9646 H2 Physics

What you will find here is definitions and short answers that will be tested. That means you should find them familiar, especially those who are studying in the same junior college with me. I have done something similar for physics.

You do need to memorise the definitions all around. They are points that you are expected to secure.

However, you do need to understand the concepts to apply them. Do note that you have used the essential key words and phrases in your answer.

You also need to know how to apply the skills that you have learnt. For physics, calculations are common, and they are rather easy marks to get, so make sure you grab them. You will also need to analyse free body diagrams, resolve vectors, read graphs, among others. There is also a planning question. I will need to leave the reinforcement of these skills in the practices that you should have been doing. You are expected to finish up the entire TYS.

You will also need to fulfil the basic requirement of the question: answer the question. Describing a chemical reaction will need naming of the reactant, type of reaction and the product. Change will require description of what is before and after.

You need to be precise in the terms that you use. For instance, you need to understand the difference between work done by and work done on, and apply them correctly. This is just one of them.

You might see that there is a lack of diagrams. I might add them some time later, but since there is a plenty of space now, you can use this opportunity to scribble on the margins.

You can use this as a framework to create your own notes. The process of making this has allowed me to expose my learning gaps and bridge them accordingly.

If you happen to use this as your revision, do keep in mind that I am also a student. There can also be mistakes.

There is no better way to appreciate my work other than pointing out these problems. It will be a feedback for me, and also allow me to correct it for users like you. If you found this from owlcove, the comments section is just below.

I am just doing what I hope others could have done, and this is what I came up with. If you do feel the same, you can also make the learning process easier for us and the future cohorts.

Enjoy!

Measurement

Base quantities are physical quantities that are independent on other quantities. They (and the SI units) are:
mass (kg) length (m) time (s) current (A) temperature (K) amount of substance (mol) luminous intensity (cd)
Derived quantities is related to the base quantities by an defining equation.

An error is **systematic** if repeating the measurement under the same conditions yields **all** measurements being **either bigger or smaller** than the **true value**. Measurements with systematic errors change in a **predictable** manner depending on the conditions. (caused by faults with the instrument or its data handling system, or because the instrument is wrongly used by the experimenter)	An error is **random** if repeating the measurement under the same conditions yields measurements **scattered about a mean value**. Random errors have an **equal chance of being either positive or negative** about the **true value.** (caused by inherently unpredictable fluctuations in the readings of a measurement apparatus or in the experimenter's interpretation of the instrumental reading)
Systematic errors can be **eliminated** after finding out the cause of the error and then by using **good experimental techniques** and by **varying the instrumentation** used. It **can never** be eliminated by taking the average of repeated measurements with the same faults.	Random error can be **reduced** by **repeating the measurement** and **taking the average** of them or by **plotting a graph** and **drawing the best fit line** for the plotted points. A large number of measurements will give an average of smaller random error because positive and negative deviations are **equally probable**.
Accuracy is the **degree of agreement** between the readings and the **true value**. It is a measure of the **correctness** of results. Good accuracy means the average value of a set of measurements is very close to the true value (**small systematic error**).	**Precision** is the **degree of agreement** among a series of measurements **of the same quantity**. It is a measure of the **reproducibility** and **certainty** of the results. Good precision means the measurements are mostly very close to their mean, (**small random error**).

Calculation of uncertainties	Additive relationship	Multiplicative relationship
(relating to random errors)	$R = mA + nB$	$R = A^m B^n$
	$\frac{\Delta R}{R} = \lvert m \rvert \frac{\Delta A}{R} + \lvert n \rvert \frac{\Delta B}{R}$	$\frac{\Delta R}{R} = \lvert m \rvert \frac{\Delta A}{A} + \lvert n \rvert \frac{\Delta B}{B}$

Kinematics

Distance travelled refers to the **length of the path travelled** by a body.	**Displacement** refers to the distance of a body **in a specified direction** from **some reference point**.
Speed is defined as the rate of change of **distance travelled** with respect to time.	**Velocity** is defined as the rate of change of **displacement** with respect to time.
Average speed refers to the **total distance travelled** divided by the time elapsed.	Average velocity refers to the **change in displacement** divided by the time elapsed.
Instantaneous speed is the **magnitude** of the instantaneous velocity at a particular point or a particular instant of time.	Instantaneous velocity is the velocity at a **particular** point or a particular instant of time.

Acceleration is defined as the **rate of change of velocity** with respect to time.
An object is said to be in **free fall** if the **only** force acting on it is the **gravitational** pull (of the Earth).

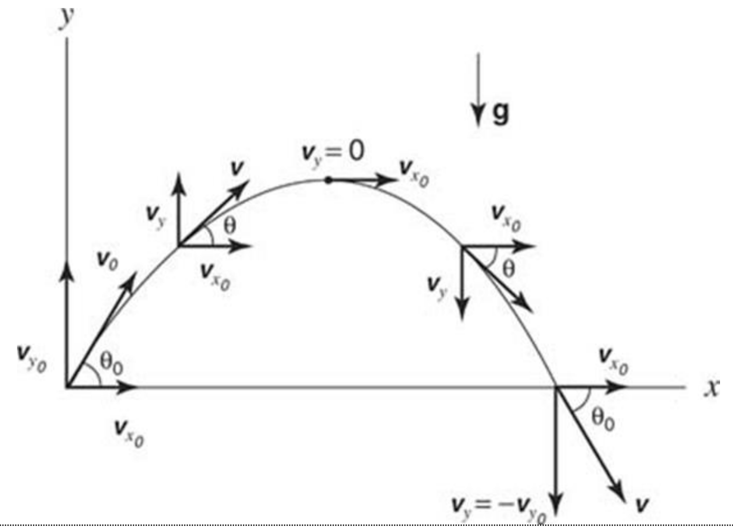
Displacement-time
"The body is moving in a constant/increasing/decreasing **velocity** as indicated by constant/increasing/decreasing **gradient**.
Direction of **velocity** is the same/opposite as displacement as indicated by the **positive/negative** gradient."

Velocity-time
"There is zero/constant/increasing/decreasing **acceleration** as indicated by the horizontal/constant/increasing/decreasing **gradient**.
Direction of the **acceleration** is the same/opposite as the velocity as indicated by the **positive/negative** gradient."

Derivation of the equation of motion in uniformly accelerated motion.	Equation of motion	s	v	u	a	t
Acceleration is the slope $\mathrm{v-t}$ graph. $\mathrm{a}=\frac{\Delta \mathrm{v}}{\Delta \mathrm{t}}=\frac{\mathrm{v-u}}{\mathrm{t}}$	$\mathrm{v=u+at}$	×				
Displacement is the area under $\mathrm{v-t}$ graph.	$\mathrm{s}=\frac{1}{2}(\mathrm{u+v})\mathrm{t}$				×	
However, $\mathrm{v=u+at}$	$\mathrm{s=ut}+\frac{1}{2}\mathrm{at}^2$			×		
Using $\mathrm{t}=\frac{\mathrm{v-u}}{\mathrm{a}}$ into the previous equation	$\mathrm{v}^2=\mathrm{u}^2+2\mathrm{as}$					×

Equations of parabolic motion

a_x	0	
v_x	u_x	$u \cos\theta$
s_x	$u_x t$	$ut \cos\theta$
a_y	$-g$	
v_x	$u_y - gt$	$u \sin\theta - gt$
s_y	$u_y t - \frac{1}{2}gt^2$	$ut \sin\theta - \frac{1}{2}gt^2$



Note that path of parabolic motion is **symmetrical** about the maximum point.

Effect of air resistance

When an object falls in the air, the air resistance **opposing** its motion **increases** as its speed rises, thereby **reducing its acceleration**.
Eventually, air resistance acting upwards **equals** to the weight of the object which is acting downwards, **balancing** each other. The **resultant force** on the object is **zero**.
Depending the **size, shape and mass** of the object, the object then falls in a **constant velocity** (**terminal velocity**).
Terminal velocity refers to the constant velocity of a falling object when the resultant force on the object is zero.

Parabolic motion with **air resistance**
With air resistance, work has to be done against the air resistance, **mechanical energy** of the ball is **lost**.
Both the vertical and horizontal component of velocity will be reduced. This results in **lower maximum height and shorter range.**
Due to air resistance, the average ascending speed is higher than the average descending speed. This results in an **asymmetrical path**.

Dynamics

Newton's First Law
states that every body **continues** to be in a state of **rest** or to move with **uniform velocity** unless a **net force** acts on it.

Newton's Second Law
states that the **rate of change of momentum** of a body is **proportional** to the **net force acting** on it and occurs **in the direction** of the force.

Newton's Third Law
states that if body A exerts a force on body B, then body B will exert a force of the **same type** that is **equal in magnitude** and **opposite in direction** on body A.

Inertia of a body is its **reluctance to start moving**, and its **reluctance to stop** once it has begun moving.
Mass of a body is a **measure of its inertia**, specifying how much **resistance** an object exhibits to changes in velocity.

Weight of the body is the gravitational force acting on it towards the centre of the Earth.

Linear momentum ρ of a body of constant mass m moving with velocity u is defined to be the **product of the mass and (linear) velocity**.
$\rho = \mathrm{mu}$

Impulse (of a force) is the product of the force acting on an object and the time during which the force acts.
$\mathrm{Ft} = \mathrm{mv} - \mathrm{mu} = \Delta\rho$

Force is the **rate of change of momentum**.
$\mathrm{F} = \mathrm{ma} = \mathrm{d}\rho/\mathrm{dt}$

The principle of conservation of momentum states that when bodies in a system interact,
the **total momentum remains constant** provided **no external force** acts on the system.

$$\mathrm{m_1u_1} + \mathrm{m_2u_2} = \mathrm{m_1v_1} + \mathrm{m_2v_2}$$

A **perfectly elastic** collision between two objects is one which the **total kinetic energy** if the system is the **same** before and after the collision.
For a perfectly elastic linear collision between two bodies, the **relative speed of approach is equal to the relative speed of separation.** $\mathrm{u_1} - \mathrm{u_2} = \mathrm{v_1} - \mathrm{v_2}$

An inelastic collision between two objects is one which the total kinetic energy of the system is lower after the collision than before.
However, momentum of an isolated system is **always conserved**.

Forces

A force is a vector quantity which **changes the state of rest or uniform motion of a body**.
It is defined as being proportional to the **rate of change of momentum** of an object which is free to move.
A force and the change in momentum are always in the **same direction**.

Field of Force is a region of space surrounding a body within which it can exert a force on another similar body which **may not be in contact** with it.

An electric field is a region of space where a force acts on a **stationary** charge.
A gravitational field is a region of space where a force acts on a mass.
A magnetic field is a region of space where a force acts on a moving charge (current) or a North Pole.

A contact force is a force between two objects that are in contact with each other. Usually, a contact force has two components.
The component perpendicular to the surface is the normal force, and the component parallel to the surface is the frictional force.

Frictional force is the tangential force that exists between **two contact surfaces** when one attempts to slides or slides along another, opposing the motion.
Viscous force (drag force) is the resistive force that an object experiences when it **moves through a fluid**.
Both viscous force and frictional force opposes relative motion, however viscous force is dynamic, while frictional force is static or kinetic.

