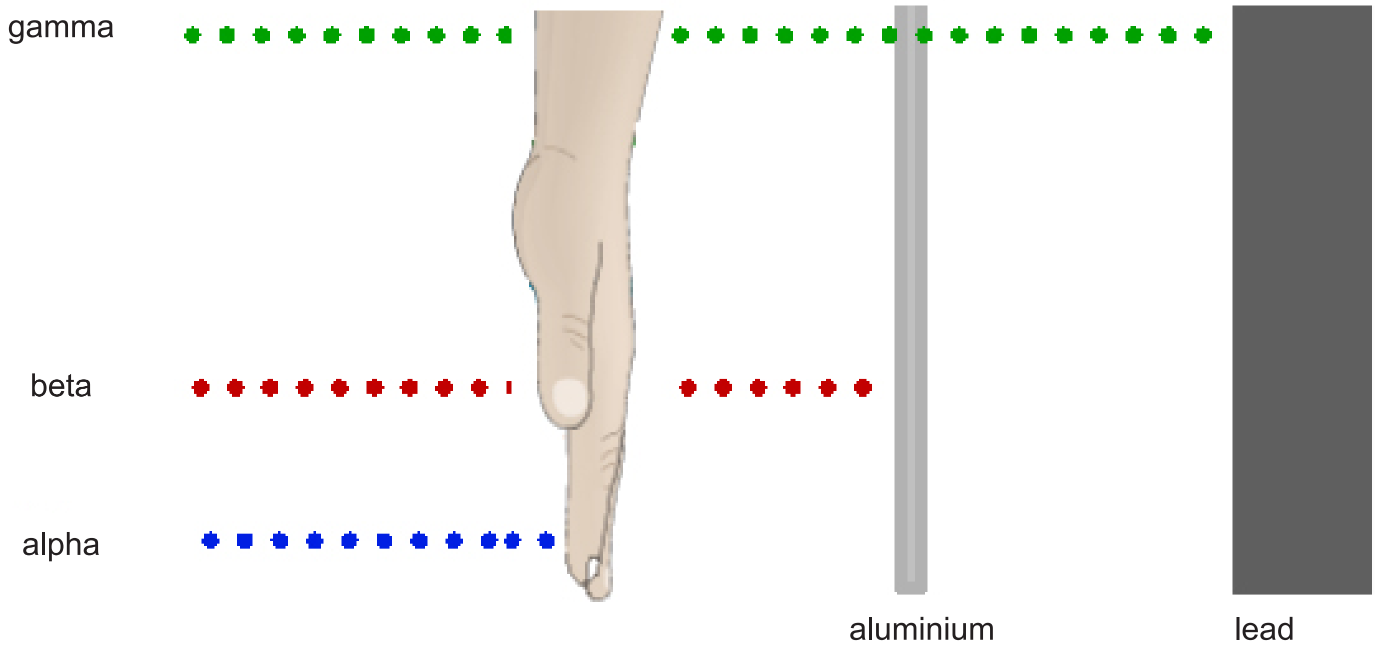


Table showing relative penetrating powers of alpha, beta and gamma radiation

Type of radiation	Penetrating power	Stopped by	Comment
alpha particles	least penetrating	sheet of paper	absorbed by the thickness of the skin
beta particles		thin sheet of aluminium	absorbed by a few centimetres of body tissue
gamma radiation	most penetrating	thick sheet of metal, such as lead, or concrete	can easily penetrate right through body tissue

Ionising power and tissue

The penetrating power of nuclear radiation depends upon the ionising power of the radiation. The radiation continues to penetrate matter until it has lost all of its energy.

One alpha particle can ionise 10 000 atoms. The fact that they are strongly ionising makes them very dangerous to life. Because they are so strongly ionising they are quickly absorbed.
The charge on beta particles is half of that of alpha particles. For this reason, they are **less** ionising and penetrate further into the body.

Gamma radiation has the lowest ionising power of the three so that they penetrate **very deeply** into matter before most of the energy has been used up.

Summary: Alpha - greatest ionising power
Gamma - least ionising power

TEST YOURSELF

1. Examples of ionising radiation are:

A alpha particles, beta particles and radio waves
B radio waves, X-rays and gamma rays
C alpha particles, beta particles, gamma rays

2. An alpha particle is:

A a high velocity electron
B a helium atom
C two protons and two neutrons

3. The half-life of iodine-131 is 8 days. How long will it take for the number of radioactive nuclei to fall to 25% of the original value?

A 24 days
B 16 days
C 8 days

4. The order of penetration from least to most penetrating is:

A	alpha	beta	gamma
B	beta	alpha	gamma
C	gamma	beta	alpha

5. The half-life of cobalt-60 is 5.2 years. After 15.6 years the activity of a cobalt-60 sample will fall to:

A 33% of the original activity
B 25% of the original activity
C 12.5% of the original activity

Medical imaging

Medical imaging involves creating images of the body to reveal and diagnose or examine disease or injury.

Medical imaging can make use of electromagnetic radiation or sound waves.

Imaging using X-rays

X-rays are able to pass through the body.
As they pass through the body, the energy from X-rays is absorbed at different rates by different parts of the body.

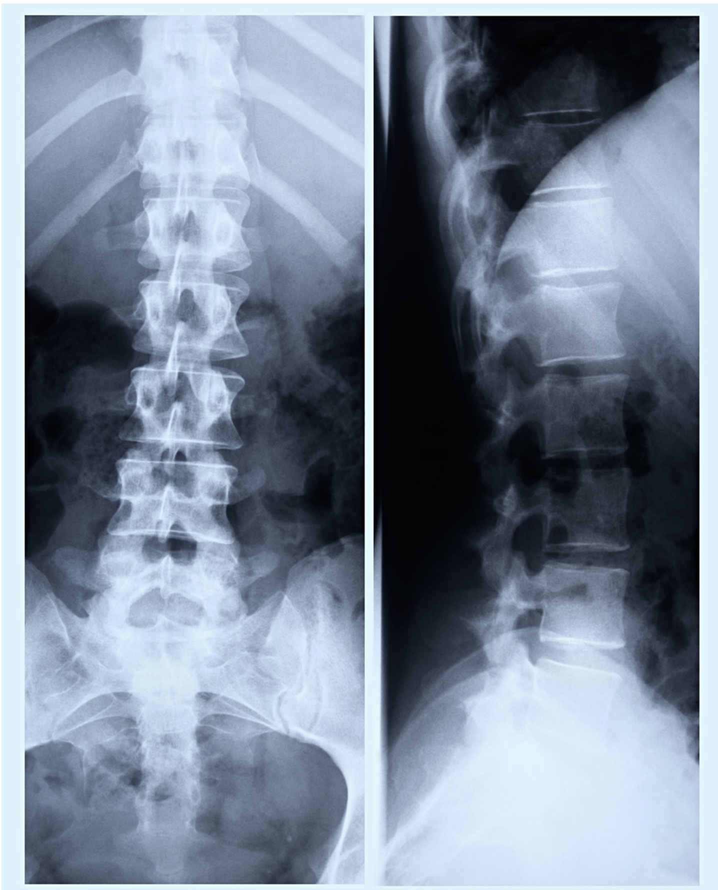
A detector on the other side of the body picks up the X-rays after they've passed through and turns them into an image.

Dense parts of the body that X-rays find it more difficult to pass through, such as bone, show up as **white areas** on the image.

Softer parts that X-rays can pass through more easily, such as your heart and lungs, show up as **darker areas**.

X-rays involve taking one image.
What is formed is a **two-dimensional image.**

X-rays are useful in applications such as medical imaging of bone fractures and dental problems.



X-ray image of the spine
Image Source Plus / Alamy Stock Photo

X-rays and CAT scans

X-rays are also used in CAT scans (sometimes called CT scans).

CAT scans can produce detailed images of many structures inside the body, e.g. internal organs, blood vessels and bones.

Patient having a CAT scan
Hero Images Inc. / Alamy Stock Photo

CAT scans are formed by processing together a large number of X-ray images taken around an axis. Once again, the more dense objects (e.g. bones) absorb some X-rays while they pass through the softer tissues.

The many two dimensional images are then combined to form a **three dimensional** image of the body.

3D CAT scan
Cultura RM / Alamy Stock Photo

What CAT scans are used for

CAT scans can produce detailed images of many structures inside the body, including the internal organs, blood vessels and bones. They can be used to:

- diagnose conditions - e.g. damage to bones, injuries to internal organs, strokes and cancer
- guide further tests or treatments - e.g. CAT scans can help to determine the location, size and shape of a tumour before having radiotherapy
- monitor conditions - e.g. checking the size of tumours before and after cancer treatment.

Are X-rays and CAT scans safe?

X-rays are ionising radiation and therefore are able to damage body cells.

As a precaution, only the part of the body being examined is exposed to a low level of radiation. Generally, the amount of radiation a person is exposed to during an X-ray is the equivalent to between a few days and a few years of exposure to natural radiation from the environment.

Being exposed to X-rays does carry a very small risk of causing cancer many years or decades later.

Health, fitness and sport (Unit 2.1)

Diagnosis and treatment (specification 2.1.2)

MRI scans

Magnetic resonance imaging (MRI) is a type of scan that uses strong magnetic fields and radio waves to produce detailed three dimensional images of inside the body.

An MRI scanner is a large tube that contains powerful magnets. A person lies inside the tube during the scan.

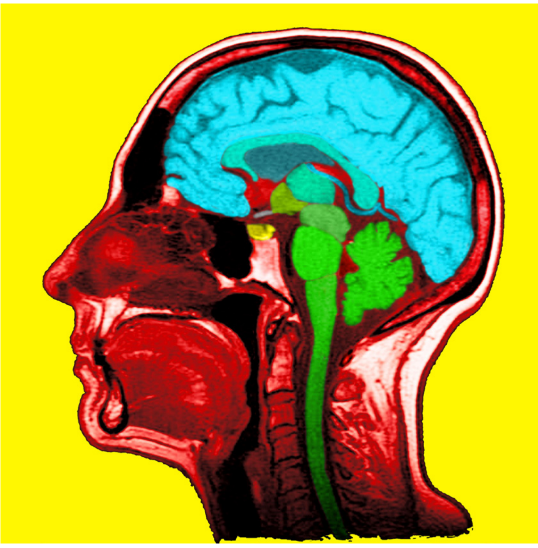
A magnetic field is set up that varies through the body.

A pulse of radio waves is sent through the body which interacts with protons in the body.

After the pulse ends the protons in the body emit radio waves which tell us about their position.

All the information from the radio waves is used to produce an image.

MRI scan
Glow Wellness / Alamy Stock Photo



MRI scan of head
BSIP SA / Alamy Stock Photo

An MRI scan can be used to examine almost any part of the body, including the:

- brain and spinal cord
- bones and joints
- breasts
- heart and blood vessels
- internal organs, such as the liver

The results of an MRI scan can be used to help diagnose conditions; plan treatments and assess how effective previous treatment has been.

Ultrasound

Ultrasound image
Robert Dant / Alamy Stock Photo

Ultrasound is the name given to sound waves with high frequencies.
These frequencies cannot be heard by humans.

Ultrasound has many applications in medicine.
These include:

- safe monitoring of a foetus during pregnancy
- diagnosis of diseases

Medical images from ultrasound

The ultrasound is sent into the patient's body. Where there is a change in density of two structures in the body (e.g. at a boundary between different tissues or organs) some of the ultrasound is reflected.

The depth of each layer is calculated using the time taken for each reflected wave to return. The reflected waves are usually processed to produce a picture of the inside of the body on a screen.

Pregnant lady having an ultrasound image taken
Tetra Images / Alamy Stock Photo

Unlike X-rays, ultrasound waves are **not** ionising. This means they are safe to use when performing a foetal scan.

Health, fitness and sport (Unit 2.1)

Diagnosis and treatment (specification 2.1.2)

Gamma camera

The gamma camera is an imaging technique which can be used in diagnosing cancer. It involves using a gamma detector (camera) together with a radioactive isotope which is attached to special drugs, called tracers, which are designed to carry the radioisotope to the organ being investigated.

Woman undergoing a gamma camera scan
Mark A. Johnson / Alamy Stock Photo

Radioisotopes with **short half-lives** are chosen to make sure that the tracer does not stay radioactive in the body for long periods.

For most examinations, the radioisotope is injected into a vein, but sometimes it may be inhaled. The tracer then carries the radioisotope to the part of your body under investigation. The radioisotope gives off gamma rays, which are detected by a gamma camera.

Image from gamma camera
BSIP SA / Alamy Stock Photo

The information is passed to a computer which produces an image.

A gamma camera scan will show how well an organ or part of your body is working, as well as what it looks like.

Are there risks?

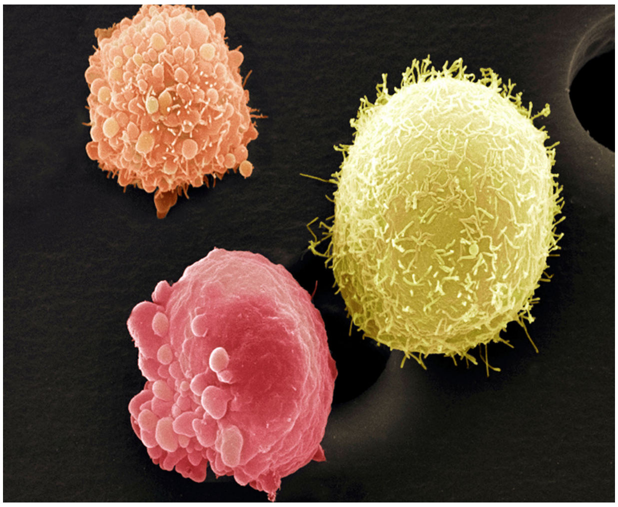
Gamma camera scanning involves the use of radioisotopes which emit gamma radiation which is ionising radiation. This means there is a small risk that the radioisotope may damage body cells.

For most tests, the extra radiation is equivalent to the background radiation (radiation from our environment) a person would receive over a period ranging from a few months up to 3 years.

Treatment of cancer

Radiotherapy

Radiotherapy is a treatment involving the use of ionising radiation. It is commonly used to treat cancer.



Skin cancer cells
Science Photo Library / Alamy Stock Photo

How it works

The **ionising radiation** used during radiotherapy damages the DNA of cancer cells.

Cancer cells are more likely to be damaged by ionising radiation than healthy cells.

As a result the cancer cells die or reproduce more slowly.

Nearby healthy tissues may also suffer cell damage from radiation, due to mutations in the cell DNA, but generally these cells are not so badly affected.
There are two types of radiotherapy:

- internal radiotherapy
- external radiotherapy.

External radiotherapy

External radiotherapy usually involves using a machine which focuses an external source of X-rays which are targeted at the tumour.

External beam radiotherapy usually involves a series of daily treatments over a number of days or weeks.

Internal radiotherapy

Internal radiotherapy involves using a radioactive isotope such as iodine-131 that is taken as a drink or injected into a vein.

The radioisotopes used in internal radiotherapy have short half-lives and so although they constantly emit radiation these emissions quickly get less.

After treatment

Patients who have internal radiotherapy may still be emitting radiation for a few days after each dose and limited contact with other people is advised. In the case of external radiation therapy, the patient does NOT emit radiation after treatment.

Selecting a radioisotope

There are nearly one hundred different radioisotopes whose radiation is used in medicine. It is important to select the correct radioisotope for an application.

- **External radiotherapy** uses radioisotopes which emit X-rays (or sometimes gamma radiation). The radiation is targeted at the tumour and so needs to penetrate through the body to get to the tumour. Ideally the radiation source (the radioisotope) used will have a long half-life so it does not need to be changed very often.
- **Internal radiotherapy** uses radioisotopes which are beta emitters. Since these do not need to penetrate through the body to the target organ, shorter range beta emitters are more suitable. Isotopes used in internal radiotherapy need to have a relatively short half-life so they are not active in the body any longer than necessary to treat the cancer. e.g. Iodine-131 with a half-life of 8 days is used in the treatment of thyroid cancer.

Chemotherapy

Chemotherapy is a type of cancer treatment, which uses drugs to kill cancer cells. It kills the cancer cells by damaging them, so they can't reproduce and spread. Most chemotherapy drugs are carried in the blood. This means that they can reach cancer cells anywhere in the body. But chemotherapy can be given in different ways. This depends on the type of cancer being treated and the chemotherapy drugs being used. Chemotherapy drugs also affect some healthy cells. These healthy cells can usually recover from damage caused by chemotherapy but cancer cells can't and eventually die. Chemotherapy and radiotherapy are often used together in cancer treatments.

SOMETHING TO WATCH

A short video giving a brief overview of chemotherapy by a Macmillan nurse:
https://youtu.be/fB13YmdLdvw

Health, fitness and sport (Unit 2.1)

Diagnosis and treatment (specification 2.1.2)

TEST YOURSELF

1. X-ray images are:
   - **A** one dimensional images
   - **B** two dimensional images
   - **C** three dimensional images

2. CAT scans combine images which were taken with:
   - **A** gamma rays
   - **B** X-rays
   - **C** radio waves

3. Ultrasound:
   - **A** can cause mutations to DNA in cells
   - **B** can be used in internal radiography
   - **C** is safe to use because it does not involve ionising radiation

4. Ultrasound scans use:
   - **A** long wavelength sound waves
   - **B** low frequency sound waves
   - **C** high frequency sound waves

5. Internal radiotherapy usually involves:
   - **A** using a machine which focuses an external source of X-rays which is targeted at the tumour
   - **B** using a radioactive isotope such as iodine-131 that is taken as a drink or injected into a vein
   - **C** using a machine which focuses an external source of alpha particles which are targeted at the tumour

6. Chemotherapy is a type of cancer treatment, which:
   - **A** uses drugs to kill cancer cells
   - **B** uses ionising radiation to kill cancer cells
   - **C** uses iodine-131 to locate cancer cells in the body

Health, fitness and sport (Unit 2.1)

Diagnosis and treatment (specification 2.1.2)

Drugs

The development of new drugs

Drugs are substances that change chemical reactions in the body. Medical drugs relieve disease and illness, and are extensively tested before being used.

The development of new drugs is a costly and long process.

- It takes an average of 12 years for a drug to go from the research lab to the patient.
- Only about 1 in every 5 000 drugs that start the development process actually makes it to the market.

Bottles of prescription medicine
Tetra Images / Alamy Stock Photo

Drug testing

1. Initial research
   Compounds may be identified as possible new drugs as a result of new understanding of a disease. These compounds are tested using computer models and laboratory tests using human cells.

   Many substances fail at this stage because they damage cells or do not seem to work.

2. Animal testing
   Drugs that pass the first stage are tested on animals.
   These tests involve giving a known amount of the drug to animals and monitoring them for any side-effects.

3. Clinical trials
   If a drug passes animal testing then it is tested on healthy volunteers in clinical trials to make sure they are safe. Only very low doses of the drug are given to begin with.
   The substances are then tested on people who suffer from the illness that the drug is intended to treat to ensure that they work. If there are no problems, further clinical trials are done to find the best dose of the drug.

Clinical trials

In order to be confident that the results of clinical trials are trustworthy and give meaningful information, it is important to build checks into the testing. Clinical testing includes ‘blind’ and ‘double-blind’ trials.

In blind and double-blind trials the volunteers are split into two groups:

- a test group which receives the new drug
- a control group which receives the existing drug for that illness or a placebo

A placebo is a fake drug that has no effect on the body.

The researchers examine the evidence to see if there are any differences between the test group and the control group.

Blind trials

In a blind trial, the volunteers do not know which group they are in, but the researchers do. However, it is possible that the researchers may unintentionally give away clues to the volunteers about which group they are in.

This is called observer bias and may make the results unreliable.

Double-blind trials

In a double-blind trial, the volunteers do not know which group they are in, and neither do the researchers, until the end of the trial.

This removes the chance of ‘observer bias’ and makes the results more reliable.

It should be remembered that medical drug trials are not without risk. Sometimes very severe and unexpected side-effects appear.

Animal testing and ethics

There are two different positions on the ethics of testing new drugs on animals. These are summarised below.

In favour - experimenting on animals is acceptable if:
- suffering is kept to a minimum
- there are human benefits which cannot be gained by other methods

Against - experimenting on animals is wrong because:
- it causes suffering to animals
- the benefits to human beings are not proven
- any benefits to human beings that animal testing does provide could be produced in other ways

Drugs and treatment

There are many different drugs that can be used in the treatment of disease. New drugs are constantly being developed.

