The Free Science Revision Guide

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Automated Teaching Machines

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The Free Science Revision Guide

About This Book

This book was written to support the intermediate science section of the Automated Teaching Machines website. The topics are aimed at 14 - 16 year old high school or college students, but may be of interest to readers of any age. This work has been written to be freely available over the Internet, so it is a general purpose document which can be used in any country and with any exam board that covers these subjects.

The content is written to be accessible to young people, to be concise and to avoid repetition. The information given is intended to create an outline of the key facts and ideas for each topic, to establish a foundation that can be built upon by the student where time permits.

In 2007 I created a piece of AI software written using the NASA CLIPS expert system tool called Robbie. It/ he assisted me in preparing for university computing science exams. Later, in 2014 I created a software robot called Akilah (meaning - intelligent one who reasons), that was used to help high school students to learn science on the Total Brain Box website. This software is now being used on the the Automated Teaching Machines website to help students to recall the science in this free revision guide.

Automated Teaching Machines Website

The Automated Teaching Machines website [1] provides the following free services:

- Free downloads of The Free Science Revision Guide
- A free online version of The Free Science Revision Guide

And the following services to subscribers::

- **Audio Book**
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Annual subscriptions cost about the same as a book (£12.50, €14.50 or $19.50 at the time of publishing).

This free revision guide was written by Robin Broad, the technical and creative director of Automated Teaching Machines and an experienced and qualified teacher. As a first class computer scientist, he knows how to make things work and solve problems. Robin achieved a distinction in his masters degree in computing science (MSc), which he studied at Newcastle University, in England from 2007 to 2008.

He worked as a full-time physics teacher from 1990 to 2007 at high schools in Gateshead, Newcastle and Northumberland, before going to study for a masters in computing science in 2007. Since graduating, he has continued to work as a part-time, self employed web programmer and as a supply teacher teaching physics, mathematics, science and computing science to high school and college students in the Newcastle upon Tyne area of the UK.

The decision to publish this book as a free revision guide under the GNU General Public License was inspired by the example of the American computer scientist Richard Stallman**.** He started the **GNU Project** in 1983, which had the goal of creating a "complete Unix-compatible software system" composed entirely of free software. Work began in 1984. Later, in 1985, Stallman started the Free Software Foundation and wrote the GNU General Public License (GNU GPL) in 1989 [2].

The GNU Free Documentation License (GFDL) is used for tutorials, reference manuals and other large works of documentation. It's a strong copyleft license for educational works, initially written for software manuals, and includes terms which specifically address common issues that arise when those works are distributed or modified.

This book was written using LibreOffice, an open source word processor, running on a GNU/ Linux computer, an open source operating system. GNU/Linux and its applications are a prominent example of **free** (to share, study and modify) **software**. This keeps us **free from licenses, patents** and **agreements, reduces costs** and **improves** the **reliability** of our systems. Free software has become the foundation of a learning society where we share our knowledge in a way that others can build upon and enjoy [3]

Free in this context means free to share, study and modify. The Automated Teaching Machines website [1] provides free downloads of The Free Science Revision Guide, but printed versions may incur a charge to cover the printing costs. If you value this book, then please make a donation at the Automated Teaching Machines website.

Richard Stallman - American computer scientist, founder and president of the Free Software Foundation and author of the GNU General Public License (GNU GPL). Photo courtesy of Free Software Foundation, Inc.

Robin Broad B.Sc., M.Sc. - British computer scientist and teacher. Founder and Technical and Creative Director of Starbird Digital web services, Automated Teaching Machines and the author of this book.

[1] http://www.automated-teaching-machines.com

[2] http://en.wikipedia.org/wiki/Linux

[3] http://www.fsf.org/about/what-is-free-software

Acknowledgements

I would like to thank the following people for their support during the writing of this book and development of the Automated Teaching Machines website:

My friends and family for their encouragement and support during the development of the content and software. Joe Giarratano and Gary Riley, for their book on Expert Systems that got me started. Chris Young, who first showed me server-side scripting at Newcastle University. The Newcastle University careers service business start-up advisers, who helped me to start a business and were always there to support me throughout the successes and failures. Newcastle University for allowing me to continue to work in their library, where much of this project was developed.

Tom Turland, an inspirational physics teacher at Prudhoe Community High School, helped me to better understand physics and Clive Sinclair first made computing affordable to me in 1981. Fujitsu-Seimens, Sony and Apple have built the reliable computers that have enabled me to complete this work. Northumbria University Department of Physics & Electrical Engineering helped me to understand the physics, electronics and programming and the Department of Education and Lifelong Learning helped me to understand how to teach.

A first glimpse into the world of Artificial Intelligence came from watching H.A.L. 9000, the intelligent computer in Stanley Kubrick's 1968 film 2001: A Space Odyssey. The screenplay was written by Kubrick and

Arthur C. Clarke. The behaviour of the intelligent agent on the Automated Teaching Machines website is partly inspired by H.A.L.. The work of Allan Turing, who is widely considered to be the father of theoretical computer science and artificial intelligence, pre-dated and influenced all of this.

Richard Stallman started the GNU Project in 1983 which led to the GNU/Linux environment that was used to build the website and write this book. The PHP server-side scripting language, created by Rasmus Lerdorf in 1994, is used extensively throughout the website for all decision making.

This service would not exist if it were not for the pioneers of networking, the ARPANET, the Internet and the World Wide Web, namely Claude Shannon, Vannevar Bush, Paul Baran, Donald Davies, Joseph Licklider, Charles Herzfeld, Bob Taylor, Douglas Engelbart, Larry Roberts, Leonard Kleinrock, Louis Pouzin, John Klensin, Bob Kahn, Vint Cerf, Steve Crocker, Jon Postel, Jake Feinler, Peter Kirstein, Danny Cohen, Paul Mockapetris, Joyce Reynolds, David Clark, Dave Mills, Radia Perlman, Dennis Jennings, Steve Wolff, Van Jacobson, Ted Nelson, Tim Berners-Lee, Mark McCahill, Robert Cailliau, Marc Andreessen and Eric Bina.

This work is dedicated to Chris and Barbara.

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Section Four

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Section One

Biology

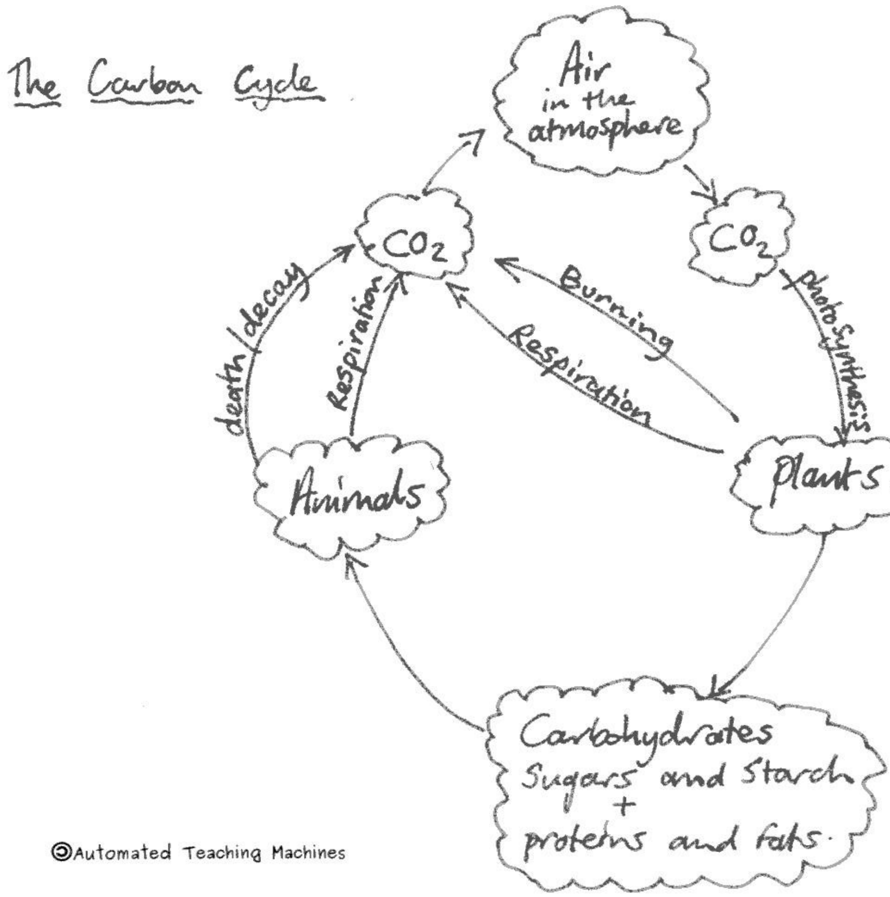
Carbon Cycle, The 1.01

The Carbon Cycle

The carbon cycle explains how carbon is recycled between the atmosphere, plants and animals. Plants absorb carbon dioxide from the air during photosynthesis to produce food (carbohydrates). The carbon compounds made by plants include carbohydrates (sugars and starch), proteins and fats.

Animals eat plants and pass the carbon compounds down the food chain. Animals breathe out carbon dioxide, back into the air. When plants and animals die, they decompose and carbon dioxide is again returned to the air.

Burning fossil fuels also returns carbon dioxide from plants back into the air.

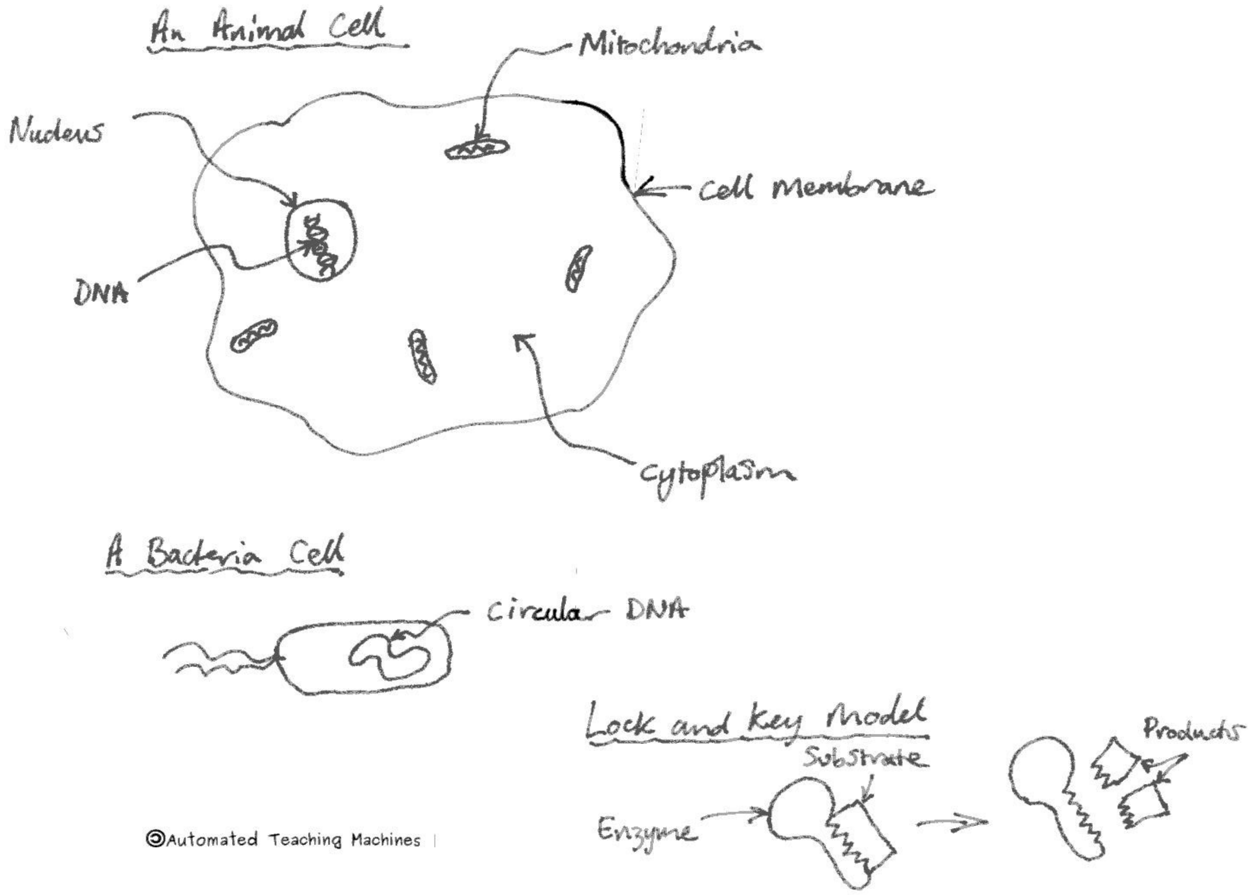


Cells and Enzymes 1.02

All animal cells have four main parts; the nucleus, cytoplasm, mitochondria and the cell membrane (cell wall). The nucleus contains DNA which carries the instructions for making proteins. Inside the cytoplasm proteins are made and some other reactions take place. Inside the mitochondria the reactions of aerobic respiration take place.

Bacteria cells are different because they don't have a nucleus. Instead of a nucleus they just have a circular molecule of DNA.

Enzymes are proteins that speed up the chemical reactions taking place inside cells. Enzymes are catalysts because they speed up reactions. The "lock and key" model is a theory that explains how an enzyme joins with the substrate at the active site.



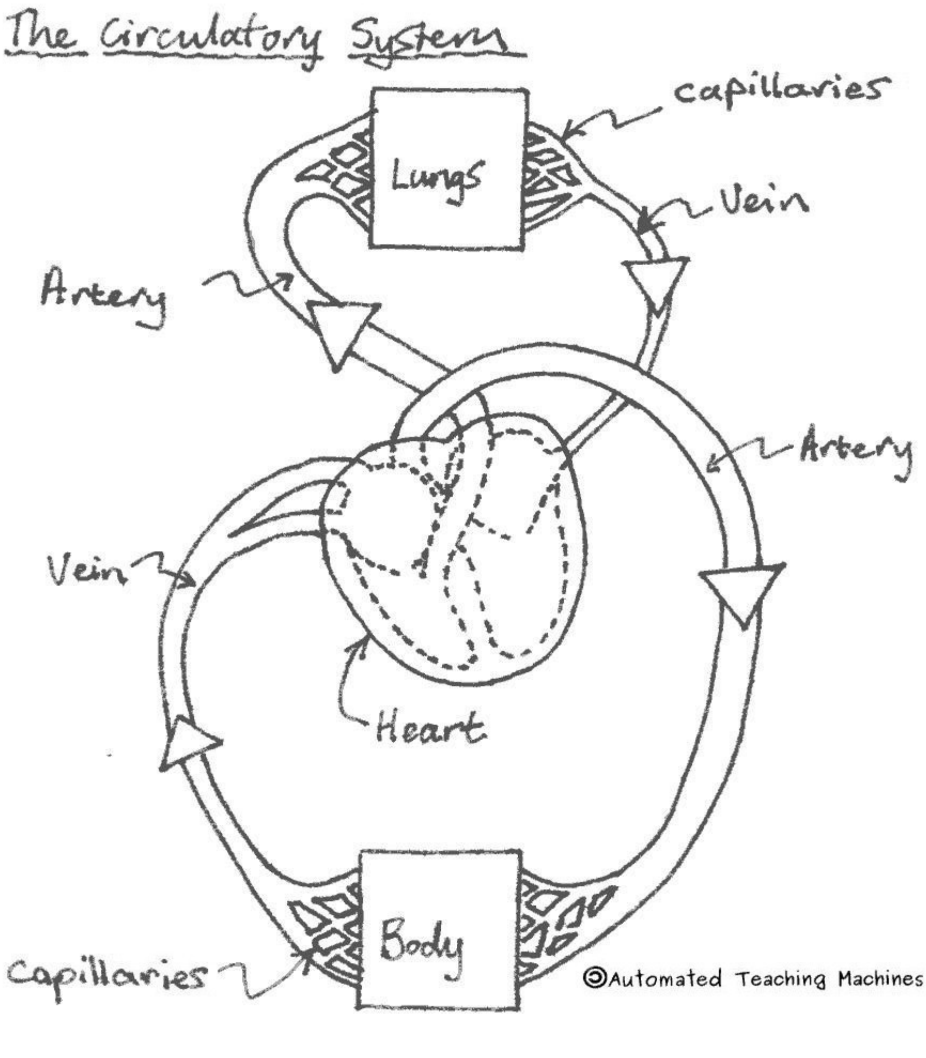
Circulatory System, The 1.03

The Circulatory System

The left side of the heart pumps blood around the body, the right side pumps it to the lungs. The three major types of blood vessel are arteries, veins and capillaries.

Arteries carry blood away from the heart, veins carry it back. Arteries are stronger, thicker and more flexible than veins because blood comes out of the heart at a high pressure. Veins have valves in them so that the blood can only flow one way.

The hole in the middle of a blood vessel is called the lumen. Veins have the largest lumen. The wall of capillaries are only one cell thick so that substances can pass through them.

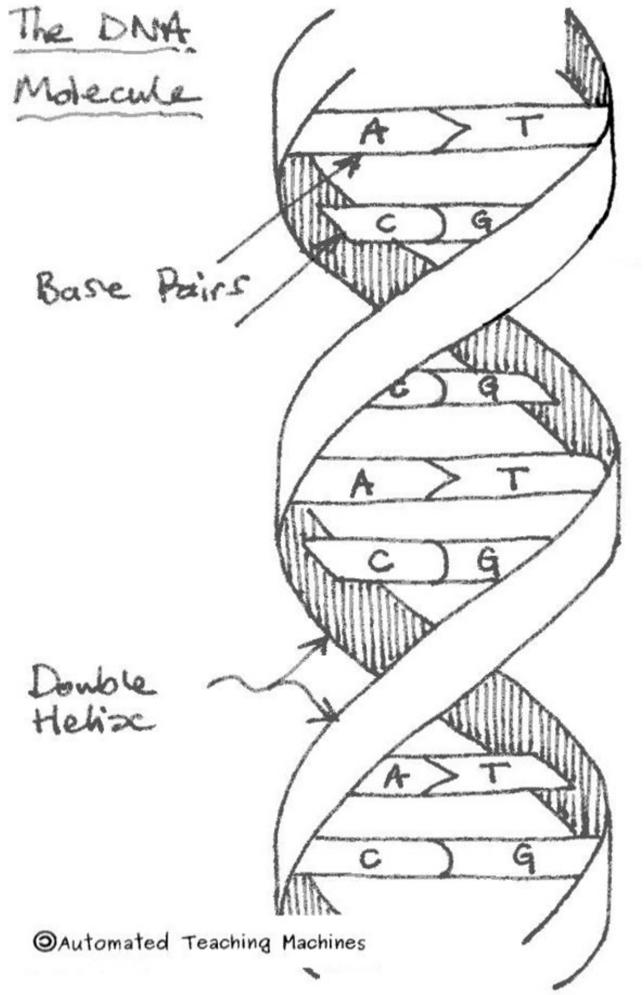


DNA 1.04

Sections of DNA are called genes. The genes carry coded instructions to make proteins. Proteins are made from long chains of amino acid molecules.

The DNA molecule is shaped like a twisted rope ladder, the shape is called a double helix. DNA is held together by two different pairs of bases. These are A-T and C-G.

Each group of three bases in the gene provides the code to make one amino acid. The gene has all of the base triplets needed to link up all of the different amino acids needed to make a protein. The proteins are made in the cell cytoplasm and some of these proteins are enzymes that control the cell.



Evolution 1.05

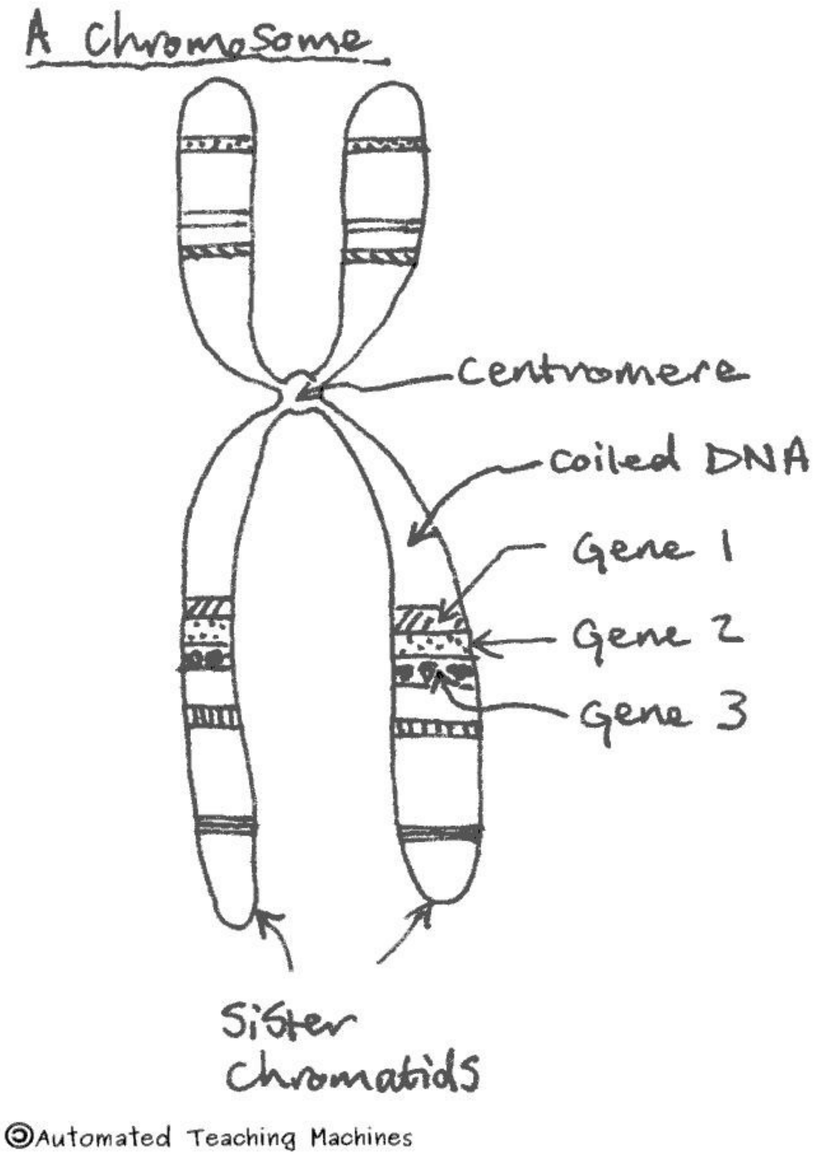
Charles Darwin developed the theory of evolution by natural selection, in which new features, caused by genetic mutation, are selected if they help the survival of a species by making them better adapted to their environment.