Tension is the force which is transmitted through a string, rope, cable, or wire when it is pulled tight by opposite ends.

Hooke's law states that for **relatively small deformations** of an object **within the elastic limit** of a solid material,
the displacement or **size of the deformation** is **directly proportional** to the **deforming force**.
$\mathrm{F} = \mathrm{kx} = \mathrm{k}(\mathrm{x}_1 - \mathrm{x}_0)$
The elastic potential energy in a deformed material is the area under the force extension graph.
$\mathrm{EPE} = \frac{1}{2}\mathrm{kx}^2$

Pressure is defined as the **normal** force exerted per unit area.

$p = F/A = \rho g h$

Upthrust is the upward force exerted on an object due to the displacement of fluid in which the object is submerged.

$U = -W = -mg = -\rho V g$

Archimedes' Principle states that when an object is totally or partially immersed in a fluid in equilibrium,
it experiences an upward force (**upthrust**) **equal to the weight of the fluid displaced**.

Principle of Flotation states that a **floating object** in equilibrium displaces a weight of fluid (upthrust) equal **to its own weight**

Centre of gravity is a single point at which the whole weight of a body may be considered to act.

Moment of a force is defined as the product of the **force** and the **perpendicular distance from the line of action** of the force to the **pivot**.

$T = F \cdot d$

Couple is a system of forces which tends to produce a turning effect (rotation) only.
A couple consists of two forces that are **anti-parallel**, of **equal magnitude** and do **not** act along the **same line of action**.

The **Principle of Moments** states that for a system in (rotational) equilibrium,
the **sum of clockwise moments** about **any point** is **equal** to the **sum of anticlockwise moments** about that point.

For a system in (complete) equilibrium,
- The **resultant force** on the body must be **zero** (**translational** equilibrium)
- The **resultant moment** on the body **about any axis** must be **zero** (**rotational** equilibrium)

Work Energy Power

Work is defined as the **product** of a **force** and the **displacement** in the **direction of the force**.
Net work done is defined as the **product** of the **net** force and the **displacement in the direction** of the net force.
$W = F \cdot s$

Energy is defined as the **capacity of a system to do work**.
Work is alternatively defined as a process of **converting energy** from one form to another **through a force**.

Kinetic energy is the energy which the object processes due to its **motion**.
$$\mathbf{E_k = \frac{1}{2}mv^2 = \frac{\rho^2}{2m}}$$
Work-energy theorem states that the **change in kinetic energy** of a rigid object is equal to the **net work done** on that object by the **net force** acting on it. $\Delta KE = W$

Derivation of kinetic energy from the equations of motion:
$v^2 = u^2 + 2as$ when $u = 0$, $a = \frac{v^2}{2s}$
Kinetic energy of the object of mass m = work done by force F on the object over displacement s
$$E_k = F(s\cos 0) = (ma)s = m\left(\frac{v^2}{2s}\right)s = \frac{1}{2}mv^2$$

Potential energy $\mathbf{E_p}$ is the energy **stored** within a system as a result of **the position, configuration or shape** of the **different parts** of the system.

Gravitational potential energy is energy associated with the conservative gravitational forces between masses in a system. $\mathbf{GPE = mgh}$ or $-\mathbf{\frac{GMm}{r}}$	**Elastic** potential energy is associated with the restoring (elastic) force that a spring or elastic object exerts when stretched or pulled. $\mathbf{EPE = \frac{1}{2}ke^2} = \frac{1}{2}k(x - x_0)^2$	**Electric** potential energy is associated with the conservative Coulomb forces between charged particles in a system. $\mathbf{EPE = \frac{1}{4\pi\varepsilon_0} \times \frac{qQ}{r}}$
Derivation of GPE Gravitational Potential energy of the object of mass m = work done by gravitational force $F(W = mg)$ on the object over displacement s $GPE = F(s\cos 0) = Wh = mgh$	**Derivation of EPE** Work done on spring = average force × extension $W = \frac{1}{2}Fx = \frac{1}{2}kx^2$ By conservation of energy, $EPE = W = \frac{1}{2}Fx = \frac{1}{2}kx^2$	

Principle of Conservation of Energy states that the **total** amount of **energy** of an **isolated** system **remains constant regardless** of **changes** within the system.
Energy can be **transformed** from one form to another but **cannot be destroyed or created**.

A cyclist travelling at **constant speed** has **constant kinetic energy** and is therefore **not transforming any form of energy into kinetic energy**.
However, in order to **maintain** constant speed, the cyclist has to **overcome various resistive forces**.
Most of the **chemical energy** stored in muscles is transformed into the **cyclist's body heat**; as well as **heat in the gears and tyres, on the road, and in the surrounding air**.
Some may be transformed into **sound** in the **form of noise**.

At equilibrium position, its **KE** (the oscillating mass) is the maximum, with some **GPE**, while it the spring contains some **EPE**. (Explain short forms)
As the mass moves **upwards** from its equilibrium position to the uppermost position, its KE and the spring's EPE are **converted into its GPE**.
At its uppermost position, its GPE is at maximum, its KE is zero, and the spring EPE is the minimum. (Continue accordingly)

For radioactive decays, the combined rest mass of the products would always be less than the mass of the parent nucleus.
The mass defect Δm and the gain in **binding energy ΔE** are related by the equation $\Delta E = \Delta mc^2$, where c is the speed of light in space.
The energy ΔE is converted partly into **kinetic energy of the products** and partly into **radiation energy such as γ-gamma radiation**.

Power is defined as the work done per unit time.
$P = W/t$

Derivation of power as the product of force and velocity
$$\textbf{Average power } \langle \mathbf{P} \rangle = \frac{\text{Total Work Done}}{\text{Total Time Taken}} = \frac{\Delta W}{\Delta T} = \frac{F\Delta x}{\Delta T} = \mathbf{F}\langle \mathbf{v} \rangle$$
$$\text{At any instant}, \Delta T \to 0, \qquad \mathbf{P} = \mathbf{Fv}$$

Energy efficiency refers to the **percentage** of **useful** energy output over the **total** energy input.
$$\text{Efficiency} = \frac{\text{Useful energy output}}{\text{Total energy input}} \times 100\%$$

Feasibility evaluation of **Kinetic Energy Restoration System** (KERS)
Effectiveness: More energy is required for the vehicle to maintain its constant speed for a short period of time, than to accelerate to that speed.
Efficiency: Such restoration system may not recover all kinetic energy.
Weight: More energy is required for the vehicle to accelerate, affecting the motor power.
Cost: Energy saved might be negligible compared to the cost of equipment.

Circular motion

Uniform circular motion of an object occurs when an object is moving in a circle at **constant speed**.

Angular displacement θ is given by the ratio of the arc length to the radius.
$s = r\theta$

Angular velocity ω is defined as the rate of change of angular displacement.
$\omega = d\theta/dt = 2\pi f = 2\pi/T$
Period T is the time taken for an object to complete one revolution.
Frequency is the number of revolutions made in a unit time.

Tangential velocity refers to the linear velocity of the object moving in a circle.
$v = r\omega$

Centripetal acceleration is the rate of change of tangential velocity.
$$a_c = r\omega^2 = \frac{v^2}{r} = r\frac{4\pi^2}{T^2}$$

Centripetal force is the **net force** acting on an object causing it to move in a circular path, and
it is directed inwards, towards the centre of the path (or perpendicular to the tangential velocity).
$F_c = ma_c = mr\omega^2 = mv^2/r$

Vertical circular motion (where circular motion is affected by gravity)
Derivation of the minimum speed for horizontal circular motion

For the object at the top of the circle A to continue travelling in a circle, $F_{\text{on object}} = F_c \ \Rightarrow\ T_A + mg = \frac{mv_A{}^2}{r}$

As the tensional force $T_A \geq 0$, $\frac{mv_A{}^2}{r} \geq mg \ \Rightarrow\ v_A{}^2 \geq rg \ \Rightarrow\ \mathbf{v_A \geq \sqrt{rg}}$

Due to the conversation of energy, $\frac{1}{2}mv_A{}^2 + mg(2r) = \frac{1}{2}mv_B{}^2 \ \Rightarrow\ v_A{}^2 + 4gr = v_B{}^2 \ \Rightarrow\ v_B \geq \sqrt{5rg}$

Gravity

Newton's Law of Gravitation states that the **force of attraction** between **two point objects**
is **directly proportional** to the **product of their masses** M, m and
inversely proportional to the **square** of the **distance** r **between them**.

$$F_g = \frac{GMm}{r^2}$$

The **gravitational field strength g** at a point in a gravitational field at a distance r from point mass M is defined as
the **gravitational force** <u>**per unit mass**</u> acting on a **point mass** placed at that point in the gravitational field.

$$g = \frac{F_g}{m} = \frac{GM}{r^2}$$

On the surface of the Earth, **field lines** appear to be **parallel**. Over **small distances**, field strength and direction does not change.
The gravitational field strength g is **approximately constant and equal** to the **acceleration of free fall**.

The **gravitational potential energy $\mathbf{U}$** of a body of mass m in a gravitational field at a distance r from point mass M is defined as
the **work done** by an **external agent** to **bring the mass $\mathbf{m}$** from **infinity to that point**.

$$U = -\frac{GMm}{r}$$

Resultant gravitational force is the gradient in the gravitational potential energy-displacement graph.

$$F_g = -\frac{dU}{dr}$$

The **gravitational potential $\mathbf{\Phi}$** at a point in a gravitational field at a distance r from point mass M is defined as
the **work done** <u>**per unit mass**</u> by an **external agent** in **bringing a point mass** from **infinity to that point**.

$$\Phi = \frac{U}{m} = -\frac{GM}{r}$$

Equipotential line (or surface) is the line (or surface) where all points on it have the same gravitational potential.

Resultant gravitational field strength is the gradient in the gravitational potential-displacement graph.

$$g = -\frac{d\Phi}{dr}$$

Derivation of Kepler's third law

$$F_c = F_g \quad \Rightarrow \quad \frac{GMm}{r^2} = mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2 \quad \Rightarrow \quad \mathbf{T^2} = \left(\frac{4\pi^2}{GM}\right)\mathbf{r^3}$$

Derivation of velocity and kinetic energy of an object in orbit

$$F_c = F_g \quad \Rightarrow \quad \frac{GMm}{r^2} = \frac{mv^2}{r} \quad \Rightarrow \quad v = \sqrt{\frac{2GM}{r}} \quad \Rightarrow \quad E_K = \frac{GMm}{2r}$$

Derivation of escape velocity

$$E_T = E_K + E_P = \frac{1}{2}mv^2 + \left(-\frac{GMm}{r}\right) > 0 \quad \Rightarrow \quad \frac{1}{2}mv^2 > \frac{GMm}{r} \quad \Rightarrow \quad v > \sqrt{\frac{2GM}{r}} = \sqrt{2gR}$$

The value of free fall measured at the equator is smaller because it is actually the field strength minus the centripetal acceleration,
and the latter is proportional to the radius of rotation which is smallest near the poles and greatest near the equator.
The equator is also further away from the centre of the Earth which is flatter at the poles. However, the differences are small.

