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1. Physical Quantities, Units and Measurements

1(a) Physical quantities

Physical quantities consist of a numerical magnitude and unit. Non-Physical Quantities cannot be measured. Examples include:

Physical Quantities	Non-Physical Quantities
Length	Happiness
Mass	Love
Time	Intelligence
Electric Current	Beauty
Thermodynamic temperature	Emotion
Amount of substance	Ethics

1(b) Base quantities

Base Quantity	SI Unit
Length	m
Mass	kg
Time	s
Electric Current	A
Thermodynamic temperature	K
Amount of substance	mol

1(c) Prefixes

Multiples / Sub-multiples	Symbol	Factor
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}

1(d) Sizes of Common Objects

Objects	Length	In standard form
Radius of hydrogen nucleus	0.000 000 000 000 001 m	$1.0 * 10^{-15}\ m$
Size of atom	0.000 000 000 1m	$1.0 * 10^{-10}\ m$
Width of human hair	0.0001 m	$1.0 * 10^{-4}\ m$
Diameter of wire	0.002 m	$2.0 * 10^{-3}\ m$
Length of chopsticks	0.2 m	$2.0 * 10^{-1}\ m$
Length of football field	100 m	$1.0 * 10^{2}\ m$
Radius of Earth	6,378,100 m	$6.4 * 10^{6}\ m$

1(e) Measuring instruments

Physical Quantity	Instruments
Length	Measuring tape, metre rule (m) Digital calipers (cm) Digital micrometre screw gauge (mm)
Volume	Measuring cylinder Burette
Force	Newton-meter
Weight	Electronic scale
Mass	Electronic balance
Time	Stopwatch
Pressure	Manometer, Barometer
Temperature	Thermometer
Angle	Protractor
Potential difference	Voltmeter
Current	Ammeter

Measuring Instruments (for Length)

Instrument	Range	Smallest Division
Measuring tape	2m / 3m / 5m 10m / 15m	1mm
Metre rule	1m	1mm
Digital calipers	15cm	0.01mm
Digital micrometre screw gauge	2.5cm	0.001mm

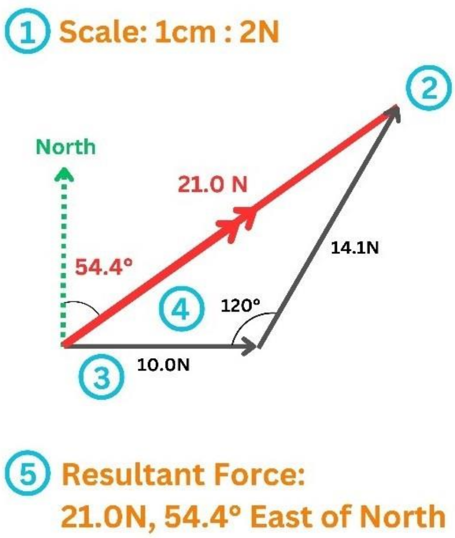
1(f) Scalar vs. Vector Quantities

Scalar quantities are physical quantities with magnitude only, while Vector quantities are physical quantities with both magnitude and direction.

Scalar	Vector
Mass	Displacement
Temperature	Velocity
Time	Acceleration
Distance	Force
Speed	Momentum
Energy	Electric field
Density	Magnetic field
Pressure	Magnetic flux
Charge	Gravitational field
Work	Torque

1(g) Vector diagram to find resultant

Point	"SALAD"	Details
1	**S**cale	Choose the most appropriate scale that occupy half of the allocated space (e.g. 1cm : 2N)
2	**A**rrow	Draw your arrow heads (single-arrowhead for individual forces, double-arrow head for resultant force)
3	**L**abel	Label your arrows with the appropriate magnitude with units (e.g. 10N)
4	**A**ngle	Label your angles if given (e.g. 60°)
5	**D**irection	State the direction of your resultant force



*Tip: you can check your answer using sine rule $\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$

Types of Error

Error	Examples
Systematic	Zero error, Parallax error
Unsystematic error (a.k.a Random Error)	Human Reaction Time

2. Kinematics

2(a) Speed vs. Velocity

Speed is the rate of change of distance, while velocity is the rate of change of displacement.

2(b) Average speed = distance travelled / time taken

$$Average\ Speed = \frac{Total\ Distance}{Total\ Time}$$

Example: If Jim travels 150km in 2hours, his average speed is 75km/h (or 20.8 m/s).

*Note: Average speed is not instantaneous speed. He may not be travelling at 75km/h throughout his journey, but his speeds combined at each instance averages to 75km/h.

2(c) Uniform acceleration

$$(Uniform) Acceleration = \frac{\Delta v}{\Delta t} = \frac{v-u}{t}$$

Example: If Jim accelerates from rest to 5.0m/s in 5 seconds, his acceleration will be 1.0 m/s^2.

2(d) Non-uniform acceleration

Acceleration does not have to be constant.

Example: While driving,

Scenario	Acceleration
(1) Jim steps hard on gas pedal	High acceleration
(2) Jim steps softly on gas pedal	Low acceleration
(3) Jim releases gas pedal	Low deceleration due to friction
(4) Jim steps on brake pedal	High deceleration

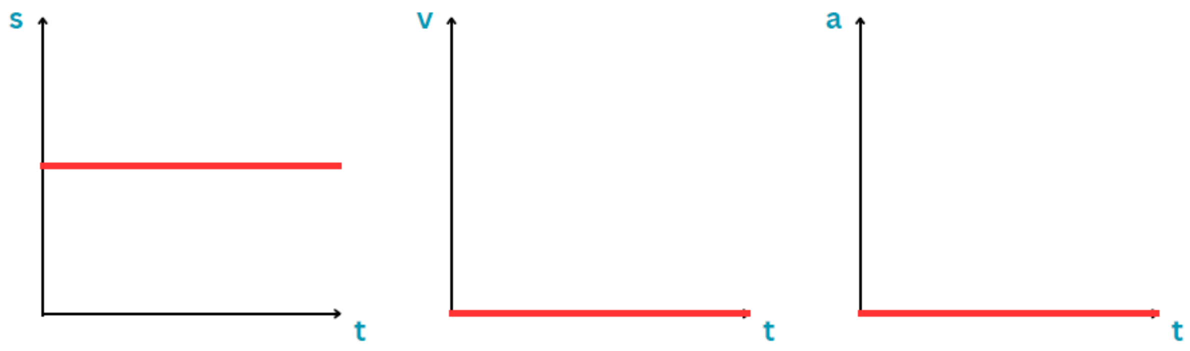
*Deceleration means negative acceleration; it means the car is slowing down. Decreasing acceleration means reducing your acceleration from high to low. You're still accelerating.

Decreasing acceleration ≠ Deceleration

2(e)/(f)/(g)/(h) Kinematics Graph

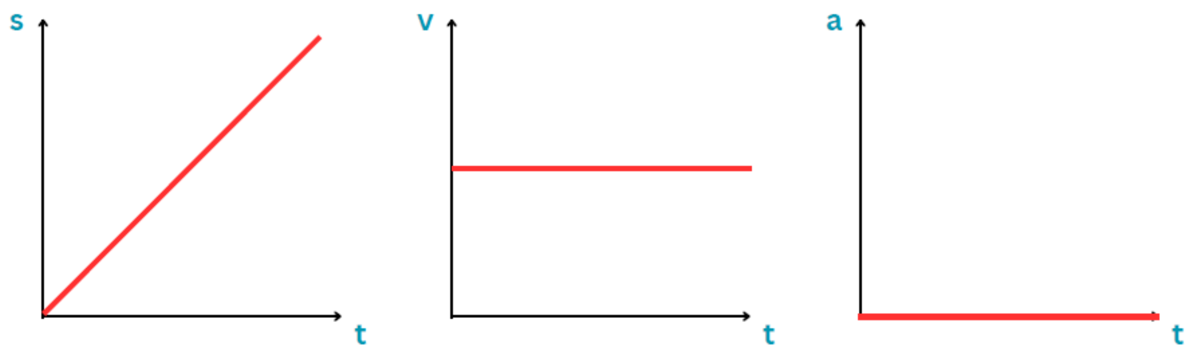
Graph Essentials	
Axes	• Displacement-time • Velocity-time • Acceleration-time
Gradient	• Constant • Zero • Increasing • Decreasing

At rest



No change in displacement | Velocity = 0 | Acceleration = 0

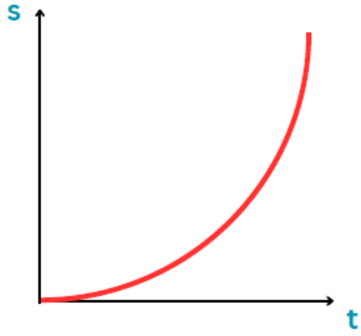
Moving with constant velocity



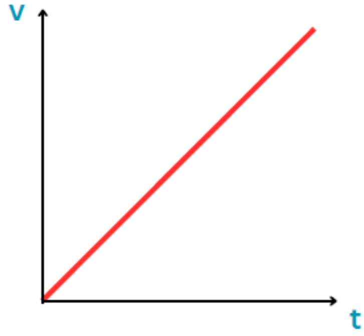
Constant increase in displacement | Velocity = constant | Acceleration = 0

Graph	Gradient	Area under Graph
Displacement-time	Velocity	
Velocity-time	Acceleration	Displacement
Acceleration-time		Velocity

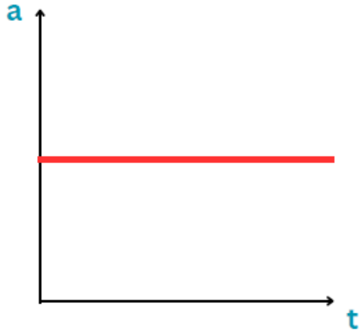
Moving with constant acceleration



Increasing increase in displacement

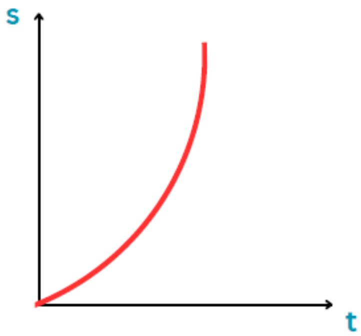


Constant increase in velocity

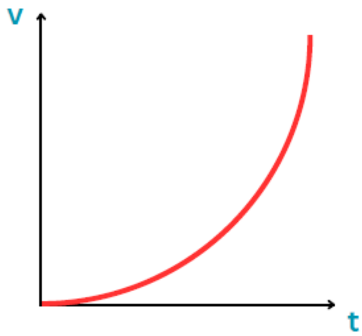


Acceleration = constant

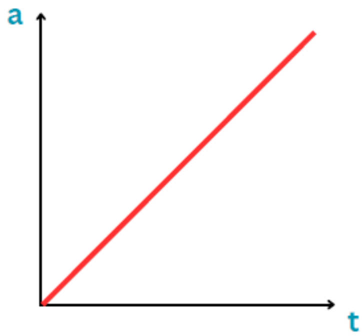
Moving with increasing acceleration



Increasing increase in displacement

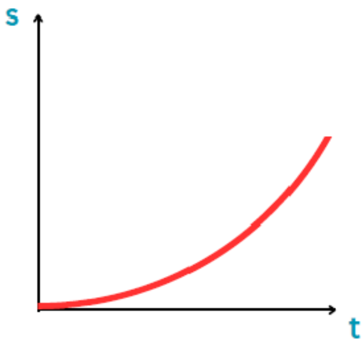


Increasing increase in velocity

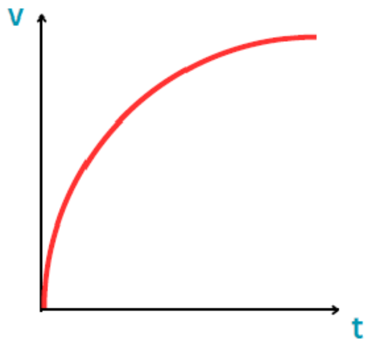


Constant increase in acceleration

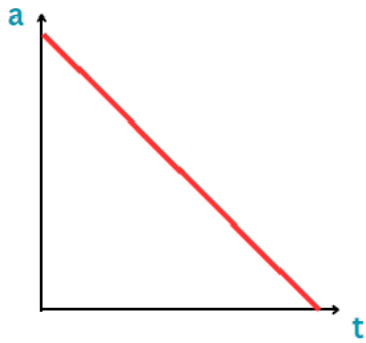
Moving with decreasing acceleration



Increasing increase in displacement



Decreasing increase in velocity



Constant decrease in acceleration

2(i) Free-fall

Acceleration of free fall for a body near to the Earth is constant and approximately 10 m/s^2.

A skydiver is NOT free-falling. Free-falling happens only in the absence of any air resistance i.e. in a vacuum. Free-fall means to fall freely without any external forces. Think of free-fall as a more theoretical concept rather than an actual phenomenon.

3. Dynamics

3(a) Contact vs. Non-contact Force

Contact Force	Non-contact force
Friction	Gravitational force
Air resistance	Electrostatic force
Tension	Magnetic force
Normal force	

3(b) Mass

Mass is a measure of the amount of matter in a body.

3(c) Gravitational field

Gravitational field is a region in which a mass experiences a force due to gravitational attraction.

3(d) Gravitational field strength

Gravitational field strength, g is the gravitational force per unit mass placed at that point.

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

3(e) Weight

To relate mass with weight and vice versa, use the formula:

$$W = mg$$

Example: If Jim is 50kg, his weight is 500N.

3(f) Mass vs. Weight

Mass	Weight
Amount of matter	gravitational force
Scalar quantity	Vector quantity
SI: kg	SI: N
Independent of the gravitational field strength	Dependent on gravitational field strength
Measured with a beam balance or a calibrated electronic balance	Measured with a spring balance

3(g) Application of Newton's Laws

Newton's Law	Application
1) Law of inertia 2) F=ma	(i) Describe the effect of balanced of unbalanced forces on a body (ii) Describe the ways in which a force may change the motion of a body
3) Action-Reaction Pair	(iii) Identify action-reaction pair on two interacting bodies

(g) (i)(ii)

Body experiencing	Effect
Balanced Force	Resultant force = 0 Body is at rest or moving at a constant speed in a straight line.
Unbalanced	Resultant force ≠ 0 Body experiences an acceleration in the direction of the resultant force. Body starts moving from rest or speeds up or slows down and/or changes direction Magnitude of acceleration depends on the force and mass of the body. $\sum F = ma$ $a = \frac{\sum F}{m}$

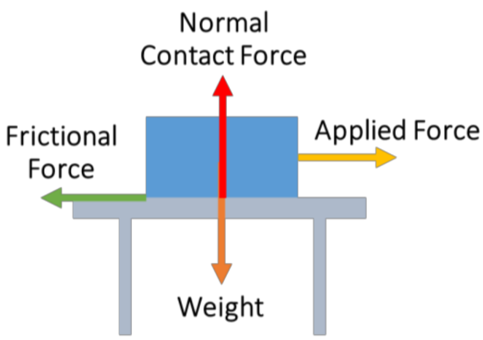
(g) (iii) Conditions for ARP:

- Equal in magnitude
- Opposite in direction
- Same type of force
- Acting on separate bodies

Example: A rocket is able to take-off because it releases a large amount of gas during the combustion process. It exerts a downwards force on the gas. The gas exerts an equal and opposite (upwards) force on the rocket, also known as thrust. This upwards thrust propels the rocket upwards. The upwards thrust and the downwards force are an action-reaction pair.

3(h) Free-body diagram

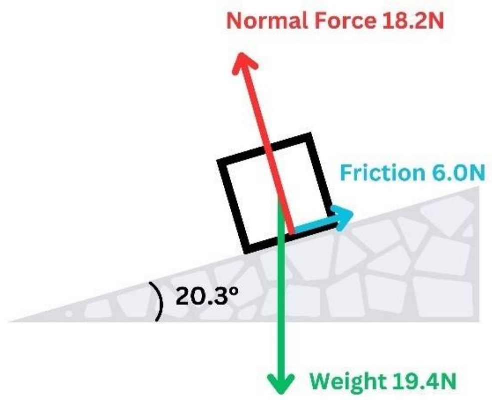
Point	"SALAD"	Details
1	**S**cale	The length of each arrow should be proportional to the magnitude of the force
2	**A**rrow	Draw arrows
3	**L**abel	Label all your forces
4	**A**ngle	Label your angles if any
5	**D**irection	Check directions of forces

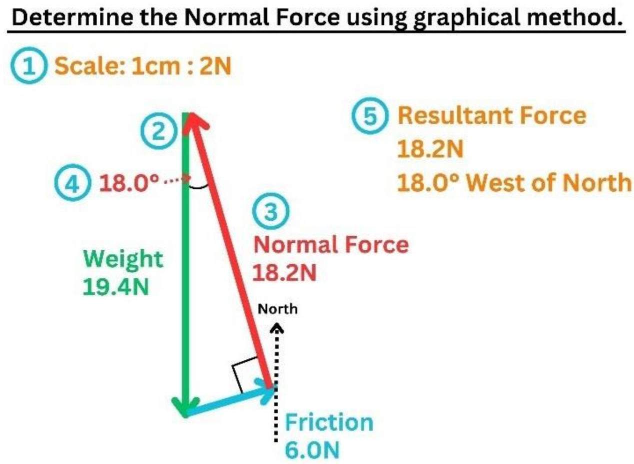


A box sliding across the table at constant velocity.

3(i) Vector diagram to find individual force

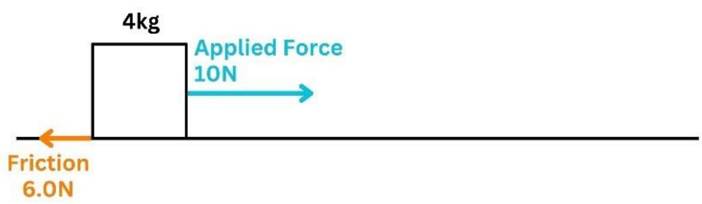
Point	"SALAD"	Details
1	**S**cale	Choose the most appropriate scale that occupy half of the allocated space (e.g. 1cm : 4N)
2	**A**rrow	Draw your arrow heads (single-arrow head for individual forces, double-arrow head for resultant force)
3	**L**abel	Label your arrows with the appropriate magnitude with units (e.g. 10N)
4	**A**ngle	Label your angles if given (e.g. 60°)
5	**D**irection	State the direction of your resultant force





Note: Draw with high precision, the margin of error could be as narrow as +/- 0.2N.

3(j) Application of $\sum F = ma$



To find force, $\sum \boldsymbol{F} = \boldsymbol{ma}$

To find mass, $\boldsymbol{m} = \frac{\sum \boldsymbol{F}}{\boldsymbol{a}}$

To find acceleration, $a = \frac{\sum \boldsymbol{F}}{m}$

There should be no problems doing this if you know how to manipulate equations.

Example: A constant 10N force is being applied on a 4.0kg block. Assume that friction is constant at 6.0N while the block is in motion. The resultant 4.0N force will cause block to accelerate at 1.0 m/s^2

3(k) Inertia

Any object with mass has inertia. The larger the mass, the greater the inertia. Inertia is an inherent property of an object that resist changes in its state of motion. It is the reluctance of an object to move from its stationary position, or to stop moving while it is in motion.

3(l) Effects of Friction

Positive	Negative
<u>Creates motion</u>: without friction, a vehicle cannot move as tyres will spin at the same spot	<u>Causes wear and tear</u>: friction leads to the deterioration of materials that are in contact
<u>Increase safety</u>: treads on car tyres increase friction between tyre and the road; reduces chance of skidding Friction between the brake pads and the spinning brake rotors slow down the wheels, allowing car to stop Air resistance (a type of friction in air) acting parachute allows skydiver to fall slowly and land safely. Chalk help rock climbers to absorb perspiration on their hands and improve their grip by increasing friction.	

