Chapter 1: Physical Quantities, Units, Measurement

What are physical quantities?

-A physical quantity is a quantity that can be measured
-It consists of a numerical value and a unit
-There are 7 basic physical quantities, of which others are derived from

Base quantity	SI unit	Symbol for SI unit
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

(luminous intensity is not tested at our level)

Prefixes for SI units

-Using decimal notation, 1 km can be expressed as 1000 m
-This is not efficient, so prefixes are more commonly used

Order of magnitude	Prefix	Symbol	Amount
10^12	tera-	T	1000000000000 (trillion)
10^9	giga-	G	1000000000 (billion)
10^6	mega-	M	1000000 (million)
10^3	kilo-	k	1000 (thousand)
10^-1	deci-	d	0.1
10^-2	centi-	c	0.01
10^-3	milli-	m	0.001
10^-6	micro-	µ	0.000001
10^-9	nano-	n	0.000000001

Standard form

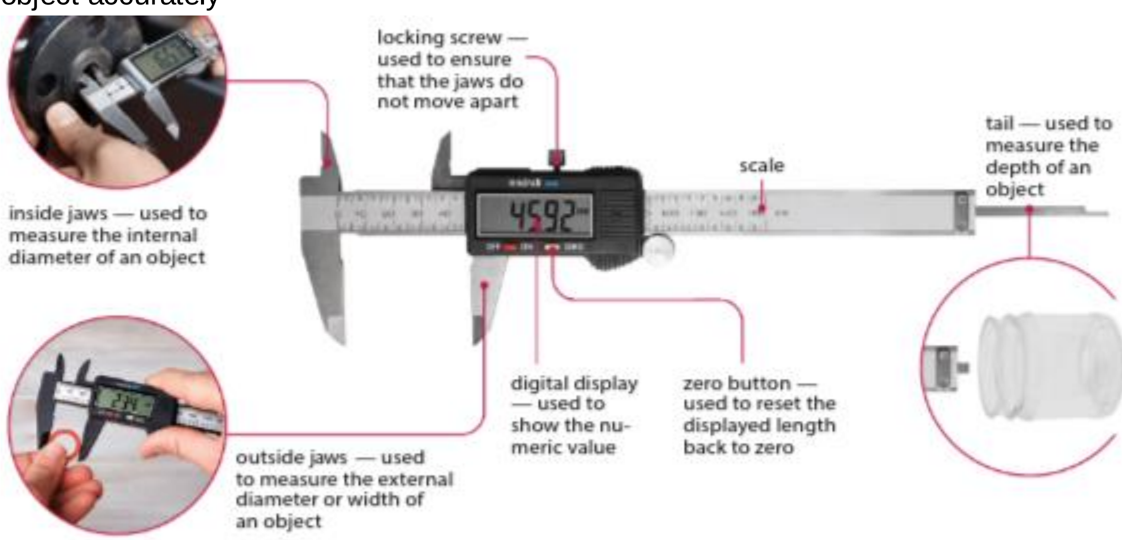
-Other than using prefixes, standard form is also a method of writing physical quantities in which 1 or 10 is multiplied by an appropriate power of 10
-e.g. 1 km = 1 x 10^3 m
-The order of magnitude of some measure is the 10^x part
-e.g.

Order of magnitude of radius of earth	10^6 m
Order of magnitude of diameter of earth	10^7 m
Order of magnitude of size of atom	10^-10 m

Measurement of length

Metre ruler and measuring tape
-The metre ruler and measuring tape are commonly used to measure length
-A metre ruler can measure distances of up to 1 metre
-The measuring tape can measure straight distances longer than 1 metre
-A cloth measuring tape can measure the length along a curved surface

Digital calipers
-Digital calipers can measure the internal and external diameter of an object and the depth of an object accurately



Digital micrometer screw gauge
-The digital micrometer screw gauge is used to measure objects which are too small to be measured using the digtial calipers

Measurement of time

Pendulum
-A pendulum consists of a heavy object called a bob tied to a string
-When a pendulum is swung, it will move back and forth at regular intervals
-Each complete back and forth motion of the pendulum is called an oscillation

Pendulum clock
-A pendulum clock is clock which keeps time using a pendulum

Clocks and stopwatches
-The oscillations of springs and the natural vibrations of crystals are other motions used to keep track of time
-Most clocks and stopwatches today use quartz crystals as they are small, accurate and require little electric power

Precision of an instrument

-The smallest unit an instrument can measure is known as its precision

Instrument	Measuring range	Precision
measuring tape	0 to several metres	0.1 cm or 1 mm
metre ruler	0 to 1 metres	0.1 cm or 1 mm
digital calipers	0 to 15 centimetres	0.001 cm or 0.01 mm
digital micrometer screw gauge	0 to 2.5 centimetres	0.0001 cm or 0.001 mm

Avoiding errors of measurment

Parallax error
-Parallax error occurs when our eyes are not positioned perpendicularly above the rule of a ruler

Zero error
-Zero error occurs when a digital instrument is not set at 0 when it is fully closed

Human reaction time
-Most stopwatches can measure time to a precision of 0.01 seconds, and digital stopwatches show time up to 2 decimal places
-However we usually take readings from a stopwatch up to 1 decimal place, as stopwatches need to be started and stopped by hand
-This introduces a random error called human reaction time
-Human reaction time is around 0.3 to 0.5 seconds for most people

What are scalars and vectors?

-Scalar quantities are quantities that have only magnitude
-Vector quantities have both magnitude and direction

Scalar	Vector
distance	displacement
speed	velocity
time	weight
mass	acceleration
energy	force

Distance and displacement

Distance
-Distance is the total length covered by a moving object regardless of the direction of motion
-It is a scalar quantity, as it only has a magnitude
-SI unit: m (metre)

Displacement
-Displacement is the distance measured in a straight line in a specified direction
-It is a vector quantity, as it has both a magnitude and a direction
-SI unit: m (metre)

Speed and velocity

Speed
-Speed is the distance moved per unit time
-It is a scalar quantity, as it only has a magnitude
-SI unit: m/s (metre per second)

Velocity
-Velocity is the rate of change of displacement
-It is a vector quantity, as it has both a magnitude and a direction
-SI unit: m/s (metre per second)

Adding two vectors by the graphical method

-We can use a vector diagram to add up two vectors
-In a vector diagram, a vector quantity is represented by an arrow
-The length of the arrow is proportional to the magnitude of the vector
-The direction of the arrow indicates the direction of the vector
-Unlike scalars, vectors have magnitude and direction, and thus when we add two vectors, we cannot add only their magntiudes
-We need to find a single vector that produces the same effect as the vectors combined
-This single vector is known as the resultant vector
-It must be equivalent to the individual vectors combined in terms of magnitude and direction

Adding two parallel vectors

-If a girl walks 100 m due east and then 40 m due west, what is her displacement?
-We can find her displacement by adding her vectors graphically

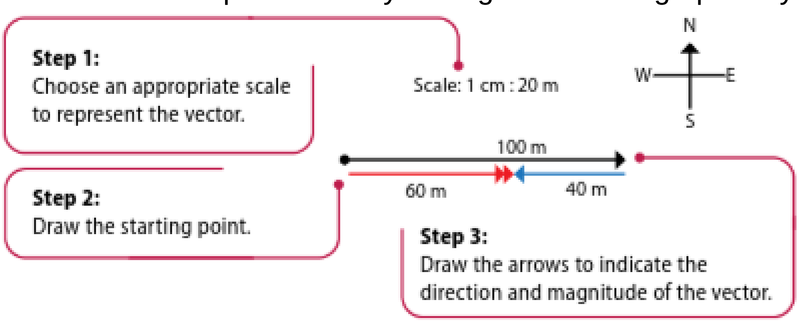


Figure 1.17 Adding two parallel vectors graphically

Figure 1.17 shows that the displacement of the girl is 60 m due east.

Adding two non-parallel vectors

-A 6 N force is exerted on a block, pushing it due east
-A 4 N force is the exerted on the same block, pushing it due north
-We can find the resultant force using the head and tail method

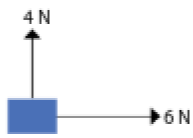


Figure 1.18 Forces acting at an angle to each other

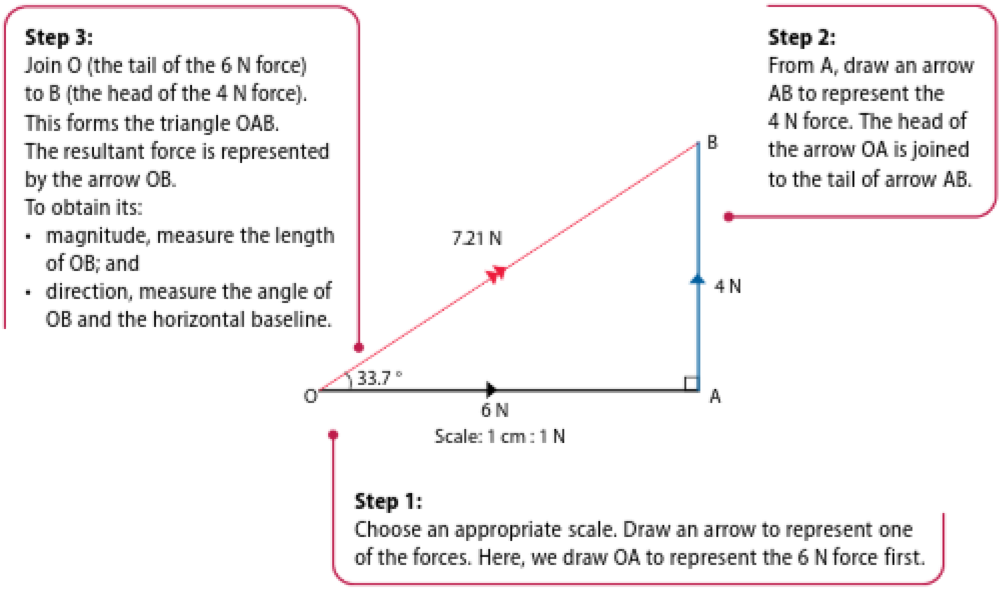


Figure 1.19 Adding two non-parallel vectors graphically

Figure 1.19 shows that the resultant force has a magnitude of 7.21 N and acts at an angle 33.7 ° to the horizontal.

-The resultant force should originate from the tail and end at the tip of the final vector

Chapter 2: Kinematics

Speed

-Speed is the distance travelled per unit time
-Formula for speed: distance / time
-Formula for average speed: total distance / total time
-Speed is a scalar quantity as it does not have a direction
-SI unit: m/s (metre per second)

Uniform speed

-When the change of distance for every unit of time is the same, the object undergoes uniform speed

Velocity

-Velocity is the rate of change of displacement
-Formula for velocity: displacement / time
-Formula for average velocity: total displacement / total time
-Velocity is a vector quantity
-SI unit: m/s (metre per second)

Acceleration

-Acceleration is the rate of change of velocity
-Formula for acceleration: change of velocity / time
-Acceleration is a vector quantity
-SI unit: m/s^2 (metre per second squared)

Uniform acceleration

-When the change of velocity of an object for every unit of time is the same, the object undergoes uniform acceleration
-Formula for uniform acceleration: (final velocity - initial velocity) / (time at which an object is at final velocity - time at which object is at initial velocity)
-Non uniform acceleration occurs if the change of velocity of an object for every unit of time is not the same

Deceleration and decrease in acceleration

-Deceleration is when the acceleration of an object decreases
-Decrease in acceleration is when the rate of acceleration decreases
-e.g. If an object is slowing down, it is decelerating, however if that object is still moving faster but at a slower rate, it is a decrease in acceleration

How do we analyse motion graphically?

Displacement time graphs
-A displacement time graph can give us some info about the motion of an object
-The displacement of an object is recorded every second and a graph is then plotted, with the displacement (m) as the y axis and the time (s) as the x axis
-The gradient of the graph is the velocity of the object

Velocity time graphs
-A velocity time graph can be used to show uniform and non uniform of an object travelling in a straight line in one direction
-Non uniform velocity occurs if the change of displacement of an object for every unit of time is not the same
-The velocity of the object (m/s) is the y axis and the time (s) is the x axis
-The gradient of the graph is the acceleration of the object
-The area under a velocity time graph gives the displacement of the object

What is acceleration of free fall?

-If an object is falling without air resistance and is thus in free fall on earth, it will have an acceleration due to gravity of 10 m/s^2, or g, which is a constant

Chapter 3: Dynamics I: Mass and Weight

What is a force?

-A force is a push or pull exerted by one object on another

Contact forces

Frictional force
-Frictional force is the force that opposes motion between two surfaces in contact
-Air resistance is a type of frictional force exerted by air which opposes the motion of moving objects
-Frictional force does not depend on surface area of contact, it only depends on the force pressing the two surfaces together and the texture of the two surfaces in contact

Normal force
-Normal force is the force exerted by a surface on an object pressing on it
-This push is always perpendicular to the surface

Tension
-Tension is the pull exerted by a stretched spring, string or rope on an object attached to it

Non contact forces

Gravitational force
-Gravitational force is the pull exerted on an object by earth's gravity

Electrostatic force
-Electrostatic force is the attractive or repulsive forces between electric charges
-There is an attractive force between unlike charges and a repulsive force between like charges

Magnetic force
-Magnetic force is the attractive or repulsive forces between magnets
-There is an attractive force between unlike poles and a repulsive force between like poles

Mass and weight

Mass
-Mass is the amount of matter in an object
-SI unit: kg (kilogram)
-It does not change with location and is a scalar quantity
-Measured using a beam balance or calibrated electronic balance

Weight
-Weight is the amount of gravitational force acting on an object that has mass
-Formula for weight: mass x gravitational field strength
-SI unit: N (newton)

-It changes with location and is a vector quantity
-Weight is directly proportional to mass
-Measured using a spring balance

Gravitational field

-A gravitational field is a region in which an object with mass experiences a force due to gravitational attraction

Gravitational field strength

-Gravitational field strength is the gravitational force per unit mass placed at that point
-Formula for gravitational field strength: weight / mass
-SI unit: N/kg (newtons per kilogram)
-The gravitational field strength of earth is 10 N/kg
-Weight changes depending on gravitational field strength

Gravitational field strength and acceleration due to gravity

-If an object is in free fall under gravity without air resistance, we can find the acceleration of the object using the equation: resultant force = mass x acceleration
-The gravitational field strength and acceleration in free fall due to gravity of an object is the same

Chapter 4: Dynamics II: Forces

Effects of forces on the motion of a body

-Forces can cause a stationary body to move, a moving body to accelerate, a moving body to decelerate and a moving body to change directions

Newton's first law of motion

-Newton's first law of motion states that every object will continue in its state of rest or uniform motion if there is no resultant force acting on it
-This tells us that if there is no resultant force on a stationary object, it will remain at rest
-It also tells us that if there is no resultant force acting on a moving object, it will travel at a uniform velocity

Inertia

-The inertia of an object refers to the reluctance of an object to change its state of rest of motion due to its mass
-Inertia is directly proportional to mass
-Thus, the heavier an object, the harder it is to change its state of motion or rest due to inertia

Newton's second law of motion

-Newton's second law of motion states that when a resultant force acts on an object with constant mass, that object will accelerate
-Formula for resultant force: mass x acceleration
-Weight is a special form of the resultant force formula, as weight is a force and gravitational field strength is the acceleration due to gravity

Newton's third law of motion

-Newton's third law of motion states that when one object exerts a force on another object, the object will exert an equal but opposite force on the first object
-Thus, every action has an equal and opposite reaction
-Action and reaction are equal in magnitude but opposite in direction
-They act on mutually opposite bodies and are of the same type (contact or non contact)

Free body diagrams

-Free body diagrams are a representation of forces acting on a body
-Frictional force is drawn between two surfaces in contact
-Gravitational force is drawn vertically downwards from the centre of gravity
-Normal force is drawn perpendicular to the surface in contact and should be drawn from the surface exerting the force
-Tension is drawn along and parallel to the string

Adding three forces with a resultant force of zero

-It is the same as drawing two vectors
-However for head to tail, all the arrows are drawn with one arrow and the triangle formed is a closed one
-For parallelogram, the resultant force is opposite to the actual force

Air resistance

-Air resistance is the frictional force acting against an object falling through air
-It always opposes the motion of moving objects, it increases with the speed of the object, increases with the surface area of the object and increases with the density of the air
-When an object falls without or in negligible air resistance, the object falls with uniform acceleration and is said to be in free fall
-If an object falls with air resistance, it will decrease in acceleration as its speed increases, eventually reaching terminal velocity
-Terminal velocity occurs when the air resistance acting against an object equals its weight, and the object cannot accelerate anymore, thus falling at a constant velocity

Chapter 5: Turning Effects of Forces

Moments

-Forces can cause things to turn, and the turning effect of a force is called the moment of the force or torque
-The moment of a force about a pivot is defined as the product of the force and the perpendicular distance from the pivot to the line of action of the force
-Formula for torque: force x perpendicular distance from the pivot to the line of action of the force
-SI unit: Nm (newton metre)
-The line of action of a force can be found by extending a force on a free body diagram with a dotted line
-In order to produce the greatest amount of torque with a certain amount of force, the direction of the force to the body must be perpendicular

Direction of moments

-Moments are vectors and thus have both magnitude and direction
-When a force is applied upwards, it has a moment with an anticlockwise direction
-When a force is applied downwards, it has a moment with a clockwise direction

The principle of moments

-The principle of moments states that when a body is in equilibrium the sum of the clockwise moments about a pivot are equal to the sum of the anticlockwise moments about a pivot
-For an object to be in equilibrium, it cannot have any rotational or translational movement
-This means that for an object to be in equilibrium, the resultant forces acting on the object is zero, and the resultant moment about any pivot is zero

Centre of gravity

-The centre of gravity of an object is an imaginary point where the entire weight of an object seems to act
-For regular objects, the centre of gravity is located at its geometrical centre
-If an object is supported on its centre of gravity, it will not move and is considered balanced
-The centre of gravity of an object can be outside the object since it is imaginary
-For irregular objects, the centre of gravity of the object is located closer to the part with more mass

Finding the centre of gravity of an irregular lamina

-A lamina is a thin sheet of material such as a card
-To find the centre of gravity of an irregular lamina, make three small holes near the edge of the lamina such that they are as far away as possible
-Suspend the lamina from a pin at one of these holes
-Hang a plumb line (a mass suspended from a string) from the same pin
-Mark the top and bottom of the plumb line and join the points with a line

-Repeat for the two other holes
-The point of intersection of the lines is the centre of gravity

Stability

-The stability of an object is its ability to return to its original position
-When an object is tilted, the point at which it touches the ground is the pivot
-If the line of action of the weight is within the base area, it will create a anticlockwise or clockwise moment about the pivot and return to its original position
-If the line of action of the weight directly passes through the pivot point, it will balance on the pivot point and the object is in equilibrium as the distance from the line of action of the weight to the pivot is zero
-If the line of action of the weight is outside the base area, it will create a anticlockwise or clockwise moment about the pivot and topple
-If the base area of the object is larger or if the centre of gravity of the object is lower, it has more stability

Chapter 6: Pressure

What is pressure?

-Pressure is the force acting on an object per unit area
-Formula for pressure: force / area
-SI unit: N/m^2 (newtons per square metre)
-It can also be measured in pascals (Pa) which is equal to 1 N/m^2
-Pressure is a scalar quantity as only the force perpendicular to the contact area is considered for calculating pressure, so since the direction remains unchanged, pressure only depends on magnitude
-Pressure in a exposed liquid container increases with depth

How is pressure transmitted through an enclosed liquid?

-Hydraulic systems are used to lift heavy loads with little force
-They make use of pascal´s principle or pascal´s law, which states that if a pressure is applied to an enclosed and incompressible liquid, the pressure is applied to all other parts of the liquid
-This means that if a force is applied on one end of a tube containing a liquid, the same amount of pressure will be exerted on the other end
-So, if there is one piston on one end and one on the other end, if the piston on the other end has a larger surface area, more force will be exerted on the piston, allowing a small force to move big objects
-By the principle of conservation of energy, which states that energy cannot be created or destroyed, only transferred in a closed system, the work done by the effort is equal to the work done on the load, and since work done is force x distance moved, we can use this to find the distance moved by the load and the effort
-Hence, F1 / A1 = F2 / A2, and F1 x d1 = F2 x d2, where F1 is the force exerted on the piston, F2 is the force exerted on the load, A1 is the area of the piston, A2 is the area of the load, d1 is the distance moved downwards by the piston and d2 is the distance moved upwards by the load
-Since the liquid cannot be compressed, the volume displaced on both sides must be the same
-The presence of air bubbles in the liquid will affect the efficiency of the hydraulic system, as air can be compressed, so some pressure is used to compress the air
-Oil is used as the liquid over water as oil does not evaporate easily, is a lubricant and also prevents corrosion

Density

-Density is defined as mass per unit volume
-Formula for density: mass / volume
-SI unit: kg/m^3 (kilograms per cubic metre)
-If a substance is less dense than another substance, it will float on top of it

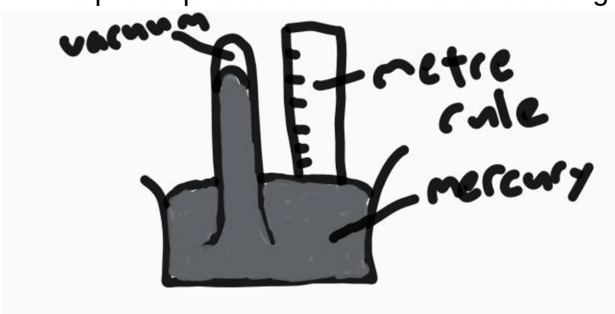
Measuring liquid pressure

-Liquid pressure is the pressure exerted by a liquid on an object inside it

-Formula for liquid pressure: hρg, where h is the depth of point below liquid in metres, ρ is the density of the liquid in kilograms per cubic metre and g is the gravitational field strength in newtons per kilogram
-Objects at the same depth beneath the liquid have the same pressure
-The deeper the depth of the object, the higher the pressure exerted on it
-The resultant force caused by the upwards pressure and the downwards pressure of a liquid is called the buoyancy force or upthrust
-If an object has a larger weight than the upthrust, it will sink

Measuring atmospheric pressure

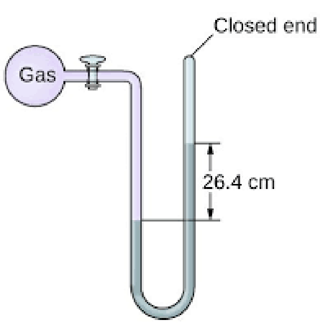
-Atmospheric pressure is the pressure exerted by the air around us due to its weight
-The atmospheric pressure at sea level is around 1 x 10^5 pascals, or 1 atmosphere (atm)
-Atmospheric pressure can be measured using a mercury barometer



-The pressure at the top of the barometer is zero due to the vacuum
-The mercury at the surface has the same pressure, which is equal to atmospheric pressure
-The pressure in the tube is due to the weight of the mercury above it
-The atmospheric pressure measured by a mercury barometer is expressed as the height of the mercury column in the barometer, which is measured from the surface of the mercury to the top of the mercury
-So, using the formula for liquid pressure, 1 atm is equal to 760 mmHg
-To check if the top of the barometer is a vacuum, the tube is tilted such that the top is below the original level of mercury, if the mercury can completely fill the tube, the space above the mercury is a vacuum

Measuring pressure differences

-To measure the difference in pressure between two gases, a manometer is used



-The difference between the two heights of the liquids shows the difference in gas pressures

-The lower the liquid level, the higher the gas pressure
-Since pressure at the same height is the same, the gas pressure from the gas supply side is equal to the pressure of 26.4 cm of the liquid in the manometer + the gas pressure on the closed end

Chapter 7: Energy

Energy

-Energy is the ability to do work
-SI unit: J (joule)

Energy stores

Kinetic store
-Energy from moving or vibrating objects
-Energy in the kinetic store is known as kinetic energy

Gravitational potential store
-Energy from the height of an object above ground
-Energy in the gravitational potential store is known as gravitational energy

Elastic potential store
-Energy from a stretched or compressed spring
-Energy in the elastic potential store is known as elastic potential energy

Chemical potential store
-Energy from food or batteries
-Energy in the chemical potential store is known as chemical potential energy

Internal store
-Energy from the temperature of an object
-Energy in the internal store is known as internal energy

Nuclear store
-Energy stored in the nuclei of atoms
-Energy from the nuclear store is known as nuclear energy

Principle of conservation of energy

-The principle of conservation of energy states that energy cannot be created or destroyed, only converted from one store to another
-It also states that the total energy of an isolated system is contant

Energy transfers

-Due to the conservation of energy, energy can only be transferred
-Energy can be transferred in four different pathways
-Energy can be transferred mechanically due to a force acting over a distance
-Energy can be transferred by heating due to a temperature difference
-Energy can be transferred by the propagation of two different types of waves, electromagnetic waves and mechanical sound waves

-Energy can be transferred electrically by an electric current

Kinetic store

-The amount of energy in the kinetic store of a moving body can be calculated using this formula: 1/2 x mass in kilograms x (velocity in metres per second) squared
-SI unit: J (joule)

Gravitational potential store

-The amount of energy in the gravitational store of a body above ground near the earth's surface can be calculated using the formula: mass of the object in kilograms x gravitational field strength in newtons per kilogram x height above the ground in metres
-SI unit: J (joule)

Work done by a force

-The work done by a force is the product of the force and the distance moved by the object in the direction of the force
-Formula for work done: force in newtons x distance moved in the direction of the force in metres
-SI unit: J (joule)
-Work is done only when the object moves in the direction the force is applied, so if a person lifts up something and walks forward, no work is done by the force lifting the object up, as the object is not moving in the direction of the force exerted by the person walking forward
-Work and energy have the same unit, as work done is equal to the energy transferred
-Work done and energy are both scalar quantities

Power

-Power is the work done or energy per unit time
-Formula for power: work done or energy converted in joules / time in seconds
-SI unit: W (watt)

Efficiency

-Efficiency is the ratio of useful energy output to the total energy input, usually expressed as a percentage
-Formula for efficiency: (useful energy output / total energy input) x 100%
-An ideal machine with an efficiency of 100% can never exist, as energy tends to be dissipated to non useful forms

How can we obtain energy?

Renewable sources
-Renewable energy is energy collected from sources which will never run out, as they are replaced by nature in less than a human lifetime

-Examples include biofuels, wind, solar and geothermal energy and tides and hydropower

Non-renewable sources
-Non renewable energy is energy collected from sources that cannot be replaced when they are used up
-Examples include fossil fuels and nuclear energy

Energy sources

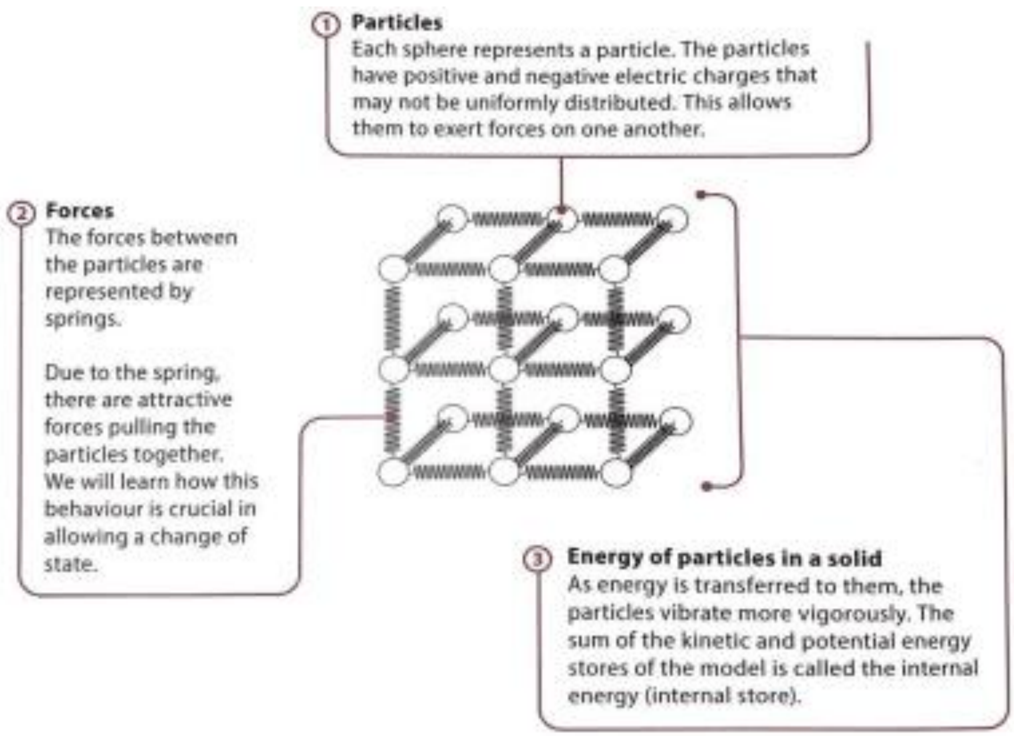
Energy resources	Efficiency	Cost	Reliability	Environmental impact
fossil fuels	efficient. most countries have well-established fossil fuel power plants.	relatively cheaper cost of production but cost rising due to declining supplies.	more reliable than others as they do not depend on environmental factors.	non-renewable. mining disrupts ecosystems. burning fossil fuels results in environmental pollution & global warming.
nuclear fuels	highly efficient - small amount of fuel needed to generate large quantities of energy.	additional cost incurred for disposal of radioactive waste.	high reliability in supplying uninterrupted power.	non-renewable. risk of accidents and contamination from improper disposal of radioactive waste.
biofuels	lower than that of fossil fuels, hydropower and tides.	relatively cheaper cost of production.	widely available on a large scale.	burning biofuels results in environmental pollution & global warming.
wind	efficiency depends on wind direction and speed.	cost falling with improving technology	intermittent power as wind speed is not consistent.	requires large open areas – loss in wildlife habitat. Noise pollution.

tides & hydropower	most efficient compared to the rest.	high cost of construction and maintainance.	more reliable than wind of solar power.	construction disrupts marine live.
geothermal reservoirs	lower than that of fossil fuels, hydropower and tides.	high cost of construction and maintainance.	not widely available as they are found only in certain regions.	environmental pollution caused by the release of poisonous gas.
solar power	efficiency depends on availablity of sunlight.	solar panel cost is falling with improving technology.	not available at night and when there is cloud cover in the day.	requires large areas to be cleared for solar panel installation.

