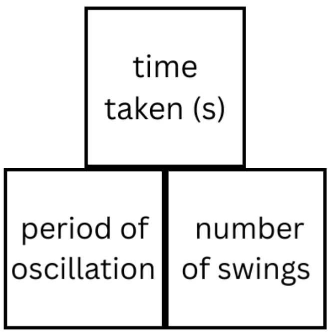
# 🏃 1. Motion, forces and energy

**1. Motion, forces and energy**

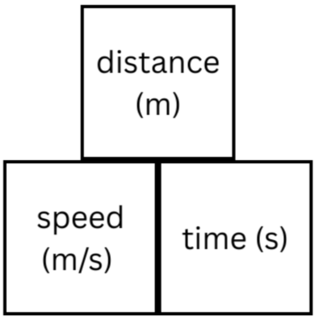
1.1: Physical quantities and measurement techniques

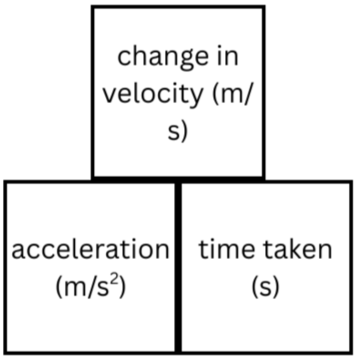
- Use rulers to measure length
    - Line up the object carefully
    - To measure a small distance(like the width of one sheet of paper) you can measure several of them together and then divide to find the thickness of one sheet
    - To measure curved lines, line up a string next to it, mark its end, and measure the length of the string
- Volume
    - Regular objects' volumes can be calculated
    - Liquids can be measured by measuring cylinders
    - The volume of irregular objects can be measured by:
        - Filling a measuring cylinder with water and noting its initial volume
        - Placing the object in it
        - Noting its final volume
        - Subtracting the final volume by the initial volume
    - When taking measurements with a measuring cylinder, make sure your eyes are level with the surface of the water and read the bottom of the meniscus
- Time
    - Stopwatch
    - Analog clock
    - Pendulum:
        - One oscillation = the time it takes for the plumb bob of a pendulum to swing from the left, to the right, and back to the left again (or vice versa)
        - Period = time it takes to complete one oscillation
        - 

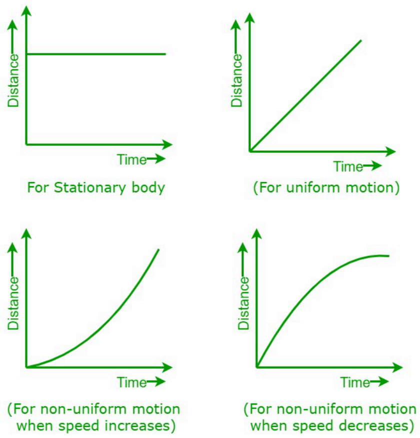
- Scalar quantity: has magnitude only
    - Distance, speed, time, mass, energy, temperature
- Vector quantity: has both magnitude and direction
    - Force, weight, velocity, acceleration, momentum, electric field strength, gravitational field strength

1.2: Motion

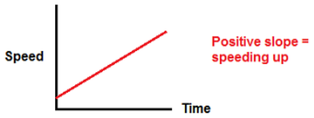
- Speed = distance travelled per unit time
    - $v = \frac{s}{t}$

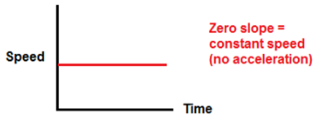
- 

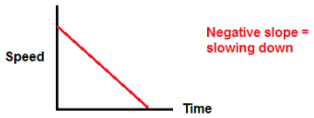
- Velocity = speed in a given direction
- Acceleration = change in velocity per unit time
    - $a = \frac{\Delta v}{\Delta t}$
    - 

    - Deceleration is negative value
- Distance-time graph
    - 

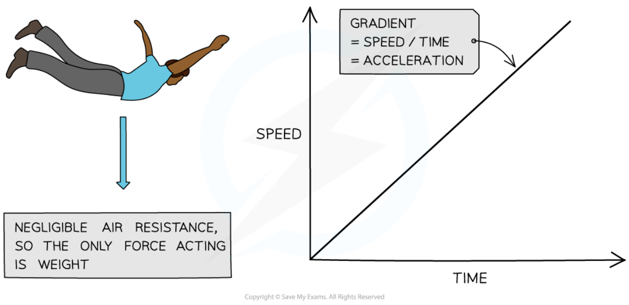
    - Gradient = speed
- Speed-time graph



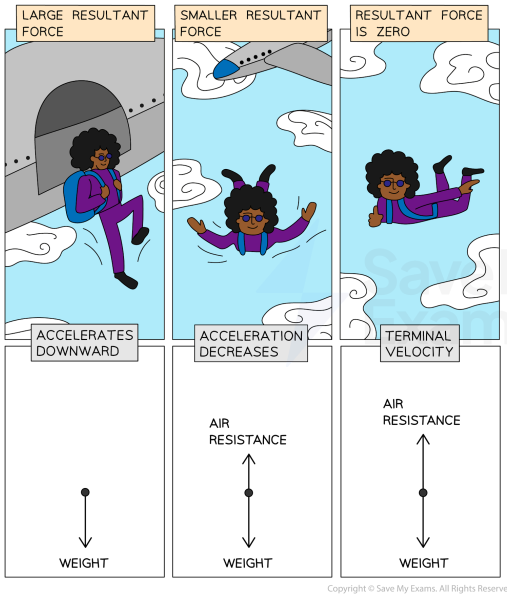



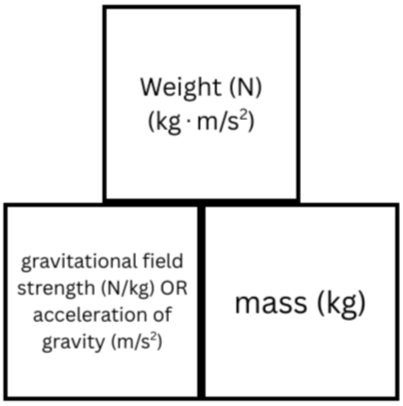

  - 
  - Constant acceleration: Straight
  - Changing acceleration: Curved
  - Gradient = acceleration
  - Area under = distance travelled
- Falling objects in a uniform gravitational field:
  - Without air resistance:
    - Objects fall with the same acceleration(speed of falling objects increase at a steady rate)




    - 
  - With air resistance:
    - Initially, air resistance isn't high
      - Weight of object > air resistance
      - Unbalanced forces, object accelerating
    - Air resistance increases as speed increases
      - Acceleration starts to decrease
    - Air resistance eventually balances the weight of the object
      - Weight of object = air resistance
      - Resultant force is zero
      - Object stops accelerating
      - Object falls at a constant speed known as *terminal velocity*

- 

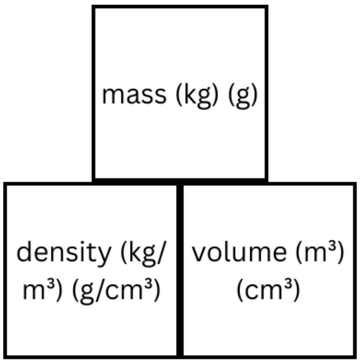

1.3: Mass and weight

- Mass: the quantity of matter in an object
- Weight: the gravitational force that acts on an object due to its mass
- Gravitational field strength: The gravitational force exerted per unit mass
    - Equivalent to acceleration of free fall: the acceleration of an object falling freely under gravity
    - 9.8 m/s$^2$ on Earth
    - $g = \frac{W}{m}$
    - 

- Balances measures an object’s mass using its weight

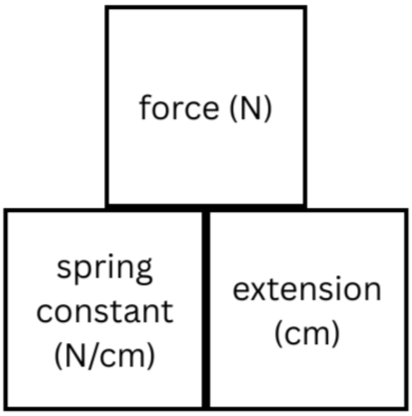
1.4: Density

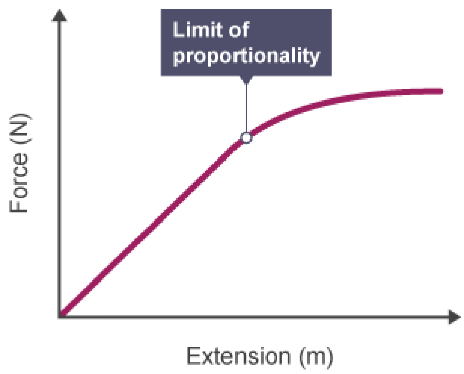
- How concentrated mass is
- Mass per unit volume
- $\rho = \frac{m}{v}$

- 

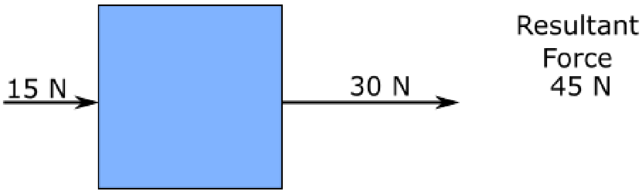
- Objects with a lower density will float on a liquid with a higher density
- A liquid with a lower density floats on top of a liquid with a higher density, so long as the two liquids do not mix

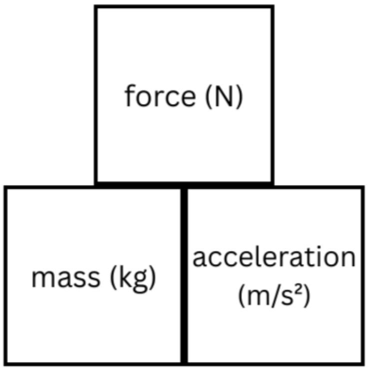
1.5: Forces

- Forces may produce changes in the size and shape of an object
- Springs:
    - Spring constant: force per unit extension
        - $k = \frac{F}{x}$
        - 

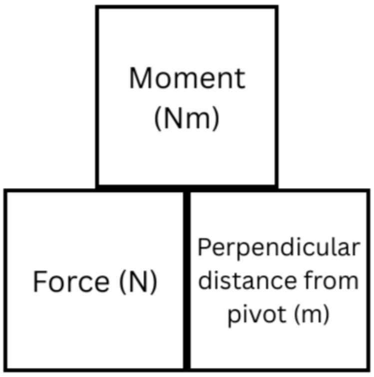
    - Limit of proportionality: The point beyond which the extension of an elastic object is no longer proportional to to force applied to it
        - 

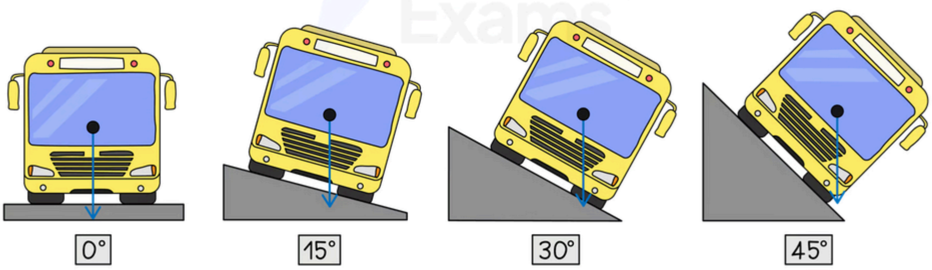
- Resultant force of forces acting in the same straight line: just add them together

- 

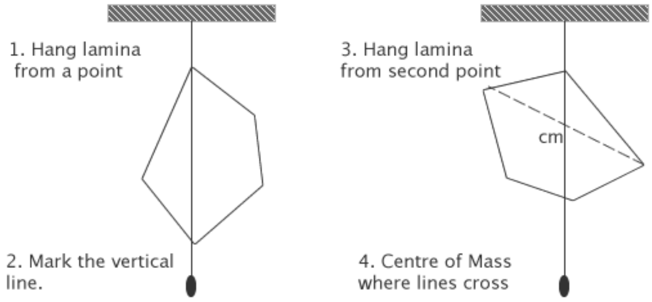
- $F = ma$
- 

- Object either remains at rest or continues in a straight line at constant speed unless acted on by a resultant force
- A resultant force may change the velocity of an object by:
    - Changing its direction
    - Changing its speed
- Motion in a circular path
    - The force acting on the object is perpendicular to its motion
    - The direction is changing constantly
        - Therefore, its velocity is constantly changing
        - A non-zero resultant force is always acting on the object to change its velocity
    - A bigger force is needed(other factors constant):
        - To increase the speed
        - To decrease the radius
        - If the mass increases
- Friction: A force that impeded motion
    - A force greater than the friction needs to be applied to make an object move
    - Solid friction:
        - The force between two surfaces
        - Occurs when two surfaces are in contact or slide against each other
        - Produces heating
    - Drag:
        - Acts on objects moving through a liquid or gas(air resistance)
- Moment:
    - A measure of the turning effect of a force
    - Turning effect: a force that causes an object to turn
    - E.g: Door hinges, seesaws, unscrewing a bolt

- 

- Principle of moments:
    - There is no resultant turning effect about a pivot, when the clockwise and anticlockwise moments are equal
- Equilibrium:
    - When there is no resultant force or resultant moment acting on an object
    - Experiment:
        - Take a meter rule and attach it to a retort stand with an optical pin, making sure it can freely rotate around the pin
            - The pin will act as the pivot
        - Hang unequal loads on either side of the pivot
        - Adjust the loads' distances until the meter rule is perfectly horizontal and does not turn (in equilibrium)
        - Calculate the moment on either side of the pivot
        - Results:
            - The moment should be the same on both sides
            - The clockwise and anticlockwise moment is equal, so there is no resultant moment and the meter rule is in equilibrium
- Centre of gravity
    - The point through which the weight of the object acts
    - An object is stable when its centre of gravity lies above its base
    - When the line of action of an object's weight is beyond the edge of the base, the object will topple
    - Stable objects have a low center of gravity and wide base
    - 

    - Finding the centre of gravity of an irregularly shaped plane lamia:
        - Suspend the lamia with a pin near the edge
        - Make sure it can rotate freely
        - Hang a plumb line from the pin
        - Draw a line on the lamina to show the position of the plumb line
        - Hang the lamina from another point and repeat the process
        - The centre of gravity is where the two lines intersect

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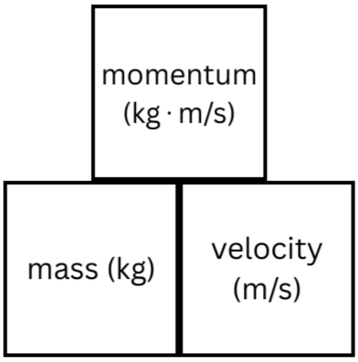
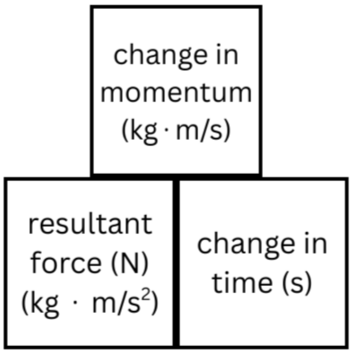
1.6: Momentum

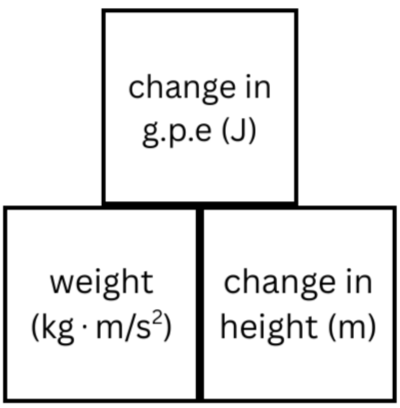
- $p = mv$
- 

- $impulse = F\Delta t = \Delta(mv) = \Delta p$
- $impulse\ (N \cdot s)\ (kg \cdot m/s) = force(N) \cdot \Delta time(s) = \Delta[mass(kg) \cdot velocity(m/s)] = \Delta momentu$
- $F = \frac{\Delta p}{\Delta t}$
- 

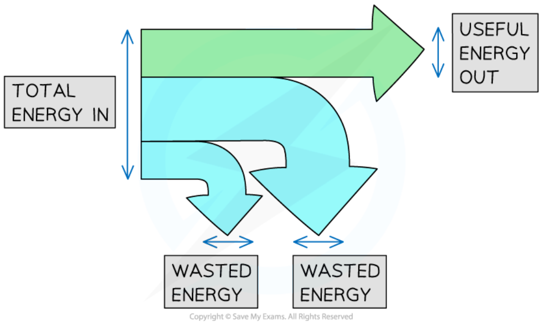
- Principle of conservation of moments:
    - The total momentum of two objects before a collision is the same as the total momentum of the objects after collision

1.7: Energy, work and power

- Energy stores:
    - Kinetic
        - Moving object
        - E.g: rolling ball, person running
    - Gravitational potential
        - Object raised against the force of gravity
        - E.g: raised ball, object stored on high shelf

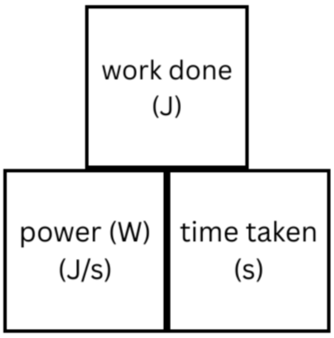
    - Chemical
        - Bonds between atoms
        - E.g: batteries, fossil fuels, foods
    - Elastic/strain
        - Object that has been squashed or stretched
        - E.g: stretched rubber band, compressed spring
    - Nuclear
        - Nucleus of atoms
        - E.g: nuclear fuel, uranium
    - Electrostatic
        - E.g: a thundercloud
    - Internal/thermal
        - Total kinetic and potential energies of an object's particles
        - E.g: a hot drink
- Energy transfers:
    - Energy is transferred between different stores during events and processes:
    - By force(mechanical work done)
        - When a force acts on an object
        - E.g: pulling, pushing, lifting
    - By electrical currents(electrical work done)
        - When a charge moves through a potential difference
    - By heating
        - When energy is transferred from from a hot object to a colder one
    - By electromagnetic waves
        - Light from the sun
    - By sound waves
        - Kinetic energy from a vibrating object is transferred through air particles until it reaches your ear
- $E_k = \frac{1}{2}mv^2$
- $kinetic\ energy\ (J)\ = \frac{1}{2} \cdot mass\ (kg)\ \cdot speed\ (m/s)^2$
- $\Delta E_p = mg\Delta h$
- 

- Principle of conservation of energy:
    - Energy cannot be created or destroyed, only transferred from one energy store to another
    - Sankey diagram:

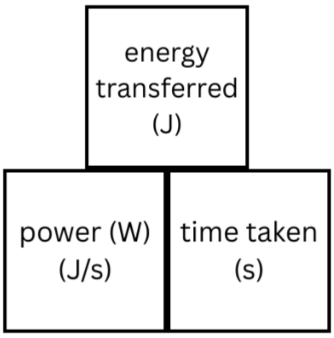



        - Most energy is lost to the internal/thermal energy of surroundings due to friction
- Work done:
    - Energy transferred
    - $W = Fd = \Delta E$
    - $work\ done\ (J)\ (Nm) = force(N) \cdot distance\ moved\ in\ the\ direction\ of\ the\ force(m) = \Delta ener$
- Energy sources:
    - Radiation from the Sun is the main source of energy for all our energy resources
    - Energy is released from the sun through nuclear fusion
    - Fossil fuels:
        - Stores chemical energy
        - Energy is released when they are burned
        - Comes from the remains of long dead organisms that were compressed deep underground
        - Energy from the sun was taken in by the organisms to grow
        - Advantages:
            - Widely available
            - Reliable
            - Little space needed
        - Disadvantages:
            - Non-renewable
            - Gases released pollutes the environment, leads to climate change
    - Biofuels:
        - Stores chemical energy
        - Energy is released when they are burned
        - Comes from recently living organisms (e.g: wood, animal dung, rotting vegetable matter)
        - Energy from the sun was taken in by the organisms to grow
        - Advantages:
            - Widely available
            - Reliable
            - Renewable
            - Does not contribute to global warming
        - Disadvantages:
            - Lots of space needed
    - Waves and tides:
        - Can spin turbines used in power stations

- Advantages:
    - Renewable
    - Does not contribute to global warming
- Disadvantages:
    - Unreliable, heights of waves can vary
    - Not widely available
- Hydroelectric dams:
  - Water is stored behind dams at high altitudes (g.p.e)
  - When water is released, the g.p.e is converted into kinetic energy and spins turbines in power stations
  - Advantages:
    - Renewable
    - Reliable
    - Doesn't contribute to global warming
  - Disadvantages:
    - Can involve flooding large areas, destroying important wildlife habitats
    - Damages nearby environments
- Geothermal resources:
  - Used where hot molten rocks and be found near the Earth's surface
  - Water is pumped underground and boiled into high-pressure steam
  - The steam is used to spin turbines in a power station
  - Advantages:
    - Renewable
    - Reliable
    - Doesn't contribute to global warming
  - Disadvantages:
    - Not widely available, only a few places can hot rocks be found near the surface
    - Harmful gases can be released from underground
- Nuclear fuel:
  - The decay of radioactive materials are sped up so they release their energy store
  - Advantages:
    - Reliable
    - Doesn't contribute to global warming
    - Very concentrated, lots of energy produced
  - Disadvantages:
    - Non-renewable
    - Radioactive waste is dangerous when not disposed properly
- Solar power:
  - Nuclear energy from the sun is transferred as electromagnetic waves
  - Solar panels contain water that are heated up by sunlight
  - Solar cells capture energy from sunlight to generate an electric current
  - Advantages:
    - Renewable
    - Doesn't contribute to global warming
    - Widely available