Lamark's theory of developed characteristics was rejected, whereas Darwin's theory is supported by the fossil record and DNA studies. Evolution shows that species are becoming more complex.

Genes 1.06

Long molecules of DNA are coiled up in chromosomes in the nucleus of cells. Short sections of these chromosomes are called genes and they make proteins which control your characteristics.

Different versions of the same gene are called alleles. Sperm and egg cells only carry one of each chromosome instead of the pair found in other body cells. This random selection of single chromosomes leads to the wide variation (differences) usually found in brothers and sisters from the same parents.

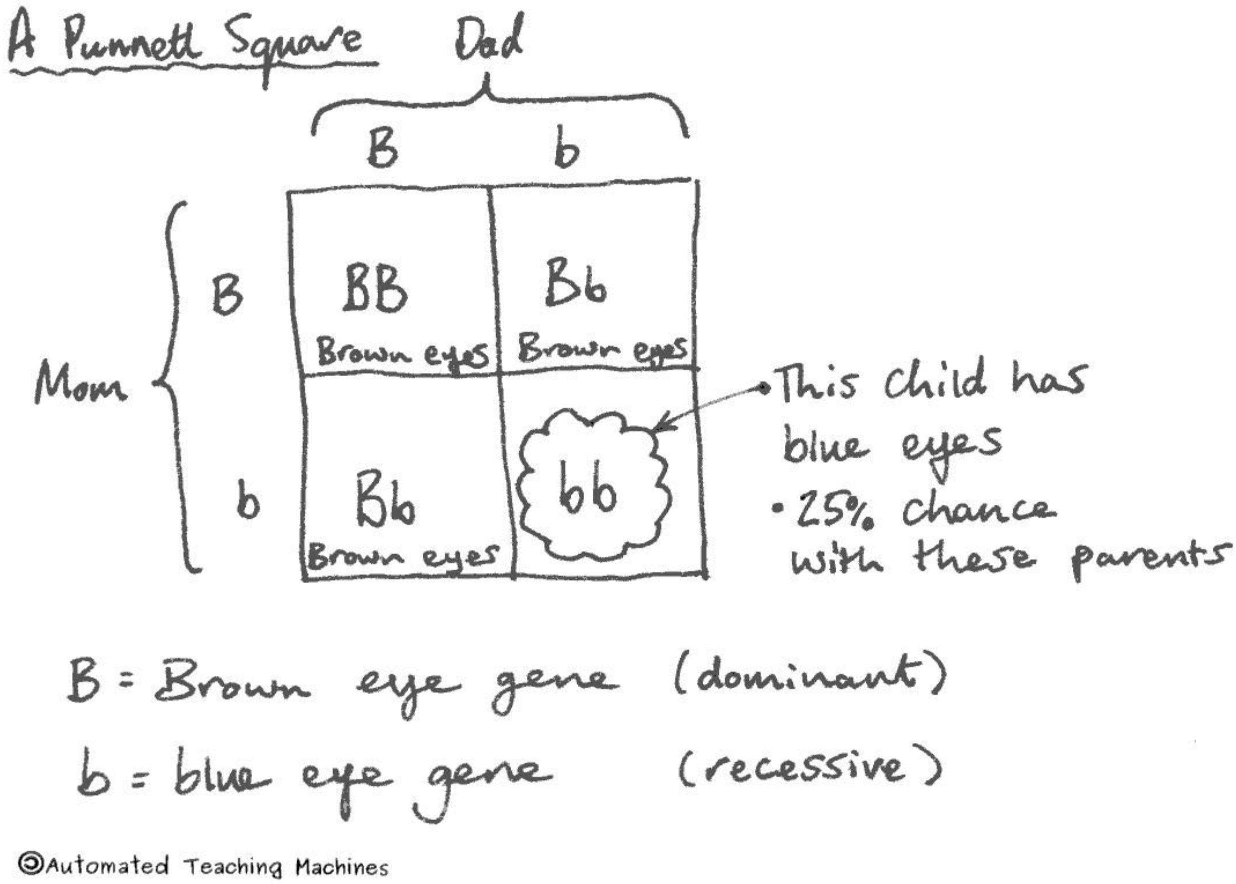


Genetic Diagrams   1.07

Punnett squares are genetic diagrams that are used to show the results of a genetic cross.

Genetic disorders caused by recessive alleles have a 25% chance of being transmitted if both parents are carriers, whereas genetic disorders caused by dominant alleles have a 50% chance of being transmitted if one parent is a sufferer and the other parent is normal.

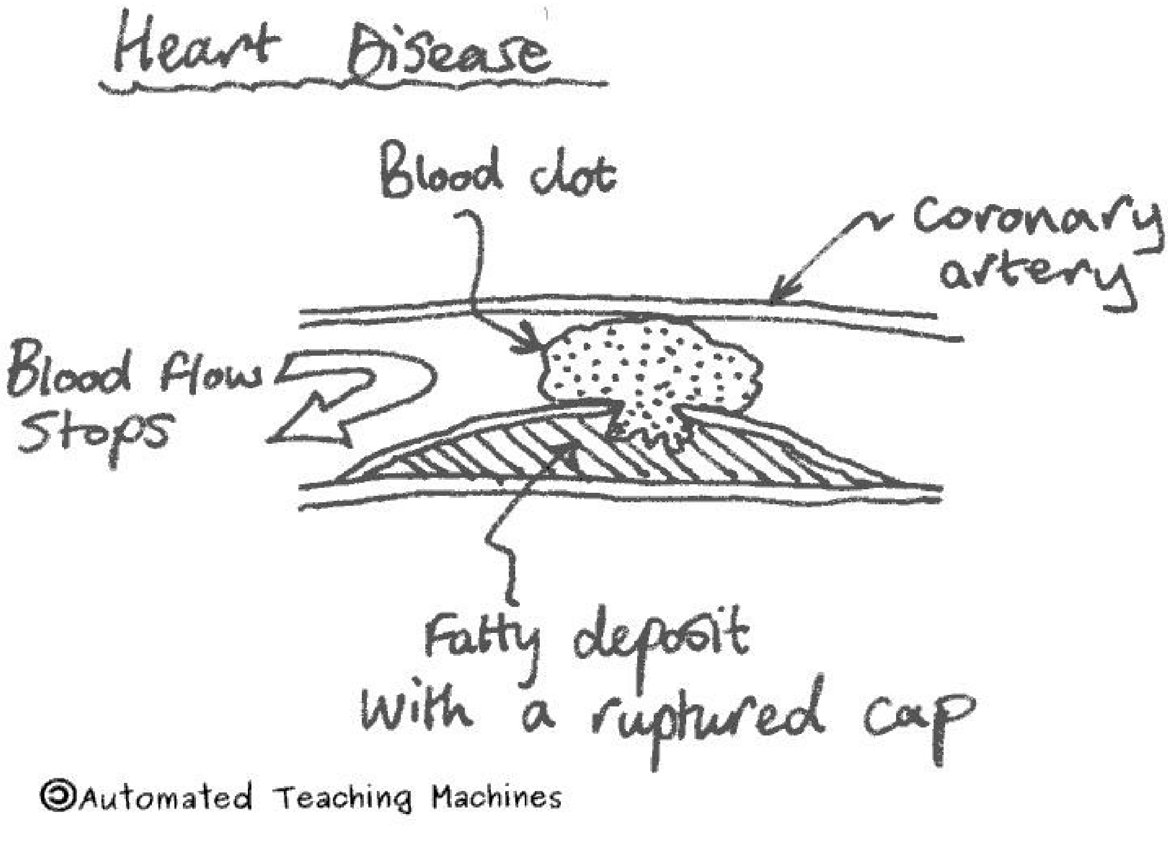
The sex chromosomes are the 23rd pair in humans with women having a pair of X chromosomes and men having both X and Y.



Heart Disease 1.08

The coronary artery supplies blood to the heart muscles to keep it beating. A blood clot can form on fatty deposits in the coronary artery and block it. If the coronary artery becomes blocked a heart attack will happen. During a heart attack, heart muscle cells can die because they don't get the oxygen and nutrients that they need.

High levels of saturated fat or salt in the diet can increase the risk of a heart attack. Smoking, drinking alcohol and using drugs can also increase the risk of a heart attack. Getting exercise and avoiding risk factors can reduce the risk of getting heart disease.

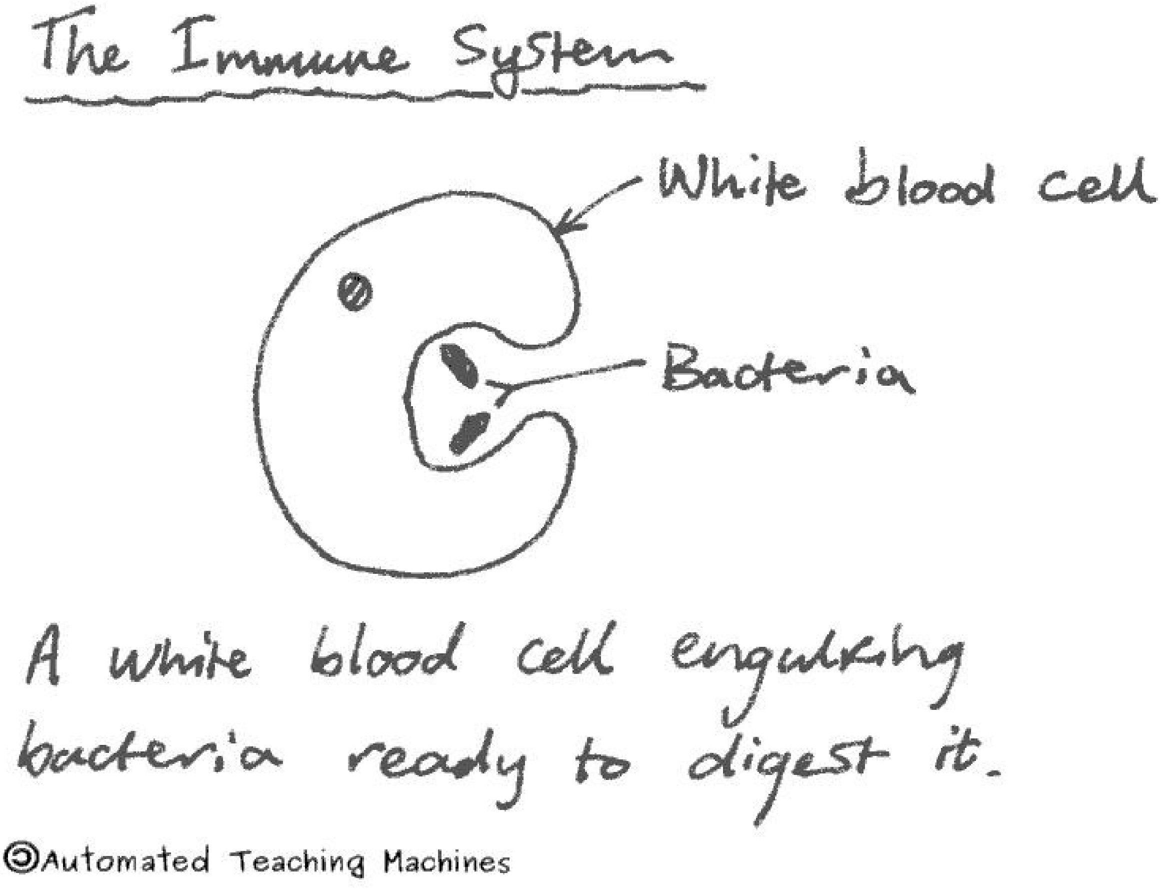


Immune System, The 1.09

The Immune System

White blood cells are part of the body's immune system to fight off unwanted microorganisms. They can either engulf and digest microrganisms to kill them or produce antibodies to kill them. The microorganisms can be recognised by the antigen molecules on their surface.

A person is immune to a disease when white "memory cells" produce antibodies to kill microorganisms that they have seen before.

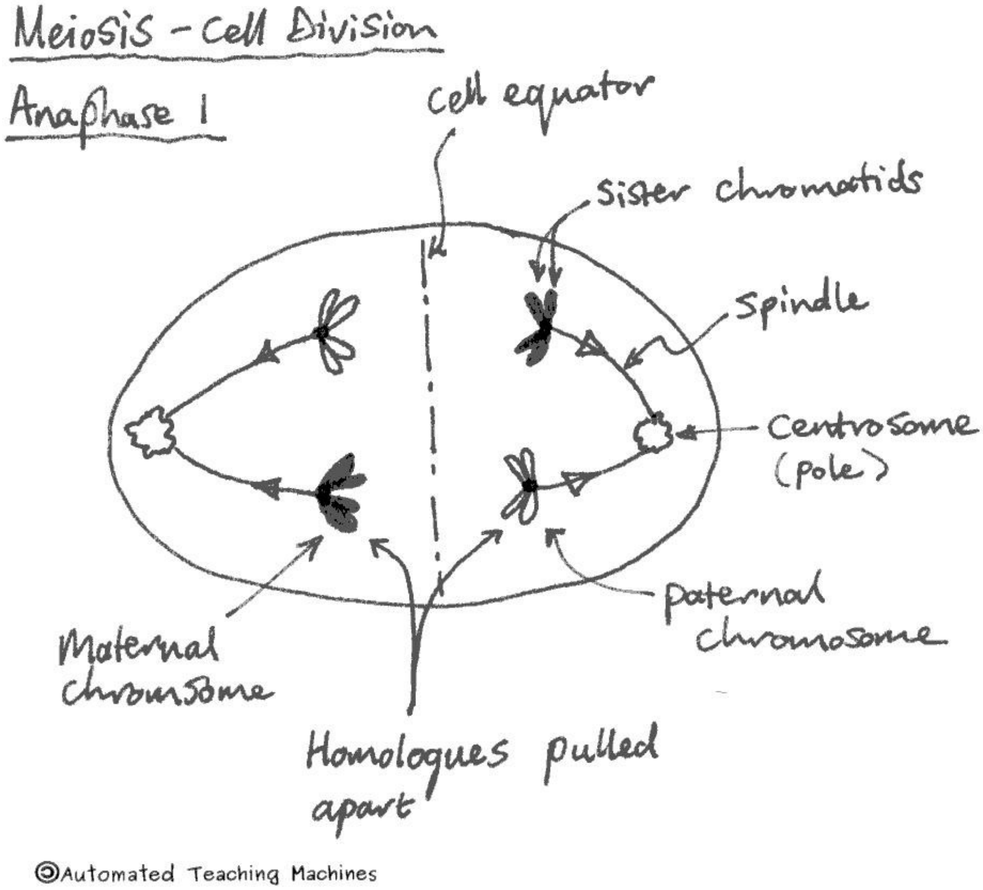


Meiosis, Cell Division 1.10

Meiosis is a type of cell division that creates four daughter sex cells that contain half the usual number of chromosomes. These cells will all contain a random mix of maternal and paternal chromosomes.

During prophase 1 chromosomes are copied and match up in homologous pairs. The pairs then trade genes in a process called "crossing over" to make new hybrid chromosomes. During metaphase 1, maternal and paternal chromosomes are placed randomly on each side of the cell equator. During anaphase 1 and telophase 1, spindles pull the homologues apart and the cell divides (each new cell contains a random mix of maternal and paternal chromosomes).

During PMAT 2 the cells divide again to create haploid cells with 23 single sets of chromosomes (not pairs) that can become sperm or egg cells.

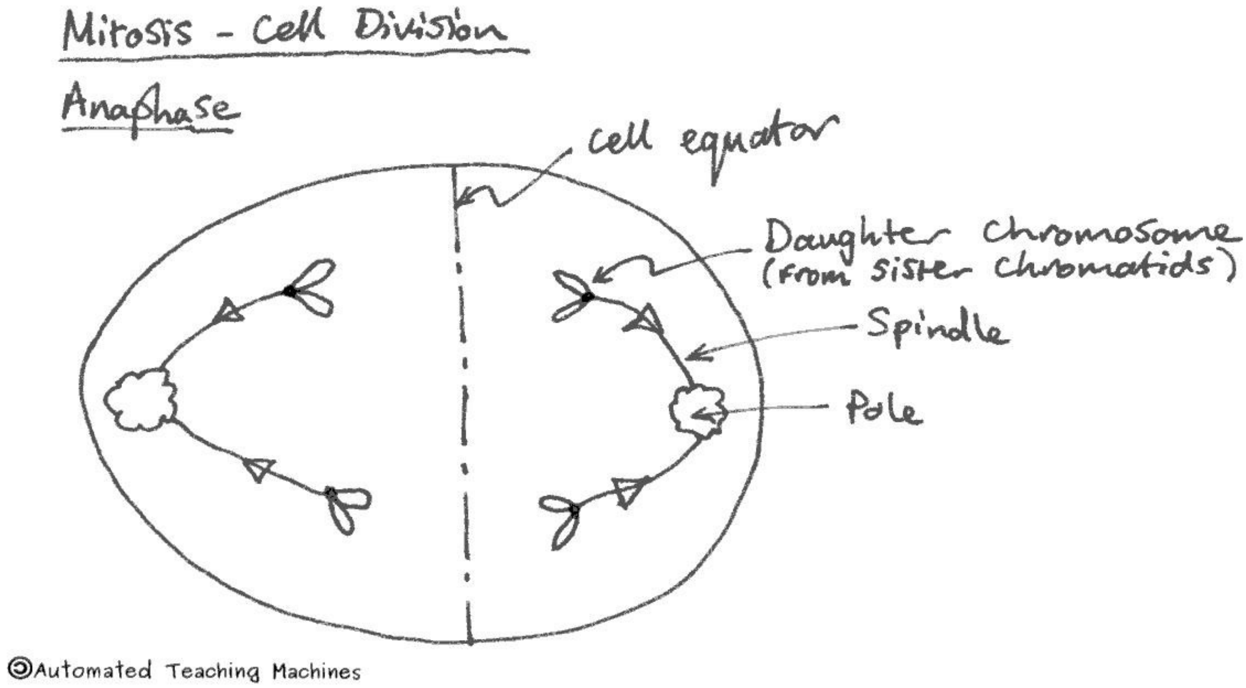


Mitosis, Cell Division 1.11

Mitosis is a type of cell division that produces two new identical cells.

During prophase the chromosomes are copied to make two copies of the cell's DNA. During metaphase the chromosomes line up along the equator of the cell. During anaphase the copied pairs of chromosomes are separated at the centromere by spindles into daughter chromosomes (from the sister chromatids), which are pulled towards opposite poles of the cell.

During telophase, two nuclei form and the cell divides.

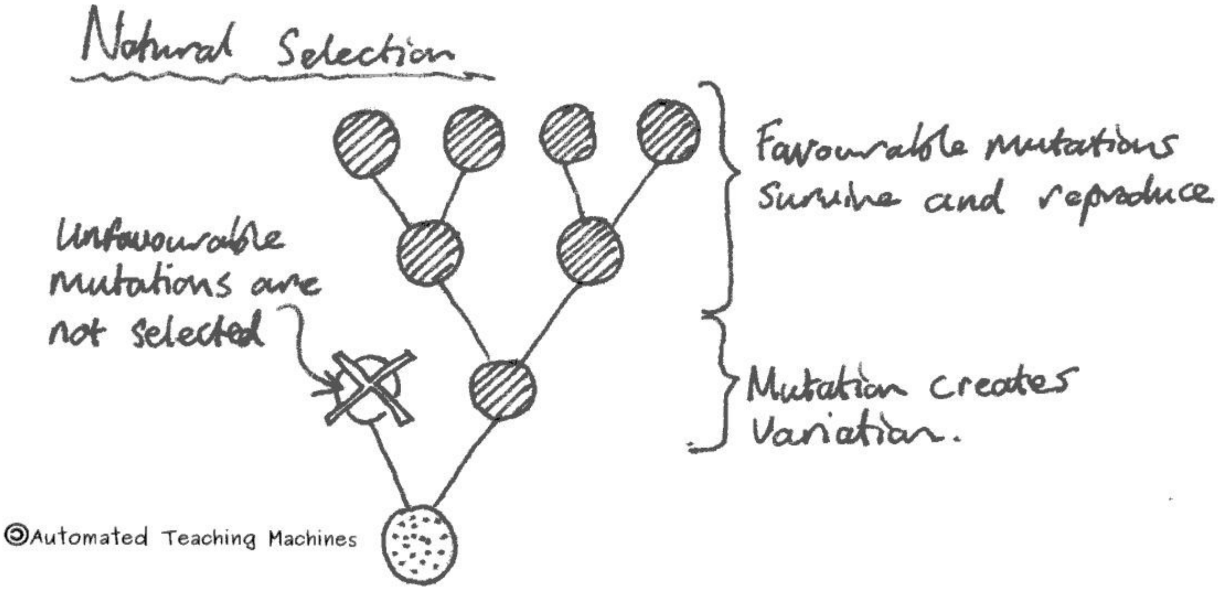


Natural Selection 1.12

Not all animals in a species are the same. We call these differences genetic variation.

Animals need to compete with each other for the resources (e.g. food, water, space) that they need to survive. Some features (for example long necks in giraffes) can help some animals to survive, which means that they are more likely to reproduce. This gives the next generation a better chance to survive. This process is called Natural Selection.

When Humans decide which plants or animals will reproduce, we call it Selective Breeding.



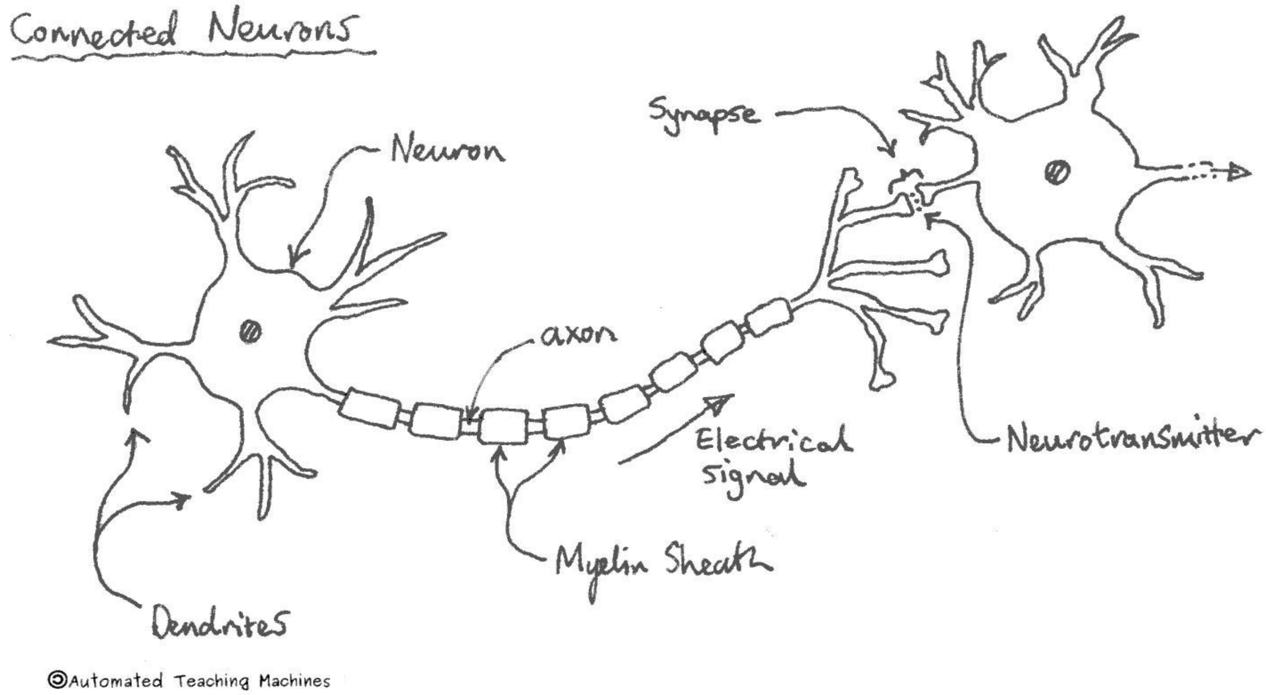
Nervous System, The 1.13

The Nervous System

The nervous system helps animals to survive by responding to stimuli. Receptor cells detect stimuli and the sensory neurons then carry messages to the central nervous system.