There are many types of medication. Some examples include:

- medicines that destroy infectious organisms e.g. antibiotics
- medicines that relieve disease but do not destroy pathogens e.g. aspirin and paracetamol
- medicines that fight cancer

Medication is given for a specific reason because of the positive effects it has. Unfortunately there may also be side-effects associated with the medication.
With new drugs it may not always be apparent what the side-effects are until a lot of people have used them.

Aspirin

Aspirin is used to relieve pain, fever, and inflammation in various conditions such as:

- lower back and neck pain
- the 'flu' and colds
- headache
- rheumatoid arthritis
- nerve pain, toothache
- muscle pain

It also has anticlotting properties and may be used to prevent a:

- heart attack
- stroke.

Unfortunately, aspirin like many other drugs has side effects associated with its use.
In the case of aspirin, prolonged use can cause bleeding in a patient's stomach and stomach ulcers.

Aspirin
Lee Brown / Alamy Stock Photo

Health, fitness and sport (Unit 2.1)

Diagnosis and treatment (specification 2.1.2)

wjec cbac

TEST YOURSELF

1. A placebo is a:

A new drug that is released for clinical trials
B tested drug whose effect on patients is well known
C fake drug

2. Aspirin and paracetamol:

A can be used to destroy bacterial infections
B do not destroy bacteria but relieve the symptoms of a disease
C destroy bacteria and relieve the symptoms of a disease

3 Clinical testing can made more reliable by stopping the observer making biased observations.

This is done by using:

A blind trials
B double-blind trials
C animal testing

PRACTICE QUESTIONS

1. Radiotherapy is a branch of medicine used for the treatment of cancerous tumours.

External radiotherapy uses a powerful gamma emitter which is heavily shielded. The gamma-ray beam is aimed at the tumour for short periods of time from different directions. The tumour cells are killed by absorbing large amounts of heat from the energy of the radiation.

Scan
Thegift777_gettyimages

Internal radiotherapy is carried out by inserting a small radioactive source, which has a short half-life, directly into the tumour. They give a very high dose of radiation to the area of the cancer cells. The radiation emitted by the source destroys the tumour from the inside. Internal radiotherapy is generally more effective than external radiotherapy.

(a) (i) State one reason why the therapist may shield parts of the patient's body. [1]

....

(ii) State one reason why the gamma-ray beam in external radiotherapy is directed at the tumour for short periods of time from different directions. [1]

....

(iii) State two reasons why internal radiotherapy is considered to be more effective than external radiotherapy. [2]

....

....

PRACTICE QUESTIONS

(b) A patient receives an implant of 200 units of iodine-125 directly into a prostate gland tumour. The patient was injected with the implant on 1 Jan 2015. On 2 March 2015 only 100 units remain.

(i) Calculate how many units of the implant remain on 1 May 2015. [2]

January

SUN	MON	TUE	WED	THU	FRI	SAT
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

February

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

March

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

April

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

May

SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

June

SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

Number of units = …………….

Science to Support our Lifestyles (Unit 2)

Health, fitness and sport (Unit 2.1)

Fighting disease (specification 2.1.3)

Health, fitness and sport (Unit 2.1)

Fighting disease (specification 2.1.3)

MICROORGANISMS AND THE BODY'S DEFENCES

Treatment of infection and disease is extremely important. Once, a small cut to the hand could have been life threatening but now modern medicine means we do not need to worry if we hurt ourselves. However as drug resistant diseases arise, it is important that new treatments are developed otherwise we may find ourselves unprotected from diseases we can currently treat.

Microorganisms

There are **three** main types of **microorganisms:**

- bacteria
- viruses
- fungi

It is important to realise that not all microorganisms are harmful; some are harmless and perform vital functions and assist in maintaining processes necessary for a healthy body.
It has been estimated that an average man (1.7 m tall, 70 kilograms, 20–30 years old) contains on **average** about 30 trillion human cells and about 39 trillion bacteria.

Some microorganisms are harmful.

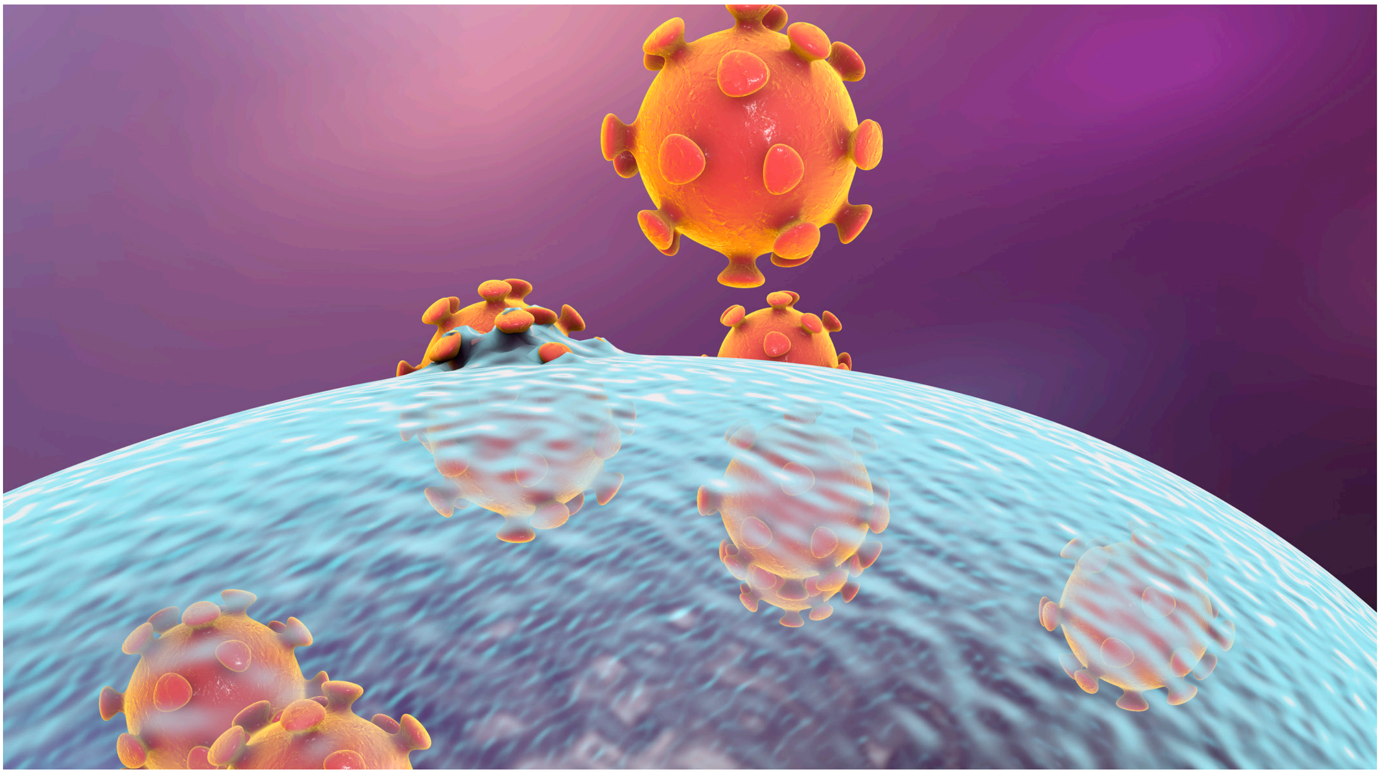
Pathogens are microorganisms that cause **infectious** disease.

Bacteria and viruses are the main pathogens.
Bacteria are living cells which are able to multiply extremely rapidly in the right conditions. Once inside the body, they release poisons or toxins that make us feel ill.
Diseases caused by bacteria include:

- food poisoning
- tuberculosis (TB)
- cholera

Rod-shaped bacteria
Science Photo Library / Alamy Stock Photo

Viruses are many times smaller than bacteria. Viruses damage cells by taking over the cell and reproducing inside them.



Viral replication in a human
KATERYNA KON/SCIENCE PHOTO LIBRARY

Diseases caused by viruses include:

- flu (influenza)
- colds
- measles

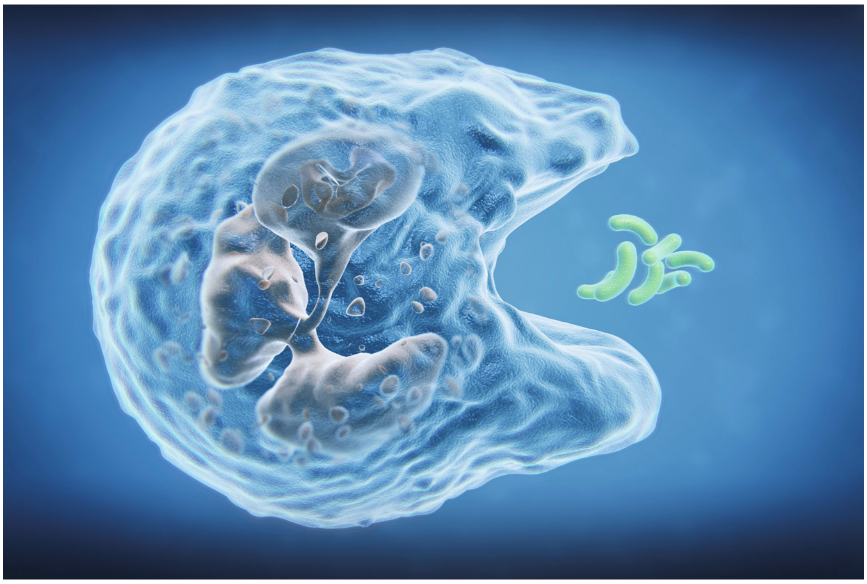
The body's defences

First line of defence: skin

The skin is the largest organ of the body. It acts as a barrier from pathogens.
Skin is a waterproof and mechanical barrier which prevents microorganisms living on the skin from getting through unless it becomes broken.

Communities of microorganisms also live on the surface of our skin, called the skin flora, which makes it difficult for pathogens to become established.

If the skin becomes damaged then blood clots seal the wound to prevent entry of microorganisms.



White blood cell engulfing bacteria
The Science Picture Company / Alamy Stock Photo

Health, fitness and sport (Unit 2.1)

Fighting disease (specification 2.1.3)

Second line of defence: immune system

If a pathogen manages to get into the body, the second line of defence takes over.
White blood cells play an important role in this.

White blood cells can:

- ingest pathogens and destroy them
- produce antibodies which inactivate particular pathogens
- produce antitoxins which counteract the toxins released by pathogens.

Some more detail: antigens, lymphocytes and antibodies

Antigens are proteins that are found on the surface of pathogens.

Antigens can be regarded as a 'signature' for a particular pathogen. The whooping cough bacterium, for example, will have different antigens on its surface from the TB bacterium.

When an antigen enters the body, the immune system produces antibodies against it. Antigens are recognised by a special type of white blood cell called a lymphocyte.

One type of white blood cell is called a **lymphocyte.** These are the cells responsible for producing antibodies.

When a lymphocyte recognises an antigen as being foreign, it multiplies quickly to form clones of cells. These produce antibodies that are specific to the antigen that is present.

Antibodies neutralise the pathogen bearing the foreign antigen.

They do this in a number of ways:

- they bind to pathogens and damage or destroy them
- they coat pathogens, clumping them together so that they are easily ingested by other white blood cells (called phagocytes)
- they bind to the pathogens and release chemical signals to attract more white blood cells (phagocytes)

Health, fitness and sport (Unit 2.1)

Fighting disease (specification 2.1.3)

Memory cells

The body's response to infection is relatively slow when it meets an antigen for the first time. However if the body encounters the same antigen a second time it is able to respond much faster, producing antibodies quickly and in large numbers. This is due to the presence of memory cells that are produced after the first infection.

After the body has been infected, lymphocytes also produce **memory cells** that stay in the body.

These cells can rapidly trigger the production of antibodies if re-infection occurs.

Vaccination

What is a vaccine?

When our body meets a pathogen, lymphocytes recognise the antigens on the surface of the pathogen and produce antibodies.

A vaccine contains an inactive form of the pathogen, antigens or parts of antigens which are derived from pathogens. This stimulates the body to produce antibodies specific to the pathogen.

Vaccines
Dina2001RF / Alamy Stock Photo

Memory cells are also produced which will enable the body to recognise the antigens in the future. This leads to a rapid immune response.

Health, fitness and sport (Unit 2.1)

Fighting disease (specification 2.1.3)

To vaccinate or not to vaccinate

Vaccines have been called 'one of the greatest success stories in public health'.

Through the use of vaccines, smallpox has been eradicated and the polio virus nearly eliminated. Other diseases such as measles and rubella have also been significantly reduced.

However there remains some controversy about the use of vaccines.

Recently controversy was caused by a flawed study published in a medical journal that claimed the MMR vaccine was responsible for autism. Unfortunately the media ran uncritical stories once the report was published which caused a loss of confidence in the vaccine. This report has been completely **discredited** but unfortunately there is still reluctance for some parents to vaccinate their children with the MMR vaccine.

The **low** level of vaccination in the general population led to an outbreak of measles in Swansea 2013 with 1 219 measles notifications. 88 people were hospitalised and one fatality recorded. The cost of the outbreak exceeded £470 000.

The NHS website gives three good reasons to have your child vaccinated:

- vaccinations are quick, safe and effective
- once your child has been vaccinated against a disease, their body can fight it off better
- if a child isn't vaccinated, they're at higher risk of catching the disease and becoming very ill.

It is possible that there are some risks from vaccines but these seem to be quite small when weighed against the risks of catching the disease.

Health, fitness and sport (Unit 2.1)

Fighting disease (specification 2.1.3)

Why can we have repeated infections?

The immune system's production of memory cells after infection means that we do not normally suffer from an infection with the same pathogen.

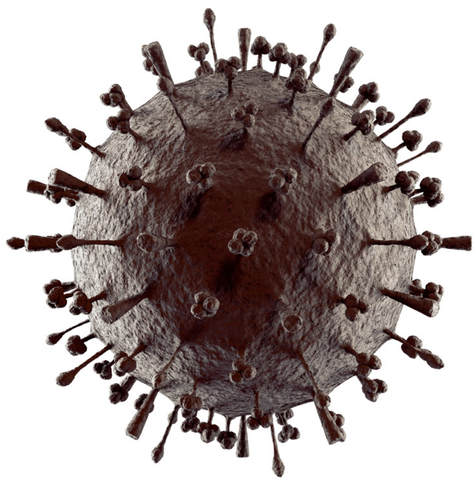
However some viral infections can occur repeatedly.

This can be explained by **natural selection**.

When viruses replicate, a **mutation** may occur which results in a strain of the virus which is resistant to the antibodies. This virus will be able to replicate and infect an individual who is immune to the original virus.

It appears that some viruses are better at doing this than others, for example, the flu virus. The ability of flu to mutate relatively frequently also makes it difficult to produce an effective vaccine.

In contrast, the polio virus and measles virus do not have a high mutation rate. As a result these vaccines have not been changed significantly since they were first developed. Induced immunity for these two viruses lasts a lifetime.



Flu virus H1N1 H5N1 influenza
Oleksiy Maksymenko Photography / Alamy Stock Photo

Antibiotics

Antibiotics were originally medicines produced by living organisms such as fungi.

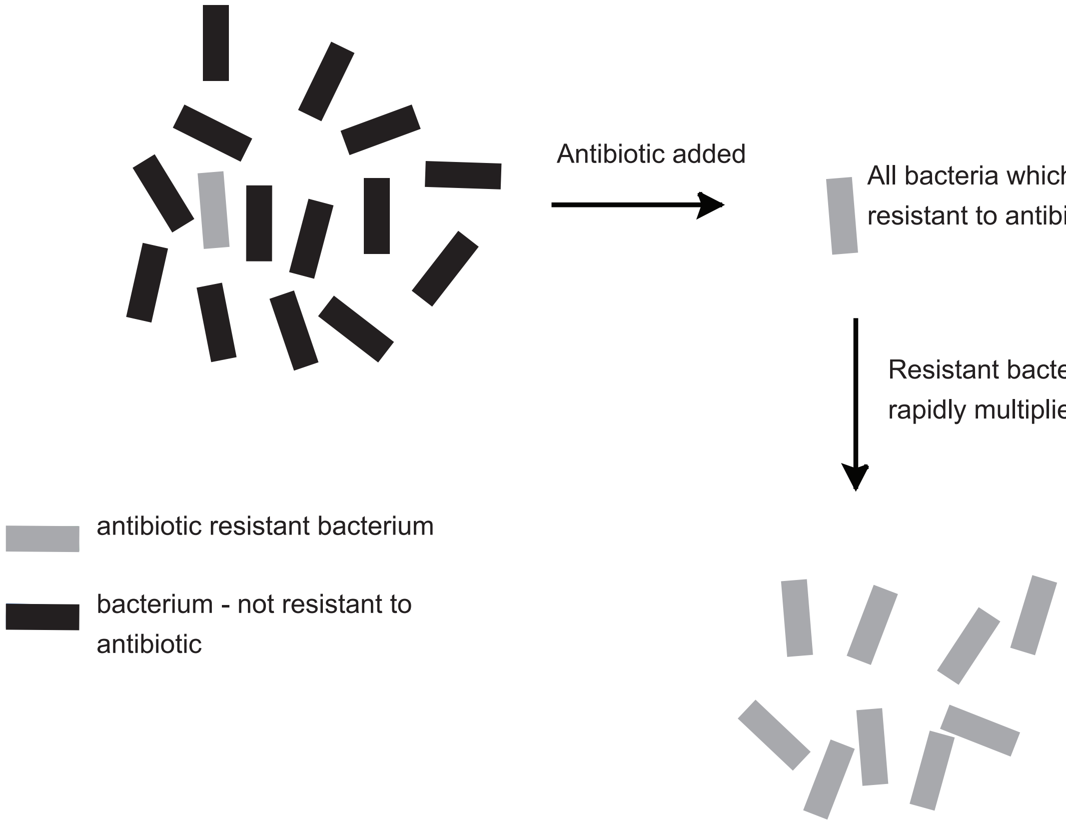
Antibiotics are substances that either kill bacteria or stop them from growing.
Antibiotics do **not** work on viruses.

The first antibiotic to be widely used was penicillin but there are a number of other antibiotics available. The introduction of antibiotics has saved millions of lives from disease that would have been once considered killers.

Resistance

Unfortunately there is a problem. More and more strains of bacteria are becoming resistant to antibiotics.

A mutation results in resistance to the antibiotic. While all other bacteria are killed, the resistant bacteria are able to survive and multiply.



This process has occurred in many different types of bacteria e.g.

- MRSA (methicillin-resistant *Staphylococcus aureus*) is very dangerous because it is resistant to most antibiotics
- multidrug resistant TB
- drug resistant gonorrhoea (a sexually transmitted disease)

Preventing MRSA

MRSA has become a problem for some hospitals and has been responsible for the deaths of some patients. In order to reduce the number of MRSA outbreaks control measures are put in place. These include:

- screening of patients before they enter a ward to see if they carry MRSA on their skin
- washing hands frequently – especially after using the toilet, and before and after eating
- following correct procedures with wound care which may otherwise lead to infection
- keeping hospital wards clean
- using hand wipes or hand gel

Effective management means that the number of death certificates mentioning MRSA as a cause of death fell by 20 % from 364 in 2011 to 292 in 2012.