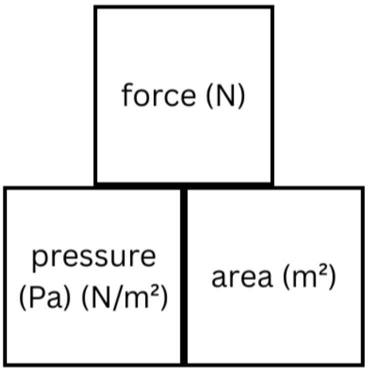
        - Disadvantages
            - Unreliable, no sunlight at night
            - Requires lots of space
    - Wind energy:
        - The Sun heats the atmosphere unevenly, which results in the movement of warm and cold air and creates wind
        - Wind can be used to spin wind turbines that are linked to power stations
        - Advantages:
            - Renewable
            - Doesn't contribute to global warming
            - Widely available
        - Disadvantages:
            - Unreliable, wind speed varies
            - Requires lots of space
    - Power stations:
        - Fossil fuels, biofuels, and nuclear fuels produce thermal energy
        - The thermal energy is used to heat water in a boiler to produce steam
        - The steam spins a turbine
        - Wind and water can spin a turbine directly
        - The turbine spins a generator, which generates electricity
    - Research is being carried out to investigate how energy released by nuclear fusion can be used to produce electrical energy on a large scale
    - Efficiency:
        - The percentage of energy supplied that is usefully transferred
        - $(\%)\ efficiency = \frac{(useful\ energy\ output)}{(total\ energy\ input)}(\%100)$
        - $(\%)\ efficiency = \frac{(useful\ power\ output)}{(total\ power\ input)}(\%100)$
- Power:
    - The rate at which work is done, or energy is transferred
    - $P = \frac{W}{t}$
    - 

    - $P = \frac{\Delta E}{t}$




## 1.8: Pressure

- $P = \frac{F}{A}$




- E.g:
    - Sharp knives have a smaller area and cut into things more easily
    - Thumb tacks are very sharp and have a small area, and can be pushed into things easily
- Pressure in a liquid increases with depth and density
    - $\Delta p = \rho g \Delta h$
    - $change\ in\ pressure\ (Pa)(N/m^2) = density(kg/m^3) \cdot gravitational\ field\ strength(N/kg) \cdot$

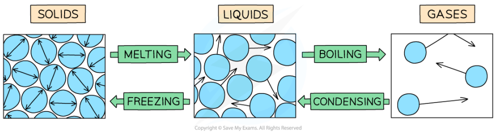
# 🔥 2. Thermal physics

**2. Thermal physics**

2.1: Kinetic particle model of matter

- When a substance is heated, its particles gain kinetic energy and move faster
- When a substance is cooled, the particles lose kinetic energy and slow down
    - Absolute zero (-273°C): lowest temperature possible, particles have the least kinetic energy

| State | Shape | In container | Arrangement of particles | Separation of particles | Motion of particles | Forces of attraction between particles |
|---|---|---|---|---|---|---|
| Solid | Fixed volume and shape | Shape not affected by container | Regular pattern | Packed closely together<br>High density, incompressible | Vibrate about fixed positions | Strong |
| Liquid | Fixed volume, no fixed shape | Takes the shape of its container | Arranged randomly | Slightly further apart than in solids<br>Slightly lower density than solids, incompressible | Freely move around each other | Weaker than in solids |
| Gas | No fixed volume and no fixed shape | Expands to fill its container | Arranged randomly | Widely spread apart<br>Low density, compressible | Freely move around at high speeds | Very weak |

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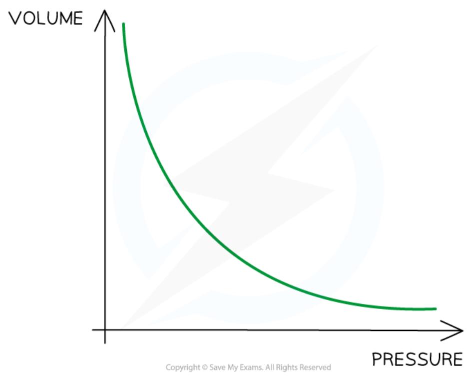
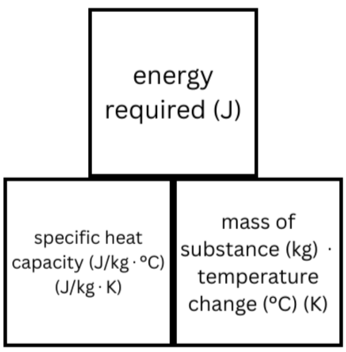
- Gas exerts pressure by moving randomly and colliding with the walls of its container, creating a force per unit area
- Brownian motion:
    - The random motion of microscopic particles in a suspension
    - The microscopic particles can be observed under a light and microscope
    - The gas or liquid molecules move very fast and will collide with the microscopic particles constantly, causing them to move about randomly
    - This is evidence for the kinetic particle model of matter
- Gas pressure:
    - Increasing the temperature will increase the pressure
        - The gas particles gain more kinetic energy and move faster
        - They collide with the walls of the container more frequently and with greater force
    - Decreasing the volume will increase the pressure
        - The particles will collide with the walls of the container more frequently, as they don't have to move as far between collisions
        - $pv = constant$
        - $p_1 v_1 = p_2 v_2$

- 

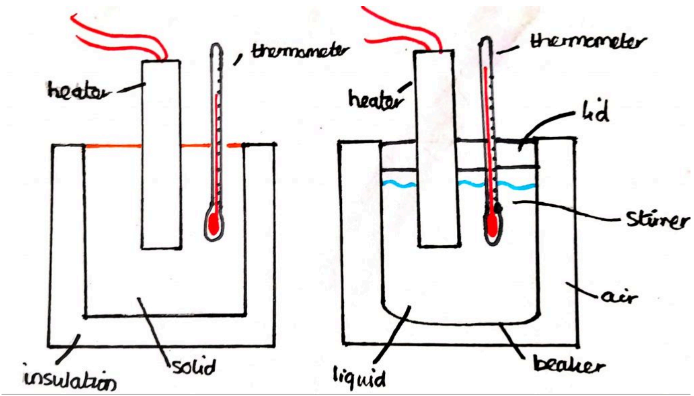
- Kelvin temperature scale (K):
    - Starts at absolute zero (-273°C)
    - $T\ (in\ K)\ =\ \theta\ (in\ °C)\ +\ 273$

2.2: Thermal properties and temperature

- Thermal expansion
    - Materials increase in volume when heated
    - Heating increases the kinetic energy of particles, so they can move around more and take up more space
    - Gases expand the most, solids expand the least
        - Solid particles have strong forces of attraction between them and are packed close together, so they can't move around much
        - Gas particles have little forces of attraction between them and are far apart, so they can easily move more
    - Applications:
        - Thermometers rely on the expansion of liquids to measure temperature
        - The lid of a jar can be heated so it expands and is easier to remove
    - Consequences:
        - Bridges and railways have gaps built in, giving them space to expand
- Temperature is a measure of the average kinetic energy of all particles in an object
- A rise in temperature of an object increases its internal energy
- Specific heat capacity:
    - The amount of thermal energy required to raise the temperature of a unit mass by one degrees
    - $c\ =\frac{\Delta E}{m\Delta\theta}$
    - 

    - Experiments:
        - Solids:

- Take a metal block with two holes drilled into it and measure its mass(m)
- Wrap the metal block in insulating cloth
- Put a heater and temperature sensor into the holes of the block
- Connect the heater to a joulemeter of power source
- Measure the initial temperature of the block ($\theta_1$)
- Turn on the heater
- When the temperature of the block has risen by 10°C, turn the heater off and record the joulemeter reading (ΔE)
- Watch the sensor and record the highest temperature it reaches ($\theta_2$)
- Calculate the specific heat capacity

- Liquids:
    - Measure the mass of the liquid(m)
    - Place a lid on the liquid's container and wrap it in insulating cloth
    - Put a heater and temperature sensor into the liquid through holes in the lid
    - Connect the heater to a joulemeter of power source
    - Measure the initial temperature of the liquid ($\theta_1$)
    - Turn on the heater
    - When the temperature of the liquid has risen by 10°C, turn the heater off and record the joulemeter reading (ΔE)
    - Watch the sensor and record the highest temperature it reaches ($\theta_2$)
    - Calculate the specific heat capacity
- 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- During melting and boiling:
    - The temperature increases until the substance's melting/boiling point
    - The temperature stays constant as the substance melts/boils
        - Energy is being taken in to break the bonds between particles
    - The temperature continues increasing after the substance has completely melted/boiled
- During condensation/solidification:
    - The particles slow down and are pulled closer into fixed positions
    - Energy is released

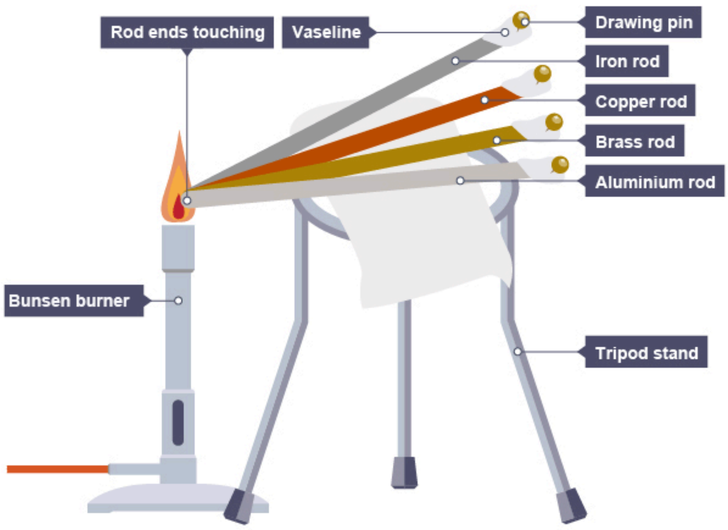
- Water at standard atmospheric pressure:
    - Melting point: 0°C
    - Boiling point: 100°C
- Evaporation
    - Particles in a liquid move at different speeds and have different amounts of kinetic energy
    - The most energetic particles have enough energy to overcome the forces of attraction between the liquid particles, and escape from the surface of the liquid into the atmosphere
    - The less energetic particles are left behind, so the average kinetic energy of the particles decrease and the liquid cools
    - If in contact with an object:
        - The liquid will absorb the thermal energy of the object and cool it down
    - Factors affecting evaporation:
        - Temperature
            - Evaporation is faster at higher temperatures
            - More particles will have enough energy to escape
        - Surface area
            - Evaporation is faster when the surface area of the liquid is greater
            - More particles are close to the surface so they can escape
        - Air movement
            - Evaporation is faster when the surrounding air is moving
            - Particles that escape from the liquid are blown away so the surrounding air is drier
            - Drier air accepts vapour more easily

| | | | | |
|---|---|---|---|---|
| Boiling | Occurs at boiling point | Happens throughout the liquid | Bubbles are formed in the liquid | External thermal energy source required |
| Evaporation | Occurs at any temperature | Only happens on the surface of the liquid | Bubbles are not formed in the liquid | External thermal energy source not required |

2.3: Transfer of thermal energy

- Thermal conduction:
    - The transfer of thermal energy by the vibration of particles
    - Thermal conductors: transfers thermal energy quickly
    - Thermal insulator: transfers very little thermal energy/transfers thermal energy slowly
    - There are many solids that conduct thermal energy better than thermal insulators but do so less well than good thermal conductors
    - Experiment:
        - Take four rods made of different materials
        - Dip their ends in melted wax and place a drawing pin on top
        - Wait for the max to harden
        - Place the rods on a tripod stand, making sure their ends are aligned
        - Place a bunsen burner under the ends of the rods without the drawing pin
        - Record the time it takes for each drawing pin to fall from the rod
        - Results:

- The rod with the drawing pin that falls the fastest has the best thermal conductivity, and the rod with the drawing pin that falls the slowest has the worst thermal conductivity

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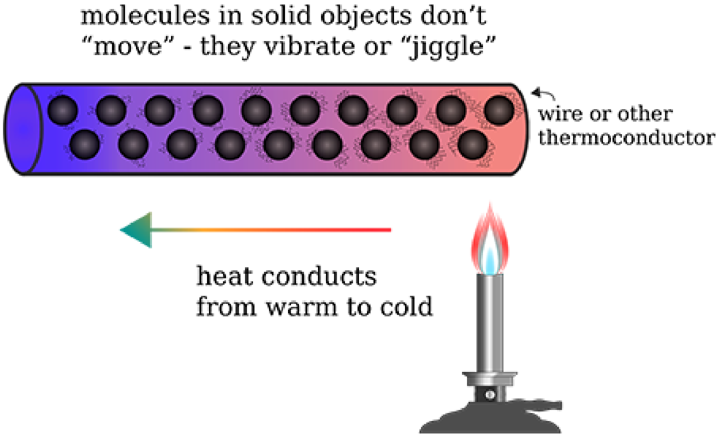
- In all solids:
    - When one end of a solid is heated, the particles there vibrate vigorously
    - They collide with neighbouring particles, making them vibrate too and become hot
        - Kinetic energy is transferred from particle to particle
    - Eventually, energy is transferred to the cooler end of the solid, causing the particles there to vibrate too and become hot

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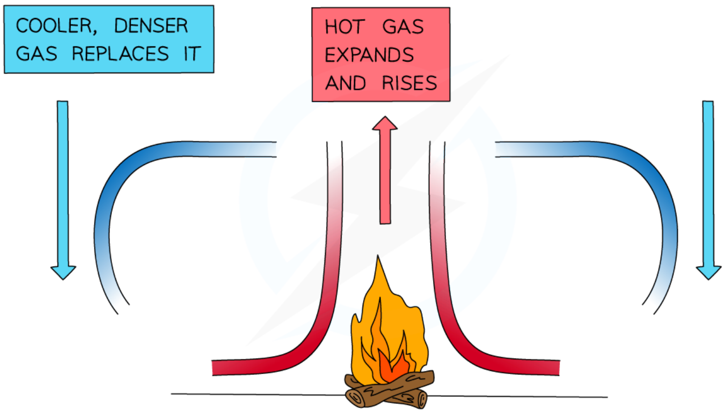
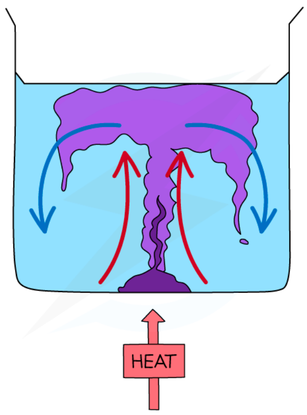
- In metals:
    - Metals tend to be the best conductors
    - Metals contain free moving electrons that can gain energy
    - They can move freely to the cooler regions of the solid, colliding with and transferring their energy to the particles there
- In liquids and gases:
    - Liquids and gases tend to be bad thermal conductors
    - Their particles are spread further apart, so the collision between particles are less frequent than in solids
- Convection

- The main mode of thermal energy transfer in liquids and gases
- Convection currents:
    - When a fluid is heated, its particles move faster, push each other apart, and expand
    - This makes the hot fluid *less dense* than its surroundings
    - The hot fluid rises
    - Cooler fluid moves to takes it place near the heat source, and is also heated
    - Eventually the hot fluid cools again, its density increases and it sinks back down near the heat source
    - This process repeats until the whole fluid is heated up





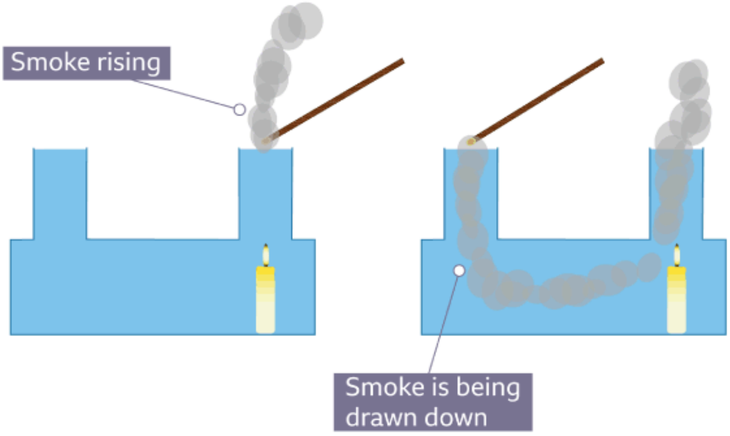
    -
- Experiments:
    - In liquid:
        - Fill a beaker with water
        - Place a couple of potassium manganate(VII) crystals at the bottom of the beaker
        - Use a bunsen burner to heat the beaker, directly below the potassium manganate(VII) crystals
        - Results
            - Potassium manganate(VII) is purple when dissolved in water, so as water moves, it will move along with it and reveal the convection current





        -
    - In gas:

- Cut two holes on the side of a cardboard box and use paper to create a makeshift chimneys around them
- Light a candle and put it below one of the chimneys
- Light an incense stick
- Hold the incense stick over the chimney with the candle below it
    - The smoke will rise as it is being heated by the candle
- Hold the incense stick over the chimney without the candle below it
    - The smoke will move down the chimney, towards the candle, and then rise up the other chimney when it is heated by the candle

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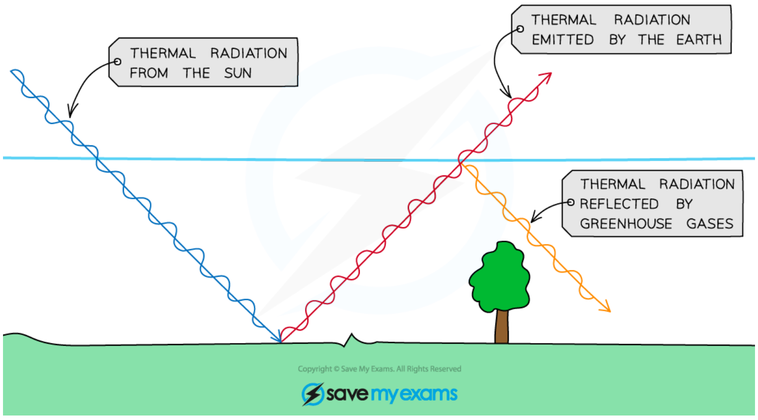
- Thermal radiation:
    - Transfer of thermal energy through infrared radiation
    - All objects emit thermal radiation
    - Doesn't require a medium
    - Dull black surfaces:
        - Good emitters and absorbers
        - Bad reflectors
    - Shiny white surfaces:
        - Bad emitters and absorbers
        - Good reflectors
    - Factors affecting the rate of emission of infrared radiation:
        - Surface temperature
            - The higher the temperature of an object is, relative to its surroundings, the higher the rate of emission
        - Surface area
            - Objects with a larger surface area have a higher rate of emission
    - If an object receives energy at a greater rate than it emits energy, it warms up
    - If an object receives energy at a lower rate than it emits energy, it cools down
    - If an object receives energy at the same rate as it emits energy, its temperature stays constant
    - Controlling Earth's surface

    - The incoming radiation and radiation emitted from the Earth's surface is balanced
    - Earth absorbs and is heated up by radiation from the sun
    - Earth emits radiation back into the atmosphere
    - Greenhouse gases absorb the radiation and re-emit it back to the Earth's surface, keeping it at a reasonable temperature
    - 

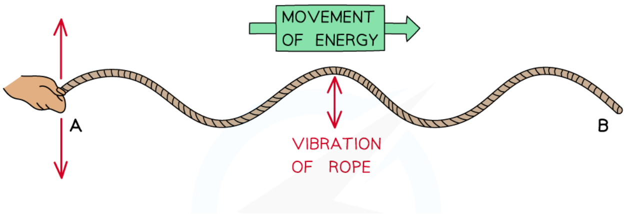
  - Experiments:
    - Emitters:
      - Take two cans, one shiny silver and one dull black
      - Fill them with an equal amount of boiling water
      - Use a thermometer to measure the temperature of each can every minute
      - Results:
        - The water in the dull black can will cool down faster
        - Dull black surfaces emit infrared radiation faster than shiny white surfaces
    - Absorbers:
      - Take two cans, one shiny silver and one dull black
      - Fill them with an equal amount of cold water
      - Place the cans equal distances away from a bunsen burner
      - Use a thermometer to measure the temperature of each can every minute
      - Results:
        - The temperature of water in the dull black can will rise more quickly
        - Dull black surfaces absorb infrared radiation faster than shiny white surfaces
- Real life examples:
  - Kitchen pans:
    - Made out of metal, as they are good thermal conductors
    - Handles are made out of wood or plastics, and they are good thermal insulators and will protect your hand from getting burned while holding it
  - Heating a room: (convection current)
    - Radiators are hot and transfers thermal energy to the air nearby
    - The particles of this hot air spread out, making it less dense

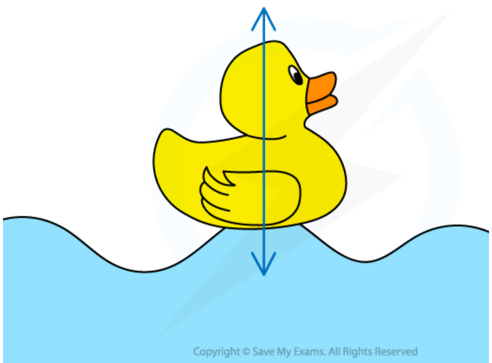
    - The spread-out air is less dense than the air above it, so this hot air rises
    - The radiator heats the cold air takes the hot air's place
    - Eventually, all the air in the room will be heated
- A fire burning wood or coal:
    - Surfaces in contact with the fire are heated through *conduction* (the ground, a pan)
    - Air surrounding the fire is heated and rises, forming a *convection current*
    - Objects close to the fire are heated by the infrared *radiation* it emits
- A radiator in a car:
    - Used for cooling engines
    - A liquid travels between the radiator and the engine
    - When it passes over the engine, the liquid absorbs heat from the engine through *conduction*
    - The liquid travels back to the radiator, and transfers heat to the fins of the radiator through *conduction*
    - The fins heat up the surrounding air
        - The hot air is blown away by a fan and replaced by cooler air, forming a *convection current*
    - The radiator transfers thermal energy to the surrounding air through infrared *radiation*
        - The radiator is painted black and has a large surface area, to increase the rate of emission

# 🌊 3. Waves

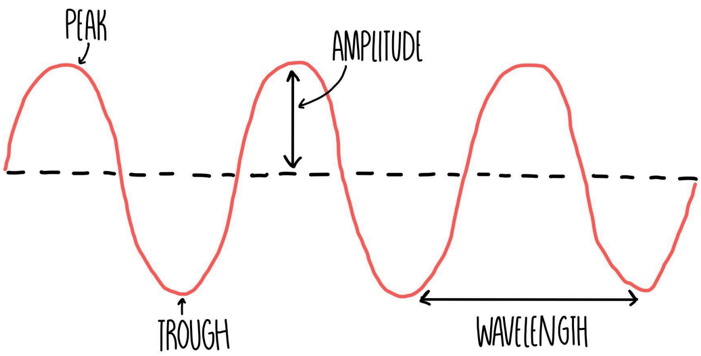
**3. Waves**

3.1: General properties of waves

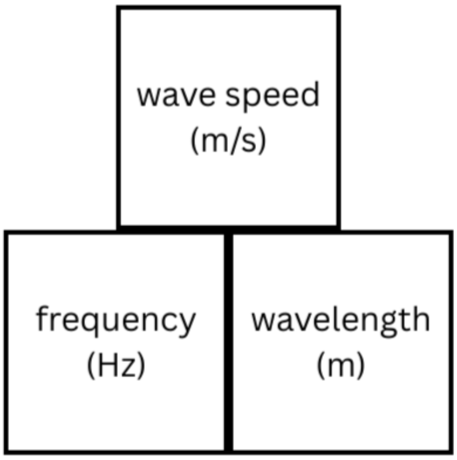
- Waves transfer energy without transferring matter
- Wave motion:
    - 