Neurons send fast electrical impulses to other cells along the axon, a long fibre. Axons are coated by an electrically insulating myelin sheath. Neurons pass messages to each other by releasing chemicals called neurotransmitters into the synapse. Poisons and drugs can interfere with this process.

The CNS consists of the brain and spinal cord in vertebrates and it makes decisions about how to respond to a stimulus. Motor neurons carry messages from the CNS to effectors e.g. muscles and glands. The sensory and motor neurons make up the peripheral nervous system.

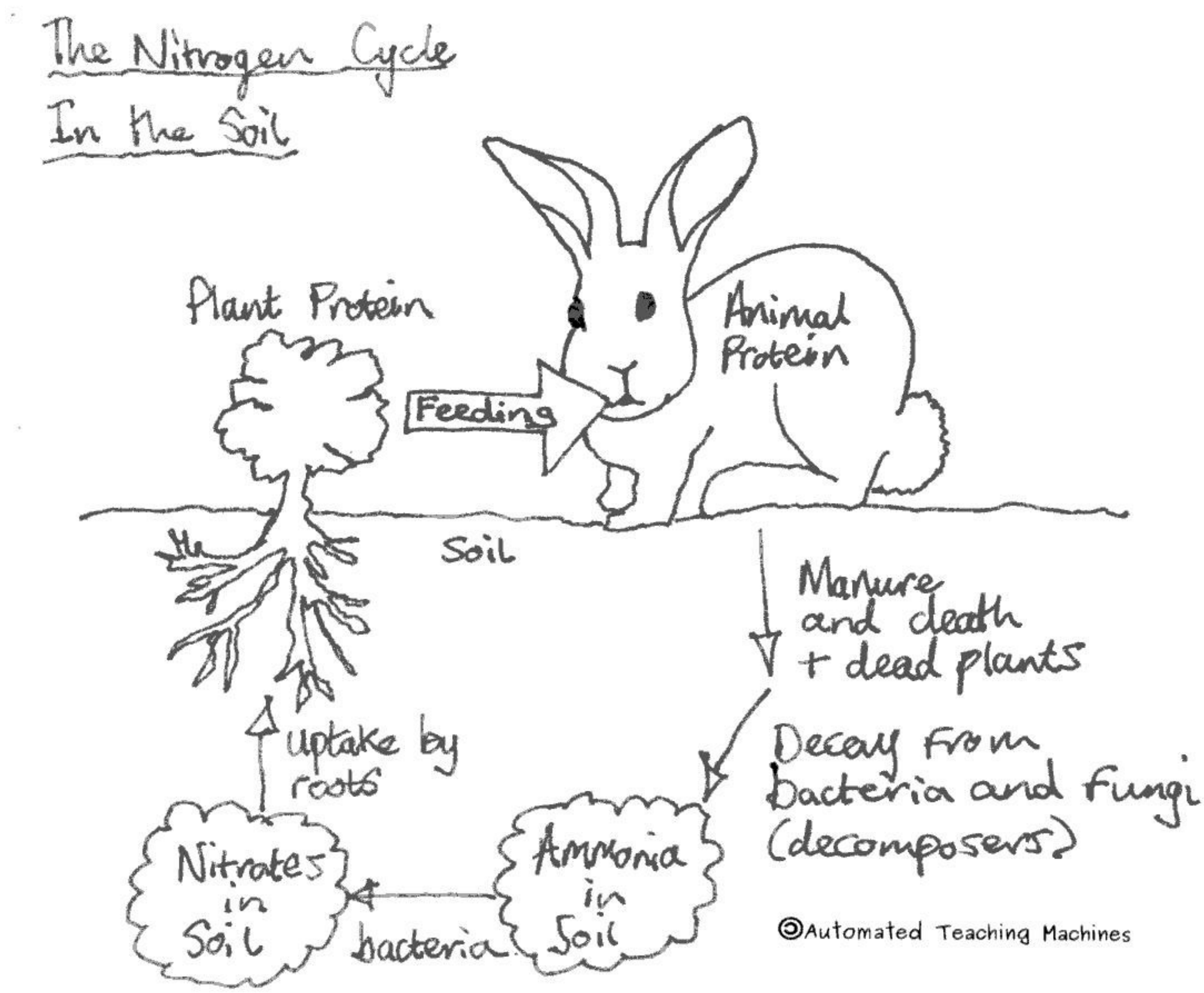


Nitrogen Cycle, The 1.14
The Nitrogen Cycle

The nitrogen cycle explains how nitrogen is recycled between the soil, plants and animals.

Plants use nitrogen in the form of nitrates to make the amino acids in proteins. Nitrates are absorbed from the soil by the roots of plants. Plants use nitrates to build up proteins which may then be eaten by animals.

Animal waste and dead plants and animals are broken down by decomposers which returns nitrogen to the soil as ammonia. Bacteria and fungi are decomposers.

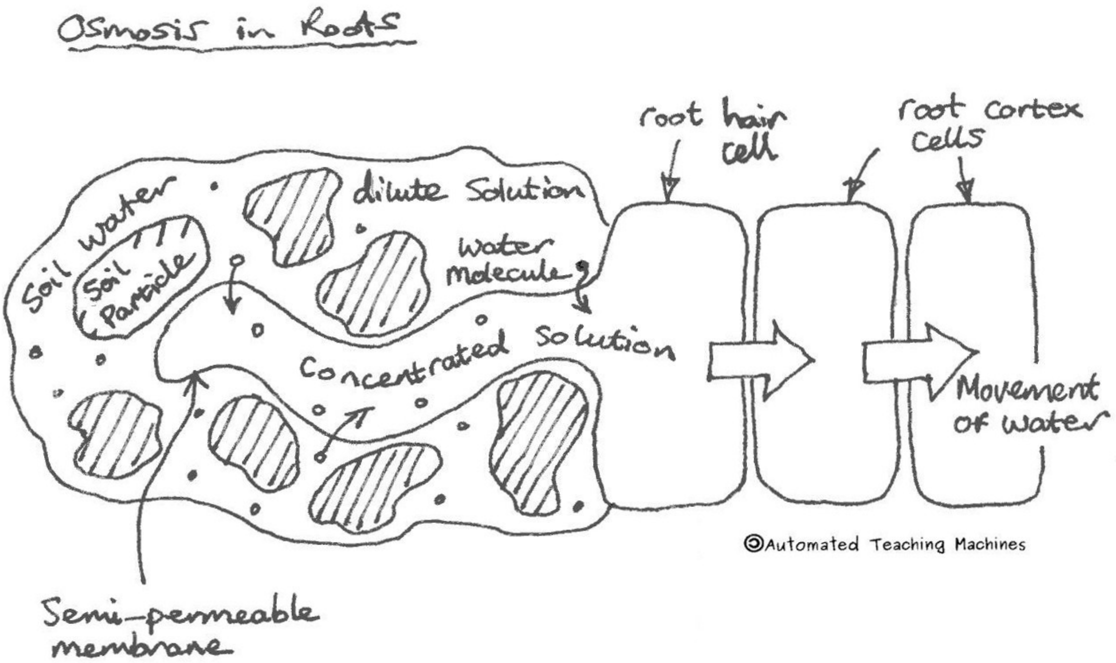


Osmosis and Diffusion 1.15

The process by which plants draw in water through their roots is called osmosis. During osmosis water passes through a semi-permeable membrane. The water molecules always move from areas of lower concentration into areas of higher concentration. This causes the more concentrated solution to become less concentrated.

Some molecules cannot pass through the semi-permeable membrane because they are too big.

During diffusion particles move from an area of high concentration into areas of low concentration. Diffusion is the process that causes carbon dioxide and oxygen to pass in and out of leaves.

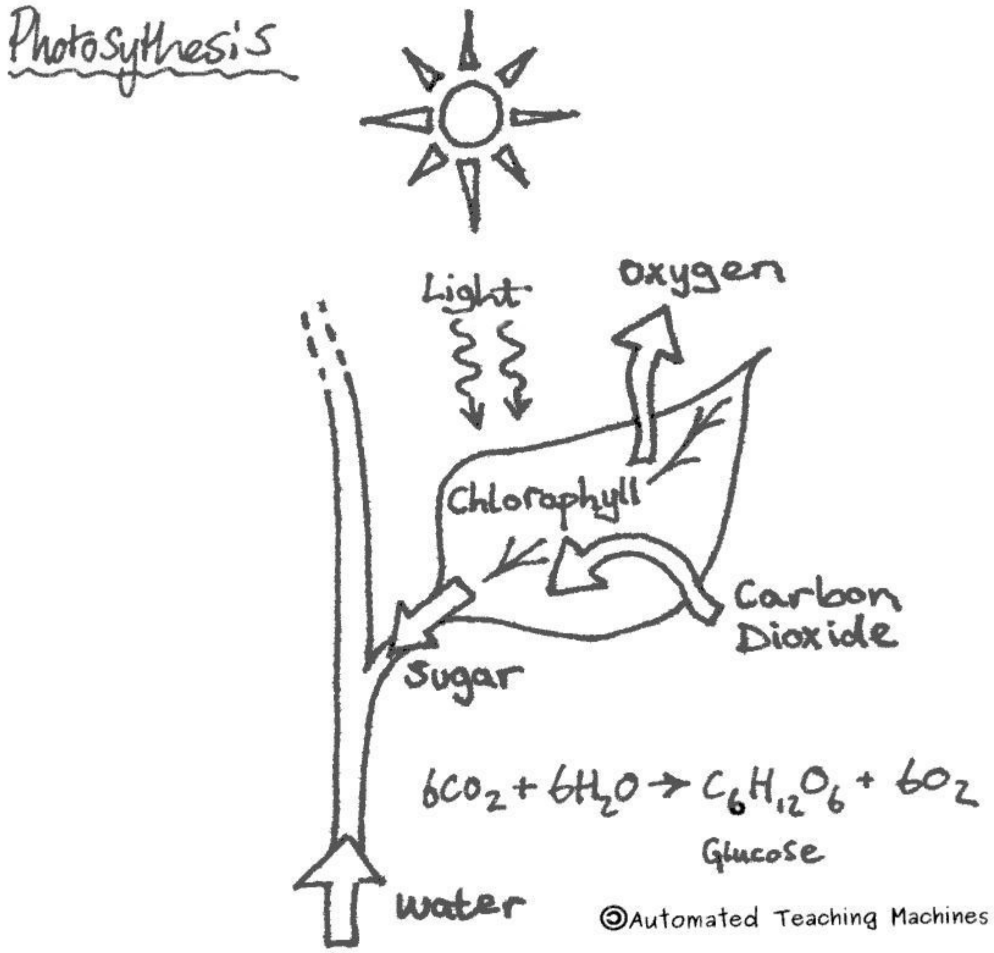


Photosynthesis 1.16

Photosynthesis takes place in the chloroplasts within the cells of leaves. The leaves contain a green substance called chlorophyll which is needed for photosynthesis.

During photosynthesis, light energy is used to convert carbon dioxide and water into glucose and oxygen. Plants use the glucose for respiration, growth or to store it as starch. Plants can also combine glucose with nitrogen to make two important substances; amino acids and proteins.

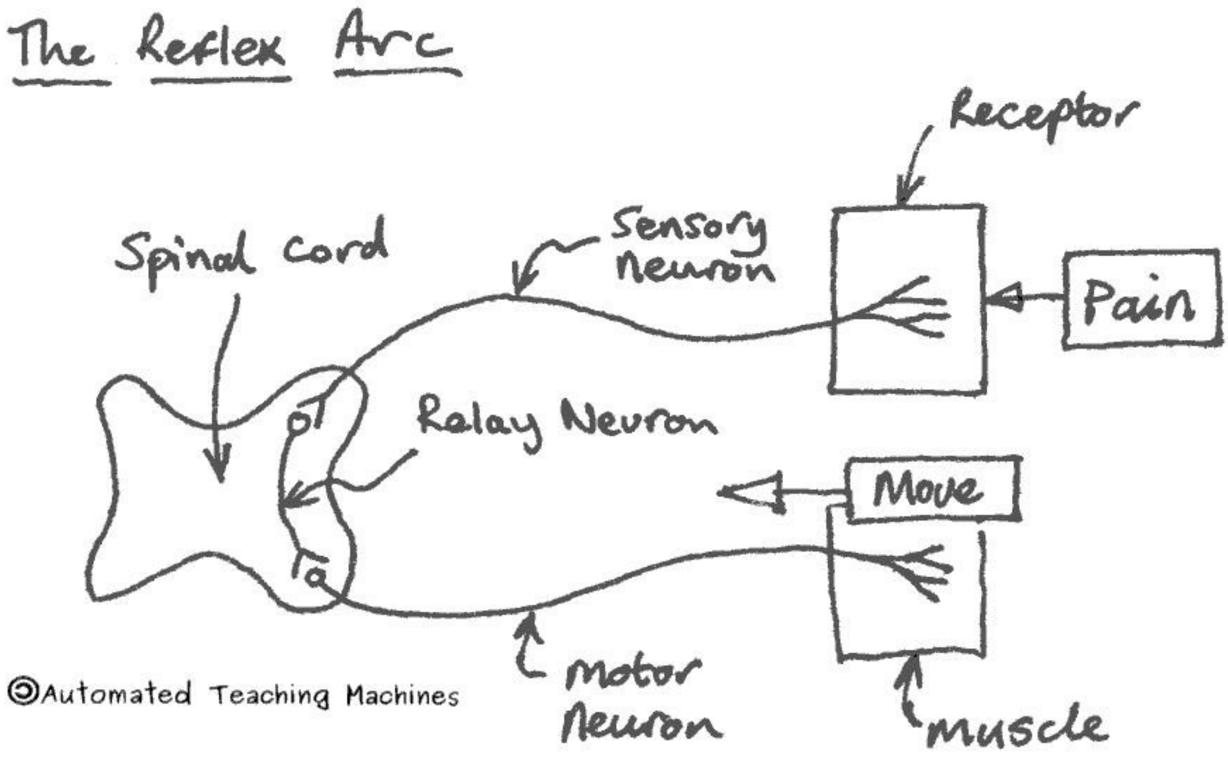
The rate of photosynthesis depends upon three things; the light level, the availability of carbon dioxide and the temperature.



Reflexes 1.17

Reflexes are a fast, automatic response to a stimulus that can protect us from harm. For example, a muscle could contract to pull your hand away from a flame. The message does not reach the brain, instead it passes through a relay neuron in the spinal cord, along a route known as a “reflex arc”.

A learned reflex is called a “conditioned reflex”. This was discovered by Pavlov when he found that he could make dogs drool by ringing a bell. This was because they had learned that the bell (a secondary stimulus) signalled food (a primary stimulus). Some predators develop a conditioned reflex not to eat brightly coloured insects because they are poisonous.



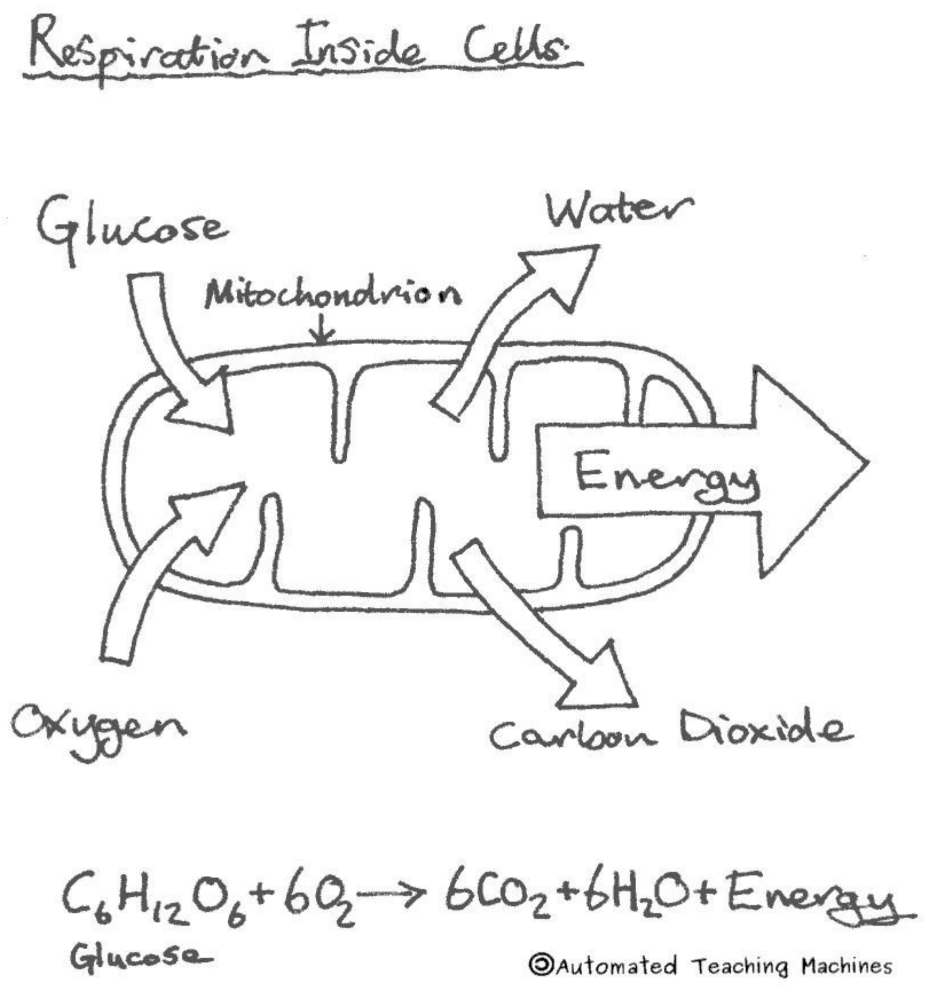
Respiration 1.18

There are two types of respiration; aerobic and anaerobic. Aerobic respiration uses oxygen but anaerobic doesn't.

In aerobic respiration glucose and oxygen are converted in the cells of the body into carbon dioxide, water and energy. That's why we breathe in oxygen and breathe out carbon dioxide. The glucose comes from the food that we eat.

During intense exercise anaerobic respiration takes place in the muscles creating lactic acid. This is what causes cramp.

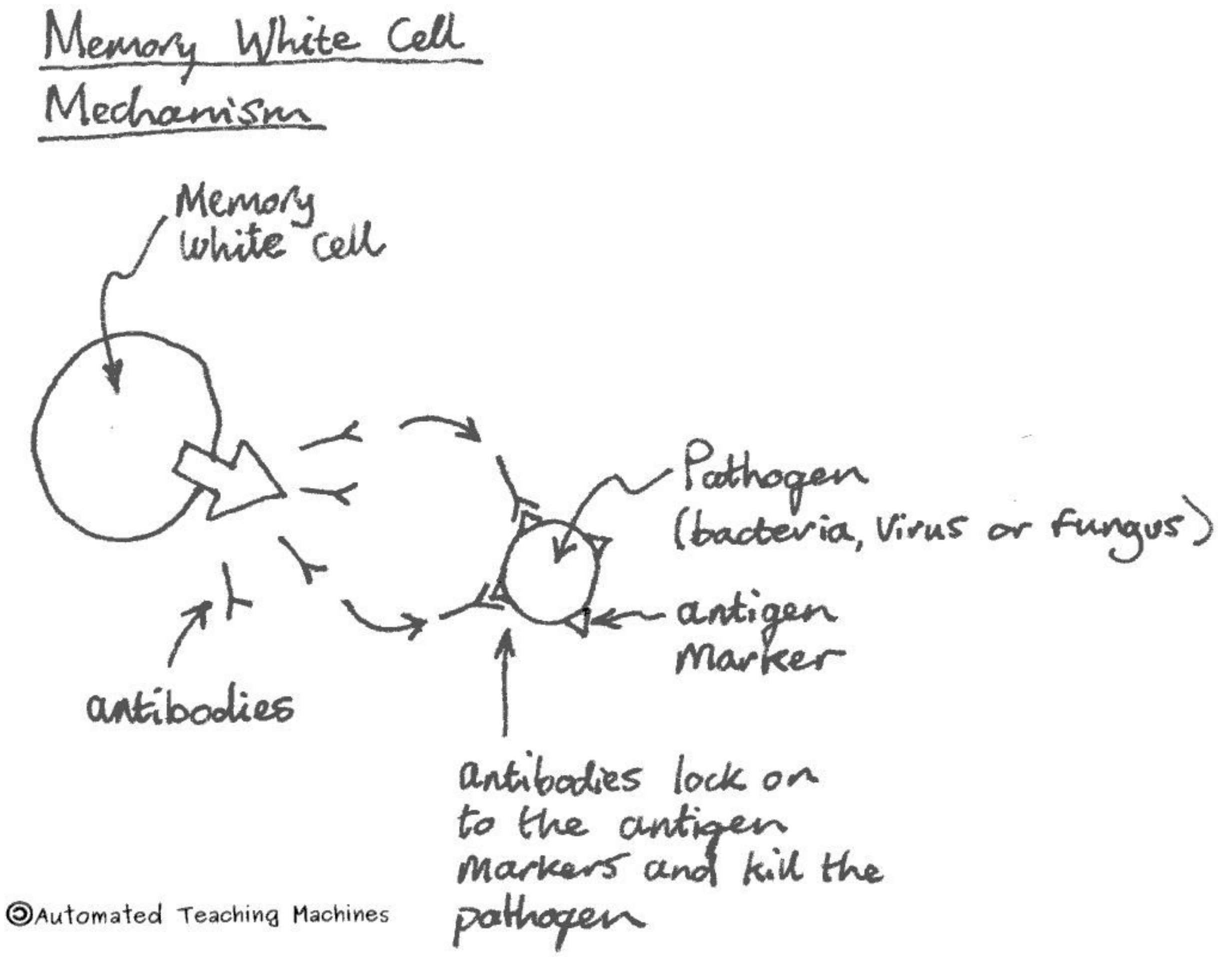
Bread, beer and wine are all made using yeast to produce fermentation. During fermentation glucose is converted into ethanol (alcohol), carbon dioxide and energy.