A **geostationary orbit** refers to a circular orbit around the Earth on which a satellite would appear stationary to an observer on the Earth surface.
To have the same angular velocity with the Earth, a geostationary satellite must have a period $T = 24$ hours, so radius of geostationary orbit $\mathbf{r = 42300km.}$
To appear stationary to the observer, its orbital is in the plane of the equator, and in a direction from West to East.

Geostationary satellites are placed in the geostationary orbits for relaying telephone, radio, and television signals.
They could remain at the **same relative location** in constant electronic line-of-sight to the stations on the Earth's surface, so that communications is better facilitated.

Weightlessness experienced by an individual in an orbiting satellite
In an orbiting satellite, both the man and the satellite experience the **same centripetal acceleration** due to gravitational pull.
The man experience weightlessness because he **does not accelerate with respect to the satellite**. Weightlessness is **not due to absence of gravitational field/force**.

The weight of a body is smaller at equator compared to that at poles because at the equator, because
the gravitational attraction of the Earth must provide both the weight and the centripetal force due to circular motion of the body.

Thermal Physics

Temperature is the measure of the degree of hotness of an object.
The Zeroth Law of Thermodynamics states that if A is in thermal equilibrium with B and if B is in thermal equilibrium with C, then A is in thermal equilibrium with C. Regions of **equal temperature are in thermal equilibrium**, and there is no net heat flow between them.
Thermal energy is naturally transferred from high temperature to low temperature until they achieve thermal equilibrium.

The thermodynamic scale is an absolute scale of temperature based on the Kelvin's scale which does not **depend on the properties** of any particular substance.
On the thermodynamic (Kelvin) scale, absolute zero is the temperature at which all substances have a **minimum** (not zero) **internal energy**.

$$\mathrm{T} = \frac{(\mathrm{pV})}{(\mathrm{pV})_{\text{triple point of water}}} \times 273.16$$

Heat is the energy transferred by **conduction, convection or radiation** from one body to another **due to a temperature difference**.

Heat capacity $\mathbf{C}$ of a substance is defined as the amount of energy Q required to produce a unit temperature rise ΔT in the body.
$Q = C\Delta T$

Specific heat capacity c of a substance is defined as the amount of energy Q required **per unit mass of the substance** to produce a unit temperature rise ΔT in the body.
$Q = mc\Delta T$

<u>Experimental determination of specific heat capacity of good thermal conductors</u> (metals):
The material is made into a **cylinder block with holes** for an **electric heater (12V, 3A)** and a **thermometer (of low heat capacity)**.
The block is lagged with **insulated jacket** (expanded polystyrene).
Measure **mass $\mathbf{m}$ of the block** and **initial temperature $\mathbf{T_1}$.**
Switch on a **suitable steady current** and **start timing** with a **stopwatch**. Record the **voltmeter and ammeter reading $\mathbf{V}$ and $\mathbf{I}$**.
When the temperature has risen by about $10\mathrm{K}$, the current is switched off. Note the time t taken and the highest reading T_2 on thermometer.
Assuming heat absorbed by thermometer and insulating jacket is negligible,
electrical energy supplied by heater = heat received by the metal block

$$Q = IVt = mc(T_2 - T_1) \qquad c = \frac{IVt}{m(T_2 - T_1)}$$

<u>Experimental determination of specific heat capacity of liquids at room temperature</u>:

Measure **mass $\mathbf{m}$ of the liquid**, **mass of the colorimeter** and **initial temperature $\mathbf{T_1}$.**

Switch on a **suitable steady current** and **start timing** with a **stopwatch**. Record the **voltmeter and ammeter reading $\mathbf{V}$ and $\mathbf{I}$**.

When the temperature has risen by about $10\mathrm{K}$, the current is switched off. Note the time t taken and the highest reading T_2 on thermometer.

Assuming heat absorbed by thermometer, insulating stand and the insulating jacket is negligible,

electrical energy supplied by heater = heat received by the metal block + energy gained by colorimeter and stirrer

$$Q = IVt = mc(T_2 - T_1) + m_c c_c (T_2 - T_1) \qquad c = \frac{IVt - m_c c_c (T_2 - T_1)}{m(T_2 - T_1)}$$

Specific latent heat of fusion L_f is the quantity of **energy** Q required to **change a unit mass of a substance** from **solid to liquid without a change of temperature**.

<u>Experimental determination of latent heat of fusion of water</u>:

A heater connected to a power supply IV is immersed in ice at $0°C$ in a funnel.

When the rate of melting has stabilised, the stopwatch is started. Record the voltmeter and ammeter reading V and I.

The heat produced by the heater melts the ice and a mass m of water is collected in time t.

Electrical energy supplied – Heat gained = Latent heat

$IVt - h = mL_f$

To eliminate heat gain $\mathbf{h}$, the experiment is now run again with a different power input $I'V'$, collecting mass m' in the same time t.

Although the rate of melting is different, **heat gain $\mathbf{h}$**, which is dependent on the time and temperature difference, remains the **same**.

$$L_f = \frac{(IV - I'V')t}{(m - m')}$$

Specific latent heat of vaporization L_v is the quantity of **energy** Q required to **change a unit mass of a substance** from **liquid to gas without a change of temperature**.

<u>Experimental determination of latent heat of fusion of water</u>:

A heater connected to a steady power supply IV is immersed in boiling water at $100°C$ in a double-walled glass vessel.

When the water is steadily boiling, the stopwatch is started. Record the voltmeter and ammeter reading V and I.

The heat produced by the heater vaporises the water and a mass m of water is collected in the condenser in time t.

Electrical energy supplied – Heat lost = Latent heat

$IVt + h = mL_v$

To eliminate the heat loss $\mathbf{h}$, the experiment is now run again with a different power input $I'V'$, collecting mass m' in the same time t.

Although the rate of melting is different, **heat loss $\mathbf{h}$**, which is dependent on the time and temperature difference, remains the **same**.

$$L_v = \frac{(IV - I'V')t}{(m - m')}$$

Kinetic model of matter suggest that all matter **consist of particles** in **random** and **continuous motion**.
In solids, motion is **limited to the vibrations** of the particles about their mean position in the lattice structure.
In liquids, particles are in random motion through the body of the liquid in closely spaced structure in **irregular alignments** and **no fixed positions**.
In gases, particles are far apart, and in random motion at high speeds throughout the space occupied.

When temperature is at melting point, the atoms and molecules **vibrate so violently** that
the molecules are able to **sufficiently overcome the intermolecular forces** between them and **break free from their fixed positions**.
Hence the **lattice structure collapses** and the **solid undergoes a phase change**.
During this process at melting point, the thermal energy supplied to the solid **does not cause an increase in kinetic energy** and hence, **temperature does not increase**.
All thermal energy, known at latent heat of fusion, goes to **increasing the potential energy** of the molecules, hence the **average space** between the molecules.

When the temperature is at boiling point, the atoms and molecules **move so violently** that
the molecules are able to **completely overcome the intermolecular forces** between them and **allowing the molecules to move independently**.
During the process at boiling point, the thermal energy supplied to the liquid **does not cause an increase in kinetic energy** and hence, **temperature does not increase**.
All thermal energy, known as latent heat of vaporisation, goes to **increasing the potential energy** of the molecules, hence the **average space** between the molecules.
In addition, energy supplied goes to enable the gas to expand against the atmospheric pressure.
Boiling will go on till all molecules have broken free of their closely spaced structure.

The heating curve of water shows the behaviour of water at various points in time when it is getting a continuous supply of energy at a constant rate.

The specific latent heat of vaporisation $\mathrm{L_v}$ is greater than specific latent heat of fusion $\mathrm{L_f}$ for the same substance.
For **boiling/vaporisation**, **more work** is required to **completely overcome** the intermolecular forces
as compared to the work required to just **sufficiently overcome** the intermolecular forces during **melting**.
Hence the **increase in potential energy** of molecules when a liquid boils is much **greater** than when a solid melts.
During boiling/vaporisation, the gas molecules also **need energy to expand against the external pressure**.

Evaporation takes at the exposed surface of a liquid at any temperature.
The **more energetic molecules** near the surface of the liquid (processing the **higher amount of kinetic energy** attained due to **random collisions**),
will be able to **completely overcome the intermolecular forces** of the molecules in the liquid and **escape** to become molecules in gaseous state.
The remaining molecules in the liquid will thus have a **lower <u>mean</u> kinetic energy**.
Since temperature is a measure of the average kinetic energy, the remaining liquid will become cooler. Hence, a cooling effect accompanies evaporation.

An ideal gas is hypothetical perfect gas which obeys the ideal gas equation $\mathbf{pV = nRT}$
where p is the pressure of the gas, V is the volume occupied by the gas,
n is the number of moles of the gas molecules, T is its absolute temperature and R is the molar gas constant.

Basic assumptions of the Ideal gas equation
Volume of gas molecules is **negligible** compared to the **volume it occupies**.
Intermolecular forcers of attraction between gas molecules are **negligible**.
All molecular collisions are perfectly **elastic**. There is **no loss of kinetic energy** during collisions.

In **real gases**, the internal energy $\mathbf{U}$, comprises mainly $\mathbf{E_K}$ of **translation, rotation** (diatomic and polyatomic) and **vibration** (diatomic and polyatomic at high T)
The potential energy component $\mathbf{E_P}$ is **significant** only when the **pressure** in high, because the **intermolecular forces cannot be ignored**.

Avogadro constant is equal to the number of atoms in 0.012 kg of $^{12}\mathrm{C}$. $\mathbf{L = 6.02 \times 10^{23}}\,\mathrm{mol^{-1}}$
One mole of any substance is the amount containing a number of particles equal to the Avogadro constant.

The ideal gas equation can also be written as $\mathbf{pV = NkT}$
where N is the total number of molecules, and k is the Boltzmann constant, the gas constant for an individual molecule. $\mathbf{k = R/L = 1.38 \times 10^{-23}}\,\mathrm{JK^{-1}}$

Based on the model of the ideal gas, the pressure p of a gas is given by

$$\mathbf{p = \frac{1}{3}\rho\langle c^2\rangle}$$

where ρ is the density of the gas, and $\langle c^2\rangle$ is the mean squared speed of the gas molecules.

Based on the Kinetic energy equation $\mathrm{p} = \frac{1}{3}\boldsymbol{\rho}\langle c^2\rangle = \frac{1}{3}\left(\frac{\mathbf{Nm}}{\mathbf{V}}\right)\langle c^2\rangle$, where N is the number of molecules, m is the mass of one molecule.
Rearranging the above equation, $\mathrm{pV} = \frac{1}{3}\mathrm{Nm}\langle c^2\rangle = \frac{2}{3}\mathrm{N}\left(\frac{\mathbf{1}}{\mathbf{2}}\mathbf{m}\langle \mathbf{c^2}\rangle\right) = \frac{2}{3}\mathrm{N}\langle \mathbf{E_K}\rangle$, where $\mathrm{E_K}$ is the kinetic energy of **one** molecule.
Based on the Ideal gas equation, $\mathbf{pV} = \mathrm{nRT} = \mathbf{NkT} = \frac{\mathbf{2}}{\mathbf{3}}\mathbf{N}\langle\mathbf{E_K}\rangle$, hence **translational** $\mathbf{E_K = \frac{3}{2}kT}$

Mean kinetic energy $\langle\mathbf{E_K}\rangle$ of a molecule of an ideal gas is **proportional** to the **thermodynamic temperature** $\mathbf{T}$.