Chapter 8: Kinetic Particle Model of Matter

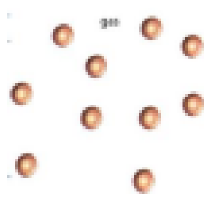
Kinetic particle model

-The kinetic particle model of matter is made up of tiny particles that are in continuous motion
-A model is different from a theory, as a model is a representation of a system or process that helps us understand a system or process, usually an incomplete representation of reality, while a theory is an explanation based on scientific facts and principle and can be used to make predictions about natural phenomena
-The kinetic particle model of matter is based on the kinetic theory of matter, which states that all matter is made up of tiny particles that are in constant, random motion



Solids, liquids and gases

States of matter	At the particle level (microscopic level)		Observable property (macroscopic level)
	Arrangement	Motion	
Solid 	Particles are closely packed and arranged in a regular pattern. They have the least energy among the 3 states of matter.	Particles vibrate about fixed positions. They are held in position by very strong attractive forces between the particles.	-Fixed shape and fixed volume -Highest density

Liquid 	Particles are slightly less closely packed than in solids and arranged in an irregular pattern.	Particles slide over each other throughout the liquid without fixed positions. The attractive forces between the particles are strong, but weaker than in solids.	-Fixed volume but no fixed shape -Lower density than solids
Gas 	Particles are very far apart from each other in an irregular pattern. They have the most energy among the 3 states of matter.	Particles move freely in any direction. The attractive forces between the particles are weak.	-No fixed shape or volume -Lowest density

Energy stores and forces of attraction between particles

-When energy is transferred to a solid, its particles vibrate more vigorously, causing an increase in energy of the kinetic store of the particles and thereby increasing its temperature
-As these vibrations increase, the particles push each other further apart, causing the solid to expand and causing the energy in the potential store to increase
-The forces of attraction between particles will decrease as particles get further apart, so if energy is continuously transferred to a solid, the forces of attraction become weaker and weaker, resulting in a phase change from solid to liquid
-The energy in the kinetic store stays constant however, resulting in a constant temperature during phase changes

Brownian motion

-If a small particle, such as a pollen grain is placed in a petri dish filled with water, it will move about in a constant and random manner without any external force applied to it
-This proves that water molecules are also moving constantly and randomly, as they are colliding with the pollen grain and causing it to move
-This also occurs with particles in air, such as smoke particles, as air molecules collide with the smoke particles as well

Temperature

-When a substance is heated, the energy in the kinetic store of the particles increases and the particles move faster
-Thus, temperature rises with the average kinetic energy of the particles in a body

-Since temperature is only the average kinetic energy of the particles, it implies that temperature is only applicable to a group of particles

Pressure

-When a gas particle collides with the inner wall of a container, it exerts a force on the wall, and the reaction force caused by the wall causes it to bounce back
-Thus, pressure at the particle level is the average force exerted by the particles per unit area
-The pressure exerted is affected by two factors, the forcefulness of each collision and the frequency of each collision
-Forcefulness is affected by the temperature, so if temperature increases, pressure increases
-Since temperature is the average kinetic energy of the particles, frequency is also affected by temperature as the particles move faster and thus collide more often
-Frequency is also affected by volume, as if the container is larger, there will be less collisions as there are less particles per unit volume, leading to a lower pressure

Chapter 9: Thermal Processes

Thermal equilibrium

-Energy is transferred from a region of higher temperature to a region of lower temperature until both objects reach the same temperature
-This state is known as thermal equilibrium
-Thermal equilibrium is the state in which two or mor objects have the same temperature and there is no net transfer in energy between them
-Energy is still being transferred on the molecular level, but on the surface level, the temperature remains the same, as the heat loss is equal to the heat gain
-Energy transfer by heating only occurs when there is a difference in temperature
-Nature has the tendency to progress towards thermal equilibrium, however an external influence can cause energy to be transferred from a colder region to a hotter region, such as with an air conditioner

Conduction

-Conduction is a process of energy transfer where energy is transferred through the passing on of vibrational motion from one particle to another
-Materials which transfer energy quickly are known as good thermal conductors, while those that transfer energy slowly are poor thermal conductors, or thermal insulators
-Conduction can occur in solids, liquids and gases

Conduction in solids

-When a non metallic object is heated on one end, the particles on that end vibrate more vigorously about their fixed positions
-Through the collisions between the particles, energy is transferred from particle to particle throughout the object, causing less energetic particles to vibrate more vigorously, leading to a rise in temperature
-When a metallic object is heated on one end, the same thing happens as in the non metallic object, however metallic objects have free electrons in their structure, which also gain energy
-Since electrons are small and fast moving, they allow for energy to be transferred quicker to less energetic particles, which is why most metals are good thermal conductors

Conduction in liquids and gases

-Compared to solids, the particles in liquids and solids are more spaced out, which is why liquids and solids are typically poorer thermal conductors than solids as the particles have a lower probability of colliding with each other
-This explains why coffee sleeves have ridges, as they trap air, which allows the sleeve to gain heat slower due to its poor thermal conductivity, insulating our hands

Convection

-Convection is the process of energy transfer by means of convection currents of a liquid or gas due to a difference in density

-In a pot, water at the bottom gains heat due to the stove, and expands due to conduction
-This reduces its density, causing it to rise up the stove and be replaced by colder, less dense water
-This process repeats, creating convection currents and heating the water
-In a room, an air conditioner cools the air around it, causing it to decrease in density and sink, being replaced by hotter, less dense air, thereby cooling the whole room

Radiation

-Radiation is the process of energy transfer by electromagnetic waves
-Unlike conduction and convection, it does not require a medium and is thus how heat is transferred to the earth from the sun
-Electromagnetic waves consist of radiowaves, microwaves, infrared, visible light, ultraviolet, x rays and gamma rays
-We cannot see any electromagnetic radiation other than visible light, but we can feel their heat
-Any object above 0K or absolute zero emits and absorbs electromagnetic radiation

Factors affecting radiation

Surface temperature
-The higher the surface temperature of an object relative to its surroundings, the higher the rate of emission of radiation
Surface area
-A larger surface area leads to a higher rate of energy transfer by radiation
Surface colour and texture
-Generally, a shiny, smooth and white object is a poorer absorber and emitter of radiation, while a matt, rough and black object is a better absorber and emitter of radiation

Differences between conduction, convection and radiation

-Convection is the transfer of thermal energy through the bulk movement of the medium, while conduction is the transfer of thermal energy through vibrations of the particles without the flow of the medium, and radiation is the transfer of thermal energy without a medium

Applications of thermal processes

Conduction
-Cooking pots and pans are made of metal to allow for faster conduction of heat to cook food, while the handles are made of poorer thermal conductors, to prevent burns
-Thermal wear for cold weather contain porous materials like feathers and microfibres to trap air
-Since air is a poor conductor of heat, the person gains heat slower
-Double or triple glazed windows trap air in between the glass panes, reducing heat loss through conduction and keeping the room warm

Convection

-Heating elements in ketttles are located at the bottom to heat water efficiently, and air conditioners and fridge cooling elements are placed at the top to cool a room or the refrigerator more efficiently respectively

Radiation

-Greenhouses are made out of glass to trap solar radiation and allow plants to grow in cold weather

-A space blanket has a shiny and smooth surface to keep a person warm as it is a poor emitter of radiation

-Greenhouse gases are good at trapping radiation, so more solar radiation is being trapped by these greenhouse gases due to global warming, leading to the temperature on earth increasing

-The hollow plastic stopper of a vacuum flask reduces heat loss or gain through conduction as plastic and air are both poor thermal conductors

-There is a double walled glass bottle in the vacuum flask with a vacuum in it, preventing heat loss or gain through conduction and convection as there is no medium

-The silver lining between the double walls reduces heat transfer via radiation as it reflects the heat in or out

-The cork at the bottom of the vacuum flask is a poor thermal conductor, reducing heat loss or gain through conduction

Chapter 10: Thermal Properties of Matter

Internal energy

-Internal energy is the sum of the total kinetic energy associated with the random motion of the particles and the total potential energy between the particles in the system
-The kinetic energy of the particles increases with temperature, while the potential energy of the particles increases with the distance between the particles

Heat capacity

-The heat capacity of an object is the change of amount of internal energy per unit change in temperature
-Formula for heat capacity: $C = Q / \Delta\theta$, where C is the heat capacity, Q is the amount of energy transferred to or from the internal store of the object by heating in joules and $\Delta\theta$ is the change in temperature in degrees celsius or kelvin
-SI unit for heat capacity: J/K
-Other units include J/°C
-It is affected by the number of particles in a body and the strength of intermolecular forces
-The heat capacity of an object is not fixed

Specific heat capacity

-Specific heat capacity of a material is the change of amount of its internal energy per unit mass for each unit change in its temperature
-Formula for specific heat capacity: $c = Q / m\Delta\theta$, where c is specific heat capacity, Q is the amount of energy transferred to or from the internal store of the object by heating in joules, m is the mass of the object in kilograms or grams, and $\Delta\theta$ is the change in temperature in degrees celsius or kelvin
-SI unit for specific heat capacity: J/(kgK)
-Other units include J/(gK) or J/(kg°C)
-The units used for specific heat capacity and heat capacity need not be in SI units, as long as they are comparable
-e.g. kilograms and grams are comparable as they are just multiplied by a factor of 1000
-The specific heat capacity of a body is fixed as it is independent of its mass

Changes of state

-Matter changes state when they gain or lose energy
-Melting is the change from the solid to liquid state, when energy is transferred into the substance
-Solidification is the change from the liquid to solid state, when energy is transferred out of the substance
-Boiling is the change from the liquid to gaseous state, when energy is transferred into the substance
-Condensation is the change from the gaseous to liquid state, when energy is transferred out of the substance

-During a change of state, the temperature of a pure substance remains constant, as energy is transferred into or out of a substance to increase or decrease the potential energy of the particles, so the distance between the particles increases or decreases
-However, the kinetic energy of the particles remains constant in both situations, so temperature remains constant

Evaporation

-Evaporation is the change of state from liquid to gas
-It occurs as particles in a liquid move at different speeds, and faster particles at the liquid surface have enough energy to overcome the attractive forces of the other liquid particles and escape into the air
-After these faster particles escape, the average kinetic energy of the particles in the liquid drops, which is why temperature drops during evaporation

Factors affecting rate of evaporation

-Higher temperature increases the rate of evaporation as warmer liquid means more liquid molecules have higher kinetic energy to escape into the air
-Higher humidity of the surrounding air decreases the rate of evaporation, as there will be more water vapour present in the air which makes it harder for liquid molecules to escape
-Larger surface area of the liquid increases the rate of evaporation as more molecules can escape from the exposed surface area
-Lower atmospheric pressure increases the rate of evaporation as there are fewer air molecules in the air
-Higher wind speed increases the rate of evaporation as moving air removes the liquid molecules as soon as they escape from the liquid surface
-Lower boiling point of the liquid increases the rate of evaporation as the attractive forces between the liquid particles with a lower boiling point are weaker

Boiling and evaporation

Boiling	Evaporation
needs a heat source	does not need a heat source
vaporisation takes place throughout the liquid	vaporisation only occurs at the liquid surface
rate of vaporisation is slower	rate of vaporisation is faster
happens only at boiling point	happens at temperatures lower than boiling point
temperature remains constant	temperature tends to drop

Latent heat

-Latent heat is the energy released or absorbed to change the state of a substance, at constant temperature
-SI unit for latent heat: J
-There are two types of latent heat, latent heat of fusion and latent heat of vaporisation
-Latent heat of fusion is used for melting and solidification
-Latent heat of vaporisation is used for boiling and condensation

Specific latent heat

-Specific latent heat of fusion is the amount of energy transferred per unit mass of a substance to change between the solid and liquid states, at constant temperature
-Formula for specific latent heat of fusion: $l_f = L_f / m$, where l_f is the specific latent heat of fusion, L_f is the latent heat of fusion in joules, and m is the mass of the substance in kilograms
-Specific latent heat of vaporisation is the amount of energy transferred per unit mass of a substance to change between the liquid and gaseous states, at constant temperature
-Formula for specific latent heat of vaporisation: $l_v = L_v / m$, where l_v is the specific latent heat of vaporisation, L_v is the latent heat of vaporisation in joules, and m is the mass of the substance in kilograms
-SI unit of specific latent heat (both): J/kg
-Specific latent heat of vaporisation is usually much higher than the specific latent heat of fusion, as changing from a liquid to a gas requires a much larger increase in volume than changing from a solid to a liquid, hence more energy is transferred to the substance to overcome the forces of attraction between the particles

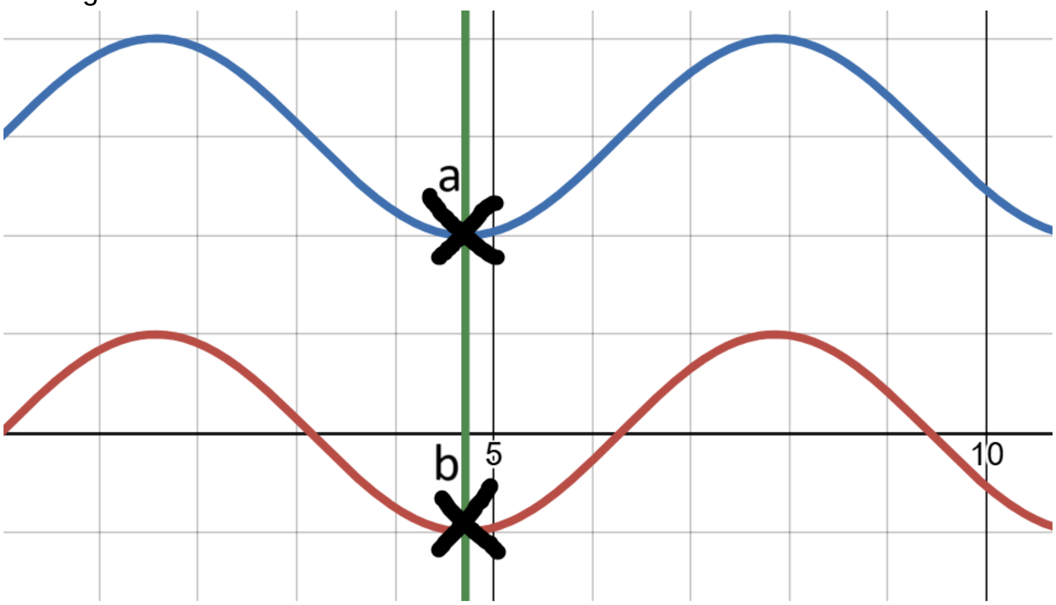
Chapter 11: General Wave Properties I

What is a wave?

-A wave is a disturbance that propagates through space, transferring energy with it but not matter

Wavefront

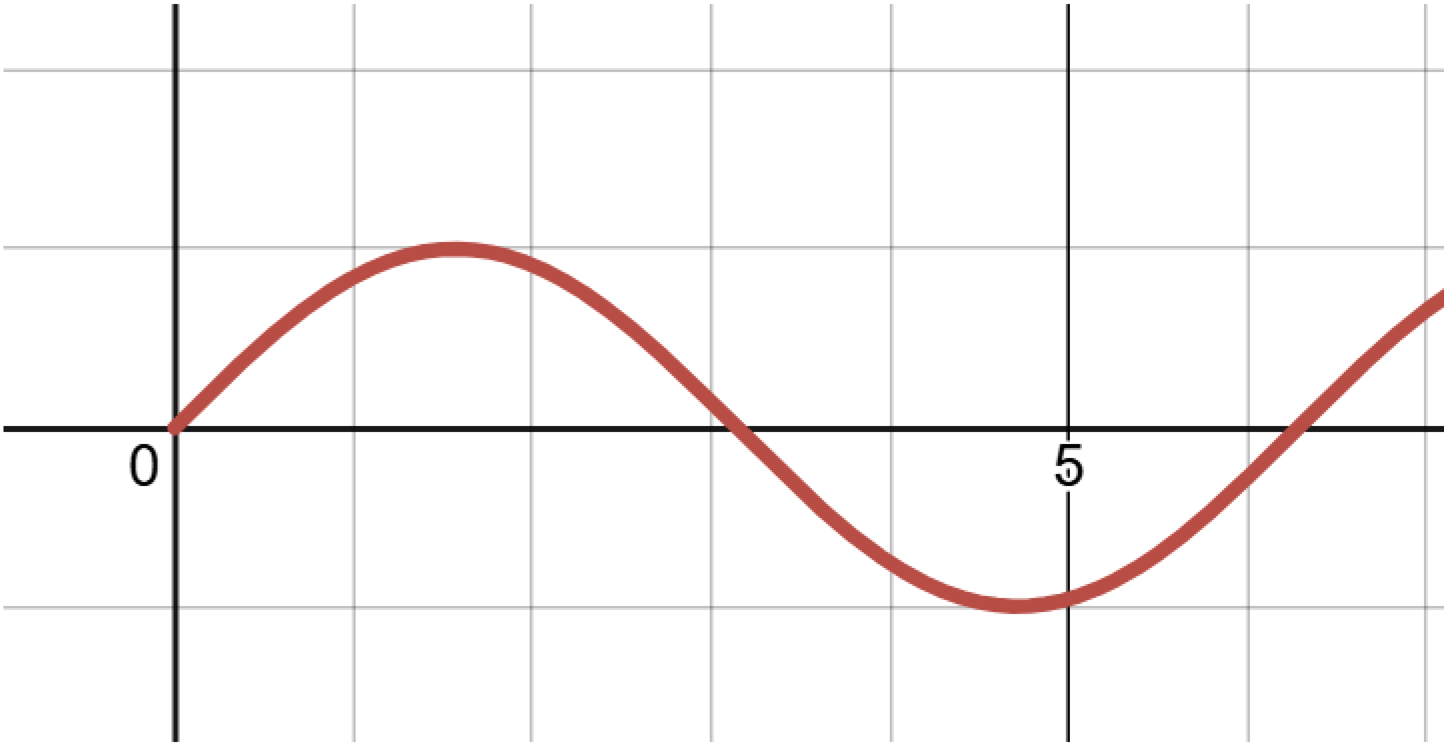
-A wavefront is an imaginary line that joins all adjacent points on a wave that are in phase
-Two points that are in phase will have the same displacement from the rest position and will be moving in the same direction



-Points a and b are in phase, hence the green line is the wavefront

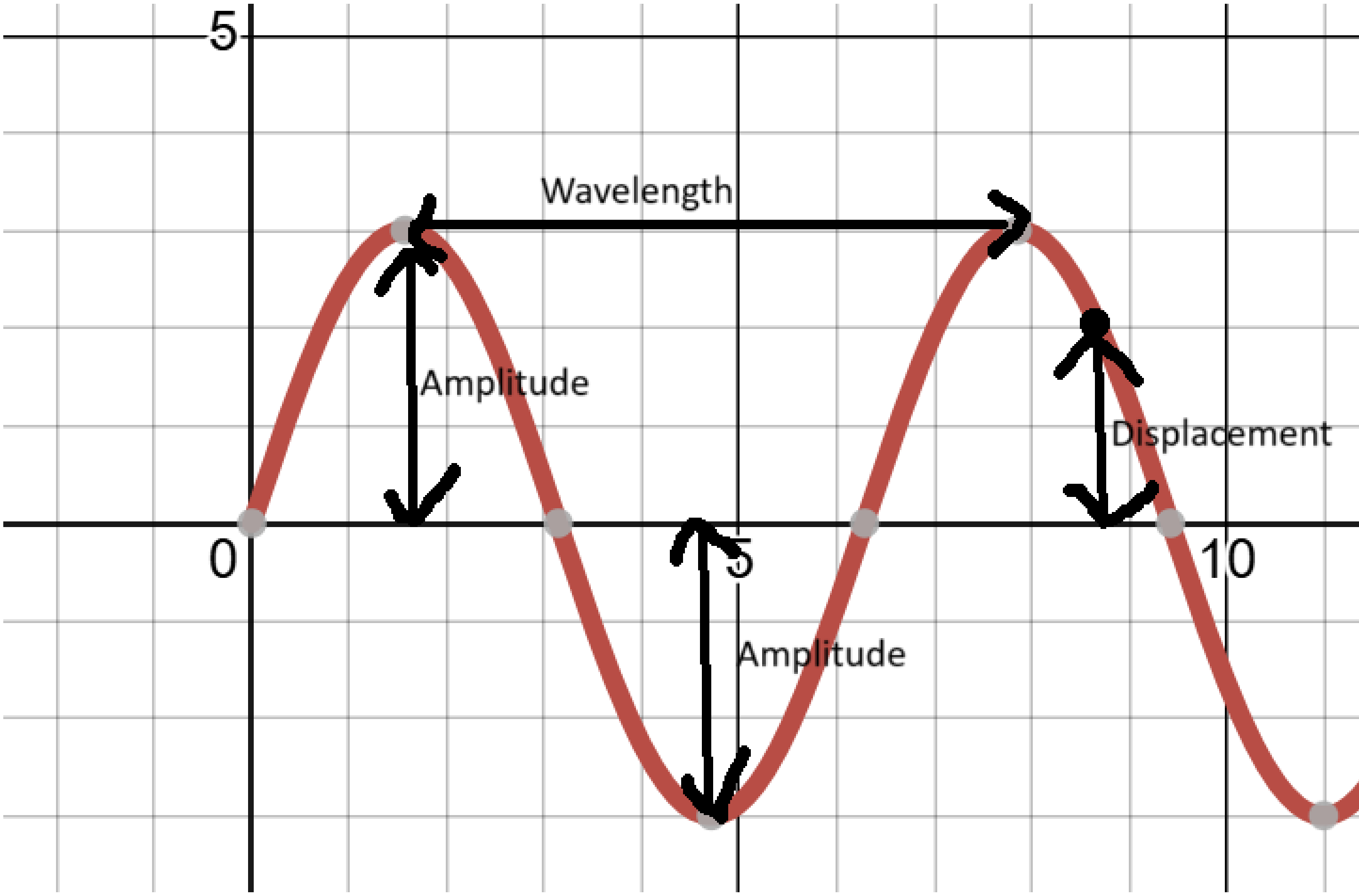
Waveform

-The shape of a wave is called the waveform
-From the image below we can see that the motion of any selected point on a wave is periodic and repetitive
-This motion is known as a vibration or a oscillation



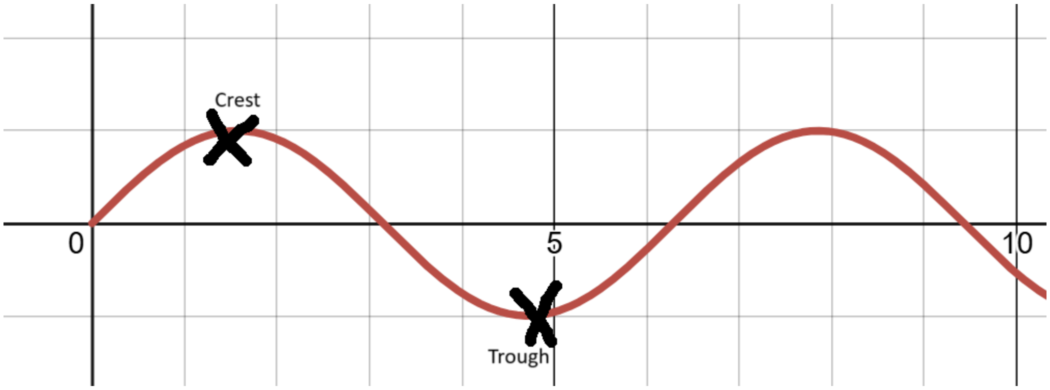
Characteristics of waves

-There are two types of waves, transverse and longitudinal
-These types of waves affect the direction of vibration of the wave
-The rest position of a wave is the line horizontally cutting through the middle of the wave
-The displacement of a point on a wave is its distance from its rest position in a specified direction
-The amplitude (A) of a wave is the maximum magnitude of displacement of a point from its rest position
-The wavelength (λ) of a wave is the shortest distance between any two points that are in phase
-The period (T) of a wave is the time taken for a point on a wave to complete one oscillation, or one wavelength



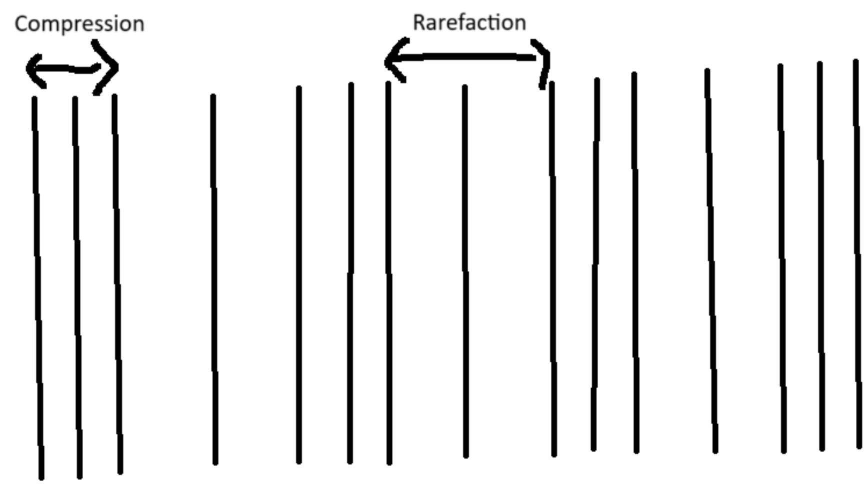
Transverse waves

-Transverse waves have a direction of vibration perpendicular to wave travel
-They have crests and troughs, where the crests are the highest points of the wave, and the troughs are the lowest points
-The wavelength of a transverse wave can be defined as the distance between two successive crests or two successive troughs
-Examples of transverse waves include electromagnetic waves as well as water waves



Longitudinal waves

-Longitudinal waves have a direction of vibration parallel to wave travel
-They have compressions and rarefactions, where compressions are points where the particles of the wave are closer together, and rarefactions are points where the particles of the wave are further apart
-The wavelength of a longitudinal wave can be defined as the distance between two successive compressions or two successive rarefactions
-Examples of longitudinal waves include sound waves as well as some waves from an earthquake



Frequency

-The frequency of a wave is the number of oscillations each point completes per second
-SI unit for frequency: Hz (hertz)
-Formula for frequency: $f = 1 / T$, where f is the frequency in hertz and T is the period in seconds

Wave speed

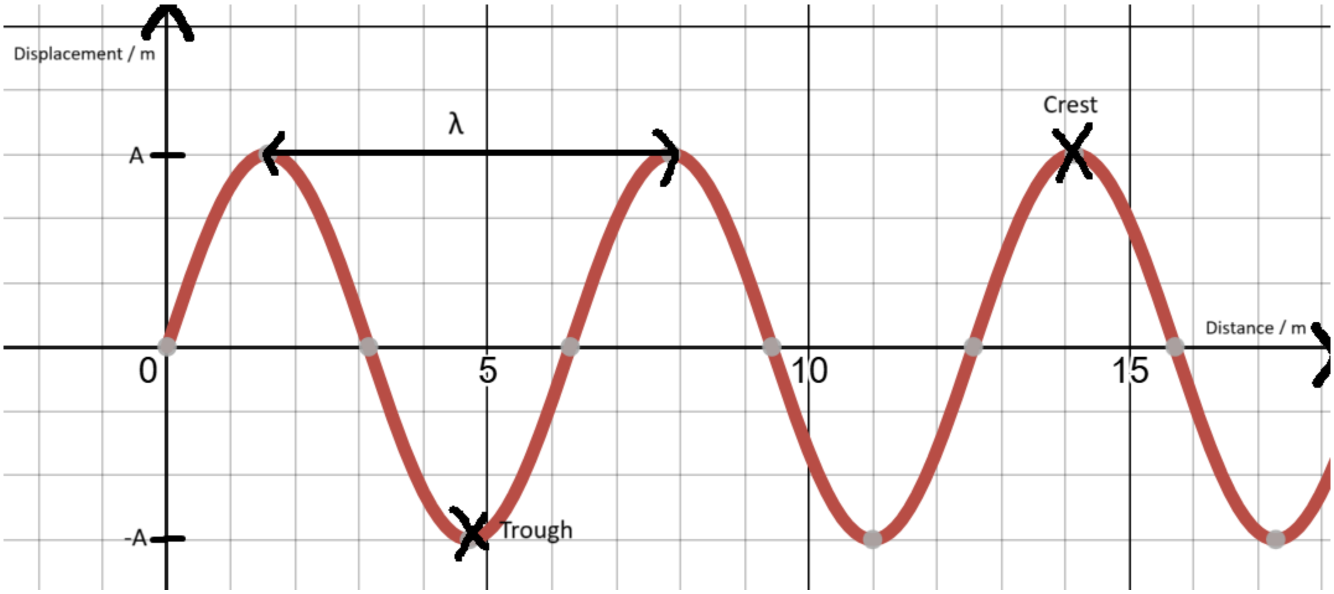
-The wave speed of a wave is the distance travelled by a wave per second
-SI unit for wave speed: m/s
-Formula for wave speed: $v=f\lambda$, where v is the wave speed in metres per second, f is the frequency in hertz, and λ is the wavelength in metres

Factors affecting a wave

-When light travels from air to glass, its speed decreases
-Hence, wave speed is affected by the medium the wave travels in
-However, the colour of light does not change when entering the glass
-Hence, frequency is determined by the source of the wave ans is not affected by the medium the wave travels in
-From $v=f\lambda$, wavelength is affected by the wave speed and frequency

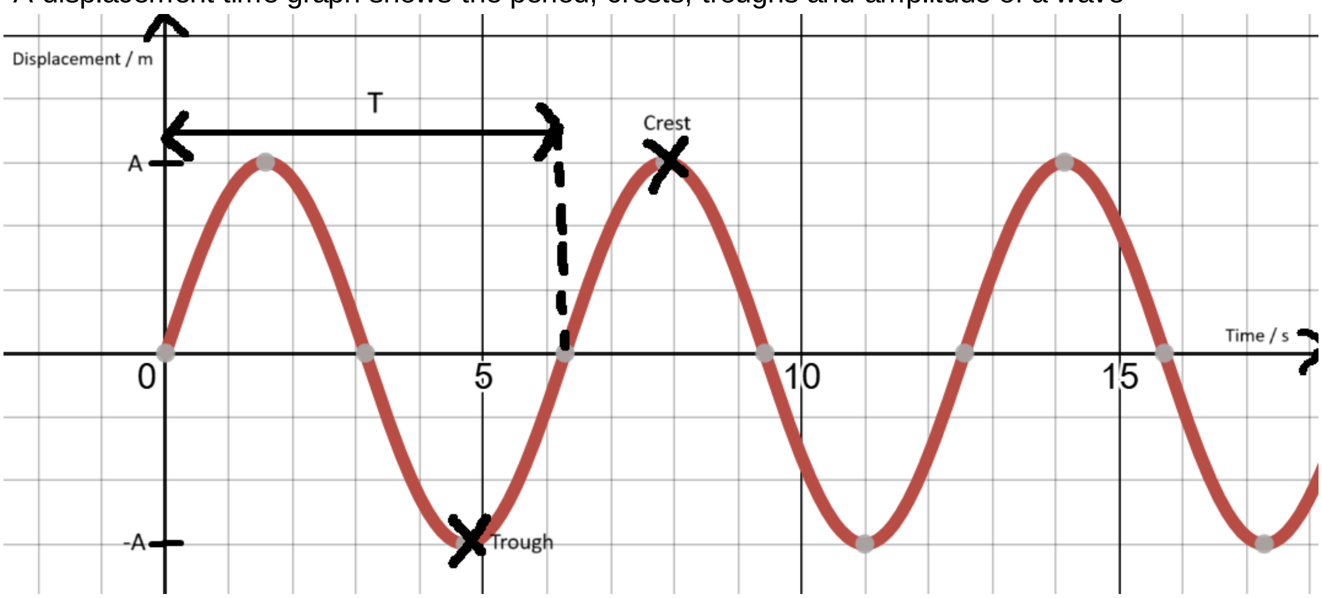
Displacement distance graph

-A wave can be shown on a displacement distance graph
-It shows multiple particles on a wave in one moment in time, hence the graph will change depending on the instance in time it is from
-A displacement time graph can show the amplitude, crests, troughs and wavelength of a wave



Displacement time graph

-A wave can be shown on a displacement time graph
-It shows the displacement of one particle over a period of time
-A displacement time graph shows the period, crests, troughs and amplitude of a wave



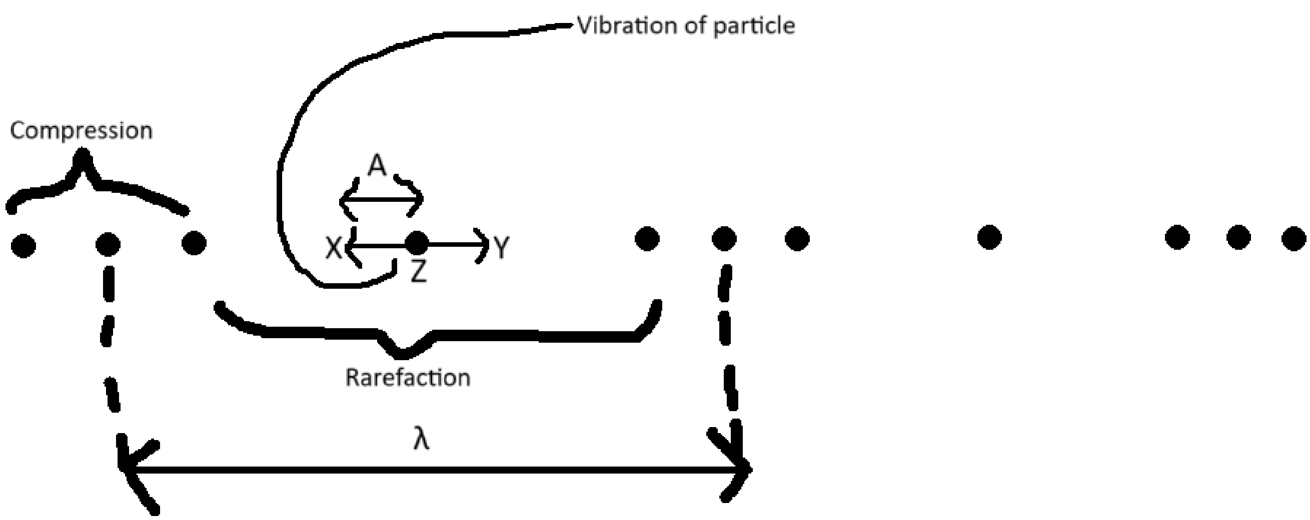
Chapter 12: General Wave Properties II: Sound

What is sound?