Vaccination and Antimicrobials 1.19

Dead or inactive microorganisms are used in vaccines to get memory white cells to quickly produce antibodies in response to a real infection. Occasionally vaccinations can produce unwanted side-effects.

Antimicrobials are drugs which kill microorganisms and antibiotics specifically kill bacteria. Bacteria can evolve into drug resistant strains which are then difficult to treat.



Section Two

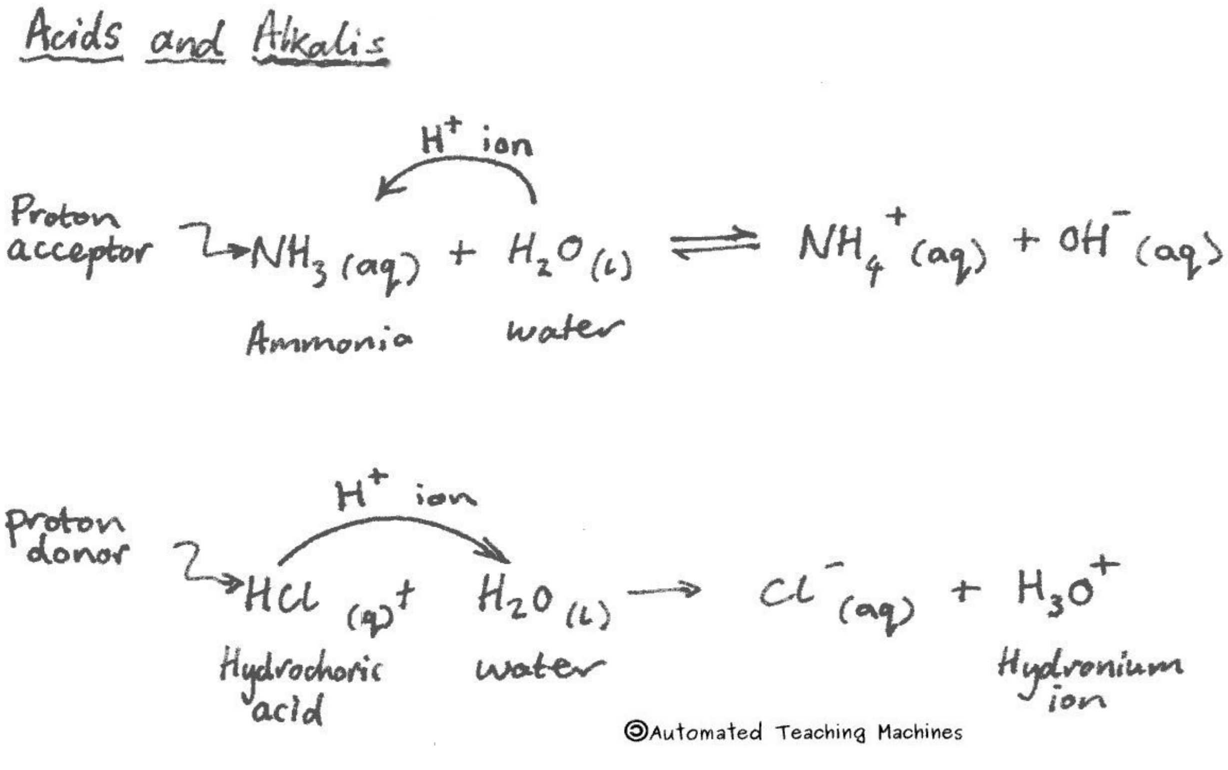
Chemistry

Acids and Alkalis 2.01

Acids have a pH less than 7 and will turn universal indicator red, orange or yellow, and litmus paper red. Acids are proton donors because they produce hydrogen ions (H+) in water.

Alkalis have a pH greater than 7 and will turn universal indicator blue or purple, and litmus blue. Alkalis are proton acceptors because they produce hydroxide ions (OH-) in water.

A neutralisation reaction takes place when acids and alkalis react to produce a salt and water. Neutral substances have a pH of 7. Bases neutralise acids and those that dissolve in water are called alkalis.



The Reactions of Acids

Acids will react with metals and their oxides, hydroxides or carbonates to make a salt. Most metals react with acid to produce a salt and hydrogen bubbles. Metal oxides and hydroxides react with acids to produce a salt and water. Metal carbonates react with acids to produce a salt, water and carbon dioxide bubbles.

Magnesium chloride, aluminium sulfate, calcium nitrate and sodium chloride are all examples of salts. The first part of the salt name comes from the metal and the second part, sulfate, chloride or nitrate comes from the acid.

Word Equations

acid + metal → salt + hydrogen
example:
hydrochloric acid + magnesium → magnesium chloride + hydrogen

acid + metal oxide → salt + water
example:
hydrochloric acid + copper oxide → copper chloride + water

acid + metal hydroxide → salt + water
example:
nitric acid + calcium hydroxide → calcium nitrate + water

acid + metal carbonate → salt + water + carbon dioxide
example:
hydrochloric acid + sodium carbonate → sodium chloride + carbon dioxide + water

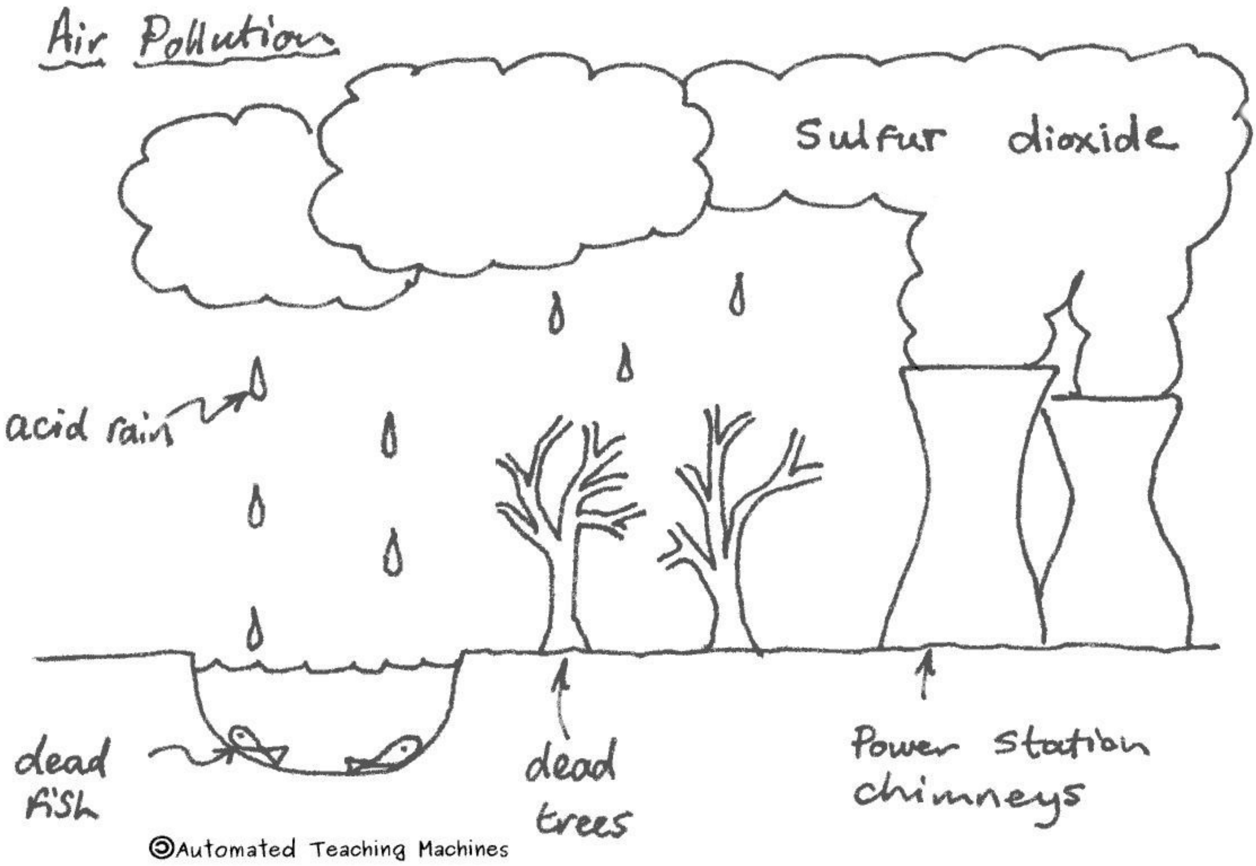
Air Pollution   2.03

Sometimes fuels burn without enough oxygen and this can produce the poisonous gas carbon monoxide (chemical formula: CO) which has only one oxygen atom.

Sulfur dioxide is produced when the impurities in some fuels burn and nitrogen oxides are produced when nitrogen in the air reacts with oxygen. Both of these gases can react with water in the clouds to produce acid rain.

Acid rain can damage stone, kill plants (e.g. trees) and animals (e.g. fish).

incomplete combustion:
hydrocarbon fuel + oxygen → carbon monoxide + carbon + water



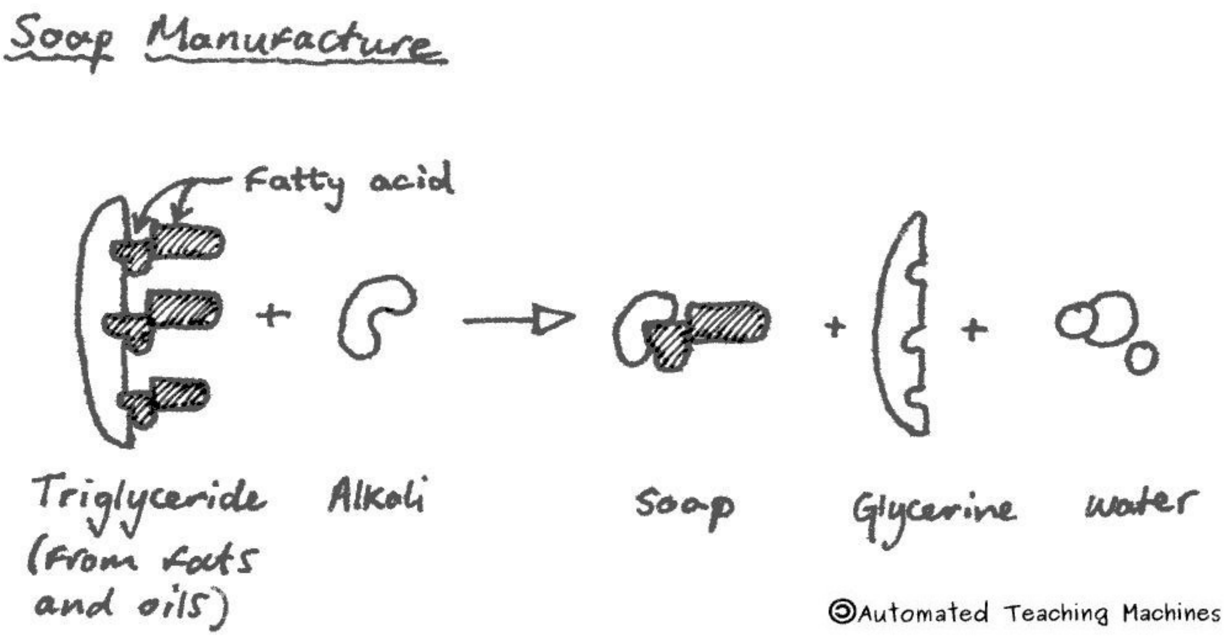
Alkalis 2.04

Alkalis produce solutions in the pH range 7-14. They can be used by farmers to neutralise acid soil or they can be used to convert fats and oils into soap.

Acids and alkalis react together to produce salt and water. For example, hydrochloric acid reacts with sodium hydroxide to produce sodium chloride and water.

hydrochloric acid + sodium hydroxide → sodium chloride + water

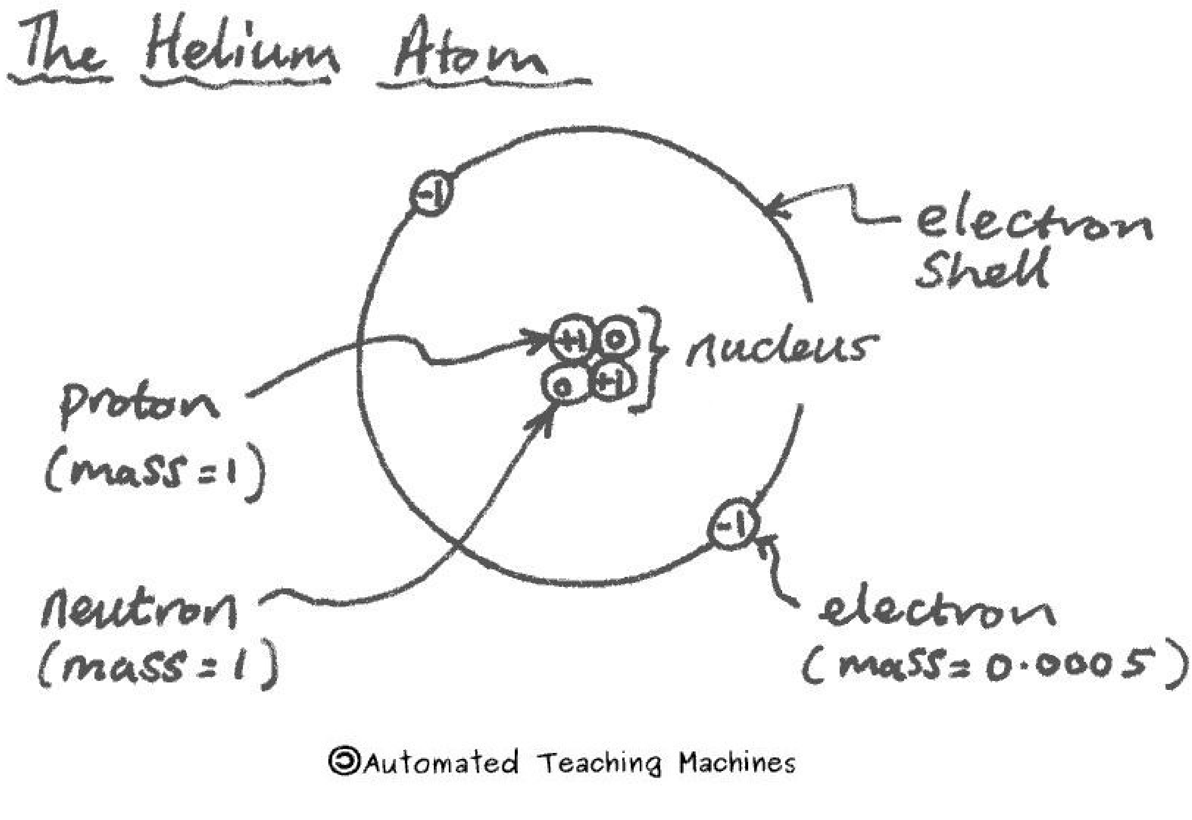
During the LeBlanc process, that was used to make the alkali sodium carbonate, the poisonous gases hydrogen chloride and hydrogen sulfide were produced.



Atoms and Equations 2.05

An atom has a small central nucleus with electrons orbiting around it in shells. Protons have a positive charge, the electron is negative and the neutron has no charge (it is neutral). Protons and neutrons both have a relative mass of 1 whereas the the electron is 2000 times lighter and only has a relative mass of 0.0005

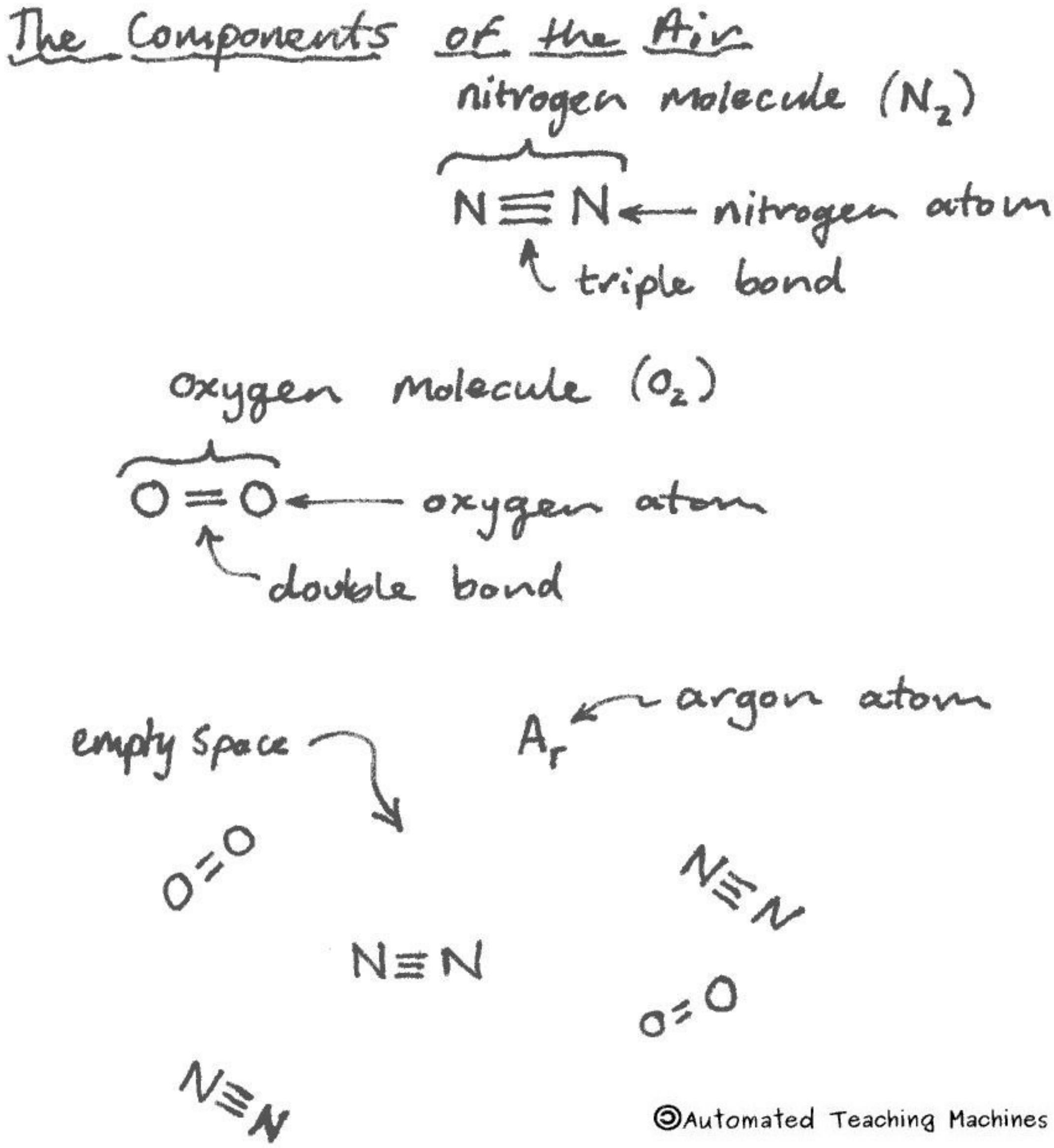
The chlorine molecule Cl_2 contains two chlorine atoms as indicated by the number 2. The equation $2H_2 + O_2 \rightarrow 2H_2O$ is balanced. This means that the number of reactant atoms of each element is equal to the number of product atoms.



Chemical Reactions 2.06

The atmosphere mainly contains nitrogen, oxygen and argon. An oxygen molecule is made from two oxygen atoms that have joined together. Between the molecules of the air there is only empty space.

During a chemical reaction the atoms in the reactants rearrange themselves to make the molecules of the products and so the number of atoms before a reaction is the same as the number after the reaction.

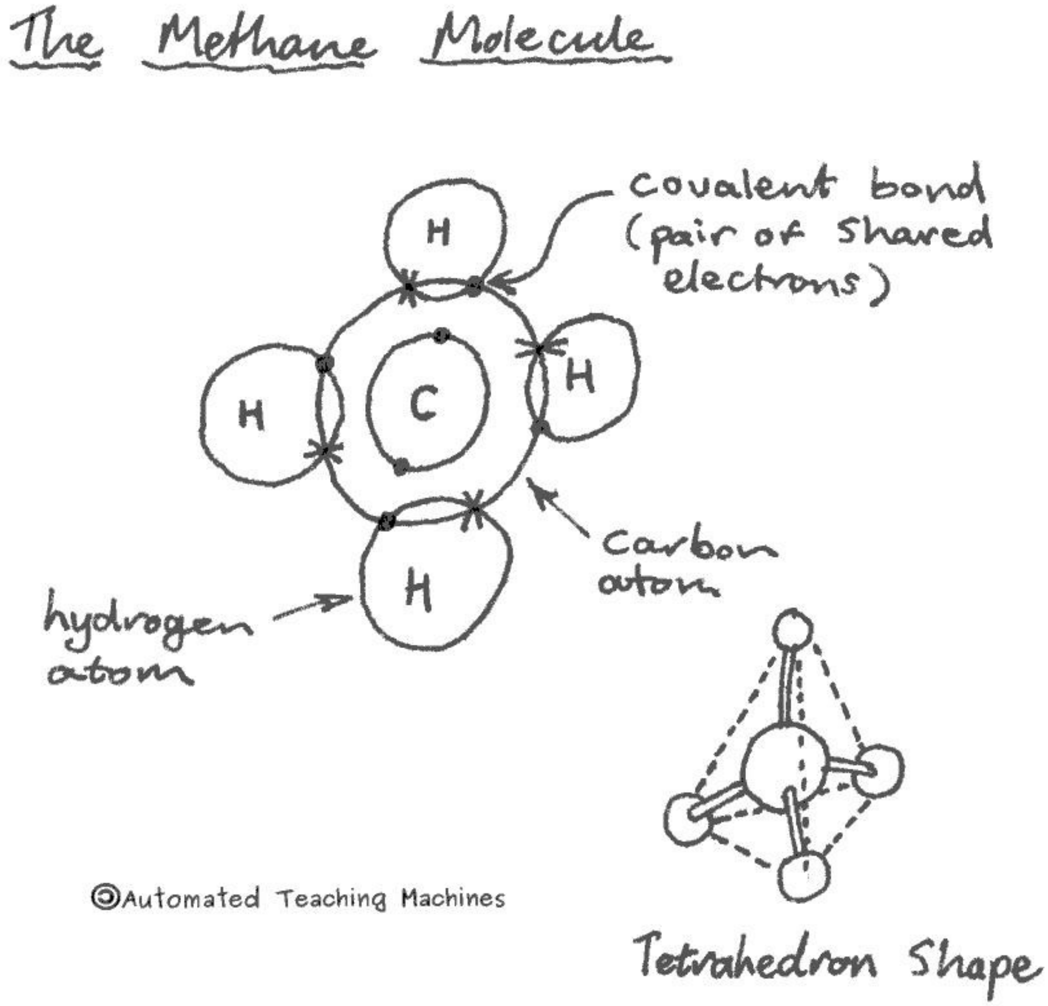


Covalent Bonding 2.07

All molecules have covalent bonds and are usually made from the atoms of nonmetals. A pair of electrons is shared in each covalent bond to achieve a full stable outer shell for each atom.