Internal energy U of a system is the sum of the **kinetic energies $\mathbf{E_K}$ due to the random motions** of the particles and the **potential energies $\mathbf{E_P}$** associated with the **relative positions of the particles** that make up the system.

In ideal gases, the internal energies are made up only by the sum of translational kinetic energy $\mathrm{E_K}$ processed by the particles, because the intermolecular forces of attraction are negligible, hence potential energies arising from the distribution of particles in the system is also negligible.

A thermodynamic process takes place when a system **changes** from an **initial equilibrium state** (temperature, pressure, volume) to **another final equilibrium state** in a system of **fixed mass of ideal gas** in a cylinder with a moving piston.

The First Law of Thermodynamics states that the **<u>increase</u> in internal energy $\Delta\mathbf{U}$** is equal to the sum of **heat <u>supplied</u> $\mathbf{Q}$** to the system and the **work done $\mathbf{W}$ <u>on</u>** the system.
$\Delta\mathbf{U} = \mathbf{Q} + \mathbf{W}$

The area under the $\mathrm{p} - \mathrm{V}$ curve represents the work done on gas. $\mathbf{W_{on\ gas}} = -\int_{\mathbf{V_i}}^{\mathbf{V_f}} \mathbf{p\ dV}$
Positive work is done by an agent when displacement and the force exerted by the agent acts in the same direction.
"Work done W **by** a gas which is expanding against a **constant external pressure** $\mathrm{W_{by\ gas}} = \mathrm{p}\Delta\mathrm{V}$"

Cylindrical process happen when internal energy remains constant (by restoring the system back to the initial state) forming a closed loop in the $\mathrm{p} - \mathrm{V}$ graph.
$\Delta\mathrm{U} = 0 \Rightarrow \mathrm{Q} = -\mathrm{W_{on\ gas}}$

Isothermal process happens when temperature remains constant (by submerging system in an external constant temperature environment).
$\Delta\mathrm{T} = 0 \Rightarrow \Delta\mathrm{U} = 0 \Rightarrow \mathrm{Q} = -\mathrm{W_{on\ gas}}$

Isovolumetric process happens when volume remains constant (by having the piston fixed in an external changing temperature environment)
$\mathrm{W_{on\ gas}} = -\mathrm{p}\Delta\mathrm{V} = 0 \Rightarrow \Delta\mathrm{U} = \mathrm{Q}$

Isobaric process happens when pressure remains constant (by having a free sliding piston to vary volume as temperature changes)
$\mathrm{W_{on\ gas}} = -\mathrm{p}\Delta\mathrm{V}$

Adiabatic process happens when thermal energy ($\propto$ kinetic energy) remains constant (no heat exchange with the external environment)
$\mathrm{Q} = 0 \Rightarrow \Delta\mathrm{U} = \mathrm{W_{on\ gas}}$

In some industrial applications, cooling of gas is done by subjecting the gas to repeated quick expansion.

Oscillations

Free oscillation is an oscillation which occurs at the **natural frequency** of a body when displaced from the equilibrium position and is allowed to oscillate freely without the application of any external periodic force.
Examples include **mass oscillating at the end of the spring**, **oscillation of a simple pendulum** and **vibration of springs**.

Simple harmonic motion is defined as motion taking place in which the **acceleration** of a body is **proportional** to the **displacement** of the body from a fixed point (equilibrium position) and is in the **opposite direction** to the displacement (always directed towards that point)
$a = -\omega^2 x$
The body is in sinusoidal motion with constant amplitude and a single frequency.

Investigation of the motion of an oscillator using experimental and graphical methods
A mass m is attached to a spring oscillates vertically up and down with
a pointer attached to the mass m leaves a record of it motion on a **sheet of paper** that is moving at **constant speed** to the right.
It is clear that the motion is about an equilibrium point, and **limited** between C and C'.
As the path marked by the pointer is **sinusoidal**, it may be described by the sine and cosine functions.

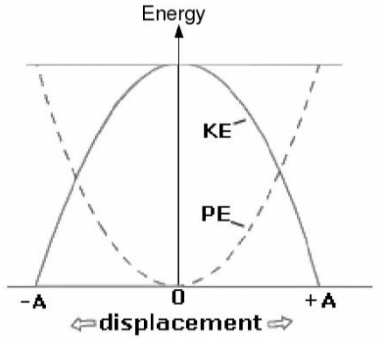
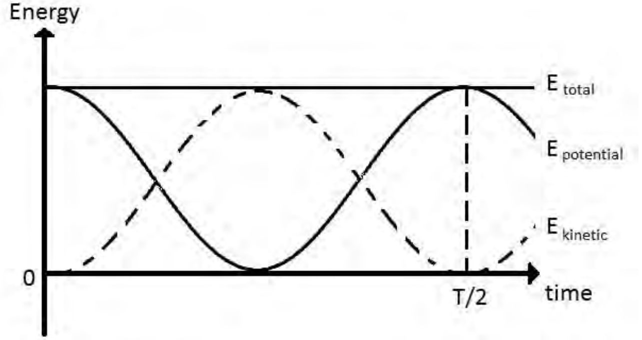
Equilibrium position is a position at which **no net force** acts on an oscillating body.
Displacement x is the **linear distance** of the oscillating body from its **equilibrium position** at any instant in **a specified direction**.
Amplitude x_0 is the magnitude of the **maximum value of displacement** from the equilibrium point.

Period T is the **time** required for **one complete oscillation**/vibration/cycle of motion.
Frequency f is the **number of complete oscillation**/vibration/cycles made **per unit time**.
$f = 1/T$
Angular frequency ω is constant of the given oscillator and is related to its natural frequency by
$\omega = 2\pi f = 2\pi/T$

Phase angle φ (in degrees or radians) which gives a measure of the **fraction of a cycle** that has been completed by an oscillating particle or wave.
Phase difference $\Delta\varphi$ is a measure of how much one oscillation (or wave) is out of step with another.
$$\Delta\varphi = 2\pi \times \frac{\Delta x}{\lambda} = 2\pi \times \frac{\Delta t}{T}$$

For a oscillating particle, starting from equilibrium position in an upward direction

	Displacement	Velocity	Acceleration
Displacement	x	$v = \pm\omega\sqrt{x_0^2 - x^2}$	$a = -\omega^2 x$
Time	$x = x_0 \sin(\omega t)$	$v = v_0 \cos(\omega t) = x_0\omega \cos(\omega t)$ obtained by differentiating with respect to t	$a = -a_0 \sin(\omega t) = -x_0\omega^2 \sin(\omega t)$ obtained by differentiating with respect to t again

	Displacement	Time
Energy (Potential energy is defined as zero at equilibrium position.)	[1] $E_T = E_K + E_P = \frac{1}{2}m\omega^2 x_0^2$ $E_K = \frac{1}{2}m\,v^2 = \frac{1}{2}m\omega^2(x_0^2 - x^2)$ $E_P = E_T - E_K = \frac{1}{2}m\omega^2 x^2$	[2] $E_T = E_K + E_P$ $E_K = E_T \sin^2 \omega t$ $E_P = E_T \cos^2 \omega t$

[1] http://www.astarmathsandphysics.com/a_level_physics_notes/waves_and_oscillations/a_level_physics_notes_energy_changes_in_simple_harmonic_motion_html_m2b927bb6.gif
[2] http://nothingnerdy.wikispaces.com/file/view/shm_energy-time_graph.jpg/223974328/shm_energy-time_graph.jpg

Damping is the process whereby **energy is taken** from the oscillating system,
resulting in the amplitude of oscillation decreasing until the system return to its equilibrium position eventually.

If a simple harmonic motion is subjected to frictional (dissipative) forces, the **amplitude** of a damped oscillating object **gradually decreases**.

In **light** damping, there is **definite oscillation**, but the amplitude of the oscillation decreases with time.
The **frequency** of the oscillation is usually only **slightly affected**.

In **heavy** damping, there is no real oscillation, the system returns very slowly to the equilibrium position.
Examples include a simple pendulum in a very viscous liquid.

In **critical damping**, there is no real oscillation; the system takes **minimum time** for the **displacement to become zero**.
Examples include an ammeter pointer and car suspension system.

Critical damping has **important** applications because
too little damping results in **a large number of oscillations** while
too much damping causes it be **displaced for too long** and the system **cannot respond to further changes**.
Instruments such as balances and electrical meters are critically damped (dead beat) so that the pointer moves quickly to the correct position without oscillating.
The shock absorbers on a car critically damp the suspension of the vehicle and so resist the setting up of vibration which could make control difficult or cause damage.

Forced oscillations is motion produced when a system is **acted upon by an external force**, examples include
a balance wheel of a watch will cease to oscillate unless energy is supplied to it from the spring of the watch.

Resonance is a phenomenon that occurs when the frequency an object is made to vibrate (forcing frequency) is equal to its **natural (resonant) frequency**, causing the object to vibrate at large amplitude.

Natural frequency of a system is the frequency at which it will oscillate if left to oscillate freely.

When the **forcing frequency** is equal to the **natural frequency**, there is a **maximum transfer of energy** from the forced vibration, setting the object into large amplitude of vibration.
When the forcing frequency deviates from the natural frequency, motion of vibration is opposed by the nature of the material, and energy from the external agent is not efficiently transferred into the system.
Hence, for a degree of damping, **amplitude** of vibration is **largest** when forcing frequency is equal to the natural frequency. $f = f_0$

With heavier damping, all amplitudes (at all frequencies) are reduced, where the resonant frequency is **less pronounced** (shorter and flatter).
The resonant frequency is **shifted to the left (lower)**.

Destructive resonance

High pitch sound waves, (external agent) acts as a forced vibration on the crystal goblet and can shatter it.
When the **forcing** frequency of note sung by the tenor equals to the **natural frequency** of the crystal goblet, there is a **maximum transfer of energy** from the forced vibration to the goblet, setting it into large amplitude of vibration.
When the amplitude is **beyond the elastic limit** of the goblet, the goblet shatters.

Applications of resonance

The **electrons** in a radio receiving **aerial** are forced to **vibrate** by the radio waves passing the aerial, generating a **current** in the receivers.
If the aerial is the correct length for the particular frequency being used, then the large amplitude of the oscillation electrons provides a stronger signal for the receivers.

A **microwave** oven uses a frequency equal to the **natural frequency of water molecules**, so that they can **absorb maximum energy** from the microwaves and consequently heating up.

Magnetic resonance is being used to detect the **presence** of particular **molecules** within any specimen.
Strong varying radio frequency electromagnetic fields are used to cause the **nuclei** of the atoms to oscillate.
The pattern of energy absorption can be used to detect the presence of particular molecules within any specimen.

<u>Wave motion</u>

A wave is a disturbance that propagates through space and time, transferring energy from one point to another with no associated matter transport.
A progressive wave is the movement of a disturbance from a source which transfers energy from the source to places around it.