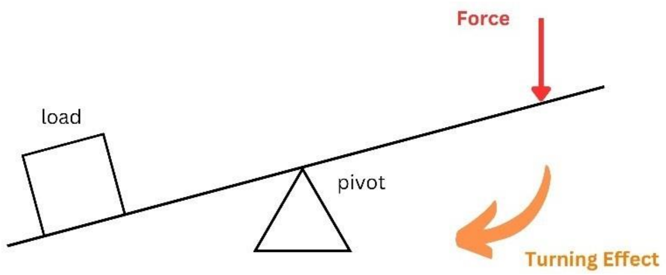
3(m) Falling bodies

Aspect	Without Air Resistance	With Air Resistance
Motion	Constant acceleration 10 m/s^2 towards the Earth's surface.	Decreasing acceleration from $10m/s^2$ to $0m/s^2$. Subsequently moves at constant velocity
Forces Acting	Weight	Weight and air resistance
Acceleration	Constant acceleration (g)	Decreasing acceleration, eventually reaching zero at terminal velocity
Velocity	Increases at a constant rate	Increases at a decreasing rate
Displacement	Increases at an increasing rate	Initially increases at an increasing rate, subsequently increases at a constant rate
Terminal Velocity	N.A.	Occurs when Weight = air resistance

4. Turning Effects of Forces

4(a) Moment of a force and everyday examples

When a force is applied, it creates a turning effect. The turning effect of a force is called its moment or torque. The load experiences a turning force. This is because the rigid bar is hinged at the pivot and can make a sweeping movement only.

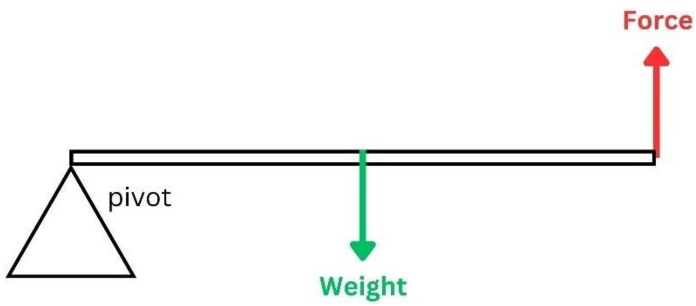


Example: A lever is a rigid bar resting on a pivot or fulcrum. It is used to move a load when a force is applied.

4(b) Application of moment of a force

$$M = Fd_{\perp}$$

Example: A 1.0m uniform plank with a mass of 10kg is placed with one end on a pivot as shown. Calculate the magnitude of the moment due to its weight.

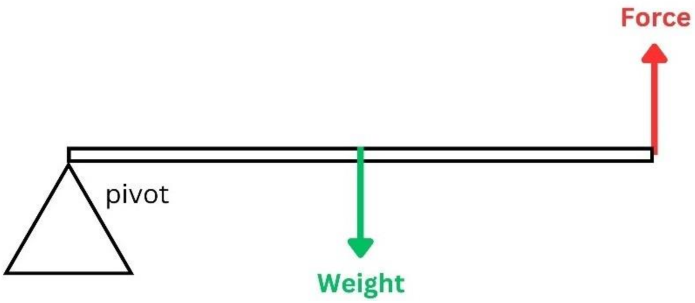


Moment, $M = (10)(10)(0.5) = 500Nm$

4(c) Principle of moments

Principle of moments states that that when a body is in equilibrium, the sum of clockwise moments about a pivot is equal to the sum of anticlockwise moments about the same pivot.

If the setup is in equilibrium the clockwise moment of Weight must be equal to the anti-clockwise moment of Force.



4(d) Application of Principle of moments

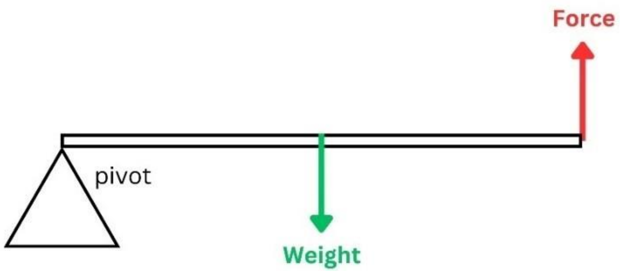
Example: A 1.0m uniform plank with a mass of 10kg is <u>held stationary</u> with one end on a pivot as shown. Calculate the magnitude of the Force.

Taking moment about pivot,

$CW = ACW$

$(10)(10)(0.5) = F\,(1.0)$

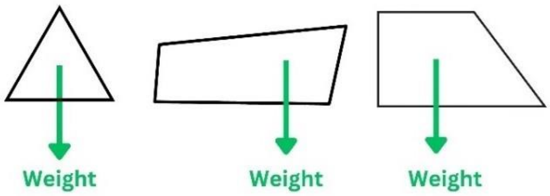
$\boldsymbol{F = 50N}$



4(e) Centre of gravity

Centre of gravity of an object is an imaginary point where the entire weight of the object seems to act.

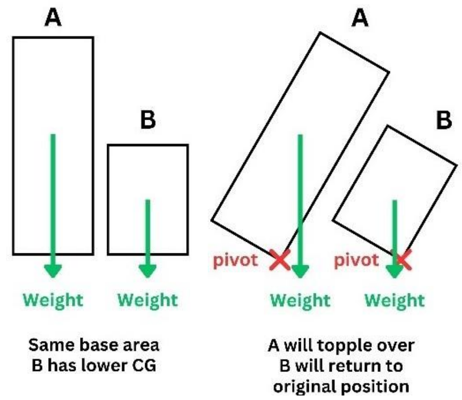
The centre of gravity will not be at the centre of the object unless it has a regular shape with uniform density.

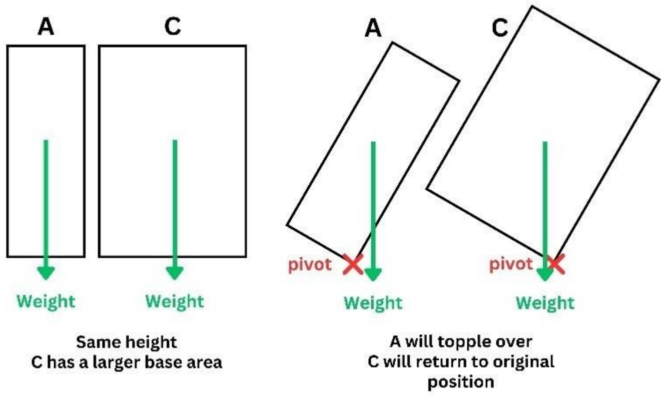


4(f) Stability

The stability of an object is measure of its ability to return to its original position.

To increase stability	How?
Lower centre of gravity	Add Weight at the Bottom: Place heavier components or add ballast at the base of the object. Reconfigure Design: Arrange the heaviest parts of the structure lower down. Use of Wide and Heavy Bases: Design with a broader and heavier base.
Increase base area	Extend the Base: Increase the dimensions of the base, either in all directions or in the direction most susceptible to tipping. Use of Stabilising Supports: Add legs, outriggers, or other forms of stabilisers that extend outward from the main structure.



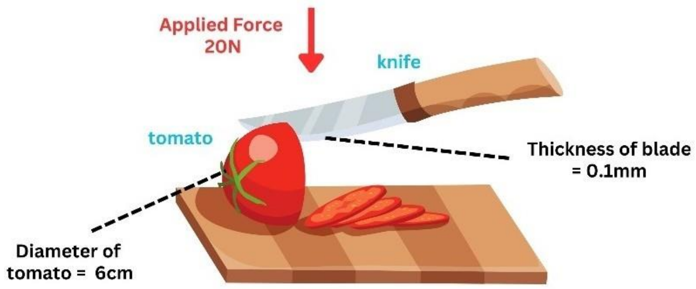


5. Pressure

5(a) Pressure

Pressure, P is the force acting per unit area.

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



5(b) Application of Pressure

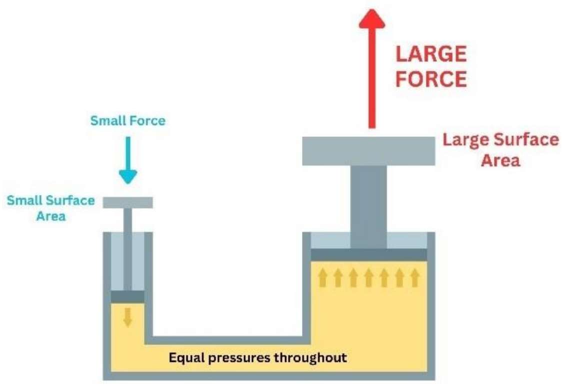
Example: Find the pressure exerted by the blade of the knife on the tomato

$$P = \frac{20N}{0.1 * 10^{-3}} = \mathbf{2.0 * 10^5\ Pa}$$

5(c) Pressure in hydraulic systems

Pascal's Law states that if a pressure is applied to an enclosed liquid, the pressure is transmitted to all other parts of the liquid undiminished.

A hydraulic press has a multiplier effect, it converts a relatively small force on a small piston into a relatively large force on a large piston



5(d) Density

Density, ρ is defined as mass per unit volume.

$$\rho = \frac{m}{V}$$

Example: If mass of a block is 1000kg, with volume 1m^3, its density is 1000kg/m^3.

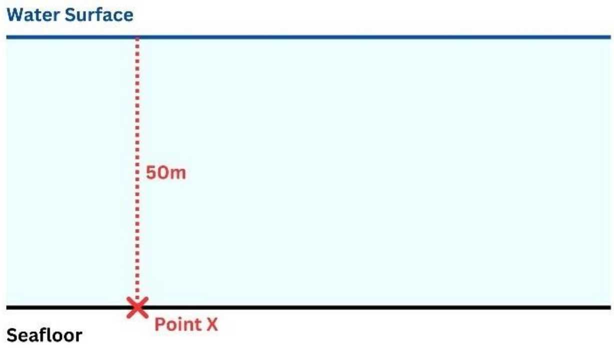
5(e) Pressure due to a liquid column

$P = h\rho g$

Example: Determine the pressure at Point X due to the ocean water.

Assume density of water = 1000kg/m^3

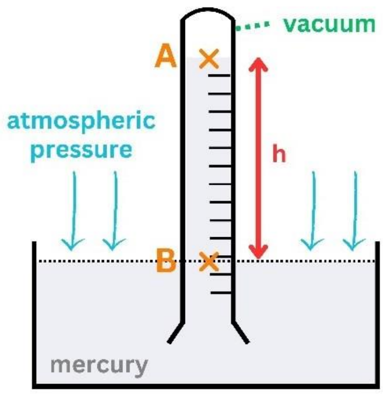
$P = (50)(1000)(10) = \mathbf{5.0 * 10^5\ Pa}$



5(f) Measuring atmospheric pressure (Barometer)

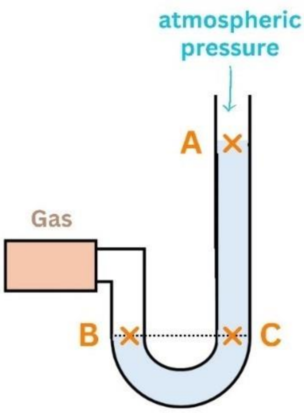
Since pressure is proportional to the height of a liquid, we can use the height of a liquid to measure pressure.

1	A 1m long thick-walled glass tube is filled with mercury. The tube is inverted into a trough containing mercury. Most mercury will remain in the tube. The space above point A is a vacuum. $P_A = 0$
2	The mercury in the tube is supported by atmospheric pressure exerted on the surface of the mercury in the trough. Thus, the pressure at B, which is level with the surface of the mercury in the trough, is the same as the atmospheric pressure. $P_B = P_{atm}$
3	$P = h\rho g$ where h is the height of the mercury, and ρ is the density of the mercury of 13 600kg/m^3



5(g) Measuring pressure difference (Manometer)

1	Liquid at A is exposed to the atmosphere. $P_A = P_{atm}$
2	Liquid at B is exposed to gas supply. $P_B = P_{gas}$ As P_B is higher than the atmospheric pressure, the liquid at A will rise until the pressure at C, $P_C = P_B$.
3	$P_B = P_C = P_A + P_{atm}$



6: Energy

6a) Energy stores

Energy stores		
Kinetic		Energy of moving objects
Potential	Gravitational	Energy due to position in a gravitational field
	Chemical	Energy stored in food, fossil fuels, or batteries
	Elastic	Energy stored when objects are stretched or compressed
Nuclear		Energy in atomic nuclei
Internal (Thermal)		Kinetic and potential energies of particles within an object

Pathways to transfer energy	Examples
Mechanically (by a force acting over a distance)	When a cart is pushed, the force accelerates it, transferring work to its kinetic energy. [Work done by force > Kinetic store of cart]
Electrically (by an electric current)	Connecting a battery to a bulb allows electric current to heat the filament, converting chemical energy into light and infrared waves. [Chemical potential store of battery > Light and infrared waves]
By heating (due to a temperature difference)	Placing butter on a heated pan transfers energy from the pan to the butter due to temperature differences. [Internal store of pan > Internal store of butter]
By propagation of waves (both electromagnetic and mechanical)	Sunlight warms a girl through electromagnetic waves, transferring energy from the sun to her. [Internal store of sun > Internal store of the girl] When cymbals (percussion instrument) are struck, they vibrate, creating sound waves that transfer energy to the boy's eardrums, causing them to vibrate. [Kinetic store of cymbals > Kinetic store of eardrums]

6(b) Kinetic energy and gravitational potential energy applications

$$E_k = \frac{1}{2}mv^2$$

$$E_p = mgh$$

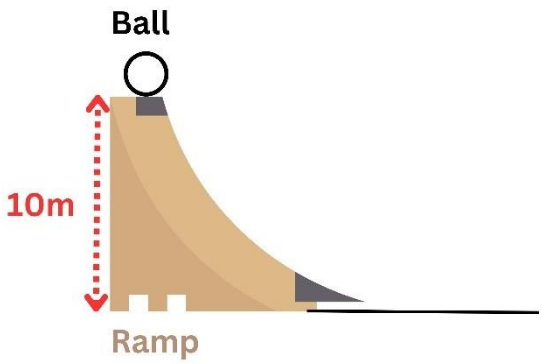
Example: a ball rolling down a 10m ramp will possess maximum gravitation potential energy at the top of the ramp, and maximum kinetic energy at the bottom of the ramp. Assuming gravitational field strength is 10N/kg,

$$mgh = \frac{1}{2}mv^2$$

$$gh = \frac{1}{2}v^2$$

$$(10)(10) = \frac{1}{2}v^2$$

$$\boldsymbol{v = 14.1\ m/s}$$



6(c) Principle of conservation of energy application

Principle of conservation of energy states that energy cannot be created or destroyed. Energy can only be transferred from one store to another. The total energy of an isolated system is constant.

6(d) Work done

Work done, W by a constant force on an object is the product of the force and the distance moved by the object in the direction of the force.

$$W = Fs$$

Example: Work done by a 1.0N force to move a mass by 5.0m is 5.0J.

6(e) Power

Power, P is defined as the work done or energy transferred per unit time. (SI: W)

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

Example: If Jim uses 1000J to climb a flight of stairs in 10seconds, the power output of Jim is 100W.

6(f) Efficiency

Efficiency is calculated when there is energy lost.

$$Efficiency, \eta = \frac{output\ power}{input\ power} \times 100\%$$

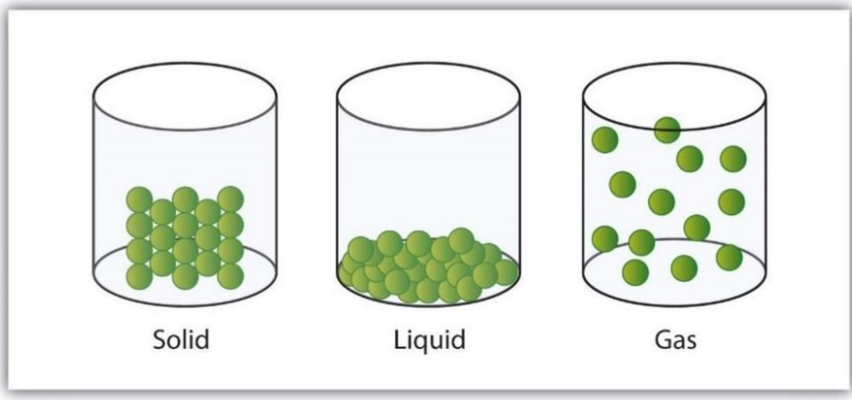
Example: If an electric motor converts 80% of the electrical energy into mechanical energy, with the remaining 20% lost as heat. We say it is 80% efficient.

6(g) Non-renewable and renewable sources of energy

Sources of Energy	Efficiency	Cost	Reliability	Environmental Impact
Fossil fuel	Moderate (32% - 45%)	Cheap	High	Pollution from burning contributes to global warming
Nuclear fuel	Moderate (33%)	High	High	Risk of accidents and pollution from improper disposal of radioactive waste
Biofuel	Low	Moderate	Moderate	Can be sustainable, but may compete with food production and cause deforestation
Wind	Low	Moderate	Low (intermittent power as it is not easy to find places where there is steady wind blowing at speeds of 20 – 25km/h)	Noise pollution and loss of habitat for wildlife as land is cleared to build wind turbines
Tides	High (up to 80%)	High cost of building tidal barrages	High	Clean, but can affect marine ecosystems
Hydropower	High (80-90%)	High cost of building dams, turbines and generators	High	Possible damage to the environment surrounding the river caused by damming of river for hydroelectric power station
Geothermal reservoirs	Low	High	High	Environmental pollution caused by the release of poisonous gases such as hydrogen sulfide into the atmosphere
Solar	Low	High	Low (no sunlight at night, weather dependent)	Requires significant land and resource use for materials production

7. Kinetic Particle Model of Matter

7(a)(b) Physical properties of solid, liquid, and gas



State of Matter	Arrangement	Motion	Energy
Solid	• Closely packed • Orderly	• Vibrate and rotate about fixed positions	• Least energetic particles
Liquid	• Slightly less closely packed • Disorderly	• Slide over each other throughout the liquid	• Moderately energetic particles
Gas	• Spaced very far apart • Disorderly	• Move freely and randomly at high speeds in all directions	• Most energetic particles

7(c) Brownian motion experiment

The Brownian motion experiment is <u>evidence for the random movement</u> of molecules in a liquid or gas, which supports the Kinetic Particle Theory.

Brownian Motion	
Evidence for	Kinetic Particle Theory / Kinetic Particle Model of Matter
Observation	Pollen grains in water exhibited erratic movement. Suspended particles in a fluid exhibit continuous, erratic, and random motion.
Conclusion	The suspended particles are bombarded by the fluid molecules. Each collision imparts a small force to the particle, causing it to move. Because these collisions occur randomly and from all directions, the motion of the suspended particle appears erratic.

7(d) Rise in temperature due to increase in average kinetic energy

Increase in average kinetic energy (not potential) of all particles in the body → Increase in temperature.

Example: If temperature of water increases from 20°C to 50°C, average kinetic and potential energies increase.
If water changes to steam (liquid → gas), no change in kinetic energy. Only potential energies increase, kinetic energies remain unchanged.