A methane molecule has one carbon atom and four hydrogen atoms. There are four covalent bonds, one for each C-H bond, i.e. four pairs of shared electrons. The molecule forms a tetrahedron shape with a hydrogen atom at each vertex of a triangular based pyramid.

Covalent compounds have weak forces between the molecules so they are usually gases or liquids and have low melting and boiling points.

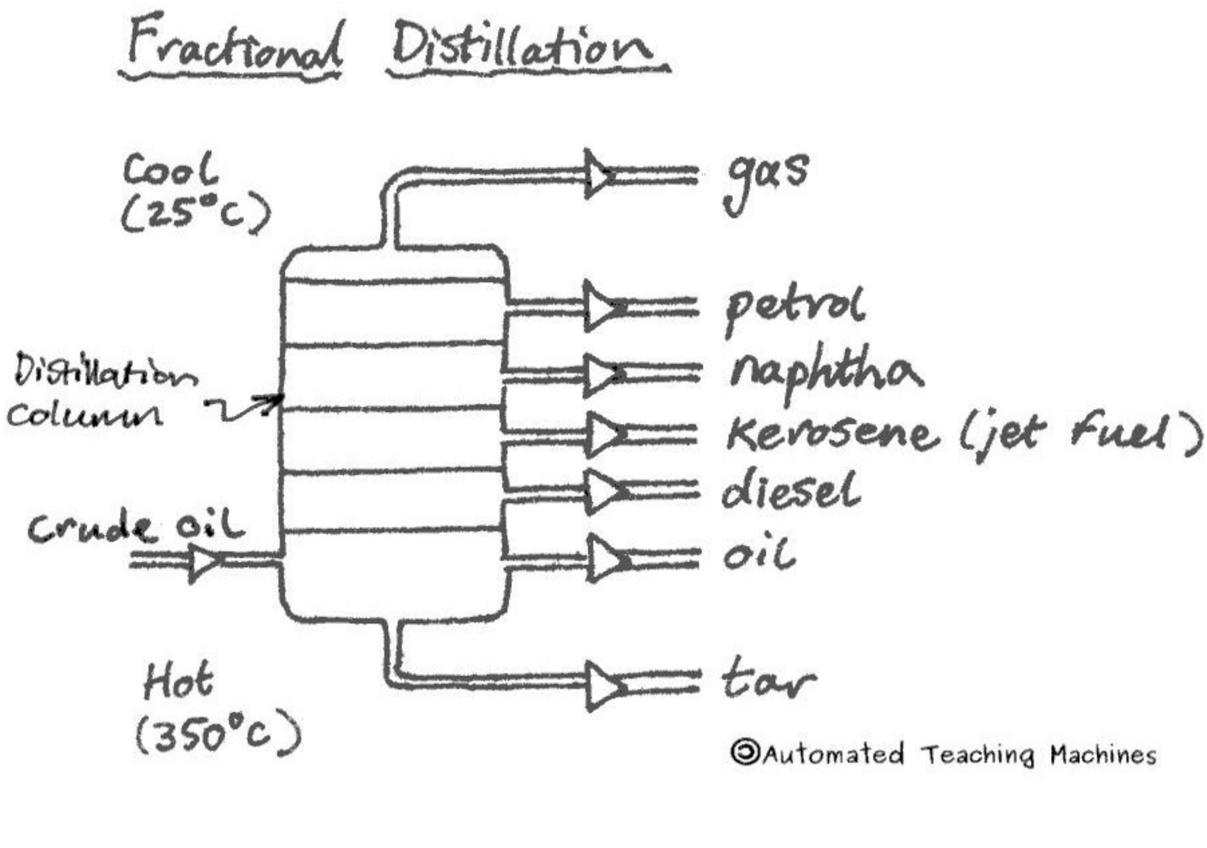


Crude Oil, Uses of 2.08

The uses of Crude Oil

Crude oil contains a mixture of molecules called hydrocarbons, all with different lengths and boiling points. The long molecules have strong attractive forces between them so they are harder to boil.

In fractional distillation, molecules of similar lengths and boiling points are separated off together. These fractions include gas, petrol, naphtha, kerosene (jet fuel), diesel, oil and tar. Naphtha is used to make new chemicals in a process called chemical synthesis.

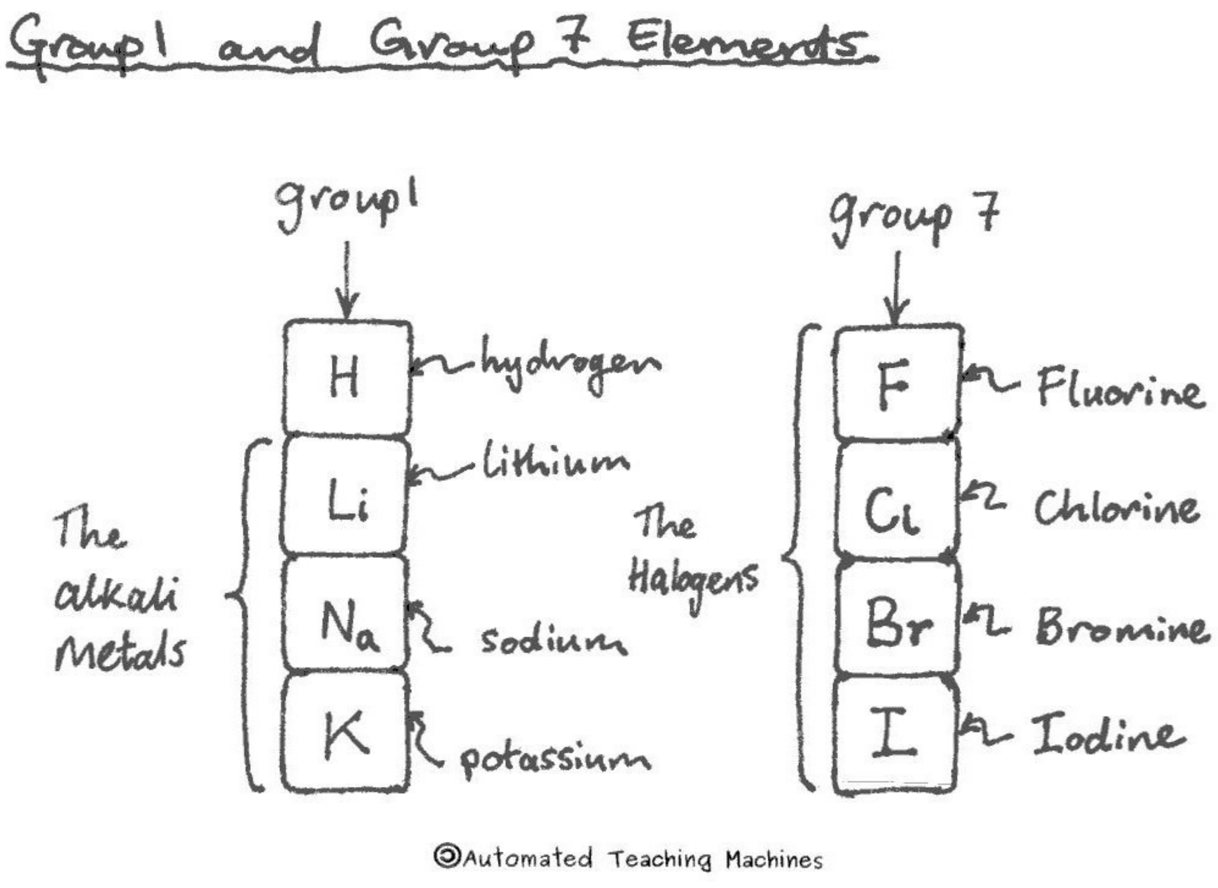


Group 1 and Group 7 2.09

The group 1 elements (except hydrogen) are known as the alkali metals. The first three alkali metals are lithium, sodium and potassium. Out of these three, potassium is the biggest, so it is the most reactive.

When the alkali metals react with water, they all produce hydrogen and form an alkali metal hydroxide solution.

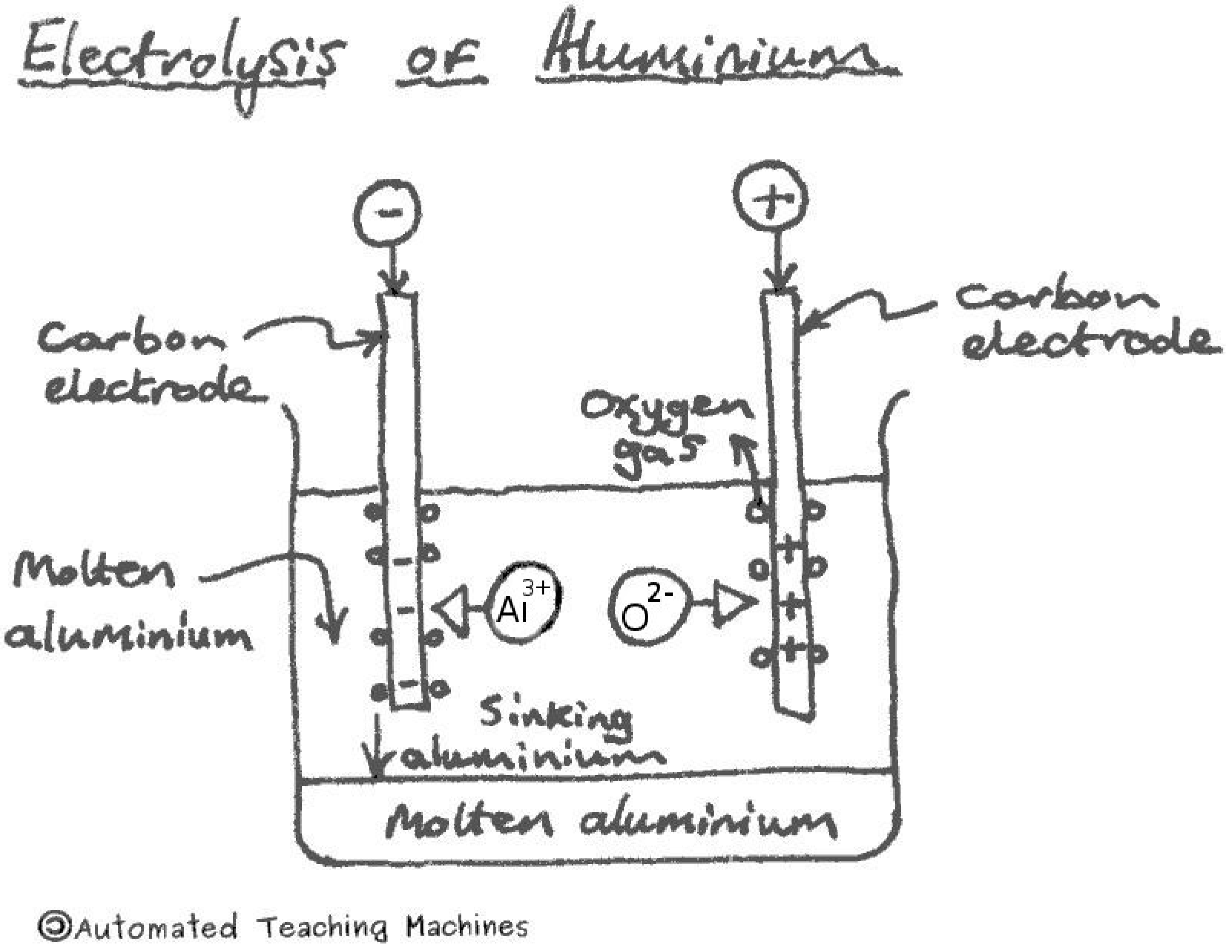
The halogens are the group 7 elements. These are all coloured non-metals.



Metal Extraction 2.10

Metals that are less reactive than carbon can be extracted by heating the powdered metal ore with carbon in the form of coke. Carbon removes oxygen from iron oxide in a blast furnace to produce iron and carbon dioxide. The ore is reduced because it loses oxygen and the carbon is oxidised.

More reactive metals, like aluminium, can be extracted by electrolysis. Electricity is passed through molten aluminium oxide and positive aluminium ions move towards the negative electrode, gain electrons and form molten aluminium metal which sinks to the bottom of the tank. Oxygen is produced at the positive electrode where oxygen ions lose electrons.

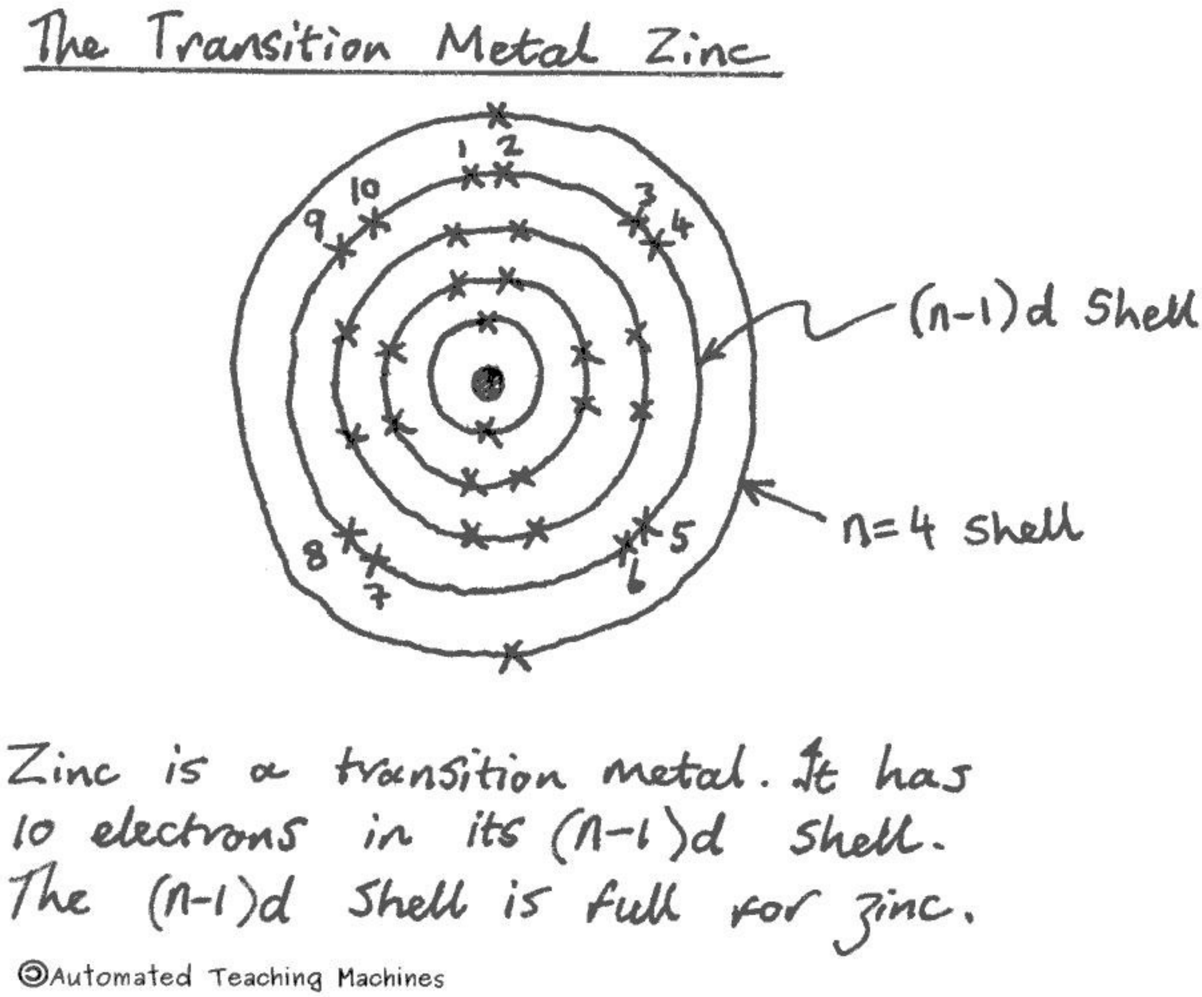


Metals and Alloys 2.11

Metal atoms are held together by strong metallic bonds so they are usually strong, malleable and have high melting points. They have free electrons which makes them good conductors of electricity and heat.

Most metals, including iron, copper, zinc and gold are transition metals which are found in the middle section of the periodic table and have electrons in the (n-1)d shell which can hold up to ten electrons. This is why this "d-block" is ten elements wide.

Alloys are mixtures of a metal with another metal or other elements. Brass is an alloy of copper and zinc, 18 carat gold is an alloy of gold and copper and steel is an alloy of iron and carbon.

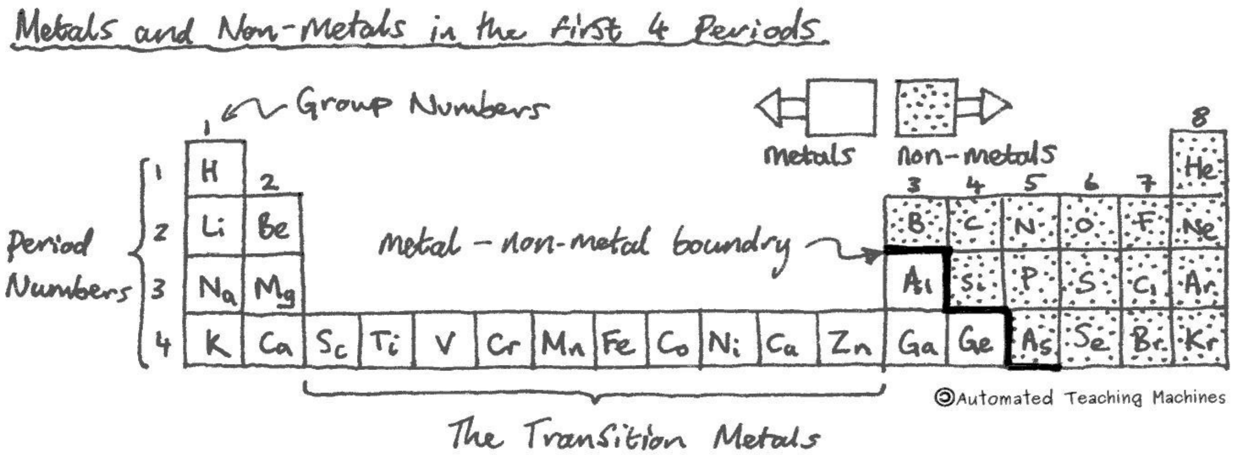


The Periodic Table

The periodic table was discovered by Dmitri Mendeleev in 1869. He put the elements in order of proton (atomic) number and placed them in rows called periods and into vertical columns called groups.

The elements on the left hand side of the periodic table are metals whereas the elements on the right hand side are non-metals.

The group number tells us how many electrons are in the outer shell and the patterns that we see in the groups enable us to predict the properties of the elements in the group.

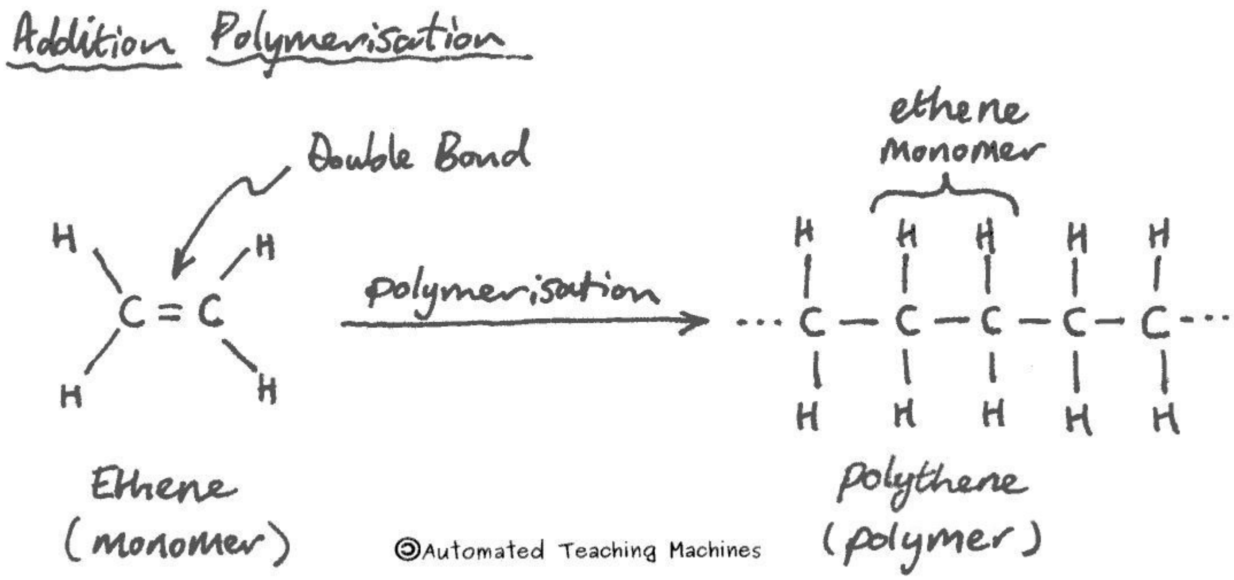


Polymerisation 2.13

Polymer literally means "many parts". Many repeating units called monomers join together to make a long chain polymer molecule.

Ethene is the monomer that is used to make the polymer called polythene (a shortened version of poly-ethene). This process is called addition polymerisation. Ethene belongs to a group of chemicals called alkenes that can be used as monomers because they are unsaturated (they have a double bond).

Plasticisers are chemicals that are used to soften polymers whereas cross-linking agents can strengthen them.