Mechanical waves (sound waves) require a medium to travel, while
non-mechanical waves (electromagnetic waves) do not require a medium to travel.

A **transverse** (**longitudinal**) wave is a wave which causes disturbances at
right angles to (**along the**) direction in which the energy of the wave is travelling.

A **crest** (**trough**) is a point in the medium through which a **transverse** wave is travelling which has the
maximum (**minimum**) amount of **positive** (**negative**) or **upward** (**downward**) **displacement** from the rest position.

A **compression** (**rarefaction**) is a point in a medium through a **longitudinal** waves is travelling has the
maximum (**minimum**) density.

Wavefront is a surface over which the disturbance has the **same phase** at all points.

Displacement is the linear distance that a particle of the medium is being displaced from its equilibrium position at any instant in a specified direction.
Amplitude is the maximum displacement of a particle from its equilibrium position.
Period is amount of time taken for one complete vibration to pass through a given point.
Phase difference $\Delta\varphi$ is a measure of how much one oscillation (or wave) is out of step with another.
$$\Delta\varphi = 2\pi \times \frac{\Delta x}{\lambda} = 2\pi \times \frac{\Delta t}{T}$$
Phase φ is an angle (in degrees or radians) which gives a measure of the fraction of a cycle that has been completed by an oscillating particle or wave.

Frequency is the number of complete oscillations or vibrations (or cycles) that pass through a given point per unit time.
Wavelength is distance between two successive points of the same phase in a progressive wave.
Wave speed (velocity of propagation) is the distance travelled by the wave per unit time.

Derivation of the wave equation
In the time Δt the number of waves with a wavelength λ pass through a fixed point is $f\Delta t$.
Speed of wave $v = \frac{\text{total distance}}{\text{time}} = \frac{f\Delta t\,\lambda}{\Delta t} = f\lambda$

Energy is transferred due to a progressive wave.
$E = f^2A^2$

The intensity I of a wave is defined as the average energy transferred by the wave per unit area.
$I \propto E \propto A^2$
In uniform propagation of radiation spherically $I = \frac{P}{4\pi r^2} \propto 1/r^2$
In uniform propagation of water waves radially $I = \frac{P}{2\pi r} \propto 1/r$

Polarisation is the process of **confining the oscillations of the vector constituting a transverse wave** to **one plane**.
In unpolarised radiation the vector oscillates in all planes perpendicular to the direction of propagation.
In the polarisation of light, the oscillations of the **electric** vector of light waves are confined to one plane.

When the axis of polarisation of B is **equal** to the axis of polarisation of A, the **all** plane polarised light from A is transmitted through B.
However, when the axis of polarisation of B is **perpendicular** to the axis of polarisation of A, **no** light from A is transmitted through B.

Applications of polarisation
Microwaves from an antenna are already plane-polarised and can be analysed by another antenna.

Superposition

The principle of superposition states that when two or more waves **meet** at a point **simultaneously**,
the **resultant displacement** at that point is the **vector sum** of the displacements **produced at that point by each of the wave separately**.

Stationary wave is formed when two progressive waves of equal amplitude and frequency travelling with the same speed in opposite directions are superposed.

Nodes are points where particles vibrate with **minimum** amplitude while
antinodes are points where particles vibrate with **maximum** amplitude.

Characteristics	Progressive Waves	Stationary Waves
Amplitude	All particles have equal amplitude.	Amplitude of vibration of the particles varies according to their positions.
Frequency	All particles vibrate in simple harmonic motion at the wave frequency …	Except for those at the nodes.
Wavelength	Defined as the distance between adjacent particles having the same phase.	Defined as twice the distance between a pair of adjacent nodes or antinode.
Particle phase	Within one wavelength, all particles have different phases.	Within two adjacent nodes, all particles have the same phase. Particles in adjacent segments are π rad out of phase.
Waveform	Advances along the wave axis at the velocity of the wave.	Does not advance
Energy	Energy is carried along the direction of the propagation.	Although vibrating particles contain energy, no energy is carried along the wave.

The **distance between two successive nodes** (or **antinodes**) is equal to **half** a wavelength $\lambda/2$ of the progressive waves. Determination of the wavelength of sound:
Move the sound sensor along the pipe to detect the **first position** where **maximum loudness** (antinode position) is measured by the oscilloscope.
Move to the next consecutive positions where maximum loudness is detected again. Take the **average** of the distance between successive antinode positions.

For **stationary waves** to be **formed** within the tube, the frequency of the sound is equal to any **resonant frequency** of the tube.
The resonant frequency of the tube **depends on the length** of the tube.
To form stationary waves, either we change the **frequency of the source** or change the **length of the tube**
which changes the resonant frequencies to **match** the frequency of the source. $\mathrm{f} = \mathrm{f}_0$

	Closed end	Open end
Type of barrier	The closed end (plunger) acts as a **hard barrier** to the sound wave.	The open end (air) acts as a **soft barrier** to the sound wave.
Reflection of wave	The reflected wave is in **anti-phase** with the incident wave.	The reflected wave is **in-phase** with the incident wave.
Phase of particle at the barrier	A direct wave superposed with a reflected wave at the hard barrier will always interfere **destructively** resulting in a **node**.	A direct wave superposed with a reflected wave at the soft barrier will always interfere **constructively** resulting in an **antinode**.

Demonstration of stationary waves		
Microwaves	Waves on a stretched spring	Waves in an air column
Set-up with the reflector placed about 1.5m away from the microwave transmitter, so the emitted microwaves will be reflected, creating a stationary wave. Move the microwave detector in the line between the transmitter and the reflector. The strength of the signal will fluctuate between the pair of minima and maxima.	When the frequency of the vibrator is same as one of the natural frequencies of the stretched spring, the amplitude of vibration will be large and it will **exhibit clearly defined nodes and segments** corresponding to the stationary waves to that particular frequency.	When the frequency of the vibrator is same as one of the natural frequencies of the air columns, **maximum loudness** will be heard.

Diffraction is the **spreading of waves** through an **aperture** or round an **obstacle**.
It is **observable** when the width of the aperture a is of the **same order** as the wavelength λ of the waves. $a \sim \lambda$
Diffraction is one of the defining characteristics of the wave.

Interference is the superposition of two or more waves travelling in the same region to give a resultant wave.
Constructive interference happens when two or more waves are all in phase at a point, and added to give maximum amplitude.
Destructive interference happens when two or more waves are in anti-phase at a point, and added to give zero or minimum amplitude.

Coherence is a property of waves that indicates the ability of the waves to interfere with each other.
Coherent waves have the **same frequency** with a **<u>constant</u> phase difference** and are (for transverse waves only) either **unpolarised** or polarised in the same plane, which can be combined to produce an unmoving distribution of constructive and destructive interference (which is observable).

Single slit diffraction pattern
When a light source is passed through slit with aperture $a \sim \lambda$,
an **intense bright central band** wider than the slit is formed,
bounded by succeeding **narrower and less intense bright bands** on both sides.
The spreading of wave occurs always in a **direction perpendicular** to the linear dimension.
Huygens's principle tells us that each part of the **wavefront at the single slit can be thought as an emitter of waves** which **superpose to produce the diffraction pattern**.
As the central angle increases there is **less constructive interference** of the wavelets, so secondary and successive intensity maxima decreases.

When $a \gg \lambda$, there is little bending of the wave.
When $a \sim \lambda$ or $a < \lambda$, there is more diffraction.

Double slit diffraction pattern
For two source interference to be observed, the sources from the two slits need to be coherent.
This can be produced by passing the monochromatic light through a narrow slit which diffracts to the double slit.
The double slit will need to be placed at equal amplitudes near each other.

The separation of fringe x is defined as the separation between two consecutive dark or bright fringes on the screen.

$$\mathbf{x = \lambda D/d}$$

where $\lambda(\sim 10^{-7})$ is the wavelength of light, $D(\sim 10^{0})$ is the distance between the slits and the screen, and $d(\sim 10^{-4})$ is the **distance between the two slits**.

Diffraction pattern modulates (forms an "envelope" around) the intensity fringes.
The interference fringes vary in intensity because there is a diffraction pattern superimposed on the interference pattern.

As the diffraction pattern from each of the slits is identical, when one of the slits is covered,
the interference fringes disappear, leaving a single slit diffraction pattern, with the intensity halved.

A **diffraction grating** is special piece of glass or plastic with many slits (which can be made by cutting closely spaced lines)

$$\mathbf{d\sin\theta = n\lambda}$$

where d is the **grating spacing**, θ is the angle of the maximum from the central maximum and n is the order of the maximum.

Two source interference	Diffraction grating
Broad fringes are observed.	Bright sharp lines are observed. There are clearer boundaries to measure the central angle θ for the determination of the wavelength.
When light containing a mixture of wavelength (white light), the broad fringes of light generated from each of the wavelength overlaps each other.	The diffracted sharp lines will not overlap each other, unless the order of diffraction or the spread of wavelengths is large.
Broad fringes are equally spaced out.	On a surface perpendicular to the central beam of light bright lines are not equally spaced out especially when θ deviates from zero.
Only limited light can pass through the two sets of slits, a strong source is required to observe two source interference.	Diffraction grating is used so that the more light superimpose and produce a more visible pattern to determine its wavelength.

<u>Current of Electricity</u>

Electric **current** I is the **rate of flow of electric charges** through a given cross-section of the conductor.

One **ampere** A is the amount of **constant current** in two straight conductors of infinite length placed at $1\mathrm{m}$ apart, which produces an **electric force per unit length** of $2 \times 10^{-7}\ \mathrm{Nm}^{-1}$ on each wire.

Charge Q is a property of some elementary particles that gives rise to an interaction between them and consequently to the host of material phenomena described as electrical force.

One **coulomb** C is the quantity of **electric charge** that passes through a given section of the circuit when $1\mathrm{A}$ of current flows for a time of 1 second.

The conventional current direction is which the positive charges will drift, that is, in the same direction of the electric field. Electrons flow in the opposite direction of the conventional current.

The **potential difference** between two points V is equal to the amount of **electrical energy** W which is converted **<u>to other</u> forms of energy** per unit **charge** Q that passes from the point at **higher potential** to the point at **lower potential**.

One **volt $\mathbf{V}$** is the potential difference between two points in a circuit when **1 J** of **electrical energy** is **dissipated into other forms of energy** as $\mathbf{1C}$ of charge flows.

Alternatively,

The **potential difference** between two points $\mathbf{V}$ can also be defined as the amount of **electrical power dissipated $\mathbf{P}$ <u>to other</u> forms of energy** per unit **current $\mathbf{I}$** between two points.

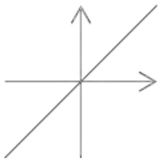
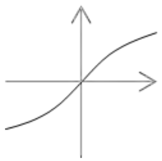
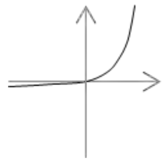
One **volt $\mathbf{V}$** is the potential difference between two points in a circuit when $\mathbf{1W}$ of **electrical power** is **dissipated into other forms of energy** as $\mathbf{1A}$ of current flows.