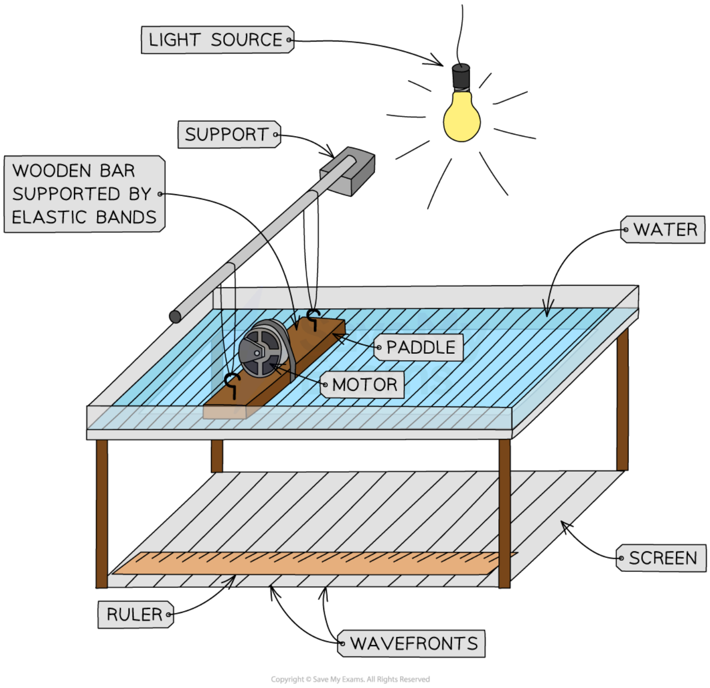
    - The kinetic energy of the hand is transferred as a rope wave to the rope particle near it, causing it to vibrate up and down
    - The kinetic energy is further transferred to the rope particle's neighbours, causing them to vibrate up and down too
    - The rope wave moves towards point B, but the rope particles only vibrate up and down and will remain in the same place after the wave has passed
    - 

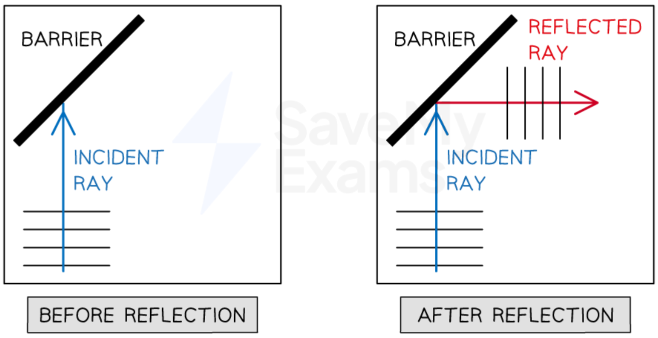
    - The rubber duck only bobs up and down, and does not change position when a wave passes through the water, demonstrating there is no movement of matter in a wave

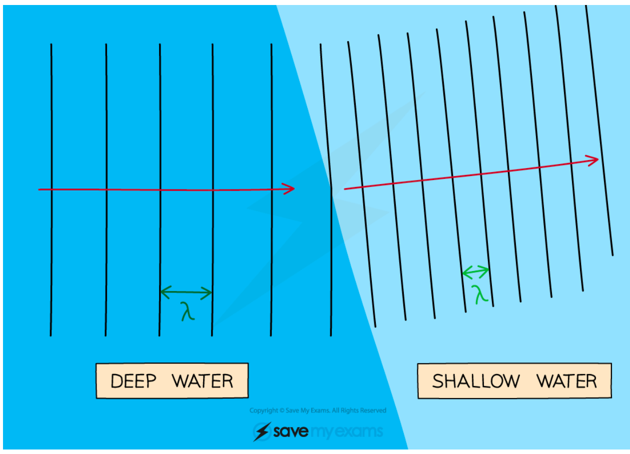



- Wave length:
    - The distance between two successive crests or troughs
- Crest(peak):
    - Highest point of a wave
- Trough:
    - Lowest point of a wave
- Amplitude:
    - The maximum displacement of a point from its rest position

- I.e: the height of the crest or the depth of the trough from the dotted line
- Frequency:
    - The number of waves produced per second
- Wave Speed
    - Distance travelled by a wave per second
    - $v = f\lambda$
    - 

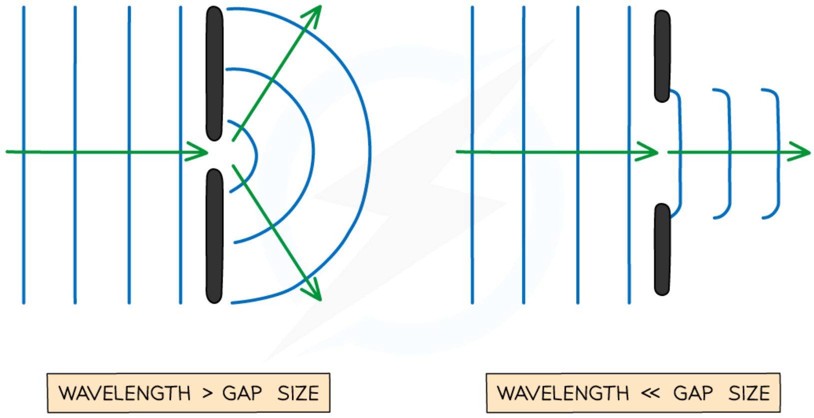
- Wavefront:
    - An imaginary line that joins all corresponding points of a wave
- Transverse waves:
    - The direction of vibration is at right angles to the direction of propagation (the direction the wave is moving in)
    - E.g: electromagnetic radiation, water waves, seismic S-waves (secondary)
- Longitudinal waves:
    - The direction of vibration is parallel to the direction of propagation (the direction the wave is moving in)
    - E.g: sound, seismic P-waves (primary)
- Ripple tank:
    - 

- The wooden bar will move up and down at a steady rate, making equally spaced ripples across the surface of the water
- The light casts a shadow of the ripples on the screen below, so the wavefronts can be observed
- Reflection:
    - The wave hits the boundary of a different medium and bounced off of it instead of passing through it
    - A metal bar can be placed in the ripple tank to demonstrate this
    - 

- Refraction:
    - The wave passes into a different medium and changes speed
        - Direction and wavelength is also changed
    - If the wave slows down, the waves bunch up and the wavelength decreases
    - If the waves speed up, the waves spread out and the wavelength increases
    - A glass plate can be placed in a ripple tank to demonstrate this
        - The depth of the water becomes shallower where the glass plate is placed
        - The waves slow down when passing from deep to shallow water
        - The wavelength decreases
        - The top of a ripple is the first to enter shallow water, it has spent longer moving at a slower speed and lags behind
        - 

- Diffraction:
    - The waves spread out has it encounters gaps or edges
    - Through gaps:
        - Diffraction is more prominent when the gap size is smaller than or equal to the wavelength

- Diffraction is less prominent when the gap size is greater than the wavelength
- At an edge:
    - The greater the wavelength, the greater the angle of diffraction
- Barriers can be placed in a ripple tank to demonstrate this

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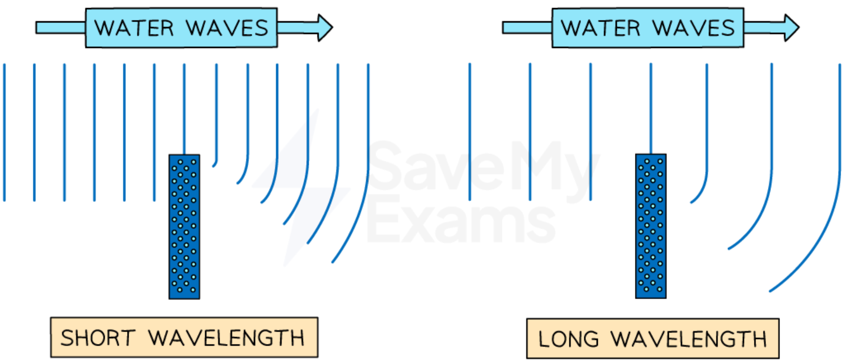


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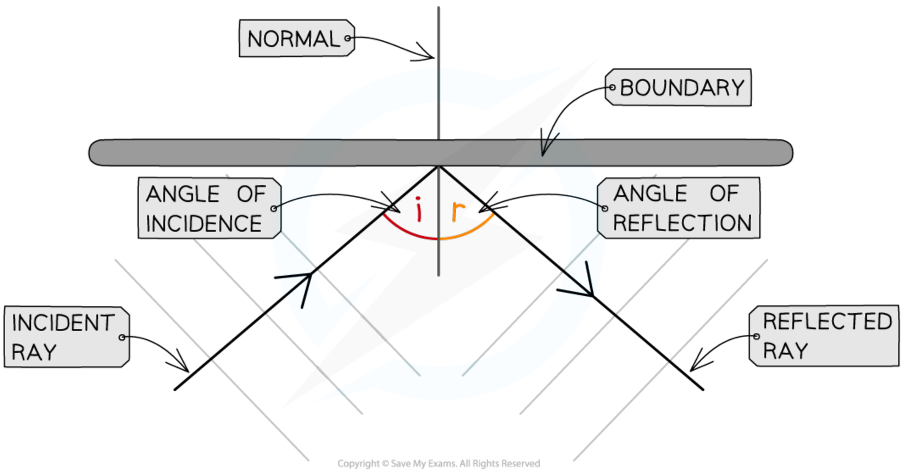
3.2: Light

- Reflection:

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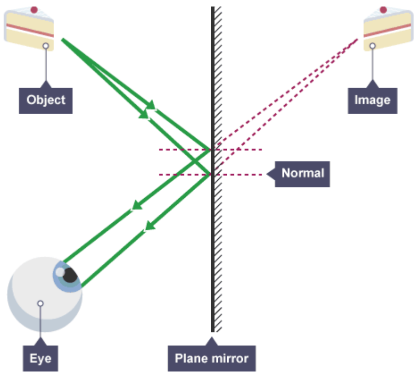
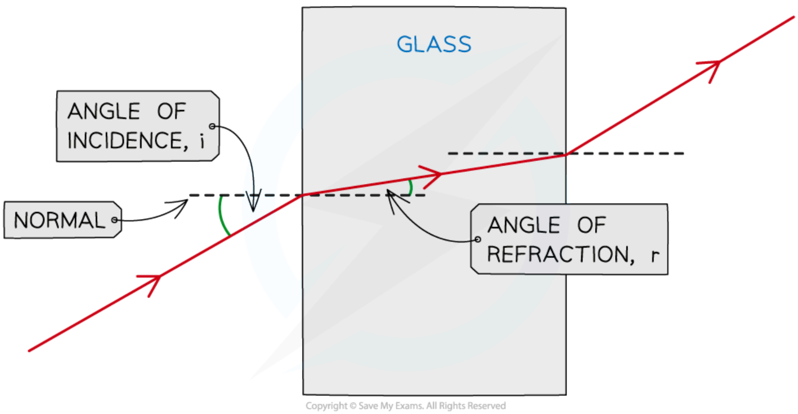
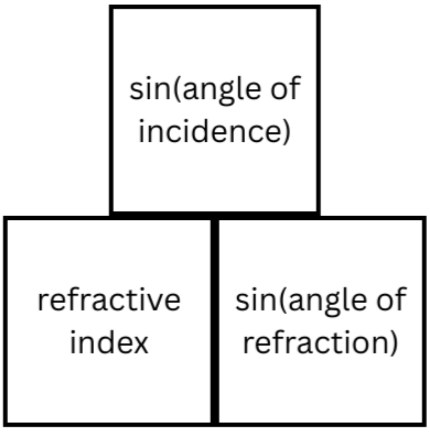
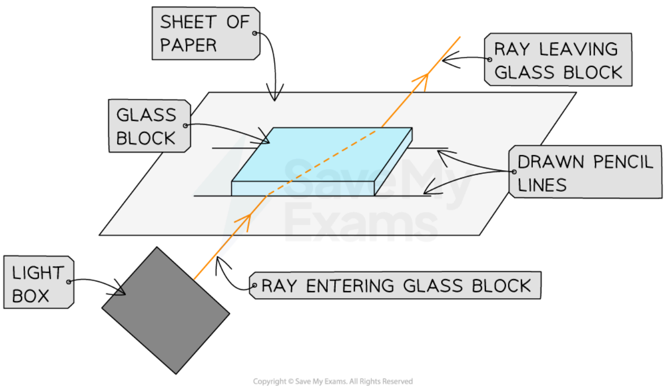
- Normal:
    - The imaginary line drawn perpendicular to the reflecting surface, at the point where the ray hits the surface
- Angle of incidence:
    - The angle between the ray approaching the surface and the normal

- Angle of reflection:
    - The angle between the ray leaving the surface and the normal
- Angle of incidence = angle of reflection
- Image in a plane mirror:
    - Rays from the object hits the mirror, and is reflected
    - The reflected ray enters the observer's eye
    - To the observer, the reflected ray appears to have come from behind the mirror
    - 

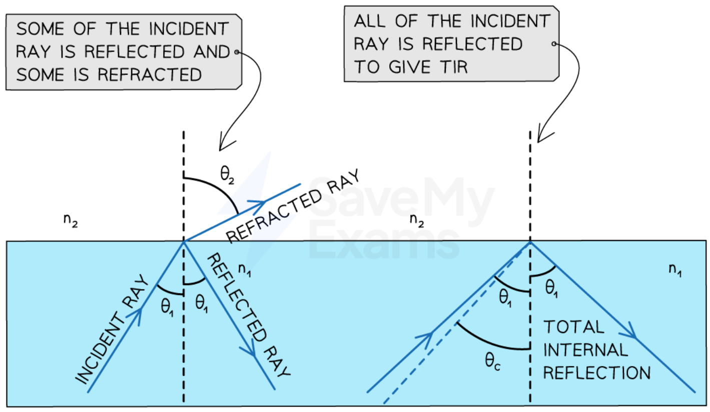
    - Characteristics of the reflected image:
        - Same size as the object
        - Same distance from the mirror as the object
        - Laterally inverted
        - Virtual
            - Can only be seen by the eye
            - Can't be projected onto a screen
- Refraction:
    - Light travels at different speeds in different media
    - When light travels into a different medium, the change in speed causes the light to bend
    - 

    - The ray bends towards the normal when entering the glass
    - The ray bends away from the normal when leaving the glass
    - Normal:
        - The imaginary line drawn perpendicular to the refracting surface, at the point where the ray hits the surface
    - Angle of incidence:
        - The angle between the ray approaching the surface and the normal
    - Angle of refraction

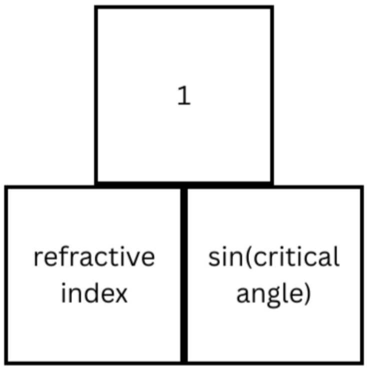
        - The angle between the refracted ray and the normal
- Refractive index
    - The ratio of the speeds of a wave in two different media
    - Measures how much the light is slowed/bent when it enters the medium
    - $n = \frac{\sin i}{\sin r}$
    - 

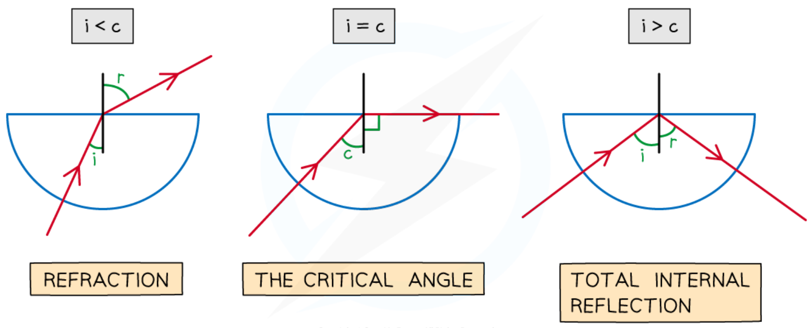
- Experiment:
    - Place a glass block on a sheet of paper and draw around it
    - Shine a ray of light into the glass block using a ray box
    - Mark:
        - A point on the ray close to the ray box
        - The point where the ray enters the block
        - The point where the ray exits the block
        - A point on the exit light ray
        - Remove the block and join the points to show the path of light through the block
        - Draw the normal with dashed lines at the points where the ray enters and leaves the block
        - Repeat this for rays entering the block at different angles
        - 

- Internal reflection
    - When light passes from an optically denser to a less dense medium, some light is reflected back into the denser medium
    - Total internal reflection:
        - When a ray of light is *completely* reflected inside of an optically denser medium, at its boundary with a less dense medium

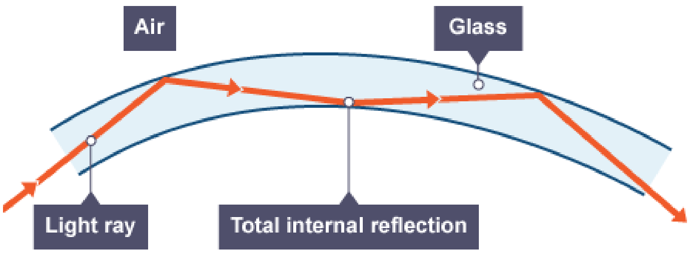
    - 



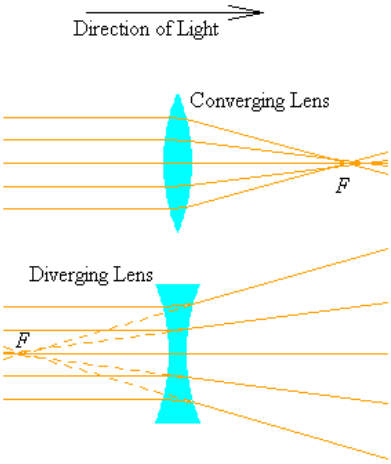
- Critical angle:
    - The angle of incidence for which the angle of refraction is 90°
    - The light ray will be refracted along the boundary line of the two mediums
    - Total internal reflection occurs when the angle of incidence is greater than the critical angle
    - $n = \frac{1}{sin\ c}$
    - 

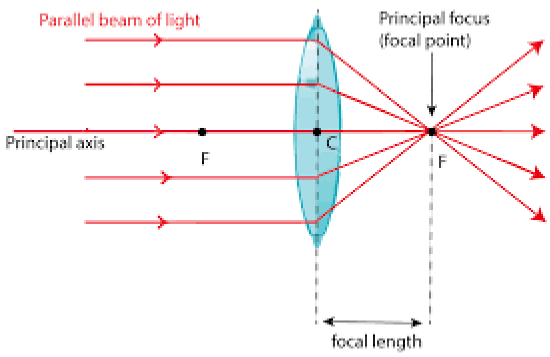
    - 


- Examples:
    - Optical fibres
        - They can transmit light over long distances through total internal reflection
        - The light ray inside an optical fibre will always strike the boundary at an angle of incidence greater than the critical angle, even when the fibre is curved, so it is always undergoes total internal reflection

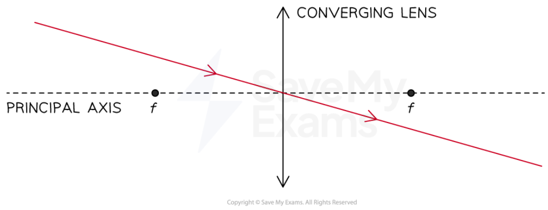
- 

- Telephone conversations, internet data, and other electronic signals are transmitted using optical fibres
- Endoscopes use optical fibres to allow doctors to see inside a patient's body

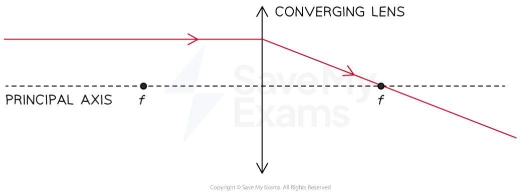
- Lenses
    - Converging lens:
        - Thicker in the centre
        - Causes light rays to converge to a point
    - Diverging lens:
        - Thinner in the centre
        - Causes light rays to diverge from a point
    - 

    - Principle axis:
        - The horizontal line passing through the centre of a lens
    - Principle focus(focal point):
        - The point at which all the rays parallel to the principal axis converge after refraction by the lens
    - Focal length:
        - The distance between the centre of a lens and its principle focus
    - 

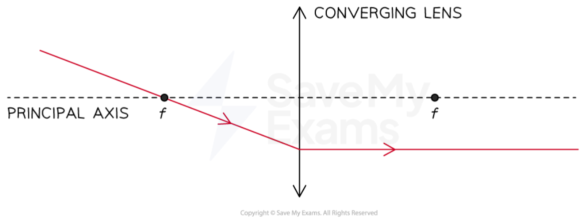
    - A ray passing through the centre of the lens doesn't bend




-
- A ray parallel to the principal axis is refracted to pass through the focal point




-
- A ray passing through the focal point is refracted parallel to the principal focus