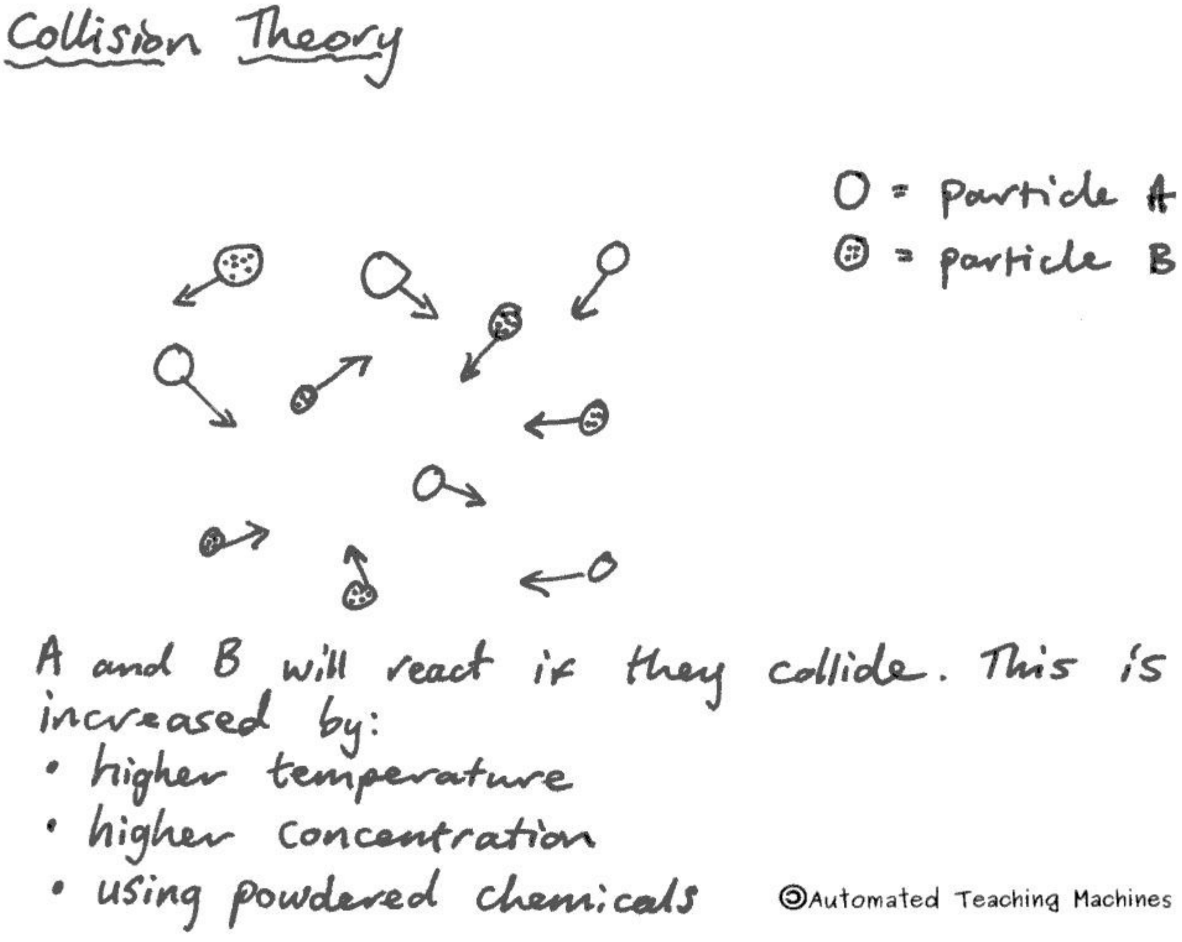


Rates of Reaction 2.14

Scientists may want to control the rate of a reaction to make it safer or to be able to produce a substance quickly and cheaply.

We can speed up chemical reactions by making them hotter, using more concentrated solutions, using powdered chemicals, or by adding a substance called a catalyst, that will speed up the reaction without being affected itself. The first three methods increase the collision frequency between the reactants.

The rate of a reaction is a measure of the amount of change in the chemicals per second. This can be determined by measuring the change in mass, volume of gas given off, or the change in colour or transparency over time.

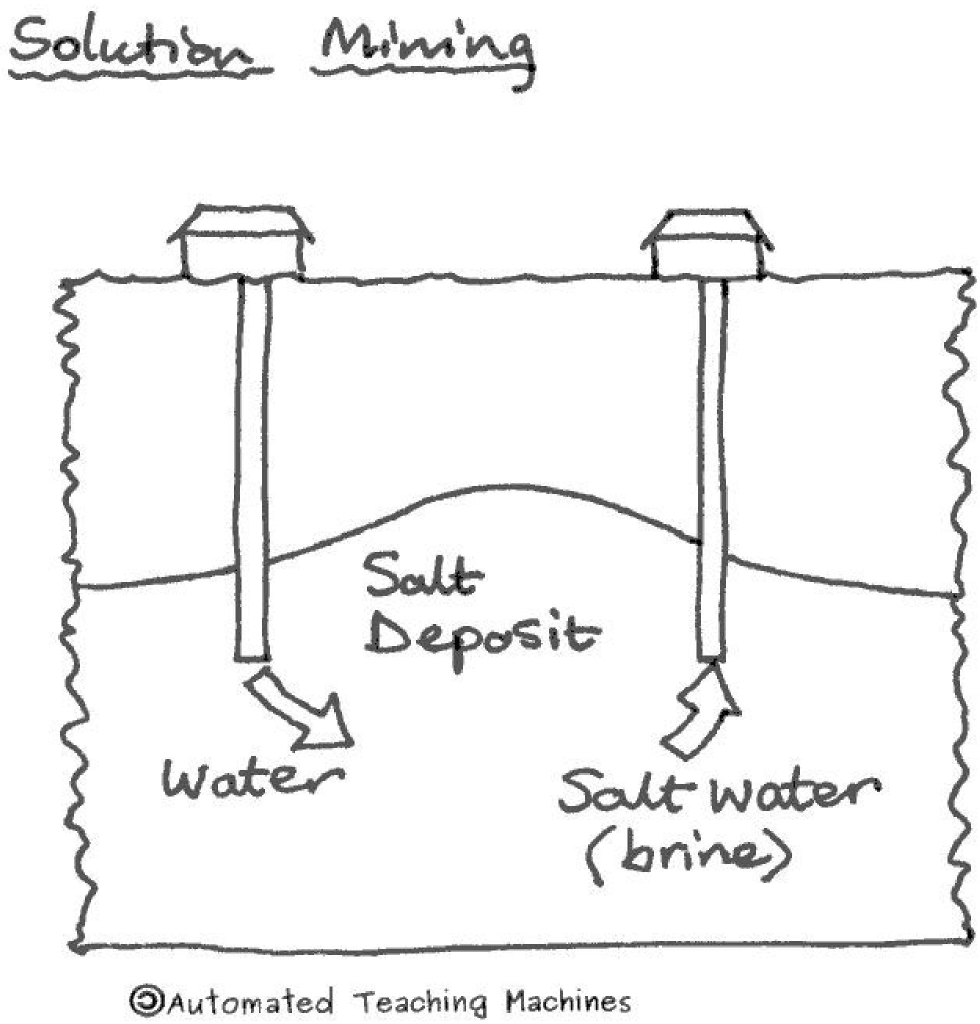


Salt 2.15

Salt (sodium chloride) can be extracted by pumping water into underground salt deposits in a process called solution mining. The salt water (brine) is brought to the surface where the water and impurities are removed to produce table salt.

Salt mining can cause buildings to fall down due to subsidence if the mine below them collapses. Air pollution can result from the burning of fossil fuels to provide the energy needed for mining.

In hot countries they can make salt by simply allowing shallow pools of sea water to dry out (by evaporation) in the sun.

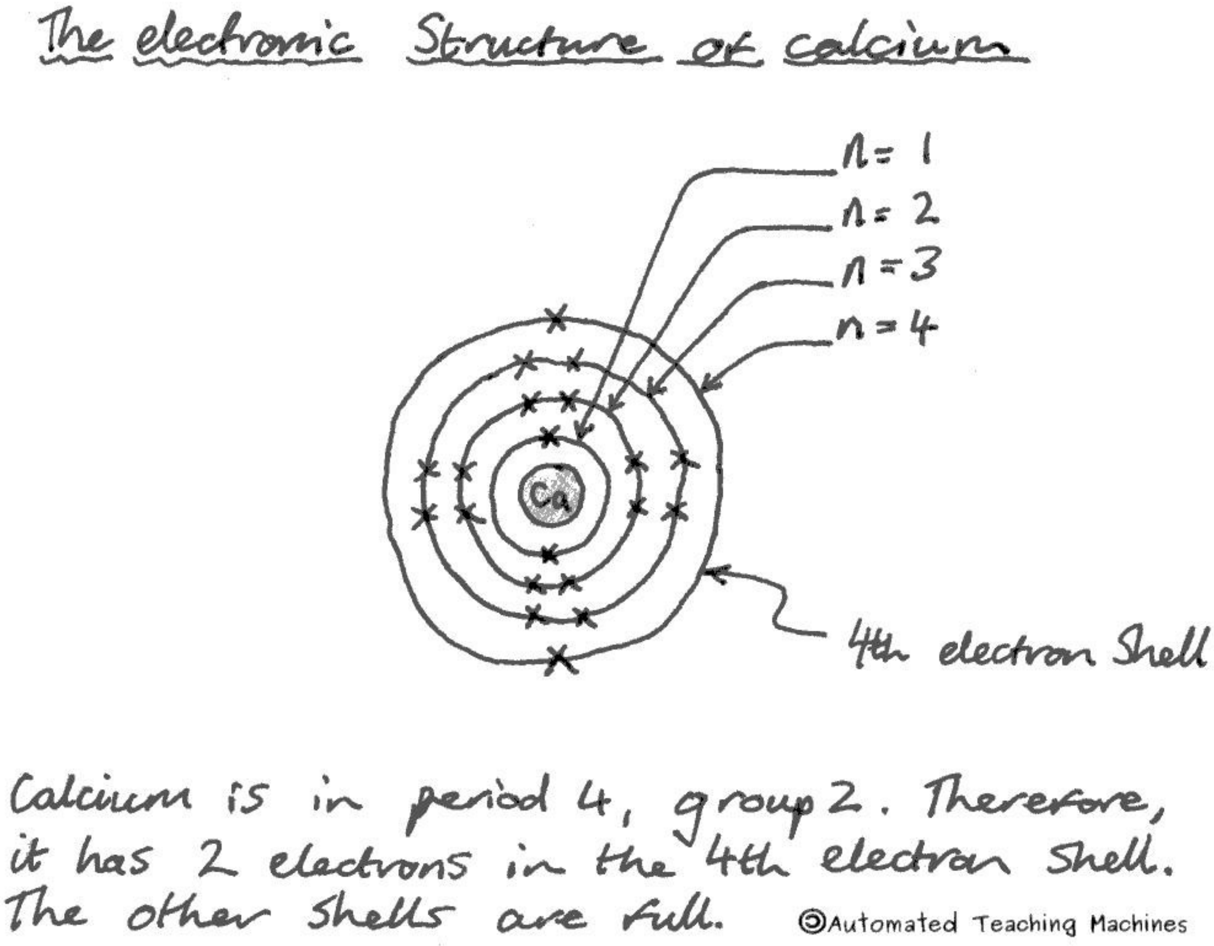


Shells and Bonding 2.16

The electronic structure of calcium is 2,8,8,2. This tells us how many electrons are in each shell. The number of electron shells in an element is the same as its period number in the periodic table.

During chemical reactions, elements in group 1 lose electrons, whereas elements in group 7 gain electrons. They do this to achieve the state of having a full outer shell. An atom which has either lost or gained electrons is called an ion.

In group 1, atoms that are larger are more reactive because it is easier for them to lose an electron. However, in group 7, larger atoms are less reactive because it is harder for them to attract electrons.



Section Three

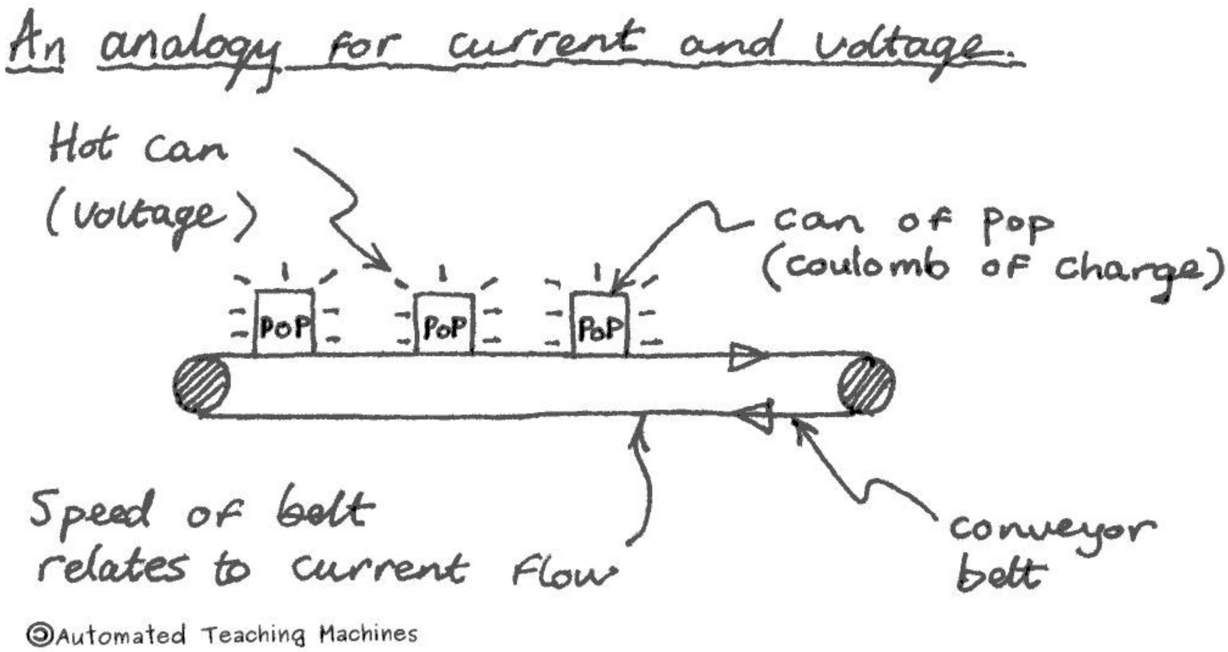
Physics

Current and Voltage 3.01

A current of one amp flows when a charge of one coulomb flows around the circuit per second.

A potential difference of one volt will supply one joule of energy to each coulomb of charge passing around the circuit.

If we imagine coulombs of charge as cans of pop travelling along a conveyor belt, then increasing the current would be like speeding up the belt. On the other hand, increasing only the voltage would be like keeping the speed of the belt the same but putting hot cans of pop onto the belt; each can contains more energy. Increasing the current and voltage at the same time would be like doing both.



Electrical Power 3.02

Energy is transferred at the rate of one joule per second by a one watt device. High powered devices are rated in kilowatts which means a thousand watts.

We can find the power rating in watts by multiplying the current and the voltage used by an electrical device.

To calculate energy used in joules we multiply watts and time in seconds. However, for more powerful devices, to calculate energy in kilowatt-hours we multiply kilowatts by the time in hours.

We can calculate the cost of using electricity if we know the cost of a kilowatt-hour (unit) of electricity.

Word Equations

$$\text{Power (Watts)} = \frac{\text{Energy Transferred (Joules)}}{\text{Time Taken (Seconds)}}$$

1 KW= 1000 Watts

Power (Watts) = Voltage (Volts) x Current (Amps)

Energy Transferred (Joules) = Power (Watts) x Time Taken (Seconds)

Energy Transferred (KW-Hours) = Power (KW) x Time Taken (Hours)

Cost (£/$) = Cost of one unit (£/$) x Number of units used

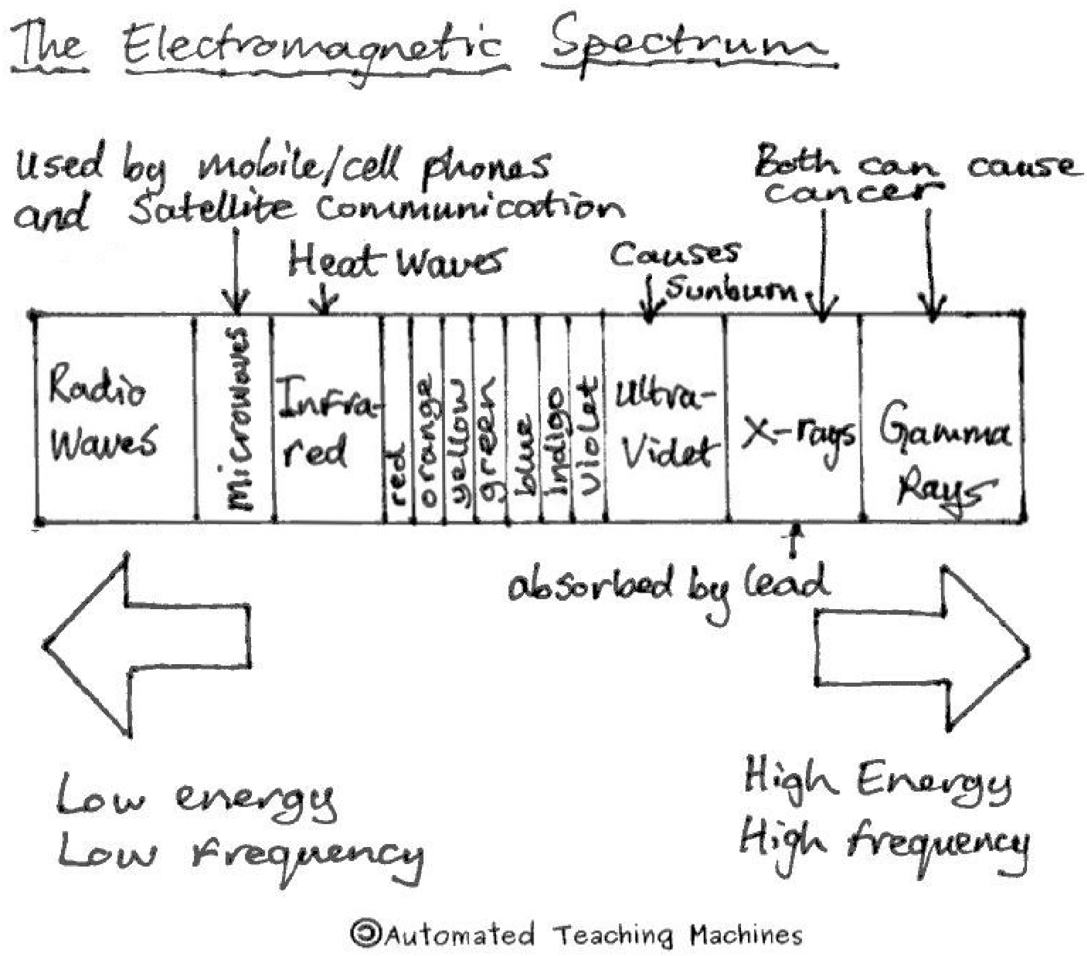
Electromagnetic Spectrum, The 3.03

The Electromagnetic Spectrum

Electromagnetic (EM) radiation carries energy in tiny packets called photons.

Radio waves have the lowest energy and frequency in the EM spectrum and gamma rays have the highest. Infrared radiation is next to red in the EM spectrum and carries heat waves. Ultraviolet is next to violet and it causes sun burn.

In hospitals, the X-ray staff stand behind lead screens because lead absorbs the X-rays.

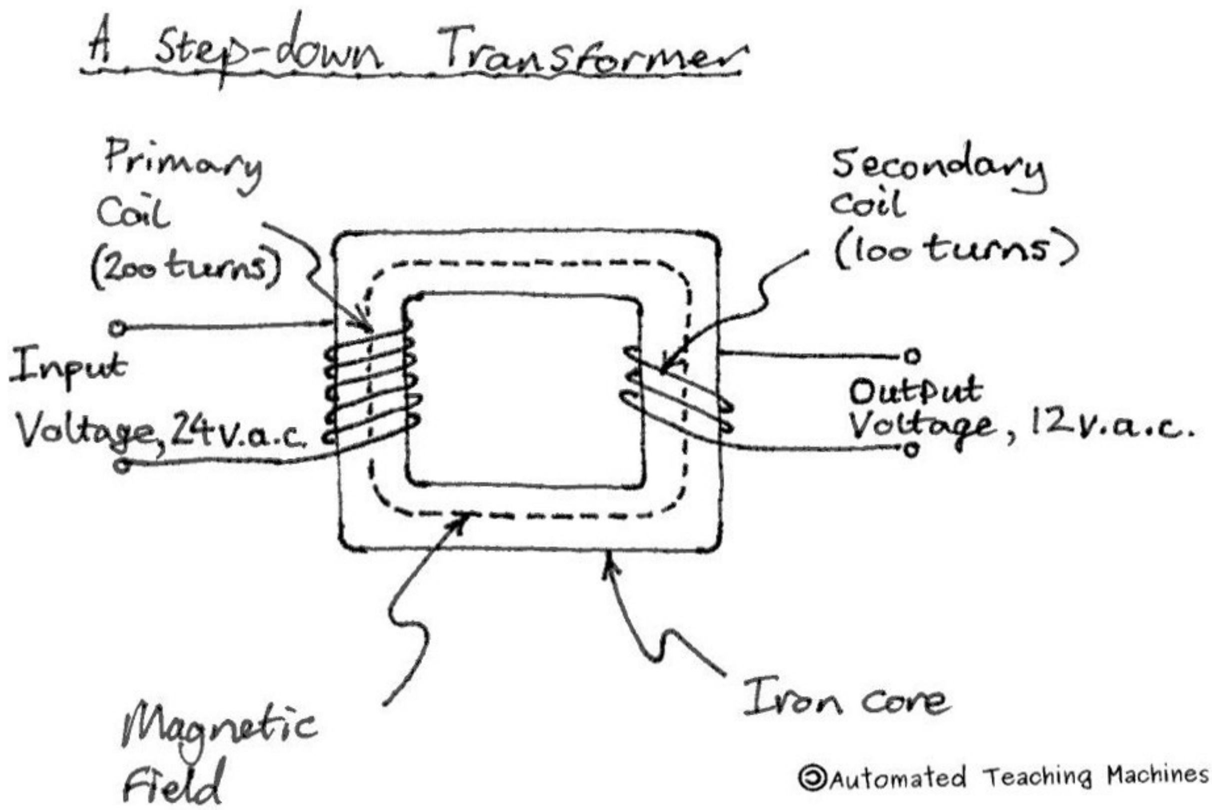


Electromagnetism 3.04

Passing electricity through a coil of wire wrapped around an iron core will produce an electromagnet. Similarly, moving a magnet inside a coil of wire will cause an electric current to flow; a process called electromagnetic induction.