SOMETHING TO WATCH

Watch these BBC news clips about:

- the danger of antibiotic resistance
  http://www.bbc.co.uk/news/health-35153795
- the source of new antibiotics
  http://www.bbc.co.uk/news/health-32722413

Health, fitness and sport (Unit 2.1)

Fighting disease (specification 2.1.3)

TEST YOURSELF

1. A pathogen is:

- **A** microorganism that produces antibodies
- **B** a disease, such as flu or measles
- **C** a microorganism that causes infectious disease

2. Diseases caused by bacteria include:

- **A** food poisoning, TB and cholera
- **B** food poisoning, TB and flu
- **C** food poisoning, measles and flu

3. Antigens are:

- **A** released by white blood cells called lymphocytes
- **B** proteins that are found on the surface of the pathogen
- **C** proteins that neutralise the pathogen carrying the foreign antibody

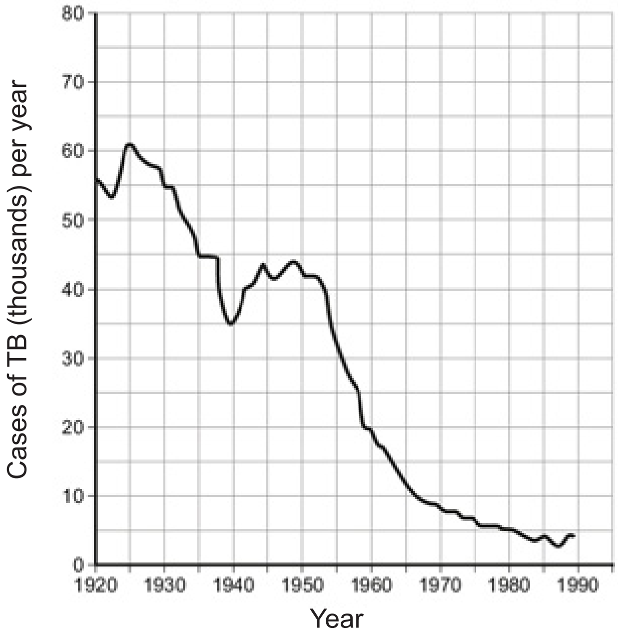
4. Antibiotics can be used to treat infections caused by:

- **A** bacteria
- **B** viruses
- **C** most pathogens

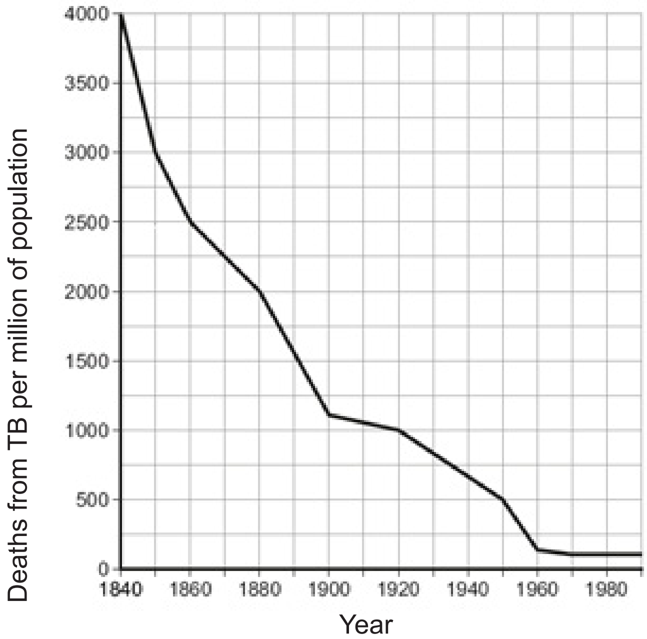
PRACTICE QUESTIONS

1. Tuberculosis (TB) is a disease caused by the bacterium *Mycobacterium tuberculosis*. The graphs below show information about TB in the UK. Antibiotics were first used to treat TB in the 1940s. Vaccination became available in the 1960s.

Graph **1**



Graph **2**



From this information

(a) (i) I Calculate the reduction in the death rate from tuberculosis between 1860 and 1900.

[2]

deaths per million population = ...

II Suggest why the death rate fell during this time.

[1]

....

PRACTICE QUESTIONS

(ii) From the graphs, what evidence is there that antibiotics were effective in reducing the death rate from TB between 1940 and 1950?

[1]

....

....

(iii) From graph 1, what evidence is there to support the idea that the vaccination against TB has been effective?

[1]

....

(b) in 2012 an investigation by the World Health Organisation (WHO) revealed a problem. 20% of cases of TB occurring in the world were caused by a strain to *Mycobacterium tuberculosis* called DRTB which had become resistant to antibiotics. Suggest how doctors and hospitals may have contributed to the problem.

[1]

....

....

....

....

Science to Support out Lifestyles (Unit 2)

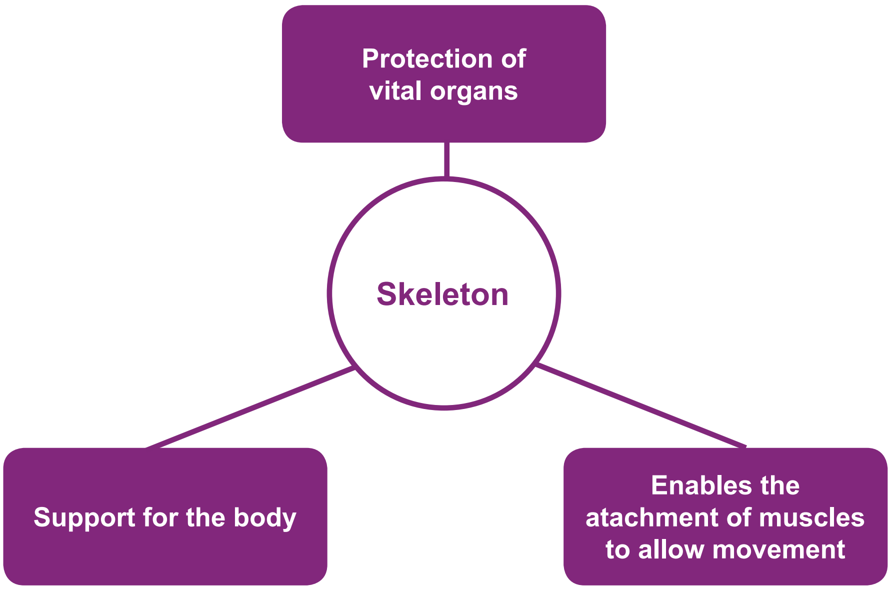
Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

The skeleton and exercise

The human skeleton serves a number of important functions:

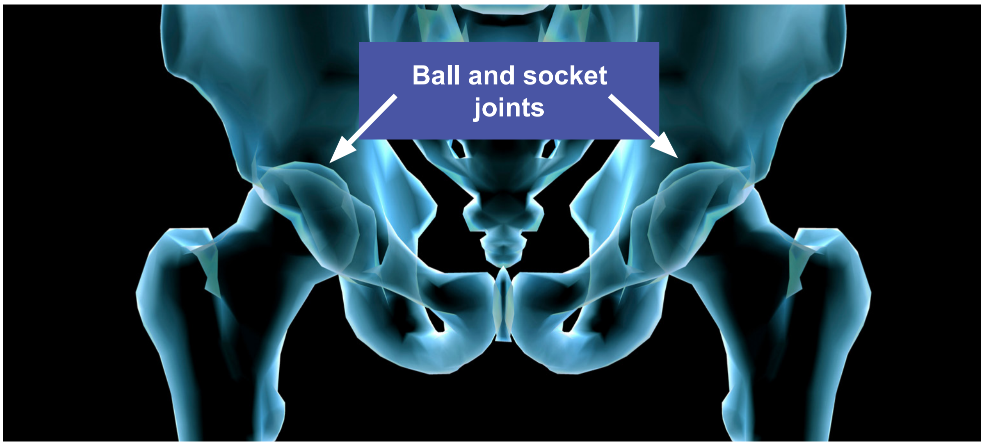
The human skeleton is made up of bone and cartilage, both of which are living tissues.



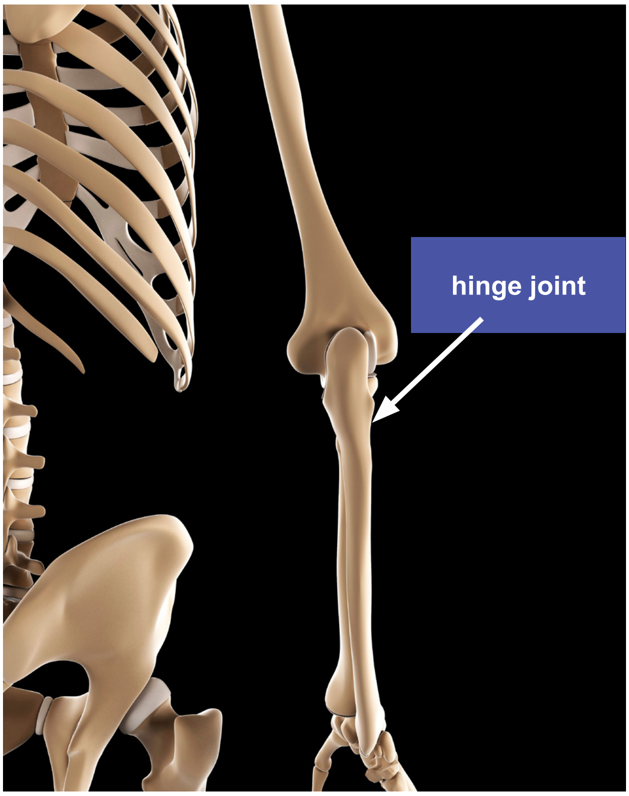
Joints

Where two bones meet there is a joint. Some of these joints are fixed but others allow for movement. There are a number of different joints in the human skeleton:

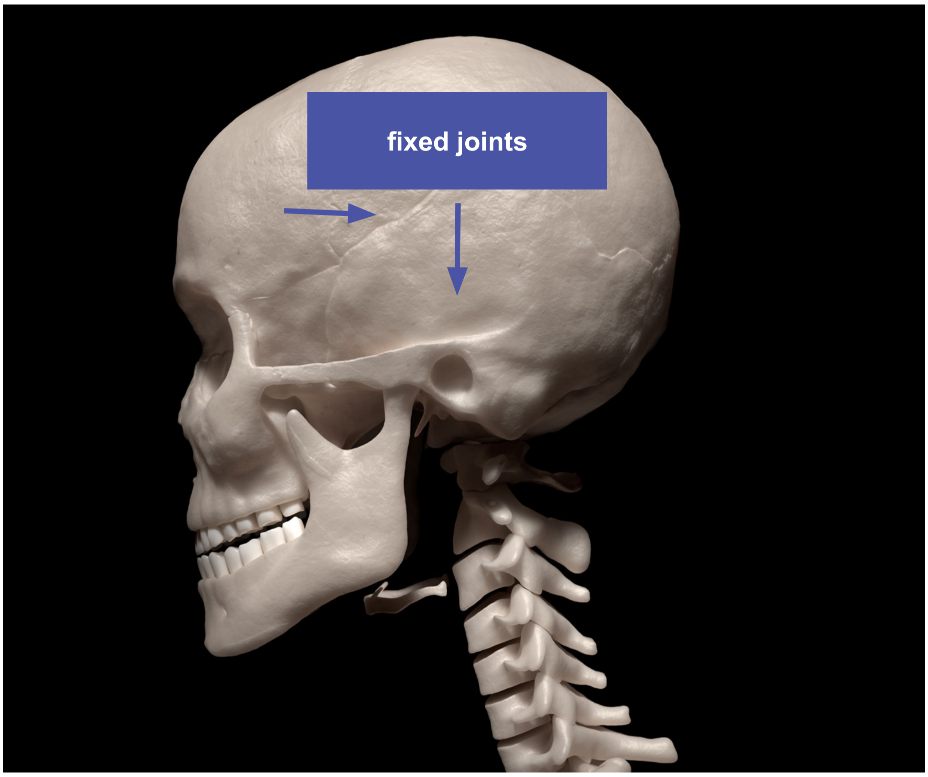
- ball and socket joint – allows almost all round movement (e.g. shoulder, hip)
- hinge joint – allows movement in one direction (e.g. elbow, hinge)
- fixed joint – no movement allowed (e.g. bones in the skull)



Ball and socket joints
Purestock / Alamy Stock Photo



Hinge joint
Science Photo Library / Alamy Stock Photo

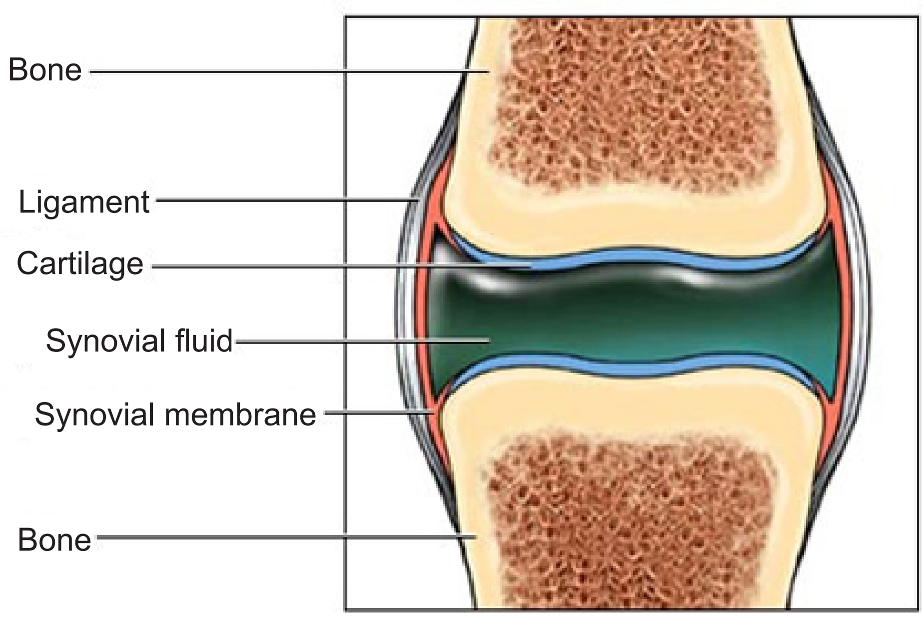


Fixed joints
David Marchal / Alamy Stock Photo

The synovial joint

The synovial joint is the most common type of moveable joint. Hinge joints and ball and socket joints are examples of synovial joints. Synovial joints are especially adapted to allow smooth movement.

The main parts of a synovial joint are shown in the diagram below:



The function of each part of the joint is summarised below:

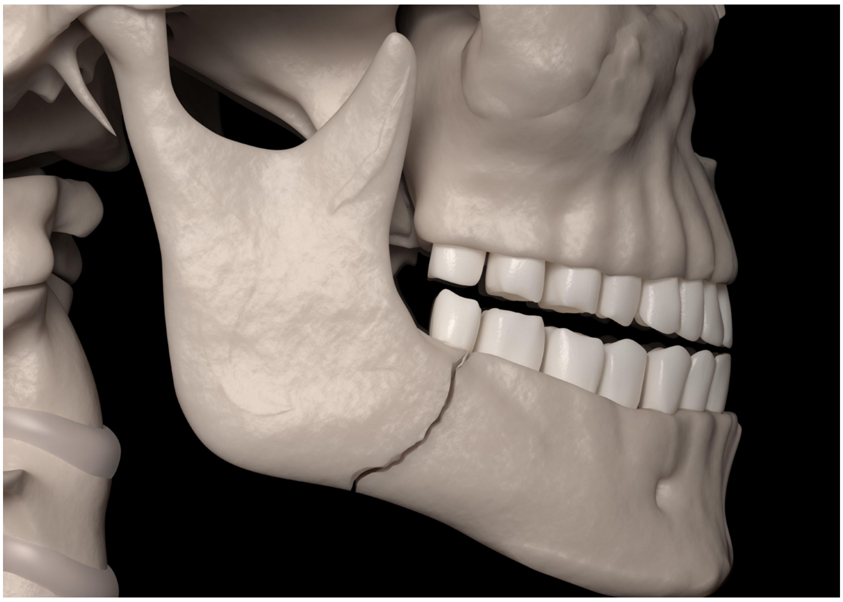
Part	Function
cartilage	reduce friction
synovial fluid	lubricates joints
ligaments	join bones to bones
tendons	join muscles to bones

Make sure you can label the parts of the synovial joint and state the function of each part.

Fractures to bones

Fractures are simply a break in a bone caused by forces that exceed the strength of the tissue in the bone.
All bone fractures are sorted into two major classes:

1. Simple fractures - The broken bones remain within the body and do not penetrate the skin.
2. Compound fractures - The broken bones penetrate through the skin and expose the bone and deep tissues to the external environment.



Simple fracture to the jaw
David Marchal / Alamy Stock Photo

Compound fracture to the forearm
Alamy Stock Photo

Within these two groups there are many specific types of fracture, one of which is greenstick fracture.

Greenstick fractures are only seen in children whose bones are more flexible than adults and therefore tend to bend and only partially break.

The X-ray below shows a bone that has been bent and partially broken.

X-ray of green stick fracture
© kidsfractures.com

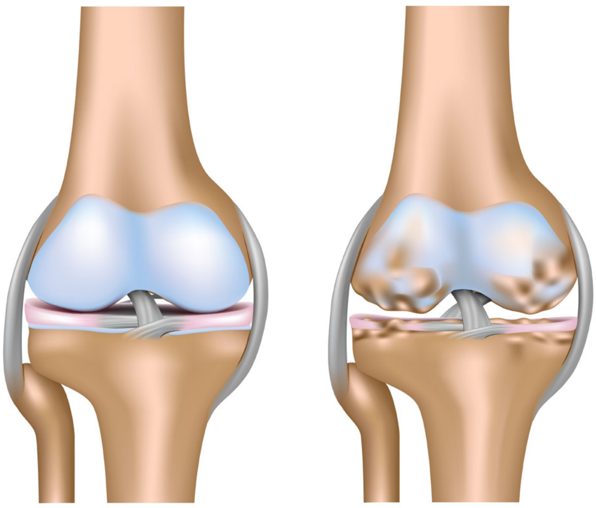
Damage to joints

Joints can be damaged through:

- injury (e.g. torn ligaments or dislocation of the joint)
- disease (e.g. by osteoarthritis)

Damage to joints will result in a limited movement of joints. The body will be able to heal most injuries with time. Damage done by disease is normally irreversible.

Osteoarthritis affects the cartilage and adjacent bone surfaces within joints. The cartilage in the knee or hip becomes damaged and worn away causing sore joints.



Healthy knee joint   Osteoarthritis

Osteoarthritis of knee joint
Alila Medical Images / Alamy Stock Photo

The symptoms of osteoarthritis include pain, stiffness in the joints and reduced movement. There may also be swelling.

Joint replacement surgery

If joints are badly damaged, worn or diseased they can be replaced by artificial joints. For example, knee replacement surgery involves replacing a damaged knee with an artificial joint. It is a routine operation for knee pain. More than 70 000 knee replacements are carried out in England and Wales each year. A replacement knee normally lasts over 10-20 years.