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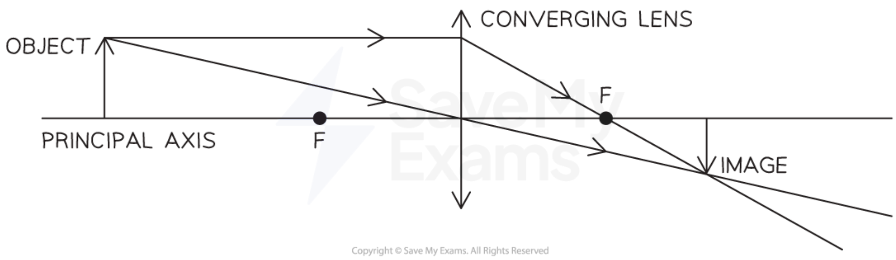
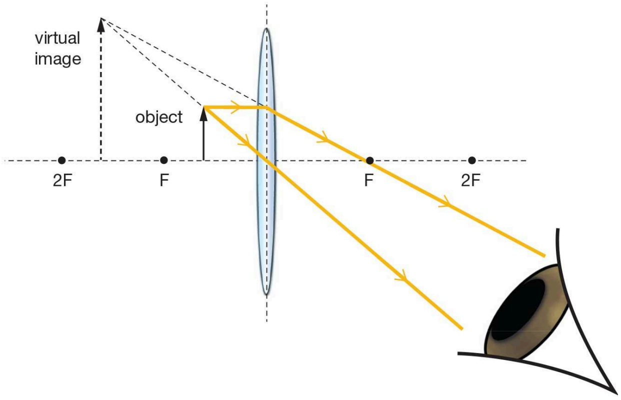
- Real image:
    - Can be projected onto a screen
    - Always inverted
    - The distance of the object from the lens is longer than the focal length
    - On the opposite side of the lens




    -
- Virtual image:
    - Can't be projected onto a screen
    - Always upright
    - The distance of the object from the lens is shorter than the focal point
    - On the same side of the lens
    - A magnifying glass is a converging lens and is used to make objects look bigger

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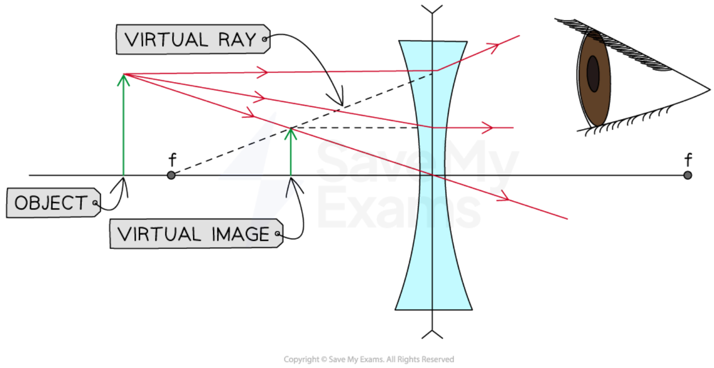
- When diverging rays are extrapolated backwards, a virtual image is formed
  - (Dotted lines are the extrapolation)

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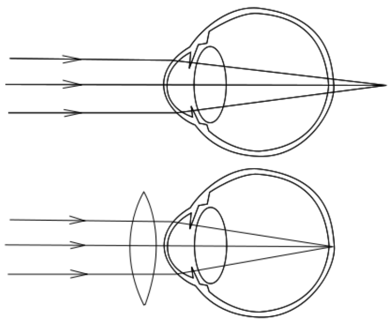
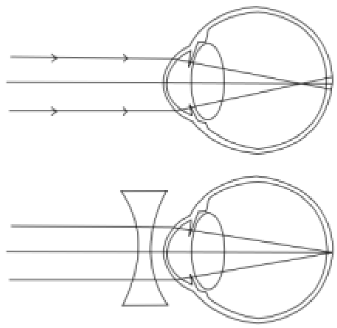
- Visual correction using lenses:
  - Long-sightedness:
    - Unable to see objects close to their eyes clearly
    - The lenses in their eyes can't become thick enough to converge light rays onto the retina
    - A converging lens can be used to converge the light rays before they enter the eyes, so they can be focused on the retina



    -
  - Short-sightedness:
    - Unable to see objects far from their eyes clearly
    - The eyeball is too long, so the light rays converge in front of the retina

- A diverging lens can be used to diverge the light rays before they enter the eyes, so they can be focused on the retina



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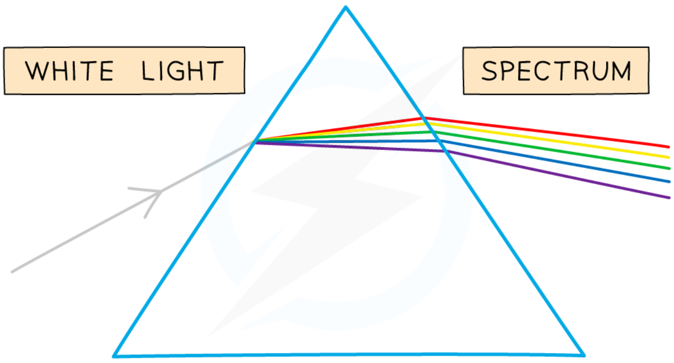
- Dispersion:
    - When white light passes through a glass prism, it splits into a spectrum colors
    - Each color has a slightly different refractive index so they are refracted by a different amount, causing them to split

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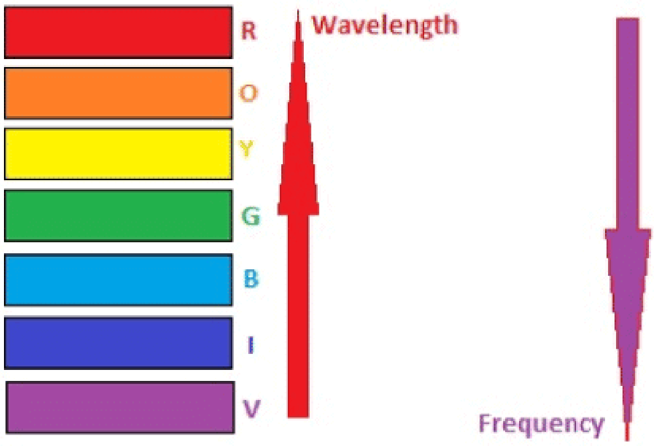
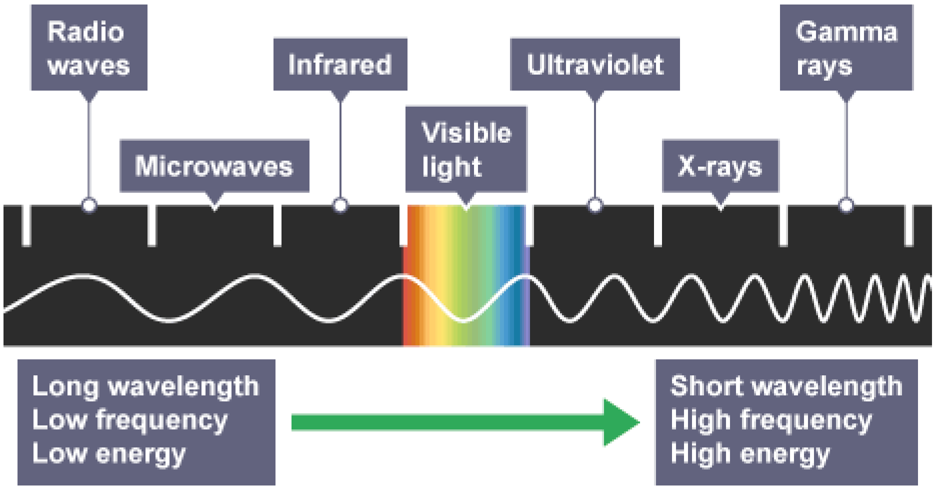



    -
    - Monochromatic light:
    - Visible light of a single frequency

3.3: Electromagnetic radiation:



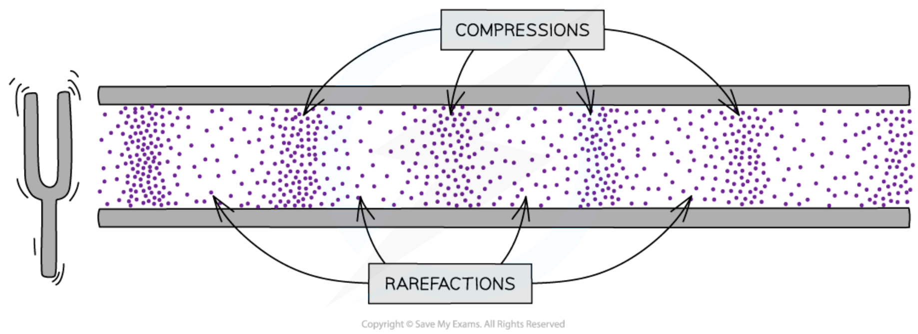

- The speed of all electromagnetic waves in a vacuum is $3.0 \times 10^8$ m/s, and approximately the same in air
- Uses:
  - Radio waves:
    - Radio and television transmission
      - Broadcast towers send out radio waves, which are captured and converted to sound and images
    - Astronomy
      - Astronomical objects emit radio waves, which we can detect
    - Radio frequency identification (RFID)
      - An RFID tag stores data and transmits it as radio waves, which can be read by an electronic reader
    - Bluetooth:
      - Radio waves can pass through walls, but the signal is weakened in doing so
  - Microwaves:
    - Communication with artificial satellites
      - Microwave signals travel to artificial satellites in space, which receive and retransmit microwave signals back to Earth
      - Low orbit satellites:
        - Closer to the Earth's surface
        - Orbit the Earth at a different rate than the Earth turns
        - Used for some satellite phones
      - Geostationary satellites:
        - Further away from the Earth's surface
        - Orbits the Earth at the same rate as the Earth turns, so they stay above one place on the Earth's surface
        - Used for direct broadcast satellite television and some satellite phones
    - Mobile phones
      - Microwaves are used to transmit mobile phone signals between cell towers
      - Microwaves can penetrate some walls
      - They only require a short aerial for transmission and reception
    - Microwave ovens

        - Food absorbs microwaves and heats up
    - Bluetooth
        - Microwaves can pass through walls, but the signal is weakened in doing so
- Infrared:
    - Electric grills
    - Short range communications (remote controllers for televisions)
        - Remote controllers send out coded signals to the television, which interprets them and makes changes accordingly
    - Intruder alarms
        - They send out beams of infrared radiation and can detect when the beams are blocked by intruders
    - Thermal imaging
        - Thermal scanners have detectors that convert infrared into electrical signals
        - They produce thermal images, which use different colors to display the temperature of objects
    - Optical fibres
        - They are used for cable television and high-speed broadband
        - Glass is transparent to infrared
        - Infrared can pass through optical fibres and carry high rates of data
        -
- Visible light:
    - Vision
    - Photography
        - Sensors that are sensitive to visible light are used in cameras for taking photographs
    - Illumination
    - Optical fibres
        - They are used for cable television and high-speed broadband
        - Glass is transparent to visible light
        - Visible light can pass through optical fibres and carry high rates of data
- Ultraviolet:
    - Security marking
    - Detecting fake bank notes
        - Some chemicals that appear transparent can glow under ultraviolet light
    - Sterilising water
        - Ultraviolet light damages microorganisms, such as bacteria and viruses
- X-rays:
    - Medical scanning
    - Security scanners
- Gamma rays:
    - Sterilising food and medical equipment

            - Gamma rays can damage or kill microorganisms, such as bacteria and viruses
        - Detection and treatment of cancer
- Harmful effects:
    - Microwaves: Internal heating of body cell
    - Infrared: Skin burns
    - Ultraviolet: Damage to surface cells and eyes, leading to skin cancer and eye conditions
    - X-rays and gamma rays: Mutation or damage to cells in the body
- Sound can be transmitted as a digital or analogue signal:
    - Digital signal:
        - Has fixed values, either on or off
    - Analogue signals:
        - Has continuous values, varies in the same way as a sound wave
    - Benefits of digital signalling:
        - Increased rate of transmission
            - Digital signals can carry more data
        - Increased range
            - Noise is created when signals are transmitted
            - Digital signals can be regenerated accurately over long distances

3.4: Sound:

- Sound waves are produced by vibrating sources
- A medium is needed to transmit sound waves
- Sound waves are longitudinal
- Compression:
    - Region where particles are pushed together
- Rarefactions
    - Region where particles are spread apart

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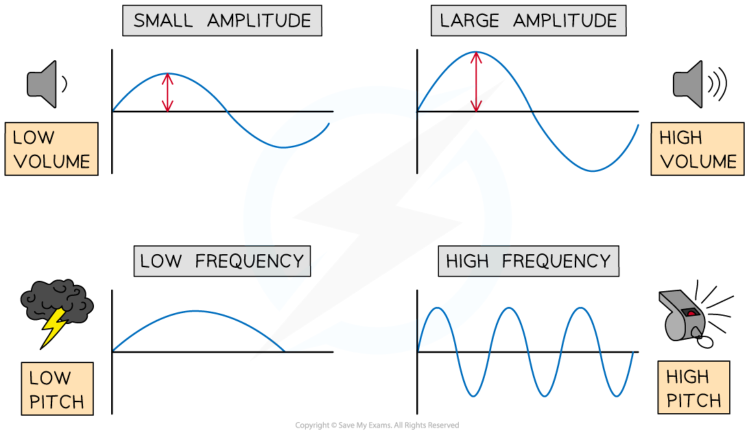
- Frequencies audible to humans: 20Hz to 20,000Hz
- Speed of sound in air: 330-350 m/s
- Speed of sound in: gas $<$ liquid $<$ solid
    - Particles are closer in denser materials, so vibrations can be passed on more easily
- Experiment:
    - Position two people 100 meters apart
    - Person A will take two wooden blocks and bang them together over their head to produce a sound wave

- Person B will start a stopwatch when they see person A banging the bocks, and stop it when they hear the sound
- Repeat this several times and calculate an average of the time taken
- Calculate the speed of sound
- Repeat the steps at different distances between the two people
- Results:
    - The speed of sound should be approximately 340 m/s for all distances
- 

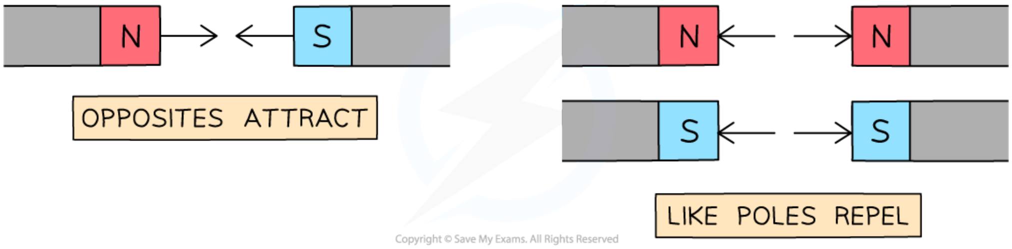
- Echo:
    - The reflection of sound waves
- Ultrasound:
    - Sound with a frequency higher than 20 kHz
    - Inaudible to humans
    - Uses:
        - Non-destructive testing of materials
            - Ultrasound is reflected back when it reaches a crack in a material
        - Medical scanning of soft tissue
            - Ultrasound is reflected back when it hits a different materials, such as a fetus in a pregnant person's womb
            - The depth of the reflecting surface can be derived, and an image can be formed by computer analysis
        - Sonar
            - An ultrasound pulse is sent into the water and reflected back when it reaches the sea bed
            - You can use the time taken for the reflected pulse to be received, and the speed of sound in water to calculate the depth of water

# 🔌 4. Electricity and magnetism

# 4. Electricity and magnetism

4.1: Simple phenomena of magnetism

- Poles: The ends of a magnet

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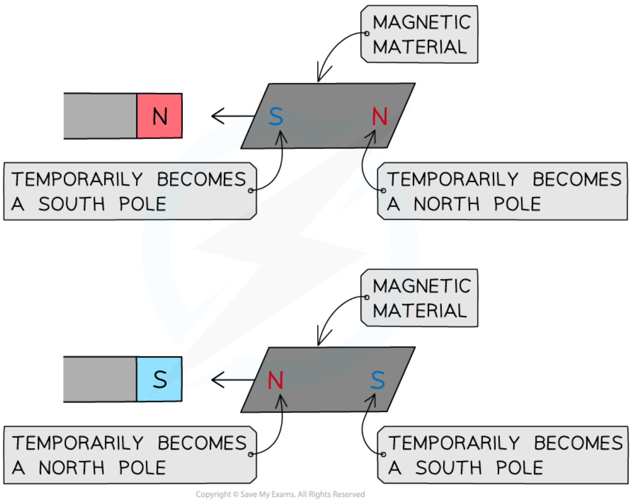
- Magnetic material: Can be attracted to a magnet
- Non-magnetic materials: Can't be attracted to a magnet

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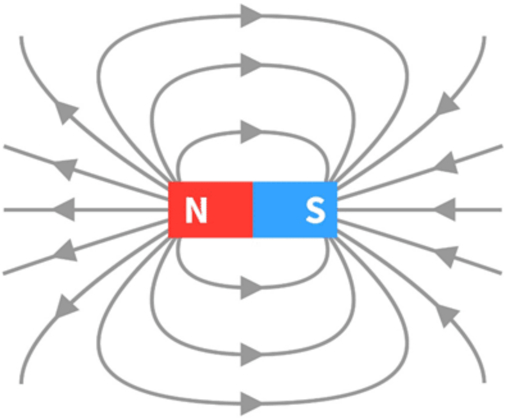
- Permanent magnets (made of steel):
    - Difficult to magnetise
    - Retains its magnetism
- Temporary magnets (made of soft iron):
    - Easily magnetised
    - Loses its magnetism easily
- Magnetic field:
    - A region in which a magnetic pole experiences a force
    - The direction of a magnetic field at a point is the direction of the force on the N pole of the magnet at that point
    - The more closely packed the magnetic field lines, the stronger the magnetic field

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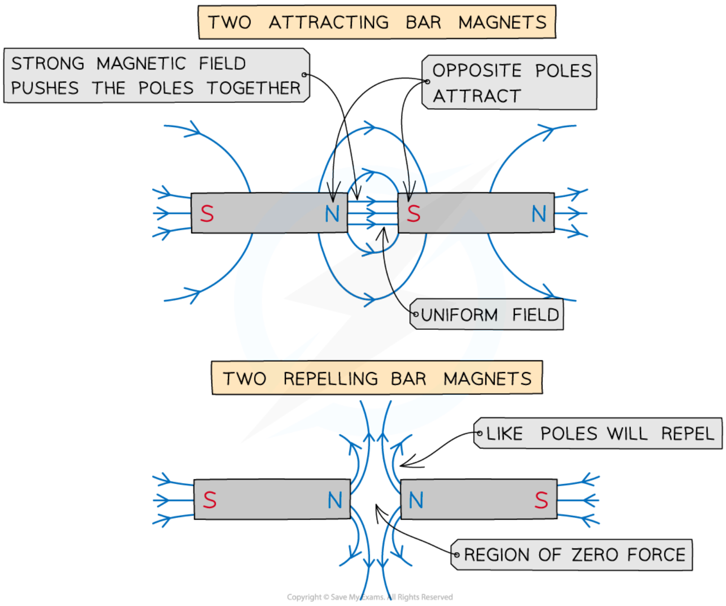
- Magnetic forces are due to the interactions between magnetic fields

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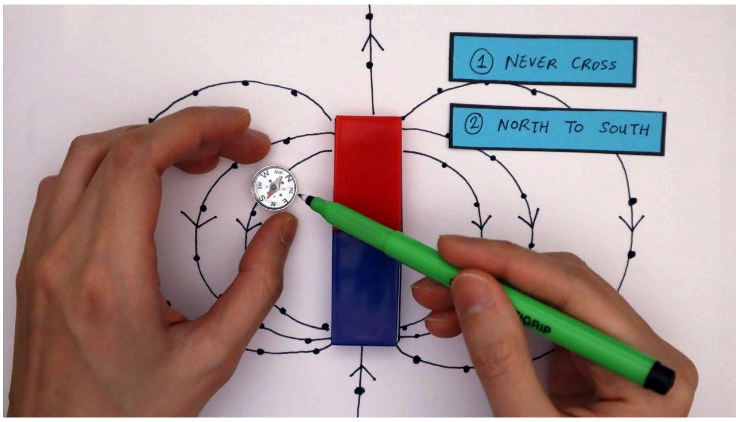
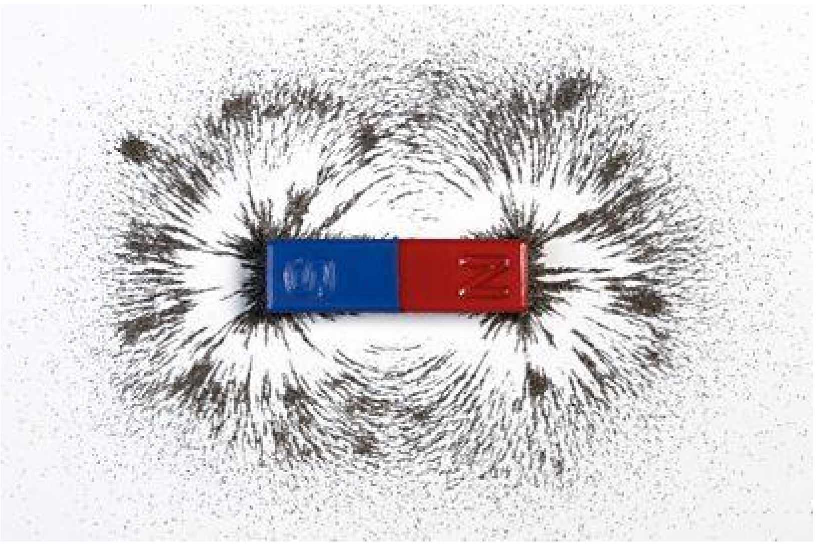
- Plotting magnetic fields:
    - With a compass:
        - Place a magnet on top of a piece of paper and draw around it
        - Draw a dot at the corner of the north pole of the magnet
        - Place a plotting compass next to the dot, so that the end of the needle of the compass points towards the dot
        - Draw a new dot on the other side of the compass needle
        - Move the compass so that its other end points towards the new dot, and repeat the process
        - Keep repeating until you reach the other pole
        - Remove the compass and link the dots together using a smooth curve, marking the direction the magnet was pointing in. This is a magnetic field line
        - Repeat the process at different points near the north pole to draw several field lines around the magnet

- 


- With iron filings:
  - Place a stiff sheet of paper on top of a magnet
  - Sprinkle iron filings over the paper
  - Tap the paper gently to allow the filings to settle on the field lines
  - 

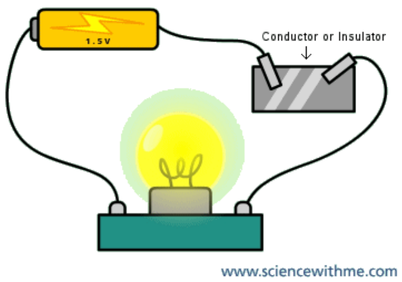
- Uses of permanent magnets: Compass, fridge magnets, magnetic door catches

4.2: Electrical quantities:

- There are positive and negative charges
  - Positive charges repel positive charges
  - Negative charges repel negative charges
  - Positive charges attract negative charges
  - Charging by friction:
    - Involves only the transfer of negative charge (electrons)
    - Experiment:
      - Rub a glass rod with a scrap of cloth
      - Hang a glass rod from a stand, making sure it can rotate freely
      - Bring the cloth close to the rod
      - The rod will move towards the cloth
      - Rub another glass rod with a scrap of cloth, and bring it close to the rod
      - The hanging rod will move away from the other rod
      - Results:

- When rubbed together, the cloth transfers electrons to the glass rod
- The cloth has lost electrons so it becomes positively charged
- The glass rods have gained electrons so it becomes negatively charged

- Electrical conductors:
  - Substances that allow charge (electrons) to flow through easily
  - Electrons are free to move throughout the substance
  - E.g: Copper, silver, gold, steel
- Electrical insulators:
  - Substances that do not allow charge (electrons) to flow through easily
  - Electrons are tightly bound to their atoms so they mostly stay put
  - E.g: Glass, wood, plastics
- Experiment:
  - Connect a cell to a lamp using wires with crocodile clips, leaving a gap in the circuit
  - Attach a material into the gap in the circuit
  - Record whether the lamp lights up
  - Repeat the process with different materials
  - Results
    - The lamp will light up when the material attached is a conductor
    - The lamp will not light up when the material attached is an insulator

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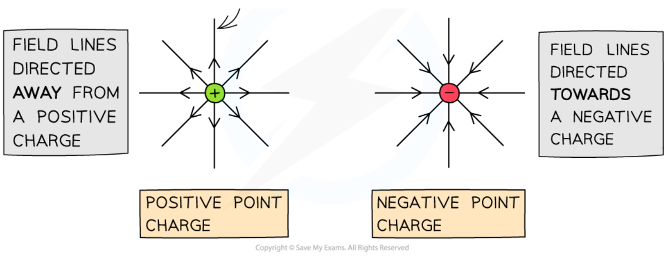
- Electric field:
  - A region in which an electric charge experiences a force
  - The direction of an electric field at a point, is the direction of the force on a positive charge at that point

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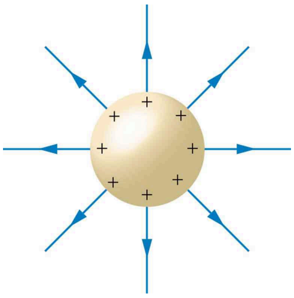
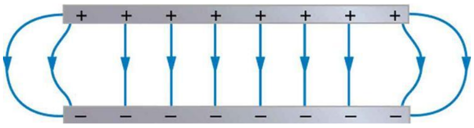
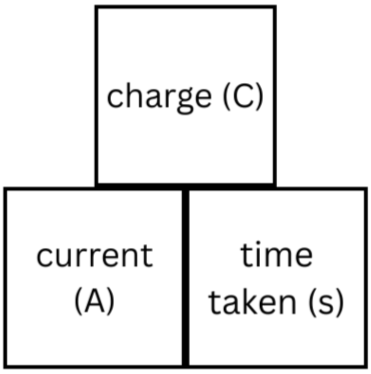
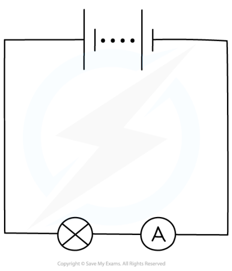
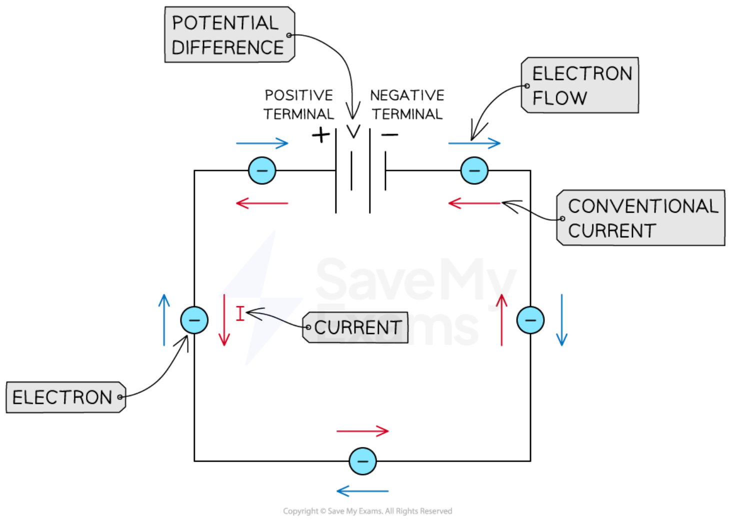
  - Conducting sphere:

    - 
    - Oppositely charged parallel plates:
    - 
- Electric current:
    - The charge passing through a point per unit time
    - $I = \frac{Q}{t}$
    - 

    - Formed by moving electrons
    - Charge is measured by coulombs
    - Ammeters:
        - Used to measure currents
        - Needs to be connected in series(between other components in the circuit)
        - An ammeter with the correct range needs to used
            - If the current is too large, the ammeter will be damaged
            - If the current is too small, the ammeter will not detect the current accurately
        - They can be analog(with a moving needle) or digital (with a numerical readout)
        - 

    - Conventional current:
        - Flows from the positive to negative terminal

- The flow of electrons is actually from the negative to positive terminal

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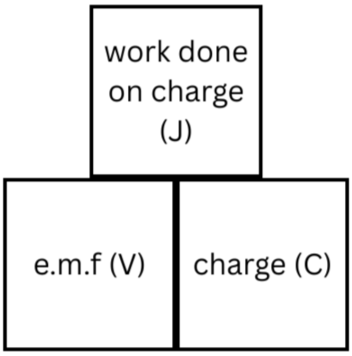
- Direct current: Flows in a single direction only
- Alternating current: Periodically changes direction
- Electromotive force (e.m.f):
  - Energy needs to be provided to drive a charge around a circuit
  - Electromotive force is the electrical work done by a source(like a cell or battery) in moving a unit charge around a complete circuit
  - $E = \frac{W}{Q}$

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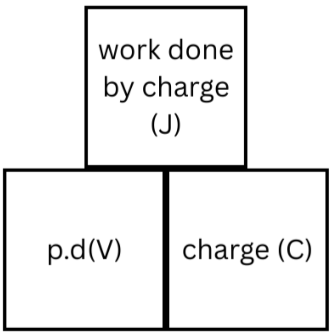
- Potential difference (p.d):
  - The work done by a unit charge passing through a component(like a resistor)
  - $V = \frac{W}{Q}$

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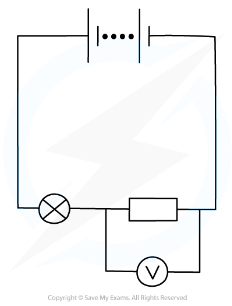
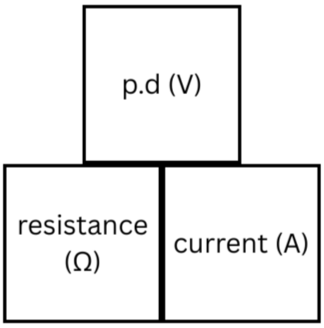
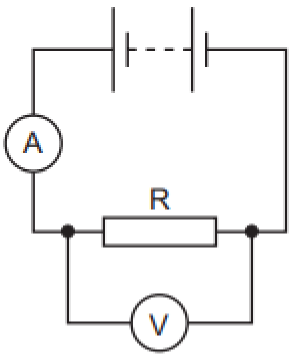
  - Voltmeters:
    - Used to measure e.m.f or p.d

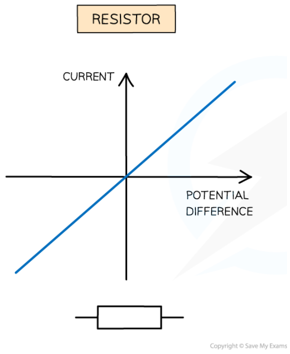
        - Needs to be connected in parallel to the component or source being measured
        - A voltmeter with the correct range needs to used
            - If the current is too large, the voltmeter will be damaged
            - If the current is too small, the voltmeter will not detect the current accurately
        - They can be analog(with a moving needle) or digital (with a numerical readout)
        - 


- Resistance:
    - A measure of how difficult it is for an electric current to flow through a component
    - The greater the resistance, the smaller the current will be
    - $R = \frac{V}{I}$
    - 

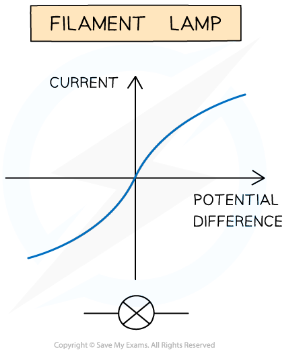

    - Ohm (Ω): How many volts are needed to make 1A flow through the resistor
    - To determine resistance:
        - Connect an ammeter into the circuit, and a voltmeter parallel to the resistor
        - Record their readings and use to formula to calculate the resistance
    - 


    - Resistance is directly proportional to length

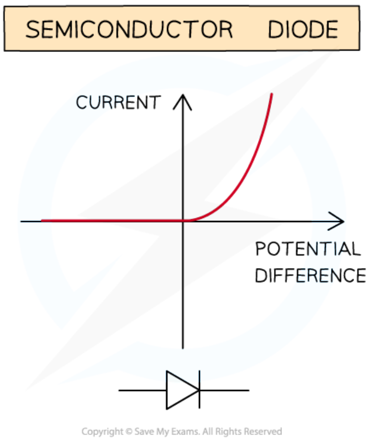
- Resistance is inversely proportional to cross-sectional area
- Current-voltage graphs:
    - Resistor of constant resistance:




        -
        - The voltage and current increase (or decrease) by the same amount
    - Filament lamp:

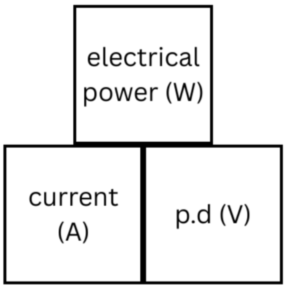



        -
        - Resistance increases as voltage increases
        - As the voltage increases, the current causes the filament to increase in temperature
        - The higher temperature causes the atoms in the metal lattice of the filament to vibrate more
        - This makes it more difficult for free electrons(the current) to pass through
    - Diode



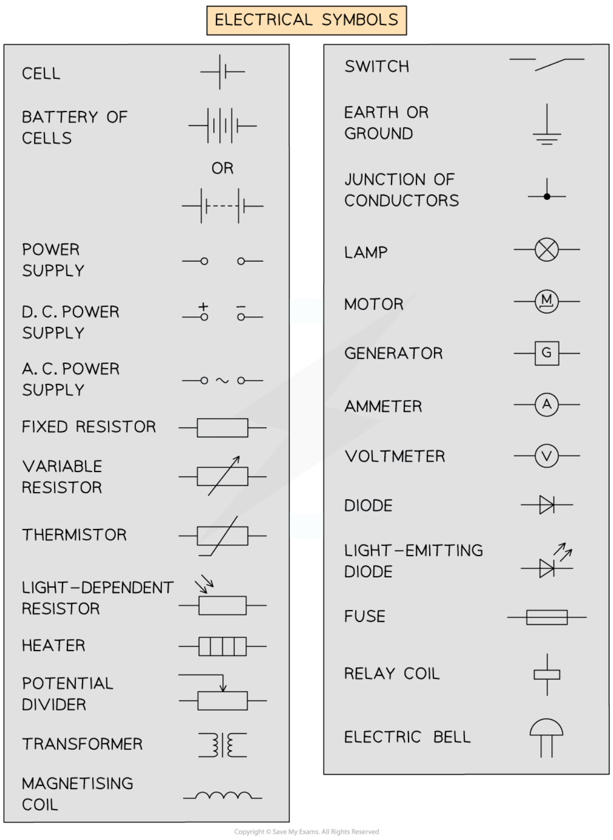

        -
        - A diode allows a current to flow in one direction only

- In the reverse direction, the diode has very high resistance, and therefore no current flows

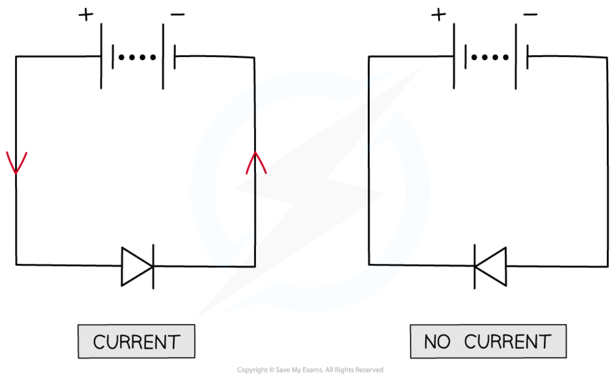
- As charge (electrons) flows around a circuit, energy is transferred from the power source to the various components
    - As electrons pass through the power supply, energy is transferred to the electrons
    - As the electrons pass through each component, energy is transferred from the electrons to the component
    - The component will often dissipate some of that energy to the surroundings
- $P = IV$
- 

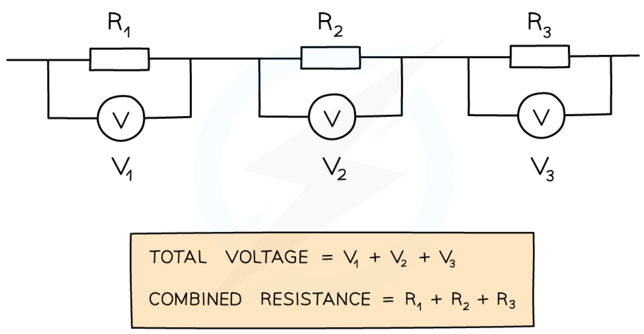
- $E = Pt = IVt$
- $electrical\ energy\ transferred\ (kWh) = power(kW) \cdot time\ (h) = current\ (A) \cdot p.d\ (V) \cdot time\ (s)$
- Kilowatt-hour (kWh):
    - A unit used to measure energy transferred electrically
    - 1 kWh is the electrical energy transferred by an appliance used for one hour

4.3: Electric circuits:

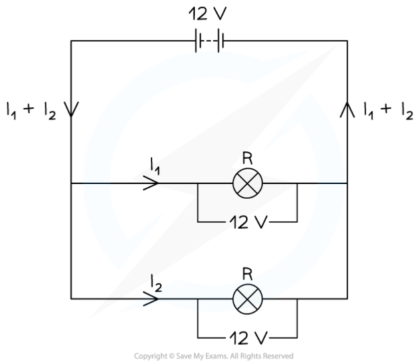
- 

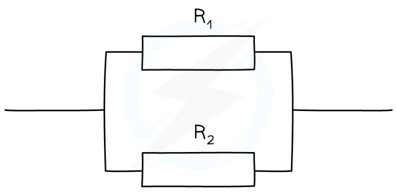
- Cells, batteries, and power supplies:

- Drives the electric charge around the circuit, supplies current
- Generators:
    - Uses kinetic energy to produce electrical energy
- Resistors:
    - Controls the amount of current flowing around the circuit
    - Variable resistor: A resistor whose resistance can be changed
        - Thermistor:
            - Resistance depends on the temperature of its environment
            - Resistance decreases as temperature increases
        - Light-dependent resistors (LDRs):
            - Resistance depends on the amount of light falling on it
            - Resistance decreases when light intensity increases
- Motors:
    - Converts electrical energy into mechanical energy
- Diodies:
    - Allows electric current to flow in one direction only
    - Direction is indicated by the way the triangle points
    - 


    - Light emitting diode (LED):
        - Gives out light when a current flows through it
- Series circuit:
    - The current at every point is the same
    - combined resistance = sum of individual resistances
    - e.m.f = p.d across all components = sum of p.d.s across each component
        - 

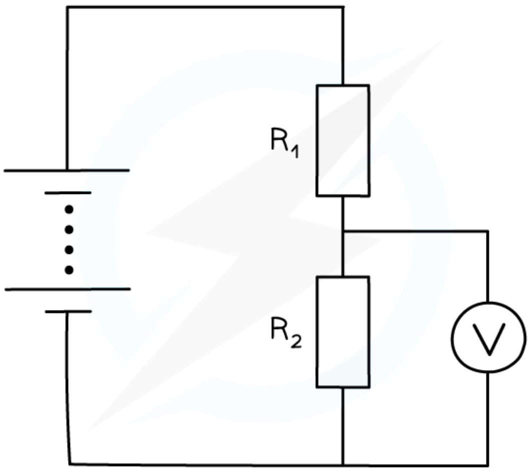
        - P.d is different across each component, calculated using $V = RI$
- Parallel circuit:
    - Current from the source is larger than the current in each branch

- Sum of currents entering a junction = sum of currents leaving the junction
- Current is different across each branch, calculated using $I = \frac{V}{R}$
- e.m.f = p.d across all components = p.d across one branch
- 

- The combined resistance is less than the resistance of any of the individual components
  - $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$
  - 

- Advantages of connecting lamps in parallel:
  - If one lamp on a branch breaks, the rest still work, as the current passes through the branches independently
  - You are able to switch on/off lights on different branches separately

- Potential divider:
  - Two resistors connected in a series
  - Used to obtain a smaller voltage than supplied
  - The e.m.f of the power source will be split between $R_1$ and $R_2$
  - The p.d of $R_2$ will be used to drive another component (like the voltmeter in the diagram)
  - Circuit which splits potential difference from a power source, so only a fraction goes to a component





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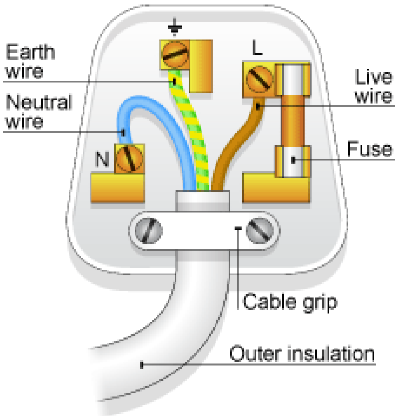
- For a constant current, the p.d across a component increases as its resistance increases
- If $R_1$'s resistance increases:
    - $R_1$ will receive a larger share of p.d
    - $R_2$ will receive a smaller share of p.d
    - A smaller voltage will be supplied to the voltmeter
- If $R_1$'s resistance decreases:
    - $R_1$ will receive a smaller share of p.d
    - $R_2$ will receive a larger share of p.d
    - A larger voltage will be supplied to the voltmeter
- $\frac{R_1}{R_2} = \frac{V_1}{V_2}$
- $\frac{resistance\ of\ R_1}{resistance\ of\ R_2} = \frac{p.d\ of\ R_1}{p.d\ of\ R_2}$

4.4: Electrical safety:

- Hazards when using a mains supply:
    - Damaged insulation:
        - Wires are wound together to form cables, which are enclosed in insulating materials like rubber
        - If insulating materials are damaged, the wire is exposed and can cause electric shocks if touched
    - Excess current:
        - An excessive current may flow if too many plugs, extension leads or sockets are connected to the mains supply
        - The this could cause the cables of overheat, making the insulation melt or even catch fire
    - Damp conditions:
        - Water is an electrical conductor
        - Could provide a conductive path for the current to flow from a livewire through a person to the earth, which causes an electric shock
- Trip switches:
    - Safety devices that can switch off the electricity supply automatically

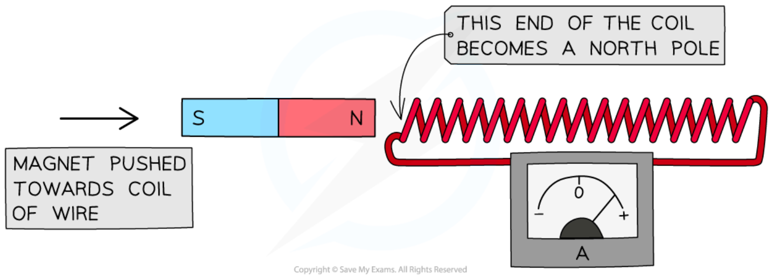
- When the current flowing through a circuit exceeds a certain value, the switch will trip and cut off the current
    - They can be reset when the problem is fixed
- Fuses:
    - Safety devices that are added to a circuit
    - Consists of thin pieces of wire
    - When the current flowing through a fuse exceeds a certain value, the wire will heat up, melt, and create a gap in the circuit
    - Fuses have ratings, which indicates the maximum current that can flow through a fuse before it melts
        - The rating of a fuse should be just above the current the appliance draws under normal conditions
    - Fuses have to be replaced after they blow
- Mains circuit:

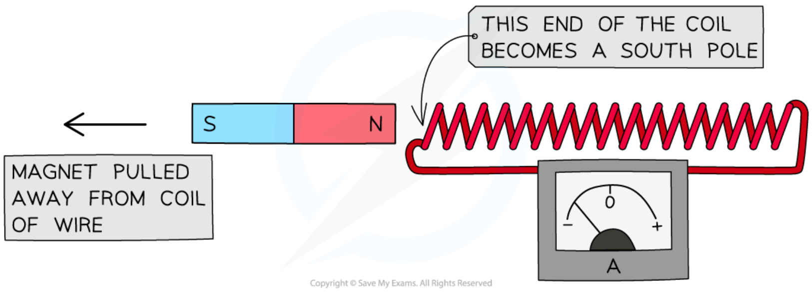



    -
    - Live wire:
        - Carries the current from the mains supply to a circuit
        - Has a high voltage
        - A switch should always be connected to the live wire
            - If the switch is placed in a neutral wire, the appliance is still connected to the live wire when the switch is open
            - A current could still pass through the appliance
            - If a person touches the appliance, they will get an electric shock
    - Neutral wire:
        - Completes the circuit by providing a return path for the current
        - Has a low voltage
    - Earth wire:
        - Safety feature
        - If a live wire fault results in it touching the metal casing of the appliance, the current will flow into the casing and anyone touching it would get an electric shock
        - The earth wire provides a lower resistance path to the ground, so the current flows from the metal casing to the earth wire instead of through the person