-Sound is produced when objects vibrate in a medium
-When sound propagates through air, air particles vibrate parallel to the direction of the sound wave
-Hence, sound is a longitudinal wave

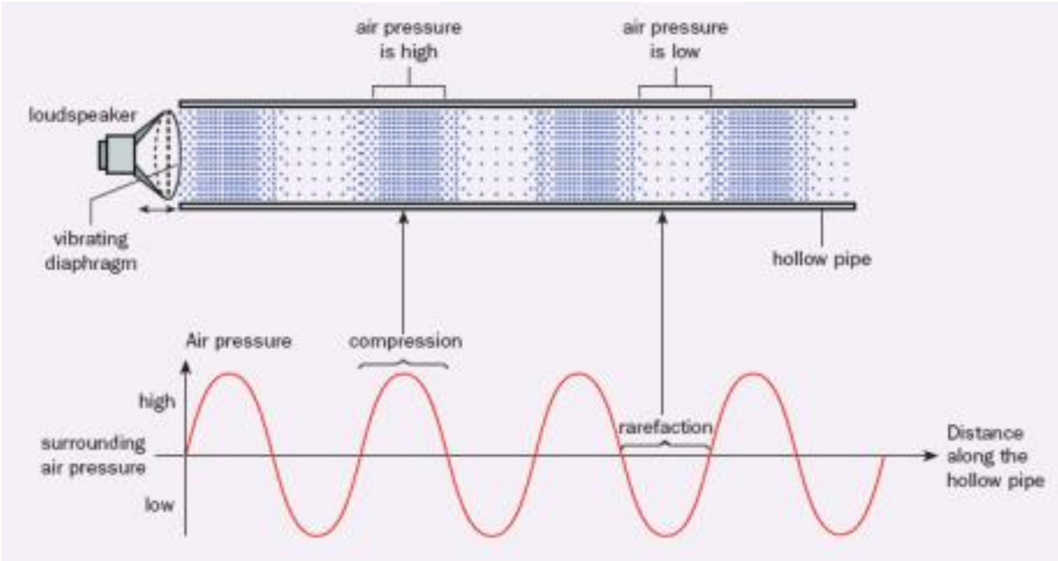
Characteristics of sound

-Like transverse waves, sound waves also have amplitudes and wavelengths
-However, they have compressions and rarefactions, where compressions are points where the particles of the wave are closer together, and rarefactions are points where the particles of the wave are further apart
-In the image below, the particle vibrates left and right from point X to Z to Y then back to Z
-The amplitude of the wave is the distance from X to Z of from Z to Y
-The wavelength of a longitudinal wave can be defined as the distance between two successive compressions or two successive rarefactions
-Sound cannot travel through a vacuum because a medium is required to transmit sound
-The speed of sound depends on how closely the atoms in a medium are
-Sound travels fastest in solids and slowest in gases



Pressure distance graph

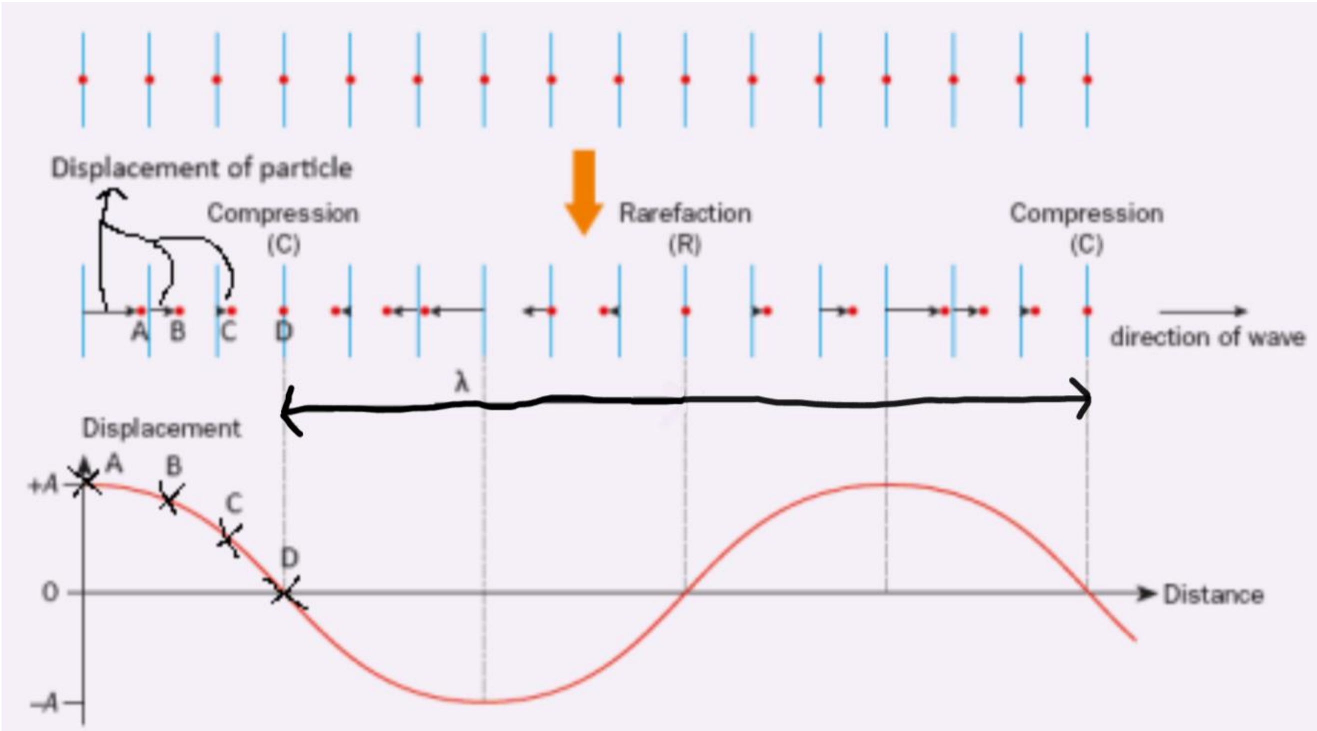
-A sound wave can be shown on a pressure distance graph
-It shows how the pressure changes with distance from the source
-When air pressure is higher than the surrounding air pressure, there will be a compression
-When air pressure is lower than surrounding air pressure, there will be a rarefaction



-Note that the x axis of the pressure distance graph is not 0, but is at the surrounding air pressure

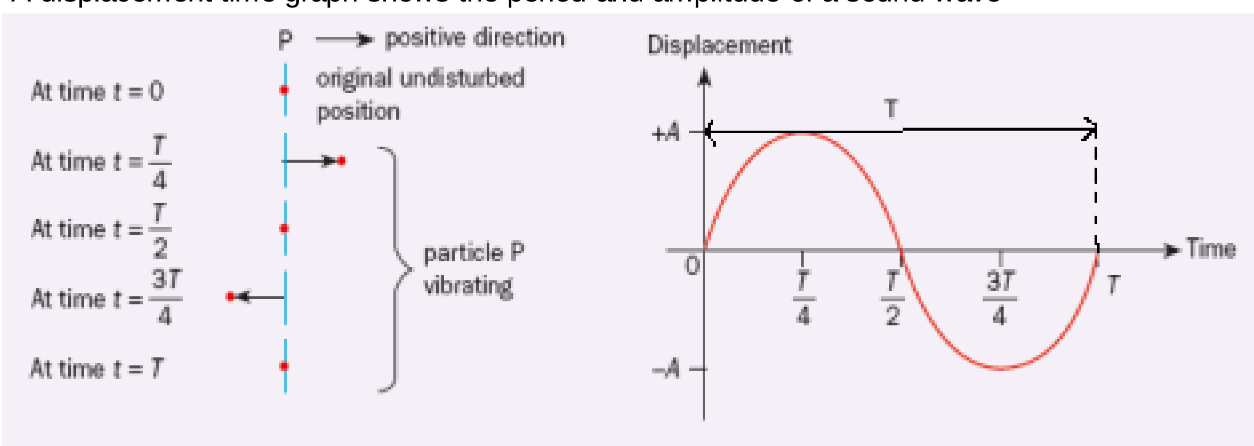
Displacement distance graph

-A sound wave can be shown on a displacement distance graph
-It shows the individual displacements for multiple particles of a sound wave from their rest positions for one moment in time
-A displacement time graph can show the amplitude, compressions, rarefactions and wavelength of the sound wave
-The compressions and rarefactions occur when the displacement of the wave is 0, with one occurring after another



Displacement time graph

-A wave can be shown on a displacement time graph
-It shows the displacement of one particle over a period of time
-A displacement time graph shows the period and amplitude of a sound wave



Loudness and pitch

-The loudness of a sound wave is affected by the amplitude
-A higher amplitude means a louder sound and vice versa
-The pitch of a sound wave is affected by the frequency
-A higher frequency means a higher pitch and vice versa
-Like light, humans have an audible range of frequencies for sound
-This range is from 20 Hz to 20000 Hz

-Sound waves below 20 Hz are called infrasound and sound waves above 20000 Hz are called ultrasound

Echoes

-Echoes are created by the reflection of sound waves which occurs when sound waves travel from one medium to another

Using echoes

Measuring the speed of sound
-By clapping your hand towards a wall and measuring the amount of time it takes for the echo to be heard, we can measure the speed of sound in air
-We can do this by using the formula for speed, or $v = d / t$
-d will be the total distance between you and the wall multiplied by two, since an echo must reflect back for you to hear it
-t is the time taken for the echo to be heard
-The speed of sound in air is around 340 m/s

Echolocation
-Animals such as bats and dolphins use echolocation to locate objects around them
-Humans can use a sound emitter and sound sensor to calculate the distance between the emitter and the reflecting surface, using $d = v \times t$, where d is the distance between the emitter and the reflecting surface multiplied by two, v is the speed of sound in the medium, and t is the time it takes for the echo to return
Using ultrasound
Sonar
-Sonar can be used to determine the distance between an object and a surface
-This can be done by sending a pulse of ultrasound from the object to the surface, and finding the time taken for the echo to return
-Ultrasound is used as it has a higher penetrating power than regular sound
-For example, a boat can detect the depth of the sea by finding the distance between them and the seabed using sonar, using $d = v \times t$, where d is the distance between the boat and the seabed multiplied by two, v is the speed of sound in water, and t is the time it takes for the echo to return

Quality control
-Ultrasound can be used to detect cracks in concrete during quality control
-If there are no cracks in concrete, a pulse of ultrasound will be returned as only one echo when it reaches the bottom of the concrete
-However, if there are cracks in the concrete, some of the ultrasound will be reflected earlier due to the air in the crack, and the rest will be reflected by the bottom of the concrete
-The presence of two echoes shows that there is a crack in the concrete
-The depth of the crack can be found using $d = v \times t$, where d is the distance between the surface of the concrete and the crack multiplied by two, v is the speed of sound in concrete, and t is the time it takes for the echo to return

-We can also find the depth of the concrete using d = v x t, where d is the depth of the concrete multiplied by two, v is the speed of sound in concrete, and t is the time it takes for the echo to return

Medical applications

-Ultrasound can be used for medical applications, such as for imaging internal organs, scanning of a baby before it is born (prenatal scanning), the break up of kidney stones and cancer treatment

Chapter 13: Electromagnetic Waves

The electromagnetic spectrum

-In order of increasing frequency and decreasing wavelength, this is the electromagnetic spectrum:

1. Radio waves
2. Microwaves
3. Infrared light
4. Visible light
5. Ultraviolet radiation
6. X rays
7. Gamma rays

Spectrum of visible light

-In sunlight and white light, light is made up of the seven colours below, in order of increasing frequency and decreasing wavelength:

1. Red light
2. Orange light
3. Yellow light
4. Green light
5. Blue light
6. Indigo light
7. Violet light

Properties of electromagnetic waves

-All bodies emit a range of electromagnetic waves, and in general, hotter bodies tend to emit more and higher frequency electromagnetic waves
-Electromagnetic waves have a range of frequencies, some of which may overlap
-All electromagnetic waves are transverse waves
-All electromagnetic waves are produced by oscillating electric and magnetic fields
-However, they do not carry electric charge
-They can travel without a medium and at the same speed of 3 x 10^8 m/s in a vacuum
-They obey the wave speed equation speed = frequency x wavelength or $v = f\lambda$
-As they travel from a vacuum to another medium, their wave speed and wavelength decrease, while their frequency remains the same as the source
-The can undergo reflection and refraction
-They transfer energy from one body to another

Uses of electromagnetic waves

Type of wave	Uses
radio wave	radio and television communication, astronomy, radio Frequency identification (RFID) tag

microwave	mobile (cell) phones, microwave oven, satellite television
infrared	infra-red remote controllers, intruder alarms, thermal imaging
visible light	photography, optical fibres in medicine and telecommunication
ultraviolet	sunbeds, bank note authentication, disinfecting water
x rays	medical radiology, security screening, industrial defect detection
gamma rays	sterilising food, detection of cancer and its treatment

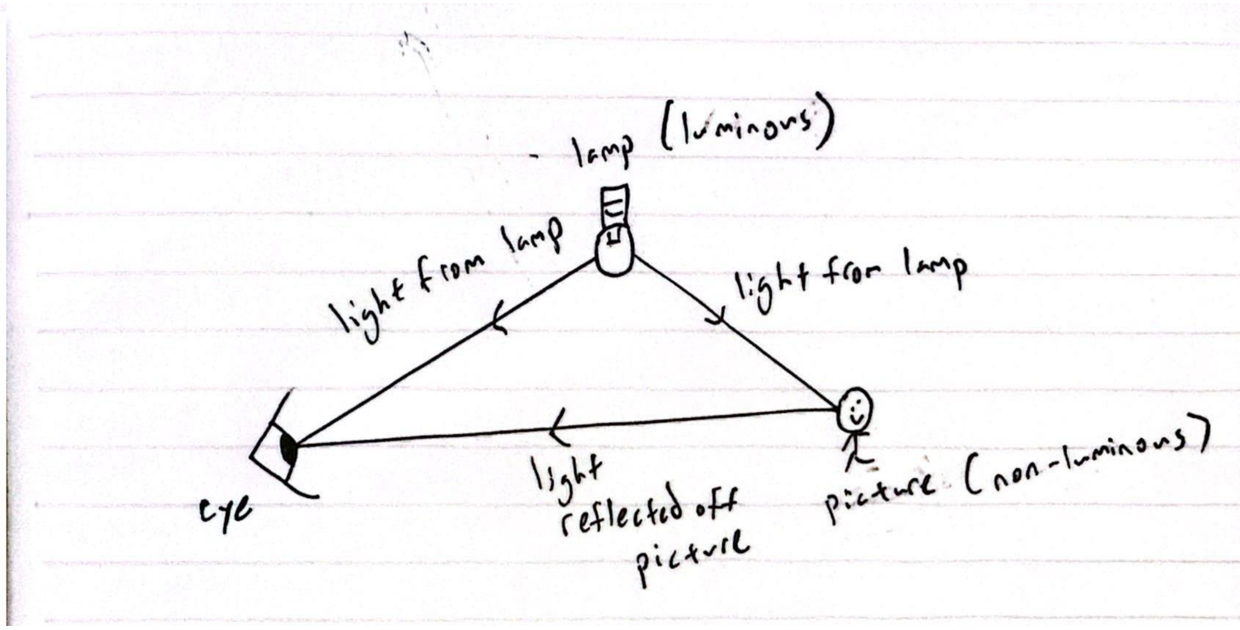
Ionising radiation

-The waves on the electromagnetic spectrum are all forms of radiation, but most of them are non ionsing and not dangerous
-However, electromagnetic waves with higher frequencies, such as ultraviolet radiation, x rays and gamma rays, have higher energies and are hence ionising
-Ionising radiation has enough energy to eject electrons from atoms and molecules to form ions, hence their name
-This ionisation can disrupt cell function and cause cells to mutate or die as their high energy can damage DNA, leading to diseases, organ failure and death
-High levels of exposure to ultraviolet radiation from the sun can lead to heightened risk of skin cancer and premature aging

Chapter 14: Light

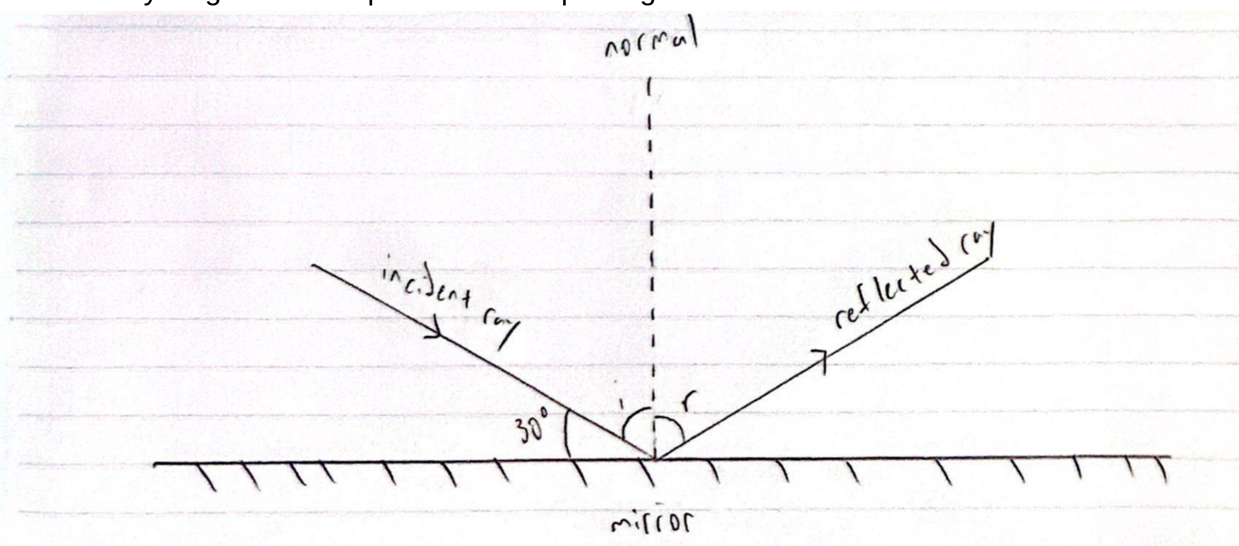
How does light allow us to see?

-We see things when light enters our eyes
-The light can come from luminous or non luminous objects



Laws of reflection

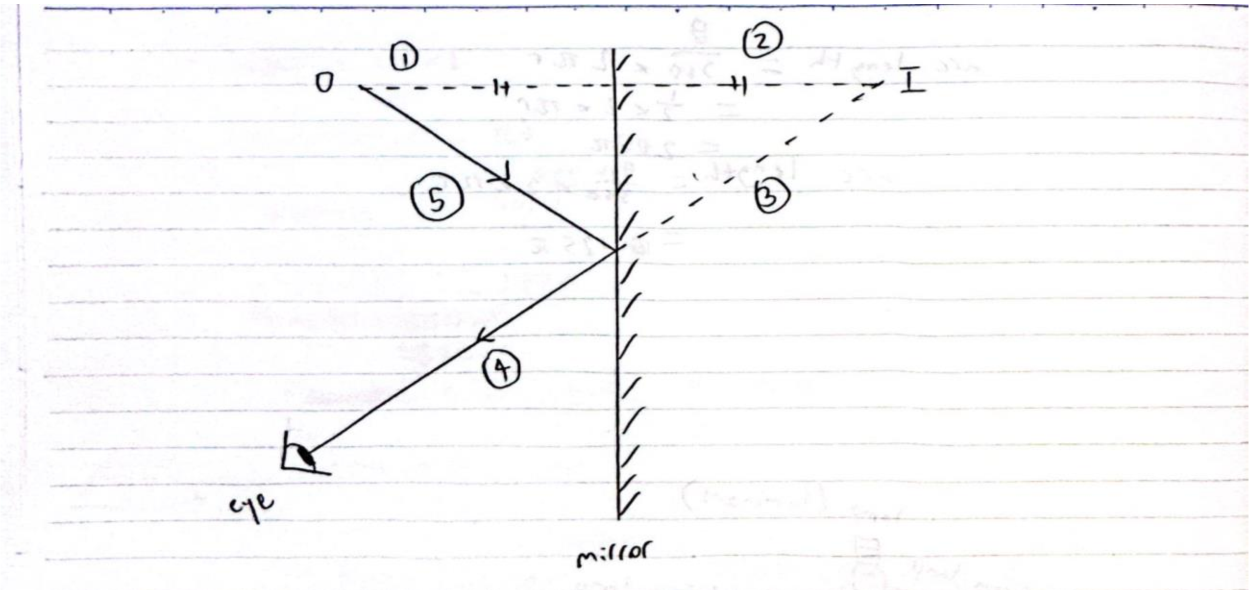
-We use ray diagrams to help visualise the path light takes



-The dotted line represents the normal, and is perpendicular to the reflecting surface
-Angle i is the angle of incidence
-Angle r is the angle of reflection
-i=r=60°
-The first law of reflection states that the incident ray, reflected ray and the normal at the point of incidence all lie on the same plane
-The second law of reflection states that the angle of incidence is equal to the angle of reflection

Characteristics of mirror images
-An image formed by a mirror is upright, laterally inverted, same size as the object, virtual and its distance from the mirror is equal to the distance of the object from the mirror

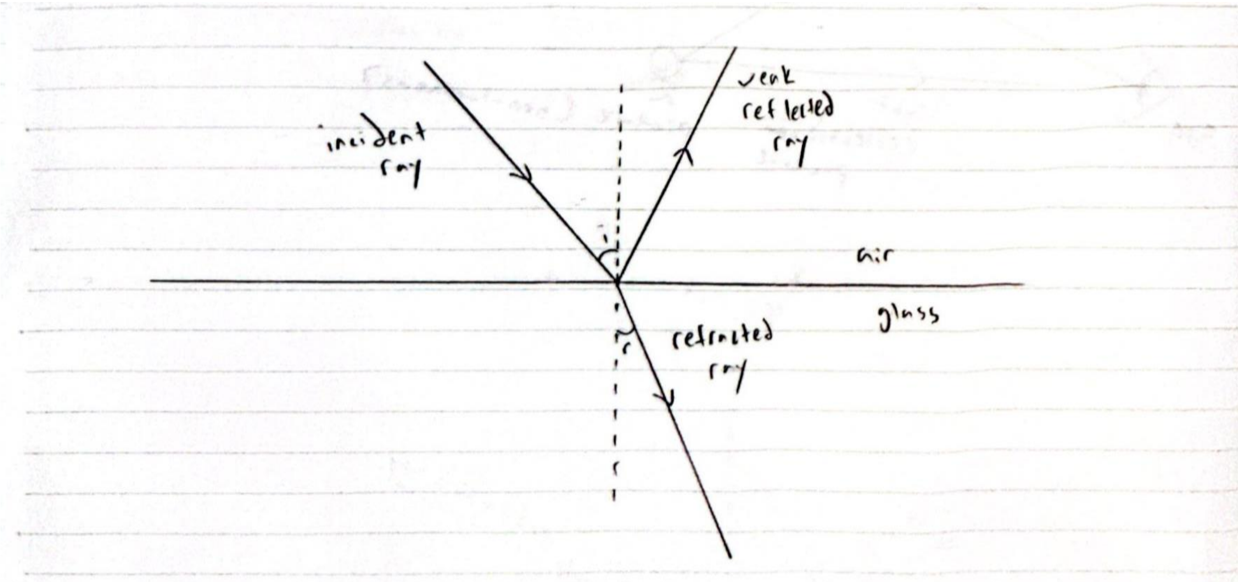
Constructing ray diagrams



1. Draw a dotted construction line from the object labelled O to the mirror, ensuring it is perpendicular to the mirror
2. Measure the distance from the object to the mirror and locate the image labelled I
3. Draw a dotted line from the image to the mirror in the direction of the center of the eye
4. Draw a solid line connecting the dotted line to the eye
5. Draw a solid line connecting the mirror the the object at the point where the light ray exits the mirror

How is light refracted?

-Refraction is the bending of light as light passes from one optical medium to another
-This is because the speed of light changes as it travels from one medium to another



-The dotted line represents the normal, perpendicular to the surface
-i is the angle of incidence
-r is the angle of refraction
-When light passes from an optically less dense medium to an optically denser medium, the light will slow down and bend towards the normal
-When light passes from an optically denser medium to an optically less dense medium, the light will speed up and bend away from the normal

Laws of refraction

-The first law of refraction states that the incident ray, refracted ray and the normal all lie on the same plane
-The second law of refraction states that for two given mediums, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant
-This means that sin i / sin r is a constant, which is the refractve index of the medium

Refractive index

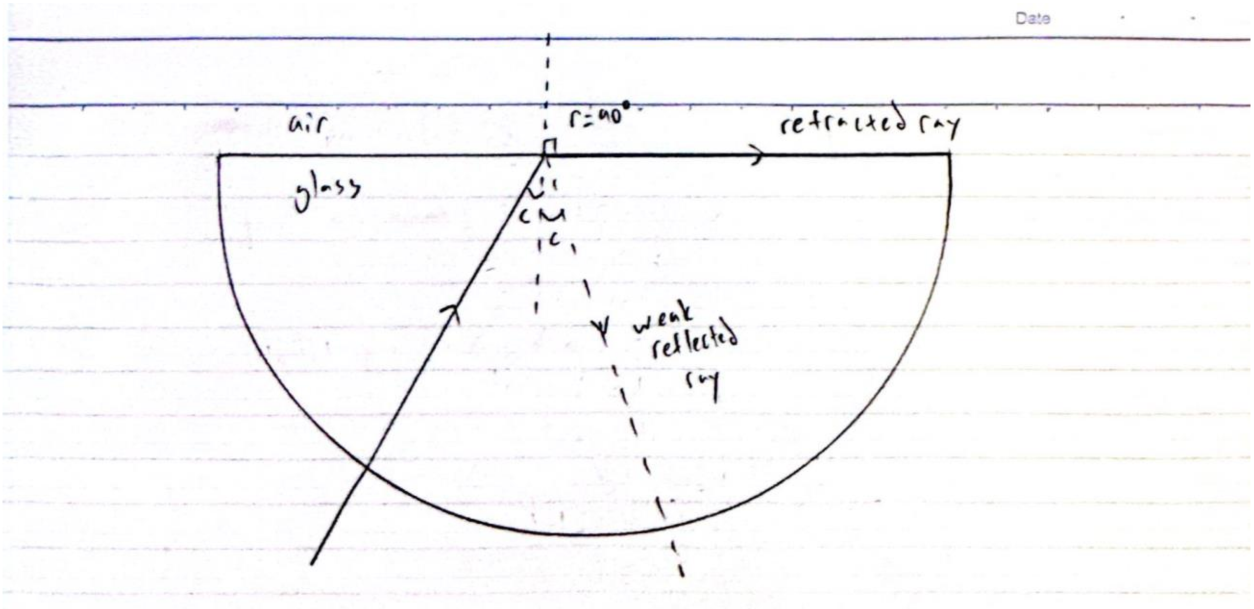
-The refractive index of a medium is defined as the ratio of the speed of light in a vacuum to the speed of light in the medium
-Formula for refractive index: n = c / v, where n is refractive index, c is the speed of light in a vacuum and v is the speed of light in the medium
Formula for refractive index: n = sin i / sin r, where n is refractive index, i is the angle of incidence, and r is the angle of refraction
-The speed of light in a vacuum is approximately 3.0×10^8 m/s, and is the fastest theoretical speed an object can travel at
-Since the speed of light in a vacuum will always be higher than the speed of light in the medium, n will always be greater than 1

Principle of reversibility of rays

-The principle of reversibility of rays states that regardless of how many times a light ray has been reflected or refreacted, it will follow the same path when its direction is reversed
-So, when light exits a glass cube, the angle of refraction of the exiting light ray will be equal to the angle of incidence of the entering light ray, and they will both be parallel

Critical angle

-When light travels from an optically denser medium to an optically less dense medium, the maximum angle of refraction is 90°



-When this happens, the angle of incidence is the critical angle, denoted by a small letter c
-Critical angle is the angle of incidence in an optically denser medium for which the angle of refraction in the optically less dense medium is 90°
-Formula for refractive index: n = 1 / sin c, where n is refractive index and c is critical angle

Total internal reflection

-When the angle of incidence exceeds the critical angle, there is no more reflection and instead the light will be reflected back into the medium of the incident ray
-Total internal relection is the complete reflection of a light ray in an optically denser medium at the boundary with an optically less dense medium
-It only occurs when light travels from an optically denser to less dense medium, and when the angle of incidence of in the optically denser medium is greater than the critical angle

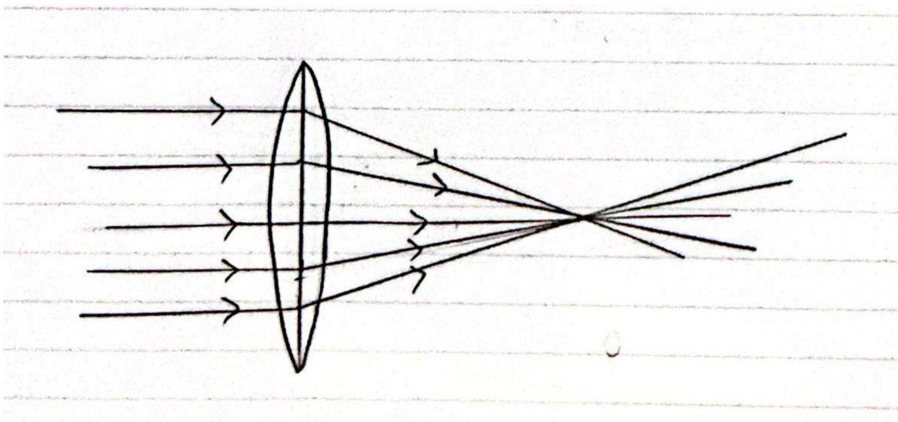
Applications of total internal reflection

-Prisms are used over mirrors to reflect light as they do not have silvered surfaces which wear off and do not produce multiple images
-Periscopes reflect light 90° to allow us to see an image

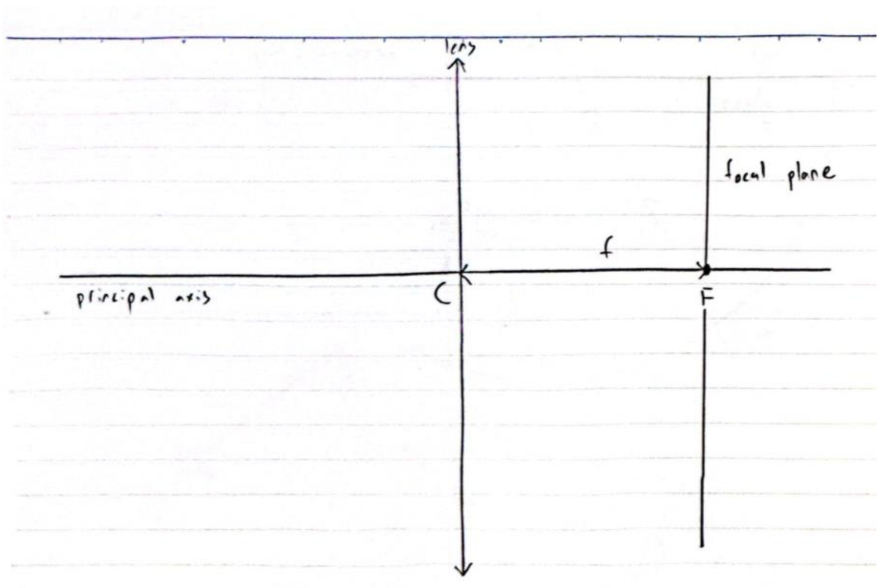
-Binoculars reflect light 180° to allow us to see an image
-An optical fibre core has a higher refractive index than its coating, so light will be internal reflected if it is bent
-This allows them to carry more information over longer distances, experience less signal loss, be lighter and be cheaper to manufacture than copper wires

Converging lenses

-A converging lens is a device usually made of glass used to concentrate light rays
-They are thicker in the centre of the lens as compared to their rims
-This causes light to refract differently at each point of the lens, making them converge to a point



Describing converging lenses



-The principal axis the the line which passes through the centre of the lens and which is perpendicular to the lens
-C is the optical centre of the lens, which is the point on the principal axis that is the midpoint between the surfaces of the lens