7(e) Pressure of a gas

Point	
1	Large number of gas particles are in constant random motion at high speeds.
2	When gas particles collide with the inner walls of the container, they exert a force on the wall.
3	The collective force exerted by all the gas particles per unit area is pressure.

8. Thermal Processes

8(a) Thermal equilibrium

Thermal equilibrium describes a state in which two or more objects have the same temperature and there is no net transfer of energy between them.

Energy is transferred (by heating) from a region of higher temperature to a region of lower temperature until thermal equilibrium is achieved between the two regions.

8(b) Conduction in solids

Conduction is a process of energy transfer where energy is transferred through the passing on of vibrational motion from one particle to another.

Non-metals

Point	
1	Energy is transferred to one end of the rod by heating. The particles nearest to the heat source will vibrate more vigorously about their fixed positions.
2	The more energetic particles collide with the neighbouring less energetic particles, causing them to vibrate more vigorously. Hence, energy is transferred to the other end of the rod.

Metals

Point	
1	Metals have free electrons that can gain energy from the heat source.
2	These small-sized particles with high speeds can move easily and quickly and collide with the particles at the cooler end of the rod, causing them to vibrate more vigorously and transferring energy at a higher rate.

8(c) Convection in fluids

Convection is a process of energy transfer by means of convection currents of a fluid (liquid or gas), due to a difference in density.

Point	
1	The liquid at the bottom of the pot expands due to heating via conduction through the bottom of the pot.
2	The warmer and less dense liquid rises to the top, displacing the cooler and denser liquid to the bottom.
3	This process repeats and causes convection currents. The circulating convection currents carry warmer liquid away from the heat source and cooler liquid towards it, allowing the entire pot of liquid to gain internal energy.

8(d) Radiation

Radiation is a process of energy transfer by electromagnetic waves. It does not require a medium.

Factors affecting rate of energy transfer	
Surface colour and texture	Dark-coloured, matt (dull and non-shiny), and rough surfaces, higher rate of emission and absorption, higher rate of energy transfer Light-coloured, shiny, smooth surfaces, lower rate of emission and absorption, lower rate of energy transfer
Surface temperature	Higher temperature, higher rate of energy transfer
Surface area	Larger surface area, higher rate of energy transfer

8(e) Application in everyday examples

Everyday examples	Heat transfer process
Hair dryer	Heating element heats up cool air via <u>conduction</u>.
Water heater	Heating element heats up cold water via <u>conduction</u>.
Thermal wear	Thermal wear contains porous materials that traps air. Trapped air in thermal wear acts as an insulating layer and reduces body heat to the surroundings via <u>conduction</u>.
Double/triple-glazed windows	Glass panes trap air that keeps building cool during summer and warm during winter by reducing heat transfer via <u>conduction</u>.
Electric kettle	Water near the bottom of the kettle gains heat from the heating element via <u>conduction</u>, expands, becomes less dense and rises to the top, displacing cooler and denser water to the bottom. This process sets up a convection current, allowing all the water be heated up quickly and evenly via <u>convection</u>.
Hot air balloons	In a hot air balloon, air at the bottom is heated up by the burner, expands, becomes less dense and rises to the top, displacing cooler and denser air to the bottom. This process sets up a convection current, allowing the air within the balloon to be heated via <u>convection</u>. The warmer air becomes less dense than the surrounding air, and the balloon rises.
Sea breeze	In the day, land heats up faster than the sea. Air above land heats up, becomes less dense and rises, creating a region a lower pressure. Cooler and denser air with higher pressure rushes to fill the space with lower pressure above the land. This sets up a convection current, creating a sea breeze.
Land breeze	At night, land cools faster than the sea. Air above sea heats up becomes less dense and rises, creating a region a lower pressure. Cooler and denser air with higher pressure rushes to fill the space with lower pressure above the sea. This sets up a convection current, creating a land breeze.
Greenhouse	Sun's radiation passes through the glass and heats up the greenhouse. The ground in the greenhouse becomes warm and re-radiates infrared radiation with longer wavelengths, with lower penetrating power. Infrared radiation is unable to pass through the glass roof, gets reflected and trapped in the greenhouse, keeping it warm.
Space Blanket	A space blanket has a shiny and smooth surface used for emergency situations, such as to keep a person, who had fallen into very cold water, warm as it is a poor emitter of infrared radiation. It can be used to wrap houses to protect them against large scale bushfires as it is a poor absorber of infrared radiation.
Global warming	Solar radiation that enters the atmosphere warms the Earth's surface. The surface re-radiates infrared radiation at longer wavelengths that are more easily absorbed by atmospheric greenhouse gases. The radiation absorbed by the greenhouse gases are re-radiated in all directions. Some radiation will escape into outer space while the remaining will go through more cycles of re-absorption and re-radiation before it escapes into space, fostering global warming.

9. Thermal Properties of Matter

9(a) Internal energy

Internal energy is an energy store that is made up of the total kinetic energy associated with the random motion of the particles and the total potential energy between the particles in the system.

9(b) Heat capacity and specific heat capacity

Heat capacity, C of an object is the change in its internal energy per unit change in its temperature.

$$Q = C\Delta\theta$$

Specific heat capacity, c of a material is the change of its internal energy per unit mass for each unit change in its temperature.

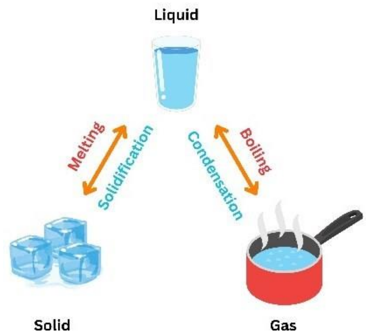
$$Q = mc\Delta\theta$$

9(c) Application of Q= mc△θ

Example: If 5.0kg of water (specific heat capacity = 4,200 J/kg °C) is heated from 20°C to 80°C, the total energy transferred = (5.0)(4200)(80-20) = **$1.26 * 10^6$ J**

9(d) Changes in State

Process	Change in State	Energy change
Melting	Solid → Liquid	Gain energy
Solidification	Liquid → Solid	Lose energy
Boiling	Liquid → Gas	Gain energy
Condensation	Gas → Liquid	Lose energy



9(e) Boiling vs. Evaporation

Boiling	Evaporation
Occurs only at boiling point	Occurs at any temperature
Vaporisation takes place throughout the liquid	Vaporisation takes place only at the surface
Requires heat source	Does not require heat source
Liquid temperature remains constant	Liquid temperature tends to drop
Rate of vaporisation is fast	Rate of vaporisation is slow

9(f) Latent heat and specific latent heat

Latent heat, L is the energy released or absorbed to change the state of a substance, at constant temperature.

Specific latent heat of fusion, l_f is the amount of energy transferred per unit mass of a substance to change between the solid and liquid states, at constant temperature.

$$L_f = l_f m$$

Specific latent heat of vaporisation, l_v is the amount of energy transferred per unit mass of a substance to change it between the liquid and gaseous states, at constant temperature.

$$L_v = l_v m$$

9(g) Application of $L_f = l_f m$

Example: If specific latent heat of vaporisation of vaporisation of water is 2,260 kJ/kg, 5.0kg of water would require (2,260 * 10^3)(5.0) = 1.13 * 10^7 J of energy to undergo a change in state to gas (steam).

9(h) Latent heat in terms of particles

When a substance is melting, energy is transferred to the substance through the work done against the attractive intermolecular forces between the particles. This increases the potential energy of the particles, but the kinetic energy of the particles remains unchanged. Hence, there is no change in temperature during melting.

9(i) Cooling curve

Point	
1	During cooling, energy is transferred out of the substance and particles move slower, causing their kinetic energy to decrease.
2	The temperature of the substance decreases.
3	Potential energy of the particles decreases as the average separation of the particles decrease.

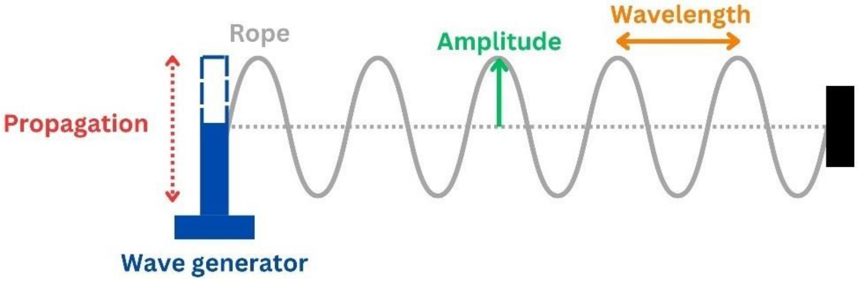
Point	
1	During condensation and solidification, energy is transferred out of the substance. The average separation of the particles decreases, and potential energy decreases.
2	The kinetic energy and temperature remain constant.

10. General Properties of Waves

10(a) Wave motion Illustration

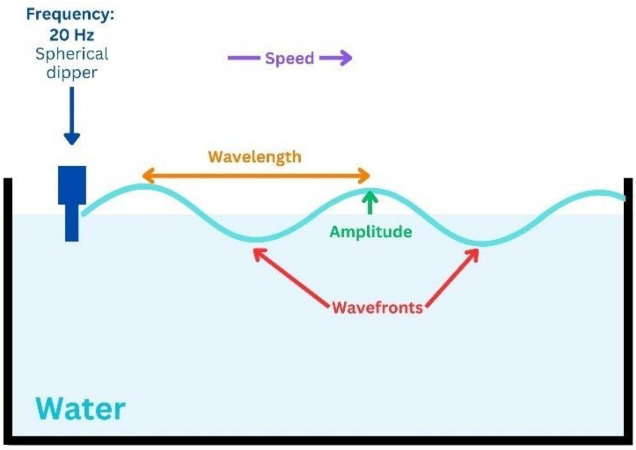
Wave is a disturbance that propagates through space, transferring energy with it but not matter.

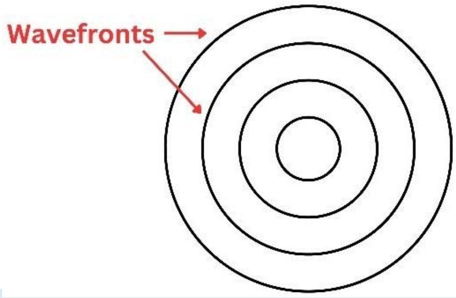
Vibrations in rope and springs



Waves in a ripple tank

Wavefront is an imaginary line joining all adjacent points on a wave that are in phase.





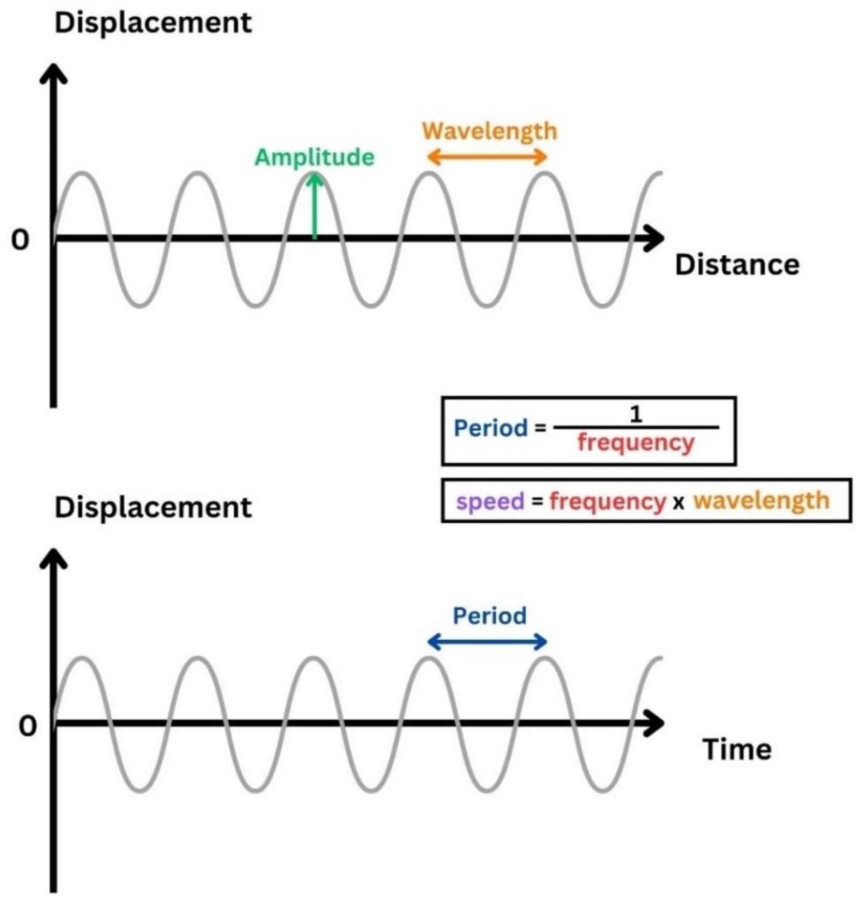
Property of wave	Description	Magnitude
Frequency	Number of wavefronts generated per second	Depends on source frequency
Wavelength	Distance between 2 consecutive wavefronts	Increase in water depth, increase in wavelength
Speed	The rate at which wavefronts move outward from the source	Increase in water depth, increase in wave speed
Amplitude	Height of the wave above or below the rest position of water surface	Depends on source amplitude

10(b) Transfer of energy

Waves transfer energy without transferring matter

10(c) Defining properties of waves

Property of wave	Definition	How to obtain?
Speed	Wave speed, v is the distance travelled by a wave per second.	$v = f\lambda$
Frequency	Frequency, f is the number of oscillations each point completes per second.	$f = \frac{1}{T}$
Wavelength	Wavelength, λ is the shortest distance between two successive crests or troughs.	Find the distance between each successive wave on the displacement-distance graph
Period	Period, T is the time taken by each point on the wave to complete one oscillation.	Find the time between each successive wave on the displacement-time graph
Amplitude	Amplitude, A of a wave is its maximum magnitude of displacement from its rest position.	Find the maximum displacement on displacement-distance graph



10(d) Application of $v = f\lambda$

Example: If the frequency of wave is 5.0Hz with a 10m wavelength, its speed = (5.0)(10) = 50m/s

10(e) Transverse vs. Longitudinal Waves

	Transverse	Longitudinal
Direction of Oscillation	Direction of vibration is perpendicular to direction of wave travel	Direction of vibration is parallel to direction of wave travel
Medium Movement	Particles move up and down	Particles move side to side
Wave Components	Crests and troughs	Compressions and rarefactions
Examples	Light waves, water waves, waves on a rope	Sound waves, waves on a slinky

10(f) Sound waves

Sound is a longitudinal wave travelling in the air, creating by a vibrating source.

A medium is always required for the transmission of sound.

10(g) Longitudinal nature of sound waves

A vibrating loudspeaker has a surface that is driven by a fluctuating electric current. Its forward and backward vibration is passed on to the air particles, which causes alternate regions of the air particles to be compressed and extended. The compressed regions are called compressions, and the extended regions are called rarefactions.

10(h) Characteristics of Sound

Chacteristics of Sound	Property	Relationship
Loudness	Amplitude	High Amplitude, Loud Sound
Pitch	Frequency	High Frequency, High Pitch

10(i) Reflection of Sound

Echolocation. With the speed of sound, a computer-controlled sound emitter and sound sensor, the distance from the emitter to the reflecting surface can be easily calculated.

10(j) Uses of Ultrasound

Ultrasounds are sounds with frequencies that exceed human audible range ≥20kHz

SONAR (Sound Navigation And Ranging)	
1	Commercial fishing boats often use sonar which emits an ultrasound pulse into the water and listens for reflected pulse.
2	Reflected pulses come from the shoal of fish and the sea floor
3	The strength of the reflected pulses will differ according to the distance and characteristic of the reflecting objects. This allows fishermen to catch fish more easily.

Medical Uses	
Medical Scanning of Soft tissues	In medical scanning, ultrasound uses high-frequency sound waves emitted by a transducer to create images of soft tissues. The sound waves reflect off different tissues and are captured by the transducer, which sends the data to a computer to form real-time images. This non-invasive technique helps diagnose and monitor various conditions without using radiation.
Prenatal Scanning	Ultrasound is used in prenatal scanning, where pulses are sent into the womb of a pregnant womb via a transmitter. The strength, direction and timing of each reflected pulse are measured, allowing for the reflecting surface within the womb to be mapped. This forms an image of the unborn baby.
Breaking up kidney stones and cancer treatment	When an ultrasound beam is focused onto a kidney stone, it's high intensity vibrations can break the stone up into smaller pieces so that they can be naturally expelled in the urine. High intensity focused ultrasound can be used to kill cancer or tumour cells. It is a safe and non-invasive method.

Example: An ultrasound transducer emits sound waves that travel through the water and reflect off the seabed. If the echoes return to the transducer in 2 seconds and the speed of sound in water is 1500 m/s, the depth of the sea is 1500m.

*Note: you have to consider that the ultrasound wave travels to and from the seabed. Distance travelled = 2 * depth of sea

11. Electromagnetic Spectrum

11(a) Properties of EM Wave

All electromagnetic waves are transverse waves that travel with the same speed in vacuum.

11(b)(c) Main regions of electromagnetic spectrum

Region	Wavelength Range	Frequency Range	Typical Uses
Radio Waves	> 1 m	< 3×10^{8} Hz	radio and television communication, astronomy and RFID tags
Microwaves	1 m to 1 mm	3×10^{8} Hz to 3×10^{11} Hz	mobile (cell) phones, microwave oven and satellite television
Infrared (IR)	1 mm to 700 nm	3×10^{11} Hz to 4.3×10^{14} Hz	infrared remote controllers, intruder alarms and thermal imaging
Visible Light	700 nm to 400 nm	4.3×10^{14} Hz to 7.5×10^{14} Hz	photography, optical fibres in medicine and telecommunications
Ultraviolet (UV)	400 nm to 10 nm	7.5×10^{14} Hz to3×10^{16} Hz	sunbeds, bank note authentication and disinfecting water
X-Rays	10 nm to 0.01 nm	3×10^{16} Hz to 3×10^{19} Hz	medical radiology, security screening and industrial defect detection
Gamma Rays	< 0.01 nm	> 3×10^{19} Hz	sterilising food, detection of cancer and its treatment

*Note: It is recommended to only remember the wavelengths, and derive the frequency based on a wave speed of 3.0×10^8 m/s

11(d) Over-exposure to electromagnetic waves

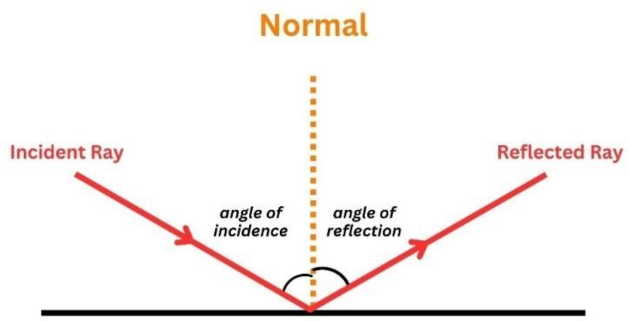
Ionising Radiation	
1	Ionising radiation can be high frequency electromagnetic waves or high energy particles
2	When a high frequency electromagnetic wave interacts with an atom or molecule of our living cells, it knocks an electron out from it, producing a charged ion
3	The charged ion may hinder certain chemical reactions which affects a particular cell process. This could lead top cell death, mutations leading to diseases and organ failure.
4	Higher frequency electromagnetic wave can penetrate deep into the body more easily to create ions, making them more harmful than high energy particles that do not penetrate as deep.