SOMETHING TO WATCH

A short video explaining how the knee works and how it can be replaced with a new joint:

http://www.nhs.uk/conditions/Knee-replacement/Pages/Kneereplacementexplained.aspx

Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

TEST YOURSELF

1. The hip is an example of a:

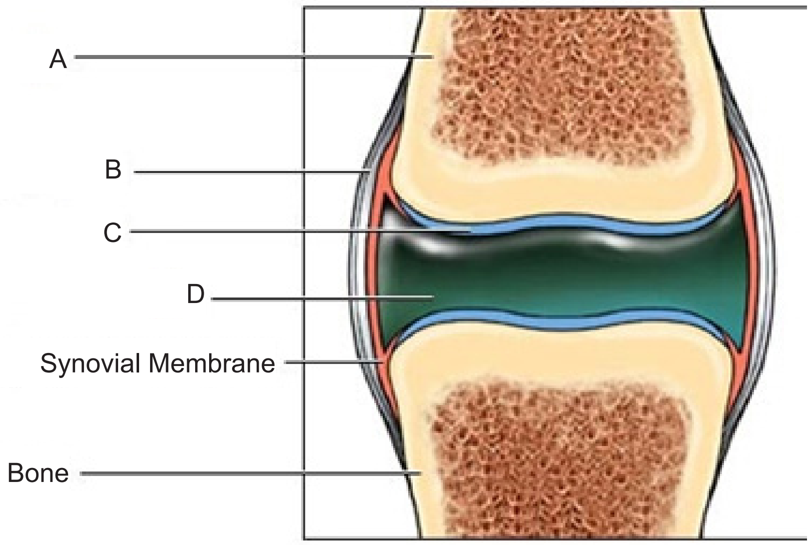
A. fixed joint
B. ball and socket joint
C. hinge joint

2. A compound fracture means:

A. the bone is broken and penetrates through the skin
B. the bone is broken in several places
C. the bone is partly broken

3. Identify **A**, **B**, **C** and **D** in the diagram below using the labels:

cartilage	bone	synovial fluid	ligament



A is:	cartilage	bone	synovial fluid	ligament
B is:	cartilage	bone	synovial fluid	ligament
C is:	cartilage	bone	synovial fluid	ligament
D is:	cartilage	bone	synovial fluid	ligament

4. The cartilage in the synovial joint:

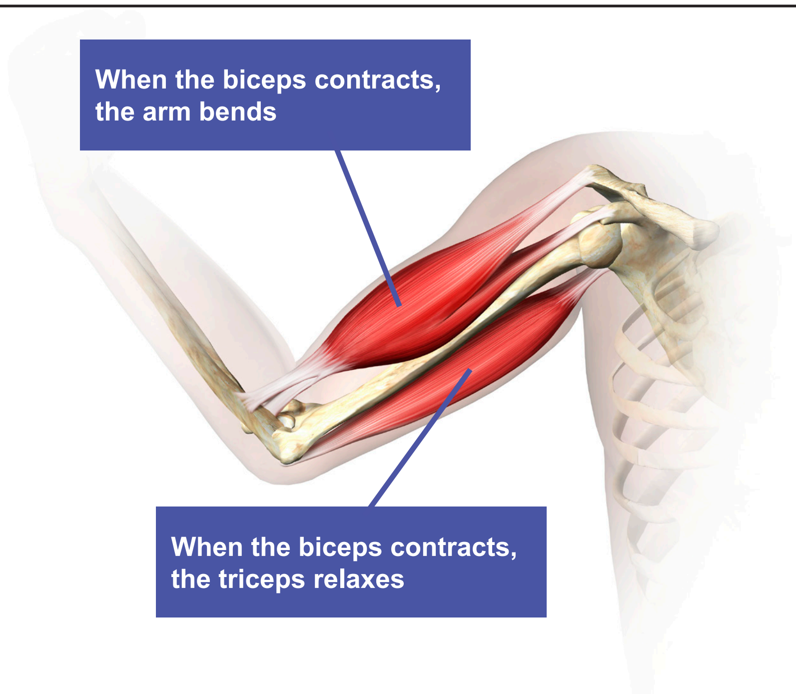
A lubricates joints
B helps reduce friction
C joins bones to bone

Antagonistic muscles

The muscles surrounding synovial joints are responsible for moving the body. The muscles around joints often work in pairs.

For example, movement about the elbow is achieved by the biceps and triceps. These two muscles are examples of an antagonistic muscle pair.

Antagonistic pairs of muscles create movement when one (the prime mover) contracts and the other (the antagonist) relaxes.



Antagonistic muscles in the arm
Henning Dalhoff / Science Photo Library

Movement about the elbow

Biceps	Triceps	Movement
biceps contract	triceps relax	arm bends
biceps relax	triceps contract	arm straightens

Movement about the knee

Another example of antagonistic muscles is the quadriceps and hamstring muscles which control the movement of the knee in the leg.

Hamstring	Quadriceps	Movement
hamstrings contracts	quadriceps relaxes	knee bends
hamstrings relaxes	quadriceps contracts	knee straightens

Energy for muscle contraction

Muscles need energy to contract.

This energy can only be provided by the breakdown of a chemical called Adenosine Triphosphate (ATP). A small amount of ATP is stored in the muscles but this is quickly used up when the muscles work.

ATP can be reformed by either aerobic or anaerobic respiration.

TEST YOURSELF

1. The arm bends when:

   A the biceps and triceps both contract
   B the biceps and triceps both relax
   C the biceps relax and triceps contract
   D the biceps contract and triceps relax

2. The arm straightens when:

   A the biceps and triceps both contract
   B the biceps and triceps both relax
   C the biceps relax and triceps contract
   D the biceps contract and triceps relax

3. Complete the following sentences by selecting the correct term from the brackets.

   Muscles around (**fixed joints / synovial joints**) work (**singly / in pairs**) to cause movement. These are called (**antagonistic / antinostic**) muscles.

Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

The nervous system

The nervous system is a complex collection of nerves and specialized cells (neurons) that transmit signals between different parts of the body. The nervous system is responsible for coordinating all of the body's activities. It not only controls normal functions but also the body's ability to cope with emergency situations.

The human nervous system consists of two parts:

- the central nervous system (CNS) - made up of the brain and spinal cord
- the peripheral nervous system - all other nerve fibres that connect to the CNS.

Information is sent through the nervous system as a series of small electrical signals.

Reflex reactions and the reflex arc

A **reflex** is a very fast, pre-programmed response to a stimulus. A reflex action is automatic and does not need to be thought about beforehand.

Reflex actions are there to protect the body.

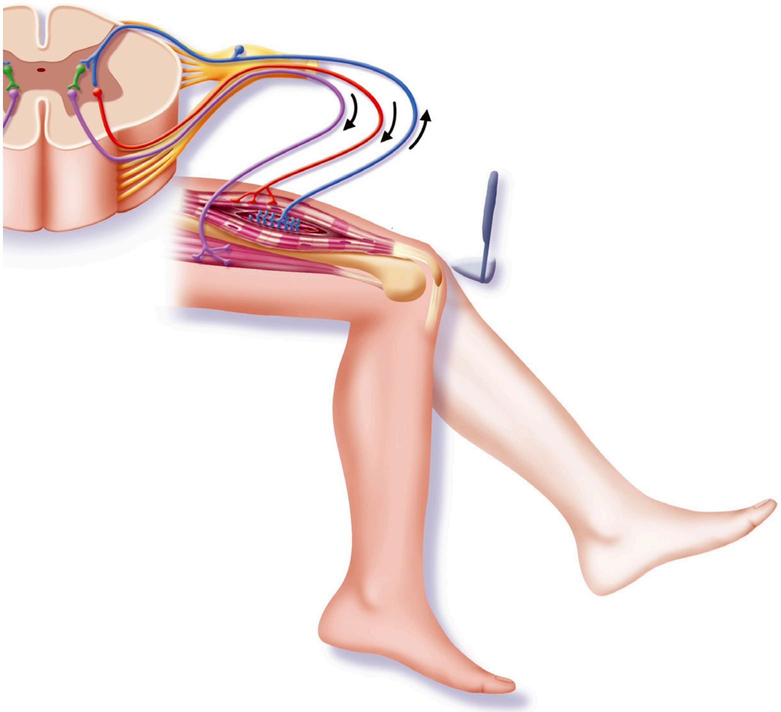
When our safety requires a very quick response, the signals are passed directly from a sensory neurone, via a relay neurone, to a motor neurone for instant action.

Reflex reactions are controlled by the reflex arc.
A reflex arc is the nerve pathway which makes such an automatic response possible.

Each reflex follows a series of steps:

stimulus → **receptor** → **sensory neurone** → **CNS** → **motor neurone** → **effector** → **response**

- The stimulus is picked up by a receptor, which transmits an impulse (electrical signal) to a sensory neurone.
- This sensory neurone passes the impulse to a relay neurone in the spinal cord (part of central nervous system).
- The relay neurone passes the signal on to a motor neurone which carries the response back to the effector organ.
- The response is carried out by the effector organ, e.g. a muscle contracts.



Reflex
Jacopin / BSIP / Science Photo Library

1. receptor detects a stimulus – hammer striking
2. sensory neurone (blue) sends signal to relay neurone (green) in the spinal cord (part of CNS)
3. relay neurone passes on signal to motor neurone (red) which carries the signal to effector (muscle)
4. effector produces a response (muscle contracts)

TEST YOURSELF

1. The central nervous system (CNS) is made up of:

   A the brain and peripheral nervous system
   B the brain and spinal cord
   C the spinal cord and peripheral nervous system

2. When our safety requires a very quick response, the signals are passed directly from a:

   A sensory neurone, via a relay neurone, to a motor neurone for instant action
   B motor neurone, via a relay neurone, to a sensory neurone for instant action
   C relay neurone, via a sensory neurone, to a motor neurone for instant action

Cardiovascular system

The **cardiovascular system** is also called the circulatory system. It is an organ system that allows blood to circulate around the body.

The cardiovascular system enables the transport of oxygen, carbon dioxide, nutrients and hormones to and from the cells in the body.

Components of the circulatory system

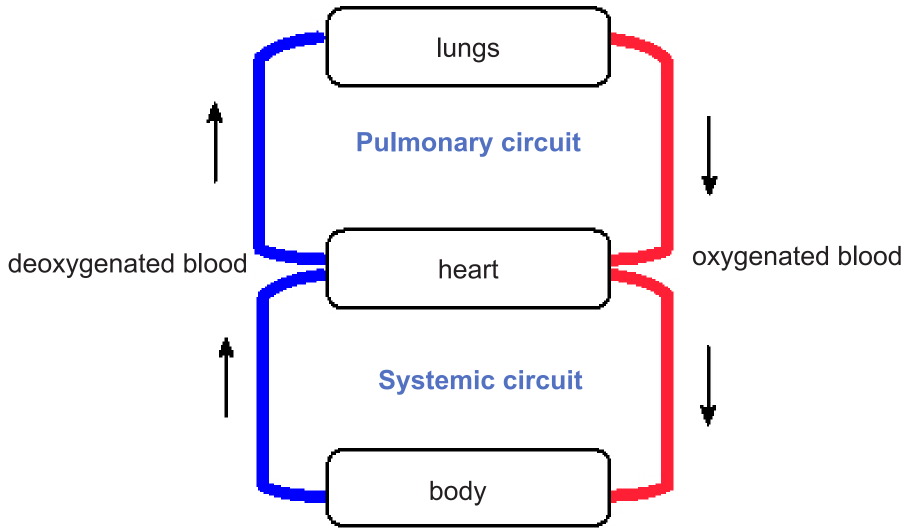
There are three components to the cardiovascular system:

- heart
- blood vessels (arteries, veins and capillaries)
- blood

The cardiovascular system is a double circulatory system. This means that it comprises of two separate circuits with blood passing twice through the heart before completing a full circuit around the body.

- one circuit links the heart and lungs (pulmonary circuit)
- the other circuit links the heart with the rest of the body (systemic circuit)

A schematic diagram of the double circulatory system is shown below:



Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

An important **advantage** of a double circulatory system is that it allows a greater flow rate to tissues around the body since it is able to maintain a higher blood pressure.

Blood pressure is reduced by the lungs so a **one circuit** circulatory system would not be able to maintain such a high pressure around the body so reducing flow rate.

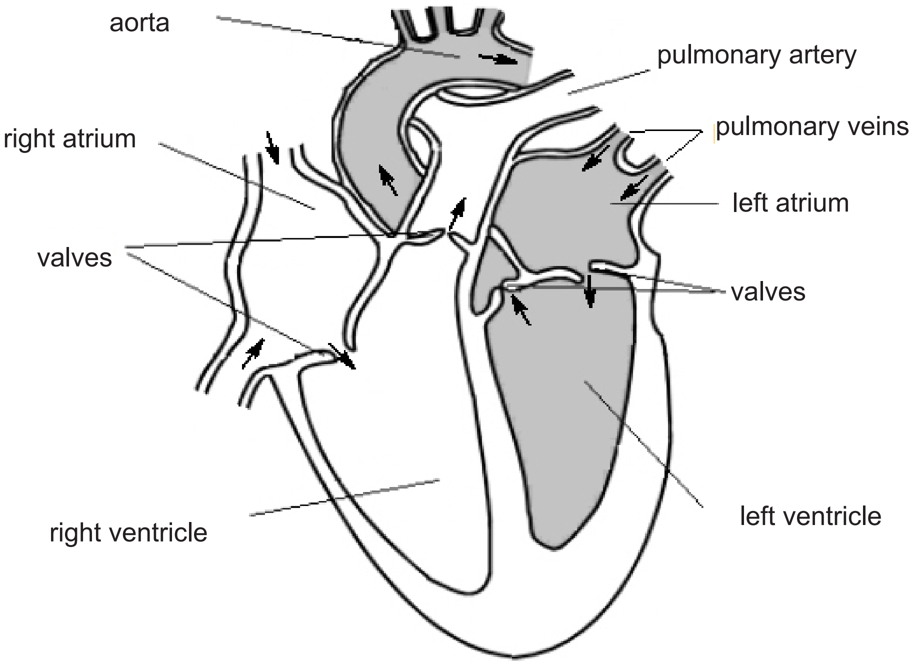
The heart

The heart is a muscular organ that pumps blood to all the tissues in your body through a network of blood vessels.

The heart pumps blood in two ways:

- the right side pumps blood to the lungs
- the left side pumps blood to the rest of the body

The diagram below shows the main parts of the heart.



The human heart has four chambers inside it. The top two chambers of the heart are called the atria (the right atrium and left atrium) and the bottom two chambers are called the ventricles.

Make sure you can label the right and left side of the heart correctly.

Look again at the labelling of the heart.

- Deoxygenated blood from the body enters the right atrium and passes into the right ventricle.
- The right ventricle pumps the blood to the lungs where it becomes oxygenated.
- Oxygenated blood returns to the heart by the pulmonary veins which enter the left atrium.
- Blood flows from the left atrium into the left ventricle. The left ventricle pumps the oxygenated blood to the aorta and then to all parts of the body.

Differences between right and left ventricles

The muscle in the left ventricle is much thicker than in the right ventricle.
This is because the left ventricle has to pump blood all the way around the body, but the right ventricle only has to pump it to the lungs.

Blood vessels

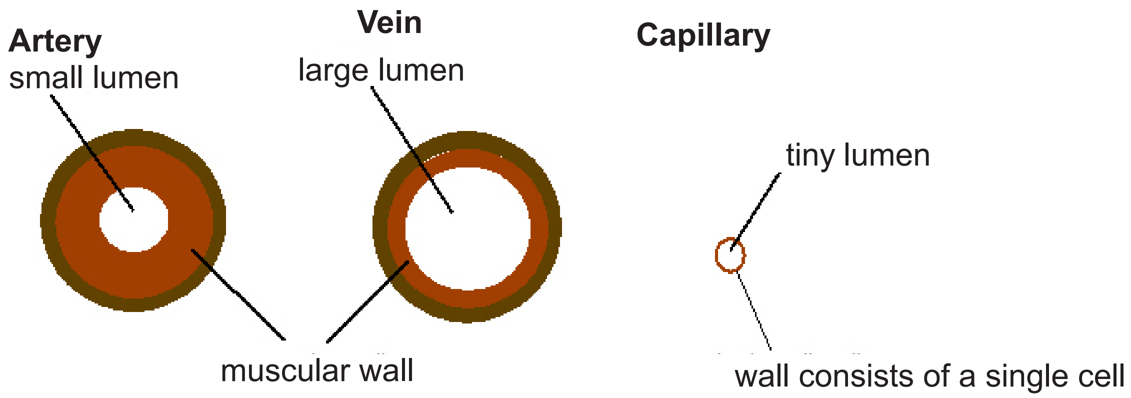
There are three types of blood vessel:

- arteries - carry blood from the heart
- veins - return blood to the heart
- capillaries - smallest of all blood vessels which allow for diffusion and exchange of substances

The structure of the different types of vessels is related to their function.

Vessel	Structure	Comment
arteries	• **thick** outer walls • thick layers of muscle	• blood in the arteries is under high pressure generated by the heart • arteries do not have valves
veins	• **thin** walls • thin layers of muscle • contain valves	• blood in veins is under lower pressure than the blood in arteries • veins have valves which stop the blood from flowing backward
Capillaries	• thin walls - only **one cell** thick	• bring nutrients and oxygen to tissues and remove waste products • thin walls needed to enable them to perform their function

Cross sectional diagram of blood vessels



Micrograph of an artery and the accompanying vein

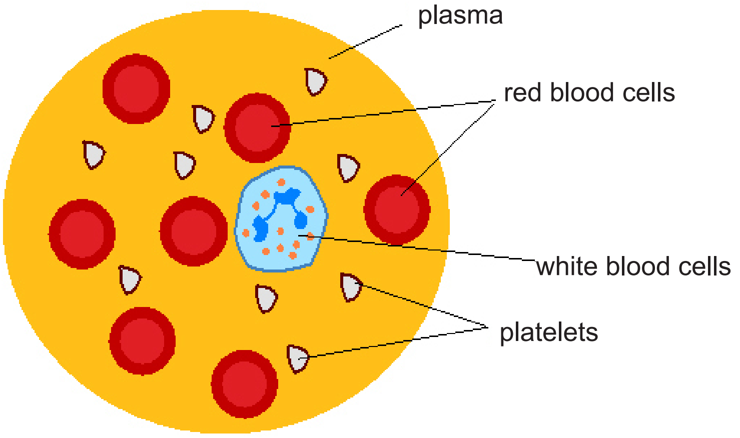
The heart also needs oxygen to keep beating.

This oxygen is delivered by the **coronary arteries.**

Coronary arteries
Agencja Fotograficzna Caro / Alamy Stock Photo

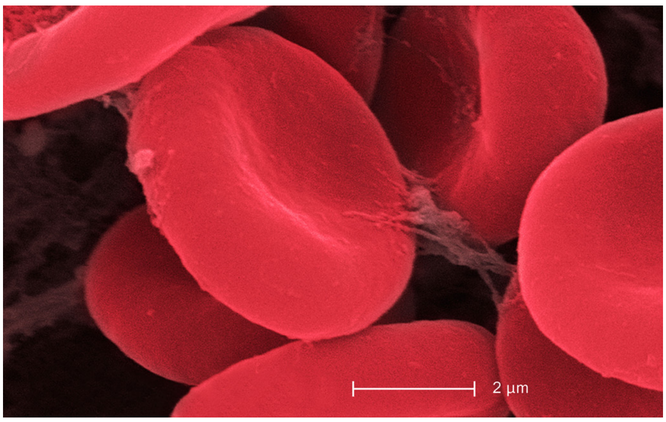
Blood

Blood transports materials around the body and protects against disease. It consists of red blood cells, white blood cells, plasma and platelets.



Each part of the blood has a special function.

Part of blood	Function	Comment
red blood cells	contain **haemoglobin** for transport of oxygen	• no nucleus • **biconcave** shape to maximise their surface area for oxygen absorption • small enough to fit through narrow blood vessels
white blood cells	defence against disease	• see immune system (earlier)
platelets	clotting	• clot at the skins surface after a cut or internally on damaged vessels
plasma	transport of CO_2, soluble food, urea, hormones and distribution of heat	• straw coloured liquid



Red blood cells showing biconcave shape
Cultura RM / Alamy Stock Photo

Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

Physiological measurements

Pulse rate and breathing rate

Taking a pulse is a direct measurement of the rate at which the heart beats. The heart rate is the number of times your heart beats each minute.

The pulse is a measure of the heart rate since the arteries expand each time the ventricles pump blood out of the heart.

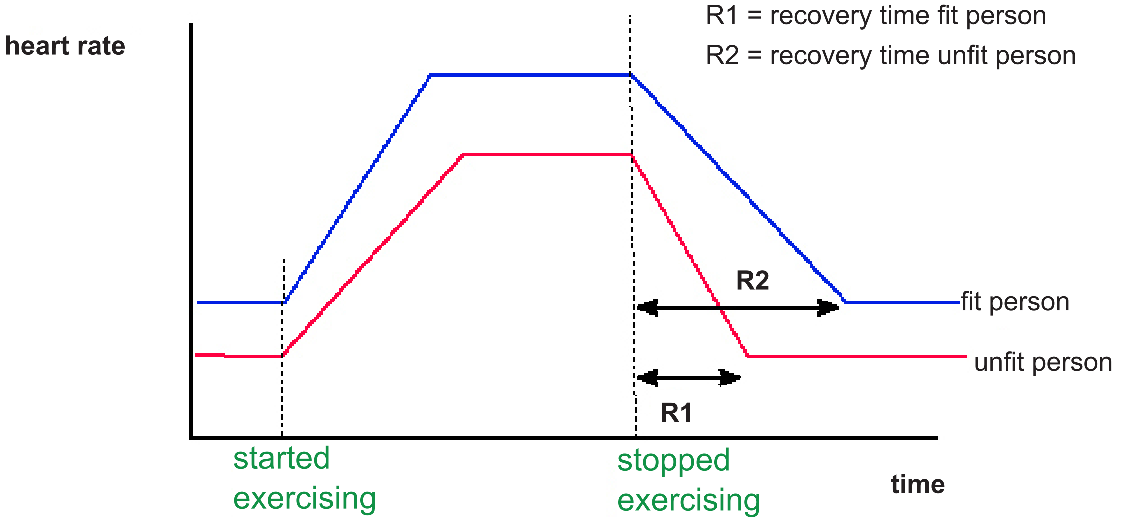
When you do exercise, you are making your muscles work harder. This means they need more glucose and oxygen for respiration than when you are at rest.