-The double arrow represents the lens
-f is the focal length, which is the distance between the optical centre and the focal point
-F is the focal point, which is the point on the principal axis where all the rays parallel to the principle axis meet after passing through the lens, with one on each side of the lens
-The focal plane is the plane perpendicular to the principle axis on which all parallel rays meet after passing through the lens, or the plane of all the focal points

Drawing ray diagrams of converging lenses

-In order to draw a ray diagram of converging lenses, we can draw 3 different rays
-The first ray passes through the optical centre and does not bend
-The second ray is parallel to the principle axis and will pass through the focal point after passing through the lens
-The third ray passes through the focal point before entering the lens and will become parallel to the principle axis after passing through the lens
-In order to find a real image, construct ray 1 and ray 2 or 3, and the point at which the two rays intersect is the image
-A virtual image will be formed if the rays do not meet at the other side of the lens, so you need to extend the rays backwards using dotted lines, and then find intersection point to locate the image
Image characteristics of converging lenses
-u is the object distance and f is the distance from the optical centre to the focal point

Object distance	Properties of image	Application
u at infinity	image formed on opposite side of lens real image diminished in size inverted image	objective lens of a telescope
$u > 2f$	image formed on opposite side of lens real image diminished in size inverted image	eye, camera
$u = 2f$	image formed on opposite side of lens real image same size inverted image	photocopier making a same sized copy
$f < u < 2f$	image formed on opposite side of lens real image magnified in size inverted image	photograph enlarger making an enlarged copy, projector
$u = f$	image on same side of lens virtual image	eyepiece lens of a telescope

	magnified in size upright image	
$u < f$	image on same side of lens virtual image magnified in size upright image	magnifying glass

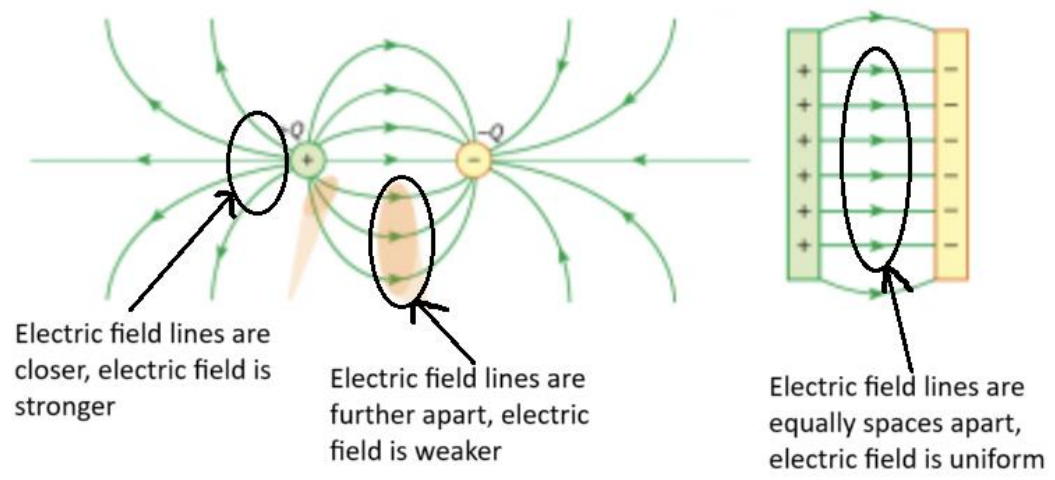
Chapter 15: Static Electricity

Electric charges

-An atom consists of electrons orbiting a nucleus that is made up of neutrons and protons
-An electron has a negative charge while a proton has a positive charge
-Charge is a physical measure of an object, and has the symbol Q
-SI unit for charge: C (coulomb)
-An atom contains an equal number of protons and electrons, hence it is neutral
-When an atom gains electrons, it becomes a negatively charged particle
-When an atom loses electrons, it becomes a positively charged particle
-When charged particles are brough near each other, they will experience a force
-Like charges repel and unlike charges attract

Electric fields

-An electric field is a region in which an electric charge experiences an electric force
-An electric field is represented by electric field lines, which can be straight or curved
-These lines do not interesect each other, and are perpendicular to the object's surface
-The strength of an electric field is indicated by how close the electric field lines are to each other

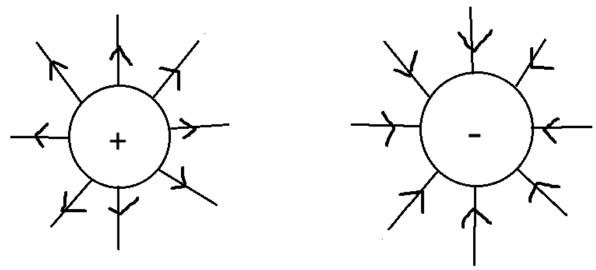


Direction of electric field

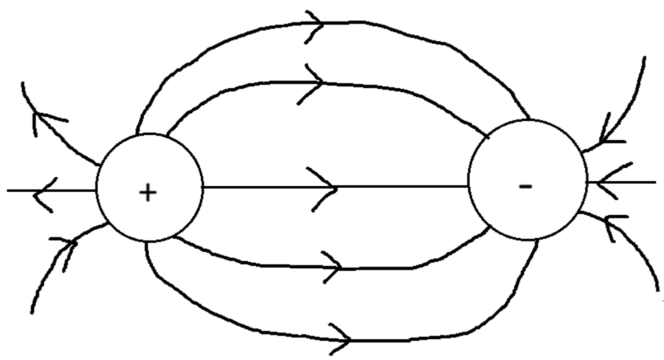
-The direction of an electric field is defined as the direction of a force that would act on a small positive test charge
-The arrows on electric field lines represent the direction of the electric field

Drawing electric fields

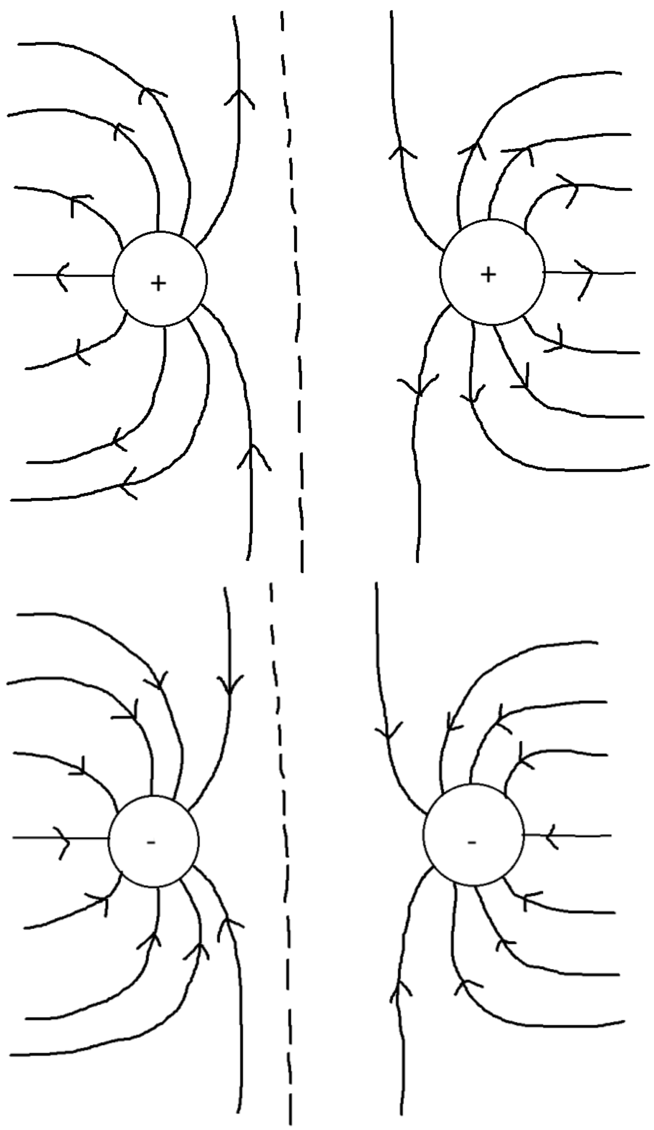
-For isolated point charges, eight electric field lines are usually drawn, with arrows corresponding to the charge of the point charge



-For two point charges of equal magnitude but opposite sign, it will look like the image below



-For two point charges of equal magnitude and same sign, it will look like the image below

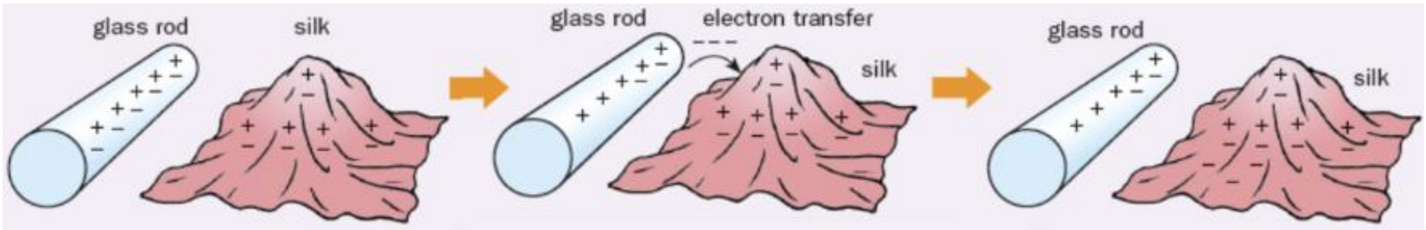


-Note that the no electric field lines should pass the dotted line

Electrostatic charging through rubbing

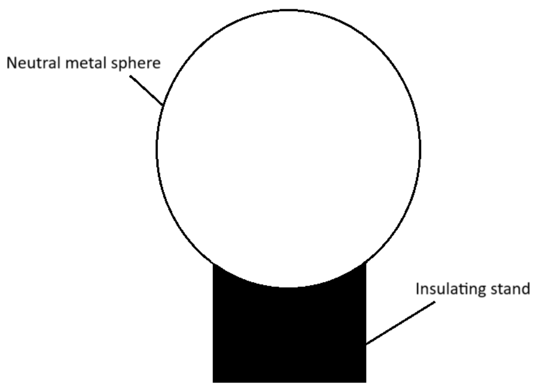
-Objects can be charged electrostatically by rubbing it with another object
-Rubbing transfers electrons onto or away from the object
-When electrons are transferred onto an object, it becomes negatively charged as there are more electrons than protons
-When electrons are transferred away from an object, it becomes positively charged as thre are more protons than electrons
-Protons cannot be added or removed from an object as they cannot be removed from the nucleus of an atom
-Hence, electrostatic charging by rubbing involves the transfer of electrons
-For example, a glass rod can be rubbed with a silk cloth to become positively charged
-When the silk cloth and glass rod are rubbed together, electrons from the surface of the glass rod are transferred to the silk cloth

-The rod now has an excess of positive charges and becomes positively charged
-Only the rubbed parts are charged as glass is an electrical insulator
-Electrostatic charging by rubbing is mostly used for insulators

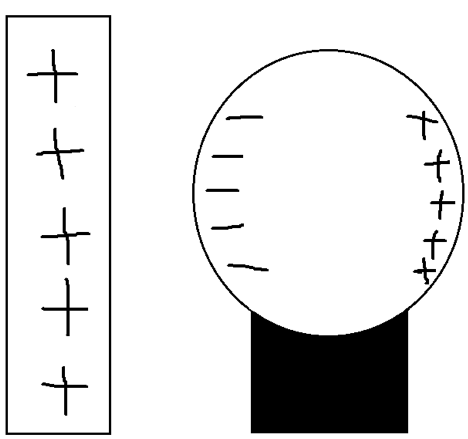


Electrostatic charging by induction

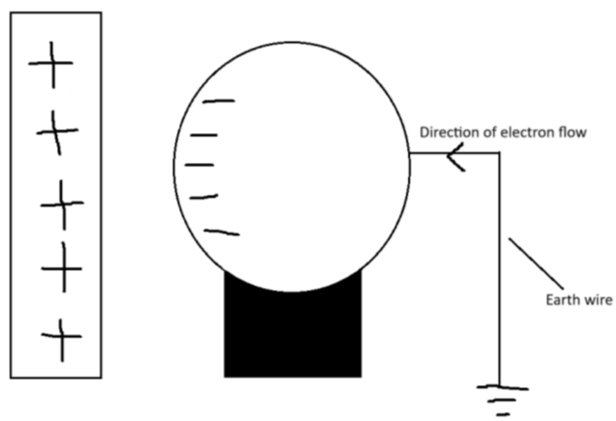
-Electrical conductors are usually charged through induction
-Induction is a process of chaging a conductor without contact
-In order to charge a metal sphere, it is first placed on a insulating stand, to prevent it from coming into contact with the ground, which will neutralise any subsequent chages induced on the sphere



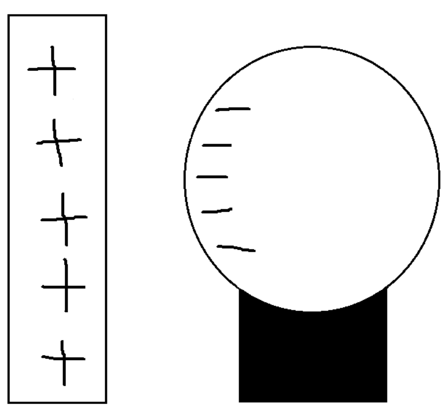
-A positively charged rod is then placed near the sphere
-The free electrons in the metal sphere will then be attracted to the positive charges in the rod
-The left hand side of the sphere will have excess electrons and the right hand side will have excess positive charges



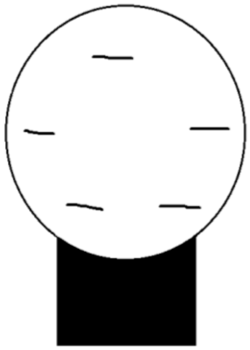
-The metal sphere is then earthed with an earth wire or finger, allowing electrons from the ground to be attracted to the positive charges on the right side of the sphere
-The electrons will then flow into the sphere to neutralise these charges and the right side of the sphere becomes neutral
-The electrons on the left side do not move as they are still attracted by the rod



-The earth wire is then removed without removing the charged rod



-The charged rod is removed, and the electrons will repel each other and distribute themselves equally throughout the metal sphere



-The metal sphere now has a negative charge
-This also shows that when charging through induction, the charged object will have a charge opposite to the object used to charge it

Test for electric charges

-Since like charges repel and unlike charges attract, we can use this to test for the charge of an unknown charged object by using an object with a known charge
-However, repulsion is the only definite test for charge, as attraction can occur between two objects with unlike charges as well as a charged object and a neutral one
-This is because if a negatively charged object is brought next to a neutral one, electrons in the neutral object are repelled away from the negative charge
-This induces a positive charge on one side of the neutral object, causing it to be attracted to the negatively charged object
-Note that since electrons do not flow out of the neutral object, its still overall neutral, just with one side being positively charged and one side being negatively charged

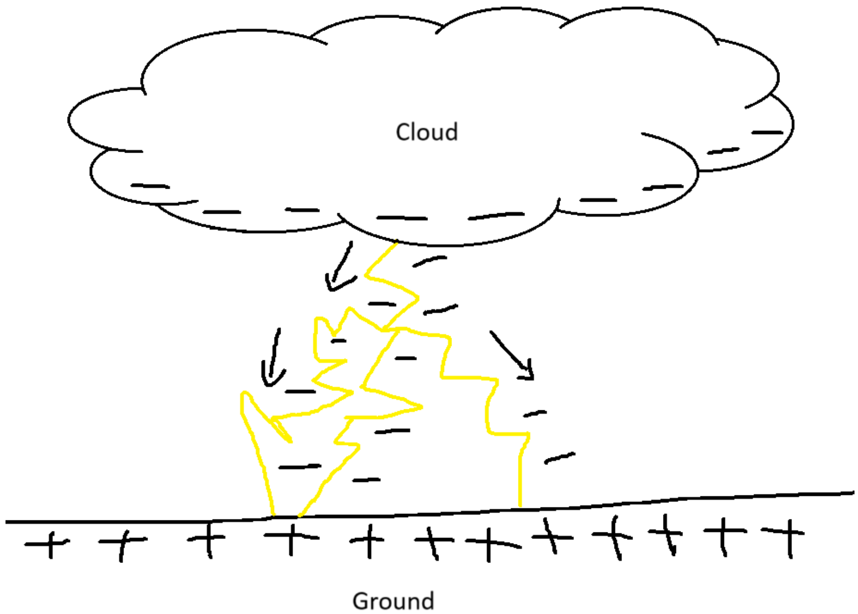
Discharging

-Discharging or neutralising is the process of making a charged object neutral
-A charged insulator can be discharged through heating or by exposing it to humid conditions
-When heating the insulator, the heat from the flame ionises the surrounding air particles, and the ions neutralise the excess charges on the insulator
-When placed in humid conditions, electrons from the insulator will be transferred away or towards water molecules in the air depending on the charge of the insulator, as water molecules are electrical conductors
-A charged conductor can be discharged through earthing, where an earth wire or a body part prodivdes a pathway for electrons to flow in and out of the conductor
-If the conductor is positively charged, electrons from the body or ground flow into the conductor
-If the conductor is negatively charged, excess electrons from the conductor flow into the body or ground

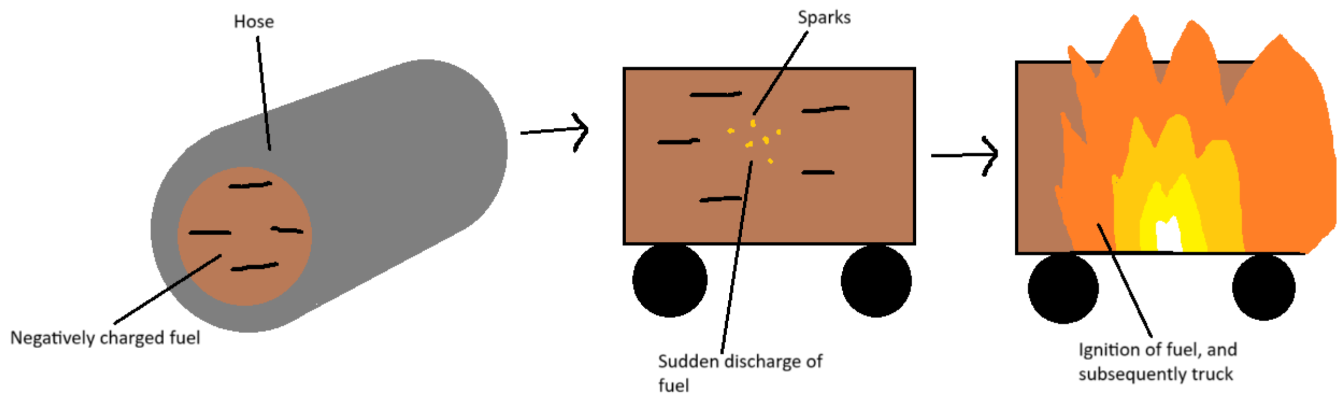
Hazards of electrostatics

Lightning

-A thundercloud can become electrically charged due to friction between water molecules in the thundercloud and air particles in the atmosphere
-Negative charges tend to gather at the bottom of the cloud, which repels electrons near the ground surface and induces a positive charge on the surface of the ground
-When the accumulation of charges is large enough, the nearby air particles are ionised, which provide a conducting path for electrons in the cloud to be conducted to the ground, forming lightning
-The risk of lightning can be reduced by using a lightning rod, which provides an alternative, safer pathway for the lightning to strike and allow the charges to flow into the earth

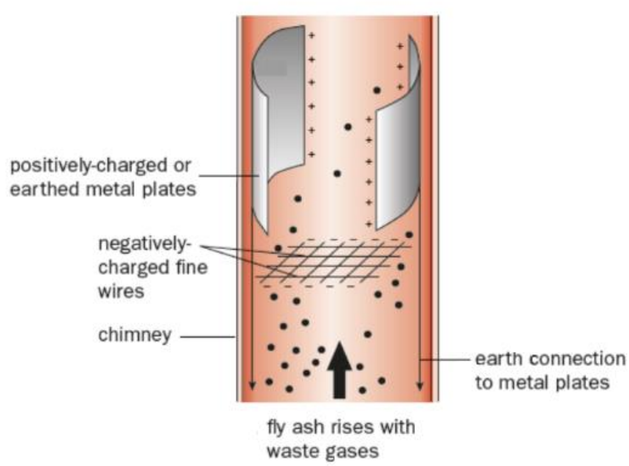


Electrostatic discharge
-When combustible substances such as fuels and petrol are loaded and unloaded into trucks, friction between the petrol and pipe walls generates electric charges
-Electric charges can also accumulate on trucks due to friction between the road and the rotating tyres, or between the surface of the truck and the air
-When a sudden discharge occurs, it can cause sparks which could ignite the petrol
-This hazard can be prevented by earthing the truck through using a metal chain attached to the vehicle or by adding carbon to tyres to help discharge the trucks

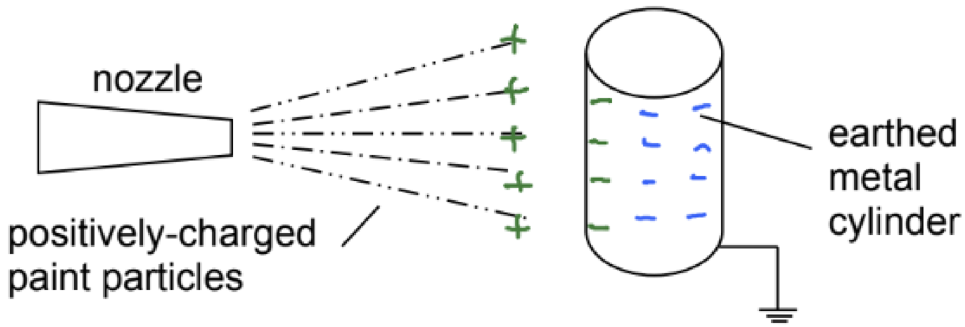


Applications of electrostatics

Electrostatic precipitators
-Electrostatic precipitators are used to reduce air pollution by cleaning the waste gases produced by power stations
-Fly ashes (mixture of smoke and dust particles) pick up negative charges from the negatively charged wires as they rise up the chimney
-These fly ashes then stick to positively charges metal plates
-Hence the gases that leave the chimney do not contain these fly ashes



Spray painting
-When spray painting, a nozzle will spray out fine paint droplets, which are charged positively when emerging
-As paint droplets approach the cylinder, electrons will flow up from the ground and accumulate on the surface of the cylinder as they are attracted to the positively charged paint particles, hence the cylinder will be negatively charged and the paint droplets will stick to the cylinder
-The paint droplets have the same charge and repel each other, so they will form an even coat of paint on the cylinder

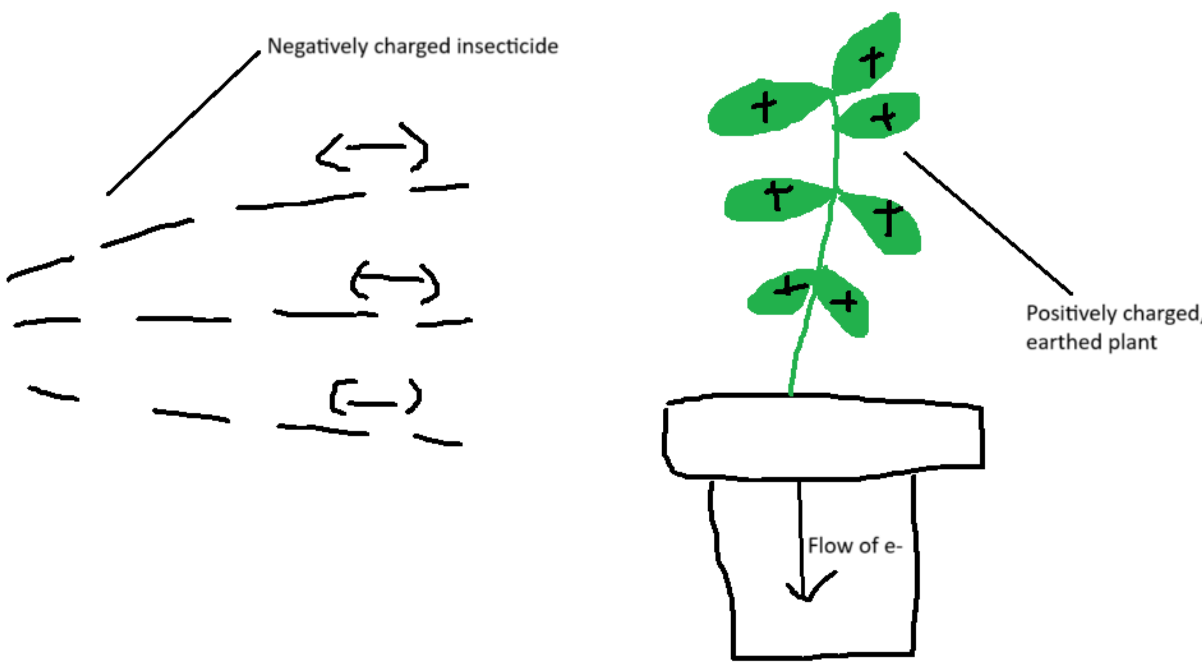


Crop spraying

-Negatively charged insecticide is sprayed onto plants

-The plants are earthed, so electrons in the plant are repelled into the ground by the negatively charged insecticide, hence the plant will be positively charged and the insecticide will stick to the plant

-The insecticide particles have the same charge and repel each other, so they will form an even coat of insecticide on the plant



Chapter 16: Current of Electricity

Electric current

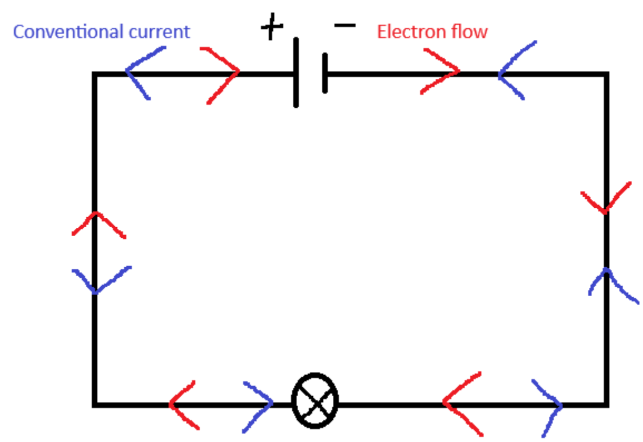
-Current is the rate of flow of charge
-Formula for current: I = Q / t, where I is the current in amperes, Q is the charge in coulombs and t is the time in seconds
-SI unit for current: A (amperes)

Power

-Power is the amount of energy transferred per unit time
-Formula for power: P = E / t, where P is power in watts, E is energy in joules, and t is time in seconds
-SI unit for power: W (watts)

Conventional current and electron flow

-Electrons flow from the negative terminal of a battery to the positive terminal
-Conventional current is the opposite of electron flow
-In our syllabus, we use conventional current when talking about current



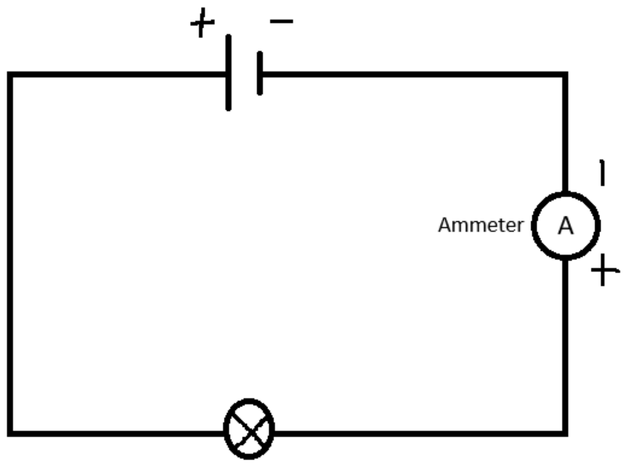
Types of current

-There are two types of current, alternating current (a.c.) and direct current (d.c.)
-Direct current only flows in one direction, such as current from a cell or battery
-Alternating current has a direction that changes periodically, such as the current froma singapore wall socket

Ammeter

-An ammeter is used to measure current
-It is connected in series to the circuit components, and has very low resistance so that potential difference across the ammeter is negligible

-The negative terminal of the ammeter is always connected to the negative terminal of the battery



Electromotive force

-The electromotive force (e.m.f) of an electrical source is the work done per unit charge by the source in driving charges around a complete circuit
-Formula for e.m.f: $\varepsilon = W / Q$, where ε is the electromotive force in volts, W is the work done in joules, and Q is the charge in coulombs
-SI unit for e.m.f: V (volts)
-Note that electromotive force is not actually a force
-When cells are arranged in series, their e.m.f Will add up, but if they are arranged in different orientations, such as with two negative terminals facing each other, the e.m.f cancels out
-In parallel, the effective e.m.f is the same as one cell

Potential difference

-The potential difference or voltage across a component in a circuit is the work done per unit charge in driving charges through a component
-Formula for potential difference: $V = W / Q$, where V is the potential difference in volts, W is the work done in joules, and Q is the charge in coulombs
-SI unit for potential difference: V

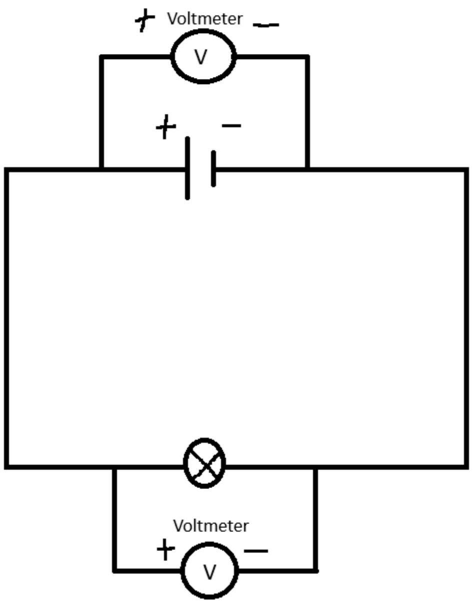
E.m.f vs potential difference

-e.m.f is not the same as potential difference, despite having the same unit
-e.m.f Is provided by a source of electrical energy, while potential difference is the electrical energy converted to other forms by a circuit component, such as a light bulb

Voltmeter

-A voltmeter is used to measure e.m.f and potential difference

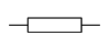
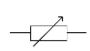
-It is connected in parallel to a cell or circuit component, and has a very high resistance so current flowing through it is negligible
-The negative terminal of the voltmeter is always connected to the negative terminal of the battery



Resistance

-The resistance of a conductor is the ratio of the potential difference across it to the current flowing through it
-Formula for resistance: R = V / I, where R is the resistance in ohms, V is the potential difference in volts, and I is the current in amperes
-From this we can see that resistance is proportional to voltage and inversely proportional to current
-SI unit for resistance: Ω (ohms)
-Resistance is the measure of how difficult it is for electric current to pass through a material, and is a property of the material that restricts the movement of electrons in that material
-Current will always try and take the path of least resistance, so if there is more than one path, current will split itself into the paths available
-For example, if there are 5A of current flowing through a 2Ω and 3Ω resistor, the current will split up, so 3A of current will flow through the 2Ω resistor, and 2A of current will flow through the 3Ω resistor
-If a resistor has 0Ω, all the current will pass through that pathway, and if it has infinite resistance, no current will pass through that pathway

Resistors

-A resistor is a device used to control the size of the current in a circuit, and is a conductor of electricity because it allows current to flow through them
-The circuit symbols are  for a fixed resistor and  for a variable resistor

-A fixed resistor has a fixed resistance, while a variable resistor, such as a rheostat, has a resistance that can be adjusted