Heating	
1	The exposure to strong ionising electromagnetic radiation such as ultraviolet light causes heating effects
2	Over-exposure to UV light can cause skin cancer and premature ageing.

12. Light

12(a) First Law of Reflection

First Law of Reflection states that the incident ray, reflected ray, and the normal at the point of incidence lie in the same plane.

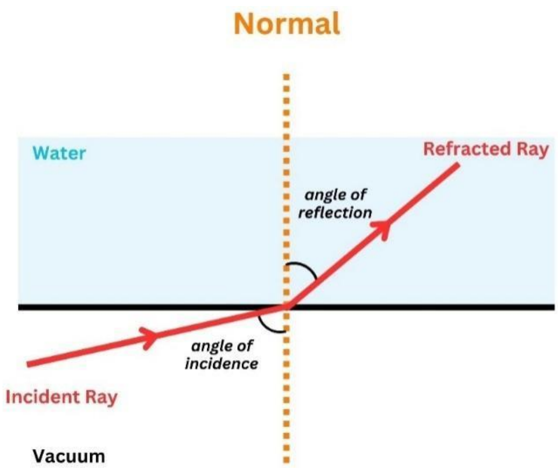


Laws of reflection	
Normal	Perpendicular line (90°) to the surface at the point of incidence is called normal.
Angle of incidence	Angle between incident ray and normal
Angle of reflection	Angle between reflected ray and normal

12(b) Second Law of Reflection

The angle of incidence θ_i. is equal to the angle of reflection θ_r.

Example: If an incident ray strikes a mirror at 30° to the normal (i.e. angle of incidence = 30°), the reflected ray will exit the mirror at 30° to the normal (i.e. angle of reflection = 30°).



12(c) Refraction of Light

First Law of Refraction states that the incident ray, refracted ray, and the normal at the point of incidence all lie in the same plane.

Second Law of Refraction states that for two given media, the ratio of the sine of angle of incidence to the sine of the angle of refraction is a constant, that is $\frac{\sin i}{\sin r} = constant$.

Laws of refraction	
Normal	Perpendicular line (90°) to the surface at the point of incidence is called normal.
Angle of incidence	Angle between incident ray and normal
Angle of refraction	Angle between refracted ray and normal

12(d) Application of $\frac{\sin i}{\sin r} = constant$

Example: If the angle of incident is 60° travelling from vacuum to water (n=1.33),

the angle of refraction = $sin^{-1}\left(\frac{\sin 60°}{1.33}\right) = 40.6°$

12(e) Refractive index

Refractive index, n of a medium is defined as the ratio of the speed of light in a vacuum to the speed of light in that medium.

$$n = \frac{c}{v}$$

12(f) Critical angle and total internal reflection

Critical angle c is defined as the angle of incidence in an optically denser medium for which the angle of refraction in the less dense medium is 90°.

Total internal reflection is the complete reflection of a light ray in an optically denser medium at the boundary with an optically less dense medium.

Conditions for Total Internal Reflection
Incident ray must travel from an optically denser medium to an optically less dense medium
Angle of incidence > Critical angle

12(g) Uses of total internal reflection

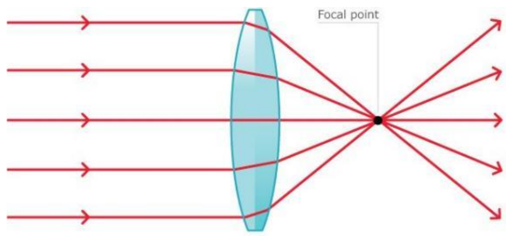
Optical fibres made from glass or plastic can carry information in the form of coded light pulses. The fibres rely on total internal reflection to transmit signals. These fibres are thin and flexible.

Optical fibres use in	How it works?	Advantages
Telecommunication	For transmission of large amount of data, optical fibres can be bundled to form thicker cables. Larger and longer undersea cables that span thousands of kilometres are used as communication links across continents.	Higher data transfer rate: ten to thousands of times faster than copper wires, radio waves or microwaves. Less signal loss: compared to copper cables Lighter and cheaper: as compared to copper cables of similar length
Medicine	An endoscope can be used to inspect the insides of hollow organs such as the digestive tract.	Thin and light: endoscopes and laparoscopes are kept small for minimally invasive examination and surgery. Flexible: endoscopes and laparoscopes can curve around obstacles when taking images inside the body.

12(h) Describe the action of a thin converging lens on a beam of light

A device made of glass or other transparent material that can concentrate light rays is called a converging lens.

Action of a thin converging lens
As the light rays are incident the lens, they slow down and bend towards the normal. Parallel rays of light strike the lens at various angles relative to the principal axis.
Rays that are further from the principal axis will refract at greater angles. Rays that are closer to the principal axis will bend less and will refract at smaller angles.
Due to the different angles of refraction, all the rays converge at the focal point on the opposite side of the lens. This creates the focusing effect of converging lenses

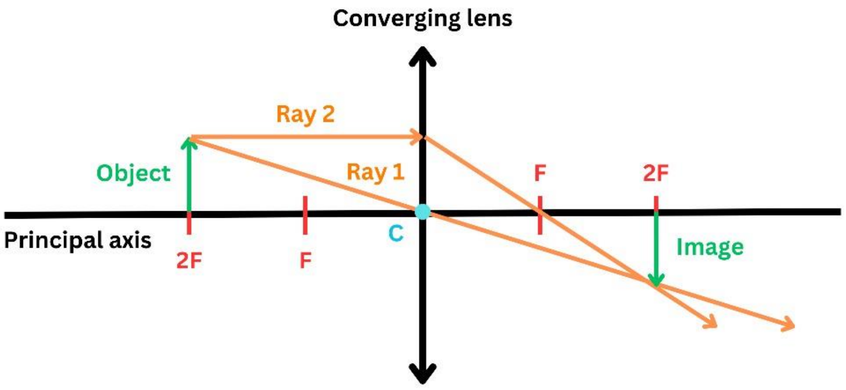


Terms to describe thin converging lens	
Principal axis	The line which passes through the centre of the lens which is perpendicular to the plane of the lens
Optical Centre, C	The point on the principal axis that is the midpoint between the surfaces of the lens.
Focal point F	The point on the principal axis where all the rays parallel to the principal axis meeting after passing through the lens.
Focal plane	The plane perpendicular to the principal axis on which all parallel rays meet after passing through the lens (plane of all possible focal points).
Focal length, f	The distance between the optical centre and the focal point.

12(i) Focal length definition

The distance between the optical centre and the focal point, the point where all rays parallel to the principal axis meet after passing through the lens.

12(j) Ray diagrams



Step	
1	Ray 1: Draw light ray from object's arrowhead passing through the optical centre C
2	Ray 2: Draw light ray from object's arrowhead parallel to principal axis, and cutting through focal point F
3	Label all your arrows
4	Label all your object and image
5	Label focal point, lens, question number (if necessary)

12(k) Characteristics of images

Characteristics of Image	
1	Real / Virtual
2	Magnified / Diminished / Same Size
3	Upright / Inverted

13. Static Electricity

13(a) Static Charges

There are positive and negative charges, and that charge is measured in coulombs C.

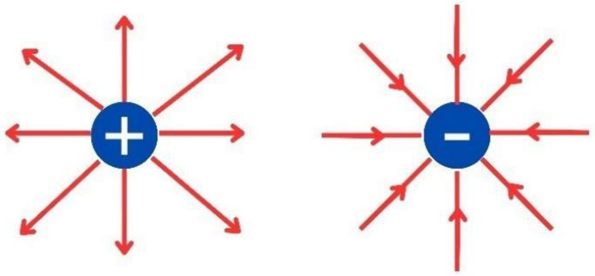
13(b) Attraction and Repulsion

Unlike charges attract, like charges repel

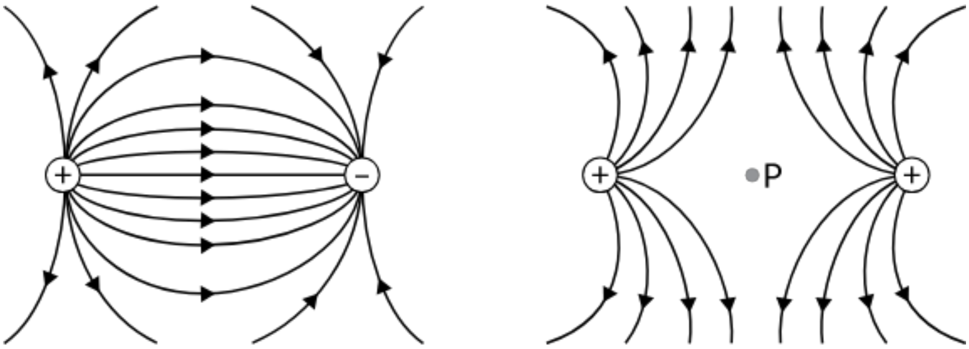
13(c) Electric field

An electric field is a region in which an electric charge experiences a force

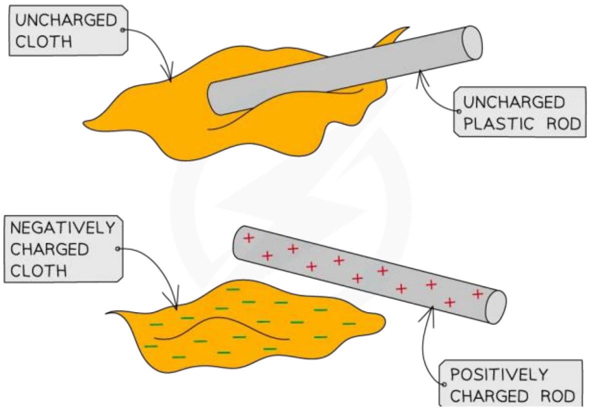
13(d) Electric field of an isolated point charge



13(e) Electric field pattern between two isolated point charges

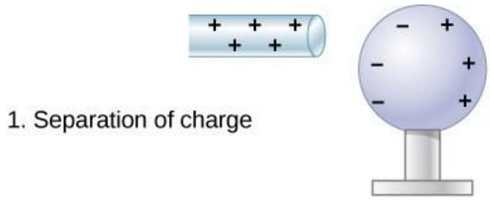
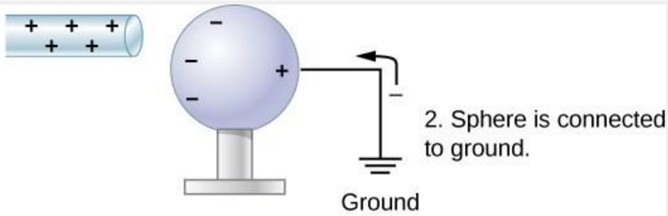
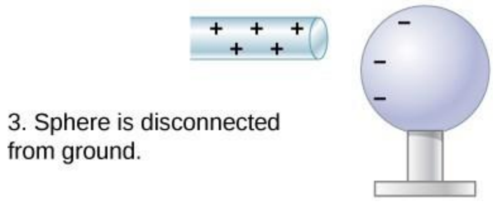


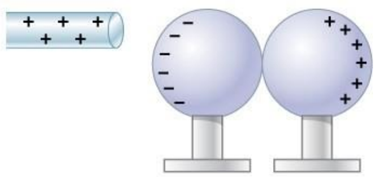
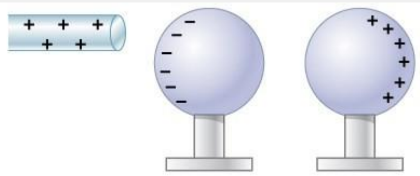
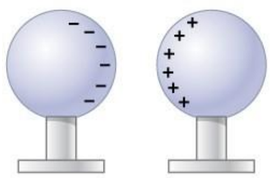
13(f) Electrostatic Charging by Rubbing



Point	Electrostatic Charging by Rubbing
1	When two different materials, such as a cloth and a rod, are rubbed together, they interact at a molecular level. Each material has a different tendency to gain or lose electrons.
2	As the cloth is rubbed against the rod, electrons are transferred from one material to the other. In this case, the cloth has a greater affinity for electrons than the rod. This means that when they are rubbed together, electrons move from the rod to the cloth.
3	As a result of this electron transfer: The cloth becomes negatively charged because it has gained extra electrons. The rod becomes positively charged because it has lost some of its electrons.
4	Once the rubbing stops, the charges remain separated. The negatively charged cloth and the positively charged rod can now exert electrostatic forces on other objects.

13(g) Electrostatic Charging by Induction

Step	Charging 1 Conductor	Diagram
1	Place a charged rod close to the conducting sphere. Since unlike charges attract and like charges repel, the electrons accumulate on the side nearer to the rod while positive charge accumulate on the other side.	
2	Connecting one end of a metal wire to earth and use the other end to touch the sphere on the right allows the electrons to be repelled further away into the person's body.	
3	Remove wire from the sphere	
4	Remove the charged rod	

Step	Charging 2 Conductors	Diagram
1	Place a charged rod close to one of the conducting spheres that are in contact. Since unlike charges attract and like charges repel, positive charges in the rod attract free electrons to the left, leaving the right side positively charged.	
2	Keeping the rod in position, separate the two spheres to isolate the two groups of opposite charges.	
3	Remove the charged rod. The 2 spheres now have equal but opposite charge.	

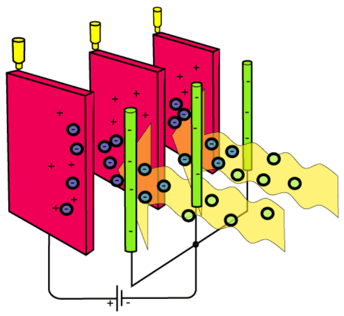
13(h) Hazards of Electrostatic Charging

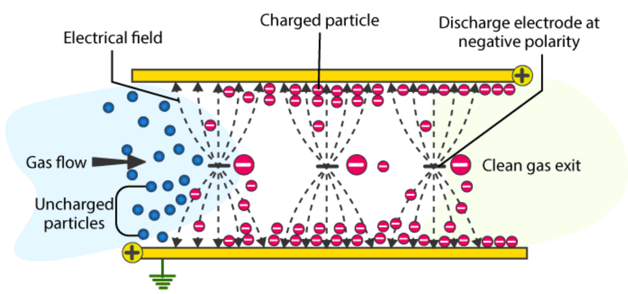
Hazards	
1	When dry bulk flows through a hose or pipe, friction against the inner walls can lead to electrostatic charging of the hose and substance, which can cause sparking. If substance is combustible, the spark can start a fire or cause an explosion. **Mitigation:** Due to danger of electrostatic charging and discharge in the presence of combustible substances, earthing is used to neutralise any excess charges and prevent the accumulation of charges.
2	When humidity is low, a moving vehicle can acquire static charges due to friction between vehicle body and the air. If passengers touch the vehicle's metal body, they may experience a non-fatal but painful shock (i.e. electric discharge). The small discharge is dangerous for trucks carrying volatile and flammable substances. **Mitigation:** The danger is reduced by using modern tyres containing carbon and embedded metal mesh which help to dissipate charges to the ground.
3	An airplane can acquire static charges due to friction with air, ice crystals and other particles in the air. This build-up of static charges on the plane will only stay on the outer metallic surface as charges repel each other and the furthest they can get away from each other is on the outermost surface. Even when the airplane was struck by lightning, the people within the airplane is not harmed. **Mitigation:** The charges on the plane will be discharged to the air via the discharge rods.

13(i) Electrostatic Charging in electrostatic precipitator and application to new situations

Applications

Electrostatic Precipitator

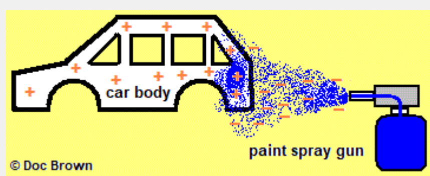




Unwanted particles in a gas (like smoke, dust, chemical droplets) pass through a charged ionising area, where they gain a negative charge.
The charged particles then move toward positively charged collection plates.
As unlike charges attract, the negatively charged unwanted particles are attracted to the plates, removing them from the gas.
A hammer knocks the plate regularly so that the accumulated particles are dropped into a bin and removed from the plates.

Spray painting

The paint droplets are negatively charged as they exit the spray nozzle.
The surface to be painted is positively charged.
Since unlike charges attract, the negatively charged paint droplets will be attracted to the positively charged surface surface.
The charged droplets evenly distribute on the surface, reducing overspray and ensuring a more efficient application.



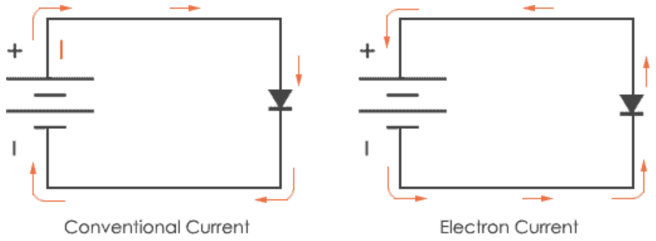
14. Current of Electricity

14(a) Current

Current is the rate of flow of charge. It is measured in Amperes (A).

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

14(b) Conventional current vs. electron flow



The direction of the flow of positive charge (positive to negative)

The direction of the flow of negative charge (negative to positive)

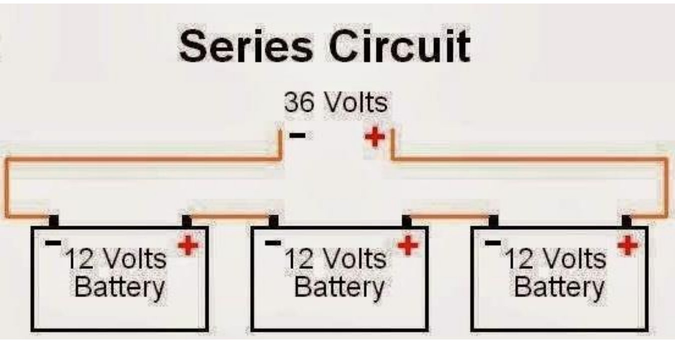
14(c) Application of charge = current x time

Example: A wire carrying current of 10A for 10s will deliver 100C charge.

14(d) Electromotive force (e.m.f.)

E.m.f of a source is the work done per unit charge by the source in driving charges around a complete circuit. It is measured in volts (V).

14(e) Calculate e.m.f. in series



Method: Add up the e.m.f.'s in series

Example: If there are 3 x 12.0V cells lined up in series, the total e.m.f. of the battery is 3(12.0) = 36.0V

14(f) Potential difference (p.d.)

Potential difference across a component in a circuit is the work done per unit charge in driving charges through the component. It is measured in volts (V).

14(g) Resistance = p.d. / current

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

14(h) Application of R = V / I

Example: If there is 5.0A of current flowing through a component with 10.0V across the same component, resistance = 10.0/5.0 = 2.0 Ω

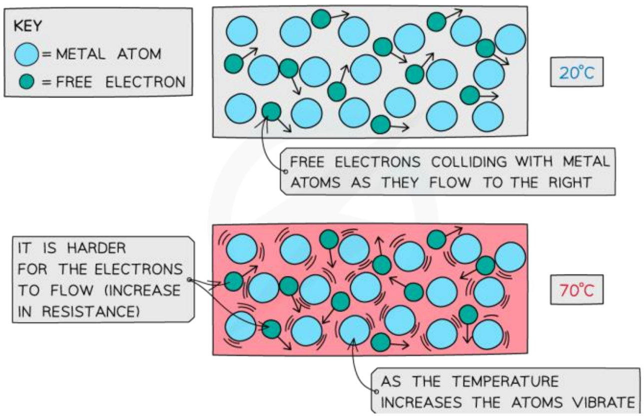
14(i) Application of R = ρℓ/A

Example: A 1m long wire with a $5mm^2$ area has a resistance of 5.0 Ω.If

the wire is 2m, its resistance will be 10.0 Ω.