As a result your:

- breathing rate increases in order to get more oxygen and also to expel more carbon dioxide
- heart beats faster in order to pump the oxygen and glucose around the body more quickly.

When an **unfit** person exercises, his/her pulse rate and breathing rate rise **more quickly** than in a **fit** person.

The time which it takes for the pulse and breathing rate to return to normal is called the **recovery time**. The fitter a person is, the shorter the recovery time.



Notice that for the fit person:
- the recovery time is less
- their resting heart rate is lower than the unfit person

Measuring your pulse

The pulse may be taken in any place that allows an artery to be compressed against a bone, e.g. in the neck, or at the wrist.

1. Measure your heart rate by lightly pressing your forefinger and middle finger across the carotid artery in the neck or the radial pulse in the wrist.
2. Count the number of beats for 15 seconds, then multiply that number by 4 to determine heart rate.

Another way to measure heart rate is through the use of a heart rate monitor.

Why can't you take a pulse using a vein instead of an artery?

Arteries deliver blood from the heart under pressure. Once blood has passed through the fine capillaries and back into veins, the force of the heart beat is too weak to be felt.

Measuring breathing rate

The respiratory rate is the number of breaths that a patient takes each minute.
- Just count the number of breaths in 15 seconds and multiply this by 4.

Long term effect of exercise

Following an exercise programme is the best way to improve your cardiovascular fitness. During a 10-week fitness program, you can expect to see a reduction of about 10 beats per minute in your resting heart rate. This is the result of:

- strengthening the heart muscle
- improved efficiency of the heart muscle.

Your body also becomes more efficient at transporting oxygen. This means you will not need to breathe so fast. All of this leads to lower recovery times in people who are fit.

Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

TEST YOURSELF

1. The components of the cardiovascular system are the:

A heart, lungs and blood vessels
B heart, blood and blood vessels
C heart, blood, lungs and blood vessels
D heart, blood and lungs

2. The human circulatory system is a:

A single circulatory system
B double circulatory system
C complex circulatory system

3. The size of the lumen in arteries, veins and capillaries, INCREASES in the order:

A	veins	arteries	capillaries
B	arteries	veins	capillaries
C	capillaries	arteries	veins

4. The cells that do not have a nucleus in the human body are:

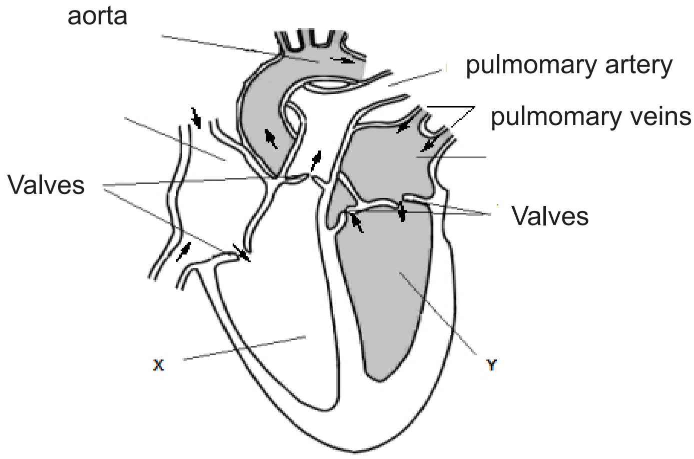
A white blood cells
B platelets
C red blood cells

5. Platelets are involved in:

A blood clotting
B carrying oxygen
C defence against disease

6. The structures marked X and Y on the heart labelled:

A X = left ventricle, Y = right ventricle
B X = right ventricle, Y = left ventricle
C X = right atrium, Y left atrium
D X = left atrium, Y right atrium



PHYSICS AND MOVEMENT

Distance, speed and velocity

Speed is measured in metres per second.

It can be calculated using the formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Examples of calculations

The world record for running the 100 meters race set in 2009 by Usain Bolt was 9.58 seconds. His average speed can be calculated using:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$= \frac{100}{9.58} = \textbf{10.4 m/s} \text{ (This is the same as 23.3 mph)}$$

In 2014, Dennis Kimeto set a marathon time of 2 hours 2 minutes and 57 seconds. The marathon is 42.195 kilometres. Calculate his mean speed around the course.

First find the time in seconds
Time in seconds = (2 × 60 × 60) + (2 × 60) + 57 = 7 377 seconds

Second find the distance in metres
Distance in metres = 42.195 × 1 000 = 42 195 m

Finally calculate the mean speed
His average speed can be calculated using:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$= \frac{42\,195}{7\,377}$$

$$= 100 / 9.58$$

$$= \textbf{5.72 m/s}$$

Speed and velocity

There are two ways of looking at a journey

- Only the **amount** of distance travelled is important. It either stays the same or increases.

  It does not matter which direction you go in. In this case, the distance travelled is just a positive number.

- The **direction** you travel in is **also** important. If you travel one way it is a positive number. If you travel in the opposite way it is a negative number. Direction matters!

The first quantity is an example of a **scalar** quantity; the second, where direction also matters, a **vector** quantity.

Speed is a scalar quantity. It does not matter which direction you walk or run in. It is always a positive number.

Velocity is a vector quantity. It matters which way you walk or run.

If you run in one direction it is positive but if you run in the opposite direction it is negative.

Running in the opposite direction

Velocity = 5 m/s

Velocity = -5 m/s

New Illustrations by Alfonsodetomas / Alamy Stock Vector

We can show information about the distance and time taken on a **distance-time graph.**

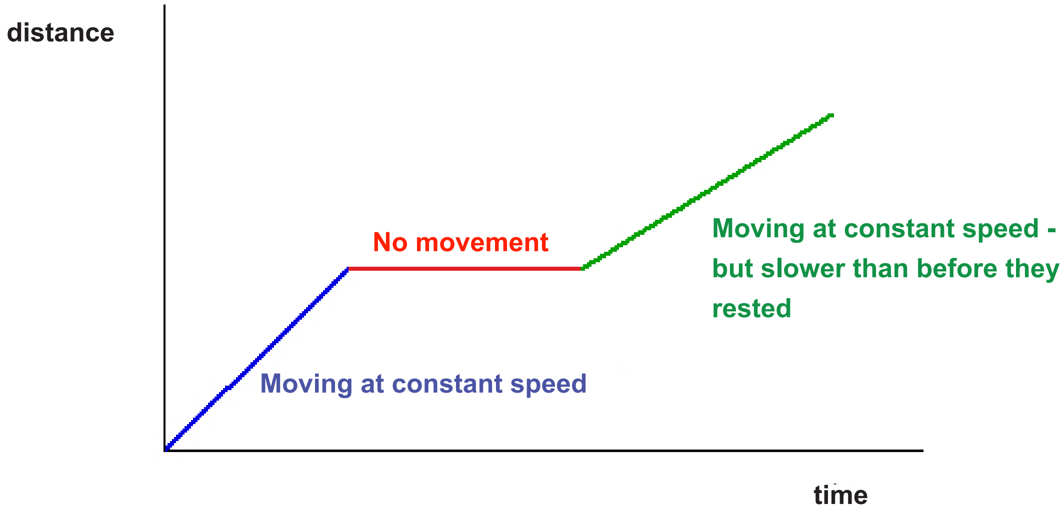
Distance-time graphs

Key things to notice on a distance time graph:

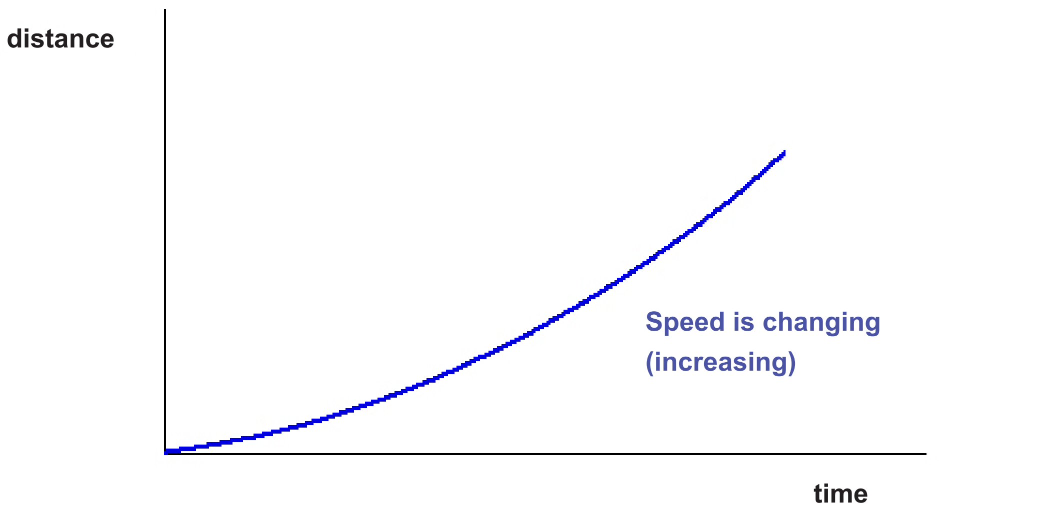
- a horizontal line means that the object is not moving
- a straight line sloping up means that the object is moving with constant speed
- the steeper the line the faster the movement
- a curved line means that the speed is changing

Look carefully at the graphs below and make sure you understand the information they give.

Graph 1

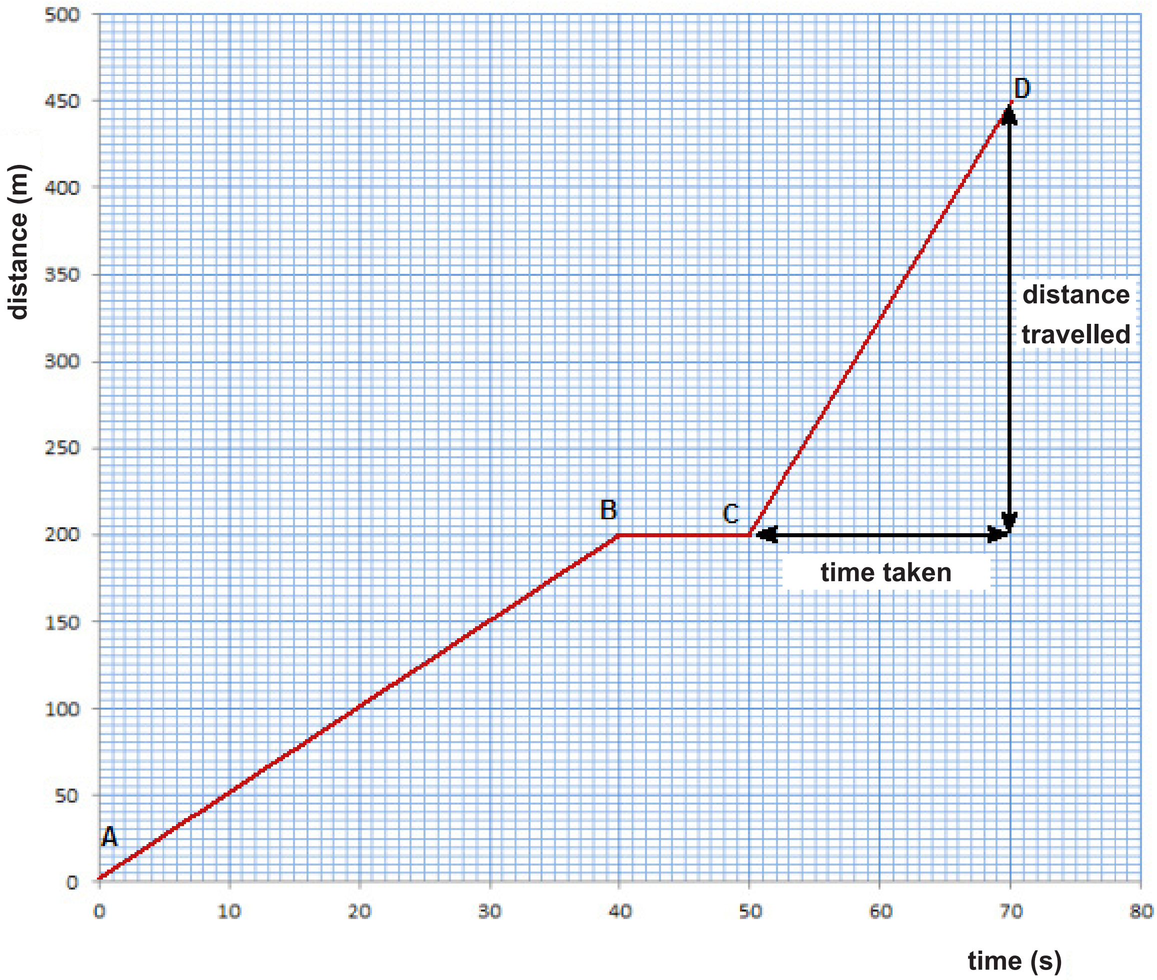


Graph 2



Example

A distance time graph for a cyclist is shown below.



The cyclist is:

- moving at constant velocity between point **A** and **B**, and between **C** and **D**
- moving faster between points **C** and **D** than between **A** and **B** (steeper slope)
- not moving between **B** and **C**

The speed between **C** and **D** can be found from the slope of the line **CD**.

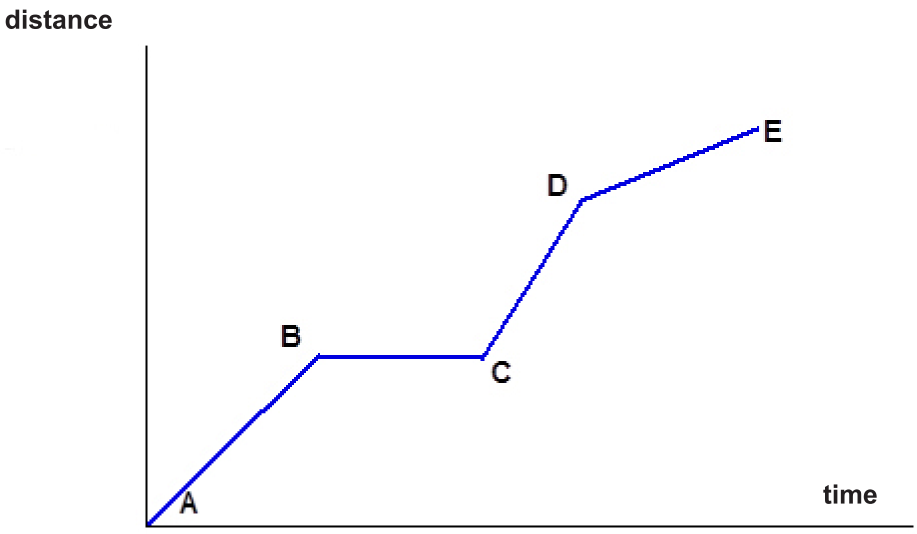
$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$= \frac{(450 - 200)}{(70 - 50)}$$

$$= \frac{250}{20} = \mathbf{12.5\ m/s}$$

TEST YOURSELF

1. A cyclist travels 100 m in 5 seconds. Her speed is:
   - A 500 m/s
   - B 0.05 m/s
   - C 20 m/s
2. A man runs 200 m in 25 seconds. His speed is:
   - A 8 m/s
   - B 500 m/s
   - C 0.50 m/s
3. Look at the distance-time graph for the cyclist below and state the points between which the cyclist is moving fastest.



(a) The cyclist is fastest between:
   - A **A** and **B**
   - B **B** and **C**
   - C **C** and **D**
   - D **D** and **E**

(b) The man does not move between:
   - A **A** and **B**
   - B **B** and **C**
   - C **C** and **D**
   - D **D** and **E**

Acceleration

A change in velocity is called **acceleration**.

Acceleration is the change in velocity per second.

The units of acceleration are:

m/s^2
(metres per second squared)

It is calculated using:

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

Examples

1. A cyclist accelerates from rest to 9 m/s in 10 seconds. Calculate the acceleration of the cyclist.

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

$$\text{acceleration} = \frac{(9 - 0)}{10} = \mathbf{0.9\ m/s^2}$$

2. Calculate the acceleration when an athlete increases his speed from 4 m/s to 7.5 m/s in 5 seconds.

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

$$\text{acceleration} = \frac{(7.5 - 4)}{5} = \frac{(3.5)}{5} = \mathbf{0.7\ m/s^2}$$

Velocity-time graphs

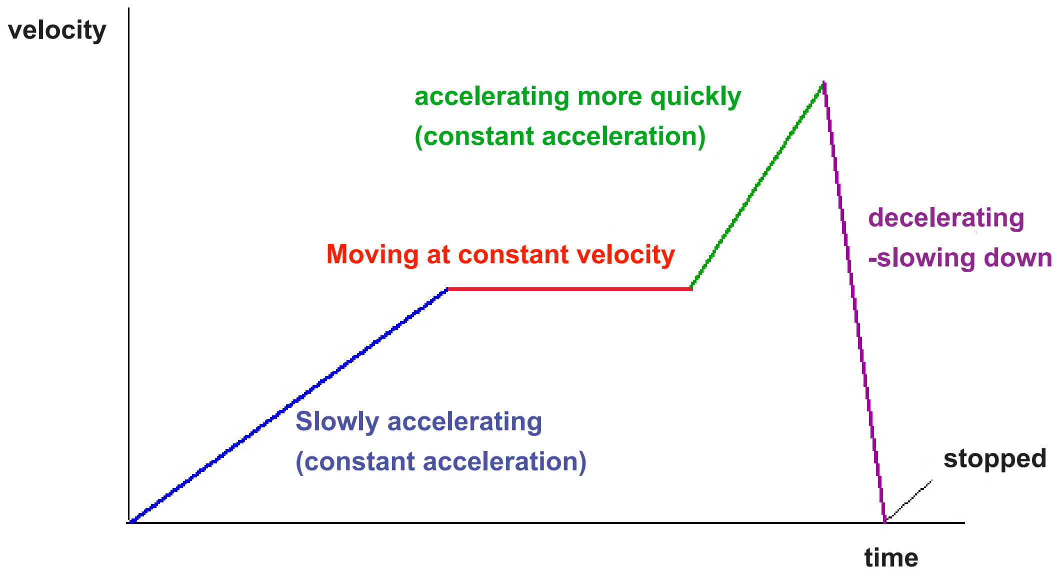
We can also represent motion using velocity-time graphs.

Key things to notice on a velocity-time graph:

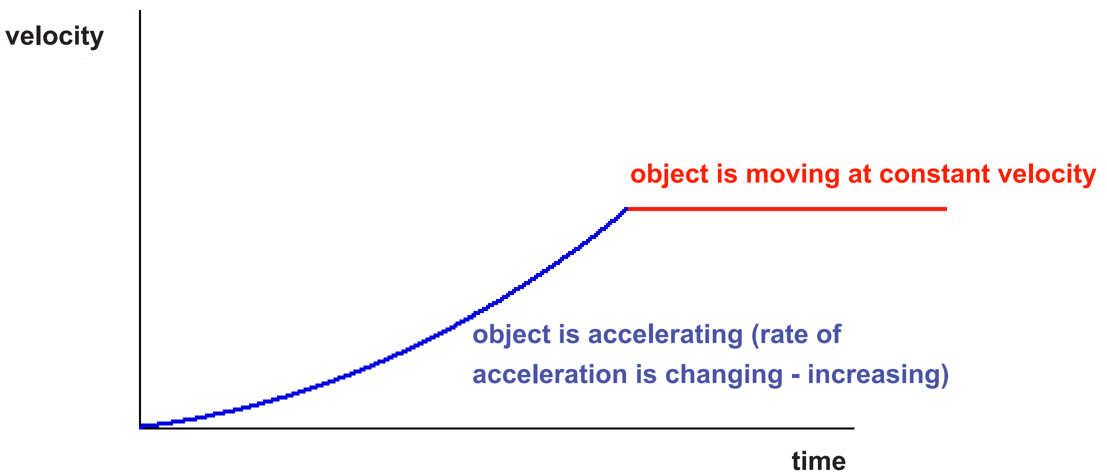
- horizontal line means that the object is travelling at a constant velocity
- a straight line slopping upwards means that the object is moving with a **constant** acceleration
- the steeper the line the faster the acceleration
- a curved sloping line means that the acceleration is changing
- a negative line means that the object is slowing down (decelerating)

Look carefully at the graphs below and make sure you understand the information they give.