Resistivity

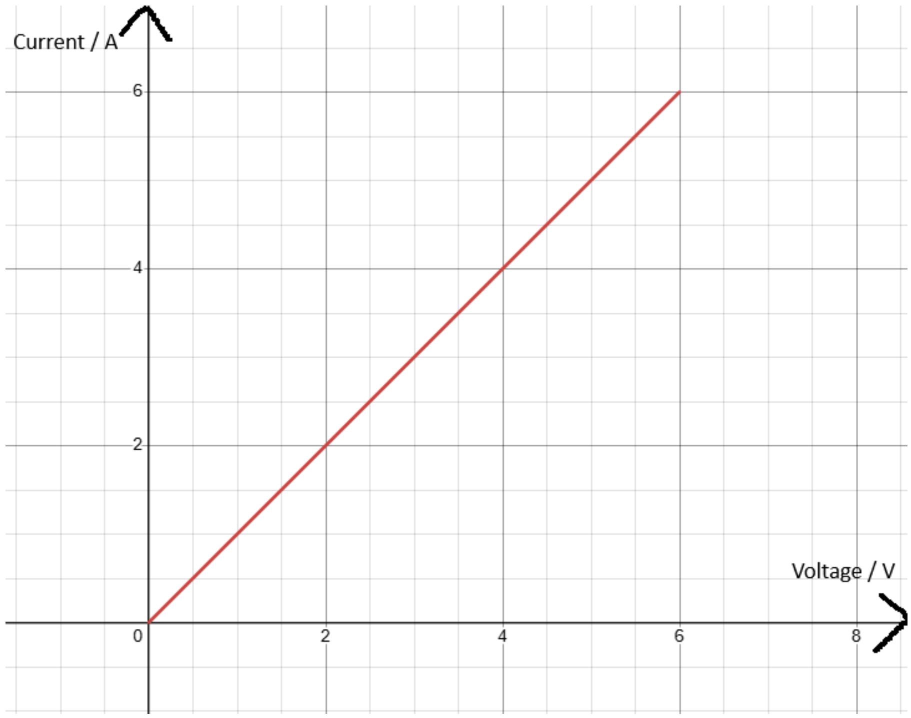
-The resistance of a conductor also depends on its length, cross sectional area, and the type of material its made of
-The longer the wire, the larger the resistance, hence resistance is proportional to length
-The larger the cross sectional area, the smaller the resistance, hence resistance is inversely proportional to cross sectional area
-From this, another formula for resistance is: $R = \rho l / A$, where ρ is the resistivity in ohm metres, l is the length in metres, and A is the cross sectional area in square metres
-SI unit for resistivity: Ωm
-The resistivity of a material is fixed, hence no matter the length or cross sectional area of a conductor, the resistivity is always constant
-Copper is used to make wires since copper has a very low resistivity, hence resistance of wires in a circuit are negligible

Ohm's law

-Ohm's law states that the current passing through a metallic conductor is directly proportional to the potential difference across it, provided that the physical conditions such as temperature are constant
-In symbols, ohm's law can be represented as so: $I \propto V$, where I is current in amperes, V is potential difference in volts and $\propto$ means "is proportional to"
-This means that V / I is a constant, and hence since $R = V / I$, the resistance of a metallic conductor remains constant under constant physical conditions
-This can also be expressed as $V = IR$, where V is potential difference in volts, I is current in amperes, and R is resistance in ohms

Ohmic conductors

-Conductors which obey ohm's law are called ohmic conductors
-They have a current-voltage graph like the one shown below
-This shows that $I = kV$, where k is a constant or the gradient of the graph
-Since $R = V / I$ and $k = I / V$, $k = 1 / R$
-Hence the gradient of a current-voltage graph is $1 / R$

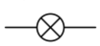


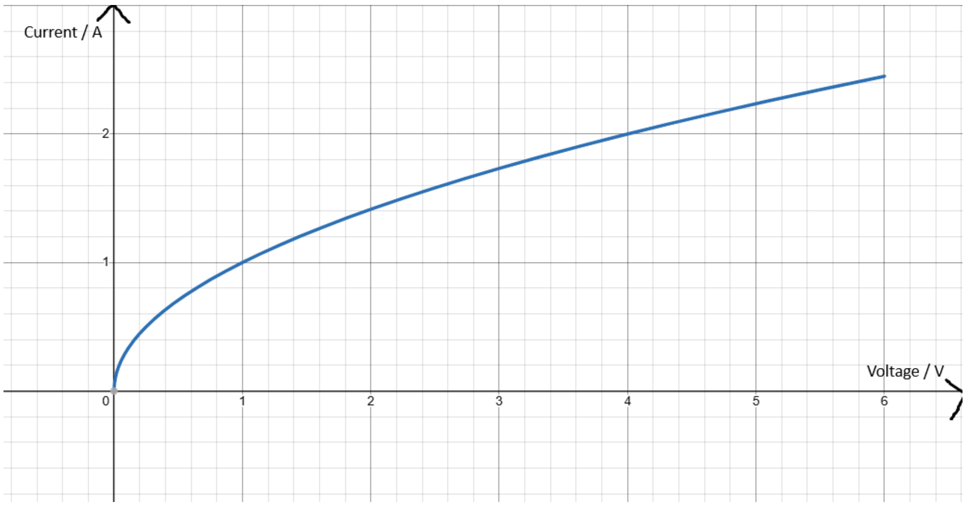
Non ohmic conductors

-Conductors that do not obey ohm's law are called non ohmic conductors
-The filament lamp and semiconductor diode are examples of non ohmic conductors

Filament lamp

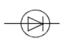
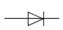
-The filament lamp is a lamp which produces light by heating up a thin filament with high resistance, usually made with tungsten

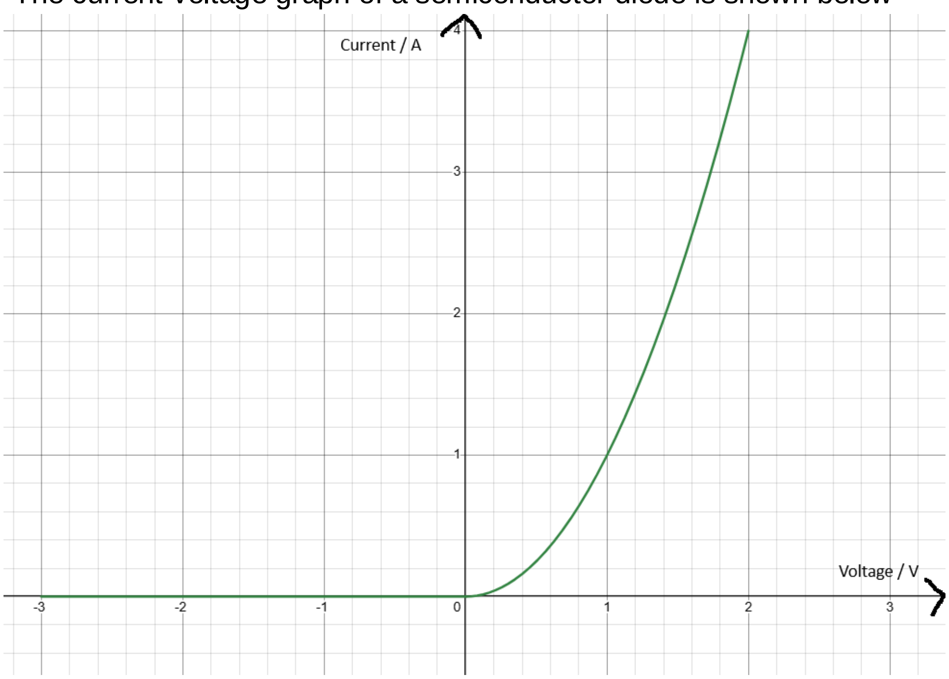
-Circuit symbol: 
-The current-voltage graph of a filament lamp is shown below
-As the potential difference across the lamp increases, it gets heated up and its temperature increases
-Since temperature increases, resistance also increases as the temperature is no longer constant



Semiconductor diode

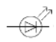
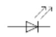
-A semiconductor diode is a device that allows current to flow in one direction only
-When the voltage is negative, resistance is extremely high, and current flowing through the diode is negligible
-Voltage is negative when the semiconductor diode is placed in the wrong direction, which is why the semiconductor diode only allows current to flow in one direction
-However, when voltage is positive, resistance decreases sharply and current flow increases sharply as well

-Circuit symbol:  or 
-The current-voltage graph of a semiconductor diode is shown below



LED

-A light emitting diode, or LED is a type of semiconductor diode

Circuit symbol:  or 

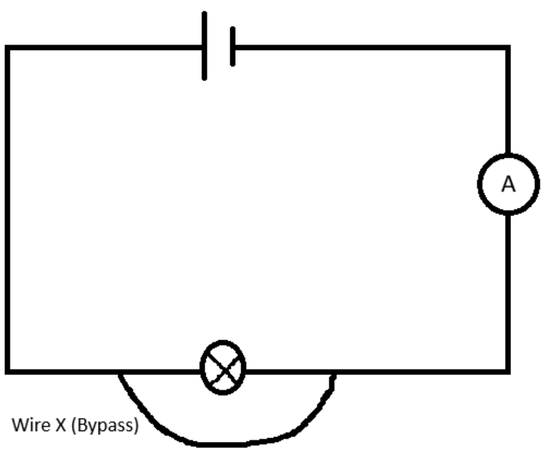
Short circuit

-When a circuit is connected like the image shown below, the ammeter will register a very large reading and the bulb will not light up

-This is because wire X has negligible resistance and all the current flows through wire X and will bypass the light bulb

-Hence, a short circuit is an electrical circuit that allows current to travel an unintended path with no or very low electrical resistance

-Short circuits are dangerous as the battery, ammeter and wires have very low resistance, so the current flowing through them is very high, which can lead to overheating and cause a fire



Chapter 17: D.C. Circuits

Circuit diagrams

-A circuit diagram is a simplified diagrammatic representation of an electrical circuit, which shows the connections between electrical components, which are represented by circuit symbols

Table 17.1 Common circuit symbols of electrical components

Symbol	Device	Symbol	Device	Symbol	Device
	switch	or	wires joined	G or	galvanometer
+ −	cell		wires crossed	A	ammeter
+ −	battery		fixed resistor	V	voltmeter
+ −	d.c. power supply		variable resistor (rheostat)		two-way switch
~	a.c. power supply		fuse		earth connector
	light bulb		coil of wire		light-emitting diode
	potentiometer		transformer		thermistor
	light-dependent resistor (LDR)		semiconductor diode		bell

Series circuits

-In a series circuit, the components are connected one after another in a closed loop, and electric current has only one path to flow
-Current in series at every point is the same, hence in series, I(source) = I1 = I2
-Total voltage in series is equal to the e.m.f of the source, hence V(source) = V1 + V2
-From these two formulas and V = RI, we can derive that effective resistance is the sum of the total resistance of all components in a circuit, or R(effective) = R1 + R2
-Note that these formulas work for circuits with components > 2, but 2 is just used as an example, and the same is true for parallel circuits

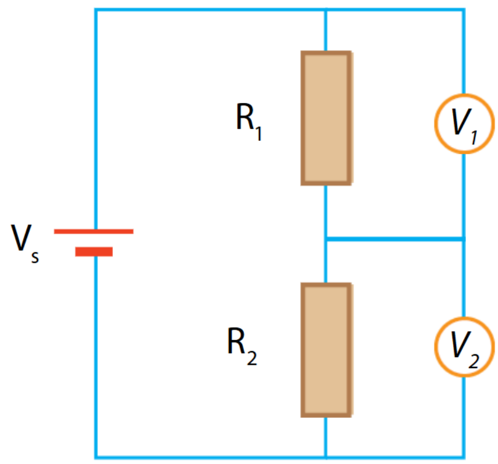
Parallel circuits

-In a parallel circuit, components are connected to the e.m.f source in two or more loops, and has more than one path through which current can flow
-To try and see if a circuit is in parallel, try and draw out the path of current and see if it splits up before returning to the source

-When current flows into a splitting branch of the circuit, it splits up, hence in parallel, I(source) = I1 + I2
-However, voltage is the same across parallel branches, and since total current is equal to the e.m.f of the source, V(source) = V1 = V2
-From these two formulas and that I = V / R, 1 / R(effective) = 1 / R1 + 1 / R2, or R(effective) = (1 / R1 + 1 / R2)^-1
-Note that when a resistor is added in parallel, effective resistance decreases, but if the resistance of a variable resistor in parallel is increased, effective resistance increases

Potential dividers

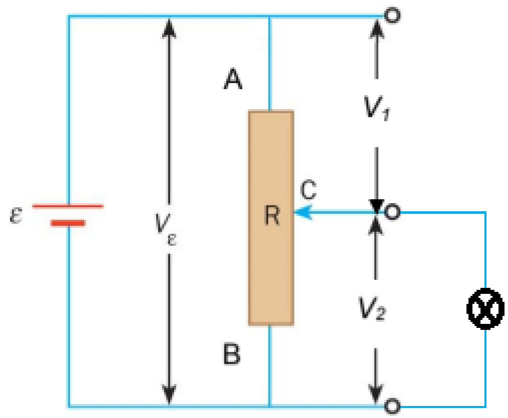
-A potential divider is a voltage divider, which uses the voltage drop across a resistor in series to divide voltage
-In the circuit below, the formula for the potential divider is V1 = [R1 / (R1 + R2)] x Vs, or V2 = [R2 / (R1 + R2)] x Vs
-Think of it like finding the ratio of two resistors and using this ratio to find the individual voltages



Potentiometer

-Potential dividers using fixed resistors such as the one above give fixed values of V1 and V2, hence if we want a range of values for V1 and V2, we use a potentiometer
-The potentiometer works using the R = ρ l / A formula, where by altering the length of wire current passes through, resistance is altered and hence voltage is altered due to the potential divider formula V1 = [R1 / (R1 + R2)] x Vs
-In the potentiometer below, the fixed resistors are replaced by a slider C
-When C moves towards B, R(BC) decreases and R(AC) increases, hence V1 increases and V2 decreases
-When C moves towards B, R(BC) increases and R(AC) decreases, hence V1 decreases and V2 increases
-If there is a lamp connected to the slider like in the image, when the slider moves all the way to A, the voltage across the lamp is equal to Vε, and when the slider is all the way at B, voltage across the lamp is 0V

-A rheostat can also be used as a potentiometer, where a two wires are connected at the bottom and one at the top of the rheostat



Input transducers

-Input transducers are electronic devices that convert changes in physical conditions such as temperature and light into electrical signals, so that these physical conditions can be measured

Thermistor
-A thermistor is an example of an input transducer
-It is a type of semiconductor whose resistance varies based on temperature
-A negative temperature coefficient (NTC) thermistor has a resistance that decreases as the temperature increases and vice versa, which is what is usually meant by in exams

Light dependent resistor
-A light dependent resistor, or LDR, is a resistor whose resistance varies based on the amount of light shining on it
-It has a resistance thast decrease as the amount of light shining on it / light intensity increases and vice versa

Chapter 18: Practical Electricity

Electrical heating

-Many household appliances, such as kettles, irons and water heaters, usea heating element to transfer energy electrically
-A heating element is a wire that heats up rapidly when an electric current passes through them due to their high resistance
-As current flows through the heating element, energy is transferred electrically to the internal store of the heating element
-Formula for power of a heating element, given resistance R: P = VI, where P is power in watts, V is voltage in volts, and I is current in amperes
-From this we can derive other equations: E = IVt, P = I^2R, P = V^2 / R, E = I^2Rt, E = V^2t / R, where E is energy in joules, I is current in amperes, t is time in seconds, P is power in watts, R is resistance in ohms, and V is voltage in volts
-P = I^2R is useful for calculating power for resistors in series as current is the same in series
-P = V^2 / R is useful for calculating power for resistors in parallel as voltage is the same in parallel

Power ratings

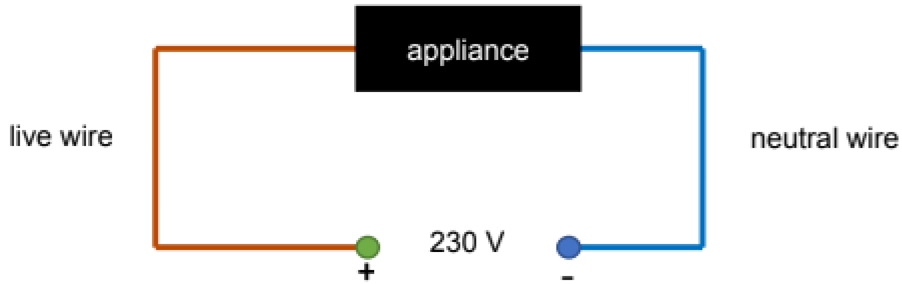
-Power ratings on appliances show the amount of power they are meant to produce at their operating voltage
-For example, if a kettle is rated 240V and 2000W, it means that when a voltage of 240V (operating voltage) is applied across the kettle’s heating element, it will transfer energy at a rate of 2000W
-We can then use P = V^2 / R to calculate the resistance of the heating element

Electricity consumption

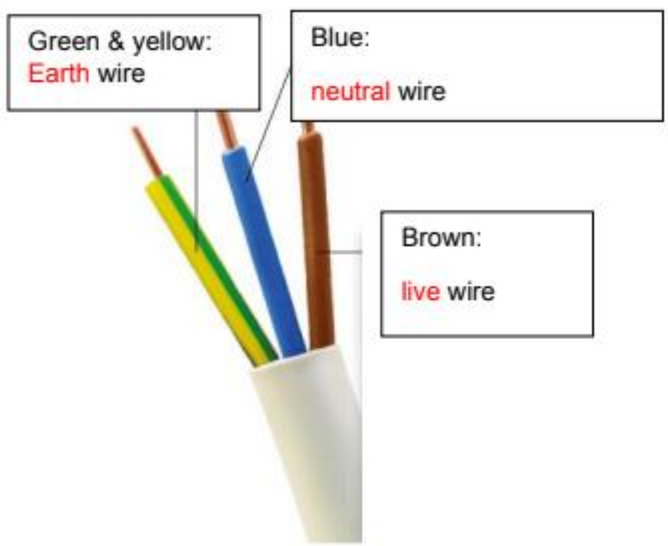
-It is very cumbersome to record the number of joules used when electrical companies are trying to charge for electricity as the number of joules can get very large
-Hence we use the kilowatt hour (kWh), which is the energy transferred by a 1 kW appliance in 1 hour
-1 kWh = 3600000 J (3.6 million joules, or 3.6 MJ)

Live and neutral wires

-An appliance connected to a power supply needs two wires to form a complete circuit
-The wire that has high potential, or the one where current flows out from, is called the live wire
-The wire that completes the circuit and has zero potential is called the neutral wire



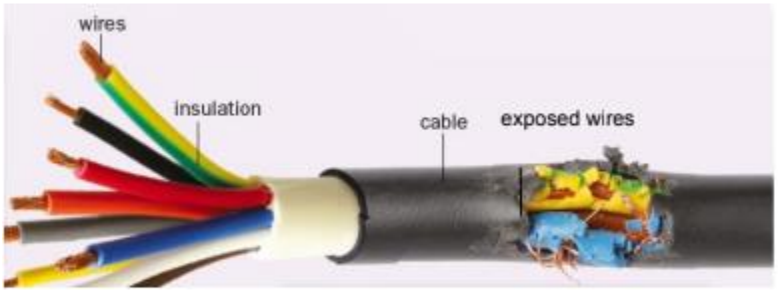
-In a home circuit, there are three types of wires, the live wire, neutral wire and earth wire
-The live wire is the brown wire, and is connected to high voltage and delivers current to the appliance, as well as being the wire to which circuit breakers, fuses and switches are fitted
-The neutral wire is the blue wire, and it completes the circuit by providing a returning path for the power supply, and has the same current as the live wire but is at 0V
-The earth wire is the green and yellow wire, and is a low resistance wire connected to the metal casing of appliances to prevent users from getting electric shocks when the metal casing is live, and is at 0V when no fault occurs



Dangers of electricity

-Electricity is dangerous as it can cause electric shocks and fires
-This can be caused by three main causes, damaged insulation, overloaded power sockets and damp conditions
-Damaged insulation occurs when the insulation around a wire is damaged, and the wires inside are exposed
-This can cause electrical shocks if someone touches the live wire, as well as a fire due to overheating of cables when the live wire touches the neutral or earth wire, creating a short circuit
-Overloaded of power sockets occurs when too many electrical appliances are connected to the socket
-This can lead to overheating of cables due to high current, which can cause a fire

-Damp conditions can cause electric shocks as water conducts electricity



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Circuit breaker

-A circuit breaker is a safety feature in a home circuit

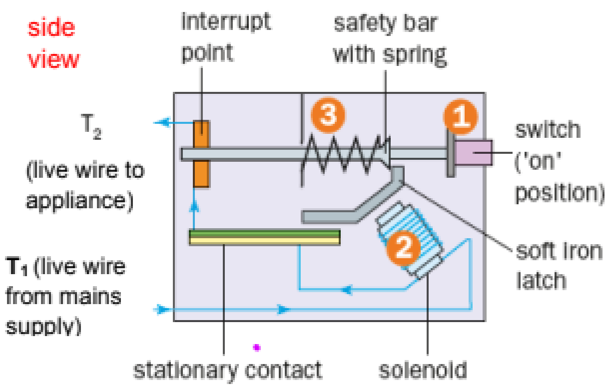
-Circuit symbol: 

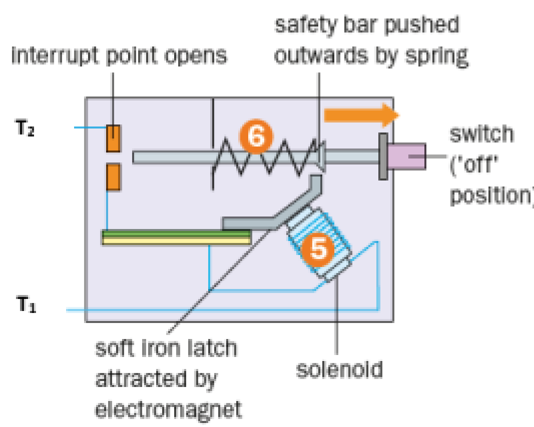
-It switches off the electrical supply when excessive current flows through the circuit, and is installed on the live wire

-In the image below, when a high current passes T1, the solenoid becomes more strongly magnetised and attracts the soft iron latch, allowing the spring to push back on the safety bar, opening the circuit

-When the fault is repaired, the circuit breaker can be reset by pressing the switch back to its original position

-Note that we say a circuit breaker trips





Fuses

-A fuse is a safety feature in a home circuit

-A fuse consists of a thin metal wire which will melt or blow when current becomes too high

-It has a fuse rating in amperes which indicates the maximum current that can flow before it blows, and is installed on the live wire

-Typical fuse ratings: 1A, 2A, 3A, 5A, 10A, 13A

-When selecting a fuse rating, always choose one higher than the current usage of an appliance, but not too high

-For example, if a kettle uses 4A of current, a 5A fuse would be most suitable
-Note that we say a fuse blows

Switches

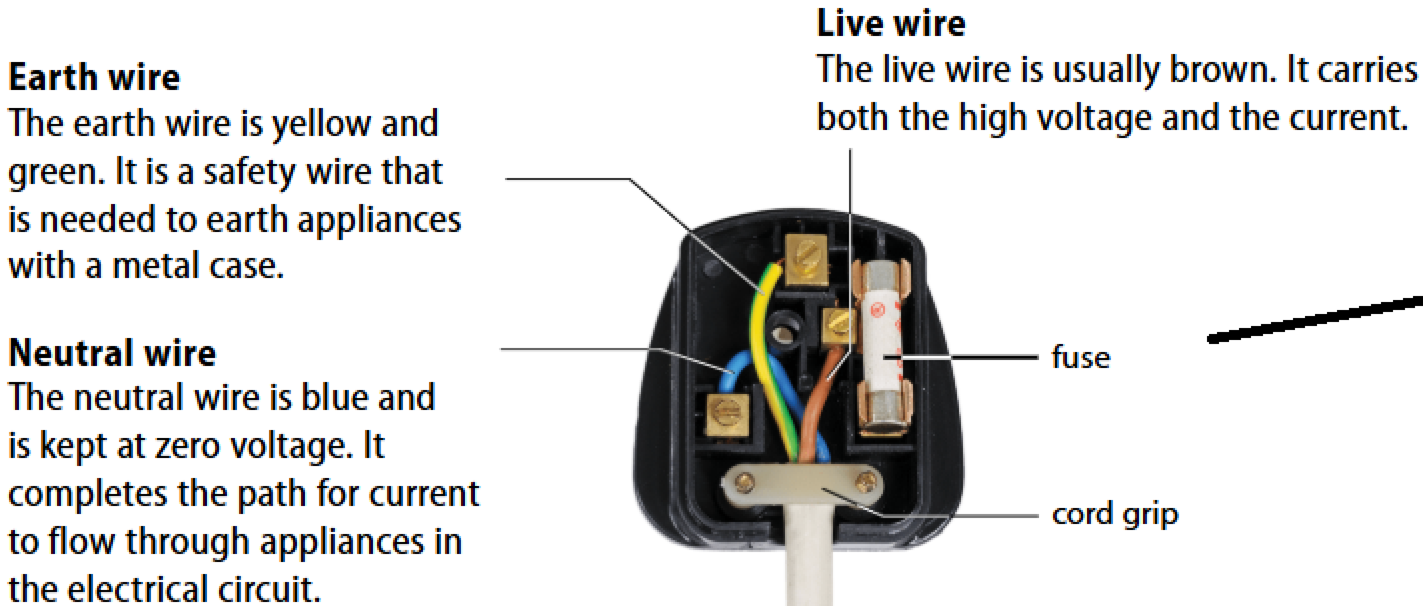
-A switch is a safety feature in a home circuit
-They are designed to break or complete an electrical circuit
-They are installed on the live wire so that the appliance will be at zero potential when the switch is open
-If the switch is connected to the neutral wire, the appliance will still be at live potential even after opening the switch, so if a fault occurs and causes the live wire to be in contact with the metal casing of the appliance, a person who touches the metal casing can still get an electric shock
-This is also why circuit breakers and fuses are installed on the live wire

Earthing

-Earthing is a safety feature in a home circuit
-If an appliance experiences a fault causing the live wire to come into contact with the metal casing, the casing would be at high electrical potential, hence a closed circuit will be formed when a person touches the metal casing, causing them to get an electric shock
-However, if the appliance is earthed, when the live wire comes into contact with the metal casing, current is diverted into the ground
-If the current is large, a fuse will blow and open the circuit
-Hence, a person who touches the metal casing will not get an electric shock as the metal casing is not at high electrical potential
-This is also why earthing should be used with a fuse to prevent fires from overheating

Three pin plug

-A three pin plug is a safety feature in a home circuit



-The fuse protects the appliance when there is an electrical fault
-The earth wire protects the user from electric shocks if the appliance becomes live
-Note that the gold parts are the pins of the three pin plug

Double insulation

-Double insulation is a safety feature in a home circuit
-Symbol: ⧈
-Note that this is not a circuit symbol, but rather a symbol which appears on appliances using double insulation
-Some appliances have plastic instead of metal casings, and have two pin plugs instead of three pin plugs
-These appliances do not have an earth wire, instead having double insulation to protect users from electric shocks
-This means that the electric cables are insulated from the internal components of the appliance, and that the internal components are insulated from the outer casing

Chapter 19: Magnetism

Properties of magnets

-Magnets have two poles, the north and south pole
-The magnetic strength of a magnet is strongest at its poles, and a freely suspended magnet comes to rest in the north south direction
-the poles of a magnet stand for the north seeking pole and south seeking pole, meaning that they will point towards the north and south poles of earth respectively when freely suspended
-This is why magnets are used as compass needles
-Like poles repel and unlike poles attract
-materials that can be attracted by magnets are called magnetic materials, and examples include iron, steel, cobalt and nickel
-Materials that cannot be attracted by a magnet are called non magnetic materials, and examples include wood, copper, plastic etc
-Repulsion is the only sure test to determine if an object is a magnet
-If a bar magnet is broken, the broken piece is still a magnet

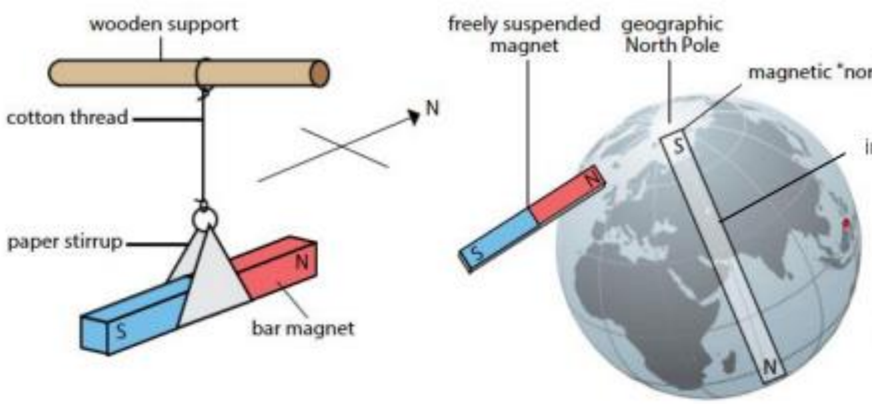


Figure 19.3 The north pole of a freely suspended magnet will align itself with Earth's magnetic field.

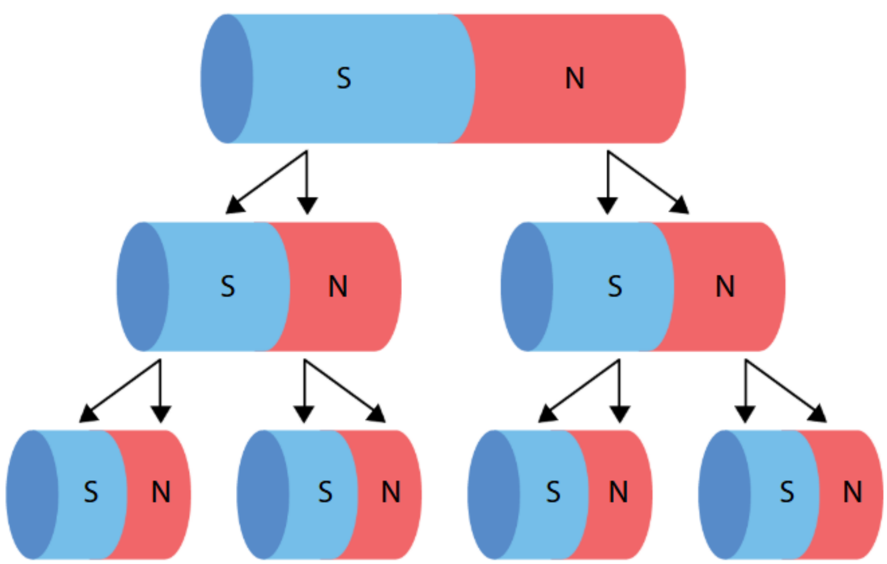


Figure 19.4 Dividing a magnet into smaller piece produces smaller pieces of magnets.

Magnetic induction

-Magnetic induction is the process whereby an object made of a magnetic material becomes a magnet when it is near or in contact with a magnet
-This is how magnets attract magnetic materials
-When an iron bar is brought near a magnet's north pole, it becomes an induced magnet due to magnetic induction
-A south pole will be induced on the iron by the magnet on the left sideside, and since unlike poles attract, the iron bar will be attracted to the magnet
-If the magnet is turned around and the south pole faces the iron bar, a north pole will be induced on the iron bar's left side and attraction occurs again
-If two paperclips are attracted to one end of a magnet, their tips will point away from each other as the bottom of the paperclips have become induced magnets with a like pole, hence they repel

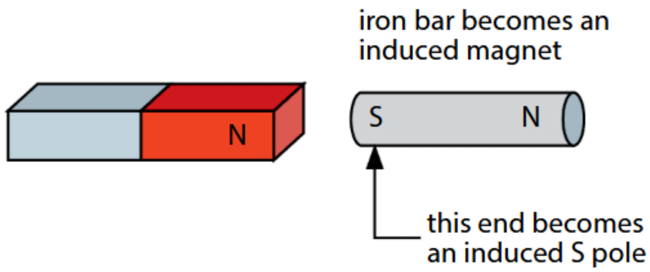


Figure 19.7 Magnetic induction can happen without physical contact.