If the wire has a $10mm^2$ area, its resistance will be 2.5 Ω.

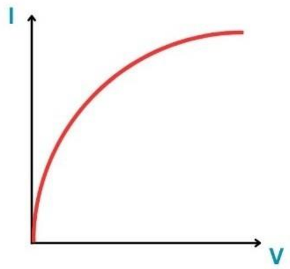
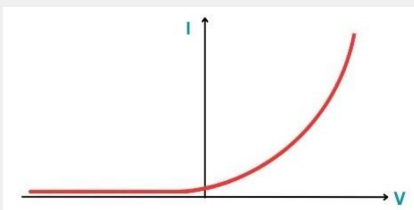
14(j) Temperature effects



When temperature increases, electrical resistance of a metallic conductor increases.

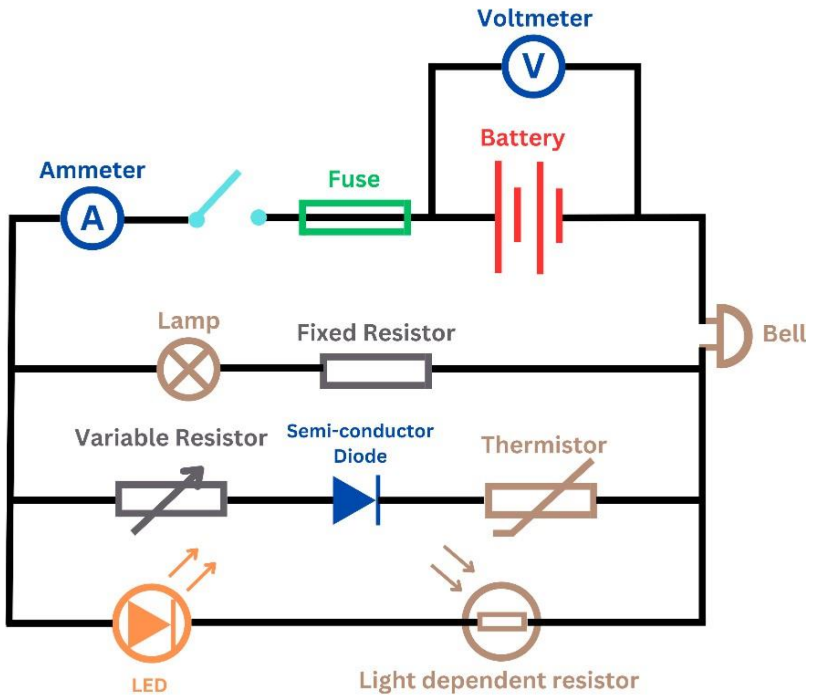
At higher temperatures, metallic ions vibrate more vigorously about their fixed positions, increasing the number of collisions between the free electrons and the metallic ions and slows down the flow of electrons.

14(k) I-V graphs of filament lamp and semiconductor diode

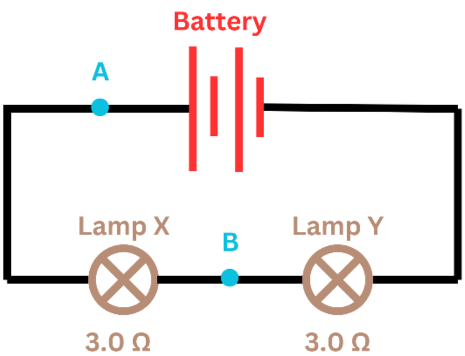
Non-ohmic conductor	I-V graph	Change in resistance
Filament lamp		As electric current increases, more energy is transferred from chemical potential store of the battery to the internet store of the filament. This increases the resistance of the filament, resulting in a decrease in gradient.
Semiconductor diode		When a positive voltage is applied, a large current flows. Resistance in the forward direction is very low. When a negative voltage is applied, the current is almost zero. Resistance in the backward direction is almost infinite.

15. D.C. Circuits

15(a) Circuit Diagrams



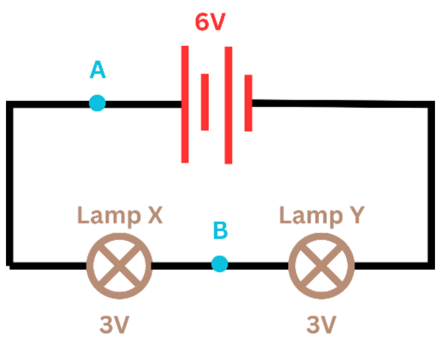
15(b) Current in a Series Circuit



Current at every in a series circuit is the same.

Example: If the current at A is 2.0A, the current at B must be 2.0A. To find the potential difference across X, we apply V = IR = (2.0)(3.0) = 6.0 Ω

15(c) Potential Difference in a Series Circuit



Sum of potential differences in a series circuit is equal to the potential difference across the whole circuit.

Example: When 2 lamps connected in series have a potential difference of 3.0V each, the total potential difference 6.0V.

15(d) Current in Parallel Circuit

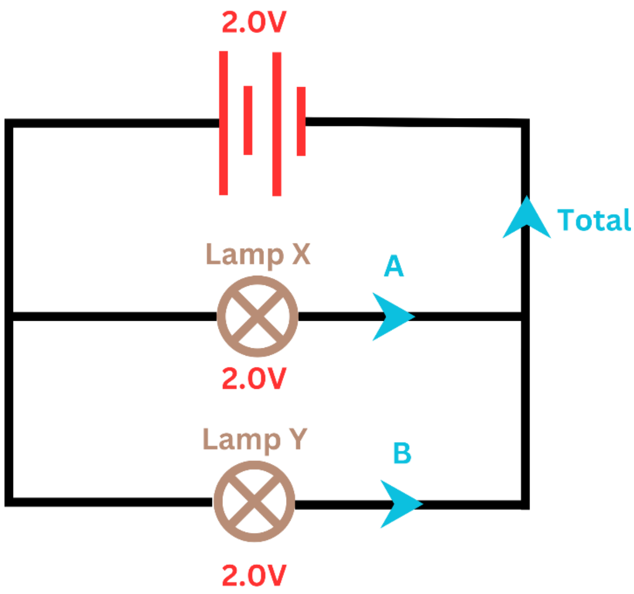
Sum of currents in the separate branches of a parallel circuit is equal to the current from the source.

Example:

Current A = 2.0A

Current B = 2.0A

Total current = 4.0A



15(e) Potential difference in Parallel Circuit

Potential difference across separate branches of a parallel circuit is the same.

Example:

If potential difference across lamp X is 2.0V, then potential difference across lamp Y is 2.0V.

15(f) Effective resistance

Series: Add the resistance

$$R_T = R_1 + R_2$$

Parallel: Take reciprocal of the sum of reciprocals

$$\mathbf{R_T} = \left(\frac{\mathbf{1}}{\mathbf{R_1}} + \frac{\mathbf{1}}{\mathbf{R_2}}\right)^{-\mathbf{1}}$$

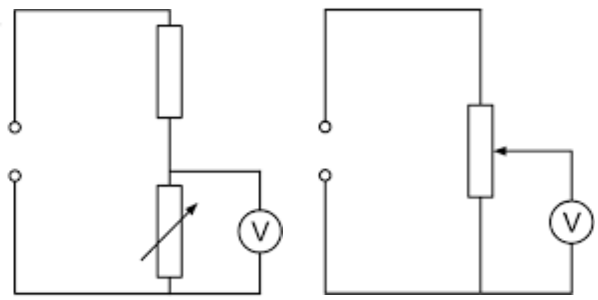
15(g) Solving Circuit diagrams

Apply R = V/I and other equations

15(h) Variable potential divider (potentiometer)

A potential divider is a voltage divider, which makes use of the voltage drop across resistors in series to divide voltage.

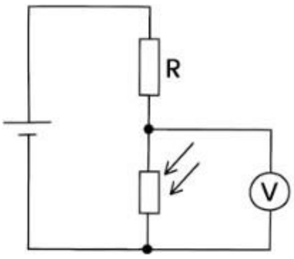
$$V_1 = \frac{R_1}{R_1 + R_2} * \varepsilon$$



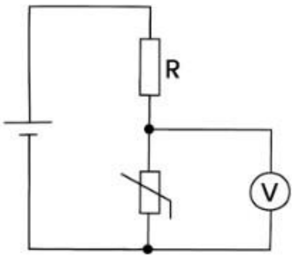
15(i) Negative temperature coefficient (NTC) thermistors and light-dependent resistors and their use as input transducers

Input transducer is an electronic device that convert changes in physical conditions, such as pressure, temperature, or light, into electrical signals so that these physical conditions can be measured.

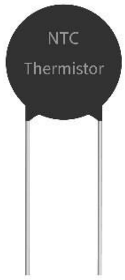
Example: Thermistors, light-dependent resistors (LDRs), photovoltaic cells, and piezoelectric sensors.

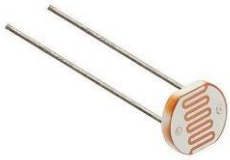


LDR POTENTIAL DIVIDER CIRCUIT



THERMISTOR POTENTIAL DIVIDER CIRCUIT





Physical Quantity	Input Transducer	Function
Temperature	Thermistor	When temperature increase, resistance decrease
Light	LDR	When light intensity increase, resistance decrease
Light	Photovoltaic cell	Converts light energy into electrical energy
Pressure	Piezoelectric sensors	Converts mechanical stress (pressure, vibration, or movement) into electrical energy, and vice versa.

15(j) Circuit problems involving NTC thermistors and light-dependent resistors

(same method as 15(h))

16. Practical Electricity

16(a) Electric kettles, ovens and heaters

Point	
1	Heating elements are made from long and thin wires of nichrome or iron-chromium-aluminium alloy.
2	When current passes through these alloys, their temperature increases rapidly. They have high electrical resistance and oppose the flow of charge.
3	Free electrons bump into ions, which are obstruction to its flow. This causes the fixed-position ions to vibrate more vigorously, which in increases the temperature of these alloys.

16(b) Application of P=IV and E=IVt

Example: A 60W lamp is connected to a 240V power supply. Current I = P/V = 60/240 = 0.25A
If the lamp is operating for 10s, Energy output = (60)(10) = 600W

16(c) Cost of electrical appliance in kWh

A 1kW lamp is operating for 5hours. The total energy = (1kW)(5h) = 5kWh. If 1kWh costs $0.30, total cost = ($0.30)(5kWh) = $1.50

16(d) Hazards of using electricity

Hazards	Causes	Impact
Damaged insulation	Stresses such as high electric field (due to high voltage supply) and temperature	Exposes live conducting wires which can cause electric shocks when touched
Overheating of cables	1) Electrical cable passes current that exceeds its limits 2) Overloading 3) Poor contact	Fire Explosions
Damp conditions	Charged ions and impurities in water makes it a good conductor of electricity	Dry skin: 100,000Ω. Wet skin: 1,000Ω, Wet skin provides a path of low resistance, potentially causing electric shocks or electrocution.

16(e) (f) Safety Features

Safety feature	How it prevents electrical hazard?
Fuses	Used in socket plugs to prevent excessive current
Circuit breaker	Used in distribution box to prevent excessive current
Earthed metal casing	To prevent live wire from causing metal casing to be a high electrical potential
Double insulation	To prevent contact with live wire
Earth wire	To earth the metal casing of appliance

16(g) Live, Neutral, Earth

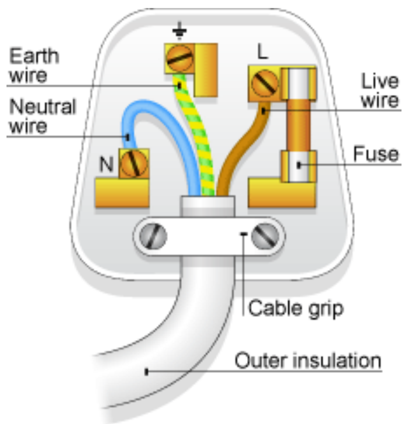
The live wire carries the electrical current from the power source to the electrical devices.

The neutral wire carries the current back to the power source to complete the electrical circuit.

The earth wire provides a safe path for electricity to flow back to the ground in case of a fault.

16(h) Wiring in a mains plug

Wire	Colour	Voltage
Live	Brown	High
Neutral	Blue	Zero
Earth	Yellow & green	Zero



Remember this.

Blue (BL): Bottom-left – Water – pH 7 – Neutral – Neutral wire

Brown (BR): Bottom-right – Coffee – feels alive – Live wire

Green and Yellow – Earth's grass is green and sky is yellow – so the one that runs from bottom to the top is Earth wire

16(i) Switches, fuses, and circuit breakers on live wire

Switches, fuses, and circuit breakers must be connected to the live wire to allow these devices to cut off the supply from the mains when excessive current passes through.

17. Magnetism

17(a) Properties of magnets

- Like poles repel, unlike poles attract
- Rest in North-South direction
- Have two poles
- Attract magnetic materials

17(b) Induced magnetism

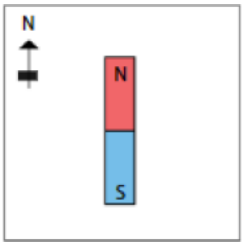
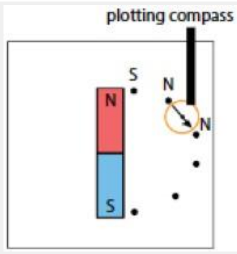
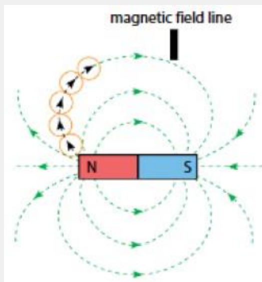
Induced magnetism (induction) can take place when a magnetic material is placed close to a strong magnet or within a current-carrying solenoid.

A current-carrying solenoid produces a magnetic field similar to a bar magnet.
By placing a magnetic material inside the current-carrying solenoid, the magnetic material becomes a magnet.

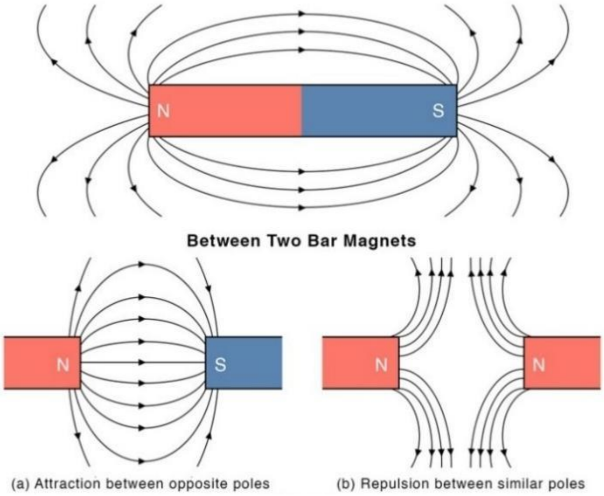
17(c) Temporary vs. Permanent magnets

Magnetic Material	Temporary (soft)	Permanent (hard)
Example	Soft iron	Steel (an alloy of iron)
Properties	Easily magnetised and demagnetised	Difficult to magnetise and demagnetise
Common Uses	Electromagnets in junkyards	Magnetic recording media in hard disk drives

17(d) Bar magnet (compass) to determine magnetic field

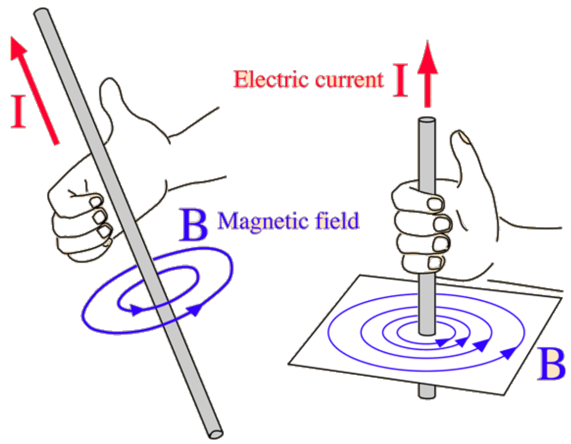
Step	Magnetic field lines drawing	Diagram
1	Place bar magnet in the centre of a piece of paper with north pole pointing to north	
2	Place a compass near on pole of the magnet	
3	Mark the north and south ends of the compass needle with an N and S respectively.	
4	Re-position the compass such that the south needle is pointing to the N marking of the previous position	
5	Repeat steps 3 and 4 until several traces have been drawn	

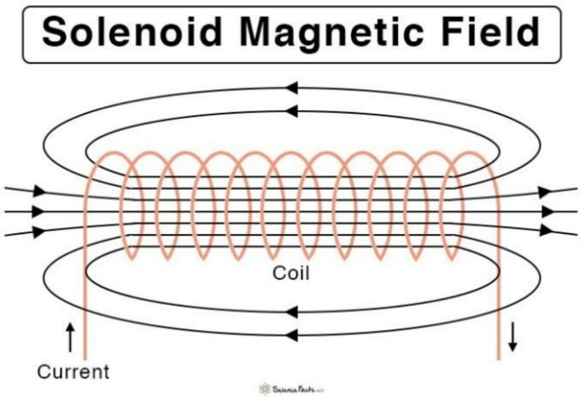
17(e) Magnetic field patterns around bar magnets



18. Electromagnetism

18(a) Magnetic field patterns in wire and solenoids





When current increases, magnetic field strength increases, magnetic field lines become closer to each other (lines are more concentrated). (The reverse is true).

When direction of current is reversed, magnetic field lines point in the opposite direction. Magnitude no change.

18(b) Application of magnetic effect of current in electromagnet (e.g. circuit breaker)

(a) Fig. 10.1 shows a simple circuit breaker.

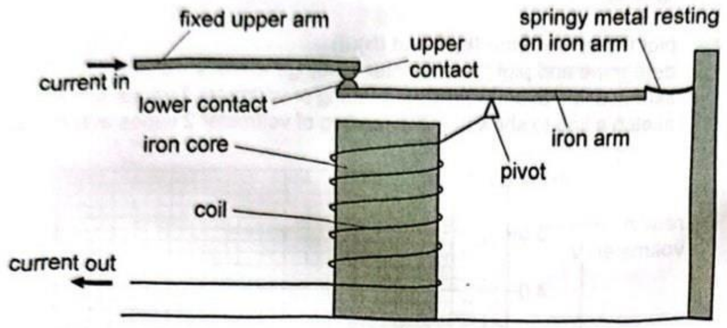


Fig. 10.1

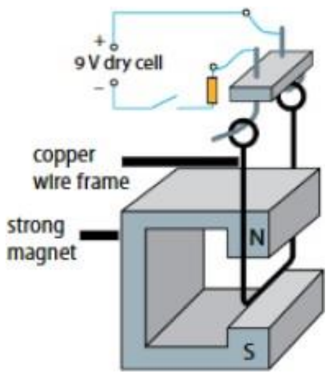
The circuit breaker breaks the circuit when the current is larger than 30A.

(i) Explain how the circuit breaker breaks the circuit.