The **resistance** R of a conductor is defined as
the **ratio** of the potential difference V across the conductor
to the current I flowing through it.

One **ohm** Ω is the resistance of a conductor in which the current is $1A$
when a potential difference of $1V$ is applied through it.

Resistance R of a given conductor at a given temperature depends on its
length l, cross-sectional area A and the resistivity of the material ρ.
$R = \rho l/A$

An **ohmic** conductor is one that its **current** I flowing through it is **directly proportional** to the **potential difference** V between its ends (or the **resistance** R is **constant**)

$I - V$ characteristics of Metallic conductor  Filament lamp  Semiconductor diode 

As **potential difference** between the material **increases**, its equilibrium **temperature increases**.
This results in an **increase** in the number of charge carriers (free electrons) which **reduces** the **resistance**.
However, the **amplitude of vibration** of the atomic cores increases. **Resistance increases** because of the
more frequent collisions between the free electrons and the atoms that **reduce the mean drift speed** of electrons.
For lamp **filaments**, resistance **increases** because the latter effect due to thermal vibration is more significant.
For **semiconductors**, resistance **decreases** because the former effect due to increase in charged carriers is more significant.

The **electromotive force** of a source $\boldsymbol{\varepsilon}$ is the **energy** converted **<u>to electrical</u>** **energy** $\mathbf{W}$ when a unit **charge** $\mathbf{Q}$ passes through it.

Maximum Power Theorem (for internal resistance $\mathbf{r}$ and external resistance $\mathbf{R}$)

$$P = I^2R = R\frac{\varepsilon^2}{(R+r)^2},$$

For P_{max}, $\quad \frac{dP}{dR} = \frac{\varepsilon^2}{(R+r)^2} - 2R\frac{\varepsilon^2}{(R+r)^3} = 0, \quad P_{max} = \frac{\varepsilon^2}{4R}$ when $R = r$

DC circuits

The appropriate circuit symbols for
Source / Switch / Resistors / Ammeters / Voltmeters / Rheostat / Thermistors / Light dependent resistors / Transformer / Diode (try to draw them yourselves)

Effective resistance of resistors in series
$R = R_1 + R_2 + R_3 + \cdots$

Effective resistance of resistors in parallel
$R = (R_1^{-1} + R_2^{-1} + R_3^{-1} + \cdots)^{-1}$

The **resistance** of a thermistor **decreases** as **temperature increases**.
The **resistance** of a light-dependent resistor **decrease** as the light **intensity** falling on it **increases**.
Electrons are being released from the donor atoms to engage in the conduction in the specific material.

Although the moving coil voltmeter is a fast and efficient method,
it has **non-infinite resistance** and will **draw current** from the circuit.
This will **lower the potential difference** between the two ends measured, affecting the circuit.

The **potential difference** measured across the terminals of a **battery** is normally **lower** than the battery's **e.m.f.** because
the electrical energy is **dissipated as heat** in the battery due to its **internal resistance** when there is a current in the circuit.
Unless when the battery is not supplying current, the potential difference across the internal resistance is zero,
then the potential difference across a battery's terminals is equal to its e.m.f.

The **potentiometer** measures the **electromotive force** of a source **without drawing a current** from it.
By trial and error, tap the jockey J along the wire AB until the galvanometer is undeflected.
The electromotive force ε is equal to the potential difference across AJ.

$$\varepsilon = V_{AJ} = V_{AB} \cdot \frac{l_{AJ}}{l_{AB}}$$

The potentiometer consists of a uniform slide-wire of which is assumed to have a constant cross sectional area, so that its resistance per unit length R/l is constant.

<u>Electric Field</u>

Coulomb's Law states that the **force of attraction** between **two point objects** is **directly proportional** to the **product of their charges** Q,q and **inversely proportional** to the **square** of the **distance** r **between them**.

$$\mathbf{F_e = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r^2}}$$

The **electric field strength** $\mathbf{E}$ at a point in an electric field at a distance r from a point charge Q is defined as the **electric force <u>per unit POSITIVE charge</u>** acting on a **point charge** placed at that point in the electric field.

$$\mathbf{E = \frac{F_e}{q} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}}$$

Between two charged plates, **field lines** appear to be **parallel**. The electric field is **uniform** throughout provided the edge of the plates is avoided.

The **electric potential energy** $\mathbf{U}$ of a small test charge q in an electric field at a distance r from a point charge Q is defined as the **work done** by an **external agent** to **bring the charge** $\mathbf{q}$ from **infinity to that point**.

$$U = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r}$$

Resultant electric force is the gradient in the electric potential energy-displacement graph.

$$F_e = -\frac{dU}{dr}$$

The **electric potential** $\mathbf{V}$ at a point in an electric field at a distance r from a point charge Q is defined as the **work done <u>per unit POSITIVE charge</u>** by an **external agent** in **bringing a point charge** from **infinity to that point**.

$$V = \frac{U}{q} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

Equipotential line (or surface) is the line (or surface) where all points on it have the same electric potential.

Resultant electric field strength is the gradient in the electric potential-displacement graph.

$$E = -\frac{dV}{dr}$$

A charge Q on an isolated conducting sphere is **uniformly distributed** over its surface due to repulsion of like charges.
Electric field within the conductor is hence zero. This is applied in electrostatic shielding.

The force on a charged particle in a uniform electric field is **constant**,
resulting in a **constant acceleration** in the direction of the electric field.
$a_y = qE/m$
The velocity **perpendicular** to the electric field v_x will be **unchanged** because there is no horizontal force.
Hence the path of the charged particle is parabolic while in the uniform electric field. Equations of motion apply.

Electric field lines and equipotential lines should intersect at right angles.
The strength of the electric field is represented by the density of electric field lines.

Magnetic Field

A magnetic field is a region of space in which a magnetic force is experienced by a moving charge or a permanent magnet.

Magnetic flux density B of a magnetic field is the **force** F acting **per unit length** L
on a **straight wire** carrying a unit current I, which is at **right angles** to the direction of the **magnetic field**.
$B = F/IL$
Relationship between the direction of the conventional current (thumb) and the magnetic field (fingers) can be determined by the **right-hand grip rule**.

One **tesla $\mathbf{T}$** is the **magnetic flux density** which causes a **force per unit length** of **$\mathbf{1N}$ per $\mathbf{1m}$**
on a **straight wire** carrying a current of **$\mathbf{1A}$**, which is at **right angles** to the direction of the **magnetic field**.

Magnetic flux density B of a magnetic field at a point r away from a **long straight wire** carrying a current I
$B = \mu_0 I/2\pi r$

Magnetic flux density B of a magnetic field at a point inside an **air-core solenoid** carrying a current I with n turns per unit length
$B = \mu_0 nI$

Iron core has **high permeability** μ (ability to concentrate magnetic field lines and strengthen magnetic flux density).
The large increase in magnetic flux density is due to the **high degree of alignment** of magnetic domains in the ferromagnetic material.
Once the solenoid is switched on, the previously unaligned domains line up and contribute to the field, increasing the magnetic flux.

Magnetic force F on a current carrying conductor I of length L at an angle θ in a magnetic field of magnetic flux density B
$F = BIL \sin\theta$

Magnetic force F on a positive charge q travelling at velocity v at an angle θ in a magnetic field of magnetic flux density B
$F = Bqv \sin\theta$

Relationship between the direction of the magnetic force (thumb), the magnetic field (index finger) and the conventional current (middle finger)
can be determined by the **Fleming's left hand rule**.

Charged particles in circular motion in a uniform electric field

$$F_C = F_B \quad \Rightarrow \quad Bqv = \frac{mv^2}{r} \quad \Rightarrow \quad r = \frac{mv}{Bq} \quad \Rightarrow \quad f = \frac{1}{2\pi}\frac{Bq}{m}$$

Balanced electric and magnetic forces on a moving charge by a uniform electric and uniform magnetic field

$$F_E = F_B \quad \Rightarrow \quad qE = Bqv \quad \Rightarrow \quad E = Bv$$

Principle of velocity selector
Only particles having a **certain speed** can pass **undeflected** through the perpendicular electric and magnetic fields.
Charged particles with greater (lower) speed will experience more (less) magnetic force than electric force, and will be deflected in the direction of the magnetic (electric) force.

Each wire acts as a **current-carrying conductor in the magnetic field** created by neighbouring wires.
A **force** is experienced in each wire in the direction of the **magnetic field is perpendicular to the current** in each wire.
Using the Fleming's left hand rule, the **direction** of the force on each turn is towards/away the neighbouring wire.
Hence there is mutual **attraction/repulsion** between the turns.

Electromagnetic Induction

The **magnetic flux** ϕ is the (dot) **product** of the **magnetic flux density** B and the **area** A normal through it.
$\phi = BA\cos\theta$

The magnetic flux **linkage** Φ in a coil is the product of the **magnetic flux** ϕ passing through the coil and the **number of turns** N in the coil.
$\Phi = N\phi = NBA\cos\theta$

A **changing magnetic flux** induces an **e.m.f.** in the circuit.
There will be **no force** exerted and **no loss** in mechanical energy to electrical energy in an **incomplete circuit**.

Lenz's Law states that the **direction** of the **induced e.m.f.** (and induced current, only if circuit is closed) is such that is tends to **oppose** the **change** causing it.

Faraday's Law states that the **e.m.f. induced** ε in a conductor is **proportional** to the **rate of change of magnetic flux linkage** $d\Phi/dt$.

Electromagnetic Induction between a **coil** and a **magnet**
When the magnet **approaches** the coil, there is an **increase in magnetic flux** linking the coil, causing an **induced e.m.f.** in one direction.
(Consistent with the principle of conservation of energy, work has to be done to move the system against
the force of repulsion between the North Pole of the magnet and the induced north pole of the solenoid.
This mechanical work is converted to electrical energy in the current)
When the magnet **leaves** the coil, there is a **decrease in magnetic flux** linking the coil, causing an **induced e.m.f.** in the **opposite** direction.
(This mechanical work to pull the magnet away from the coil is once again transformed into electrical energy of the coil)

The **change in flux** linking the coil when the magnet **approaches** the coil would be the **same** as when the magnet **leaves** the coil,
thus there is **no net change** in magnetic flux (and thus the **area** of the graph of induced e.m.f. against time **above** and **below** the x-axis is the **same**)

When the **speed** is **constant**, the change in flux in both directions would take place over the same period of time,
hence the e.m.f. has the **same maximum value**.
When the **speed** is **increasing** (decreasing), the **time** taken for the change in flux to occur upon leaving the magnet will be **shorter** (longer),
hence the e.m.f. has a **higher** (lower) **maximum** value.

When the whole magnet is in a **long solenoid**, there is no change in flux, hence no e.m.f. is induced.

Electromagnetic Induction in a **straight conductor** of length L **moving** at velocity v.

$$\varepsilon = -\frac{d\Phi}{dt} = -\frac{d(NBA\cos\theta)}{dt} = -\frac{d(NBLx\cos\theta)}{dt} = -NBL\cos\theta\frac{dx}{dt} = -NBLv\cos\theta$$

Relationship between the direction of the motion of the conductor (thumb), the magnetic field (index finger) and the induced current (middle finger) can be determined by the **Fleming's right hand rule**.