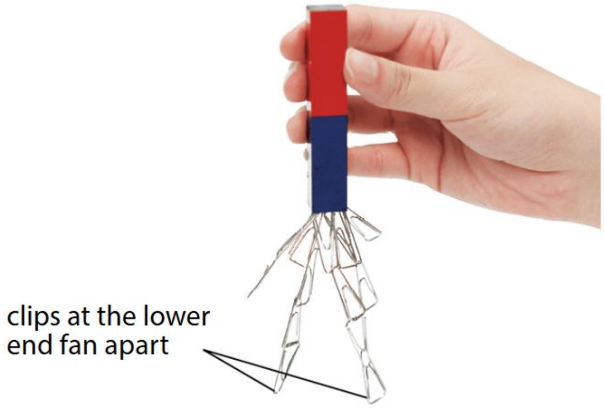
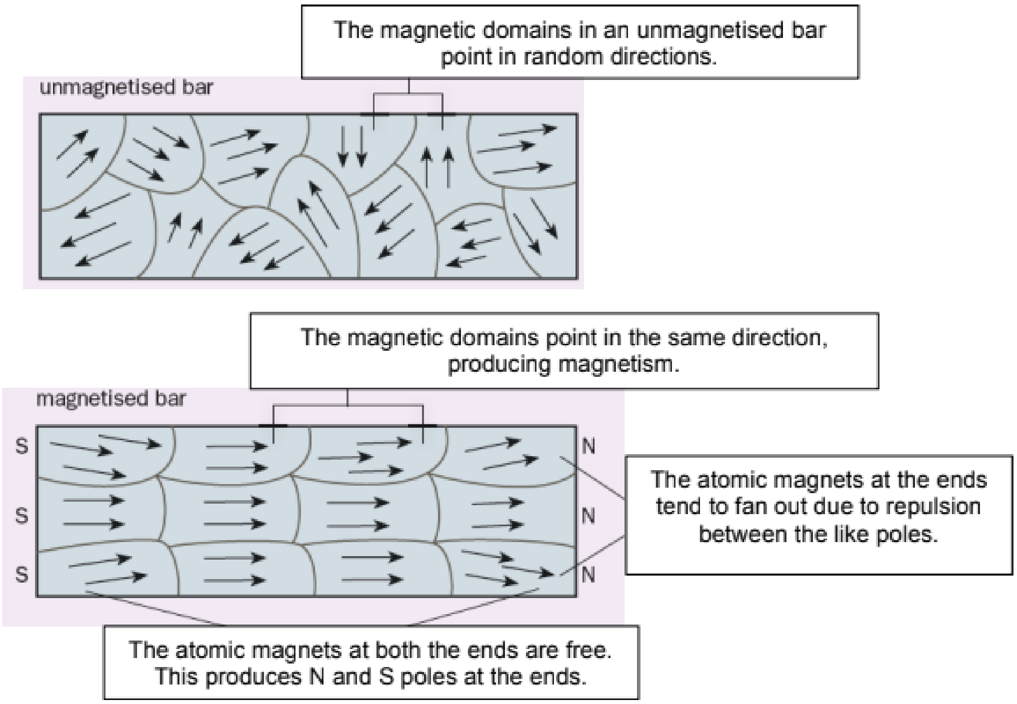


Figure 19.8 A paper clip attracted to a magnet becomes an induced magnet that attract other clips.

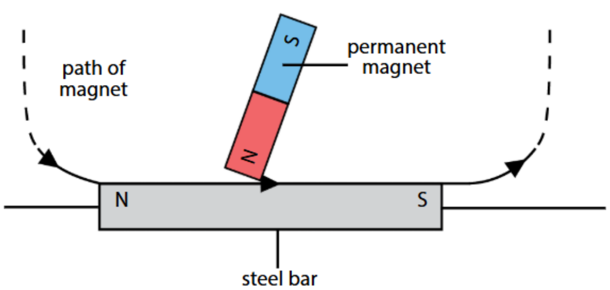
Magnetic domains

-Magnets are made of atoms, and each atom is an atomic magnet due to the orbiting motion of electrons around the nucleus of the atom
-A group of atomic magnets pointing in the same direction form a magnetic domain
-In an unmagnetised object, magnetic domains are in random directions and hence cancel out
-However, once the object becomes magnetised, the magnetic domains point in the same direction, producing magnetism



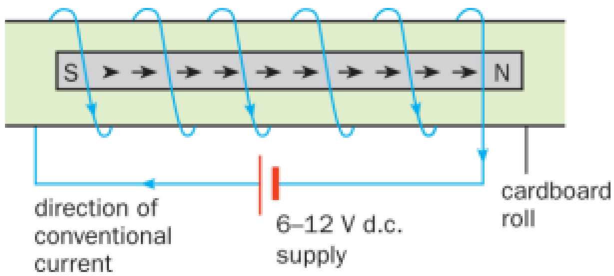
Magnetisation

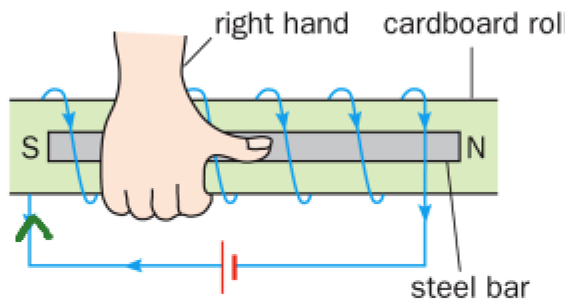
Stroking
-An object can be magnetised by stroking it with a magnet, causing magnetic domains to be aligned in the same direction



Electrical method
-A solenoid can be used to magnetise an object
-A solenoid is a coiled piece of wire with current flowing through it

-The magnetic field from the current in the solenoid causes the magnetic domains to be aligned in the same direction
-The poles of the new magnet can be determined using the right hand grip rule, where you grip the solenoid with your right hand, and curl your fingers in the direction of conventional current flow, and the thumb will point in the direction of the north pole



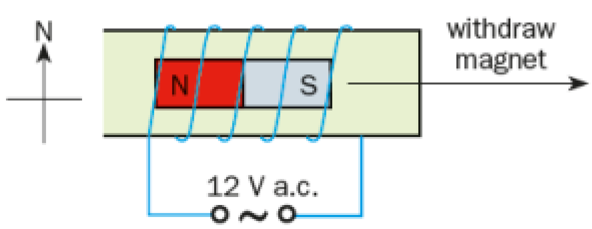


Demagnetisation

Heating
-A magnet, when heated and then cooled while placed in the east west direction, will become demagnetised

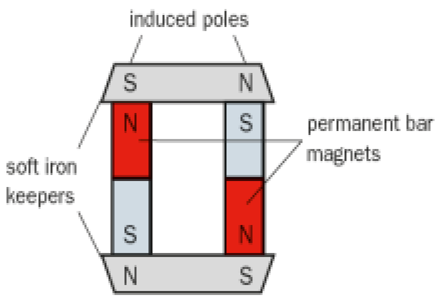
Hammering
-Hammering, or just applying sufficient blunt force on a magnet while it is placed in the east west direction will demagnetise it

Electrical method
-A magnet that is placed into a solenoid with an alternating current running through it, before slowly withdrawing it from the solenoid in the east west direction with the alternating current still running until the magnet is a certain distance away from the solenoid, will be demagnetised
-The alternating current alternates at around 50 times per second, which causes the magnetic domains of the magnet to reverse in polarity at the same rate, and alignment in the east west direction minimises the effect of the earth's magnetic field in magnetising the magnet



Storing of magnets

-Magnets tend to become weaker over time if not stored properly
-This is because the free poles at the ends of the magnet repel one another, alerting the magnetic domains
-Soft iron keepers ensure that the magnetic domains remain in closed loops with no free poles

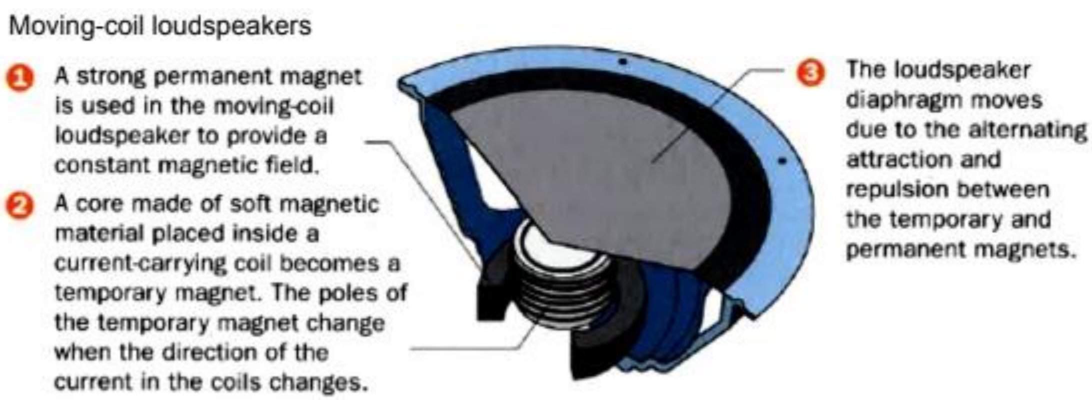


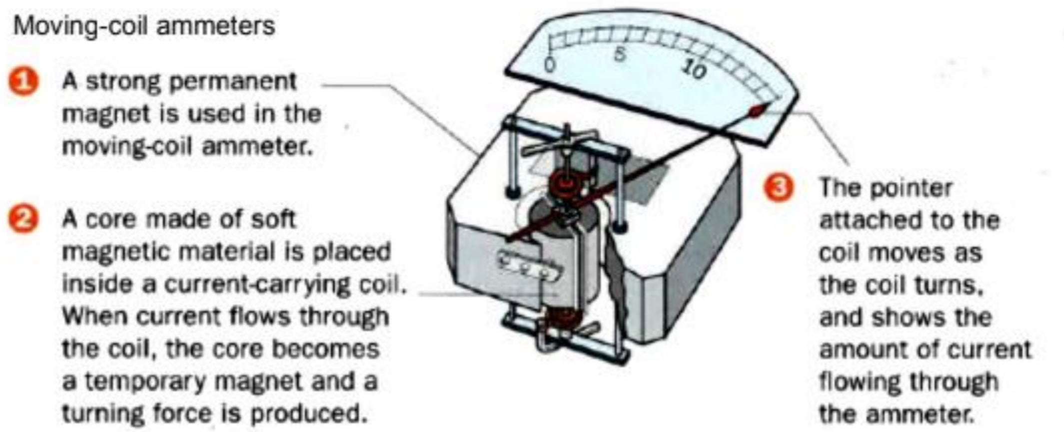
Types of magnetic materials

-There are two types of magnetic materials, hard and soft
-Soft magnetic materials, such as iron, are easily magnetised and demagnetised, and are hence used as temporary magnets
-Hard magnetic materials, such as steel, are difficult to magnetise and demagnetise, and are hence used as permanent magnets
-Soft magnetic materials tend to have stronger induced magnetism than hard magnetic materials, as they are easier to magnetise

Uses of magnets

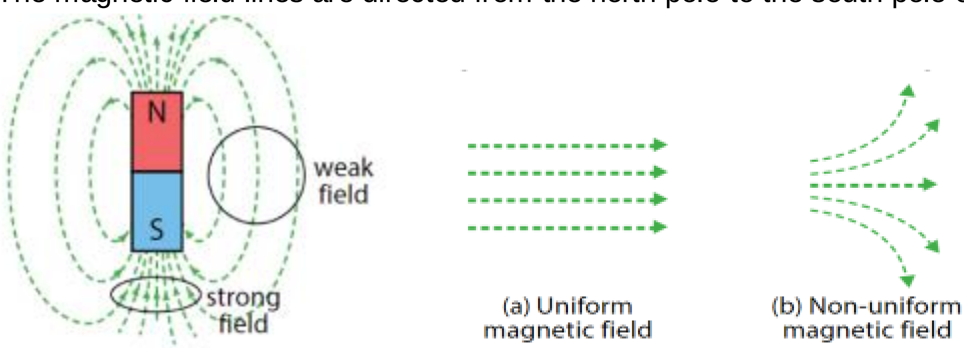
-Permanent magnets are used to make magnetic door catches on refrigerator doors
-Temporary magnets are used to make electromagnets
-Moving coil loduspeakers and ammeters make use of both permanent and temporary magnets



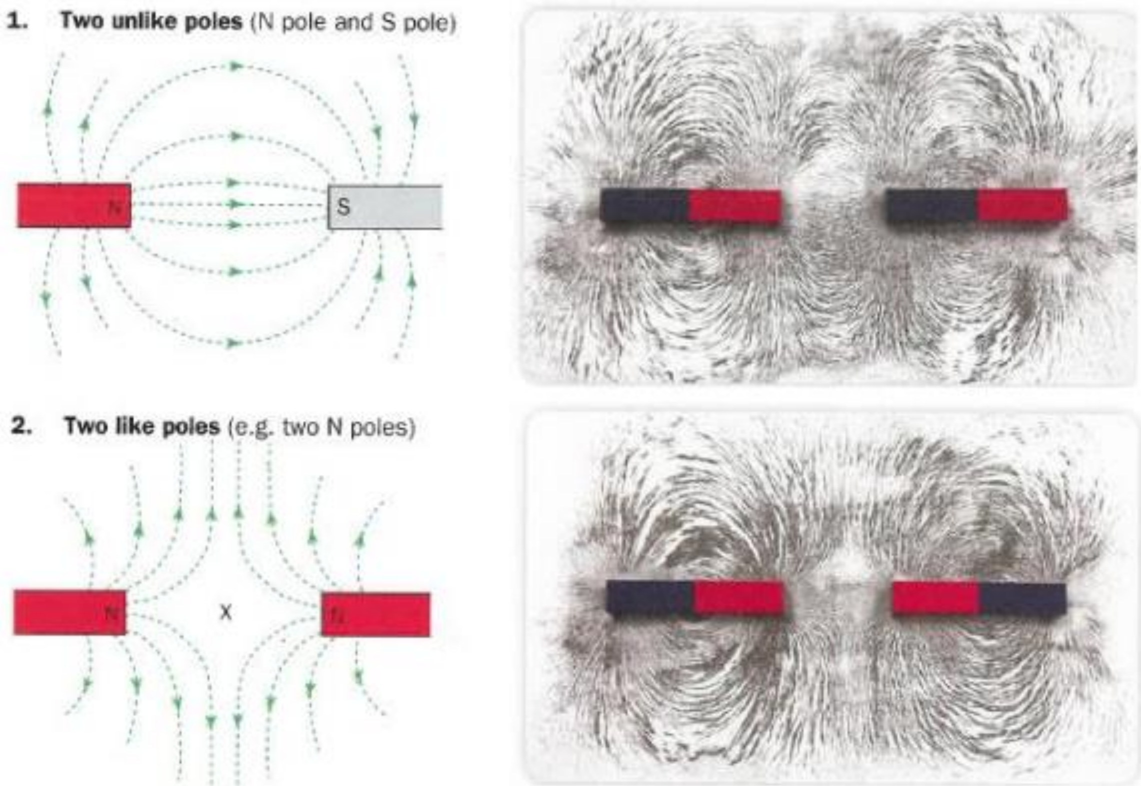


Magnetic fields

-A magnetic field is a region in which the force of magnetism acts
-A magnetic field is represented by magnetic lines of force, which can be straight or curved
-These lines do not interesect each other, and are perpendicular to the object's surface
-The strength of a magnetic field is indicated by how close the magnetic field lines are to each other, and equally spaced magnetic field lines means a uniform magnetic field
-The magnetic field lines are directed from the north pole to the south pole outside the magnet



-A group of magnetic lines of force form a magnetic field pattern, which can be shown using iron filings



Drawing magnetic field patterns

-A magnetic field pattern can be drawn using a plotting compass
-A bar magnet is placed in the center of a piece of paper with the north pole pointing to the north, and the compass is placed near a pole of the magnet
-The north and south pole of the compass is then marked, and the compass is moved such that the south needle is pointing to the position of the original north pole
-These steps are repeated to form a magnetic field line, and the direction of the magnetic field lines are determined by the direction of the plotting compass needle

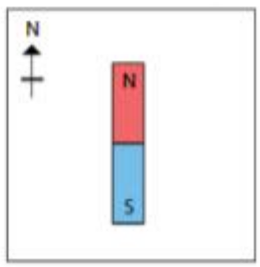


Figure 19.20
The north pole of the magnet points to the north

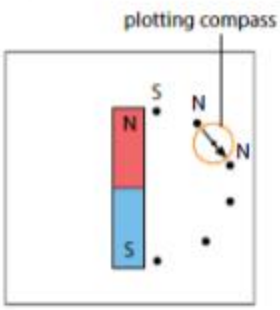


Figure 19.21
Mark the poles of the magnets by compass dots.

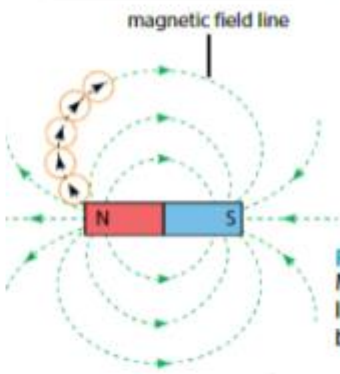
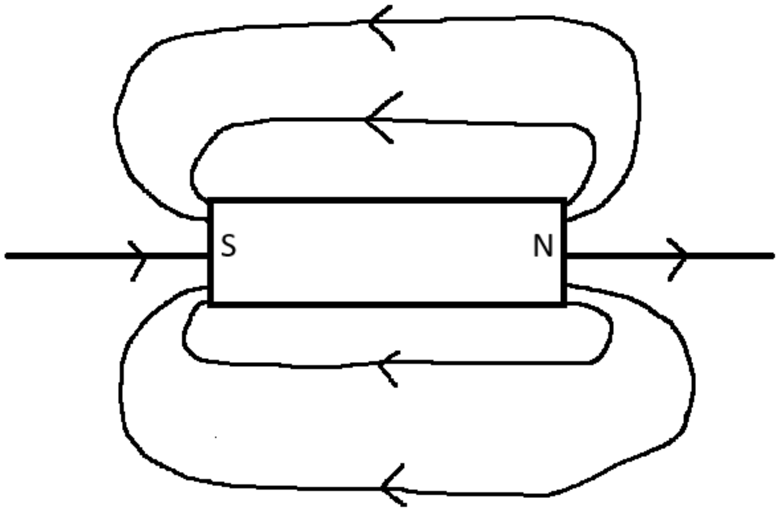
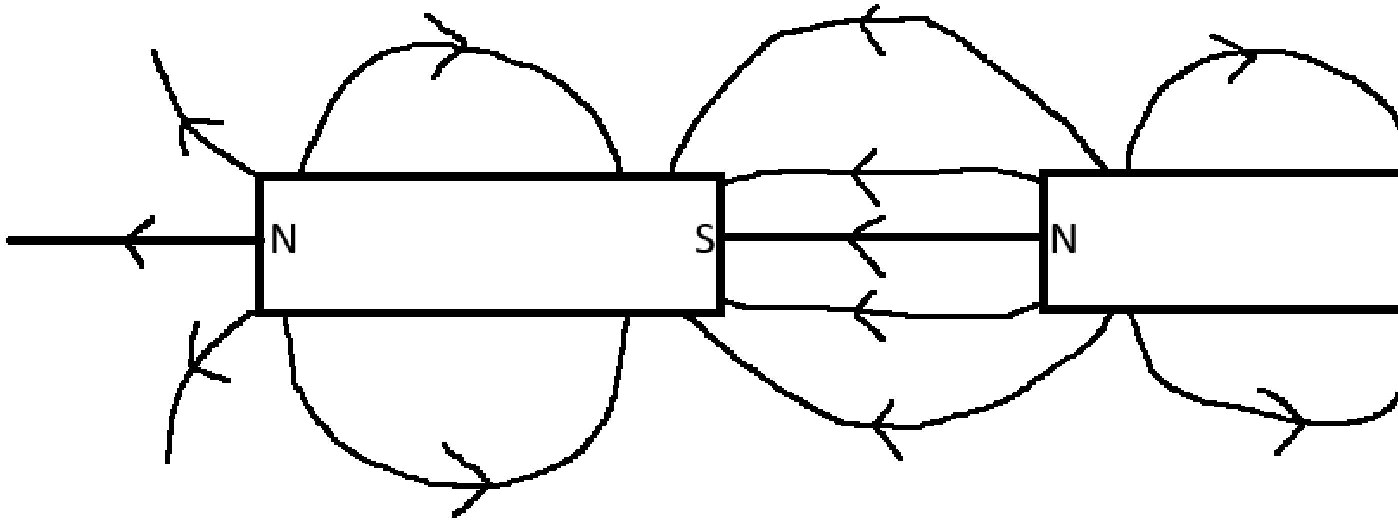


Figure 19.22
Magnetic field lines around a bar magnet

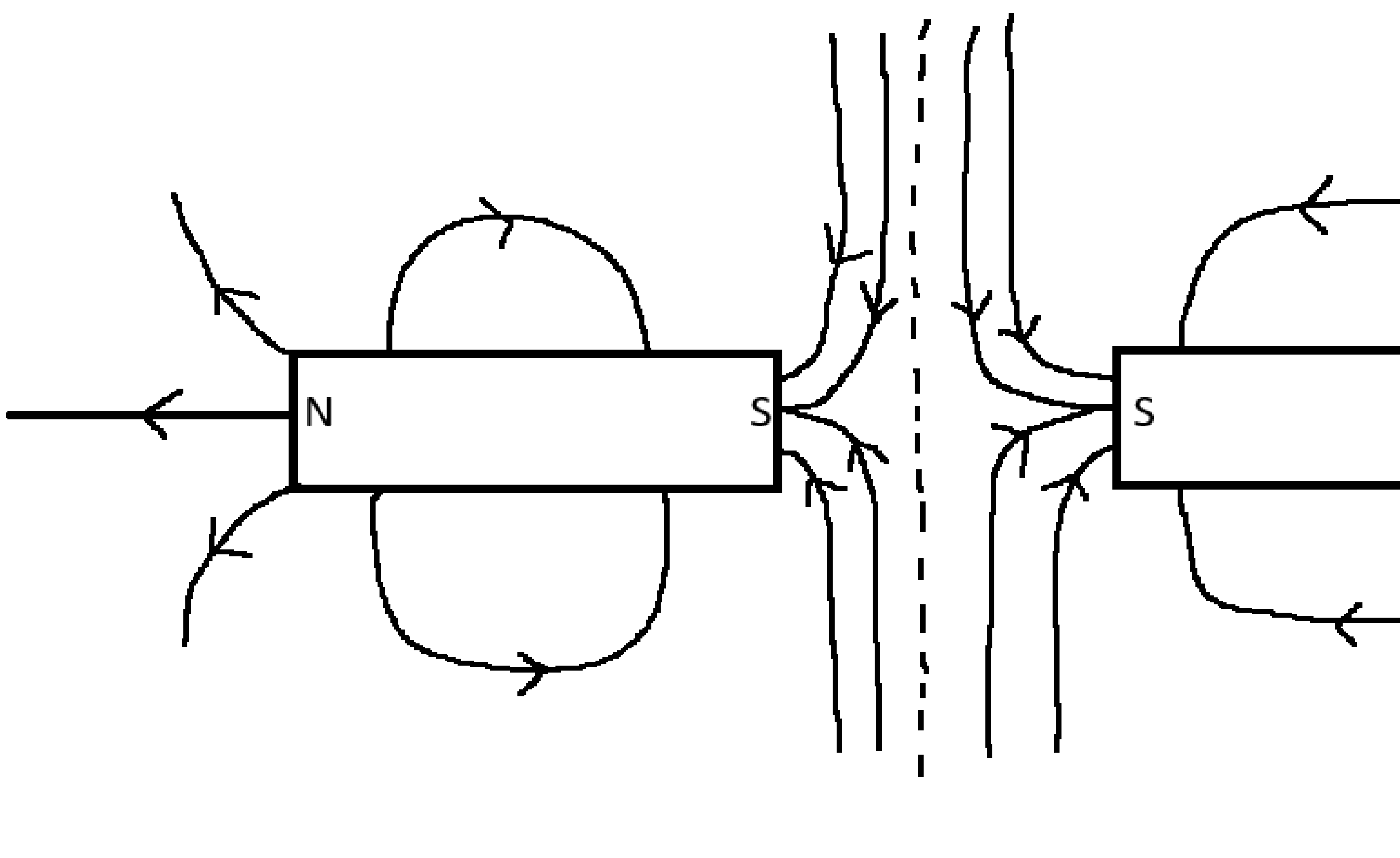
For a single magnet, the magnetic field is as shown below

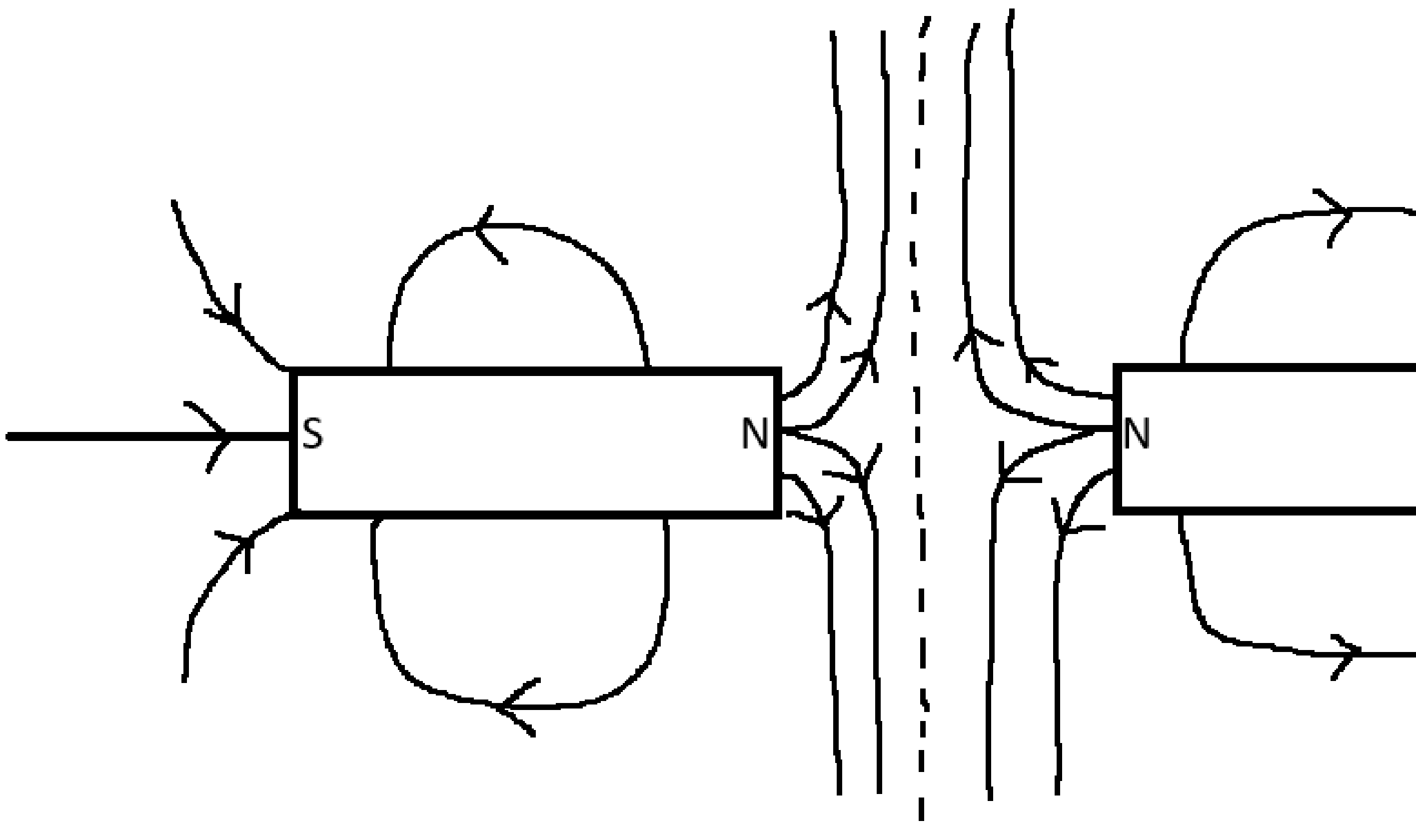


-For two magnets with unlike poles, the magnetic field is as shown below



-For two magnets with like poles, the magnetic field is as shown below



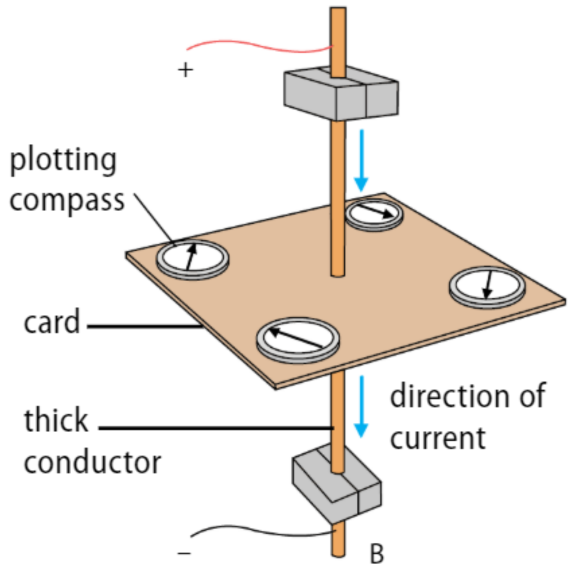


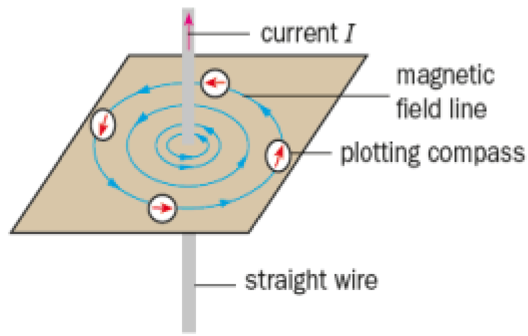
-Note that no magnetic field lines should pass the dotted line

Chapter 20: Electromagnetism

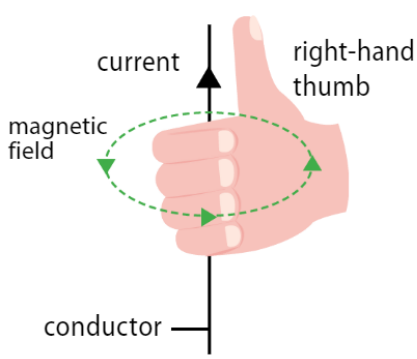
Magnetic effect of a current

-In the set up below, when no current is flowing through the conductor, the compasses come to rest in the north-south direction
-However, when a large current passes through the conductor, the needles immediately deflect as shown below, showing that a magnetic field is created around the conductor





-When the card is raised or lowered, the directions of needles do not change, suggesting that the magnetic field produced around the conducted forms concentric cylinders around the conductor
-When the direction of current is reversed, the needles deflect in the opposite direction
-An increased current results in a stronger magnetic field and closer magnetic field lines
-The right hand grip rule can be used to determine the direction of the magnetic field created by a straight conductor, where you grip the conductor with your right hand, and the thumb points in the direction of the current, and the other fingers point in the direction of the magnetic field as shown below



-To represent the direction of current in a wire, we use the symbols □ and ⊗, where □ represents current flowing towards you, and ⊗represents current flowing away from you

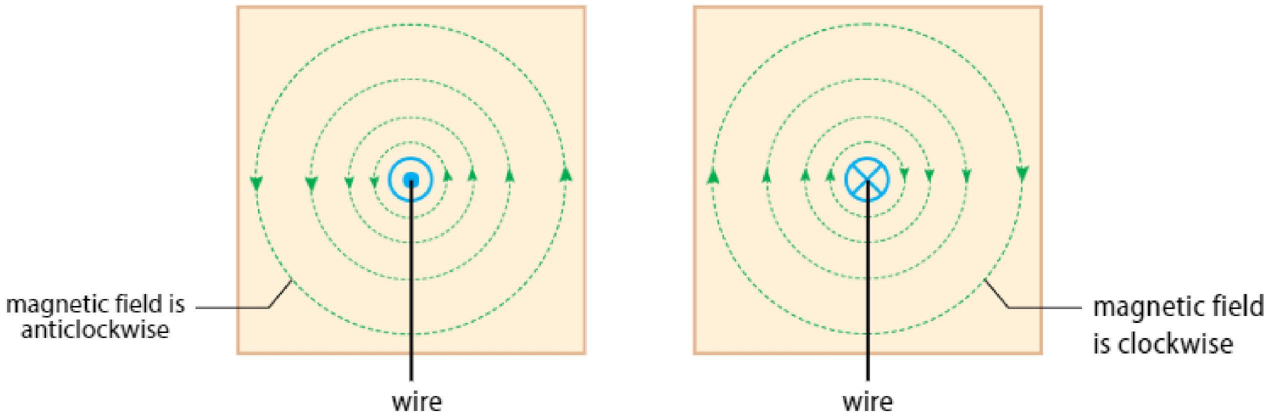
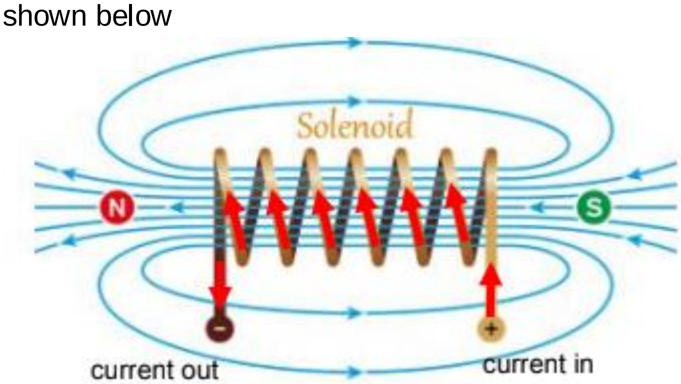
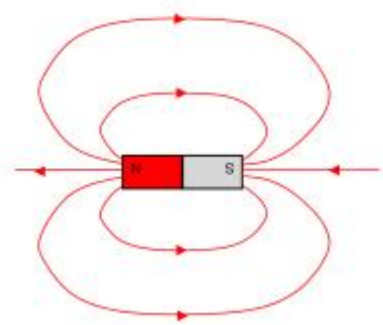


Figure 20.6 Top view of the strength of magnetic field: The direction of the magnetic field is reversed when the direction of the current is reversed.