Combining these two ideas, Michael Faraday invented the transformer in 1831, in London. Transformers can change the output voltage to be either higher or lower than the input voltage by adjusting the turns ratio between the primary and secondary coil.

The electric motor, also invented by Michael Faraday, works because a current carrying wire can experience a force when placed in a magnetic field. The direction of the force can be found using Fleming's left-hand rule.



Electronic Communications 3.05

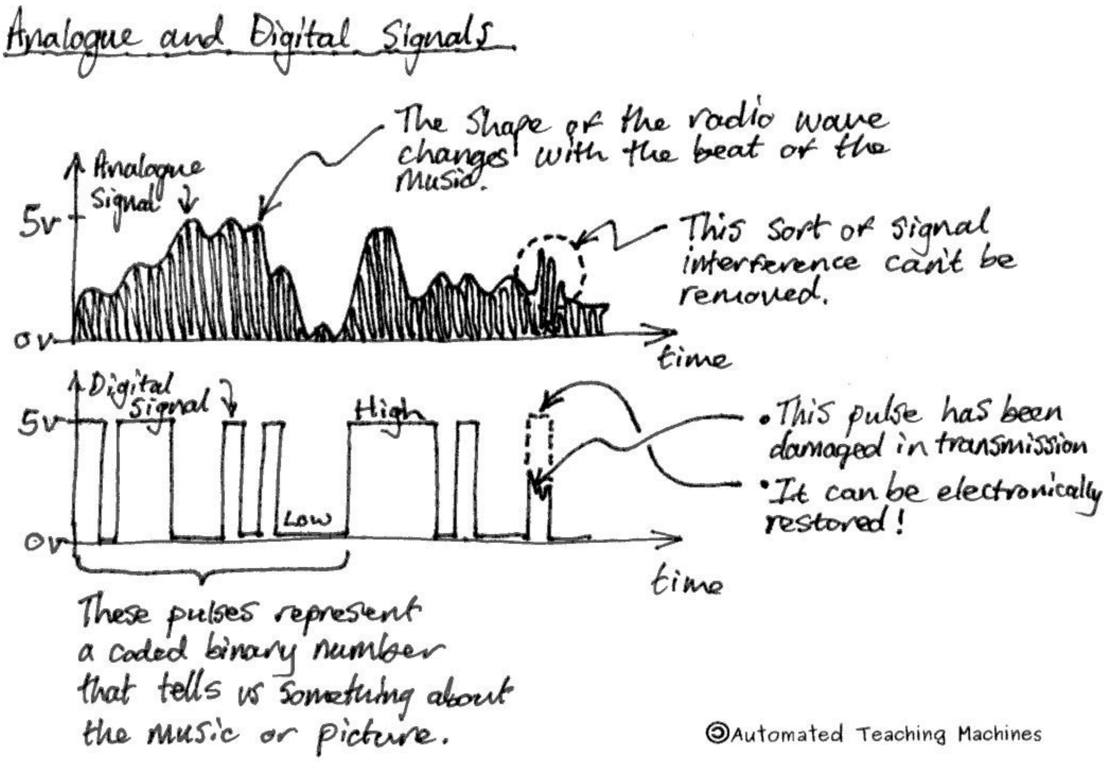
Engineers can use radio waves, microwaves, infra-red and light to transmit messages.

- Radio waves are used to send TV, radio and radar signals.
- Microwaves are used to send mobile phone and satellite signals.
- Infra-red rays are used by TV remote controls and night-vision cameras. Infra-red and light waves can also carry messages down optical fibres.

In analogue transmission, the shape of the radio wave changes with the beat of the music in the message.

In digital transmission, the sound or picture is converted into binary pulses of 1's and 0's that represent digital numbers.

Unwanted noise in digital signals can be cleaned up making digital transmission very good quality.



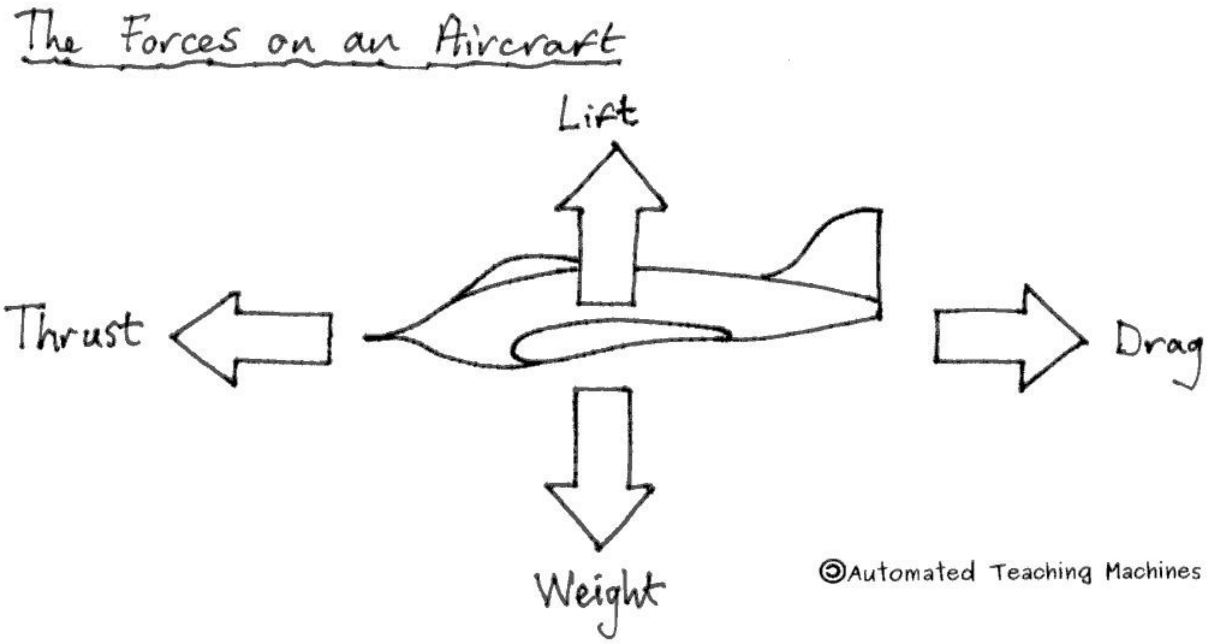
Force and Momentum 3.06

On an aircraft the opposing pair of forces that are trying to speed up and slow down the aircraft are the thrust and drag. The opposing pair of forces that are trying to pull the aircraft up and down are the lift and the weight.

If the forces on an object are unbalanced, and it is free to move, it will accelerate (or decelerate).

Momentum is calculated by multiplying mass and velocity. We can calculate the change in momentum by multiplying the force on the object by the time that the force acts. A large force is needed to produce a sudden change in momentum.

Newton's second law of motion states that force = mass x acceleration (f=ma).



Word Equations

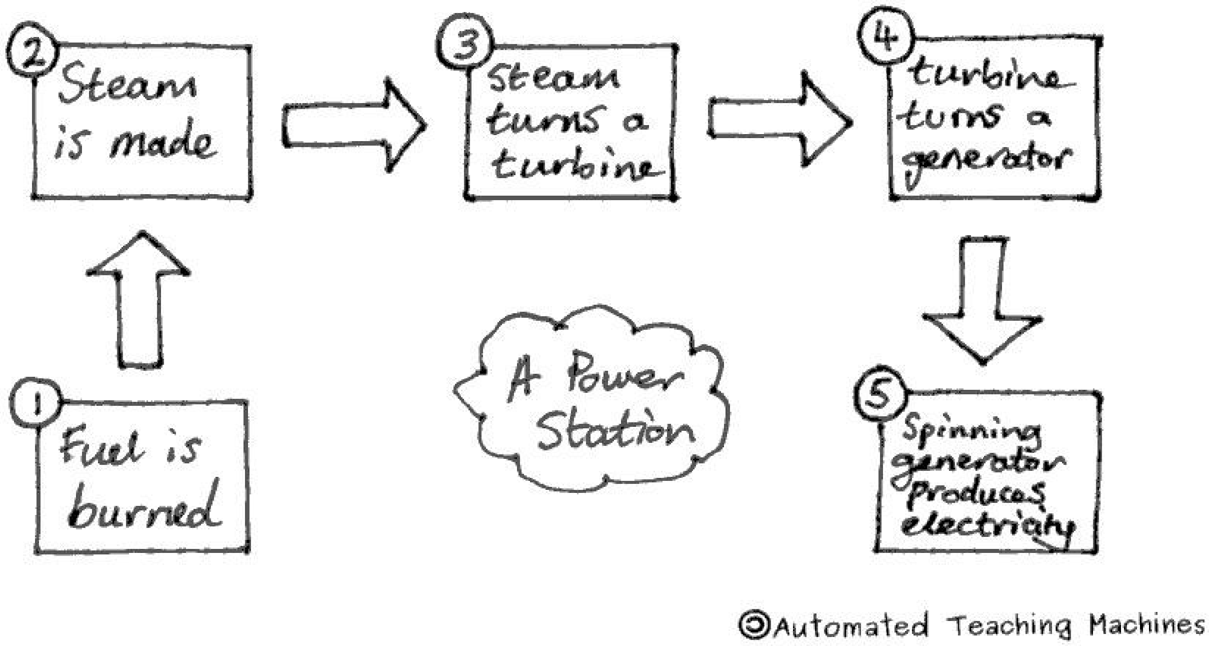
Momentum (Kg.m.s^{-1}) = Mass (Kg) x Velocity (m.s^{-1})
Impulse (Change in Momentum) = Force (N) x Time (s) *
(* provided that the force and mass don't change)
Force (N) = Mass (Kg) x Acceleration (m.s^{-2})

Generating Electricity 3.07

Coal, gas and nuclear power stations all generate electricity by heating water to produce steam.

Coal and gas are fossil fuels which are burned. This produces carbon dioxide which adds to global warming. Nuclear fuels get hot due to nuclear fission but there is no burning taking place, so they don't produce any carbon dioxide. However, radioactive waste can be very dangerous and it has to be mixed with molten glass and poured into steel drums which are then welded shut before being buried in deep mines!

All of these fuels heat water to produce steam to drive a steam turbine which then turns an electrical generator at high speed. The generator contains a spinning magnet inside a coil which is made of thousands of turns of wire and this produces a.c. electricity.

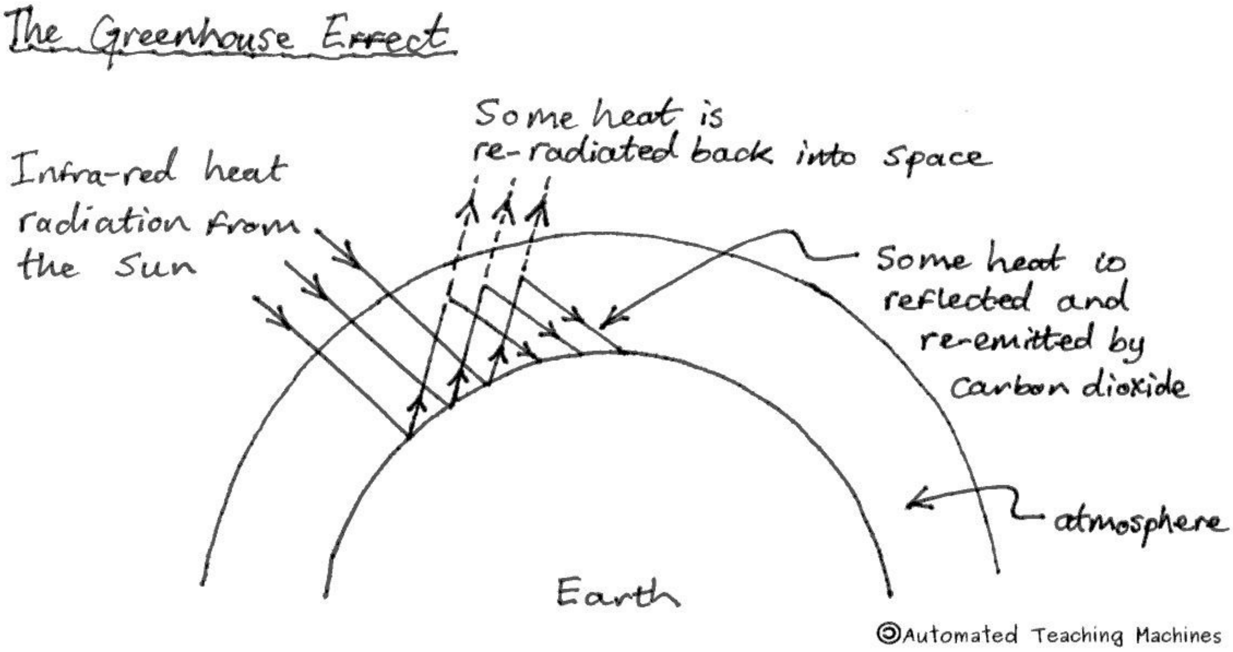


Global Warming 3.08

The Earth absorbs infra-red heat radiation from the Sun and this heat is re-radiated back into space. However, some of this heat energy is reflected and re-emitted back down down to Earth, mainly by carbon dioxide gas, in a process called the greenhouse effect.

The greenhouse effect is causing global warming which means that the temperature of the planet is rising. This is causing the sea levels to rise because the ice caps are melting and the sea is expanding, and it is leading to extreme weather and crop failure.

The carbon dioxide levels are rising because humans are burning a lot of fossil fuels including gas and petrol (which is made from crude oil).

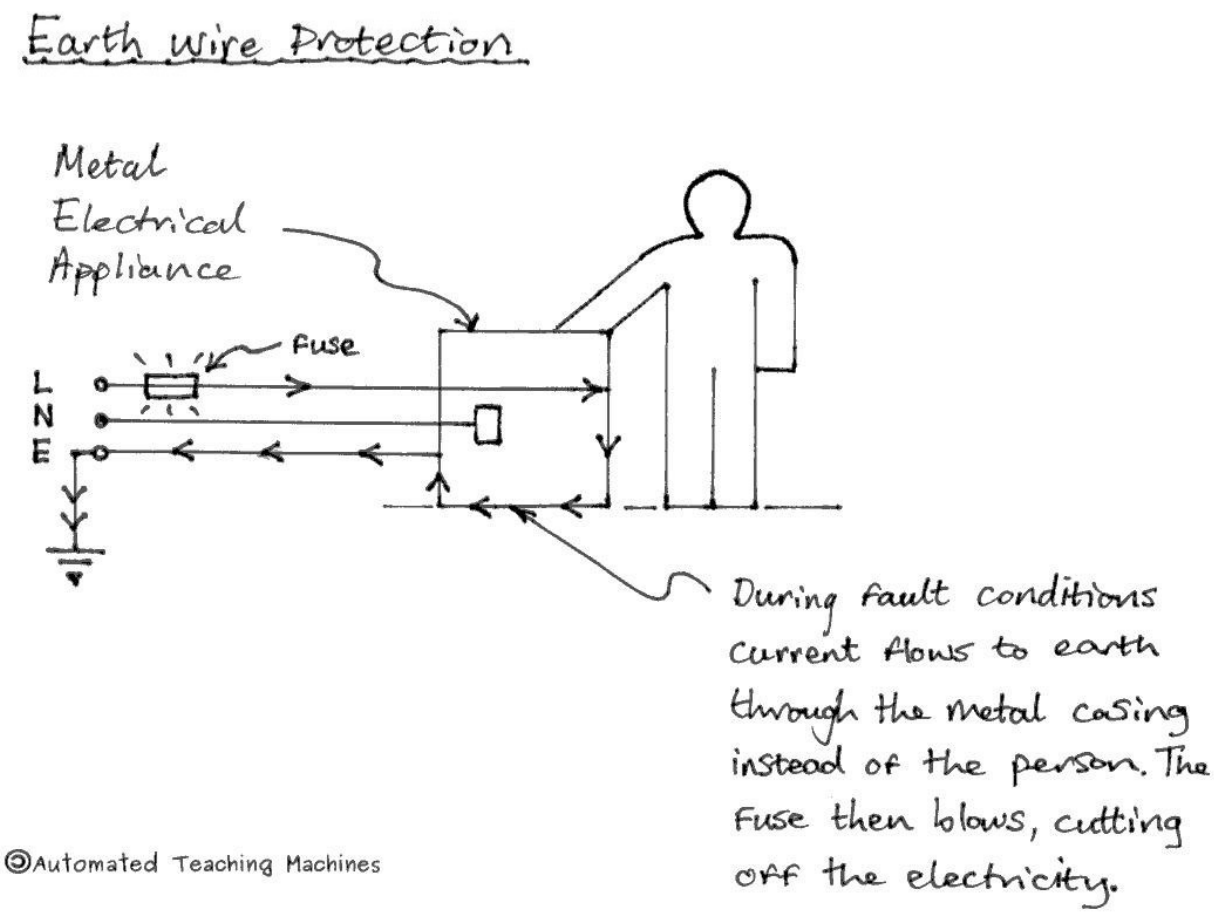


Mains Electricity 3.09

In the USA and Canada, mains electricity is supplied to mains sockets as 120V a.c.. In the UK, Ireland, Europe, Australia, New Zealand, Nigeria and South Africa it is 230V a.c. and in Jamaica it is 110V a.c.

A.c. means "alternating current". This means that the direction of the electric current goes backwards and forwards very quickly; 60 times a second in America and 50 times a second in Europe, Australia and Africa.

Fuses are used to prevent fires as they will cut off the power if too much current accidentally flows. RCDs will prevent electric shocks by tripping the supply if not all of the current leaving the live wire returns down the neutral wire; this happens during shock or fault conditions. Earth wires also prevent electric shock risks as they prevent metal casings from ever becoming electrically live.



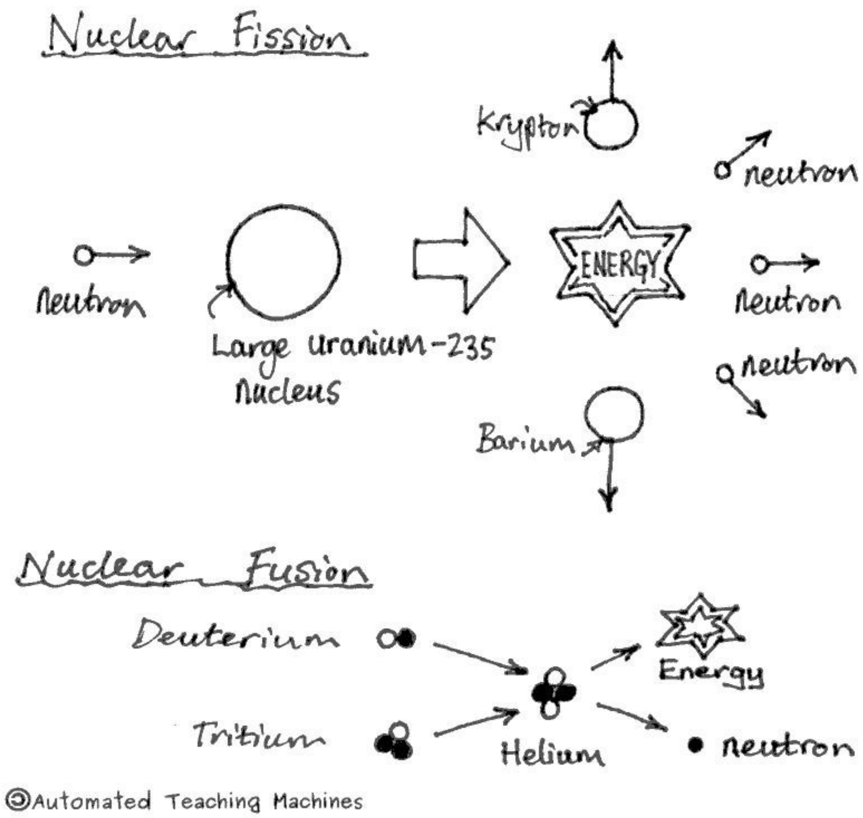
Nuclear Fission and Fusion 3.10

Nuclear power stations split atoms in a process called nuclear fission. An incoming neutron splits the uranium (or plutonium) nucleus, releasing energy and more neutrons. Mass is converted into energy during this process.

Control rods are used to absorb neutrons and control the speed of the reaction. No carbon dioxide is released into the atmosphere.

A coolant is circulated around the reactor to remove heat and make steam which is used to generate electricity using turbines and generators.

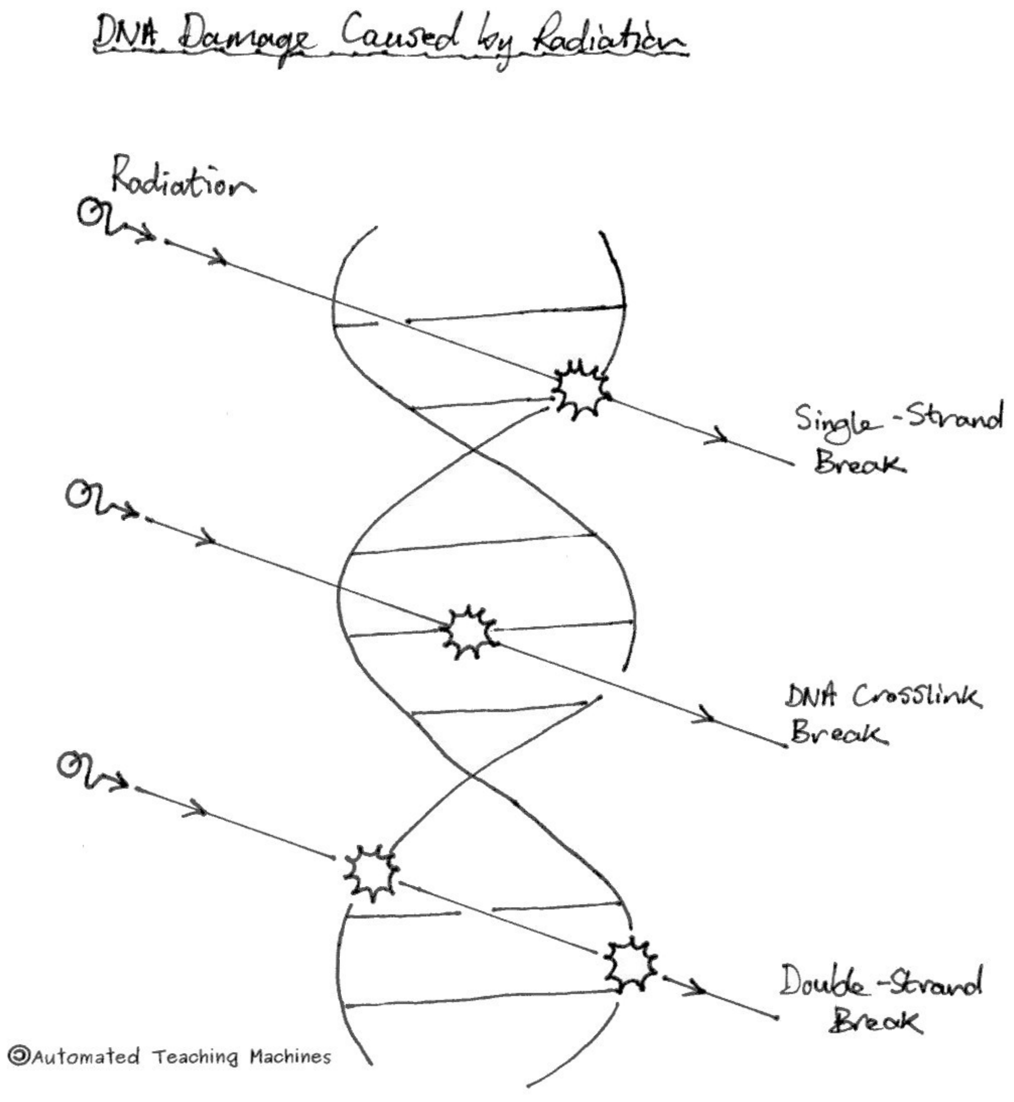
The sun and other stars generate heat from nuclear fusion. Two hydrogen nuclei fuse to create a helium nucleus. Again, mass is converted into energy which is released as heat and light.