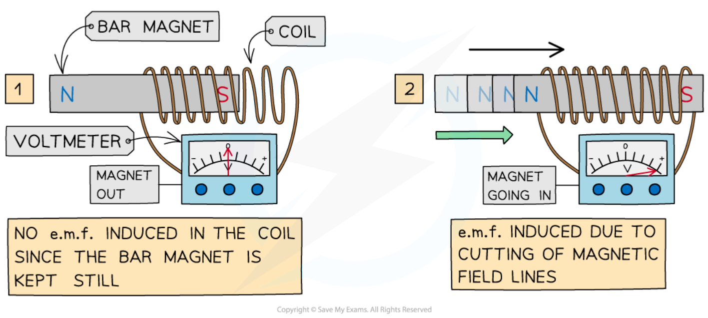
- Because the resistance of the path is low and the voltage is high, a surge of current will be created, causing the fuse in live wire to blow and cutting off the current
- Double-insulation:
  - A safety feature that can replace the earth wire
  - Both the wires and the inside of the casing is insulated, so there is no way that a live wire can touch the metal casing
  - 
  - A fuse without an earth wire protects the circuit and the cabling for a double-insulated appliance

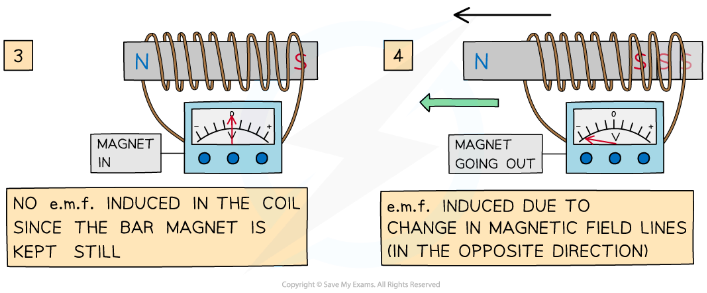
4.5: Electromagnetic effects:
- Electromagnets:
  - A type of magnet in which the magnetic field is produced by an electric current
  - Typically created by passing a current through a coil of wire (a solenoid)
  - Can be demagnetised by simply switching the current off
  - Uses:
    - Cranes to separate metals from nonmetals in a scrapyard
    - Relays
    - Transformers
    - Loudspeakers
- Electromagnetic induction:
  - The production of an e.m.f across an electrical conductor when there is relative movement between the conductor and a magnetic field
  - An e.m.f can be induced in a conductor when:
    - The conductor moves across a stationary magnetic field
    - The conductor is stationary in a changing magnetic field
  - Induced e.m.f can be increased by:
    - Using a stronger magnet
    - Moving the conductor or magnet more quickly relative to each other
    - Using a coil with more turns of wire
  - The direction of an induced e.m.f always opposes the change causing it

- 

    - The changing magnetic field from moving the magnet *towards* the coil induces an e.m.f in the coil
    - The induced e.m.f causes a current to flow and generates a magnetic field in the coil
    - To oppose the movement of the magnet, the pole created on the left will be the north pole
    - This *repels* the magnet
- 

    - The changing magnetic field from moving the magnet *away from* the coil induces an e.m.f in the coil
    - The induced e.m.f causes a current to flow and generates a magnetic field in the coil
    - To oppose the movement of the magnet, the pole created on the left will be the south pole
    - This *attracts* the magnet

- Experiment:
    - Connect a coil to a sensitive voltmeter
    - Move a bar magnet in and out of the coil, and observe the readings on the voltmeter
    - Results:
        - 

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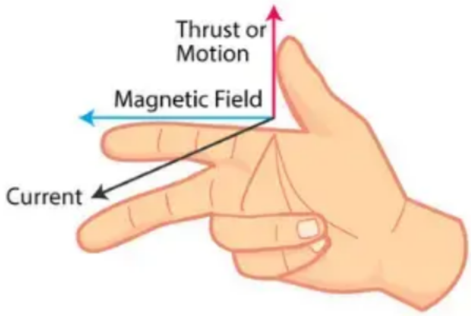
- Flemming's right hand rule:
    - Used to find the direction of an induced current

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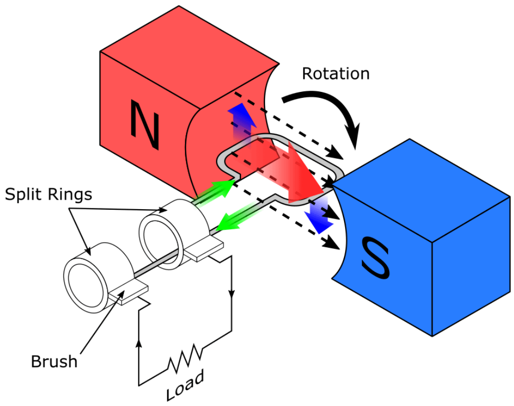
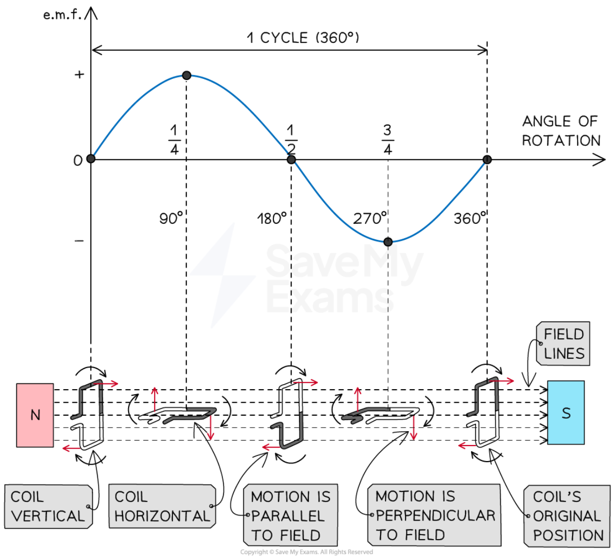
- The a.c generator:
    - Converts mechanical energy into electrical energy in the form of an alternating current

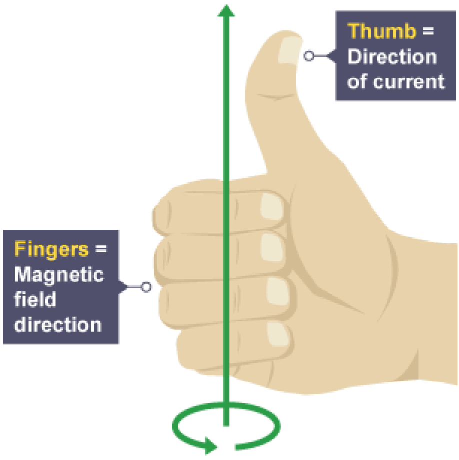



    -
    - Permanent magnets: provide a uniform magnetic field
    - Coil: cuts the magnetic field as it rotates and allow an induced current to flow
    - Slip rings and brushes:
        - The slip rings turn with coil and rub against the brushes, which allows the induced current in the coil to flow to the external circuit
    - Induced e.m.f of an a.c generator can be increased by:
        - Using stronger magnets
        - Turning the coil more rapidly
        - Using a coil with more turns of wire
        - Inserting a soft iron core into the coil
    - Graph of e.m.f against time:




- 
- 90°:
    - The motion of the coil is perpendicular to the magnetic field
    - The sides of the coil are cutting across the magnetic field lines at the greatest rate
    - This gives the maximum induced e.m.f
- 180:
    - The motion of the coil is parallel to the magnetic field
    - The sides of the coil are not cutting across the magnetic field lines
    - This gives no induced e.m.f
- 270:
    - The motion of the coil is perpendicular to the magnetic field
    - The sides of the coil are cutting across the magnetic field lines at the greatest rate
    - This gives the maximum induced e.m.f again, but in the opposite direction

- Magnetic effect of a current:
    - Every electric current creates a magnetic field around it
    - Increasing the magnitude of the current increases the strength of the magnetic field
    - Reversing the direction of the current reverses the direction of the magnetic field
    - Right hand grip rule:
        - Used to determine the direction of the magnetic field due to a current

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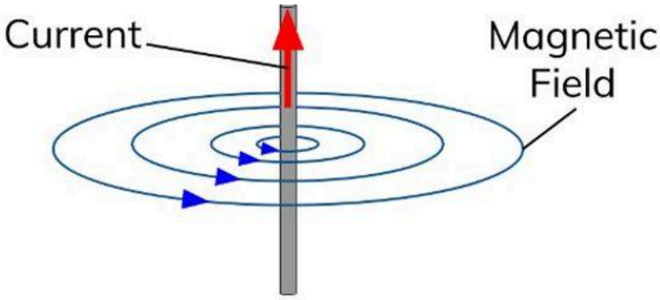
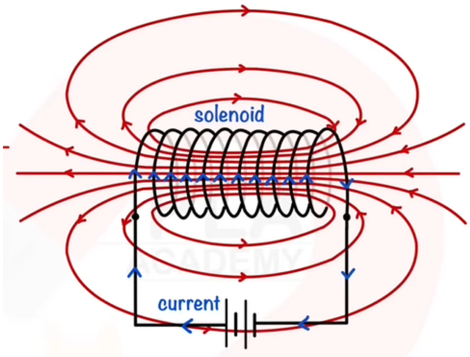
- Straight wires:

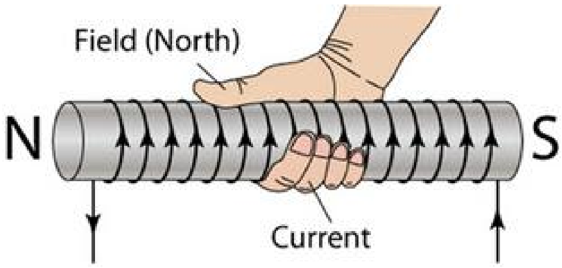


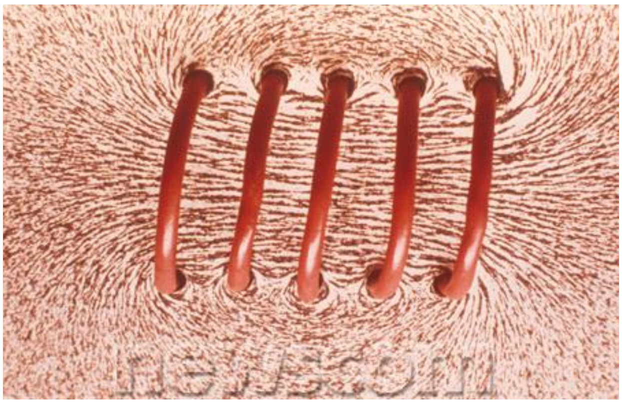

    -
    - Made up of concentric circles centered around the wire
    - The magnetic field is stronger closer to the wire, represented by circles that are closer together
    - Experiment:
        - Cut a small hole through the centre of a cardboard sheet
        - Clamp the cardboard onto a stand horizontally
        - Pass a wire through the hole, making sure it is perpendicular to the cardboard
        - Connect the ends of the wire to an e.m.f source so that a current flows through it
        - Sprinkle iron filings over the cardboard
        - Tap the paper gently to allow the filings to settle on the field lines

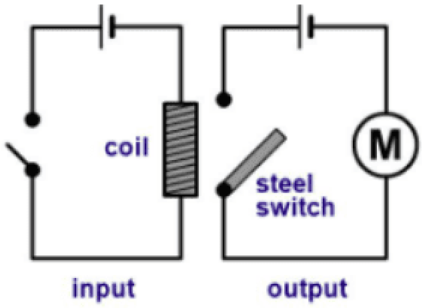
        -

- Solenoids:

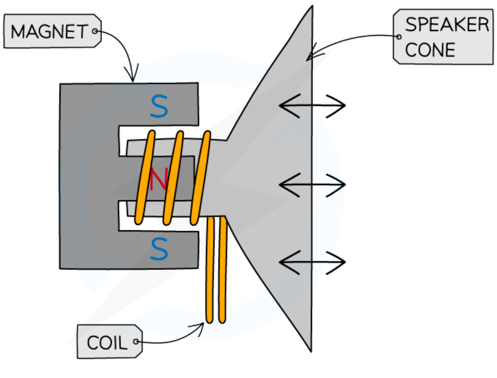
- 

- Field lines are similar to that of a bar magnet
- It has a north and south pole
- The field lines inside the solenoid and strong and uniform
- The magnetic field gets weaker further from the solenoid
- 

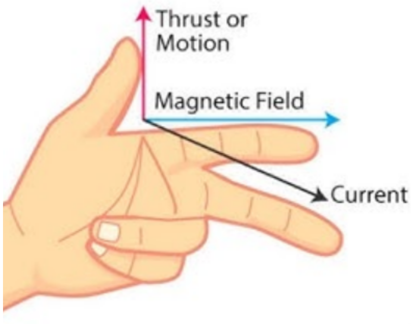
- The magnetic field strength of a solenoid can be increased by:
    - Increasing the current
    - Increasing the number of turns on the coil
    - Inserting a soft iron core into the solenoid
        - The iron core becomes an induced magnet when a current flows through the coils and enhances the magnetic field strength
- Experiment:
    - Cut small holes in a cardboard sheet
    - Clamp the cardboard onto a stand horizontally
    - Thread a wire through the holes to create a coil
    - Connect the ends of the wire to an e.m.f source so that a current flows through it
    - Sprinkle iron filings over the cardboard
    - Tap the paper gently to allow the filings to settle on the field lines
    - 

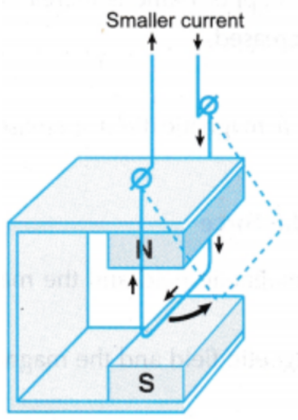
- Relays:
    - A switch controlled by an electromagnet
    - Consists of two circuits:
        - An electromagnet in one circuit
        - The switch controlled by the electromagnet in the other
    - When a current flows through the first circuit:
        - The electromagnet becomes magnetised
        - The switch in the second circuit is attracted and pulled closed by the electromagnet, completing the second circuit and allowing a current to flow through it
    - When the current stops flowing through the first circuit:
        - The electromagnet loses its magnetism
        - The switch in the second circuit stops being attracted by the electromagnet and opens, stopping the current
    - 

    - Applications:
        - The user can activate the second circuit remotely, which is helpful when:
            - The second circuit contains a very high voltage that is unsafe to activate directly
            - The second circuit is a large distance away
        - Car engines, electric bells
- Loudspeakers:
    - An alternating current passes through the coil of the loudspeaker, creating a magnetic field around it
    - As the current is constantly changing direction, the magnetic poles of the coil are constantly reversing
    - The magnetic fields of of the permanent magnet and the coil interact, alternating between attraction and repulsion depending on the poles of the coil
    - This makes the speaker cone vibrate and produce sound

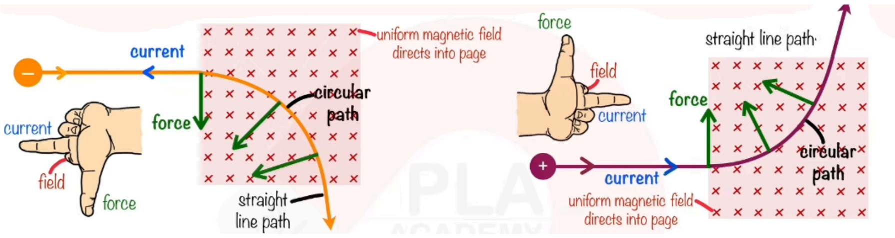


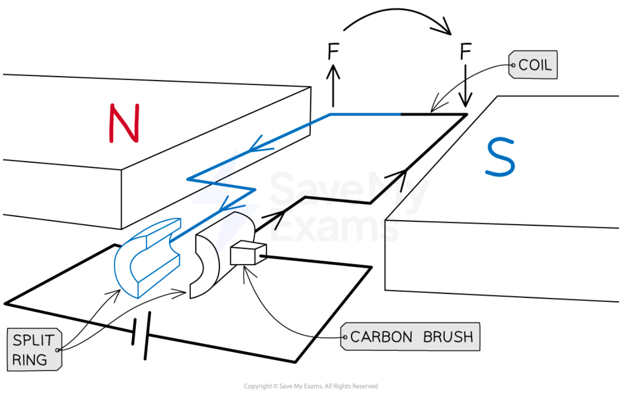


- The motor effect:
    - When a current carrying conductor is placed in a magnetic field, a force is exerted on it
    - Doesn't work if the current is parallel to the magnetic field
    - The direction of the force can be reversed by:
        - Reversing the direction of the current
        - Reversing the direction of the magnetic field
    - Flemming's left hand rule:
        - Used to determine the direction of force on a conductor in a magnetic field
        - 

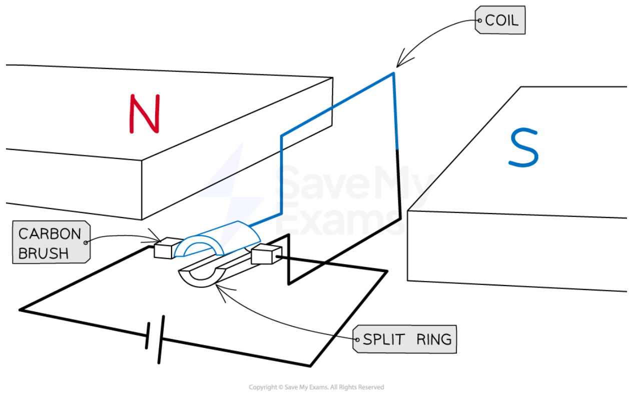
    - Experiment:
        - Bend a wire into the shape of a swing
        - Hang the wire up between a u-shaped magnet and connect the ends to a power supply
        - Switch on the power supply and observe what happens
        - 

        - Results:

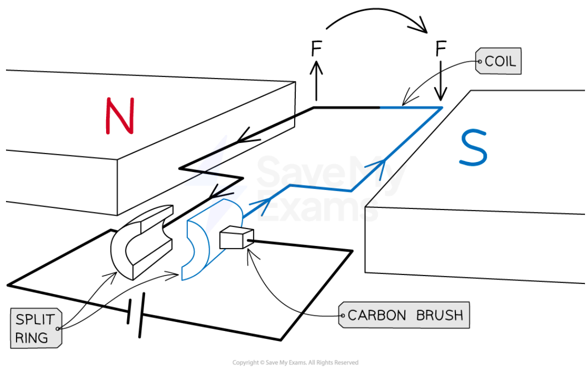
        - The wire will swing outwards
        - If you invert the magnet so that the S pole is upwards, or reverse the current, the wire will swing inwards
- A magnetic field can also be used to deflect a beam of electrically charged particles
    - 

    - Electron flow is the opposite of conventional current, so negatively charged particles will move in the opposite direction of the current
    - The particle travels in a circular path, because the force exerted on the particle is always at a right angle
- The d.c motor:
    - Converts electrical energy from a direct current into mechanical energy
    - A current carrying coil in a magnetic field experiences a turning effect
    - The turning effect can be increased by increasing:
        - The number of turns on the coil
        - The current
        - The strength of the magnetic field
    - A current runs through the wire placed between the two magnets, so a force is exerted on it
    - The split ring commutator rotates with the coil
    - The brushes make contact with the commutator and provide the electric current to the coil
    - 

        - An upward force will act on the blue side
        - A downward force will act on the black side
        - The coil will rotate clockwise until it reaches a vertical position

-


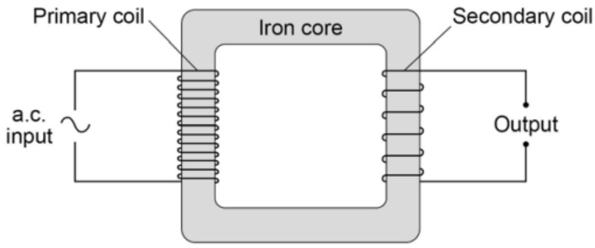

- No force acts on the coil when it is vertical, as the split ring commutator is not in contact with the brushes
- The momentum of the coil causes it to rotate further

-



- The split right commutator reverses the direction of the current to ensure the coil will always rotate in one direction
- An upward force will act on the black side
- A downward force will act on the blue side
- The coil will continue to rotate clockwise

- The transformer:
  - A device that can change the voltage of alternating currents
  - Electricity is transmitted at a high voltage through power lines, and reduced to a lower value when supplied to households and industries to use safely
  - Advantages of high voltage transmission:
    - When current flows in a wire, there is heating in the wire due to resistance
    - Therefore, energy is dissipated to the surroundings, this energy is wasted
    - The lower the current, the less energy wasted and more efficient the energy transfer
    - A lower current can be achieved by increasing the voltage

**Figure 12**

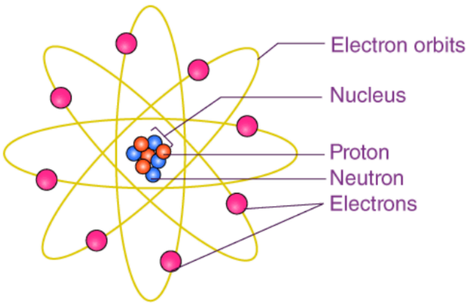


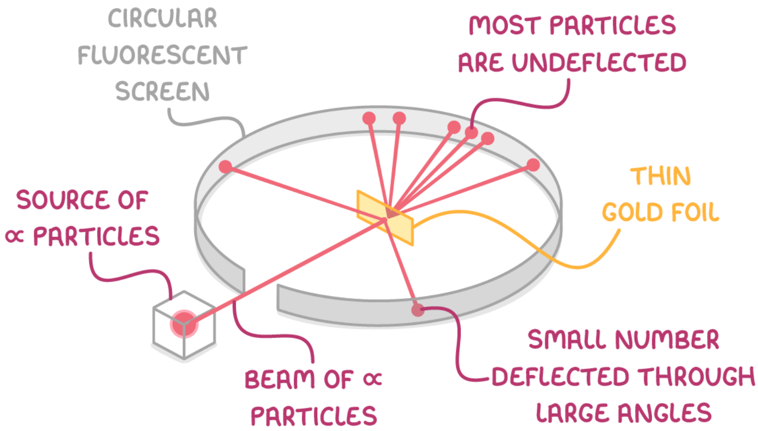

-
- Primary coil: The input coil
- Secondary coil: The output coil
- Step-up transformer:
    - The number of turns in the secondary coil is greater than that in the first coil
    - Results in a higher output voltage
- Step-down transformer:
    - The number of turns in the secondary coil is less than that in the first coil
    - Results in a lower output voltage
- Step-up transformer:
    - The number of turns in the secondary coil is more than that in the first coil
    - Results in a higher output voltage
- How they work:
    - An alternating current is supplied to the primary coil
    - It produces a changing magnetic field around the primary coil
    - The iron core is magnetised, and the changing magnetic field passes through it
    - The changing field cuts through the secondary coil and induces an e.m.f
    - The secondary coil is part of a circuit and causes an alternating current to flow
- $\frac{V_p}{V_s} = \frac{N_p}{N_s}$
- $\frac{primary\ voltage}{secondary\ voltage} = \frac{number\ of\ turns\ in\ primary\ coil}{number\ of\ turns\ in\ secondary\ coil}$
- When the transformer is 100% efficient:
    - $I_p V_p = I_s V_s$
    - $primary\ current\ \cdot\ primary\ voltage = secondary\ current\ \cdot\ secondary\ voltage$
- $P = I^2 R$
- $power\ loss = current^2 \cdot resistance$