Graph 1

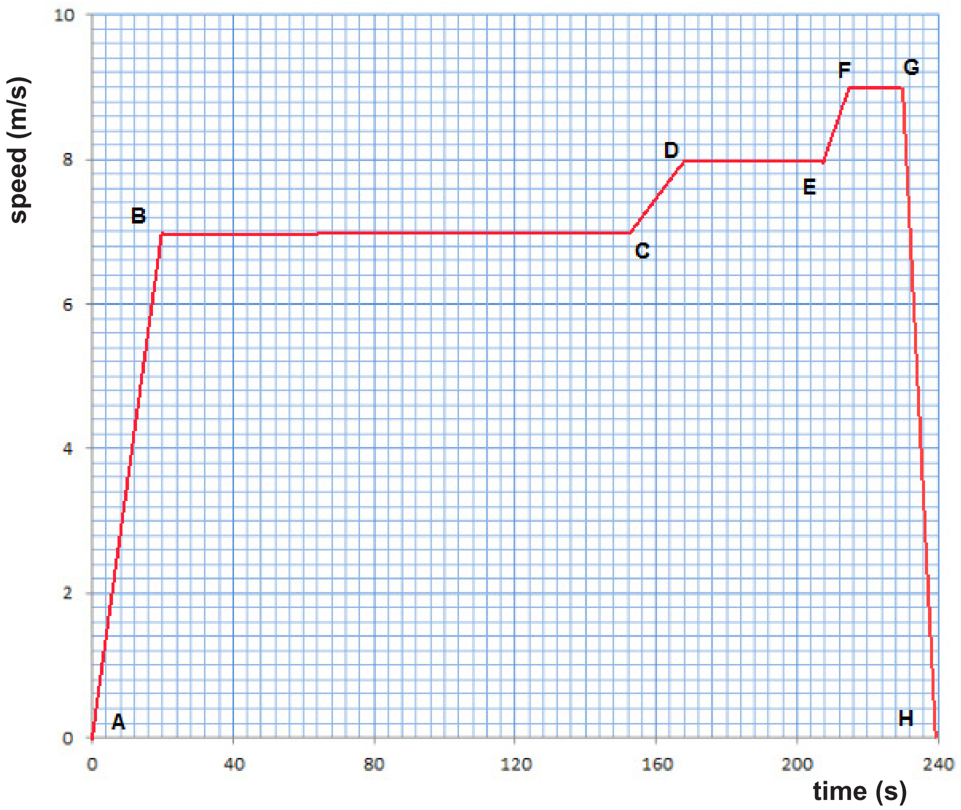


Graph 2



Example

The speed of an athlete running a 1 500 m race was recorded and the result shown on a speed-time graph.



The athlete was running with constant speed between points **B** and **C**, **D** and **E**, **F** and **G**.
At 120 seconds his speed was 7.0 m/s
The athlete accelerated between points **A** and **B**, **C** and **D**, **E** and **F**.
He slowed down (decelerated) between **G** and **H**
The acceleration was fastest between **A** and **B** **(steepest line upwards)**

$$\text{acceleration between A and B} = \frac{\text{change in velocity}}{\text{time}}$$

$$= \frac{(7.0 - 0)}{20} = \mathbf{0.35\ m/s^2}$$

Health, fitness and sport (Unit 2.1)

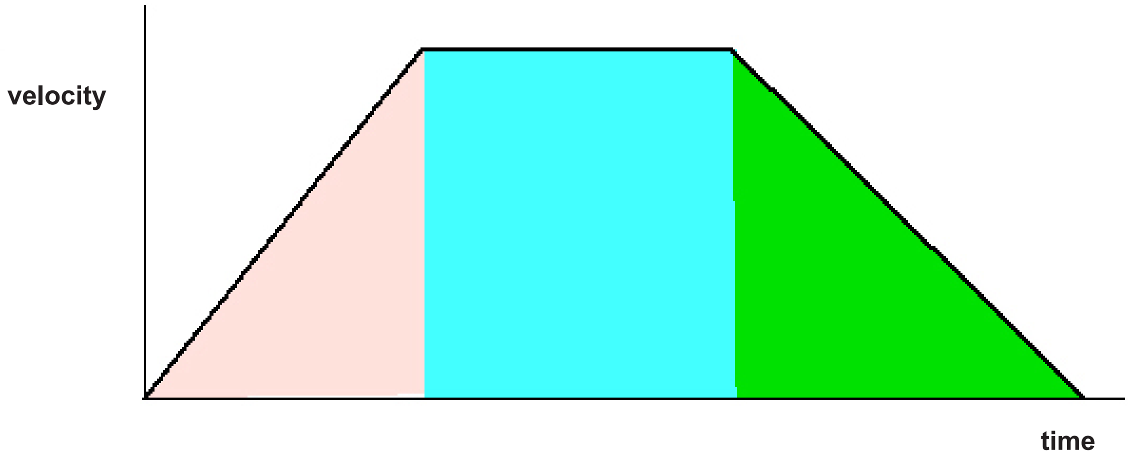
Exercise and fitness in humans (specification 2.1.4)

Higher tier only

Finding distance travelled from a velocity-time graph

The area under the graph is the distance travelled by an object in a velocity-time graph

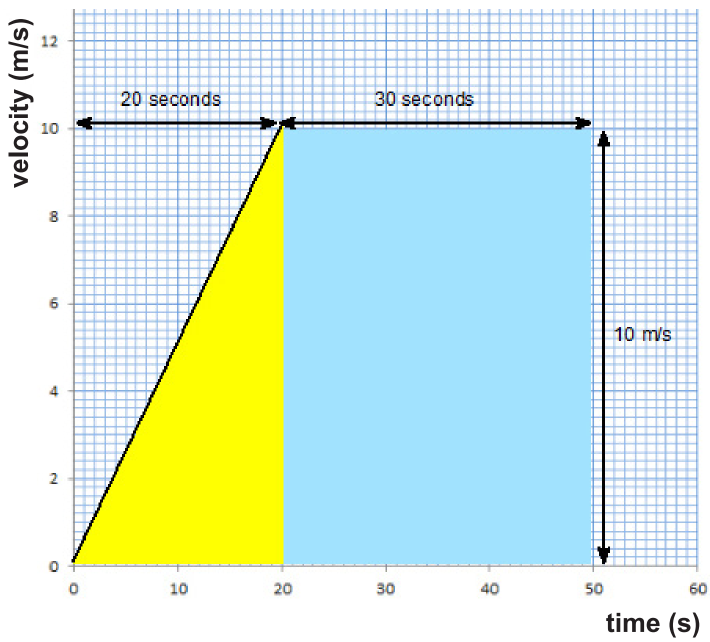
The graph shows an object accelerating from rest and then travelling at constant velocity until it slows to rest. The total distance travelled by the object will be the area between the graph and the time axis.



All that needs to be done is to calculate this area. This is best done by splitting the shaded area into three shapes, two triangles and a rectangle as shown above.

Example

Calculate the distance travelled by the cyclist in 50 seconds from the graph below.



Calculate the area that is shaded:

Blue rectangle = 30 × 10
= 300 m

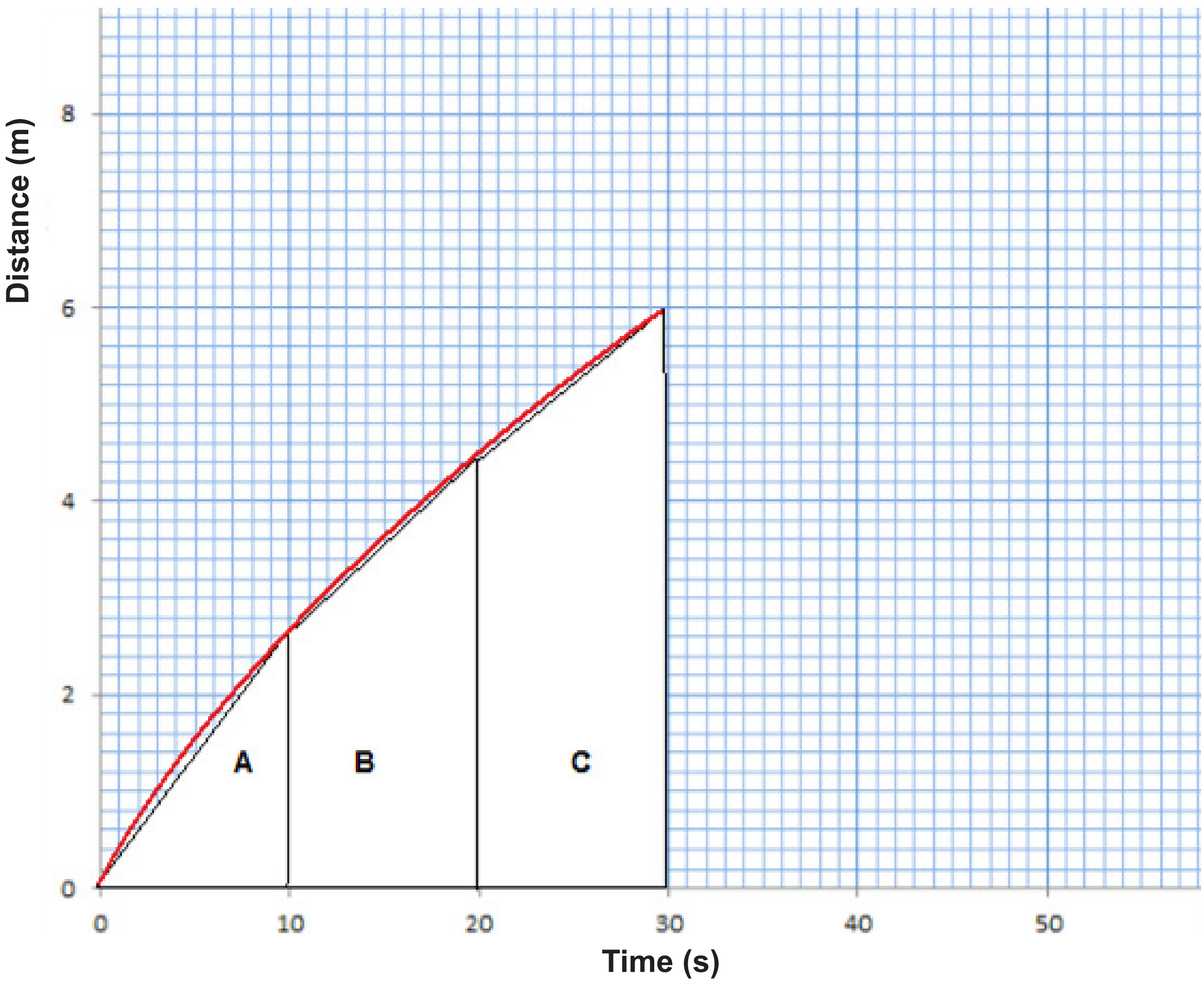
yellow triangle = ½ × 20 × 10
= 100 m

Total distance travelled
= 300 + 100
= **400 m**

Distance travelled when the acceleration is not constant

If the acceleration is not increasing at a constant rate then you will need to estimate the area under the curve.

In the example below we have broken the area up into three shapes, **A**, **B** and **C**.



The area of the right angled triangle, **A** = ½ × 2.6 × 10 = 13

The area of trapezium **B** = ½ (2.6 + 4.4) × 10 = 35

The area of trapezium **C** = ½ (4.4 + 6.0) × 10 = 52

Total area = 13 + 35 + 52 = 100 metres

This is an estimation of the area.

TEST YOURSELF

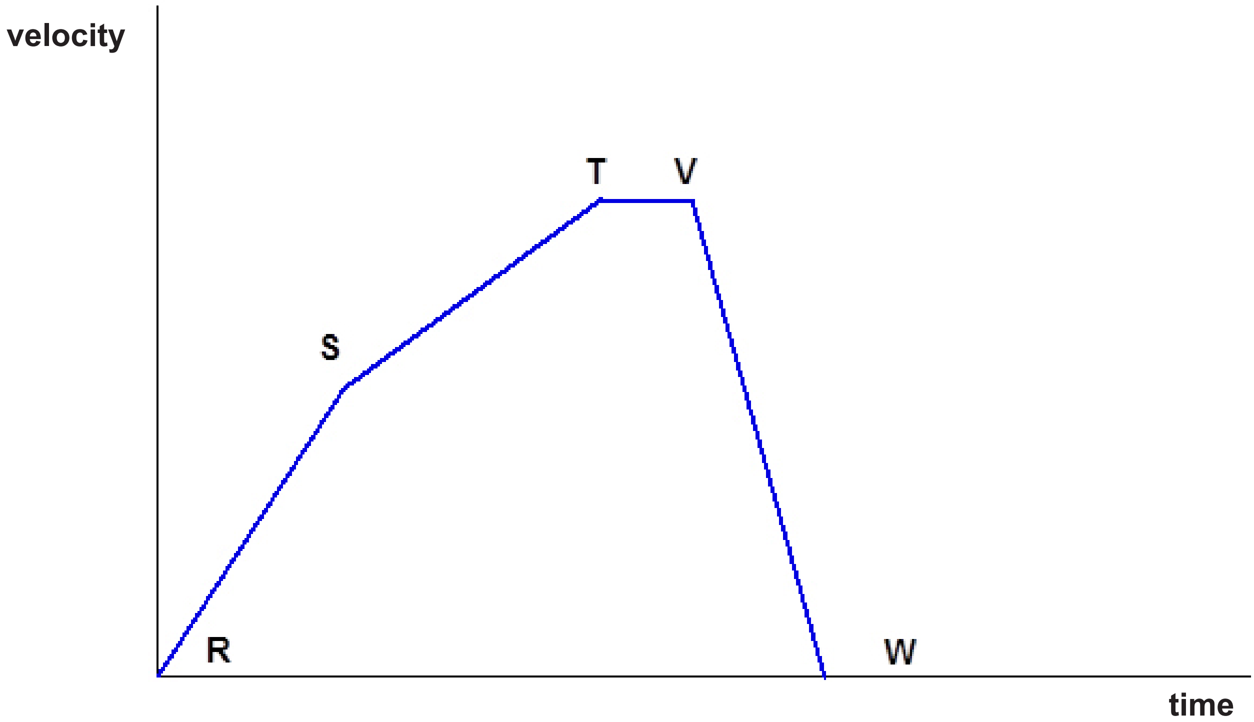
1. A man accelerates from 3.0 m/s to 6.0 m/s in 4 seconds. His acceleration is:

A 0.75 m/s^2
B 1.3 m/s^2
C 12 m/s^2

2. A cyclist accelerates from 5 m/s to 10 m/s in 5 seconds. Her acceleration is:

A 2 m/s^2
B 1 m/s^2
C 0.5 m/s^2

3. Use the velocity-time graph for the cyclist below to answer the questions that follow.



(a) The cyclist is accelerating fastest between:

A **R** and **S** **B** **S** and **T** **C** **T** and **V** **D** **V** and **W**

(b) The cyclist is decelerating between:

A **R** and **S** **B** **S** and **T** **C** **T** and **V** **D** **V** and **W**

(c) The cyclist is moving at constant velocity between:

A **R** and **S** **B** **S** and **T** **C** **T** and **V** **D** **V** and **W**

(d) The cyclist is not moving at:

A Point T **B** Point T **C** Point W

PRACTICE QUESTIONS

1. Dan works out on an exercise bicycle.

Cycling machine
walter zerla/gettyimages

Dan says he is fitter than Alex because his breathing rate returns to normal after exercise sooner than Alex's. You decide to test Dan's claim by carrying out a comparison of the effect of exercise on the breathing rate (number of breaths per minute) of these two students.

Describe your investigation. Make sure that it is a fair test. [6 QER]

....
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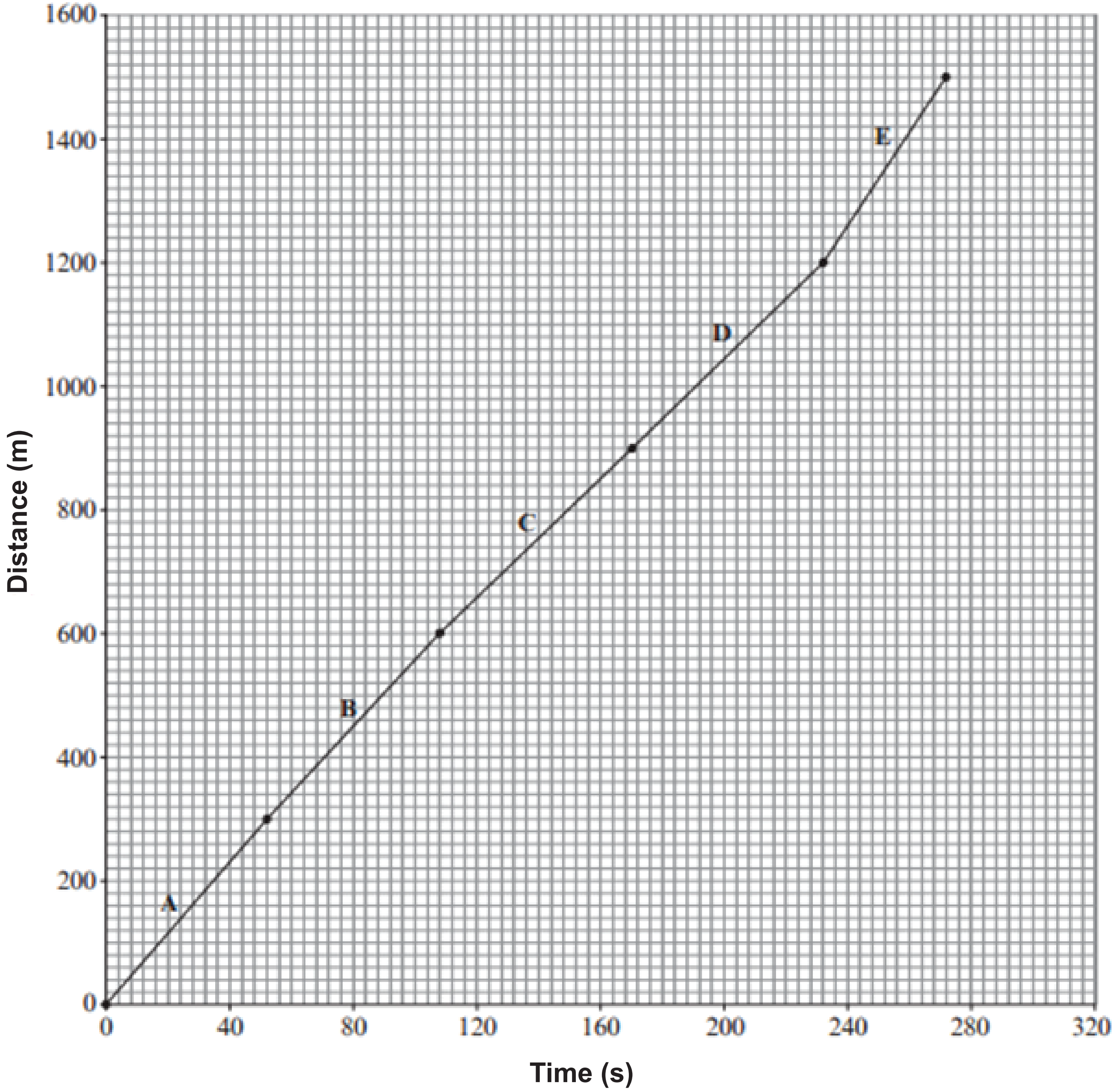
2. Gareth and Kevin entered a 1 500 m race. Their performance during the race was measured. The time they take to complete each 300 m stage of the race was measured. A distance–time graph is plotted below for Kevin.



(a) Use the graph to find the:

(i) time taken by Kevin to complete the race. [1]

.... seconds

(ii) fastest 300 m section (**A**, **B**, **C**, **D** or **E**) ran by Kevin. [1]

....

(b) Gareth's performance in the same race is recorded in the table below.