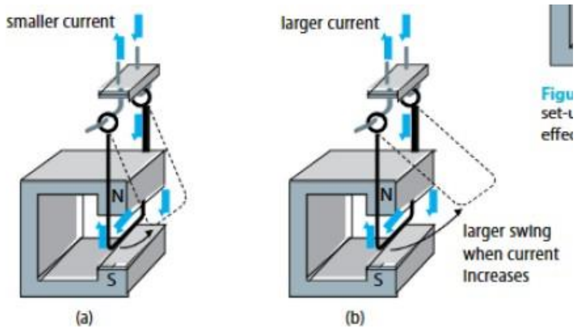
	Point
1	When a sufficiently large current (>30A) passes through the coil, the iron core is induced with a sufficiently large magnetic field that generates sufficient attractive force on the left end of the iron arm.
2	The magnetic force exerts a large anti-clockwise moment about the pivot on the iron that is greater than the clockwise moment exerted by the springy metal, causing it to rotate anti-clockwise, breaking the circuit.

18(c) Experiments to show force on a current-carrying conductor and on beam of charged particles in a magnetic field, in a magnetic field

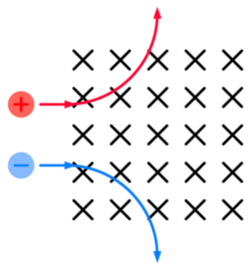
	Force on current-carrying conductor
1	Place the U-shaped magnet on a horizontal surface with the magnetic field directed from north to south.
2	Connect the straight conductor to the power source and place it in the magnetic field such that it is perpendicular to the field lines.
3	Close the switch to allow current to flow through the conductor.
4	Observe the conductor; it should experience a force and move.

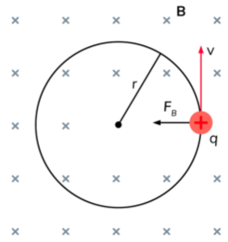


- Increase current, larger swing
- Increase magnetic field strength, larger swing
- Reversing current, swing in opposite direction
- Reversing magnet polarity, swing in opposite direction



Force on beam of charged particles	
1	Create a beam of charged particles (for instance, using an electron gun).
2	Place the magnetic field source perpendicular to the path of the particle beam.
3	Activate the particle source and allow the beam to pass through the magnetic field.
4	Observe the deflection of the particle beam.





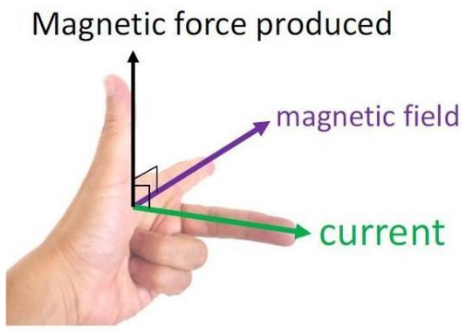
- Increase charge, increase force
- Increase magnetic field strength, increase force
- Opposite charge, force in opposite direction
- Opposite direction of magnetic field or velocity of charged particle, force in opposite direction

18(d) Fleming's Left Hand Rule

Current - middle finger

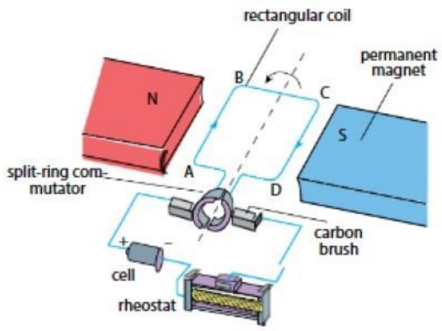
Magnetic field - index finger

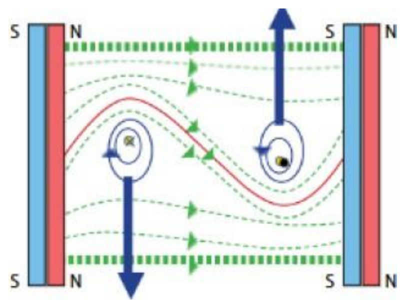
Induced force - thumb



Fleming's Left Hand Rule

18(e) Current-carrying coil in a magnetic field





Why is there a force?	
1	When an electric current flows through the coil, it generates its own magnetic field. When the coil is placed in an external magnetic field, the two magnetic fields interact.
2	The current-carrying coil experiences an equal force on parts AB and CD of the wire. This force is created by the motor ("catapult") effect on each side of the coil.
3	The forces produce a turning effect that is equal in magnitude on both wires and cause the coil to turn anticlockwise.

Turning effect is increased by increasing

(i) number of turns of the coil

(ii) current

18(f) Split-ring commutator and soft-iron cylinder

Split-ring commutator: To allow the direction of the current in the coil to reverse every half a revolution to ensure continuous rotation.

Soft iron cylinder increases the concentration of magnetic field lines, increase strength of magnetic field and increase magnetic force, improves torque.

19. Electromagnetic Induction

19(a) Faraday's experiments

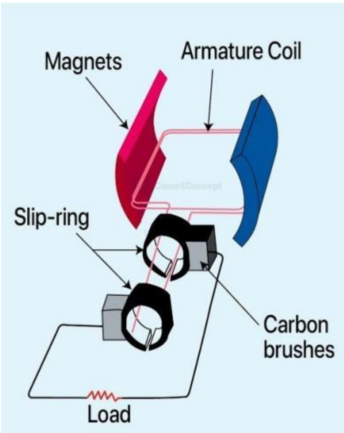
Deductions from Faraday's experiments	
1	A changing magnetic field can induce an e.m.f. in a circuit
2	Direction of the induced e.m.f. opposes the change producing it
3	Factors affecting the magnitude of the induced e.m.f

Factors affecting the magnitude of the induced e.m.f	
1	Magnetic field strength
2	Rate of change of magnetic flux
3	Number of turns in the Coil
4	Area of Coil

19(b) A.C. generator

Slip rings ensure that ends of the rotating coil do not get tangled.

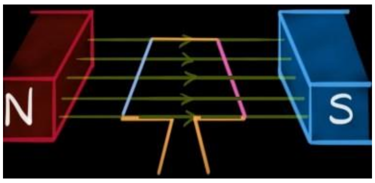
Provide the electric contact with the brushes so that electric current can flow continuously in the a.c. generator.



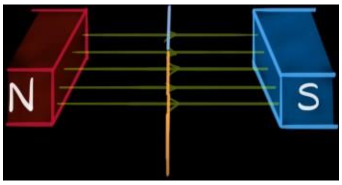
Simple a.c. generator	
1	In a generator, the coil is rotated by turning the handle. The rotating coil experiences a change in magnetic flux. By Faraday's Law of Electromagnetic Induction, this generates an e.m.f.
2	Carbon brush and slip rings provide connection to an external circuit.
3	The induced e.m.f. will cause a current to flow in the external circuit.

19(c) Voltage-time graph

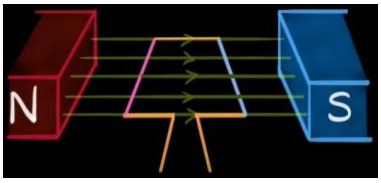
Position 1



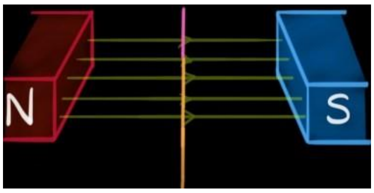
Position 2



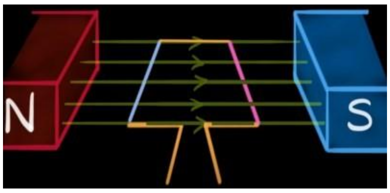
Position 3

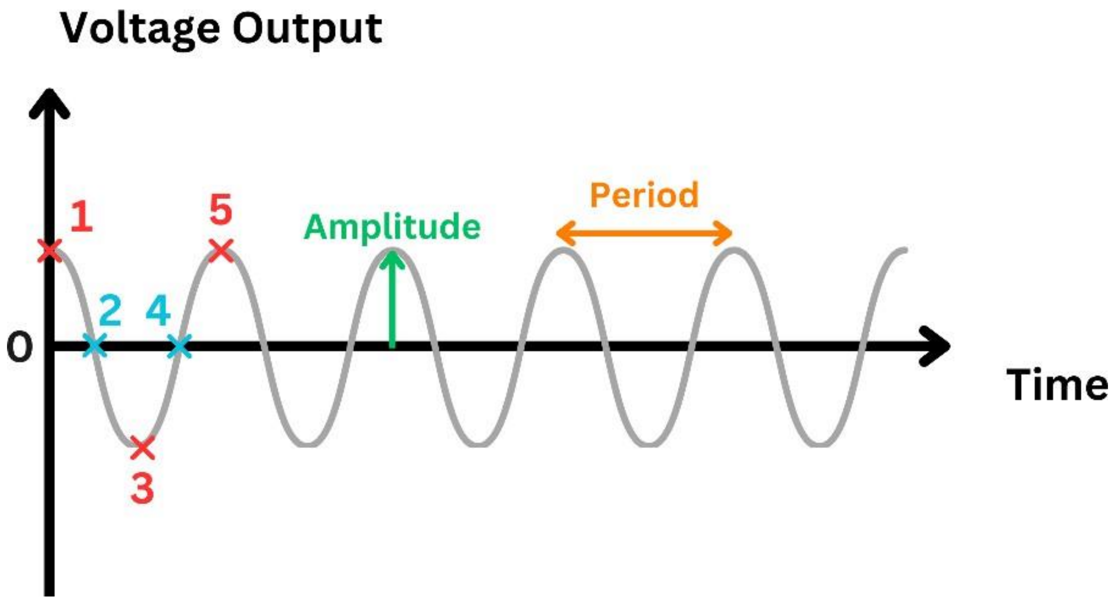


Position 4



Position 5

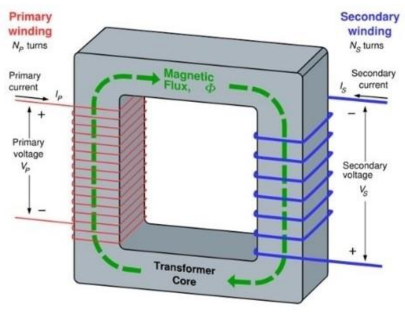




	Factors affecting the magnitude of the induced e.m.f
1	At position 1, the rate at which AD and BC cut the magnetic field lines is the greatest since the movement of the coil is perpendicular to the magnetic field lines. Hence, the magnitude of the induced e.m.f. is also the greatest.
2	At position 2, AD and BC do not cut the magnetic field lines since the movement of the coil would be parallel to the direction of field lines. Hence the magnitude of the induced e.m.f. is zero.
3	At position 3, the rate at which AD and BC cut the magnetic field lines is the greatest. However, since the induced current in the coil is flowing in the reverse direction, the induced e.m.f. is also in the opposite direction to that at position 1. The e.m.f. is negative to indicate the change in direction
4	At position 4, AD and BC once again do not cut the magnetic field lines. Hence, the magnitude of the induced e.m.f. is zero.
5	At position 5, the coil returns to its starting point after having completed one revolution. The rate at which AD and BC cut the field lines is once again the greatest and the magnitude of the induced e.m.f. is the greatest.

19(d)Transformer

Structure of Transformer	
Laminated soft iron core	Increase concentration of magnetic field lines, increase magnetic flux linkage. Gets easily magnetised and demagnetised so that secondary coil experiences large change in magnetic flux.
Primary coil	Connected to input a/c voltage
Secondary coil	Connected to load



Principle of operation	
1	When an alternating current (AC) flows through the primary coil, it creates an alternating magnetic field.
2	This magnetic field induces a changing magnetic field in the iron core that is channelled to the secondary coil.
3	According to Faraday's law of electromagnetic induction, the changing magnetic flux induces an electromotive force (EMF) in the secondary coil.
4	The induced voltage in the secondary coil is proportional to the number of turns in the coil.

19(e) Application of V_P / V_S = N_P / N_S and $V_P I_P = V_S I_S$

For example,

No. of turns in primary coil = 10
No. of turns in secondary coil = 100

Primary voltage = 70V

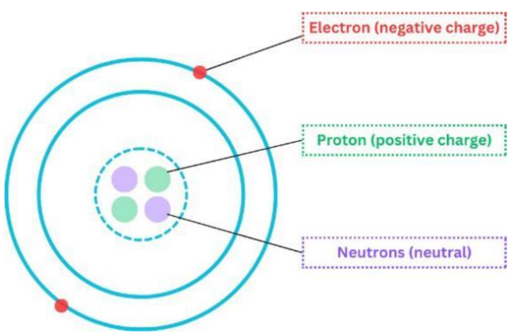
Is this a step-up or step-down transformer? Step-up. What is the secondary voltage? 700V

19(f) Energy loss in cables ($P=I^2R$)

Energy loss in cables exist due to the internal resistance of cables. Long cables carry high resistance. To reduce power loss, we use a step-up transformer to increase voltage. This reduces current and reduces power loss. $P = I^2R$.

20. Radioactivity

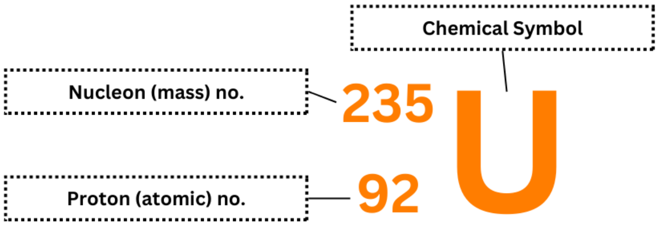
20(a) Composition of an Atom



20(b) Proton number Z, Nucleon number A, and isotope

Terms	
Proton number Z	No. of protons
Nucleon number A	No. of neutrons + no. of protons
Isotope	2 nuclei with same no. of protons, but different no. of neutrons

20(c) Nuclide notation



20(d) Nuclear decay

Nuclear decay is a random process by which an unstable atomic nucleus loses its energy by emission of electromagnetic radiation and/or particle(s).

Characteristics of process	Interpretation
Spontaneous	Not influenced by external factors
Random	Unpredictable

20(e) Types of emission

Nuclear emission	Nature	Relative Ionising Effect	Relative Penetrating Ability
alpha(α)-particle	Helium nucleus	Highest	Least (paper)
beta(β)-particle	electron	Medium	Medium (Few mm of thick aluminium)
gamma (γ) ray	Electromagnetic radiation	Lowest	Highest (Few cm of thick lead)

20(f) Nuclear equations

Emission	Example
α-particle:	${}^{222}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$
γ-ray	${}^{234}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} + 2\gamma$
β-particle	${}^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$

20(g) Background radiation

Background radiation refers to nuclear radiation in an environment where no radioactive source has been deliberately introduced.

Sources	Example
Artificial sources	Medical X-rays Building materials Waste products from nuclear power stations
Natural sources	Rocks Radon gas in the air Food and drink (e.g. radioactive potassium-40 in bananas, carrots, and salts)

Measuring Instrument: Geiger-Muller (GM counter)

SI Unit: Becquerel (Bq) (1 Bq = 1 disintegration per second)

20(h) Half-life

The half-life of a radioactive nuclide is the time taken for half the nuclei of that nuclide in any sample to decay.

Time/ half-life's	**0**	**1**	**2**	**3**	**4**
% left	100%	50%	25%	12.5%	6.25%
% decayed	0%	50%	75%	87.5%	93.75%

Example: A radioactive sample has a half-life of 15 hours. After 60 hours (4 half-life's), only 6.25% of the original sample will be left.

20(i) Applications and Hazards of radioactivity

Nuclear emission	**Type**	**Uses**
alpha(α)-particle	Geology	Uranium-238 used to estimate rocks' age. 1. Isotope decays to stable lead-206 2. Determining the relative amounts of uranium-238 and lead-206 in sample allows the age of rock to be known. 3. Greater proportion of lead-206 present implies older rock.
	Safety	Americium-241 used in smoke detectors 1. α-particles emitted fall on the detector 2. current flows in the detector as α-particles have high ionising ability 3. when smoke enters the detector, it absorbs the radiation and disrupts the flow of current 4. This triggers the detector's alarm
beta(β)-particle	Medical	Iodine-131 used in treatment of thyroid disorder 1. Small amount of isotope is taken to destroy the thyroid cells including cancer cells 2. Short half-life (8 days)
beta(β)-particle or gamma (γ) ray	Industrial	β-particle or γ-ray used to measure thickness of materials 1. β-particles or γ-rays from radioactive source are directed at the material 2. A detector measures the amount of radiation passing through 3. If the material is too thick, the amount of radiation is low and vice versa.
gamma (γ) ray	Medical	Technetium-99 used in detection of tumours. 1. Small amount of isotope is taken. 2. γ-rays emitted allow images of internal organs to be captured by a gamma camera 3. short half-life (6 hour) Cobalt-60 used in gamma knife radiosurgery 1. γ-rays are directed at brain to destroy braintumours.

		2. long half-life (5.3 years). Hence, only a small quantity is used.
	Safety	γ-rays used to reverse food decays 1. γ-rays used to kill microbes to ensure food is safe for consumption and last longer. 2. Long half-life (few years) γ-rays used to sanitise medical equipment 1. Medical equipment like syringes are scalpels are kept in sealed packaging and exposed to γ-rays 2. Microbes present are killed and equipment is sterile 3. Long half-life (few years)

Hazards of radioactivity	
1	Kill cells, and cause mutation and cancer
2	Stunt growth

Precautionary Measures		
1	Limit Contamination	1. Leave contaminated area immediately 2. Remove outer layer of clothing to reduce risk of contamination 3. Wash all exposed body parts with soap and lukewarm water
2	Reduce Exposure	1. Reduce exposure time. Experiments involving radioactive materials should only be carried out in designated locations 2. Increase distance between source: use long tongs or remote-controlled devices to increase the distance between radioactive materials and the body. 3. Shielding. Use materials that absorb ionising radiation such as lead-lined gloves and suits. Thick concrete walls and lead-lined doors for rooms. 4. Storage: store radioactive materials in sealed containers such as a lead box. Clearly label the boxes and keep in a secure place that is not easily accessible.

20(j) Nuclear fusion and fission

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

Nuclear fission is a process in which the nucleus of an atom splits (usually into two parts) and releases a huge amount of energy.

Nuclear fission	
1	Isotopes uranium-233, uranium-235 and plutonium-239 are commonly involved in nuclear fission. When the unstable nuclei of these atoms are hit by a slow-moving neutron, they split. Thus, two daughter nuclei and two or more neutrons are created.
2	During nuclear fission, energy is transferred from the nuclear store of the unstable nucleus to: The kinetic, internal and nuclear stores of the daughter nuclei and neutrons; and The internal store of the surroundings The internal store of the surroundings is used to heat water so that it changes into steam. The steam turns the turbine to generate electricity.
3	The neutrons produced in the nuclear fission will go on to split more nuclei. This creates a self-sustaining chain reaction that is controlled in a nuclear reactor. The processes involved in mining, refining, purifying, using and disposing of nuclear fuel are collectively known as the nuclear cycle.