# ⚛️ 5. Nuclear physics

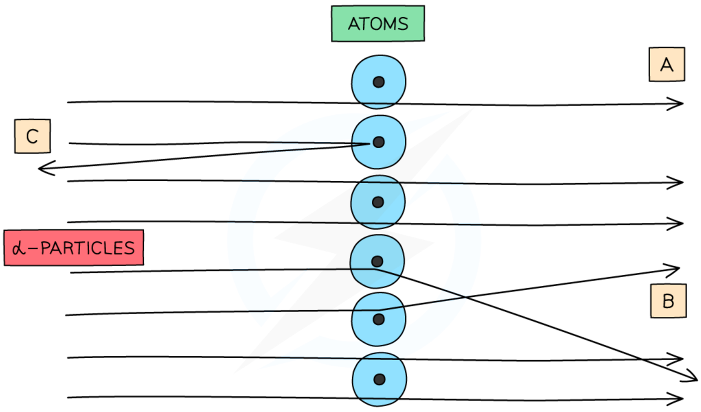
**5. Nuclear physics**

5.1: The nuclear model of the atom

- 

- The nucleus is positively charged
    - Consists of protons and neutrons
- The electrons are negatively charged and orbit around the nucleus
- Atoms:
    - Form positive ions by losing electrons
    - Form negative ions by gaining electrons
- Evidence for the nuclear model of the atom:
    - A beam of alpha particles (α-particles) was directed at a thin metal foil
    - Most α-particles passed straight through the foil
    - Some α-particles were deflected slightly
    - A few α-particles bounced back towards the source
    - 

    - This proves that:
        - An atom is mostly empty space and has a very small nucleus
        - A nucleus is positively charged
            - α-particles are positively charged, so when they came close to the nucleus, they were repelled
        - A nucleus contains most of the mass of the atom




- 
- Relative charge of:
  - Protons: +1
  - Neutrons: 0
  - Electrons: -1
- Nuclide notation:
  - $^{A}_{Z}X$
  - X = symbol of element
  - A = nucleon number (mass number)
    - Number of protons + neutrons
  - Z = Proton number (atomic number)
    - Number of protons
- Number of neutrons = nucleon number - proton number
- Relative charge on a nucleus = proton number
- Relative mass of a nucleus = nucleon number
- Isotopes:
  - Atoms of an element that have the same number of protons but a different number of neutrons
  - An element may have more than one isotope
- Nuclear fission:
  - The splitting of a large, unstable (parent) nucleus into two smaller (daughter) nuclei
  - The nucleus of an atom is hit by a neutron, which causes it be to become unstable and split
  - The original atom becomes atoms of two different elements
  - $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3\,^{1}_{0}n + \text{energy}$
    - The sum of the nucleon numbers and proton numbers of the products and reactants are the same
  - The mass of products is less than the mass of the reactants
    - The lost mass is converted into energy
  - Energy is transferred from the nuclear store of the parent nucleus to the kinetic store of daughter nuclei
- Nuclear fusion:

- When two light nuclei join to form a heavier nucleus
- Requires extremely high temperature and pressure

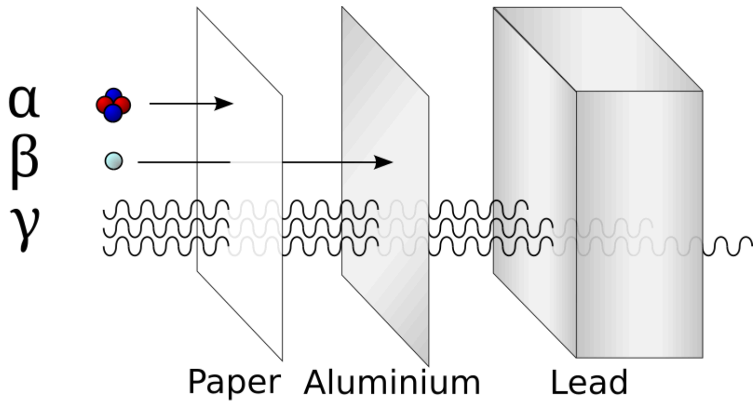
$${}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + E$$

-
    - The sum of the nucleon numbers and proton numbers of the products and reactants are the same
- The mass of products is less than the mass of the reactants
    - The lost mass is converted into energy

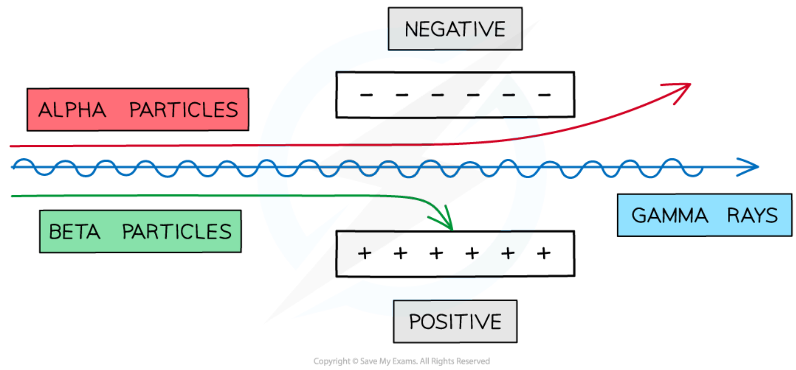
5.2: Radioactivity:

- Background radiation:
    - Radiation that is always present in the environment
    - Sources:
        - Radon gas in the air
        - Rocks and buildings
        - Food and drink
        - Cosmic rays
- Measuring ionising nuclear radiation:
    - Can be measured using a detector connected to a counter
    - Count rate is measured in counts/s or counts/minute
    - When measuring radioactive sources:
        - You should first measure the count rate without the source to determine the background count rate
        - Subtract the background count rate from the count rate with the source to obtain a corrected count rate
- Radioactive decay:
    - A change in an unstable nucleus that results in the emission of radiation
    - The emission is spontaneous and random in direction
    - Some isotopes of an element may be radioactive due to an unstable nucleus:
        - The nucleus has an excess of neutrons
        - The nucleus is too heavy
    - As the radiation moves away from the nucleus, it takes some energy from the nucleus with it and makes it more stable
    - There are three types of nuclear emissions:

| | Nature | Relative charge | Penetrating ability | Ionising effects |
|---|---|---|---|---|
| alpha α | 2 protons + 2 neutrons | +2 | Low<br>Absorbed easily by a thin sheet of paper | High |
| beta β | An electron | -1 | Moderate<br>Absorbed by a few millimeters of aluminium | Moderate |
| gamma γ | Electromagnetic radiation | 0 | High<br>Absorbed by several centimetres of dense metal, or several meters of concrete | Low |

- 

- Ionising effects:
    - Nuclear radiation can ionise atoms that it hits by knocking out their electrons
    - The greater the charge of radiation, the more ionising it is
        - Alpha radiation has a charge of +2 so it is the most ionising
        - Beta radiation has a charge of -1 so it is moderately ionising
        - Gamma radiation has no charge so it is the least ionising
    - The higher the kinetic energy of radiation, the more ionising it is
        - Alpha radiation has the greatest mass, so carries the most kinetic energy
        - Beta radiation travels at high speeds, so it carries a lot of kinetic energy
        - Gamma radiation has virtually no mass, so it carries the least kinetic energy
- Deflection in an electric field:
    - Alpha particles are positively charged and attracted to the negative plate
    - Beta particles are negatively charged and attracted to the positive plate
        - They are deflected more than alpha particles as they have a smaller mass
    - Gamma radiation has no charge and travels straight through the plates

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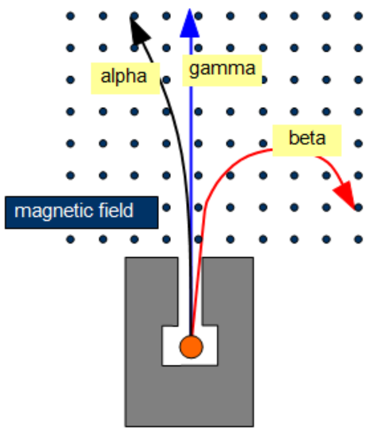
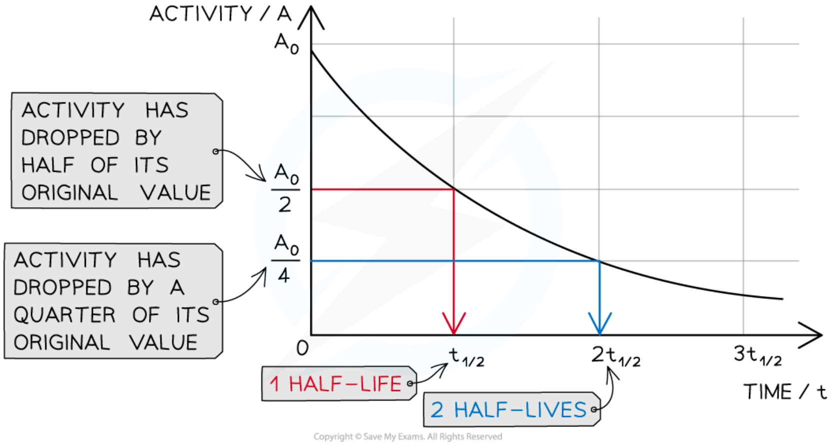
- Deflection in a magnetic field:
  - Behaves in the same way as a beam of electrically charged particles
  - The direction of deflection can be determined using Fleming's left hand rule
    - Remember: beta particles are negatively charged and travel in the opposite direction of conventional current
  - Alpha and beta particles are deflected in opposite directions
  - Beta are deflected more than alpha particles as they have a smaller mass
  - Gamma radiation has no charge and travels straight through the field
  - 


- During alpha and beta decay, the nucleus changes to that of a different element
- Alpha decay:
  - Two neutrons and two protons are emitted
  - Proton number decreases by two, nucleon number decreases by four
  - $^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}\alpha$
- Beta decay:
  - A neutron splits into a proton and an electron
    - $n^{1}_{0} \rightarrow p^{1}_{1} + e^{0}_{-1}$
  - The electron is emitted
  - Proton number increases by one, nucleon number remains the same

- $^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + {}_{-1}^{0}\beta$
- Gamma emissions:
    - Reduces the energy of the nucleus
    - No change in proton or nucleon number
    - $^{A}_{Z}X \rightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$
- Half-life:
    - The time taken for half the nuclei of an isotope in any sample to decay
    - 

    - Background radiation needs to be subtracted before calculating half-life
- Applications of radiation:
    - Household smoke alarms
        - Type used: alpha particles
            - Have the highest ionising ability and are easily stopped by smoke particles
        - Half-life: Long
            - Don't need replacing often
        - Alpha particles ionise the air within the detector, creating a current
        - When smoke particles enter the alarm, the alpha emitter is blocked
        - The sensor no longer detects the alpha particles and triggers the alarm
    - Irradiating food to kill bacteria:
        - Typed used: gamma rays
            - Have the highest penetrating ability
        - Half-life: Long
        - Gamma rays kill bacteria in food
        - This makes the food last longer and reduce the risk of food-borne infections
    - Sterilisation of equipment:
        - Typed used: gamma rays
            - Have the highest penetrating ability
            - Equipment can be sterilised inside sealed packages
        - Half life: Long
            - Sterilising equipment doesn't need to be replaced often
        - Gamma rays kill microbes on the equipment
        - This ensures they are clean, which is important for medical equipment

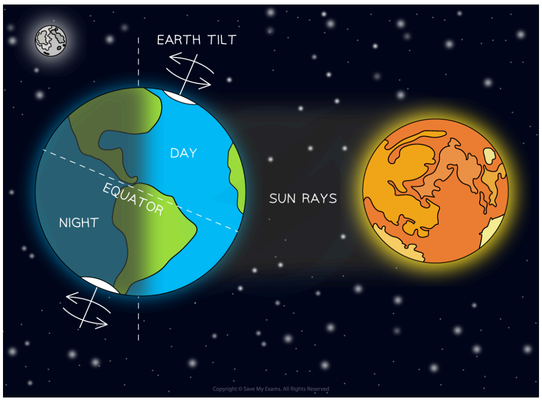
- Measuring and controlling the thickness of materials:
    - Type used: depends on the thickness of the material
        - The radiation needs to be able to penetrate the material, but not too easily or its change in count rate won't be drastic enough to be measured
        - Beta particles: thin materials, paper, plastic film, aluminium foil
        - Gamma rays: thick materials, metal plates
    - Half life: Long
        - The count rate needs to remain relatively constant each day
    - Radiation is passed through the material
    - The change in count rate is monitored by a detector
    - If the material is thick, more radiation will penetrate it and less will be absorbed, so there is a greater change in count rate
    - If the material is thin, more radiation will penetrate it and less will be absorbed, so there is a lesser change in count rate
    - The machine can use this information to make adjustments that keep the thickness of the material constant
- Diagnosis and treatment of cancer:
    - Type used: gamma rays
        - Can penetrate the body
        - Less ionising
    - Half-life: short
        - Won't remain in the body
        - Lowers the amount of radiation emitted from the patient
    - Diagnosis:
        - Patient takes in small dose of material that emit gamma rays
        - The journey of material around the body can be traced via its radioactive emissions
        - This can be used to determine the location of the cancerous tumor
    - Treatment:
        - Beams of gamma rays are directed at the cancerous tumour and damages the cancer cells
        - The beams are moved around to minimise harm to healthy tissue whilst still being aimed at the tumour

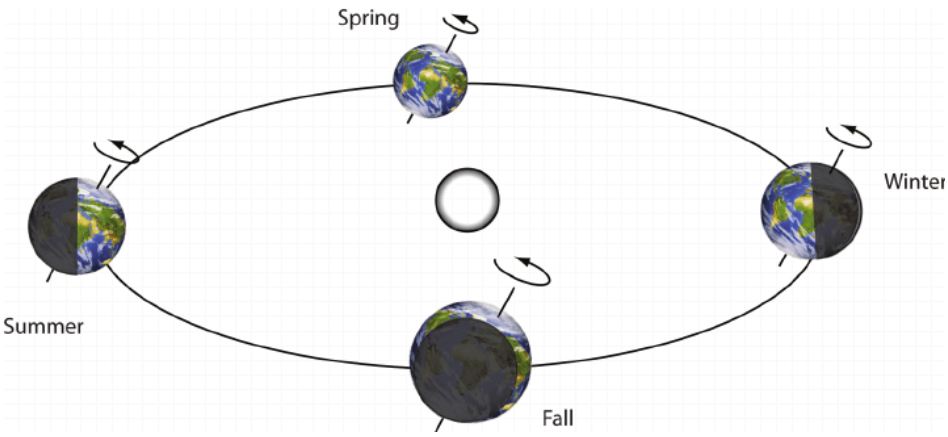
- Dangers of radiation: Cell death, mutations, cancer
- Safety precautions:
    - Reducing exposure time:
        - Limit the amount of time spent near radioactive sources
    - Increasing distance between source and living tissue:
        - Use tongs or remove operators to move sources
        - Construct nuclear power plants and dispose of nuclear waste in remote areas
    - Using shielding to absorb radiation:
        - Wear lead-lined gloves and suits that can absorb radiation
        - Store radioactive sources securely in lead boxes

# 6. Space physics

**6. Space physics**

6.1: Earth and the Solar System

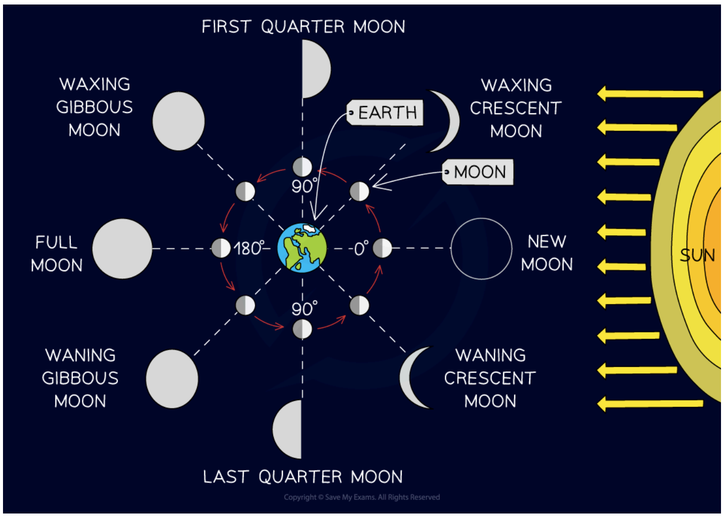
- The Earth rotates on its axis once every ~24 hours, which is responsible for:
    - The day and night cycle
        - The side of the Earth facing the Sun has light shining down on it and experiences daytime
        - The side of the Earth away from the Sun is in darkness and experiences nighttime
    - The apparent daily motion of the Sun across the sky
        - At sunrise at a particular spot on Earth, the spot moves into sunlight, so the Sun appears to be rising on the eastern horizon
        - At midday, the spot is in the full glare of the Sun, so the Sun appears to have moved directly overhead
        - At sunset, the spot moves out of sunlight, so the Sun appears to have sunk below the western horizon
    - 

- The Earth orbits the Sun once every ~365 days
    - The axis of the Earth is tilted, which causes seasons
    - At different times in a year, places on the Earth receive different amounts of the Sun's rays
    - 

    - Northern/southern hemisphere
        - The Sun's rays hit them at different angles throughout the year, so they experience different seasons
        - In summer:
            - The hemisphere is tilted towards the Sun, so the temperature is hot

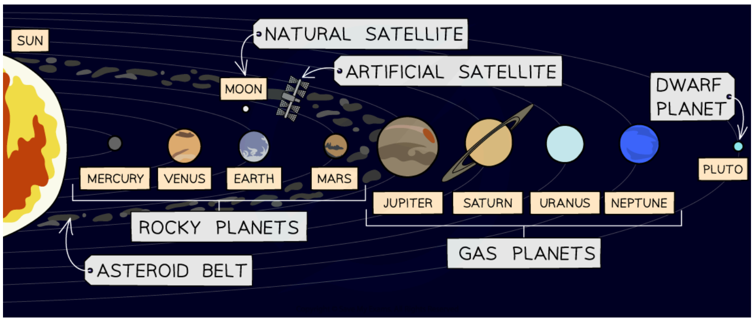
- The hemisphere receives more hours of direct sunlight, so the days are long
- In autumn:
    - The hemisphere no longer tilts towards the Sun, so the temperature gets cooler
    - The hemisphere receives less hours of direct sunlight, so the days get shorter
- In winter:
    - The hemisphere is tilted away from the Sun, so the temperature is cold
    - The hemisphere receives less hours of direct sunlight, so the days are short
- In spring:
    - The hemisphere no longer tilts away from the Sun, so the temperature gets warmer
    - The hemisphere receives more hours of direct sunlight, so the days get longer
- Equator:
    - The Sun's rays always hit them at the same angle, so they do not experience seasons
- North/south pole
    - In summer:
        - The pole will be tilted towards the Sun, and be in daylight for the entire day
    - In winter:
        - The pole will be tilted away from the Sun, and be in darkness for the entire day

- It takes ~1 month for the Moon to orbit the Earth
    - The moon does not produce its own light and is only visible because it reflects light from the Sun
    - Phases of the moon: different ways the moon looks when viewed from the Earth, which changes over a period of one month
        - Depends on how much of the illuminated side of the moon we can see




        -

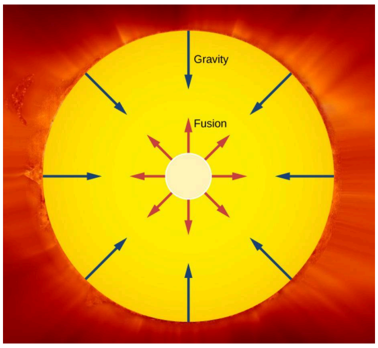
- Orbital speed: the speed at which an object moves in orbit around another object

- Orbital radius: the distance between the object in orbit, and the object it is orbiting
- Orbital period: the time taken for the object to complete one full orbit
- $v = \frac{2\pi r}{T}$
- $average\ orbital\ speed = \frac{2 \cdot \pi \cdot average\ orbital\ radius}{orbital\ period}$
- The solar system contains:
    - One star: the Sun
    - Eight planets: Mercury, Venus, Earth, Mars, Jupiter, Satur, Uranus, Neptune
    - Dwarf planets: Smaller planets like Pluto
    - Asteroids: a small rocky object, found in the asteroid belt
    - Moons: A natural satellite which orbits planets
    - Comets: Frozen balls of gas and dust, orbit the Sun in a highly elliptical path, the ice melts when they get close to the Sun and forms the comet's tail
    - 

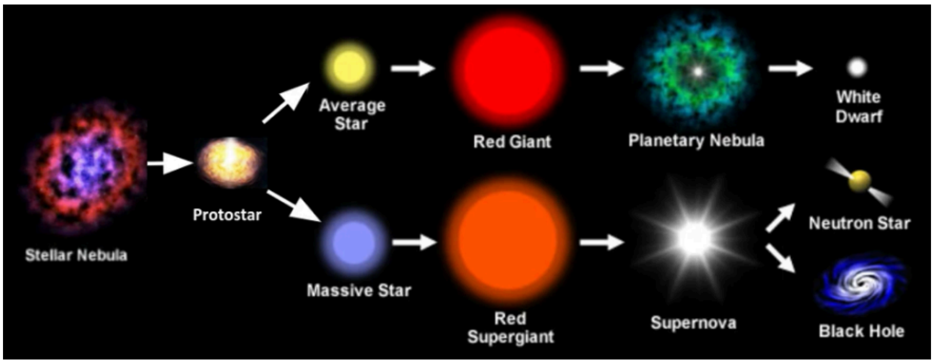
- Formation of the solar system:
    - Began as a nebula, which is a huge swirling cloud of dust and gas
    - Consists of mainly hydrogen, but had a mixture of heavier elements
    - Gravity pulled this mass together
    - The rotation the dust and gas formed an accretion disc
    - Matter underwent accretion:
        - Gravitational forces of attraction between particles caused them to join together to form larger bodies
    - The Sun formed at the centre of the accretion disc
    - Inner planets:
        - The four planets closer to the Sun
        - Only heavy elements (e.g metals) can exist in a solid state near the Sun (high temperature)
        - The original nebula only contained a small amount of heavy elements
        - The material closer to the Sun underwent accretion to form small, rocky planets
    - Outer planets:
        - The four planets farthest from the Sun
        - Light elements(e.g water, hydrogen, methane) can exist in a solid state further from the Sun (low temperature)
        - The original nebula contained a large amount of light elements
        - The material further from the Sun underwent accretion to form large, gaseous planets
- Gravitational field strength at the surface of a planet is greater when the mass of the planet is greater