Time (seconds)	Distance (meters)
0	0
60	300
120	600
180	900
240	1 200
320	1 500

(i) On the same graph, plot the performance of Gareth using the values shown in the table above. [3]

(ii) Calculate the mean speed for Gareth during the first 900 m using the equation: [2]

$$\text{mean speed} = \frac{\text{distance}}{\text{time}}$$

answer = ………….. m/s

(c) Use the data to explain how the fitness of Gareth compares with Kevin. [2]

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

TEST YOURSELF - ANSWERS FOR UNIT 2.1

Genes, inheritance and health

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

Lifestyle and health

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

Controlling blood glucose level

1. C
2. C
3. glucagon (B) insulin (A)
4. C
5. C
6. A

Ionising radiation

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

Medical imaging

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

Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

Drugs

1. C
2. B
3. B

Microorganisms and the body's defences

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

Joints

1. B
2. A
3. A – bone B – ligament C – cartilage D – synovial fluid
4. B

Antagonistic muscles

1. D
2. C
3. synovial joints, in pairs, antagonistic

Nervous system

1. B
2. A

Cardiovascular system

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

Speed and velocity

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

Acceleration

1. A
2. B
3. (a) A (b) D (c) C (d) C

Unit 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

Unit 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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

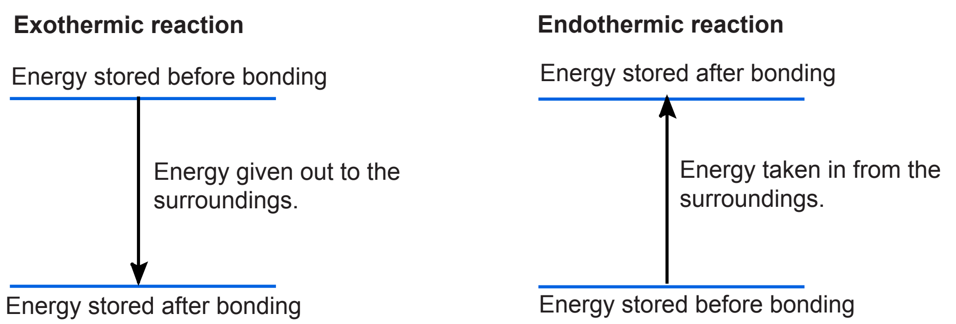
There is almost always a change in energy associated with a chemical reaction and as a result there is often a temperature change. Energy may be given out in a chemical reaction or it may be taken in during the reaction.

> 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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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

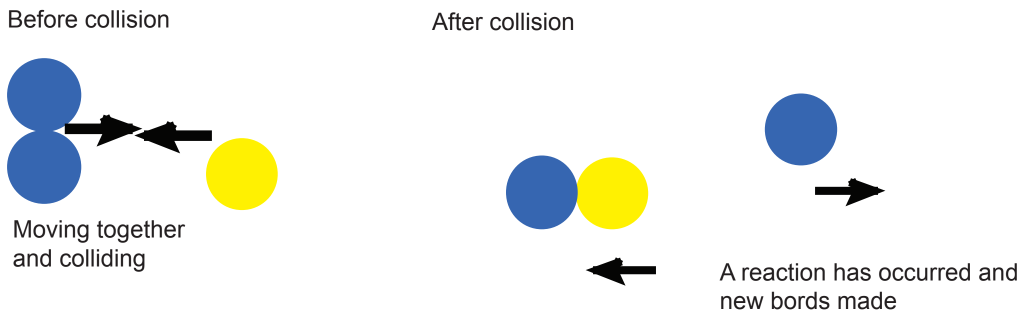
The **rate** of a chemical reaction can be **increased** in several different ways:

- 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.

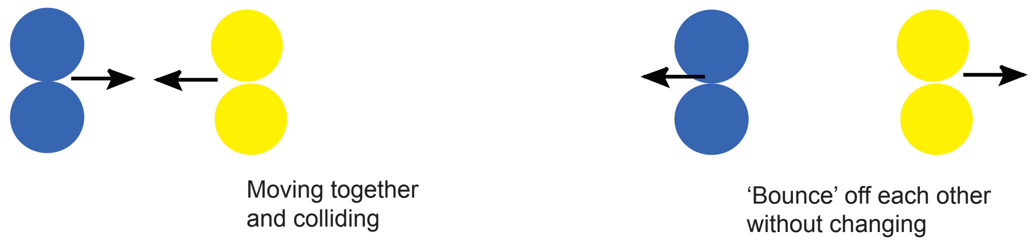
Unit 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

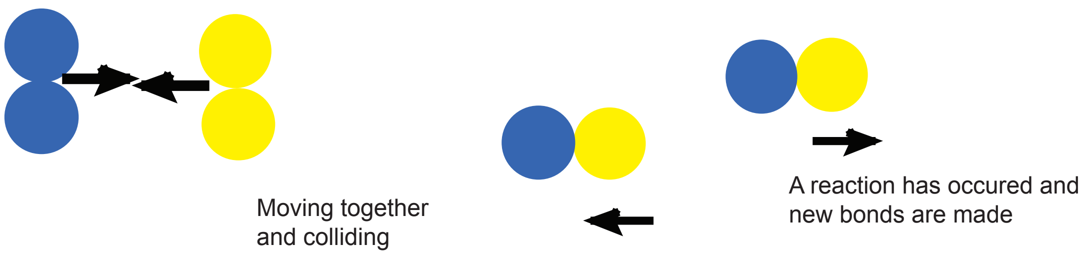
Do all collisions result in a chemical change?

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

The effect of concentration (and pressure)

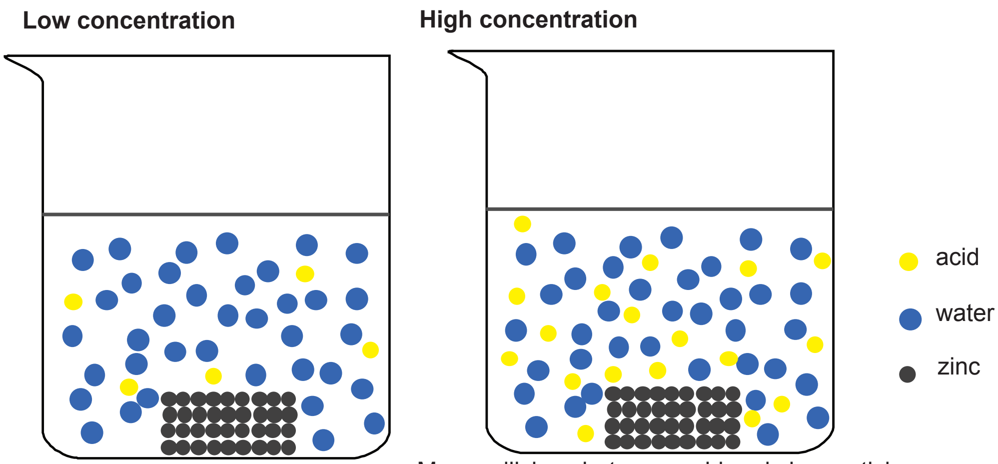
Increasing the concentration of the reactants means there are more reactant particles in the solution and therefore a greater chance of successful collision.

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**.

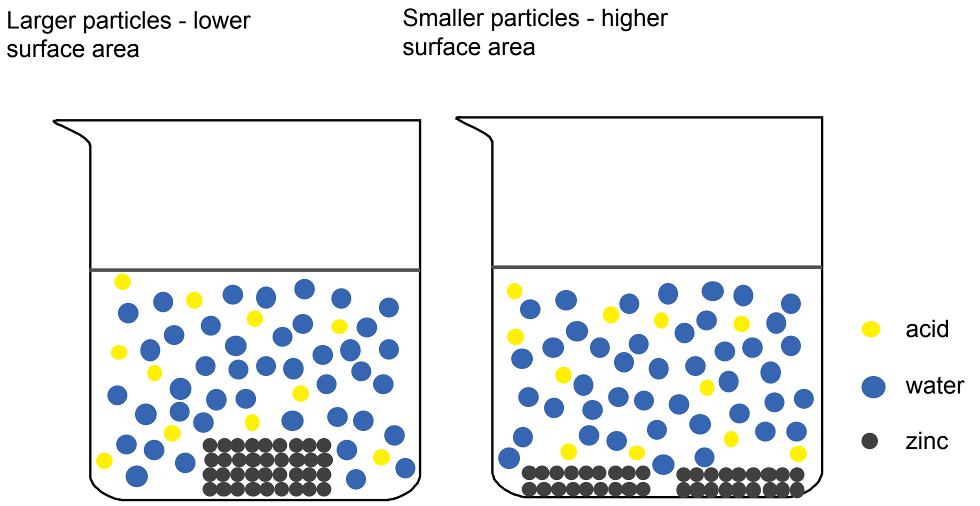
- At low pressure there is only a small chance particles will collide.
- Increasing the pressure increases the chances of collisions.
- Since collisions occur more often, the reaction is faster.

Unit 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

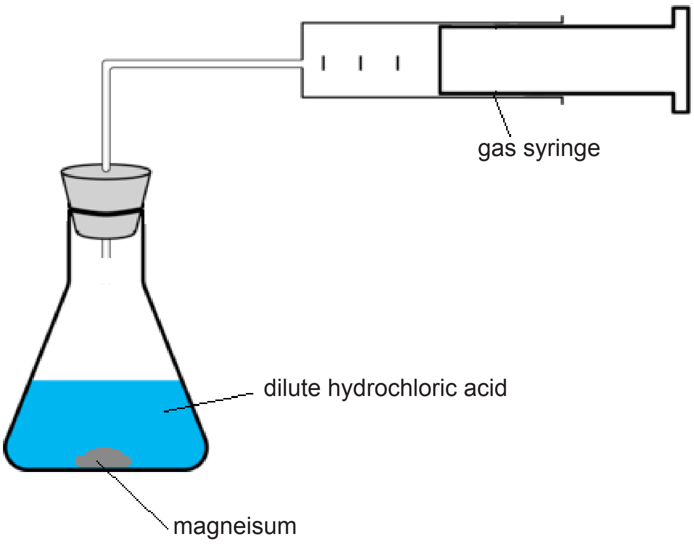
The rate of reaction between magnesium and hydrochloric acid

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

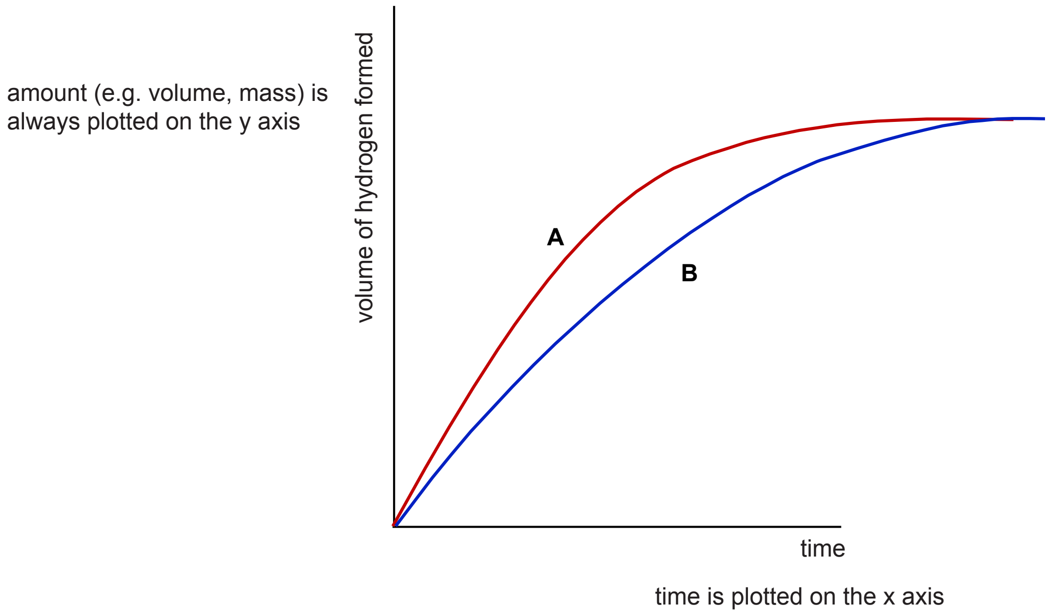
We could measure the rate of this reaction by:

- 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

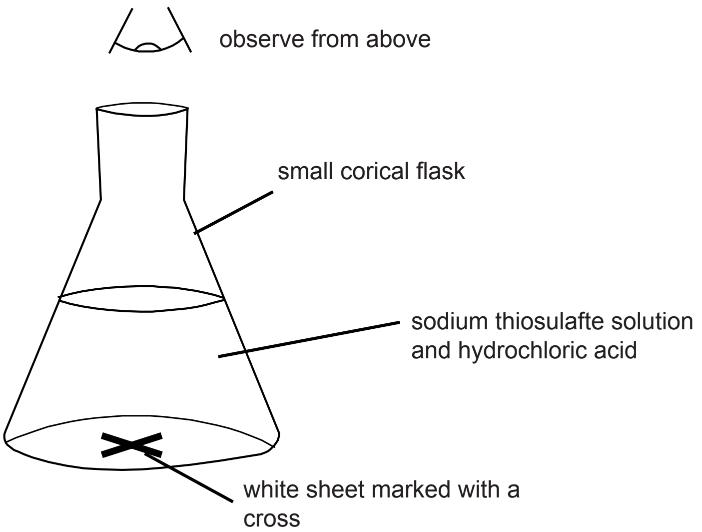
Symbol equation:

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

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.

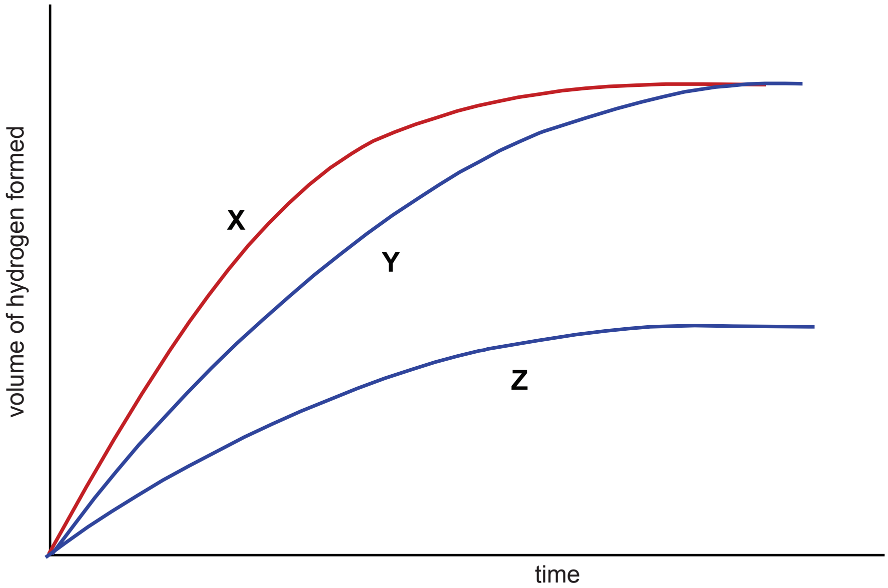
Unit 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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

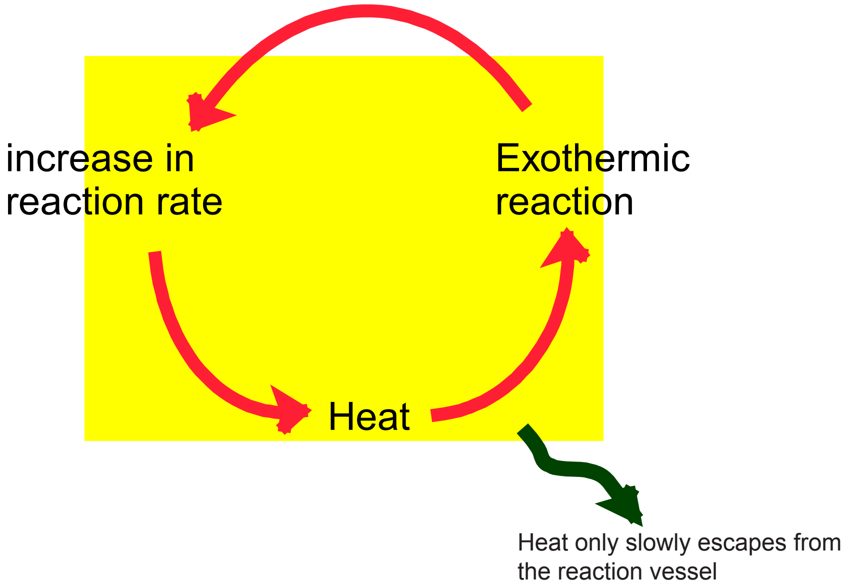
Unit 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling chemical reactions (specification 2.2.1)

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 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

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.

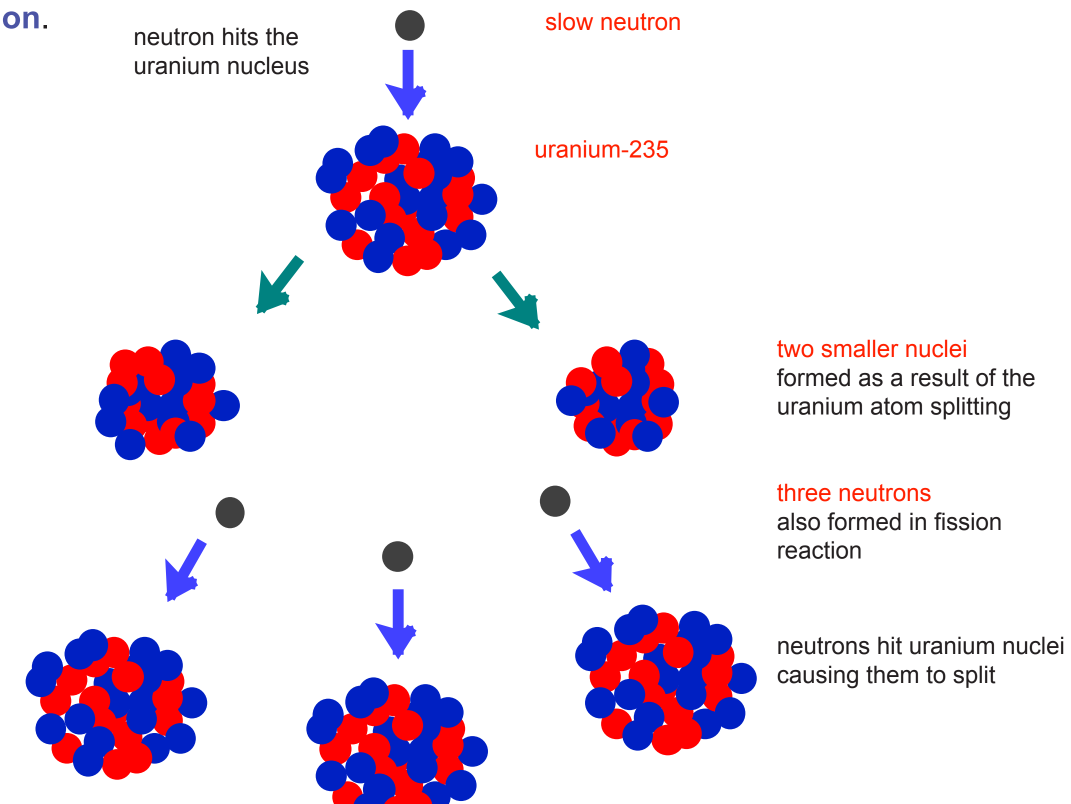
Nuclear fission reactions

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 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

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 → 235
atomic number → 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 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

Example question

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

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

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**

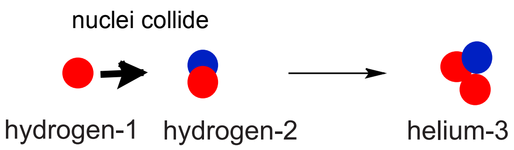
Nuclear fusion reactions

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

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

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

atomic number RHS = **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 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

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.