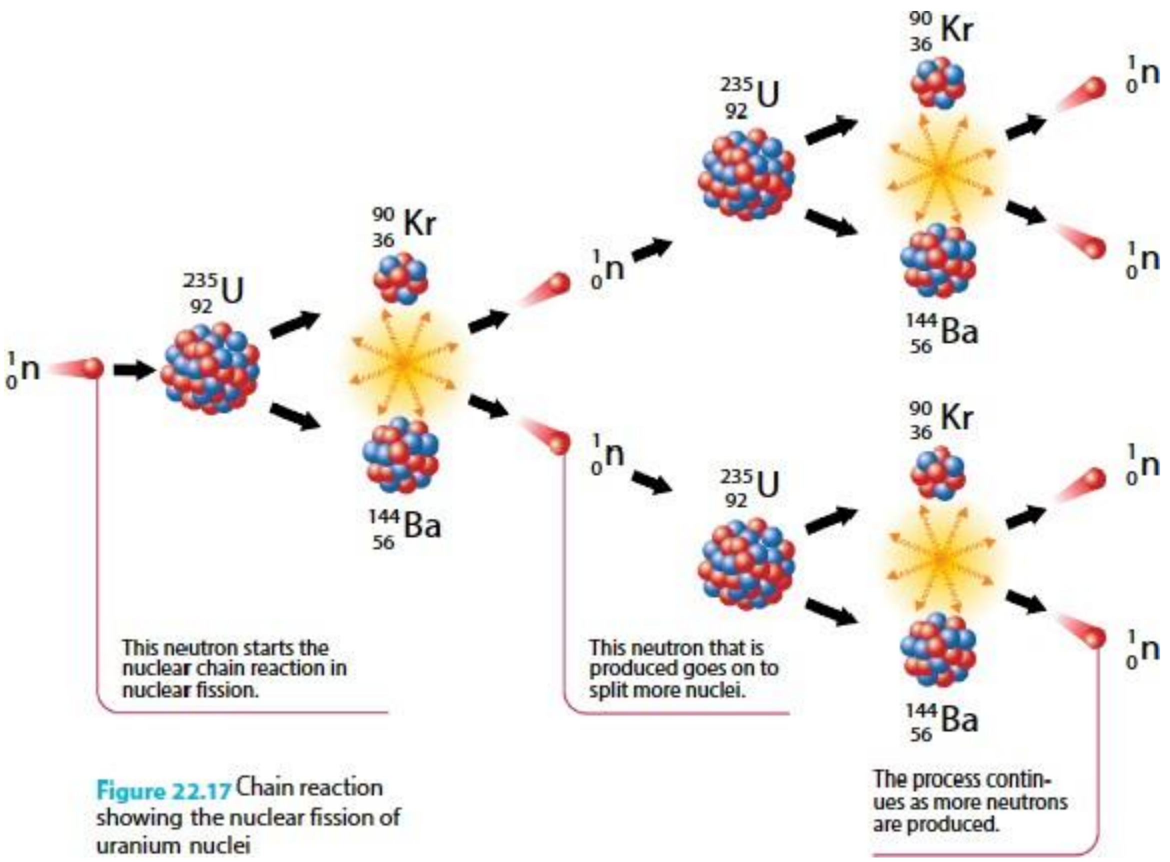
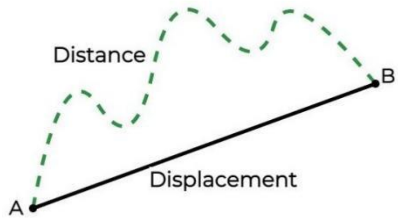


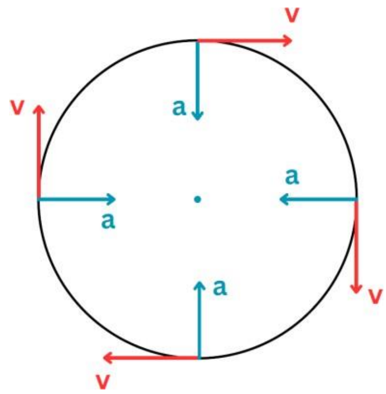
Figure 22.17 Chain reaction showing the nuclear fission of uranium nuclei

Distance vs. Displacement



If you ran from points A to B using the track in green, the green track is your distance travelled. Your displacement is the shortest distance from point A to B (solid black line).

Acceleration



Acceleration is non-zero when speed and/or direction of velocity changes.

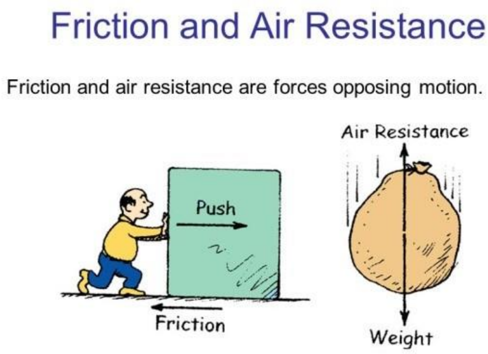
In a circular path, speed is constant, but the direction of velocity changes every second. We say that there IS acceleration.

Notice how the velocity, v has the same magnitude at all points around the circular path. Yet, there is an acceleration towards the centre of the circle. This acceleration causes the change in direction of velocity.

Difference between Friction and Air Resistance

Air resistance is a type of drag force. Drag force is basically fluid resistance, and fluids include air and water.

At an atomic level, Friction is due to the interaction between particles on the surfaces of the materials that are in contact. When surfaces slide, their microscopic irregularities come into contact and interlock. This interlocking creates resistance to motion, which we perceive as friction.



Deeper understanding of Mass and Weight

The concept of Weight only exists because there is a gravitational field – due to a massive celestial body, usually Earth. It is a 'conditional' force, it only exists while placed in a region in space near another body. Mass is different, mass is the amount of matter within an object itself, and it's value NEVER changes. Mass is always conserved, just like energy $E = mc^2$.

The Earth's gravitational field strength is 6 times weaker than the Moon's. As such, your weight on the Moon would just be 1/6 of your weight on Earth, even though your mass remains unchanged.

Balanced Forces

We often neglect the importance of having balanced forces. Most of the things you see around have balanced forces. There are 3 states of motion. A body can only be (1) at rest, (2) moving with constant velocity, or (3) with acceleration. Notice how I didn't write 'moving with acceleration'. An object can have an acceleration even though it is stationary. At the instant when a ball is just released from the top of a building, its velocity is zero, meaning it's stationary at that instant.

Balanced forces imply that resultant force = 0.

Implications of Newton's Law

Newton's Law	Condition	Implication
1st Law	Balanced Forces	Inertia
2nd Law	Unbalanced Forces	F = ma
3rd Law		Action-reaction pair

Principle of moment application questions

90% of the moment questions can be solved using principle of moments.

Step		How?
1	Ensure that the setup is in equilibrium	Look for keywords such as 'stationary', 'at rest', 'balanced'.
2	Determine the unknowns	Look at the question, does it want you to find particular force or distance?
3	Identify the pivot	Imagine there is large clockwise or anti-clockwise moment. Look for the point in the setup that will not move. Even though there can be more than 1 pivot in a setup, there is only <u>1 appropriate pivot</u> for your analysis.
4	Solve for unknowns	*CW = ACW* $F_1 * d_{1,\perp} = F_2 * d_{2,\perp}$

Take a look at the example on the right. It seems like a confusing piece of question with so many elements moving about.

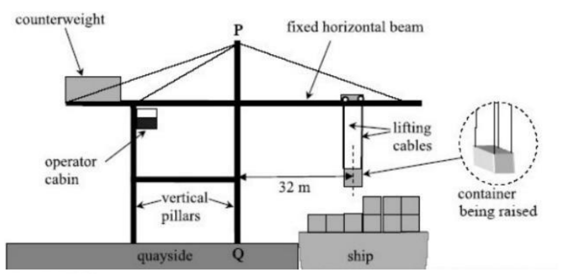
Let's follow the steps –

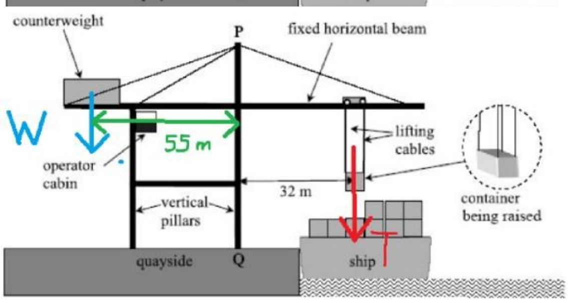
(1) *Is the setup in equilibrium?*
Yes. "lifted at constant velocity"

(2) *What is the unknown?*
Tension in each cable. There are 4 cables, each cable will produce an equal amount of force, hence we can simplify the unknown to be the collective force of the lifting cables, 4T.

(3) *Where is the pivot?*
Assuming that there is a 1,000,000,000N force due to the lifting cables, the whole set-up will rotate clockwise. The point that will not move is Q. Q is the pivot.

The diagram below shows a dockside crane that is used to lift a container from a cargo ship onto the quayside. The container is lifted by four identical 'lifting' cables attached to the top corners of the container. The counterweight is 12800 kg, and its centre of mass is at a horizontal distance 55 m from the nearest vertical pillar PQ of the crane's supporting frame.





(4) *Can we solve for the unknowns?*

Yes.

Taking pivot about Q.

$$CW = ACW$$

$$F_1 * d_{1,\perp} = F_2 * d_{2,\perp}$$

$$4T(32) = (12800)(10)(55)$$

$$\boldsymbol{T = 55\ 000N}$$

What does it mean to be at equilibrium?

Equilibrium means that resultant force = 0 and resultant moment = 0.

Understanding Pressure

$Pressure \neq Force$

While we always draw Forces as single arrows, think of Pressure as multiple arrows spread over a unit area.

Here is a simple exercise you can do at home to understand pressure.

(1) Step on the weighing scale
(2) Look at your weight
(3) Now lift your left foot up

Did the reading change?

It might fluctuate a little, but it shouldn't change by much. The weight is the force, it doesn't change.

The pressure is the impact felt by your feet. When you were standing with both feet initially, both feet absorb the same impact. Once you lift your left foot, the impact on your right foot doubles while the impact on your left foot becomes zero.

In summary, the pressure due to your foot is the action of all atoms on your foot 'pressing' on the collective area that it occupies on the floor with a total force equal to that of your weight (Read that again).

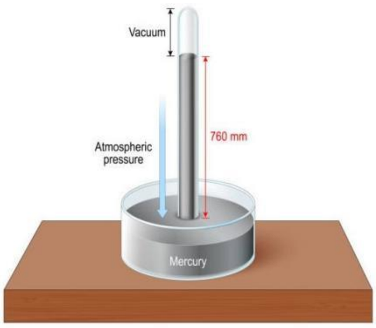
Mercury Barometer

What on earth is a mercury barometer?

Well, we often hear that it's to measure pressure. But how exactly does it work?

How is mercury able to overcome gravity and rise 760mm above mercury reservoir?

The simple answer is atmospheric pressure. The pressure from a 'gazillion' air molecules pressing against the mercury pushes the mercury up this glass tube, creating what we know as the **mercury column**.

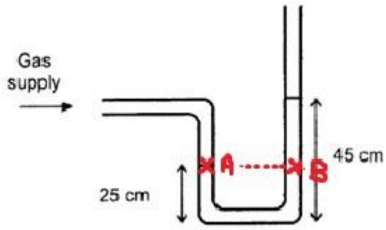


It is important that there is a vacuum above the mercury column, as it ensures that there is no pressure pushing the mercury down, but only pressure pushing it up.

How to resolve pressure questions?

A manometer is filled with a liquid of density 880 kg/ m^3.

The gravitational field strength g is 10 N/ kg.



What is the excess pressure of the gas supply compared to atmospheric pressure?

A 1760 Pa
B 2200 Pa
C 3960 Pa
D 17 600 Pa

Step		How?
1	Identify points with the same pressure	Label points 'A' and 'B'
2	Equate the pressures at both of these points	$P_{gas} = P_{liquid} + P_{atm}$
3	Solve for the unknown	$P_{gas} – P_{atm} = P_{liquid}$ $P_{liquid} = h\rho g$ $= (20 * 10^{-2})\ (880)\ (10)$ $= 1760$ Pa

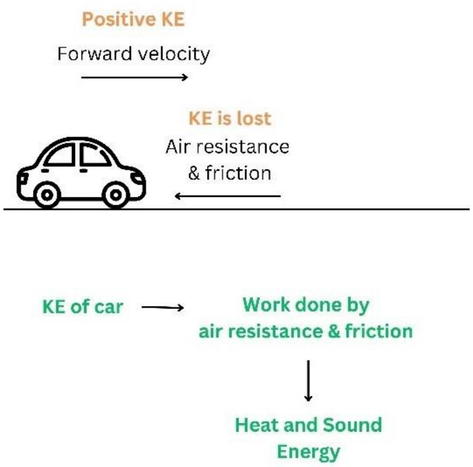
- Take note that the question is asking for <u>excess pressure</u>, meaning $P_{gas} – P_{atm}$.

What % of energy questions require the use of the principle of Conservation of Energy?

100%. All energy questions make use of the fact that energy is conserved. Otherwise, you can't solve for any variables because you can't equate total energy (before) to total energy (after).

Kinetic Energy concepts

If a car has a non-zero velocity, it must have positive kinetic energy. If the car slows down, it must mean that the kinetic energy is lost to other sources. The most common ways kinetic energy is lost is through work done by air resistance & friction, especially during braking. When we apply brakes on our car, we make use of friction to slow our car down. This work done by friction is converted to heat (mainly) and sound energy.



Work done concepts

It's tough to make sense of work done in the real-life context. We usually associate how much energy we use by how tired we feel.

Imagine pushing against a stationary tree. It is hard to imagine that you are doing 0 work on the tree, because the tree is not moving. Recall that Work done = Force * displacement. If I am doing 0 work on the tree, the where did my energy go? Why do I still feel tired? Does this violate the principle of conservation of energy?

Pushing against a stationary tree

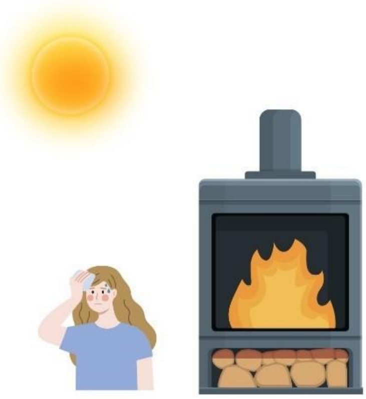
Not really… energy is lost to many other factors including:

Muscle metabolism
Heat Production
Metabolic Waste Products
Nervous System Activity
Respiratory and Cardiovascular Efforts

In summary, the energy you expend when applying a force to a stationary object like a tree is lost through internal metabolic processes, heat production, and the effort of maintaining physiological functions, rather than through mechanical work done on the tree.

Power concepts

You probably wouldn't die if you stood in the sun for 24 hours with proper hydration, but absolutely would if you stood in the blast furnace for a mere 10 seconds, even though both radiate you with the same amount of energy. Why's that?



The idea of rate is important. Rate introduces the concept of time. The rate of work done / energy transfer over time has serious implications.

Instead of looking at how MUCH energy is transferred on an absolute term, we look at how fast energy is transferred i.e. energy transferred per second.

When we think about conserving electricity, we should look to reduce consumptions of high-powered appliances, as these appliances consume the most electricity in the shortest duration. Appliances like water heaters, air conditioning, and refrigerators all use a ton of energy in a very short time.

Kinetic Particle Model of Matter

Kinetic means moving, particle means small things, and model means a framework.

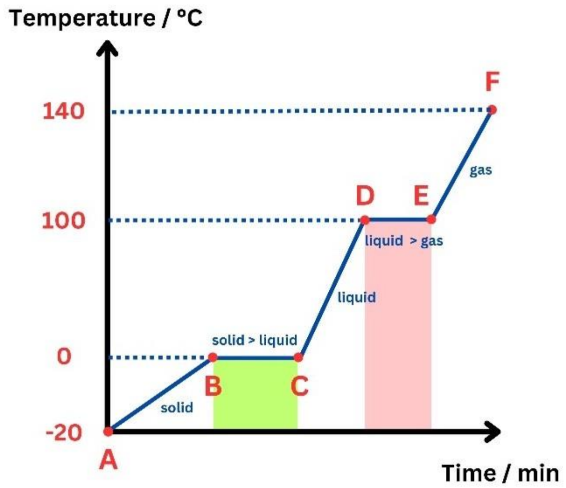
Essentially, this chapter is just a framework of moving small things. Because we can't see these 'small things' i.e. the particles, we have to have a strong visualisation skill. You have to literally imagine these particles in your head, in all the matter around you. That's the trick to remembering stuff. It's also the reason why textbooks are filled with pictures, and not just text.

Internal Energy of Particles

SO MANY people make this mistake! And I get it, it's hard to imagine that particles are not moving faster during boiling and melting, but they really don't. The average kinetic energies of the particles do not change during a change in state, that's why temperature is constant.

Internal Energy = Kinetic Energy + Potential Energy.

Kinetic energy is directly related to how fast the particles are moving, and potential energy is directly related to how far apart the particles are.



Step	Average Kinetic Energy	Average Potential Energy	Total Internal Energy
A → B	↑	↑	↑↑
B → C	-	↑↑	↑↑
C → D	↑	↑	↑↑
D → E	-	↑↑	↑↑
E → F	↑	↑	↑↑

A → B:

- Average kinetic energies of the particles increase as they vibrate faster and more vigorously.
- Average potential energies of the particles increase as the particles move further apart. It is the same reason why solids expand when heated.

B → C:

- Average kinetic energies of the particles remain unchanged, as temperature is constant.
- Average potential energies of the particles increase, as matter experiences a change in state from solid to liquid

> The energy transfer by heating occurs only when there is a difference in temperature (Figure 9.2).

Yes. Contrary to what the textbook says, there is going to be heat transfer. There is, however, no NET heat transfer. Some particles from Body A will collide with particles from Body B, transferring kinetic energy to them. Similarly, particles from Body B will also collide with particles from Body A. At the same temperature, the rate of energy transfer from A to B will be equal to the rate of energy transfer from B to A. Hence, even though there is no net energy transfer, there IS still energy transfer between the 2 bodies.

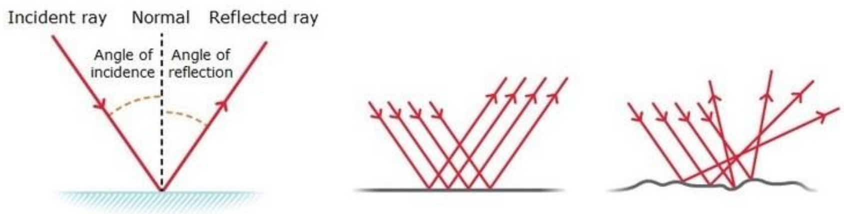
Types of Thermal Processes

Thermal Processes	Conduction	Convection	Radiation
Personal Interpretation	Heat transfer through collision of particles	A process that accelerates heat transfer by making use of different densities of fluid when heated.	Heat transfer through electromagnetic waves
Requires a medium?	Yes	Yes	No
What influences its rate of transfer?	How close the particles are and whether there is presence of free electrons.	Fluid density and viscosity	Material. Black and rough surfaces are good absorbers and emitters of heat. Silver and shiny are poor absorbers and emitters of heat.

Why are black and rough surfaces better absorbers and emitters of heat?

They are not better absorbers because they are black. They are black because they are better absorbers. If something is blue, it's because it absorbs all other light, and reflects blue light. Similarly, something is black because it absorbs most coloured lights, and reflects little light. An object's black colour appearance is due to little reflected light. So, just from the object's colour, we know that it has a high/low tendency to absorb/reflect light.

Roughness is slightly different. Recall our laws of reflection, the angle of incidence is always equal to the angle of reflection. Hence, for smooth surfaces, most of the thermal radiation coming in gets reflected back, leading to relatively low rates of absorption. In contrast, for rough surfaces, the irregularities can result in multiple internal reflections of radiation within the material, increasing absorption.



Wait a minute! Didn't we say that rough surfaces are better emitters? Why does it seem like smooth surfaces can emit radiation better… given that they are better at reflecting heat?

Reflecting heat =/= Emitting heat

Reflecting means deflecting or 'pushing away' heat that comes in from an external source, resulting in low rates of absorption.