- Gravitational field strength around a planet decreases as the distance from the planet increases
- The Sun's gravitational field:
    - The sun contains most of the mass of the solar system, so it has the greatest gravitational field strength
    - It pulls planets, asteroids, and comets in orbit around it
    - The force that keeps objects in orbit around the Sun is its gravitational attraction
    - As distance from the Sun increases:
        - Its gravitational field decreases
        - The orbital strength of planets decrease
- Elliptical orbit:
    - Orbits that are not completely circular, like a squashed circle
    - Planets, minor planets, and comets have elliptical orbits
    - The Sun is not at the centre of the elliptical orbit, except when the orbit is approximately circular (like for planets)
    - An object in elliptical orbit travels faster when closer to the Sun:
        - The Sun's gravitational field pulls the object towards it, so it speeds up
        - As the object moves away from the from the Sun, the gravitational field isn't as strong, so it slows down
        - Energy is conserved:
            - When the comet approaches the sun, energy is transferred from its gravitational potential energy store to its kinetic energy store
                - The increase in kinetic energy causes it to speed up
            - When the comet moves away from the sun, energy is transferred from its kinetic energy store to its gravitational potential energy store
                - The decrease in kinetic energy causes it to slow down
- $time\ taken\ for\ light\ to\ travel\ between\ objects\ (s) = \frac{distance\ (m)}{3\times10^{8} m/s}$

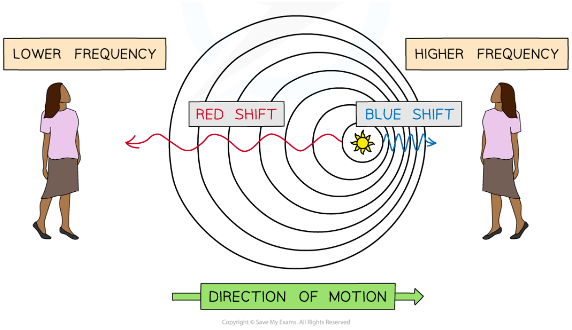
6.2: Stars and the Universe
- The Sun:
    - Is star of medium size
    - Consists mostly of hydrogen and helium
    - Radiates most of its energy through infrared, visible light, and ultraviolet
    - Is in the galaxy known as the Milky Way
- Stars:
    - Powered by nuclear reactions that release energy
    - In stable stars, the nuclear reactions involve the fusion of hydrogen into helium
    - Galaxies are each made up of many billions of stars
    - Other stars that make up the Milky Way are much further away from the Earth than our Sun is
- Light years:
    - Used to measure astronomical distances
    - One light-year is:
        - The distance travelled in the vacuum of space by light in one year

        - $9.5 \times 10^{15}$ m
- Life cycle of a star:
    - A star is formed from interstellar clouds of gas and dust that contain hydrogen
    - Gravitational attraction causes the interstellar cloud to collapse and pull closer together, forming a hot ball of spinning gas known as a *protostar*
    - The protostar continues pulling in more materials, becoming hotter and denser
    - When the protostar is dense and hot enough, nuclear fusion will occur at its centre and it becomes a *stable star*
    - A star is stable when the forces acting on it is balanced:
        - It is pulled *inward* by gravitational attraction
        - It is pulled *outward* due to high temperatures in the centre of the star, caused by nuclear fusion
        - 

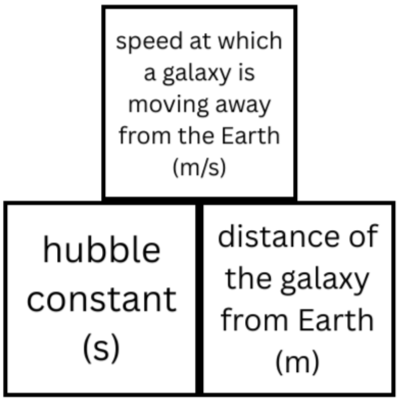
    - All stars eventually run out of hydrogen as fuel for nuclear reaction
    - The inward force due to gravitational attraction becomes greater than the outward force due to high temperatures, so the core shrinks and heats up
    - The core becomes hot enough for helium to fuse into carbon
    - The outer layers of the star expand and cool
    - For less massive stars:
        - The star becomes a *red giant*
        - Once the helium in the core runs out, fusion cannot continue and the core collapses under its own gravity
        - The outer shell of the star is pushed away and becomes a *planetary nebula*
        - The core becomes a white dwarf at the centre of the nebula
    - For more massive stars:
        - The star becomes a *red supergiant*
        - Once the helium in the core runs out, the temperature is still high enough for further fusion reactions to occur
        - Successively heavier elements are formed, and the core collapses and expands repeatedly
        - The fusion reactions cannot continue once iron is formed
        - The core collapses rapidly under its own gravity and explodes as a *supernova*
        - This provides the energy needed to create heavier elements than iron
        - A nebula containing hydrogen and the new heavier elements formed
            - The nebula may eventually form new stars and planets
        - The core becomes a *neutron star* at the centre of the supernova
        - The neutron star may collapse further into a *black hole*




- 
- The Milky Way:
  - One of the many billions of galaxies making up the Universe
  - Has a diameter of ~100,000 light years
- Redshift:
  - The increase in observed wavelength of electromagnetic radiation emitted from receding stars and galaxies
  - If a source of light moves away from an observer, the observed wavelength increases and
  - The wavelength of light shifts towards the red end of the spectrum



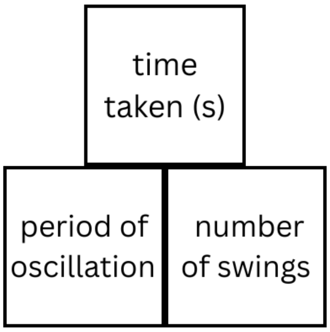

  - 
  - Light emitted from distant galaxies appear redshifted in comparison with light emitted on Earth
    - Indicates that distant galaxies are getting further away from us
    - This is evidence that the Universe is expanding and supports the Big Bang Theory
    - The galaxies themselves to do not move, but the spaces between them expands
- Cosmic microwave background radiation (CMBR)
  - Observed at all points in space around us
  - Produced shortly after the universe was formed
  - It would've existed as short wavelength gamma radiation at first, but the expansion of the universe has caused it to redshift and expand into the microwave region of the electromagnetic spectrum
- Hubble constant:
  - The ratio of speed at which the galaxy is moving away from the Earth to its distance from the Earth
  - Current estimate: $2.2 \times 10^{-18}$ per second
  - Speed *v* can be found from the change in wavelength of a galaxy's starlight due to redshift

- Distance *d* can be determined using the brightness of a supernova in that galaxy
- $H_0 = \frac{v}{d}$
- 

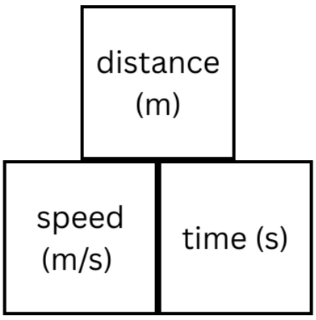
- $estimate\ of\ the\ age\ of\ Universe = \frac{d}{v} = \frac{1}{H_0}$
    - Evidence for the idea that all the matter in the Universe was present at a single point
-

# Equations

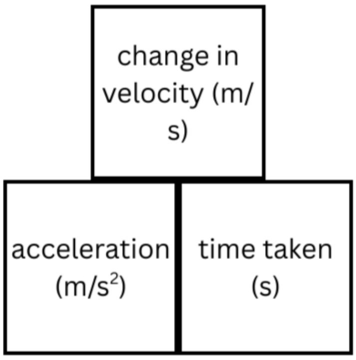
Pendulum:

- 

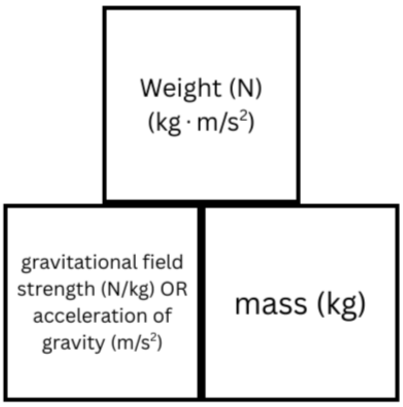

Speed / distance/ time

- $v = \frac{s}{t}$
- 

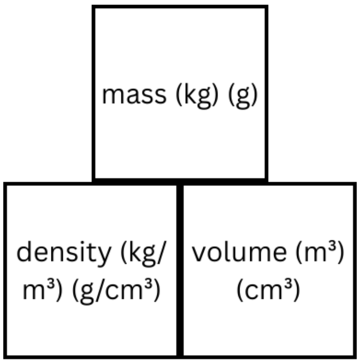

Acceleration / velocity / time

- $a = \frac{\Delta v}{\Delta t}$
- 

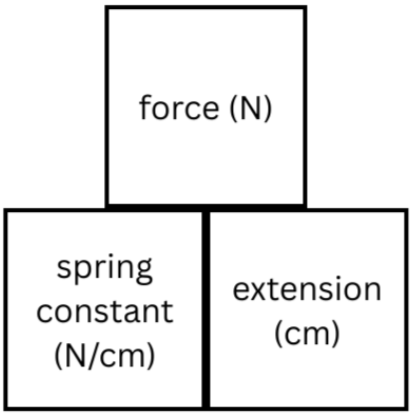

Weight / gravitational field strength / mass"

- $g = \frac{W}{m}$
- 

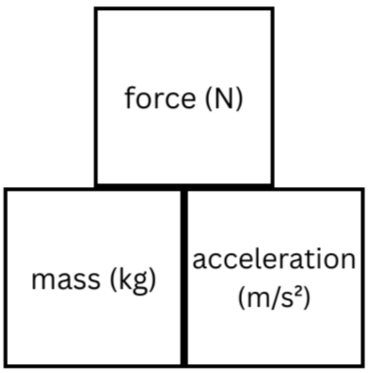
Density / mass / volume:

- $\rho = \frac{m}{v}$
- 

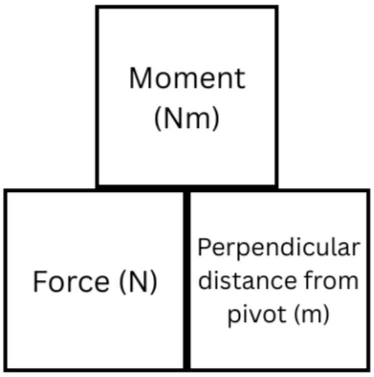

Spring constant / force / extension

- $k = \frac{F}{x}$
- 

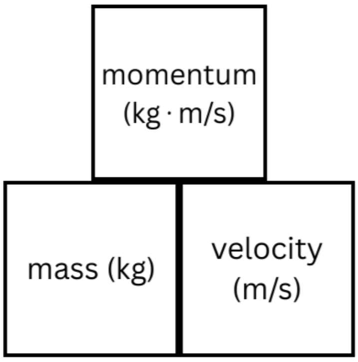

Force / mass / acceleration:

- $F = ma$
- 

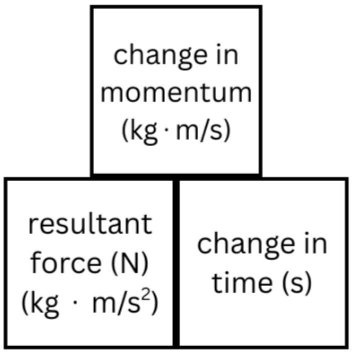

Moment / force / distance

- 


Momentum / mass / velocity

- $p = mv$
- 


Impulse / force / momentum:

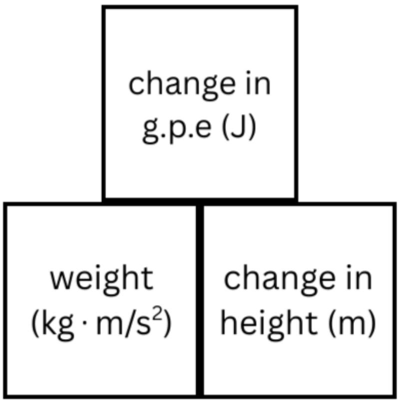
- $impulse = F\Delta t = \Delta(mv) = \Delta p$
- $impulse\ (N \cdot s)\ (kg \cdot m/s) = force(N) \cdot \Delta time(s) = \Delta[mass(kg) \cdot velocity(m/s)] = \Delta momentu$
- $F = \frac{\Delta p}{\Delta t}$
- 


Kinetic energy / mass / velocity:

- $E_k = \frac{1}{2}mv^2$
- $kinetic\ energy\ (J) = \frac{1}{2} \cdot mass\ (kg) \cdot speed\ (m/s)^2$

Gravitational potential energy / mass / gravitational field strength / height

- $\Delta E_p = mg\Delta h$

- 

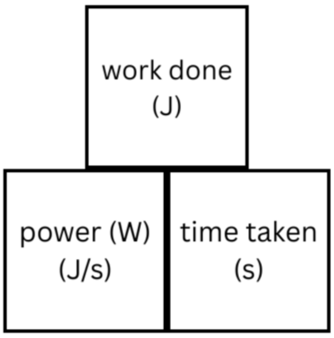

Work done / force / distance / energy:

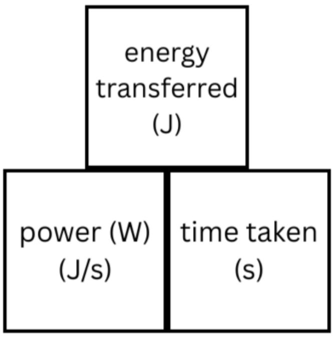
- $W = Fd = \Delta E$
- $work\ done\ (J)\ (Nm) = force(N) \cdot distance\ moved\ in\ the\ direction\ of\ the\ force(m) = \Delta energy$

Efficiency:

- $(\%)\ efficiency = \frac{(useful\ energy\ output)}{(total\ energy\ input)} (\%100)$
- $(\%)\ efficiency = \frac{(useful\ power\ output)}{(total\ power\ input)} (\%100)$

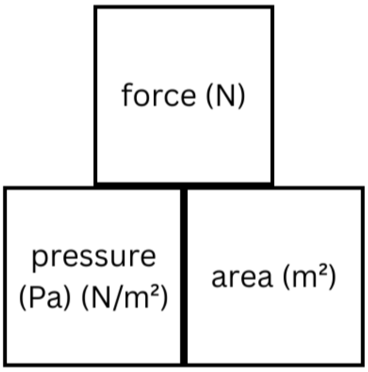
Power / work done / energy

- $P = \frac{W}{t}$
- 

- $P = \frac{\Delta E}{t}$
- 


Pressure / force / area

- $P = \frac{F}{A}$

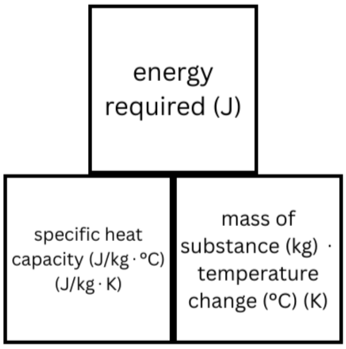
- 

- $\Delta p = \rho g \Delta h$
- $change\ in\ pressure\ (Pa)(N/m^2) = density(kg/m^3) \cdot gravitational\ field\ strength(N/kg) \cdot change$
- $pv = constant$
- $p_1 v_1 = p_2 v_2$

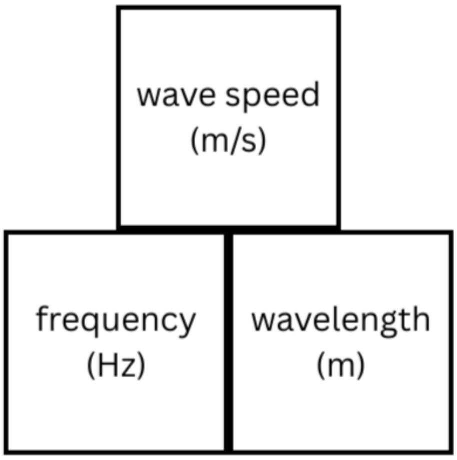
Temperature in Kelvin:

- $T\ (in\ K) = \theta\ (in\ °C) + 273$

Specific heat capacity / mass / temperature / energy:

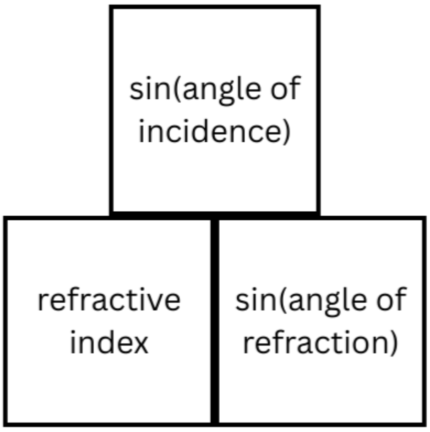
- $c = \frac{\Delta E}{m \Delta \theta}$
- 


Wavelength / frequency / velocity

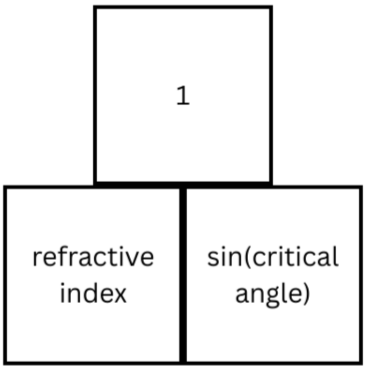
- $v = f\lambda$
- 


Refractive index:

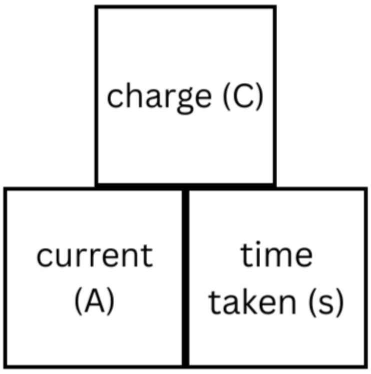
- $n = \frac{\sin i}{\sin r}$

- 


Critical angle:

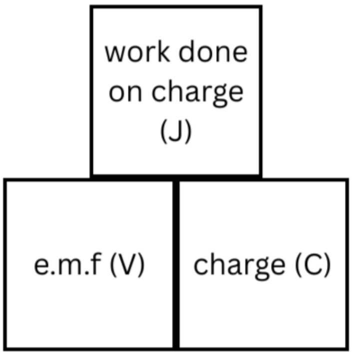
- $n = \frac{1}{\sin c}$
- 

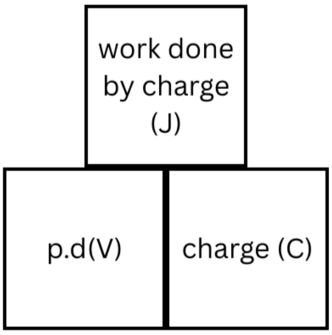

Charge / current / time

- $I = \frac{Q}{t}$
- 

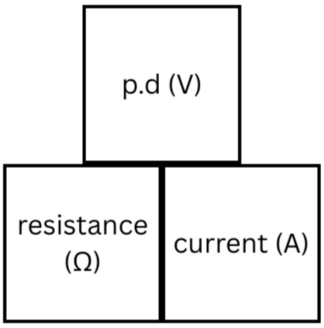

Voltage / work done / energy / charge:

- $E = \frac{W}{Q}$

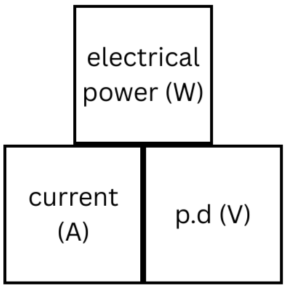
- 

- $V = \frac{W}{Q}$
- 


Resistance / voltage / current:

- $R = \frac{V}{I}$
- 


Power / current / voltage:

- $P = IV$
- 


Energy / power / time / current / voltage

- $E = Pt = IVt$
- $electrical\ energy\ transferred\ (kWh) = power(kW) \cdot time\ (s) = current\ (A) \cdot p.d\ (V) \cdot time\ (s)$

Potential dividers:

- $\frac{R_1}{R_2} = \frac{V_1}{V_2}$
- $\frac{resistance\ of\ R_1}{resistance\ of\ R_2} = \frac{p.d\ of\ R_1}{p.d\ of\ R_2}$

Transformers:

- $\frac{V_p}{V_s} = \frac{N_p}{N_s}$
- $\frac{primary\ voltage}{secondary\ voltage} = \frac{number\ of\ turns\ in\ primary\ coil}{number\ of\ turns\ in\ secondary\ coil}$
- When the transformer is 100% efficient:
  - $I_p V_p = I_s V_s$
  - $primary\ current \cdot primary\ voltage = secondary\ current \cdot secondary\ voltage$
- $P = I^2 R$
- $power\ less = current^2 \cdot resistance$

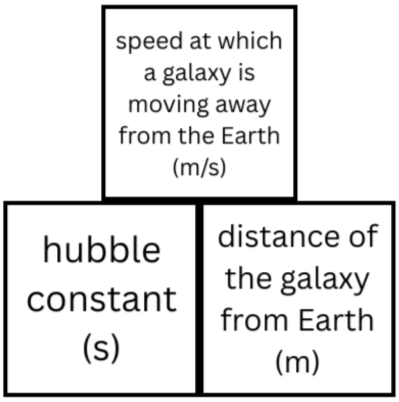
Orbital speed:

- $v = \frac{2\pi r}{T}$
- $average\ orbital\ speed = \frac{2 \cdot \pi \cdot average\ orbital\ radius}{orbital\ period}$

Light:

- $time\ taken\ for\ light\ to\ travel\ between\ objects\ (s) = \frac{distance\ (m)}{3 \times 10^8 m/s}$

Hubble constant:

- $H_0 = \frac{v}{d}$
- 

- $estimate\ of\ the\ age\ of\ Universe = \frac{d}{v} = \frac{1}{H_0}$