Radiation Hazards 3.11

High doses of radiation can kill living cells so they can be used to treat cancer. Medium doses, however, can damage the DNA of a cell causing it to go out of control and divide rapidly. The damaged cells can cause cancer. Those cancerous cells can then be killed either by high doses of radiation or by using drugs in chemotherapy.

Alpha radiation is the most dangerous radiation if swallowed and beta and gamma are the most dangerous outside the body. Exposure to radiation is measured in millisieverts (mSv). Background radiation is about 2mSv/ year and the legal limit for radiation workers is 20mSv/ year.

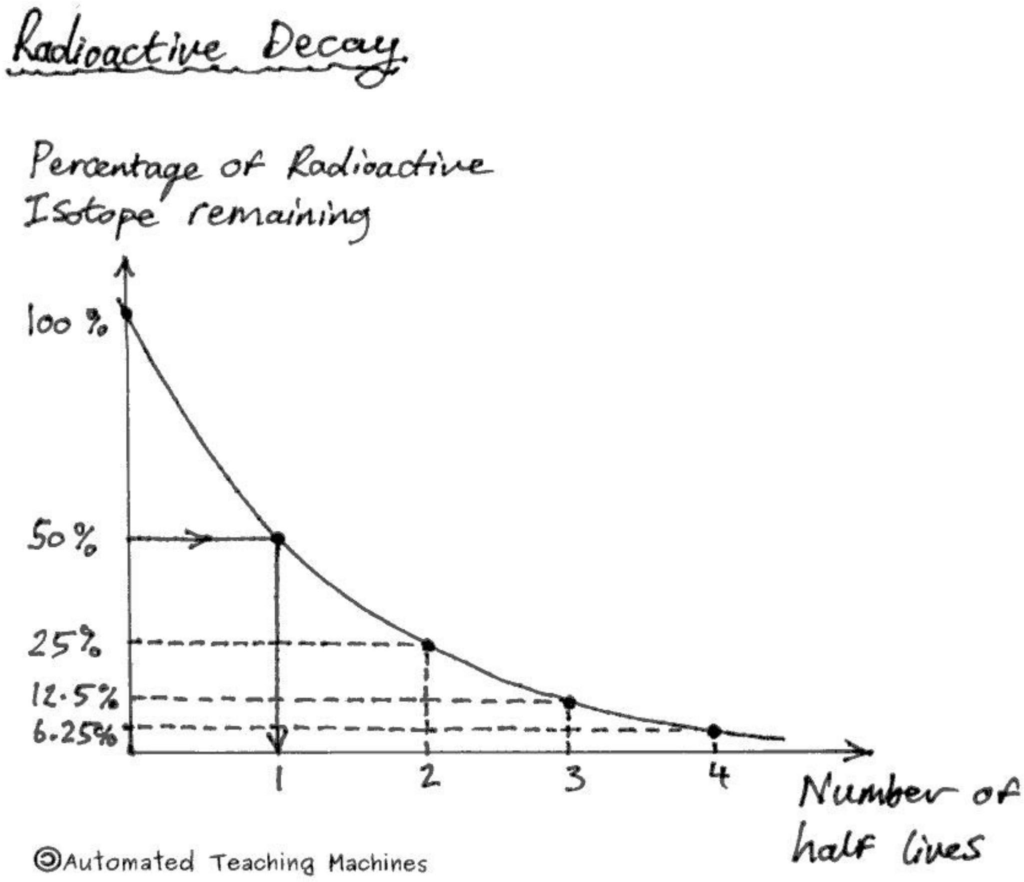


Radioactivity and Half-Life 3.12

There are three types of nuclear radiation; alpha, beta and gamma. Alpha, a helium nucleus, is the least penetrating and is stopped by a sheet of paper. Beta, a high-energy electron, is stopped by a thin sheet of aluminium, and gamma, a high-energy photon is stopped by a thick sheet of lead.

These radiations are all ionising, which means that they can pull the electrons out of atoms.

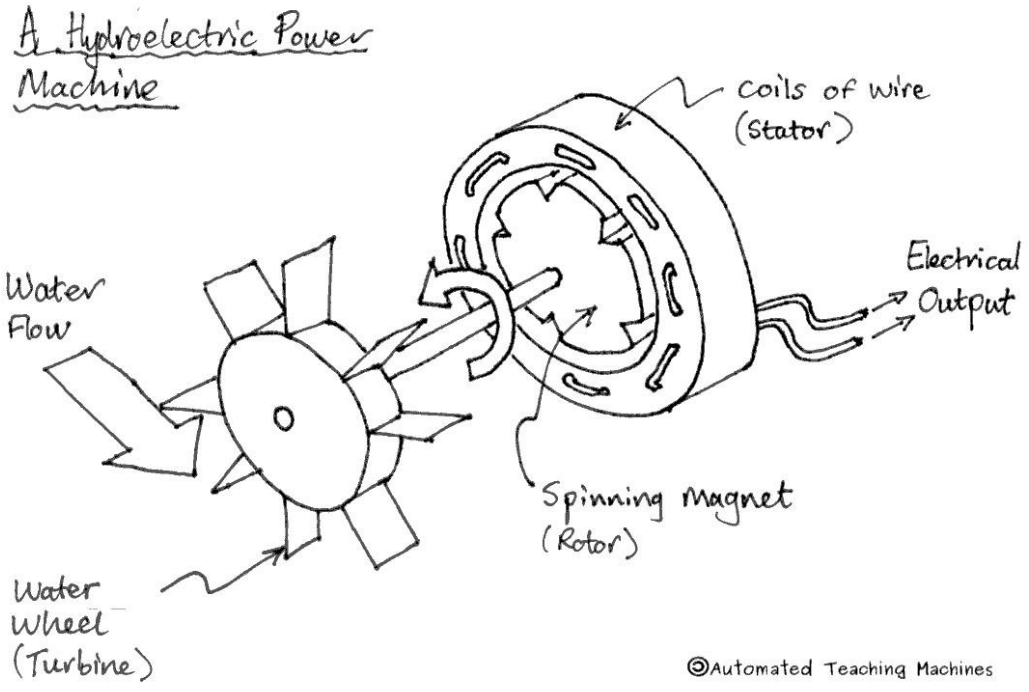
Different radioactive materials have different half-lives ranging from seconds to millions of years! The half-life is the time taken for the radioactivity of a sample to drop by half. Radiation can be used to date rocks and bones, treat cancer, kill germs and detect smoke or the thickness of paper.



Renewable Energy 3.13

Renewable energy sources will not run out. This is because they don't use fossil fuels or nuclear fuels.

- **Hydroelectric power** stations release water from behind a dam to spin a water turbine and then drive an electrical generator.
- **Windmills** are expensive to build and don't work when there's no wind. However, wind costs nothing and they don't pollute the planet.
- In a **geothermal power** station cold water is pumped down to hot rocks under the ground and it comes back as steam. The steam can drive a turbine and generator to make electricity.
- **Solar** panels are most useful when it is sunny and there is no other power supply. E.g. in space, in Africa and for electric road signs.
- **Biofuels** can be made from vegetable oils, ethanol from fermentation or biogas from rotting materials.
- **Wave machines** use the kinetic energy of waves to drive turbines and electrical generators.
- **Tidal barrages** release trapped water from high tide, during low tide, to produce energy.



Resistance 3.14

Resistance is measured in ohms(Ω) and it is a measure of how well something can restrict the flow of electric current.

Resistance (R) can be calculated by dividing the voltage across a component (V) by the current flowing through it(I), in amps.

Light dependent resistors (LDR) and thermistors both conduct electricity better when there is more energy around. This happens when it is brighter or warmer.

Resistors in series add up, but resistors in parallel go down, usually to 1/2, ⅓, and ¼ of the original resistance as you add more resistors in parallel.

Equations

Voltage (V) = Current (I) x Resistance (R)

$V=IR$, $R=V/I$, $I=V/R$

in series,
$R_{Total} = R_1 + R_2 + R_3 + \ldots$

but in parallel,
$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots$

e.g., for two 1 Ω resistors in parallel,

$1/R_{Total} = 1/R_1 + 1/R_2$

$= 1/1 + 1/1 = 1 + 1 = 2$

therefore,

$R_{total} = 1/2\ \Omega$

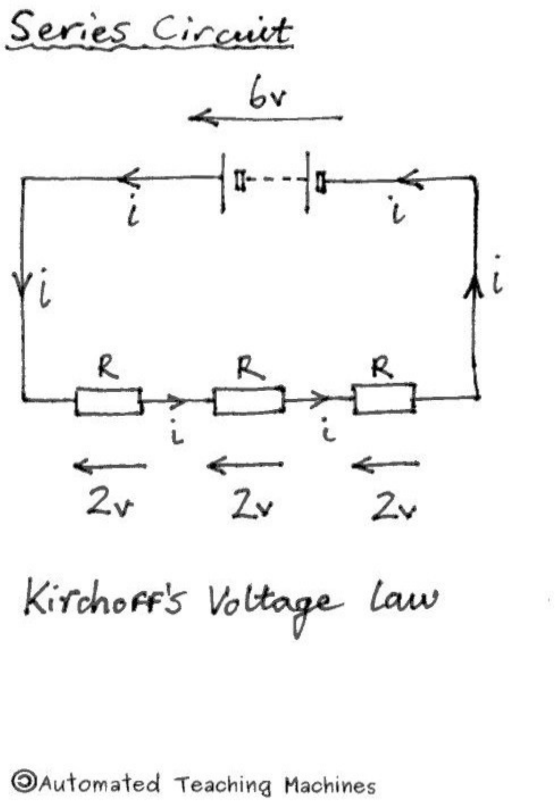
Series and Parallel Circuits 3.15

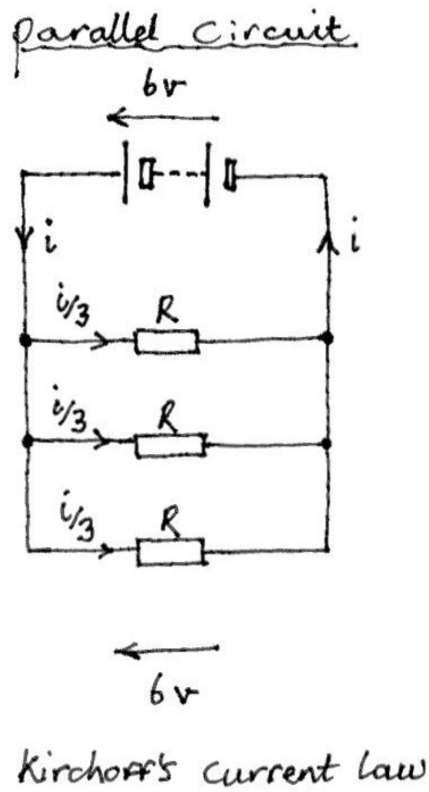
Components in a series circuit are in a loop like a daisy chain. Components in a parallel circuit are stacked up like the rungs of a ladder.

In a series circuit, the voltages (p.d. or potential difference) across each component add up to the same voltage as the battery or power supply. The current is the same everywhere.

In a parallel circuit, the currents through each component add up to equal the current leaving the battery or power supply. The voltage is the same everywhere.

When cells or batteries are connected in series, their voltages add up, provided that they are all facing the same way.



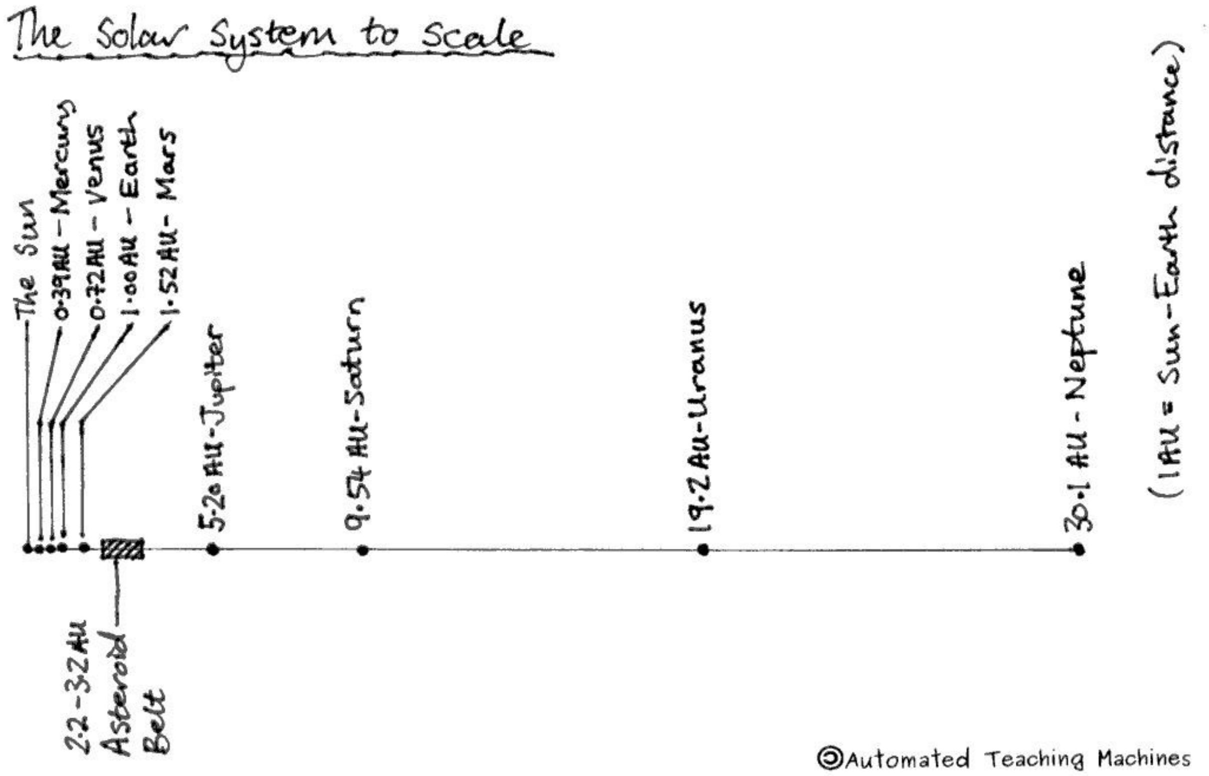


Solar System, The

The Solar System 3.16

Planet Earth is one of eight planets in our Solar System that orbit around the Sun. Over a million fragments of rock orbit the Sun in the asteroid belt between Mars and Jupiter.

Our Sun is a star which produces heat energy from the process of nuclear hydrogen fusion in its core. Other stars in the universe appear to be so small and dim because they are so far away from Earth.



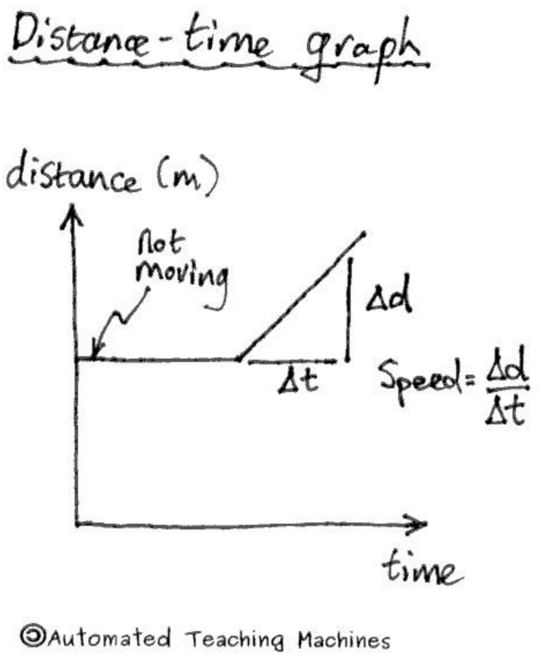
Speed and Acceleration 3.17

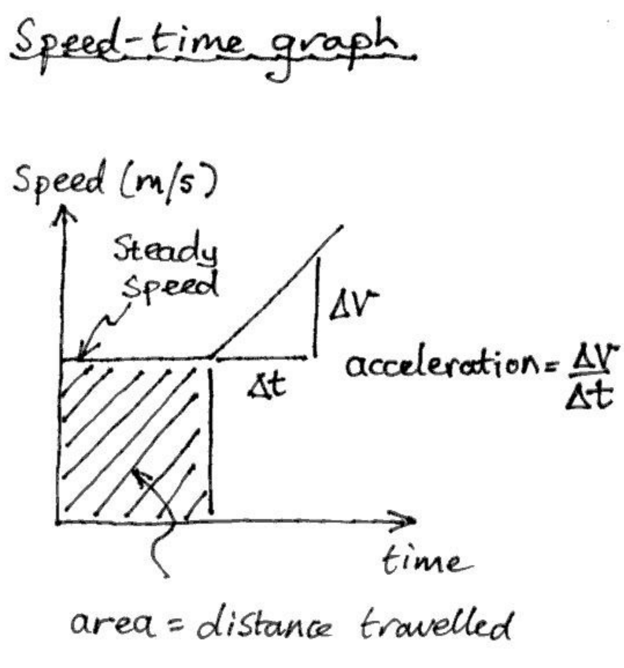
Speed is calculated using the equation speed=distance/ time.

A flat horizontal line on a distance-time graph shows that the object is not moving. The gradient of a sloping line tells us the speed of the object.

The acceleration of an object is the change in velocity (speed) divided by the time taken.

A flat horizontal line on a speed-time graph shows that the object is travelling at a constant (steady) speed. The gradient of a sloping line tells us the acceleration of the object. The area under a speed-time graph tells us how far the object has travelled.





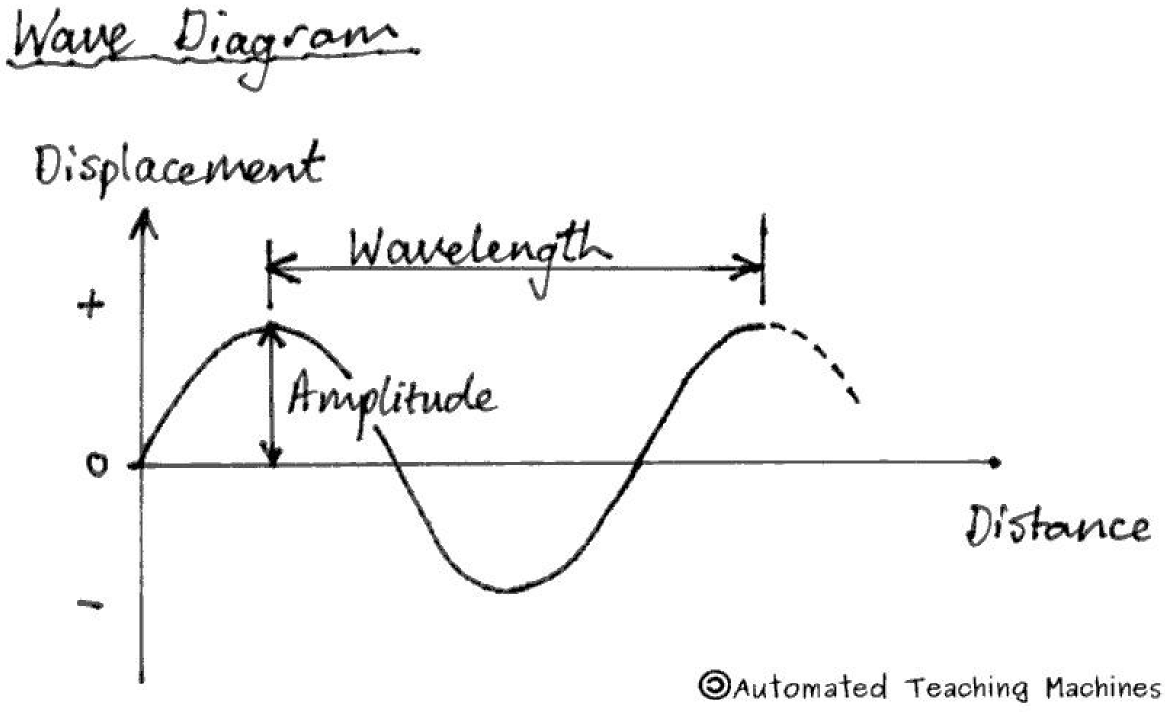
Waves 3.18

The distance between two peaks of a wave is the wavelength and the distance from the rest position to a peak (or trough) is the amplitude.

Transverse waves, for example light and earthquake S-waves, vibrate at 90 degrees to their direction of motion whereas longitudinal waves vibrate along the direction of travel.

The speed of a wave can be calculated using this equation:

speed = frequency x wavelength



Work and Energy 3.19

"Work done" is a measure of energy transfer. It is calculated by multiplying the force by the distance through which it acts.

Work is measured in joules, force is measured in newtons and distance is measured in metres.

Objects which are raised above the ground have gravitational potential energy (GPE). This is calculated using the equation GPE=mgh, where m=mass, g=10 and h=height.

When an object falls its GPE is converted into kinetic energy. We can calculate kinetic energy using the equation $KE=1/2mv^2$.

Equations

Work Done (J) = Force (N) x Distance (m)

GPE (on Earth) = Mass (Kg) x 10 x Height (m)

$KE=1/2mv^2$

Section Four

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Section 4.01

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Version 1.3, 3 November 2008

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