Emitting means 'giving out' your own heat. In general, emission is affected by surface area, and rough surfaces have greater surface area, because of their irregularities, and can thus emit heat better. It can also be affected by wavelength, the degree of emission may be different for radiations of different wavelengths, but that's not central to our discussion.

Insulation examples that are easy to understand

Think about how you want to keep cool, or how you want to keep warm. The main purpose of the vacuum is to reduce the rate of heat transfer. Why we say reduce and not eliminate heat transfer is because, while a vacuum flask doesn't allow any heat transfer, there is still heat transfer from the solid particles that make up the vacuum flask.

Understanding Heat capacity

'Heat capacity' is made of two words – 'heat' and 'capacity'. Heat is thermal energy, and capacity is how much of something you can store. Combined, heat capacity, is how much thermal energy can be stored (in a particular body). If you have a high heat capacity, it means that you can store a lot of energy, so it takes a lot of energy to change your temperature by 1 degree Celsius.

So what affects a body's ability to store energy?

Recall that the amount of energy a body stores is the total internal energy of its particles. This comes in the form of potential energy (how far apart particles are spaced) and kinetic energy (how fast they are moving). They can store a lot of energy if there is a lot of room for the particles to gain potential and/or kinetic energy. Now this comparison cannot be fair if the masses of the bodies are different. A 100,000 kg body will very likely be able to store more energy than a 1kg body. That's why to make the comparisons fair, we introduce specific heat capacity, whereby we divide the heat capacity by the mass to give specific heat capacity.

Solids, especially metals, usually have lower specific heat capacities than liquids because there is little room for them to gain potential / kinetic energy as they are held in fixed positions and can only vibrate / rotate more vigorously.

Gases, usually have the least specific heat capacities because of the fewer degrees of freedom for energy storage and weak intermolecular forces. When intermolecular forces are weak, little energy is required to overcome them, hence increase in potential energy is low. Degrees of freedom refer to the independent ways in which a system, such as a molecule, can move or store energy, including translational, rotational, and vibrational motions. Gases have low degrees of freedom because, unlike solids and liquids, they have fewer ways to store energy. For example, in simple gases like helium, atoms can only move in three directions (translational motion), while they can't rotate or vibrate like molecules in liquids or solids. So, gases have fewer ways to "move around" and store energy.

In general, the comparison of specific heat capacities is as follows:

Liquid > Solid > Gas

This means liquids typically have the highest specific heat capacities, followed by solids, with gases having the lowest specific heat capacities.

The specific heat capacities of water in its different states (liquid, solid, and gas) are as follows:

Liquid Water: ≈ 4.18 J/g·K or 4180 J/kg·K

Ice (Solid Water): ≈ 2.09 J/g·K or 2090 J/kg·K

Steam (Gaseous Water): ≈ 2.01 J/g·K or 2010 J/kg·K

These values illustrate that liquid water has the highest specific heat capacity compared to ice and steam.

Latent heat of fusion/vaporisation

If you understand (specific) heat capacity, then you should have no issue understanding (specific) latent heat of fusion/vaporisation. Basically, it is the amount of energy needed to cause a change in state for a body. If it is specific latent heat, then it is 1kg of the body. Why is there a need for such a distinction? Because at this point, the temperature doesn't change, so we can't account for the heat gained using temperatures like what we did for (specific) heat capacity.

Pressure changes due to temperature

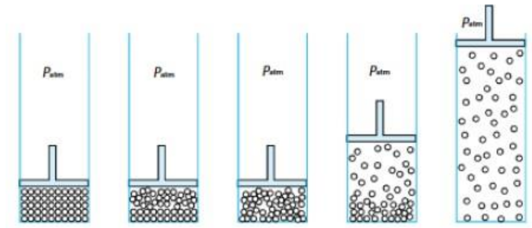


Figure 10.14 How the temperature of a substance and its arrangement of particles change during heating or cooling

Pressure only applies to gas, because only gas can be compressed. The reason why only gas can be compressed is because there are sufficient spaces between gas molecules, and these spaces can vary. By pushing them together (closing the gaps between the particles), the particles will exert an equal and opposite force on the 'compressor', causing a pressure.

Temperature increases the speed of particles, and increases the kinetic energy possessed by them. They collide with the walls of the container with greater force, hence the average force per unit area exerted by these particles (pressure definition) will increase, causing pressure to increase.

Explaining a wave

Wave is such a confusing thing to laymen, because we usually perceive waves as those we see at the beach. We seldom see 'perfectly' formed waves that's why it's so easy to misunderstand them.

Take note of these 3 things when dealing with waves:

(1) In a transverse wave, the particles never move left and right. They only move up and down.
(2) In a longitudinal wave, the particles only move left and right with their individual positive amplitude and negative amplitude.
(3) Wave only serves to transfer energy.

How do I interpret the lines on a ripple diagram?

Each of these lines are called wavefronts. Each line that you see on the ripple diagram represents a wavefront. It joins all adjacent points that are in phase in the wave. The adjacent points that are in phase don't have to be the crest or trough, it could be any points in between, as long as they are in phase.

Usually, we only need to know the distance between each wavefront from the diagram. The distance between each wavefront is the wavelength of the wave, because essentially you are measuring the distance from one trough to the next trough, or one crest to the next crest, and any points in between to a similar point of the next cycle.

Sound waves

Based on your understanding of waves, explain what type of wave do you think sound is? Think about how energy is transferred through the medium. Think about the particles, how do they move when there is a source of sound? The cones of the speaker vibrate, pushing the air particles near it. The air particles that are being pushed collide with its neighbouring air particles, and this effect continues rapidly at a speed of roughly 330m/s in air. When you hear a sound, it's because the collisions of air particles have reached your ear drums and collided with your ear drums as well, allowing you to hear the sound. People with damaged ear drums will have impaired hearing, because even though the sound energy is present, it is unable to transmit the energy to their ears for them to hear.

In a vacuum, where there are no air particles, there would be no sound waves because of the very fact that it is created by air particles colliding into each other.

Audible and Inaudible sounds

Audible means 'can hear'. Audible range means the range in which you can hear something, and it's measured in Hertz (Hz). Whether you can or cannot hear something depends on how loud it is, but it also depends on the pitch. There are sounds which your cat can hear but you can't. There are sounds that you can hear but an elephant can't. Every animal has a different audible range. Even among humans, your audible range will decrease as you grow older. Any sounds greater than 20kHz we call them ultrasound; these sounds are beyond human's typical audible range of (20Hz – 20kHz).

What is an echo?

Sounds reflect, just like any other waves. The reflected sound wave is called an echo. Usually echo will be 'softer' than the original sound wave, because energy is lost to the kinetic energies of the particles the of object it bounces off, causing the reflected wave to carry less energy.

What are electromagnetic waves?

We have to think of electromagnetic waves differently. When we see 'light' and we think of 'light', we often associate it with brightness and illumination. The light in your room brightens up your room, allowing you to see things. We think that light is a thing on its own. Actually, light is part of a bigger spectrum of things, called the electromagnetic wave spectrum. The light that we can actually see only constitutes a small part of the entire spectrum. Most of the spectrum is made of waves that are beyond what our eyes can see. Just like how there's an audible sound range for humans, there's also a visible light spectrum for us. This range is extremely narrow, only 450nm to 700nm wavelengths can be seen by the naked eye.

Electromagnetic waves do not require a medium, because they consist of oscillating electric and magnetic fields. Electric and magnetic fields exist without a medium. The Earth generates its own magnetic field from the motion of molten iron and nickel in its outer core.

That is why some waves, like sound and water waves, require a medium, because the wave is propagated through particles (matter), while other waves, like electromagnetic waves, don't require a medium, because the wave is propagated through electric and magnetic fields (non-matter).

How to draw Mirror Image?

For every point on the object, make sure the object distance to the mirror is the same as the image distance to the mirror.

How do I tell whether an object is real or virtual?

Real images can be projected on a screen, virtual images can't. You can't project an image of yourself in the mirror on a screen.

How to know which is the angle of incidence and which is the angle of refraction?

If you're good with mathematics and have a decent foundation in physics, I recommend you use the equation Snell's Law. $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Otherwise, just make sure that no matter what you do, your refractive index must ALWAYS be >0.

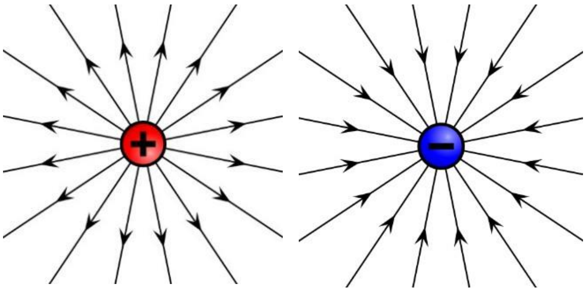
What is a refractive index?

Refractive index is the ratio of the speed of light in vacuum to the speed of light in the medium. Essentially, the refractive index of the medium measures how much light slows down by from its speed in vacuum. For example, if diamond has a refractive index of 2.50, it means that the speed of light slows down by 2.50x from its vacuum speed when it passes through diamond.

How to explain Electric Charge questions?

(1) Like charges repel / unlike charges attract
(2) The negative charges are repelled away / attracted towards the conductor
(3) Hence…

Why do we draw electric field lines pointing away from positive charge and pointing towards negative charge?



Because the electric field lines show the direction of that a positive charge will take when placed at that point. In the presence of another positive charge, the positive charge will be repelled away.

In the presence of another negative charge, the positive charge will be attracted towards the negative charge.

What happens during lightning?

Charge Accumulation: Inside a storm cloud, particles of ice and water are constantly moving and colliding. These collisions cause the particles to become electrically charged. Usually, the top of the cloud becomes positively charged, and the bottom becomes negatively charged.

Discharge of Charges: The large difference in charges between the cloud and the ground (or between different parts of the cloud) creates a strong electric field. When this electric field becomes strong enough, it overcomes the resistance of the air, leading to a sudden discharge of electricity.

Lightning: This discharge of electricity is what we see as lightning. It's a rapid flow of electrical energy that travels through the air, creating a bright flash and often a loud sound called thunder due to the rapid expansion of heated air.

Why do we need to ground/earth trucks carrying dry bulk (commodity materials such as coal, grains, metals, fuels)?

Friction against the inner walls can lead to electrostatic charging of hose and substance. At the outlet, the opposite charges between the hose and the substance can cause sparking. If the substance is combustile, the saprk can cause fire/explosion.As such, grounding/earthing is important as it serves to neutralise any built-up excess charges.

What is potential difference?

It's hard to imagine what potential difference is because there isn't any real-life visual examples that we can make sense of. I am going to give you this simple analogy to make sense of what potential difference is and how it is different from electromotive force (e.m.f.)

Imagine a boy carrying a ball. The name of this boy is Charge. The ball that he is carrying is called Energy.

Now imagine, instead of 1 boy, I clone 1000 copies of the same boy. Because they are clones, they all have the same name – Charge.

All 1000 boys, carrying the same ball (same amount of Energy) is going to run one round each around a 400m track, at the same speed, and maintaining an equal distance between their adjacent runners.

How this works is this - At the 0m mark, they will pick up a ball from the pick-up point. At the 200m, they will drop the ball off at the drop-off point. At 400m, when they are returning from their round, they will be empty-handed, because they have already deposited the ball at the 200m mark.

Now, I am going to ask you a question and see if you can answer them.

1) How many balls were transferred from A to B in total?

2) How many balls were picked up from A by each boy?

3) How many balls were dropped off at B by each boy?

Answers:

1) 1000

2) 1

3) 1

1) A total of 1000 balls were transferred from A to B. A is your battery, and B is your lamp. Assuming each ball represents 1J, the battery has transferred 1000J of energy to the lamp. The total amount of energy transferred is 1000J. This is represented by W, total work done by the battery = 1000J.

2) Each boy only picks up one ball from the pick-up point. The electromotive force of the source, $\varepsilon = \frac{W}{Q} = \frac{1000J}{1000C}$ = 1V. Essentially, the electromotive force is a measure of the number of balls that is allowed to be carried by each boy at any one time. If the boy carries 1 ball at a time, the e.m.f. is 1V. If the boy carries 2 balls at once, the e.m.f. is 2V.

3) Each boy drops off one ball at the pick-up point. The potential difference across the lamp, measures the number of balls that is dropped off at that pick-up point by each boy. ,

$V = \frac{W}{Q} = \frac{1000J}{1000C} = 1.0V$

Now, imagine instead of 1 pick-up point, you have 2 pick-up points. Both the pick-up points are identical. So, instead of dropping 1 ball at each pick-up point, I will choose to drop 0.5 ball at each point. The potential difference across each lamp will be halved.

$$V = \frac{W}{Q} = \frac{500J}{1000C} = 0.5V$$

Learn about I-V graphs

The I-V graph just tracks how current will behave when I apply a potential. Our syllabus requires us to have a good understanding of 2 non-ohmic conductors (meaning their I-V graph is not a straight line).

1) Filament lamp. When the potential difference across the filament lamp increases, the current passing through it increases. This increases the temperature of the tungsten metal. As temperature rises, the atomic vibrations within the metals increase, impeding the flow of electrons, causing increased resistance, and reducing current. Hence, current does not increase proportionally with the potential difference.

2) Semi-conductor diode. The purpose of a diode is to only allow current to flow in one direction when the circuit is connected to an alternating current. When there is positive voltage applied, resistance is very low, current increases exponentially. The resistance has to be low, because the diode is supposed to be behave like a typical wire in one direction. When a negative voltage is applied, resistance becomes very high, current is very low or almost zero. We draw a close to flat horizontal line.

Solving Circuit Diagrams!

If you're solving circuit diagrams by purely memorising certain relations, like series means add and parallel means taking the reciprocal of .. it's time to take it to the next level.

Solving circuit diagrams is fun because it's like a puzzle, and if you've ever played those phone games that requires you to solve puzzles, this can be something like that too.

In every diagram, you need to identify the points ….

Practical electricity.. what can they test?

Most common concepts tested are

1) Positionings of the live/neutral/earth wire
2) Uses of fuses and circuit breakers
3) Earthing excess charges
4) Double insulation
5) Electricity Consumption

Safety Features

Fuse

- Protects circuits by melting and breaking the circuit during overcurrent.
- Melts a metal wire or strip when excessive current flows.
- Single-use; requires replacement after blowing
- Fuse rating is the maximum current that a fuse can safely carry without blowing or melting

Circuit Breaker

- Protects circuits by automatically switching off during overcurrent.
- Reusable; can be reset after tripping.
- Simple reset by switching back on.

Earthing metal casing

- Protects users from electric shock by providing a path for fault current to flow directly to the ground.
- Metal casing of electrical appliances is connected to the ground using a conductive wire.
- The earth wire offers a low resistance path, allowing fault current to bypass the user and flow to the ground.
- In case of a fault, the high current flowing to the ground causes the circuit breaker or fuse to trip, disconnecting the electrical supply.

Double insulation

- Primary Insulation: This is the first layer that protects against electric shock under normal operating conditions. It surrounds the live parts of the appliance.

- Secondary Insulation: This is an additional layer that acts as a backup. If the primary insulation fails, the secondary insulation prevents access to live components.

Nuclear decay is about 'decomposition' of the nucleus of an atom. An atom is made up of a nucleus and electron shells that are very far away from nucleus. We are not concerned about the electrons nor the whole atom at all! We are only focusing on the nucleus, because that's what the whole of radioactivity is about.

When a nucleus decay, 3 types of things will be emitted.

1) Alpha particle: this is a nucleus with 2 protons and 2 neutrons, which is also called the helium nucleus (nucleus only, NOT atom!). The emission of this particle causes the identity of the nucleus to change. Because now it has lost 2 protons, it is no longer the same element is used to be. For example, if I am a Lithium nucleus (with 3 protons and 4 neutrons), and I lose 2 protons along with 2 neutrons, I will be left with 1 proton and 2 neutrons, making me a hydrogen with 2 neutrons (deuterium).
2) Beta particle: In short, this is an electron. No change in mass to the parent nucleus, just an increase in positive charge.
3) Gamma ray: In short, gamma rays are emitted. No change in mass or charge, just emission of energy.

Nuclear decays are spontaneous and random. Spontaneous means it happens by itself, no external factors can influence its rate of decay. Random means it is unpredictable, we cannot predict when it will happen or in what direction will the particle/gamma ray be emitted.

Half-life is one confusing thing when you first learn about it but it's actually pretty straightforward. If I have 100 nuclei, with half-life of 1 hour,

in 1 hour I will be left with 50.

2 hour 25,

3 hour 12.5,

4 hour 6.25, and so on.

Nuclear fusion / fission

Have you ever wondered why positively charged protons are able to come so close together in a nucleus? Won't they repel each other?

They will. It's just that there's a stronger source of energy that's keeping them together. That energy is nuclear energy. Nuclear energy is responsible for keeping positively charged protons, and neutrons together in a confined space smaller than the size of an atom. This is one of the most powerful forms of energy in the universe and we see politicians and government talking about nuclear war, nuclear weapons… they are talking about these stuffs.

The difference between this concept and what you learn in Chemistry is very different. In Chemistry, you learn that forming bonds release energy, and breaking bonds absorb energy. In nuclear fusion and fission, both processes release a ton of energy.

Nuclear fission is a process in which the nucleus splits, while nuclear fusion is a process where 2 nuclei combine. Nuclear fission happens in nuclear reactors, while nuclear fusion happens mostly in the sun, as high temperature and pressure are needed for positively charged protons to come together.

Exam Tips

Can I score an A if I memorise everything here?

NO. Knowing this stuff by heart will get you from a B to an A, but it won't help you to get from a D to an B. If you notice, I didn't label the topics. If you can't figure out which topic each formula, definition, or concept belong to, close this file. You shouldn't be reading this. Go back to your revision.

How do I know which formula to use?

If you don't know which formula to use, you are not ready. Close the file.

Do I have to memorise the definitions word-for-word?

No, you have to internalise it word-for-word.

Wait, what's the difference?

Memorise means to remember the words. For example, Faraday's Law of Electromagnetic Induction states that the magnitude of induced emf is directly proportional to the rate of change of magnetic flux.

I can write out this entire definition without knowing whatever this law means. If you internalise it, and understand it fully, you can even paraphrase and explain to me what faraday's law is.

What separates an A student from a B student?

I assume if you're asking this question that your goal is to get an A in O Levels. If that is the case, you should be targeting way higher in school exams. 75% isn't going to cut it. You don't want to be fluctuating between 65% and 75% and only performing well on your best days. You want to be fluctuating comfortably between 75% and 85%, so that even on your worst days (e.g. exam stress, super tough questions, mind blank during exams), you can still score 75%.

Conclusion

I promise you that I have spent countless hours on this file, and I want to make sure that 100% of the content here is needed. I don't want to be wasting your time reading this. If you have read this whole thing, I truly appreciate your time and effort. Exams are not the most important thing. As you grow older, the value of the examination falls. No one is going to ask you what your L1R5 or RP was when you're 30 years old.

That said, the value of exams/studies comes not from the result but from the process. Studies teach you to do things you don't like – an essential part of life and discipline. Exams train you to think under pressure. Your brain is a muscle. Every time you solve a math problem, the neurons fire and form connections, strengthening this muscle. A person who studies consistently can 100% think better and more critically than someone who shuns away from this important endeavour.

The key to improving each day is to always blame yourself. No matter how bad the situation is, always look at things that YOU can do better. Look at factors that you CAN control.

Whatever you do in the future after this milestone, be kind and never spread hate. Hate only comes from broken / insecure people. Don't be one of them.

Good luck.