Solenoids

-A coil with many turns is called a solenoid, and the magnetic field pattern of a solenoid is shown below





-Note that you have to draw at least 5 field lines in the solenoid equal distance away from each other, as there is a uniform magnetic field in the solenoid
-The magnetic field of the solenoid is identical to that of a bar magnet as shown above
-The right hand grip rule from chapter 19 can be used to determine the poles and direction of current in the solenoid, where you grip the solenoid with your right hand, and curl your fingers in the direction of conventional current flow, and the thumb will point in the direction of the north pole
-To increase the magnetic field strength of a solenoid, you can increase the number of turns per unit length of solenoid, increase the magnitude of the current and place a soft iron core within the solenoid
-The soft iron core increases the strength of the magnetic field as shown below

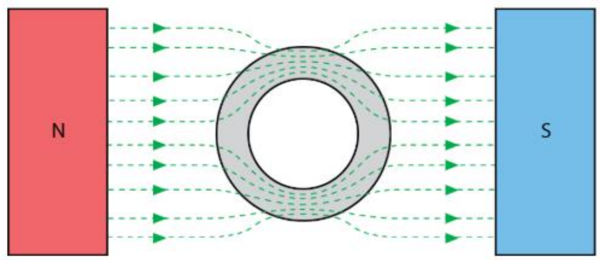
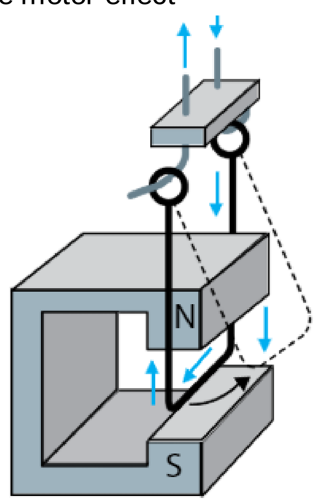
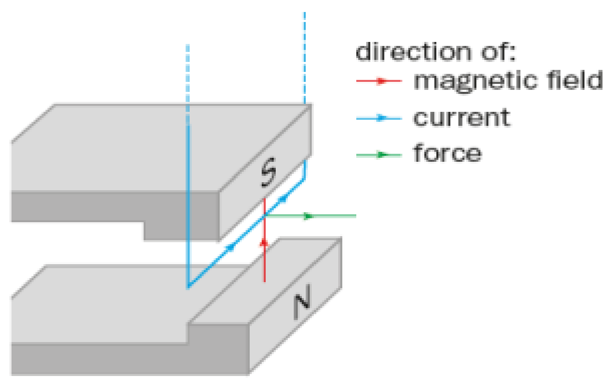


Figure 20.22 A soft iron cylinder concentrates the magnetic field lines and increases the strength of magnetic field.

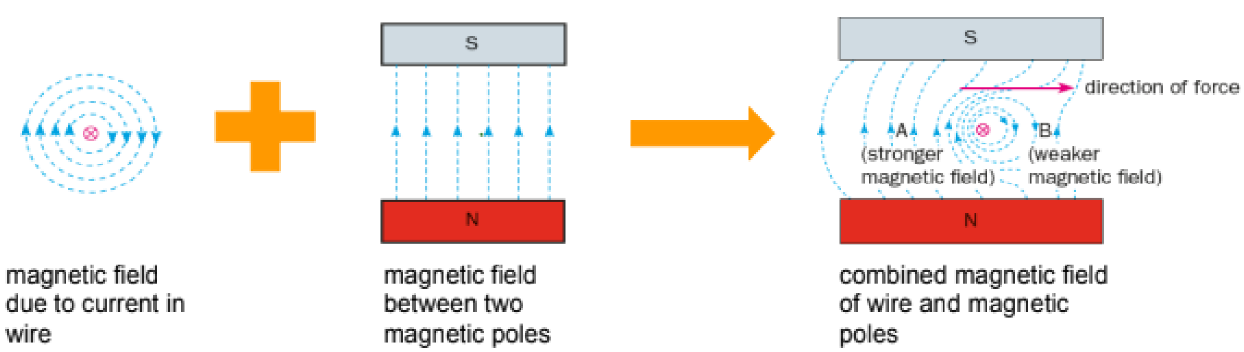
Force on a current carrying conductor

-In the set up below, wire BC is hung between two poles of a strong magnet
-When the switch is closed, the wire experiences a force, which is due to the interaction between the magnetic fields of the magnet and the current carrying wire, and this effect is called the motor effect





-The interaction between the magnetic fields result in a combined magnetic field that has a region with stronger magnetic field and a region with a weaker magnetic field as shown below

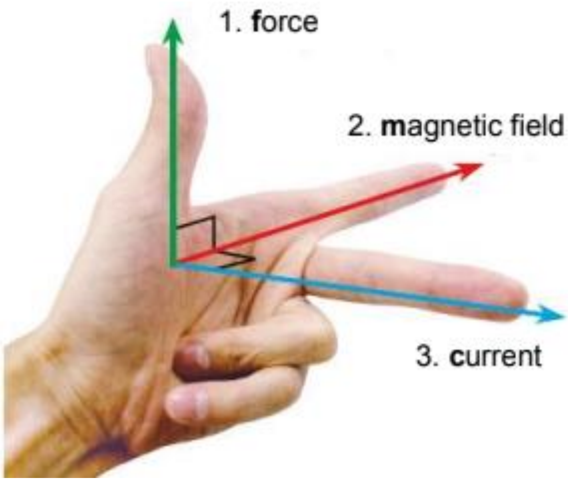


-This results in a force that acts from the stronger magnetic field to the weaker magnetic field

-You can think of it like a strong object pushing a weaker object, creating a force towards the weaker object

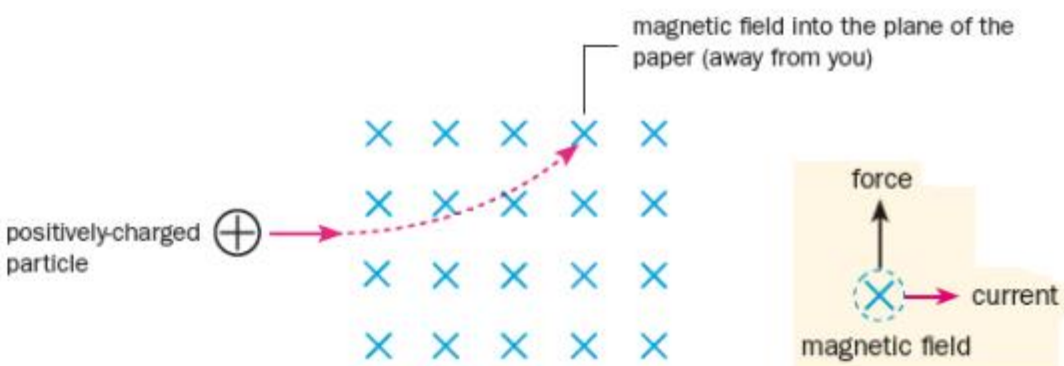
Fleming’s left hand rule

-For the scenario above, the force, current and magnetic field are art right angles to one another
-Hence, we can use fleming’s left hand rule to determine the direction of the force acting on a current carrying conductor in a magnetic field
-On the left hand below, the thumb points in the direction of the force, the forefinger points in the direction of the magnetic field, and the second finger points in the direction of conventional current



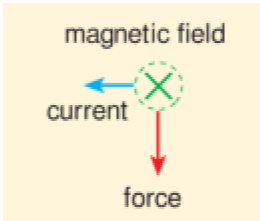
Force on particles

-If a positively charged particle moves through a magnetic field as shown below, we can use fleming’s left hand rule to determine the direction where it is deflected



-The particle moves upwards since the direction of conventional current is away from the positively charged particle, or to the right
-For a negatively charged particle with the same set up, the particle will move downwards as the direction of conventional current is towards the negatively charged particle, or to the left

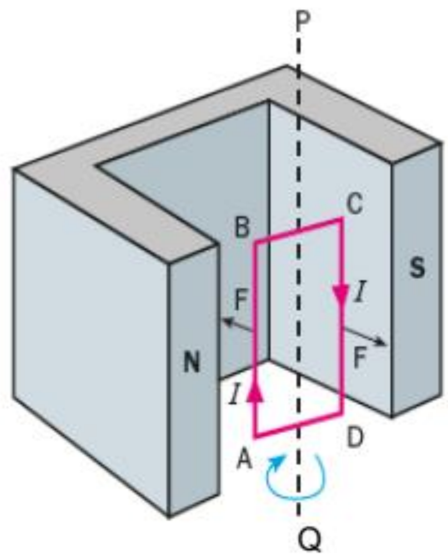
Negatively charged particle

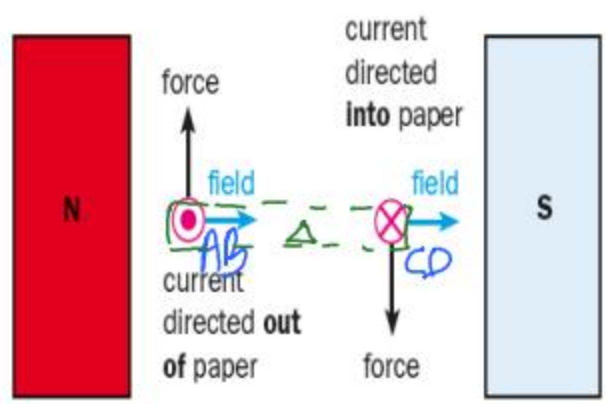


-The path is parabolic because the direction of motion, and hence direction of force, keeps changing

Turning effect on a current carrying coil in a magnetic field

-In the set up below, a coil ABCD is placed between the poles of a magnet

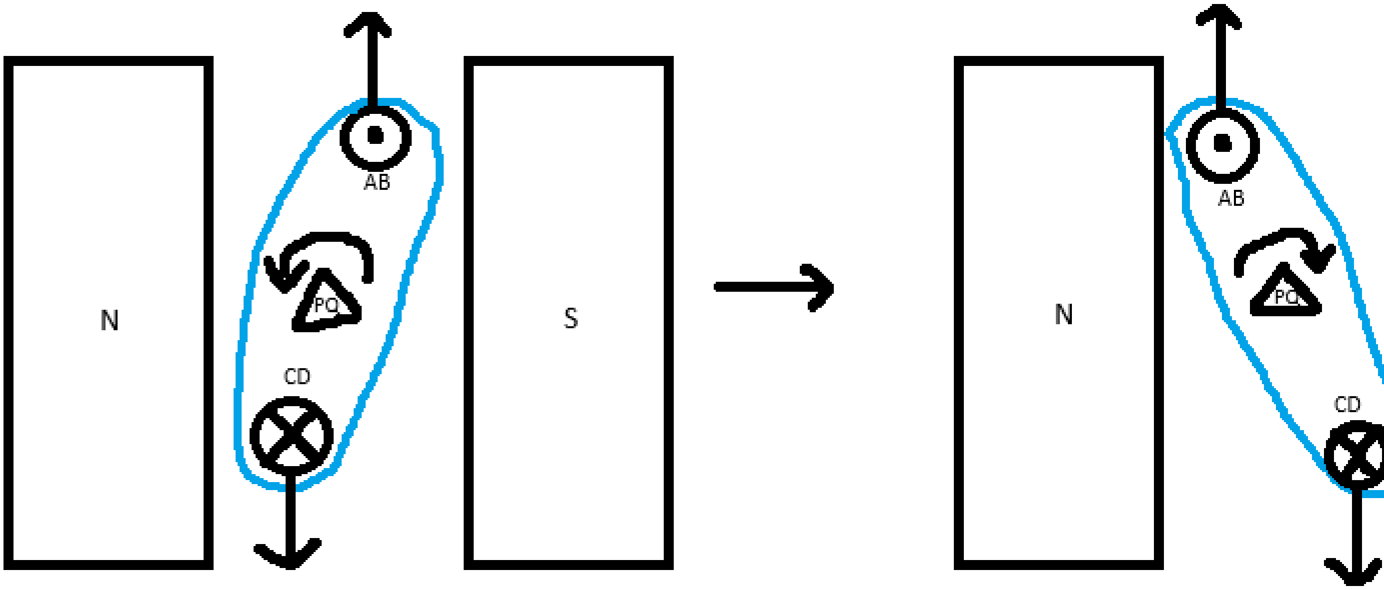




applying Fleming's left-hand rule
(top view of cross-section of coil ABCD)

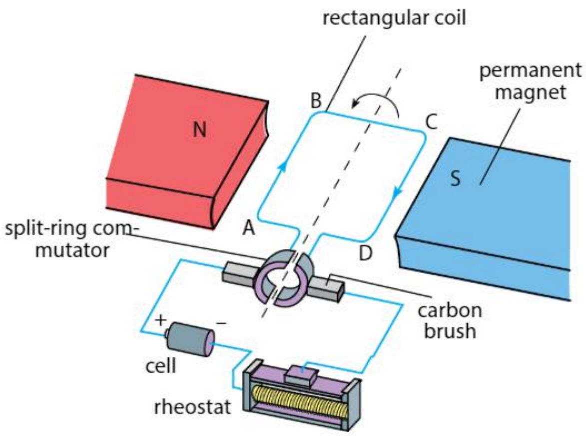
-Applying fleming's left hand rule, and upward force is produced on the left side of the coil and a downward force on the right side
-This creates a turning effect in the clockwise direction or a clockwise moment about the axis of rotation PQ, causing the coil to turn in the clockwise direction
-However, when the coil has turned past the vertical position to the right, an anticlockwise moment is produced instead about PQ, pushing it back towards the left
-This happens because current in the coil does not change direction, hence the forces acting on each side of the coil do not change direction, causing the moment to reverse when it crosses the vertical axis
-However, when the coil has turned past the vertical position to the left, the clockwise moment is produced again about PQ, pushing it towards the right
-This creates a loop where the coil wobbles left and right before eventually coming to rest at the vertical position

-Note that this is because although there are still forces acting on the coil, no moment is created because the line of action of the force to the pivot (PQ) is zero, as the forces are pointing perpendicularly in opposite directions



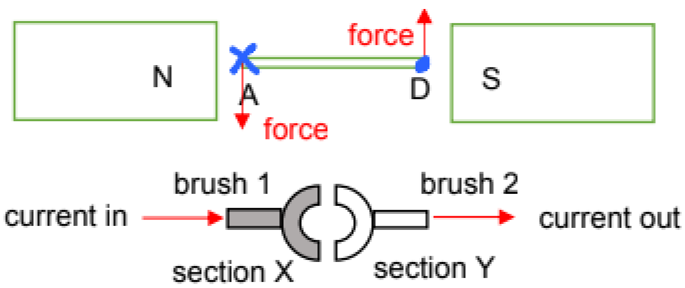
D.C. electric motor

-Below is the structure of a simple direct current electric motor

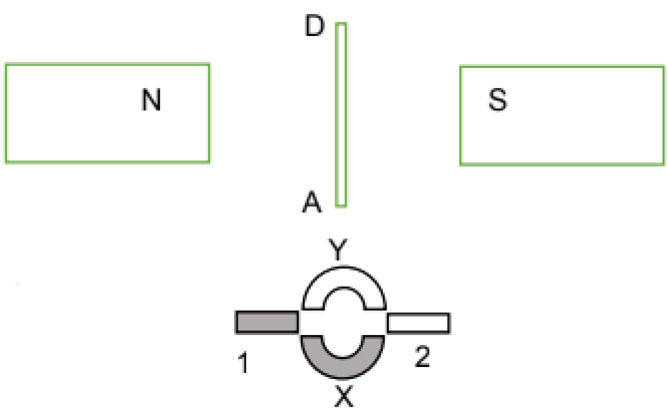


-It comprises of a split-ring commutator, a single rectangular coil mounted on an axle, a permanent magnet, and two carbon brushes connected to an external circuit with a cell and rheostat

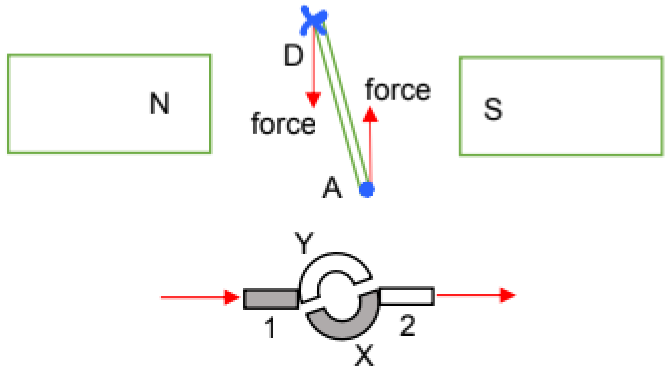
-The split ring commutator is fixed to the coil and rotates along with it, allowing the current in the coil to change direction every half a revolution, causing the forces acting on the sides of the coil to reverse every half a revolution
-This ensures that the direction of turning effect created due to the forces is always the same and causes the coil to rotate continuously in one direction
-The carbon brushes are fixed to the external circuit and do not move with the coil
-When the coil is at the horizontal position, current flows into brush 1 and section X, connected to side AB, so the direction of current is ABCD and the forces cause the coil to turn anticlockwise



-After one quarter of a revolution or 90°, the coil is at the vertical position and current is cut off due to the open circuit created by the gaps in the split ring commutator



-The coil then rotates past the vertical position due to inertia, reconnecting the split ring commutator to the carbon brushes
-However, ring X is now connected to brush 2 instead of brush 1, so the current flows into section Y, connected to side DC, and current flows in the direction DCBA
-This means that current direction in the coil is reversed and the forces acting on sides AB and CD are also reversed, causing the coil to continue rotating in the clockwise direction

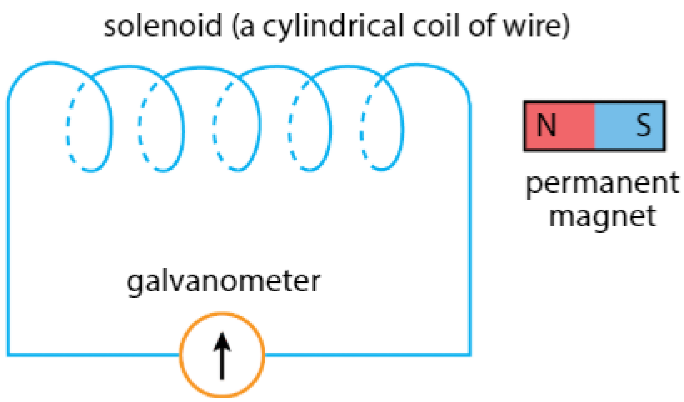


-To increase the turning effect of the DC motor, you can increase the current, increase the number of turns of the coil, or insert a soft iron core into the coil

Chapter 21: Electromagnetic Induction

Principles of electromagnetic induction

-Electromagnetic induction is a process through which an induced e.m.f is produced in a conductor due to a changing magnetic field
-This is shown in faraday's solenoid experiment where when a magnet is inserted into a solenoid, the galvanometer needle was deflected in one direction momentarily
-When the magnet was withdrawn from the solenoid, the galvanometer needle was deflected in the other direction momentarily
-When the magnet was stationary in the solenoid, the needle was not deflected
-Note that a galvanometer is an instrument used to detect the direction and magnitude of a small current or voltage, and that the needle is deflected due to the induced e.m.f inducing a current to move the needle
-The needle points in the direction where conventional current enters the galvanometer

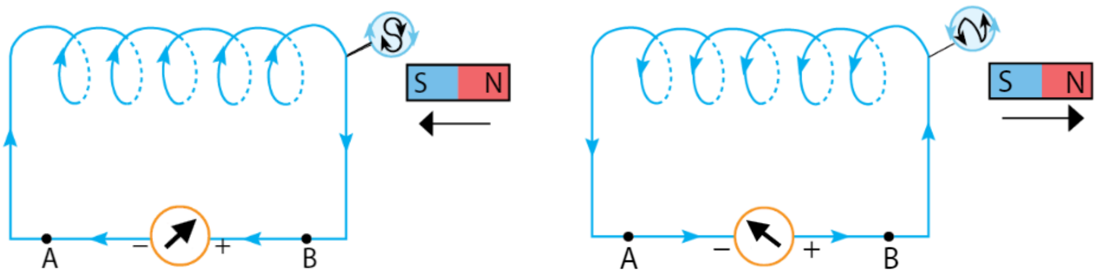


Faraday's law of electromagnetic induction

-Faraday's law of electromagnetic induction states that the magnitude of the induced e.m.f in a circuit is directly proportional to the rate of change of magnetic flux in the circuit
-Magnetic flux is a measurement of the total magnetic field which passes through a given area
-This means that the magnitude of induced e.m.f could be increased by increasing the number of turns in the solenoid, the strength of the magnet and the speed at which the magnet moved with respect to the solenoid
-This is because increasing the number of turns and strength of the magnet increases magnetic flux in the coil, and increasing the speed of the magnet increases the rate of change of magnetic flux in the coil

Lenz's law

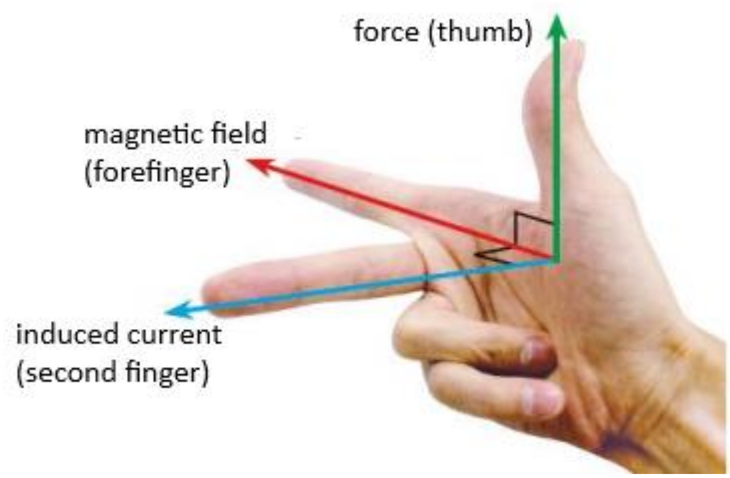
-Lenz's law states that the direction of the induced e.m.f and hence the induced current in a closed circuit is always such that its magnetic effect opposes the motion or change producing it
-Note that when there is a change in the number of magnetic field lines cutting a coil or change in magnetic flux, there will always be an induced e.m.f, but only if the circuit is closed will there be induced current
-Lenz's law is shown in the following set ups



-When the south pole approaches the right end of the solenoid, an induced current will flow in the solenoid such that a south pole is produced at that right end of the solenoid to oppose the incoming magnet, preventing it from entering
-When the south pole is withdrawn from the right end oif the solenoid, an induced current will flow in the solenoid such that a north pole is produced at that right end to oppose the outgoing magnet, preventing it from leaving

Fleming's right hand rule

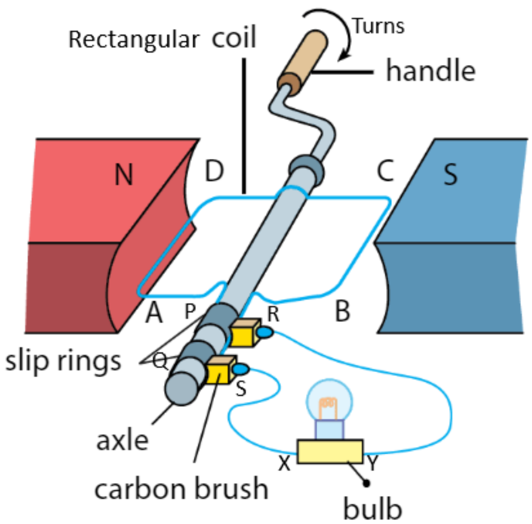
-If a straight conductor moves in a magnetic field, an e.m.f will be induced in the conductor, and if the conductor forms a complete circuit, an induced current will flow as well
-The direction of this induced current can be deduced using fleming's right hand rule, where the thumb points in the direction of the force, the forefinger points in the direction of the magnetic field, and the second finger points in the direction of induced conventional current



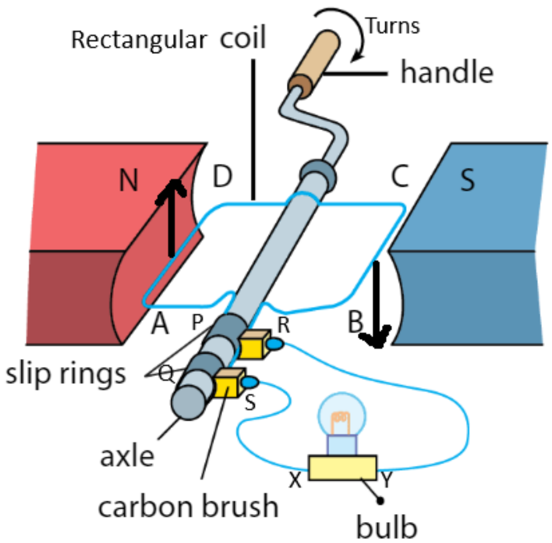
-Note that fleming's left hand rule is used for electric motors while fleming's right hand rule is used for electromagnetic induction
-One way to see which rule to use is to check if there is a battery, so if there is a battery you use fleming's left hand rule, and if there isn't, you use fleming's right hand rule

A.C. generator

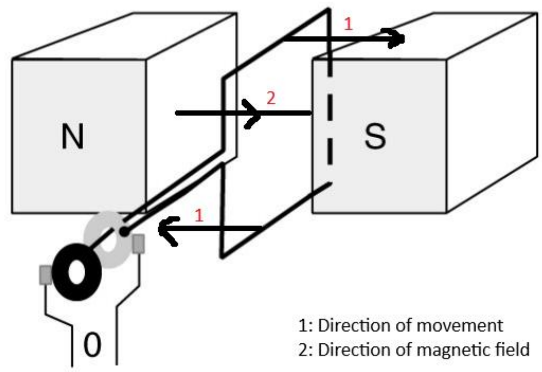
-Below is the structure of a simple alternating current generator



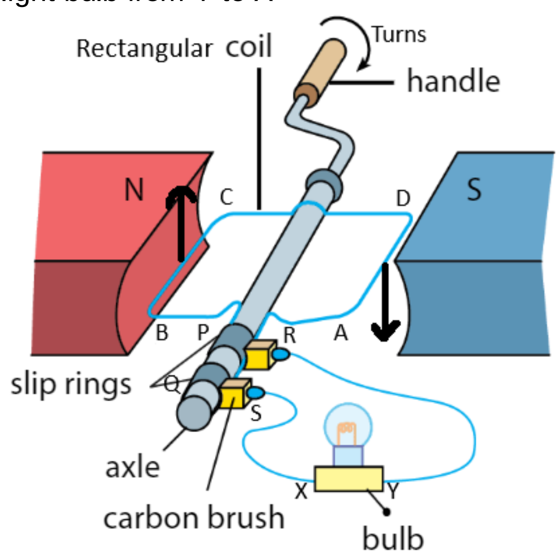
-It is similar to the DC motor in that it has a single rectangular coil of wire between two magnetic poles and two carbon brushes connected to an external circuit, in this case with a bulb
-However, the AC generator has slip rings instead of split ring commutators
-In the example above, the coil is rotated manually using the handle, and the slip rings also rotate with the coil
-Wire AD is connected to ring P and wire BC is connected to ring Q
-The slip rings are in contact with the carbon brushes to ensure that the induced current is transferred to the external circuit when the coil rotates
-When wire AD moves upwards and wire BC moves downwards, an induced current is produced due to electromagnetic induction
-Fleming's right hand rule tells us that the induced current flows in the direction ADCB
-Since BC is connected to brush S, the induced current flows out of brush S and through the light bulb from X to Y



-After the coil has rotated 90°, the plane of the coil is perpendicular to the magnetic field, hence there is no change in magnetic flux in the coil as the direction of movement is parallel to the direction of the magnetic field and thus there is no induced current in the coil



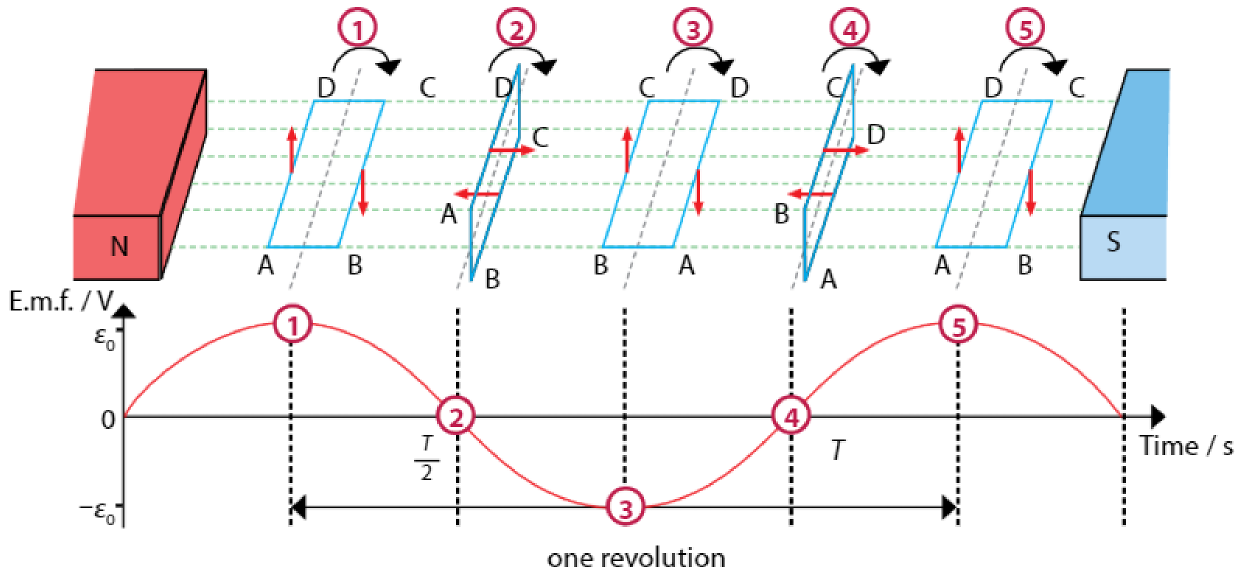
-Half a revolution later, AB and CD have switched sides, so when AD moves downwards and BC moves upwards, there is a change in magnetic flux in the coil
-Fleming's right hand rule tells us that the induced current flows in the direction BCDA
-Since AD is connected to brush R, the induced current flows out of brush R and through the light bulb from Y to X



-This means that as the coil rotates, the induced current flows from X to Y through the bulb, and then reverses direction and flows from Y to X through the bulb, hence inducing an alternating current

Voltage-time graph

-The voltage generated by an AC generator is an alternating voltage, and follows the graph below

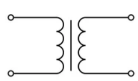


-The magnitude of induced e.m.f can be increased by increasing the number of turns in the coil and frequency of rotation, using stronger permanent magnets and winding the coil around a soft iron core to increase the magnetic flux linking the coil

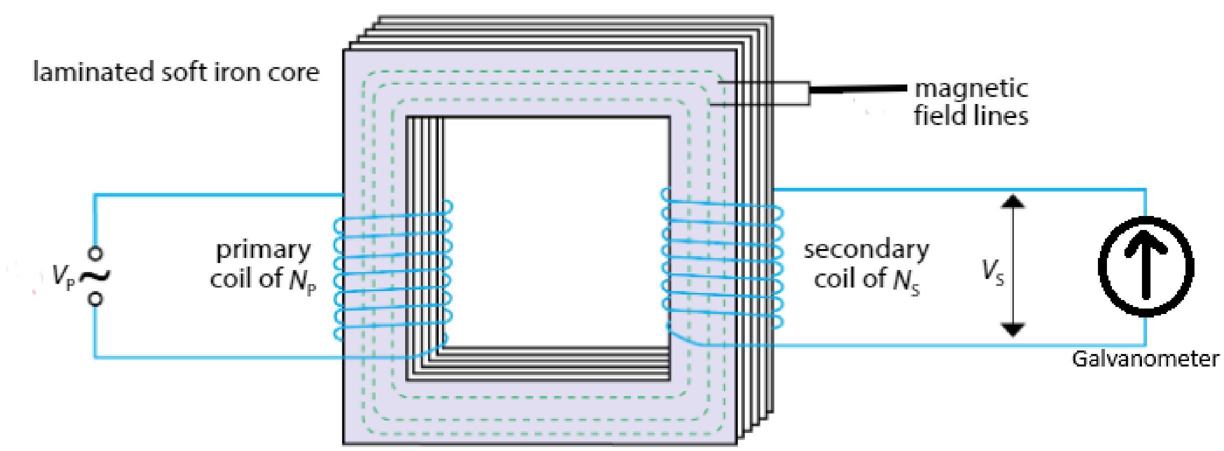
-This is all because of faraday's law

Transformers

-A transformer is a device that can change a high alternating voltage to a low alternating voltage, or vice versa

-Circuit symbol: 

-The structure of a transformer is shown below



-Vp is the alternating input voltage or primary voltage and Vs is the output voltage or secondary voltage

-Np is the number of turns in the primary coil and Ns is the number of turns in the secondary coil

-The laminated soft iron core is to reduce heat loss due to eddy currents which are local induced currents that flow in loops, as lamination cuts off the path taken by these eddy currents
-It also ensures a better magnetic flux linkage between the two coils as soft iron is able to concentrate the magnetic field lines

How does a transformer work?