Applications of Electromagnetic Induction

Search coil to measure magnetic flux density

A coil with N turns and area A is placed perpendicular to a magnetic field of flux density B and is connected to a ballistic galvanometer $\theta = \Delta Q/k$ (that has a high amount of inertia) with the total resistance of the circuit as R.
When coil is sharply pulled away from the magnetic field, a deflection of θ is observed, and the magnetic flux density can be calculated:

$$\varepsilon = -\frac{d\Phi}{dt} = RI = R\frac{dQ}{dt} \qquad \Delta Q = \frac{\Delta\Phi}{R} = \frac{NBA}{R} = k\theta \qquad B = \frac{k\theta R}{NA}$$

Disc Generator

A copper disc of area A is placed perpendicular to the magnetic field of flux density B and is rotated at a constant frequency f, which induces an constant e.m.f. between its centre and the rim. In one revolution, the area swept out by a radius r is $\pi r^2 = A$.

$$\varepsilon = -\frac{d\Phi}{dt} = \frac{B\Delta A}{\Delta T} = B\pi r^2 f$$

AC Generator

A coil with N turns and area A is rotating with a constant angular velocity ω in a uniform magnetic field of flux density B.
The normal of the plane of the coil makes and angle θ with the direction of the field.

$$\varepsilon = -\frac{d\Phi}{dt} = -\frac{d(NBA\cos\theta)}{dt} = -NBA\frac{d(\cos\omega t)}{dt} = -NBA(-\omega\sin\omega t) = NBA\omega(\sin\omega t)$$

Eddy currents

When moving in a magnetic field or is exposed into a changing one, the conductor has induced e.m.f., and thus eddy currents, which circulate in direction such that the magnetic fields they create oppose the motion (or the flux change) creating them, resulting in wasted energy.
By creating slots in the plate, the eddy currents will be confined within each slab, which increases total resistance and less energy is wasted.

Alternating Current

In an alternating current (AC), current varies in magnitude and direction with time.

For sinusoidal AC, the instantaneous value of the current I
$\mathrm{I} = \mathrm{I}_0 \sin(\omega t) = \mathrm{I}_0 \sin(2\pi f t)$
where I_0 refers to the maximum or peak value of the current.

$\mathrm{P} = \mathrm{IV} = \mathrm{I}_0 \sin(2\pi f t) \times \mathrm{V}_0 \sin(2\pi f t) = \mathrm{I}_0 \mathrm{V}_0 \sin^2(2\pi f t) = \mathrm{P}_0 \sin^2(2\pi f t)$
As the curve is symmetrical about $\mathrm{P}_0/2$, the **mean power** $\mathrm{P}_{\mathrm{mean}}$ in a resistive load is **half** the **maximum power** P_0 for a sinusoidal AC: $\mathrm{P}_{\mathrm{mean}} = \mathrm{P}_{\mathrm{r.m.s.}} = \mathrm{P}_0/2$
Power has a frequency of $2f$ because maximum current occurs twice per cycle.

The **root-mean-square** current/voltage is defined as the **equivalent** value of the **steady** DC which will **dissipate heat** at the **same rate** as the AC with a **given resistance**.

$$\mathrm{I}_{\mathrm{r.m.s.}} = \frac{\mathrm{I}_0}{\sqrt{2}} \qquad \mathrm{V}_{\mathrm{r.m.s.}} = \frac{\mathrm{V}_0}{\sqrt{2}}$$

The fuse rating is usually 85% of peak current I_0.

A changing primary current causes a changing magnetic flux, as a result of electromagnetic induction; a changing e.m.f. is produced in the secondary coil.
The voltage can be stepped up/down because the e.m.f. is proportional to the rate of change of magnetic flux linkage $\mathrm{d}\Phi/\mathrm{dt}$, which is proportional to the number of turns.

The coils are wound on a laminated soft-iron core to couple the field of the primary and the secondary coil,
and concentrate the magnetic field in the primary coil to provide more flux linkage by the alignment of magnetic domains.
The soft iron core is laminated to reduce eddy currents and magnetic hysteresis, as well as to facilitate the removal of heat.

For an ideal transformer with fully efficient power transfer:

$$\frac{\mathrm{V}_s}{\mathrm{V}_p} = \frac{\mathrm{N}_s}{\mathrm{N}_p} = \frac{\mathrm{I}_p}{\mathrm{I}_s}$$

Rationale for AC
For a **<u>given</u> power** $\mathrm{P} = \mathrm{IV}$, by transmitting **high voltage**, **low current** will flow through the transmission cable. Thus, the **heat loss** in cable $\mathrm{P}_{\mathrm{loss}} = \mathrm{I}^2\mathrm{R}$ is **minimised**.
With a **transformer**, Voltage can be **<u>efficiently</u> stepped up**, initially for transmission through the cable, and **stepped down**, when it reaches the consumer.

Quantum Physics

The amount of energy E carried by a quantum of radiation (photon) of frequency f is given by

$$\mathrm{E} = \mathrm{hf}$$

The **photoelectric effect** provides evidence for a **particulate** nature of electromagnetic radiation.

- No photoelectrons are emitted **below a threshold frequency** of photons.
The threshold frequency $\mathrm{f_o}$ is the lowest frequency of radiation that ejects electrons from a particular metal surface, of work function energy Φ
The work function energy Φ is the **minimum** energy needed (that is used to overcome the electric field) to remove an electron from the metal surface.

$$\mathrm{hf_o} = \Phi$$

The energy of the photoelectron is the energy of the photon less of Φ because it has to overcome the work function energy of the metal.
When photon-electron interaction takes place below the surface, the photoelectron needs more than the work function energy to escape and thus is less energetic.

- Above $\mathrm{f_o}$, the **maximum kinetic energy** $\mathrm{E_{k_{max}}}$ of the photoelectrons, which can be deduced from the stopping potential $\mathrm{V_s}$,
increases with increasing light frequency, and is **independent of the light intensity**.

$$\mathrm{E_{k_{max}}} = \frac{1}{2}\mathrm{mv_{max}^2} = \mathrm{eV_s} = \mathrm{E_{p_{max}}} = \mathrm{hf} - \Phi$$

- Photoelectrons are emitted from the surface of the metal **almost instantaneously**, even at very low intensities.
There is a one-to-one interaction between photons and electrons.
There may be only a few photons arriving per unit time, but each one can have the sufficient energy to eject a photoelectron immediately.

Interference and diffraction provide evidence for a **wave** nature of electromagnetic radiation.
When a beam of particles strikes a thin layer of graphite (or a crystal) which its periodic structure acts as a diffraction grating, a diffraction pattern is observed.
When a monochromatic light is passed through a single slit and followed by a double silt, a **fringe pattern** is produced on the screen.

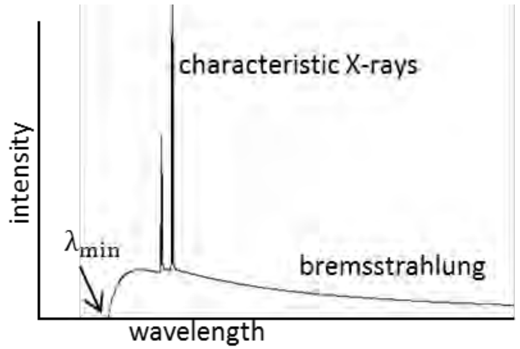
The wavelength of the particle is given by the de Broglie equation

$$\lambda = \mathrm{h/p} = \mathrm{h/mv}$$

The emission (absorption) spectrum of a substance is the spectrum of frequencies of electromagnetic radiation emitted (absorbed)
due to an atom's electrons making a transition from a higher (lower) energy state to a lower (higher) energy state.
As there **discrete energy levels** for an electron in an isolated atom, when an electron makes the transition,
a photon of only a certain frequency will be emitted (absorbed). This leads to emission (absorption) spectra **lines**.

The energy hf of the photon emitted in a transition of electron between levels of energies E_1 and E_2 is given by

$$hf = hc/\lambda = E_1 - E_2$$



Bremsstrahlung (braking radiation) is the electromagnetic radiation emitted when fast moving electrons are **rapidly** slowed down as they pass through the **electric field** around the nucleus. As the final speed of the electrons v is a variable, this effect results in a continuous spectrum of the wavelength of emitted photons.

The minimum wavelength λ_{min} of the emitted photons depends on the kinetic energy E_K of the electrons, and is independent of the type of metal.

$$hc/\lambda_{min} = hf_{max} = \Delta E_{K_{max}} = E_1 - 0$$

Characteristic x-rays are emitted when an electron in an upper state of an atom drops down to fill the vacated lower state that had its electron dislodged by the bombarding electrons. The wavelength of these x-rays is different for each type of element.

Heisenberg's uncertainty principle asserts a limit to the **precision** to the **knowledge** of the **displacement** x and **momentum** p_x of a particle simultaneously,

$$\Delta x \, \Delta p_x \geq h/4\pi$$

or the **energy** E and the **time** t of a body simultaneously.

$$\Delta E \, \Delta t \geq h/4\pi$$

An electron can be described by a wave function Ψ where
the square the amplitude of wave function $|\Psi|^2$ gives the probability of finding the electron at a point.

Based on classical mechanics, an electron with energy E should not be able to overcome a potential barrier if it does not have the sufficient energy U.
However, experimentally, some electrons can tunnel through the barrier at a probability.
The transmission coefficient T represents the probability of the electron passing through the rectangular barrier of height U and length L.

$$T \approx e^{-2kL}, \qquad \text{where } k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$$

The reflection coefficient R represents the probability of a particle being reflected off a barrier, and since the particle is either reflected or transmitted,

$$R + T = 1$$

The space d between the atoms and the probing tip of the scanning tunnelling microscope acts as the potential barrier.
When a potential difference is applied, electrons are able to tunnel between the tip and the sample.

$$I \propto e^{-2kd}$$

Lasers and Semiconductors

Spontaneous emission is the process in which an atom in an excited state undergoes a transition to a state with a lower energy and emits a photon.

Stimulated emission is the process in which an excited atom is triggered by an external photon of a certain frequency and drops to the lower energy level, emitting another photon. The **new photon** created has the **same** phase, frequency, polarisation, and direction of travel as the incident photon.

Stimulated absorption is the process by which an atomic electron absorbs a photon of a certain frequency and is raised to the higher energy level.

Laser light is monochromatic, coherent, directional and has a high intensity.
A laser makes use of the stimulated emission process to amplify the intensity of light. Conditions needed to sustain such a chain of events:

- The system must be in state of **population inversion**, where there are more atoms in the higher energy state than the lower one.
Amplification could only happen if the rate of **stimulated emission** is **larger** than the rate of **stimulated absorption**.

- The excited state of the system must be in a **metastable** state, so that
it lasts for a relatively long time so that spontaneous emission will not occur before stimulated emission.

- The emitted **photons** must be **confined** in the system long enough **to allow time** for further stimulated emission from other excited atoms.

As atoms are brought together, the **overlapping of electron wave functions** causes energy levels to split.
In a crystalline solid with N atoms, each E level of an atom is split into N levels which are so closely spaced and may be regarded as a continuous band of energy levels.