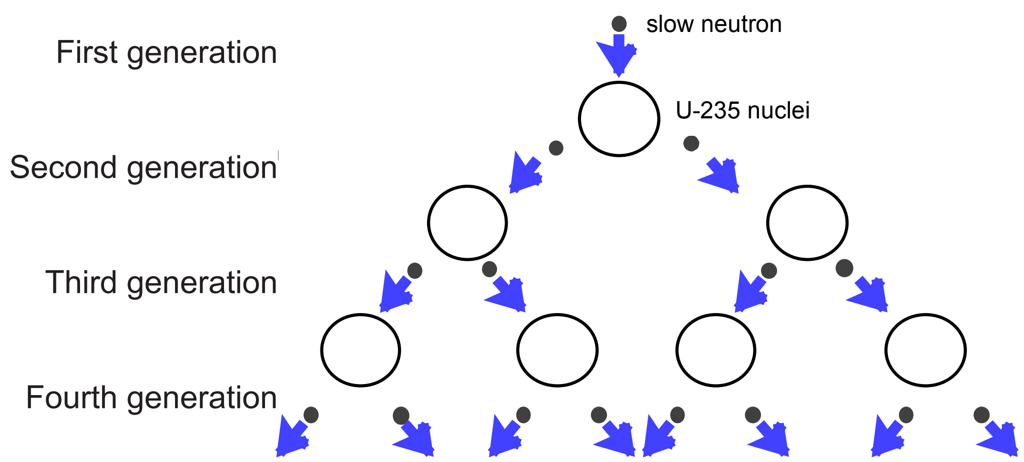
In the nuclear reaction, a small amount of mass has been lost and changed into a large amount of energy. Nuclear power stations use this energy to produce electricity.

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:

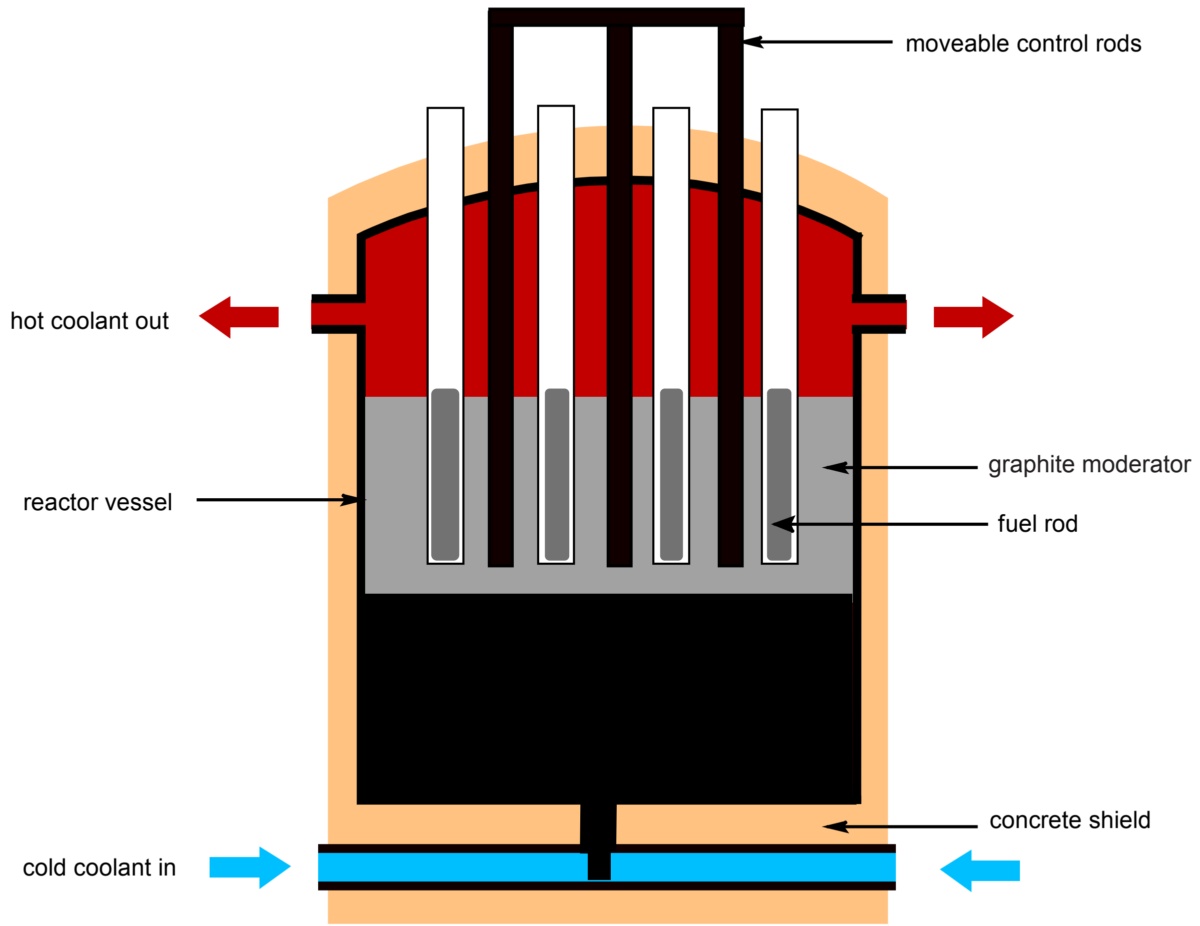
- control the speed of the neutrons (only **slow** neutrons will split nuclei)
- control the number of neutrons available to split nuclei

Unit 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

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.

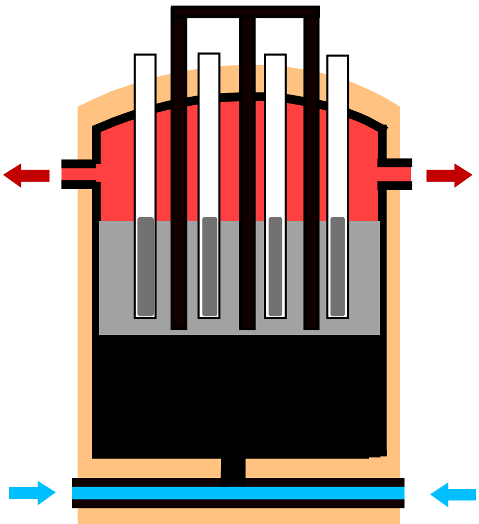
Unit 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

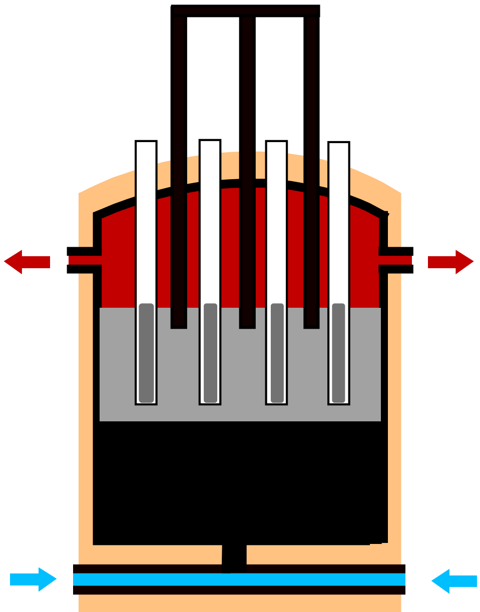
Control rods and the chain reaction

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.

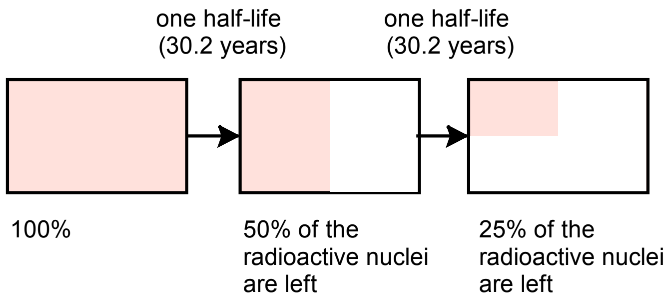
There is a large variation in the lifetime of different radioactive isotopes in nuclear waste.

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.

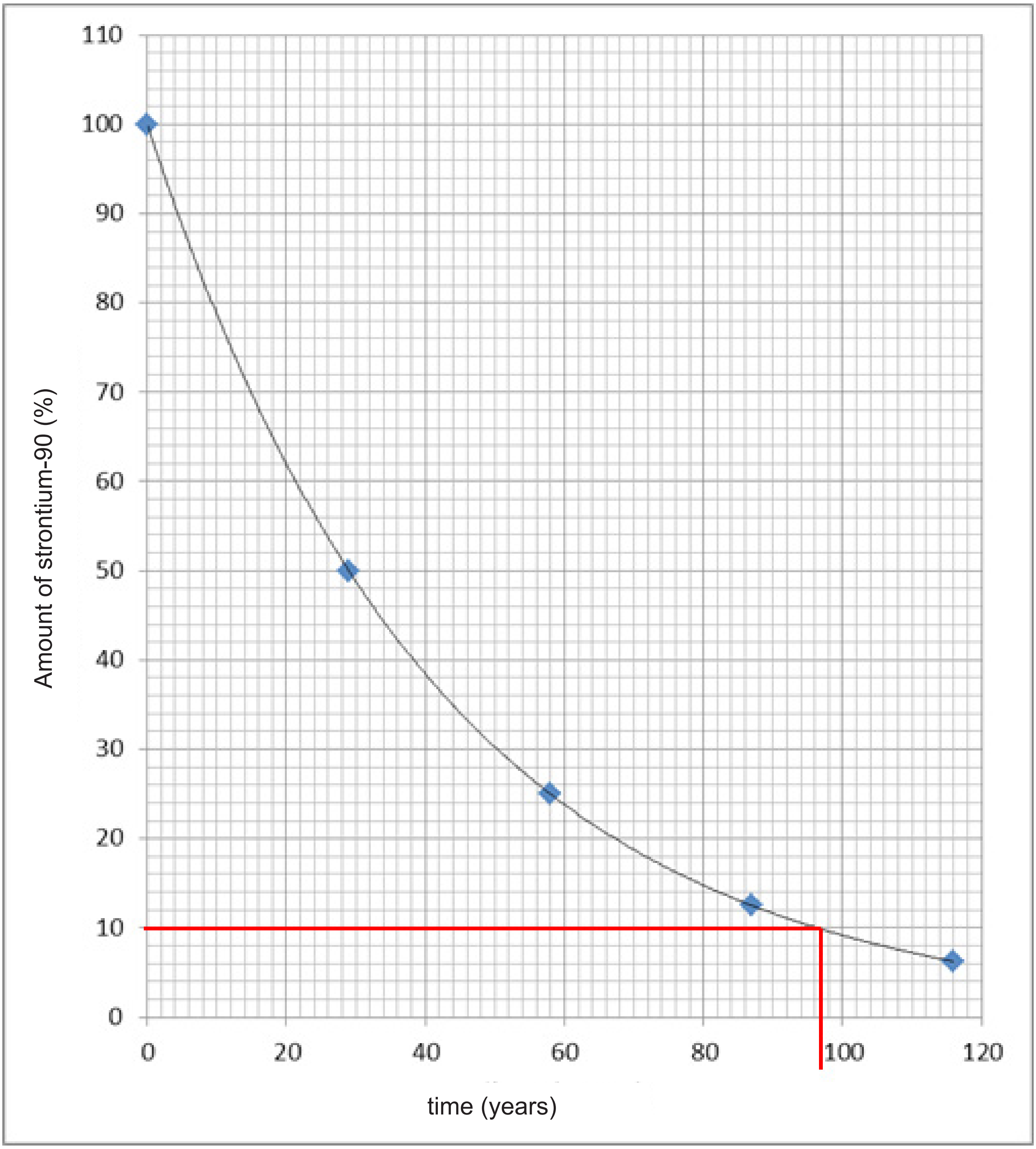
Examples of half-life problems

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 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

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

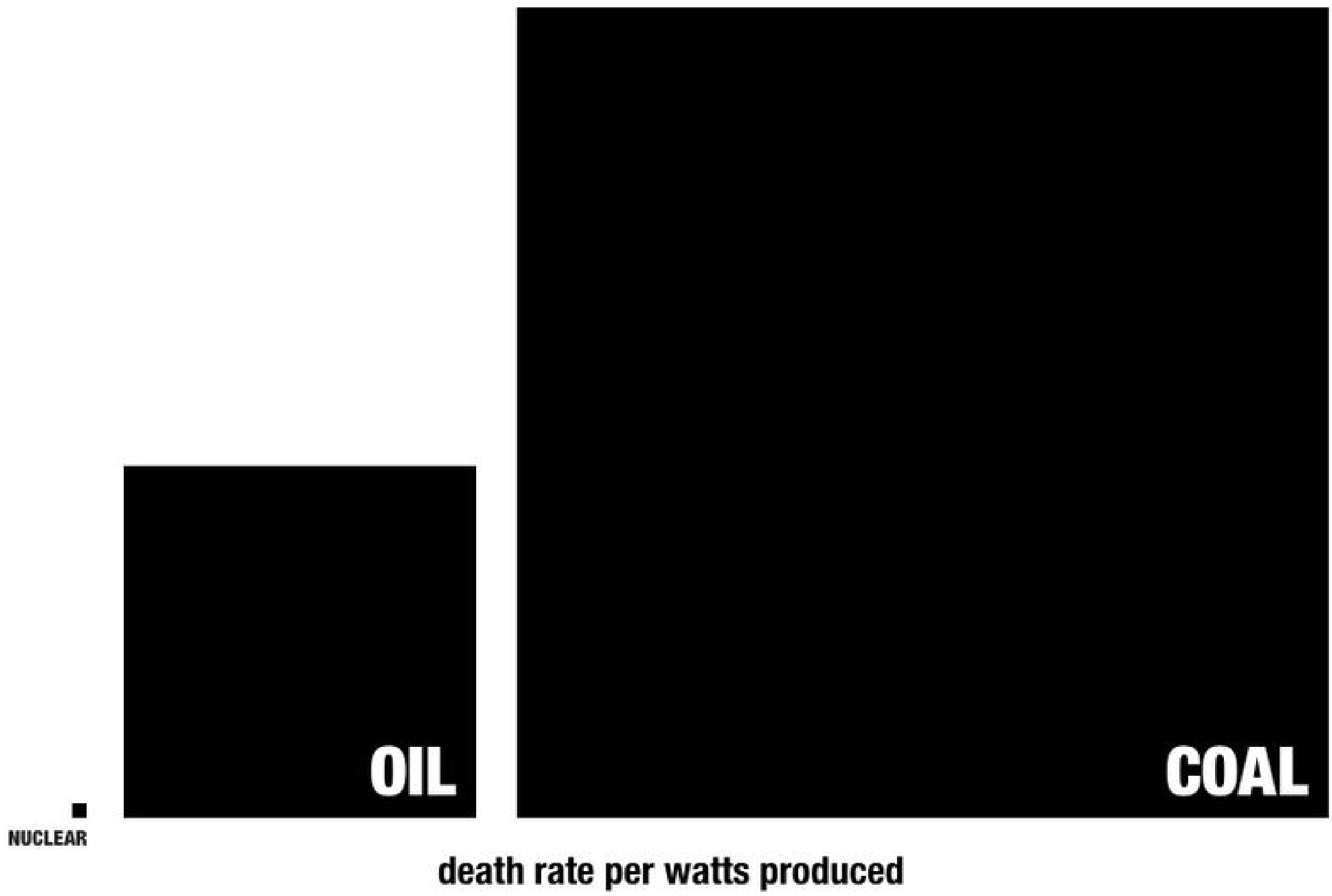
Watch a short clip on the Chernobyl disaster
http://www.bbc.co.uk/news/magazine-36129318

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 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

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%

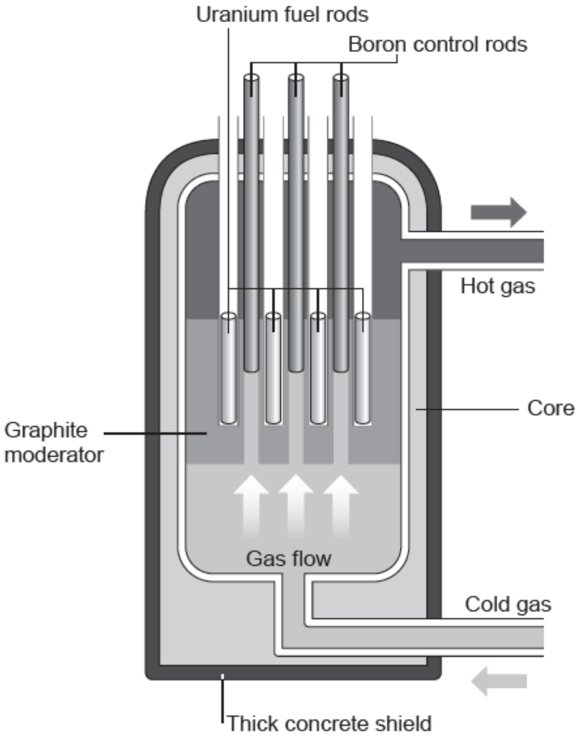
3. In the Chernobyl accident iodine-131 (half-life = 8 days), caesium-134 (half-life = 2 years) and caesium-137 (half-life = 30.2 years) were released into the atmosphere. Which of these poses the longest term threat to the environment?

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]

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

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

Unit 2.2: Controlling processes

Controlling nuclear reactions (specification 2.2.2)

TEST YOURSELF - ANSWERS FOR UNIT 2.2

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

Factors affecting human health

1.		(i)	They have the highest energy content.	1
		(ii)	Diabetes (1) Cardiovascular disease (1)	2
		(iii)	37 000 kJ	1
		(iv)	kcal equivalent = 37 000 x 0.24 = 8 880 kcal/month (1) = 296 kcal/day (1)	2
2.	(a)		More affluent (money), able to buy a balanced/ healthy diet.	1
	(b)	(i)	3 410 Correct workings but wrong answer	2

		(ii)		All obese people are registered by the GP/have a GP	
		(iii)		Survey the populations (in the different regions)	

Health, fitness and sport

1.	(a)	(i)		Prevent radiation passing through healthy organs	1
		(ii)		Different directions so does not always pass through the same healthy tissue / Short time so dose to healthy tissues is limited	
		(iii)		Provides a steady & continuous source of radiation to the tumour (1) Less risk of damaging healthy surrounding tissue (1)	2
	(b)	(i)		Time difference is same or 60 days (1) So halves again to 50 units (1)	2

Microorganisms and the body's defences

1.	(a)	(i)	I	2 500 – 1 125 (1) = 1 375(1)	2
			II	Improved hygiene/improved living conditions/im-proved water quality	1
		(ii)		Number of cases increases **and** While death rate falls	1
		(iii)		Incidence fell and remained low 1960 onwards	1
	(b)			Overuse / over-prescription /poor hygiene / cross-contamination among patients	1

Health, fitness and sport (Unit 2.1)

Exercise and fitness in humans (specification 2.1.4)

PRACTICE QUESTIONS - ANSWERS FOR UNIT 2

Exercise and fitness in humans

1.

Indicative content
Record Dan's (breathing) rate at rest
then exercise (bike or other)
exercise specified (distance/speed/load)
for a certain time
record rate after exercise
rate must return to rest
repeat with Alex – must ref to same exercise regime
compare results to see which breathing rate returned to normal the fastest.

5 – 6 marks: Detailed description of the entire investigation to include specified exercise regime and ref. to same exercise again with Alex and take rate till return to resting level.
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: Outline general description of the investigation
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: Ref only to counting breathing rate and then exercise by Dan and repeat with Alex + comparison
There is a basic line of reasoning which is not coherent, largely irrelevant, supported by limited evidence and with very little structure. The candidate uses limited scientific terminology and inaccuracies in spelling, punctuation and grammar.

0 marks: *No attempt made or no response worthy of credit. (6 QER)*

2.	(a)	(i)	272 ± 2(s)	1
		(ii)	E	1

(b)	(i)	Points all correct (2). 4 or 5 correct (1) Line (1).	3
	(ii)	900 / 180 (1)= 5.0 (m/s)(1)	2
(c)		Kevin is fitter than Gareth (1) because he has a lower time (1) **or** Kevin has trained more than Gareth (1) since he is able to complete the race in a shorter time. (1) Two marks can only be awarded for coherently and correctly linking points.	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 (2)
   Which may damage human health/cause cancer

   (c) DNA is unique to the individual (3)
   92
   U-235
   U-230

   (d) 234 (2)
   $^{234}_{92}U$