-When an alternating current passes through the primary coil, it sets up a changing magnetic field in the soft iron core
-This induces an e.m.f in the secondary coil as it is linked to the changing magnetic field in the iron core
-The galvamometer will deflect left and right continuously as the direction of the induced e.m.f alternates at the same frequency as the alternating primary current
-Note that no current from the coils flows into the iron core as the coils are insulated
-If the alternating primary current is changed to direct current, the galvanometer needle will deflect momentarily as the magnetic flux in the secondary coil only changes briefly when the switch is closed
-The needle will then not deflect as there is no more change in magnetic flux in the secondary coil
-If the switch is opened, the galvanometer will deflect momentarily in the opposite direction, as the magnetic effect produced is now opposite to the initial magnetic effect

Voltage in a transformer

-The voltage and number of turns in the primary and secondary coils are related by the formula Vs/Vp = Ns/Np, where Vs is the secondary voltage, Vp is the primary voltage, Ns is the number of turns in the secondary coil, and Np is the number of turns in the primary coil
-Note that Vp/Vs + Np/Ns also works
-Ns/Np is known as the turns ratio
-From the principle of conservation of energy, power in the primary coil is transferred to the secondary coil, so from P=IV, we get the formula VpIp = VsIs, where Vs is the secondary voltage, Vp is the primary voltage, Is is the secondary current, and Ip is the primary current
-This is assuming that the transformer is 100% efficient with no power loss
-However, this is not true in reality as there is heat loss due to the resistance of the primary and secondary coils, leakage of magnetic field lines between the primary and secondary coils and heat loss due to eddy currents induced in the iron core, even despite lamination
-If Ns > Np, Vs > Vp and Is < Ip, and the transformer is a step up transformer, increasing voltage as Vs > Vp
-If Ns < Np, Vs < Vp and Is > Ip, and the transformer is a step down transformed, decreasing voltage as Vs < Vp

Transimission of electrical energy

-Electrical energy generated at a power station is transmitted to households and factories using metal cables

-Due to the resistance in the cables, some of the energy is lost in the form of heat, known as joule heating or I^2R losses

-To minimise the energy lost, we consider the equation $P = I^2R$, where P is the power lost

-One way to minimise energy lost is to increase the thickness of the cables to reduce the resistance, but this increases cable cost

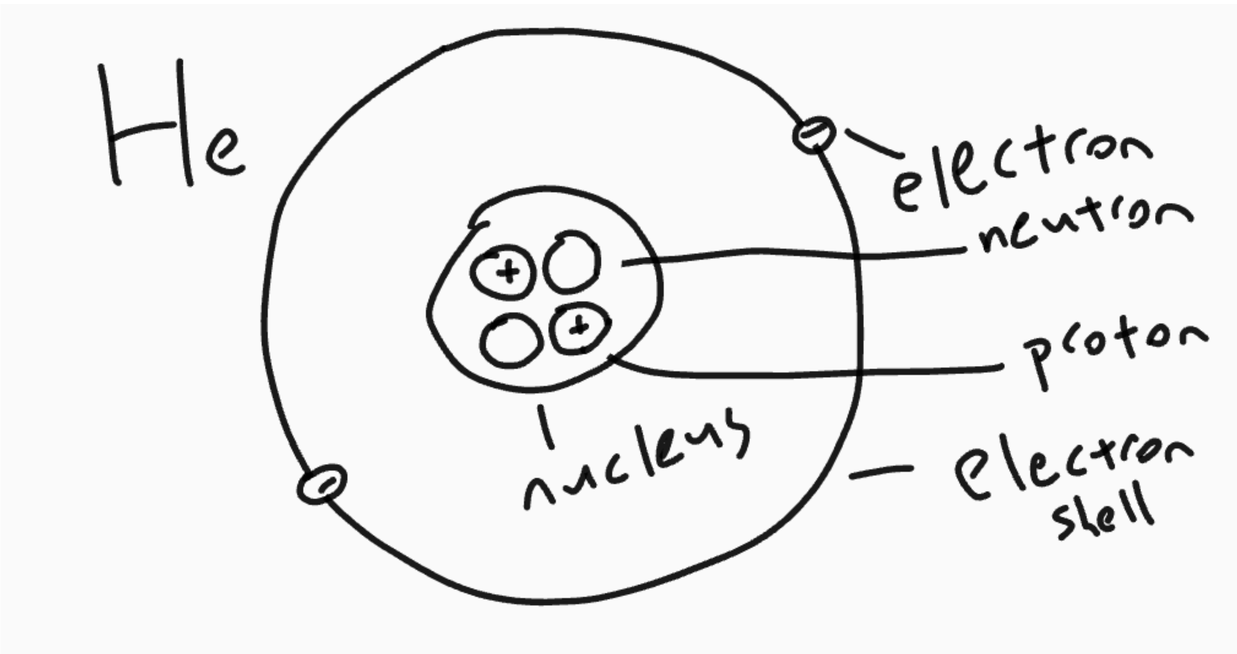
-Another way is to transmit power at a high voltage and low current to minimise the power lost as $P = IV$, which can be done through step up transformers

-A lowered current allows for thinner cables as well, resulting in cost savings

Chapter 22: Radioactivity

The atom

-The atom consists of a positively charged nucleus and negatively charged electrons
-The nucleus consist of positively charged protons and negatively charged neutrons
-Protons, neutrons and electrons are known as sub atomic particles, and both the proton and neutron carry a charge of 1.6 x 10^-19 C
-Since this charge is so low, the charge of subatomic particles is expressed as relative charge, where an electron has a relative charge of -1, a proton has a relative charge of +1, and a neutron has a relative charge of 0
-The proton and neutron both have relative masses of 1, while the electron has a relative mass of 1/1840, which is considered negligible



Proton number

-The proton number is the number of protons in an atom, and is also known as the atomic number
-Symbol for proton number: Z
-In a neutral atom, the proton number is equal to the number of electrons
-Each element has a unique proton number, so an atom with 92 protons will always be an uranium atom

Nucleon number

-Protons and neutrons are also called nucleons
-The nucleon number is the total number of neutrons and protons in the nucleus of an atom, and is also known as the mass number
-Symbol for nucleon number: A

-Formula for number of neutrons: number of neutrons = A - Z, where A is the nucleon number and Z is the proton number

Nuclei notation

-The various species of atoms whose nuclei contain a particular number of protons and neutrons are called nuclides
-The nucleus of an atom can be represented by the nuclide notation, where the superscript number is the mass number, and the subscript number is the proton number
-The big letter is the chemical symbol from the periodic table

$$^{12}_{6}C$$

-For example the atom shown above has a mass number of 12, and an atomic number of 6, and is a carbon atom from the chemical symbol
-A nuclide equation represents the changes in composition of the nucleus
-For example, the nuclide equation for the decay of tungsten-159 is $^{159}_{74}W \rightarrow \ ^{155}_{72}Hf + \ ^{4}_{2}He$
-Note that the total number of nucleons (159) and protons (74) before and after the reaction remains the same
-The total relative charge before and after a nuclear emission should also remain the same

Isotopes

-Isotopes are atoms of the same element that have the same number of protons but different number of neutrons
-For example, uranium-235 and uranium-238 are both isotopes of uranium, having 143 and 146 neutrons respectively

Nuclear decay

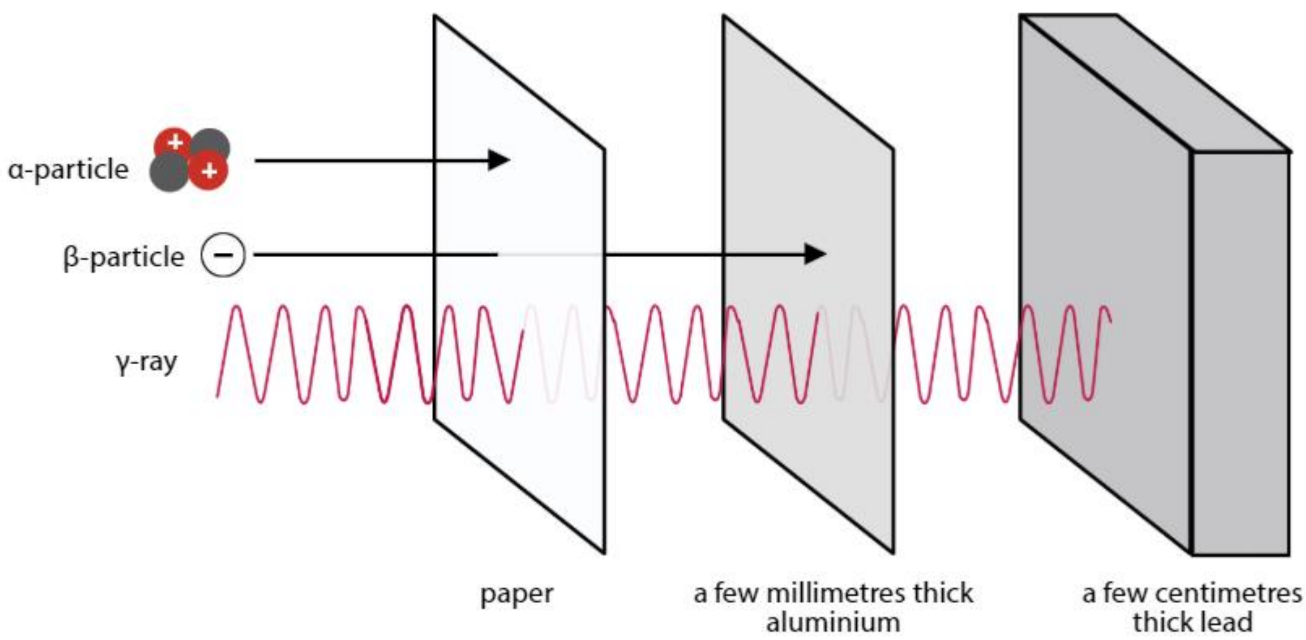
-Nuclear decay is a random process by which an unstable atomic nucleus loses its energy by emission of electromagnetic radiation or particles
-It is also known as radioactive decay or radioactivity
-A material containing unstable nuclei is considered radioactive, and is unstable as the nuclear forces within the nuclei are not enough to bring the nucleons together
-The radiation emitted by a radioactive nucleus is spontaneous and random in direction, hence it is not possible to make the radioactive nucleus emit radiation by heating, cooling, by chemical means or by any other method, predict when a radioactive nucleus will emit radiation, and know the direction in which the emitted radiation will leave a nucleus

Types of nuclear emission

-There are 3 types of nuclear emission, alpha (α) particles, beta (β) particles and gamma (γ) rays

-The nuclei of the same isotope will emit the same type of nuclear emission, and during a nuclear emission, the nucleus changes to that of a different element

emission	Nature	Relative ionising effect	Relative penetrating powe
les $^{4}_{2}\alpha$ 	-An α -particle consists of two protons and two neutrons tightly bound together, and is identical to a helium nucleus	-Highest	-Least, easily absorbed by piece of paper, thin alumin or human skin -Range in air is less than 5
es 	-A β-particle is a fast moving electron ejected from a radioactive nucleus	-Medium	-Medium, absorbed by a p aluminium a few millimetre
	-A ɣ-ray is electromagnetic radiation emitted by a radioactive nucleus with excess energy	-Lowest	-Highest, they pass throug materials easily and requir a few centimetres think or thick concrete to be absior



Alpha decay

-When a nucleus undergoes α-decay, it emits an α-particle, resulting in the nucleon number decreases by 4, and the proton number decreases by 2
-For example, the nuclide equation for the α-decay of radium-226 is $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$
-From this, you can see that when radium-226 emits an α-particle, it decays into radon-222

Beta decay

-When a nucleus undergoes β-decay, it emits a β-particle, resulting in the nucleon number remaining the same and the proton number increasing by 1
-For example, the nuclide equation for the β-decay of carbon-14 is $^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$
-From this, you can see that when carbon-14 emits a β-particle, it decays into nitrogen-14

Gamma radiation

-Very often, gamma radiation happens together with alpha or beta decay
-For example, when uranium-238 undergoes α-decay, it decays into thorium-234 and two ɣ-rays of different energies are emitted
-Nuclide equation for the α-decay of uranium-238: $^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He + 2\ ^{0}_{0}\gamma$
-The 2 next to the $^{0}_{0}\gamma$ indicates the 2 ɣ-rays emitted

Background radiation

-Background radiation refers to nuclear radiation in an environment where no radioactive source has been deliberately introduced
-We encounter background radiation from artificial sources such as medical X-rays, building metrials and waste products from nuclear reactors, or natural sources such as rocks, radon gas in the air, or food and drink (food high in potassium such as bananas can contain radioactive potassium-40), and it does not present a serious health risk to humans

Measuring ionising nuclear radiation

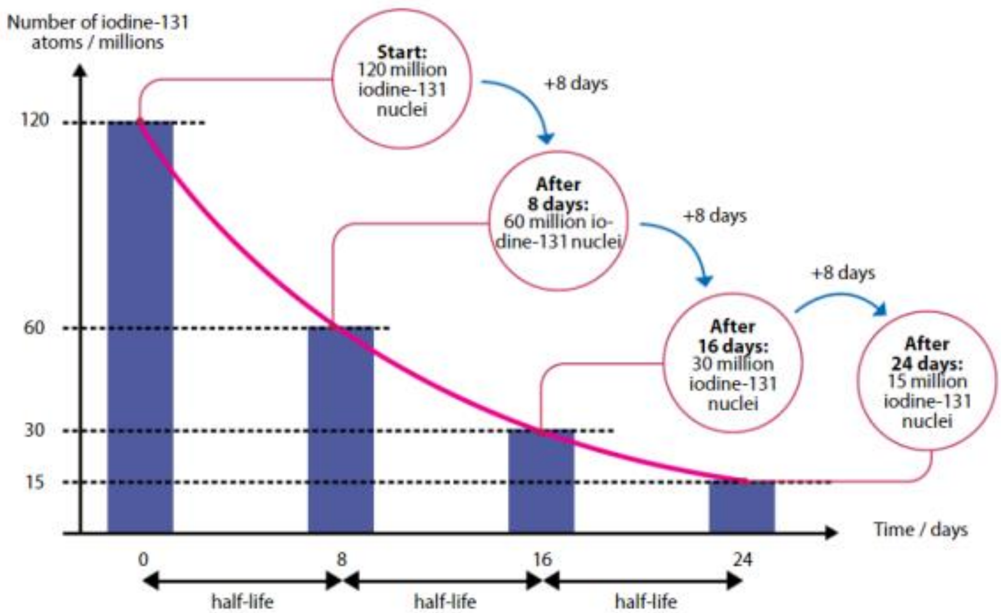
-Ionising radiation is radiation with high energies that can knock off electrons from atoms to form ions
-Ionising radiation can be measured using a geiger-muller (GM) counter
-SI unit for amount of radioactivity: Bq (becquerel)
-It can also be expressed as counts per unit time, also known as count rate
-This unit is either counts/min (counts per minute) or counts/s (counts per second)
-Note that a larger sample size corresponds to more radioactivity or a larger count rate

detector and counter

single unit

Half-life

-Although nuclear decay is spontaneous and random, every nuclide has a fixed rate of decay
-The half-life of a radioactive nuclide is the time taken for half the nuclei of that nuclide in any sample to decay
-For example, the half-life of iodine-131 is eight days, and follows the decay curve shown below



-As you can see, after every 8 days, the number of iodine-131 atoms decreases by half and after 16 days, it decreases by one quarter
-Note that the half-life of a nuclide can also be understood as the time taken for the count rate of the radioactive emission to fall by half
-So, if a sample of iodine-131 has a count rate of 50 counts/min, after 8 days it would have a count rate of 25 counts/min and after 16 days its 12.5 counts/min
-It is important to note that after the half-life, half of the sample doesn't disappear, but rather becomes other elements known as decay products

Nuclear fission

-Nuclear fission is a process in which the nucleus of an atom splits and releases a huge amount of energy

-For example, the nuclide equation for the fission of uranium-235 is $^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\ {}^{1}_{0}n$

-Note that $^{1}_{0}n$ represents a neutron

-The original atom is called the parent nucleus, so in this case $^{235}_{92}U$ is the parent nucleus

-The parent nucleus decays to form other atoms called daughter nuclei, so in this case $^{144}_{56}Ba$ and $^{90}_{36}Kr$ are the daughter nuclei

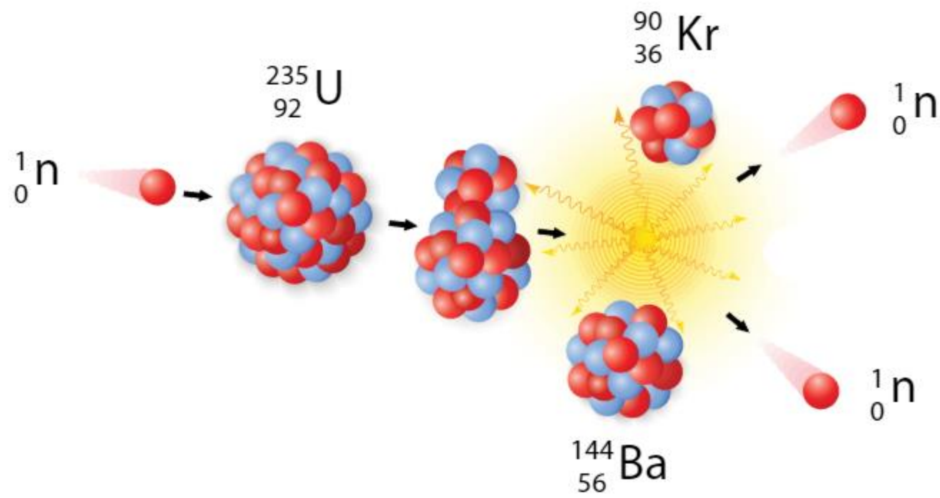
-The daughter nuclei can be stable or decay further

-In a nuclear fission, there are several possible fission products, so there are several possible nuclide equations

-For example, another nuclide equation for the fission of uranium-235 can be $^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{139}_{56}Ba + {}^{94}_{36}Kr + 2\ {}^{1}_{0}n$

-However, the total number of nucleons (235) and the total relative charge (0) before and after the reaction are always the same

-Some mass is lost during fission as energy

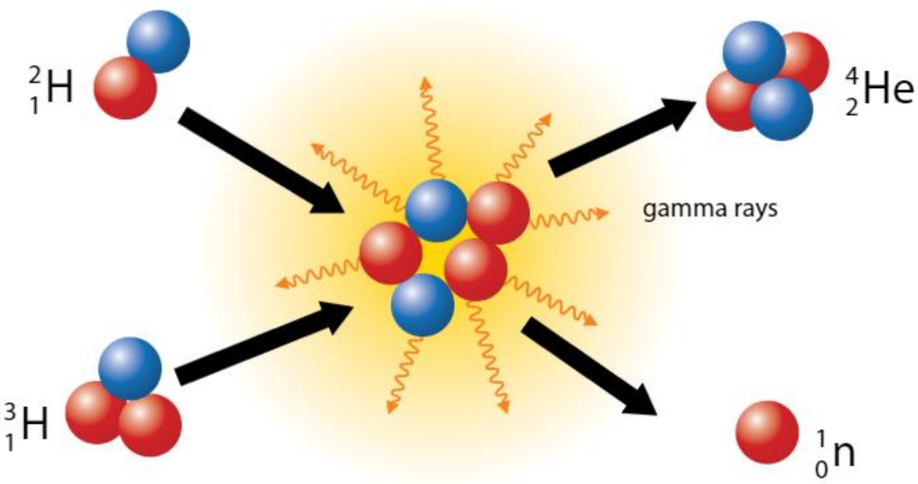


Nuclear fusion

-Nuclear fusion is a process in which two light atomic nuclei combine to form one heavier atomic nucleus and releases a huge amount of energy

-For example, the nuclide equation fot the nuclear fusion of hydrogen-2 and hydrogen-3 is $^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$

-Some mass is lost during fusion as energy



Energy changes during nuclear processes

-Energy is often released during nuclear processes

Energy changes during nuclear fission
-Nuclear fuel is a material used in nuclear power stations
-Some examples include uranium and plutonium, and common isotopes of these include uranium-233, uranium-235 and plutonium-239
-These nuclear fuels undergo nuclear reactions to release energy
-During nuclear fission, energy is transferred from the nuclear store of the unstable nucleus to the kinetic, internal and nucler stores of the daughter nuceli and neutrons and the internal store of the surroundings
-The internal store of the surroundings is used to heat water to change it to steam, which then turns turbines in generators to generate electricity
-the neutrons produced in the nuclear fission will go on to split more nuclei, creating a self sustaining controlled chain reaction in the nuclear reactor
-The processes involved in mining, refining, purifying, using and disposing of nuclear fuel are collectively known as the nuclear fuel cycle

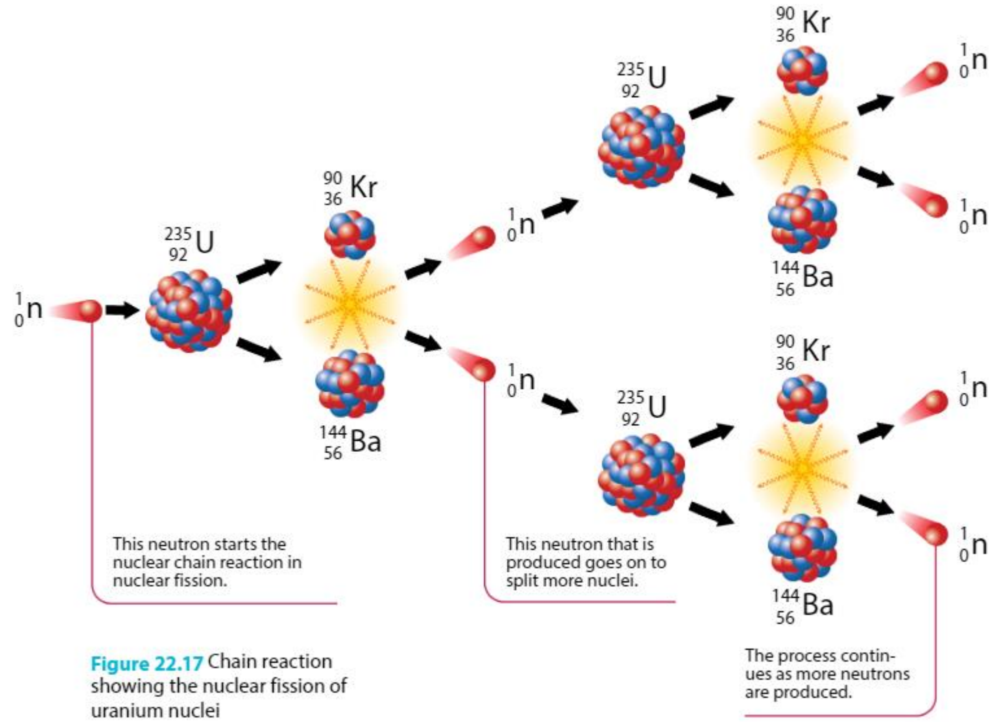


Figure 22.17 Chain reaction showing the nuclear fission of uranium nuclei

Energy changes during nuclear fusion
-Electricity can also be generated from nuclear fusion
-During nuclear fusion, energy is transferred from the nuclear stores of the two nuclei to the kinetic, internal and nuclear stores of the bigger nucleus, and the internal store of the surroundings
-The internal store of the surroundings is used in the electrical power generation process
-The nuclei of atoms are positively charged, so a lot of work is done to overcome the repulsive forces between the nuclei during nuclear fusion
-So, nuclear fusion cannot happen at low temperature and pressure as the two nuclei cannot come into close range of each other due to these repulsive forces
-Hence, nuclear fusion requires high temperatures and pressures and is not currently used in nuclear power plants, but nuclear fusion can take place naturally in the sun and other stars where temperature and pressure are high

Uses of radioactivity

-Radioactivity has many uses, mainly uses related to the damage of cells, uses related to radioactive decay and half life, and uses related to penetrating abilities and ionising effects

Uses related to the damage of cells
-There are medicinal uses for radioactive isotopes
-When small amounts of technetium-99 is taken into the body, the ɣ-rays it emits allows images of internal organs to be taken using a gamma camera, which helps doctors in the diagnosis of diseases

-Iodine-131 is used in the treatment of thyroid disease, as when a small amount of the isotope is ingested, the emitted β-particles can destroy cancer cells
-In gamma knife surgery, ɣ-rays from cobalt-60 are used to destroy brain tumours
-For medicinal use, the isotopes taken into the body must have short half-lives so that they do not have harmful after effects on the body
-If it used as an external source, it can have a longer half-life

Uses related to radioactive decay and half life
-As the decay rates of some radioactive substances are known, we can determine how old an object or material is using this information
-For example, uranium-238 has a half life of 4.5 billion years and is found in most rocks, so it is used to estimate the age of the rocks
-Uranium-238 decays through α-decay into a stable isotope, lead-206, hence by determining the relative amounts of uranium-238 and lead-206 in a sample, the age of the rock can be known
-The greater the amount of lead-206, the older the rock

Uses related to penetrating abilities and ionising effects
-Americium-241 is used in smoke detectors as when the α-particles it emits falls onto a detector, a current flows in the detector as α-particles have a high ionising ability
-However, when smoke enters the detector, it easily absorbs the radiation and the flow of current is disrupted, triggering the alarm
-β-particles or ɣ-rays are used to measure the thickness of materials, as when a manufacturer wants to ensure that materials are of uniform thickness, β-particles or ɣ-rays from a radioactive source are directed at the material, and a detector measures the amount of radiation passing through
-α-particles aren't used due to their low penetrating power, and β-particles or ɣ-rays are used depending on the type of material, so β-particles for thinner materials and ɣ-rays for thicker materials \

Hazards of radioactivity

-When radioactive isotopes are used in the diagnosis and treatment of cancer, they can also damage healthy cells
-The energy carried by radiation can kill cells or cause mutation and cancer
-Hence, in order to protect ourselves from radiation, we can reduce exposure time, increase the distance between the source and living tissue and use proper shielding and storage methods
-For example, when handling radioactive material, the experimental set up should be prepared first, it should be handled with long tongs or remote devices if possible, lead lined gloves and suits should be worn and the material should be stored in a lead box and handled in a room with thick concrete walls and lead lined doors

Formulas

Kinematics

$v = d / t$
$a = (v - u) / t$ or $a = \Delta v / \Delta t$
Average speed = total distance / total time

For a body moving with uniform acceleration,
Average speed in m/s= $(u+v) / 2$ and $d = [(u+v) / 2] \times t$ or area under v-t graph

-v is speed in m/s, d is distance moved in m, t is time in s, a is acceleration in m/s^2, u is initial velocity in m/s and v is final velocity in m/s

Dynamics I: Mass and Weight

$W = mg$

g on earth = 10 m/s^2

-W is weight in N, m is mass in kg, g is acceleration of free fall in m/s^2

Dynamics II: Forces

$F = ma$

-F is resultant force in N, m is mass in kg, a is acceleration in m/s^2

Turning Effects of Forces

Moment of a force = $F \times d$

By principe of moments, when in equilibrium,
sum of clockwise moments = sum of anticlockwise moments

-F is force and d is perpendicular distance from line of action of force to the pivot

Pressure

$P = F / A$
$\rho = m / V$

Liquid pressure = $h\rho g$

For transmission of pressure in liquids,
$F1 / A1 = F2 / A2$
$F1 \times d1 = F2 \times d2$

-P is pressure in Pa or N/m^2, F is force in N, A is area in m^2, ρ is density in kg/m^3, m is mass in kg, V is volume in m^3, h is depth of point below liquid in m, g is gravitational field strength in N/kg, F1 is the force exerted on the piston, F2 is the force exerted on the load, A1 is the area of the piston, A2 is the area of the load, d1 is the distance moved downwards by the piston and d2 is the distance moved upwards by the load

Energy

Ek = 1/2 mv^2
Ep = mgh

W = F x s
P = W / t or P = E / t
Efficiency = (useful energy output / total energy output) x 100%

-Ek is kinetic energy in J, m is mass in kg, v is velocity in m/s, Ep is potential energy in J, m is mass in kg, g is acceleration of free fall in m/s^2, h is height in m, W is work done in J, F is force in N, s is distance moved in direction of force in m, P is power in W, E is energy change in J and t is time

Thermal Properties of Matter

C = Q / Δθ
c = Q / mcΔθ

Latent heat, Q = ml

P = Q / t

-C is heat capacity in J/K, c is specific heat capacity in J/(kgK), m is mass in kg, Q is thermal energy in J, Δθ is change in temperature in K, l is specific latent heat of fusion or vaporisation in J/kg and P is power in W

General Wave Properties 1: Introduction

f = 1 / T
v = fλ

-f is frequency in Hz, T is period in s, v is wave speed in m/s and λ is wavelength in m

Light

n = sin i / sin r
n = c / v
n = 1 / sin c

$c = 3.0 \times 10^8$ m/s

-n is the refractive index, i is the angle of incidence in °, r is the angle of refraction in °, c is the speed of light in a vacuum in m/s, v is the speed of light in the second medium in m/s and angle c is the critical angle in °

Current of Electricity

$I = Q / t$
$\varepsilon = W / Q$
$V = W / Q$
$R = V / I$

$R = \rho l / A$

Ohm's law, $I \propto V$

-I is current in A, Q is charge in C, t is time in s, ε is electromotive force in V, V is potential difference in V, W is work done in J, R is resistance in Ω, ρ is resistivity in Ωm, l is length in m and A is cross sectional area in m^2

D.C. Circuits

In series,
I(source) = I1 = I2
V(source) = V1 + V2
R(effective) = R1 + R2

In parallel,
I(source) = I1 + I2V(source) = V1 = V2
1 / R(effective) = 1 / R1 + 1 / R2, or R(effective) = (1 / R1 + 1 / R2)^-1

V1 = [R1 / (R1 + R2)] x Vs

-I is current in A, V is potential difference in V and R is resistance in Ω

Practical Electricity

$P = IV$
$P = I^2R$
$P = V^2 / R$

$E = VIt$
$E = I^2Rt$
$E = V^2t / R$

-P is power in W, I is current in A, V is potential difference in V, R is resistance in Ω, E is energy in J and t is time in s

Electromagnetic Induction

$V_s/V_p = N_s/N_p$

In an ideal transformer,
$V_pI_p = V_sI_s$

Efficiency of a transformer = (output power / input power) x 100%

-Vs is the secondary voltage in V, Vp is the primary voltage in V, Ns is the number of turns in the secondary coil, Np is the number of turns in the primary coil, Is is the secondary current in A and Ip is the primary current in A

Radioactivity

Number of neutrons = A - Z
-A is nucleon number and Z is proton number