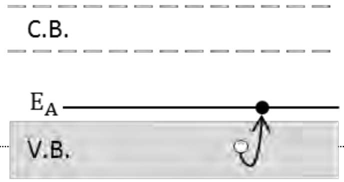
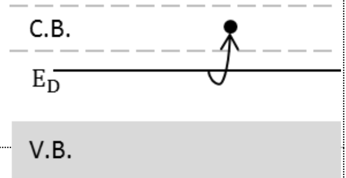
When the atoms are closer, the further overlapping of electronic wave functions **mixes** the s and p bands, and a single band with a capacity of $8\mathrm{N}$ electrons is created.
When the atoms are even closer, the extreme overlapping of electronic wave function **divides** the band into two separate bands, each with a capacity of $4\mathrm{N}$ electrons.

The **valence band** is the highest range of electron energies in which electrons are normally present at absolute zero temperature.
The **conduction band** is the range of electron energies enough to free an electron from binding with its atom to move freely within the atomic lattice of the material as a 'delocalized electron'.

Metals are good conductors due to either having a partially filled conduction band (sodium) which allows electrons to move freely among unoccupied states, or having an overlapping of the valance band and the conduction band (magnesium).

Insulators like carbon has four valance electrons, the lower $4\mathrm{N}$ states are completely filled and the upper $4\mathrm{N}$ states of the conduction band are completely empty.
Due to the large band gap $\mathrm{E_G}$, electrons in the valance band cannot be promoted to the conduction band and conduct electricity.

For **intrinsic (or undoped) conductors**, at low temperature, the valance bands remain full while the conduction band is empty and hence act as insulators.
As temperature increases, conductivity increases in tandem because some valence electrons acquire thermal energy greater than the energy band gap and is excited to the conduction band, leaving behind holes in the valance band.
Both free **electrons** (in the **conduction** band) and **holes** (electron vacancies in the **valance** band) are the charge carriers of electricity.

p-type semiconductor	**n-type semiconductor**
The dopant is an acceptor impurity, which has 3 valance electrons (trivalent). 3 of the 4 covalent bonds will be filled and the vacancy in the 4th bond constitutes a hole and will be available as a positive carrier of current.  	The dopant is a donor impurity, which has 5 valance electrons (pentavalent). 4 of its valance electrons will occupy covalent bond and the 5th electron can easily enter the conduction band and will be available as a negative carrier of current. 
These acceptor impurities will introduce an allowable discrete energy level a small distance above the valance band. At room temperature, electrons in the valance band are raised to occupy the acceptor energy level, leaving behind holes generated in the valance band. **Majority** charge carriers are **holes** in the valance band.	The donor impurities will introduce an allowable discrete energy level a small distance below the conduction band. At room temperature almost all the 5th electrons of the donor impurities are raised into the conduction band. **Majority** charge carriers are **electrons** in the conduction band.

When the p-n junction is made, electrons (holes) from the n(p) region **diffuse** into the p(n) region, **leaving** the n(p)-type positively (negatively) **charged** at the junction.
The regions nearby the p–n junction lose their neutrality and become charged, forming the **depletion layer**.

When a forward (reverse)-bias voltage is applied, the holes in the p-type region and the electrons in the n-type region are pushed towards (pulled away from) the junction.
This **reduces (increases) the width of the depletion layer**, reducing (increasing) the voltage barrier and offer a low (high) resistance to the flow of charge carriers.

However, due to **heat**, a small number of hole-electron pairs are generated throughout the material.
The minority carriers generated near/within the depletion region are **swept across** the depletion region **due to the electric field**, which produces a small current.

Nuclear Physics

α-particle scattering experiment and interpretation

Majority of the **scintillations** (flashes of light) were observed at an angle of 0° when the detector was aligned along the path of the alpha particles.
→ A vast majority of the alpha particles were able to pass straight through the gold foil without being deflected.
→ Much of the atom is **made up of empty space**.

Little scintillations were observed at an angle to the direct path.
→ There are **positively charged objects** in the gold foil that repelled the alpha particles.

Scintillations were observed, but very **rare**, at a scattering angle of more than 90° (backscattering).
→ The alpha particles must have collided with **comparatively massive particles** to make an about turn.
→ There is a **very small, and very dense** positively charged centre core (nucleus) in the atom.

Proton number (atomic number) is the number of protons in the nucleus of the atom.
Nucleon number (mass number) is the number of **nucleons** (both protons and neutrons) in the nucleus of the atom.

Isotopes are two or more atoms of the same element, each have the **same number of protons** but **different number of nucleons** (neutrons) in their nuclei.
They exhibit **similar chemical properties** as they have the same number of electrons, but **different physical properties** because their mass is different.

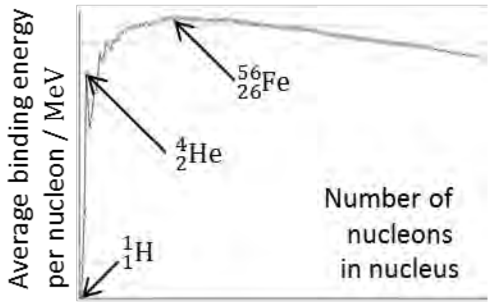
The total mass of a **stable atom** or nucleus is always **less** than the sum of the masses of **constituent** protons and nucleons.
The **mass defect** is the difference in mass between the constituent particles of an atom and the smaller mass of the whole atom.

Nuclear **binding energy** is defined as the energy **released** (required) when the nucleus is **formed from** (separated into) its constituent particles.

The relationship between mass defect $\Delta\mathrm{m}$ and binding energy $\Delta\mathrm{E}$ is shown by this mass-energy relation.
$\Delta\mathrm{E} = (\Delta\mathrm{m})\mathrm{c}^2$

The **binding energy per nucleon** is the average energy released (required) per nucleon
when a nucleus is formed from (separated into) its constituent particles.

Iron nucleus $^{56}\mathrm{Fe}$ has the maximum binding energy per nucleon at $8.8\mathrm{MeV}$
On either side of the maximum, the nuclei are less stable because they have a lower value of binding energy per nucleon.



The falling part of the curve shows that large nuclides such as uranium can produce energy by fission of their nuclei to lighter nuclei with higher binding energy per nucleon.
Nuclear Fission is the **splitting of a nucleus** of **high nucleon number** into **two smaller nuclei** of approximately equal mass with the **release of energy and neutrons**.
This reaction does not occur naturally, the process is usually man-made.

The rising part of the curve shows that elements with lower mass number can produce energy by fusion to form heavier nuclei with higher binding energy per nucleon.
Nuclear Fusion is the **formation of a larger nucleus** from **two nuclei of low nucleon number**, with the release of energy.
However, in order to fuse the two nuclei, a large amount of energy is required to overcome the mutual electric repulsion.

The sum of atomic/mass numbers of nuclides before and after the reaction is the same.
The total amount of mass and energy before and after the reaction is the same.

Radioactive decay is the **spontaneous** (not affected by any external factors) and **random** (not emitted at an equal time interval) decay of the nucleus with the emission of an alpha or a beta particle, and usually accompanied by the emission of a gamma ray photon.

The clicks made by the Geiger–Müller tube due to radioactive particles will be irregular, indicating the random nature of radioactive decay.

Any radiation detector placed in a location with no radioactive sources nearby will usually register a count C of 20-50 per minute, due to background radiation.
Sources include cosmic rays from outer space and radioactivity emission from contaminated apparatus, rocks, soil and buildings.

Activity A is the number of **nuclear disintegrations** per unit time.
Decay constant λ of a **particular radioactive nuclide** is the **probability** of **decay per unit time** of a nucleus, where N is the number of undecayed nucleus.

$$\mathrm{A} = -\mathrm{dN/dt} = \lambda\mathrm{N}$$

One Becquerel is defined as the number of **nuclear disintegrations** per 1 second.

The **half-life** $\mathrm{t}_{1/2}$ is the <u>**average**</u> **time taken** for the **activity** of the particular **radioactive nuclide** to **fall** to **half** of its **initial** value.

$$\lambda = \ln 2/\mathrm{t}_{1/2}$$

The Rutherford law of radioactive decay states that at any time t, (where C is the number of radioactive particles from the radioactive source measured by the detector)

$$\mathrm{N} = \mathrm{N}_0\mathrm{e}^{-\lambda\mathrm{t}} \quad \propto \quad \mathrm{A} = \mathrm{A}_0\mathrm{e}^{-\lambda\mathrm{t}} \quad \propto \quad \mathrm{C} = \mathrm{C}_0\mathrm{e}^{-\lambda\mathrm{t}}$$

$$\frac{\mathrm{t}}{\mathrm{t}_{1/2}} = \log_2\frac{N_0}{N} = \log_2\frac{A_0}{A} = \log_2\frac{C_0}{C}$$

	α	β	γ
Particle	$^4_2He^{2+}$ helium nuclei	fast moving e^-	electromagnetic radiation of very short wavelength
Rest mass	$6.65\ \times 10^{-27}\text{kg} = 4.00151\text{u}$	$9.11\ \times 10^{-31}\text{kg} = 0.00055\text{u}$	$-$
Speed	$\sim 10^7 \text{ms}^{-1}$	$\sim 10^8\ \text{ms}^{-1}$	$3 \times 10^8\ \text{ms}^{-1} = \text{c}$
Charge	$+2\text{e}$	$-\text{e}$	0
Deflection in Electric Field	Towards negative	Towards positive	No deflection
Deflection in Magnetic Field	Anti-clockwise in magnetic field into the plane	Clockwise in magnetic field into the plane	No deflection
Ionising Properties	Most ionising	Less ionising	Least ionising
Range in air	A few cm	A few m	A few hundred m
Penetrate up to	A few sheet of paper	A few mm of Al	Several cm of Pb
Emission properties	In alpha decay, a radioactive isotope emits an alpha particle to form another nucleus of a different element. As alpha decay is a two-body reaction, alpha particles is emitted discrete kinetic energies.	Beta particles emerge from a weak decay process when a neutron inside the nucleus decays to produce a proton, the beta electron and anti-electron neutrino. As alpha decay is a three-body reaction, beta particles are emitted over a spectrum of energies.	In gamma decay, a nucleus in an excited state (following the emission of an alpha or beta particle) will emit gamma radiation to achieve a more stable state.
Hazards	Ionising radiation carries enough energy to liberate electrons from atoms or molecules, thereby breaking some of its bonds. The body attempts to repair the damage, but sometimes the damage cannot be repaired, or is too widespread or severe to the repaired. Mistakes made in the natural reparation process can lead to the spreading in cancerous cells.		
	External alpha irradiation is completely absorbed by the dead skin cells in the outermost skin layer, so it is little of a hazard. However, if alpha emitters have been inhaled, ingested or absorbed into the bloodstream, living tissues can ionised by alpha particles.	External exposure to beta particles can redden or even burn the skin. Emissions from inhaled or ingested beta particle emitters can cause great harm. As beta particles are more penetrating, it results in more dispersed damage.	A large portion of the gamma radiation passes through the body. However, gamma rays can excite atomic particles such as electrons which then ionises molecules in tissues.