

NATURAL SCIENCE SOLUTION

Accelerating Academic Skills



Summary Notes (Edexcel AS Physics unit-2)

Topics:

1. **Electric Circuit**
2. **Wave, Particle Nature of light.**
3. **Quantum Physics**

“Knowing the path is good but not enough, walking the path with determination leads to destiny”

Current and Voltage

Charge (Q or q):

It is a property by which particles attract or repel each other. The charge on one electron is actually -1.60×10^{-19} C. *This means that it takes 6.25×10^{18} electrons to transfer 1C of charge.*

The SI unit of the charge is coulombs (C). The SI base unit is AS (i.e. $C = AS$).

The charge of one electron is referred as *elementary charge*.

$$1e = 1.6 \times 10^{-19} \text{C}$$

Current (I):

Movement of charges is referred as current. More appropriately *“rate of flow of charges is called current”*.

$$I = \frac{\Delta q}{\Delta t}$$

Current is measured in amperes (or amps), A ($A = CS^{-1}$).

The amount of charge can now be found as;

$$q = It$$

If amount of Charge is given then *number of electrons n can be found by;*

$$n = \frac{q}{e}$$

Where, e is the charge on one electron.

Voltage/potential difference (p.d):

Potential is *electrical energy* which charges carry along.

When energy is transferred by charges to a component, then there is a difference of potential across the component called potential difference or voltage

“Potential difference or voltage is energy transferred by per unit/per coulomb of charge”.

“Voltage is the work done per unit/per coulomb of charge”. Or “Energy per unit/per coulomb of charge”.

$$V = \frac{W}{q} \quad \text{OR} \quad V = \frac{E}{q}$$

Voltage is measured in volt, V ($V = JC^{-1}$).

The energy of charge can now be found by

$$E = Vq$$

We can find the speed of the charged particle using $E = \frac{1}{2} mv^2$

Ohm's Law and Resistance

Ohm's Law:

At constant temperature, for a given conductor current through the conductor is proportional to the voltage across the conductor;

$$V = IR$$

Where R is the resistance of the conductor.

The resistance can be found by; $R = \frac{V}{I}$

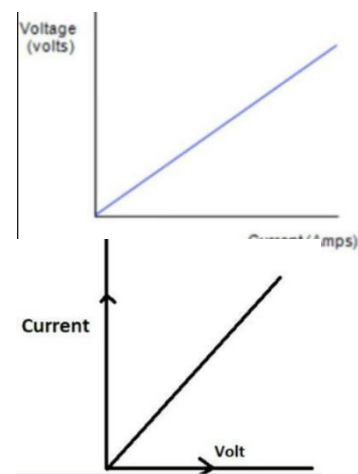
Resistance is measured in ohm, Ω ($\Omega = VA^{-1}$).

Ohm's law graph: (V-I and I-V)

The V-I and I-V graphs are straight line passing through origin.

Gradient of V-I graph gives resistance. $R = \text{gradient}$

Gradient of I-V graph gives 1/ resistance. $R = \frac{1}{\text{gradient}}$



Resistance:

Resistance is the **hindrance** in flow of charges/electrons due to **collisions of the moving charges/electrons with the oscillation positive lattice ions** of the conductor. For a metal conductor (copper, Aluminium, filament lamp etc.) resistance depends upon the **type of conductor, dimensions (size/length, and width) and temperature** of the conductor.

Effect of temperature:

"If temperature of a conductor is increased the resistance is also increased due to the fact that increasing temperature causing energy of the oscillating atom/lattice ions to increase. The lattice ions oscillate with larger amplitude causing the collisions to increase so the resistance is increased".

Ohmic and Non-Ohmic conductors:

The metal that obeys Ohm's law is called an **Ohmic** conductor. It's V-I or I-V graph is a straight line passing through origin. Since the gradient of straight line is constant that means resistance of the **Ohmic** conductor is constant. **At normal temperature Copper, Silver, behaves as an Ohmic conductors.**

The metal that do not obey Ohm's law is called **Non-Ohmic** conductor. It's V-I and I-V graph is a curve passing through origin. Since the gradient of a curve keeps changing that means resistance of the **Non-Ohmic** conductor is not constant. **Tungsten Filament, is a Non-Ohmic conductor.**

Tungsten filament lamp:

At low current the tungsten obeys Ohm's law. **As the potential difference and current increase so does the temperature. Increase in temperature causing energy of the oscillating atom/lattice ions of the filament to increase. The lattice ions oscillate with larger amplitude causing more collisions so the resistance is increased.**



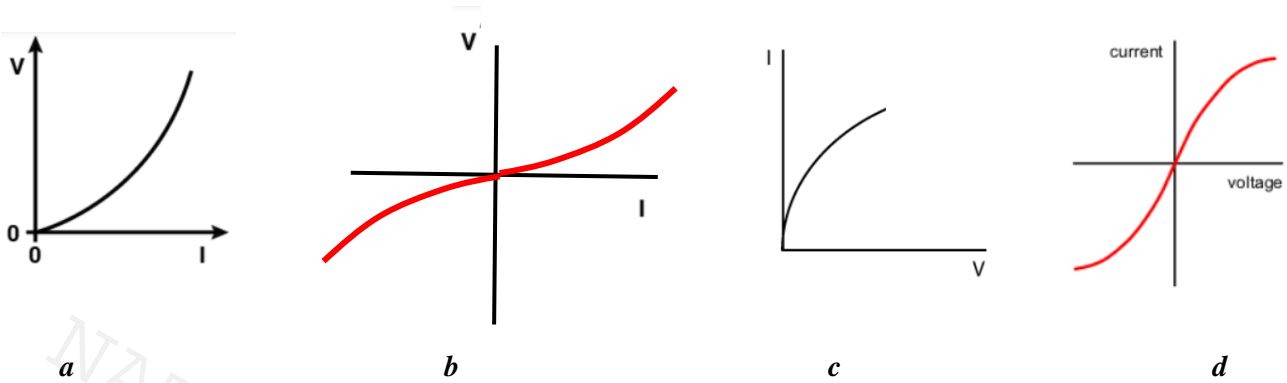
The increase in resistance causing V-I or I-V graphs curves, since resistance changes it no longer obeys Ohm's law.

The tungsten filament is a Non-Ohmic conductor. It does not obey Ohm's Law

Graph of Tungsten filament lamp:

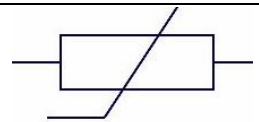
Since the resistance of the tungsten filament lamp increase with voltage/current/temperature.

- V-I graph is a curve with **increasing gradient**. It is because the gradient of V-I graph is the resistance. (graphs a, and b)
- I-V graph is a curve with **decreasing gradient**. It is because $\frac{1}{\text{gradient}}$ is the resistance. (graphs c, and d)



Thermistor: (negative temperature coefficient/NTC)

Thermistor is a semi-conductor. Its resistance decreases with increase in temperature.

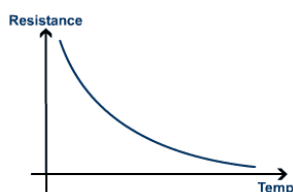
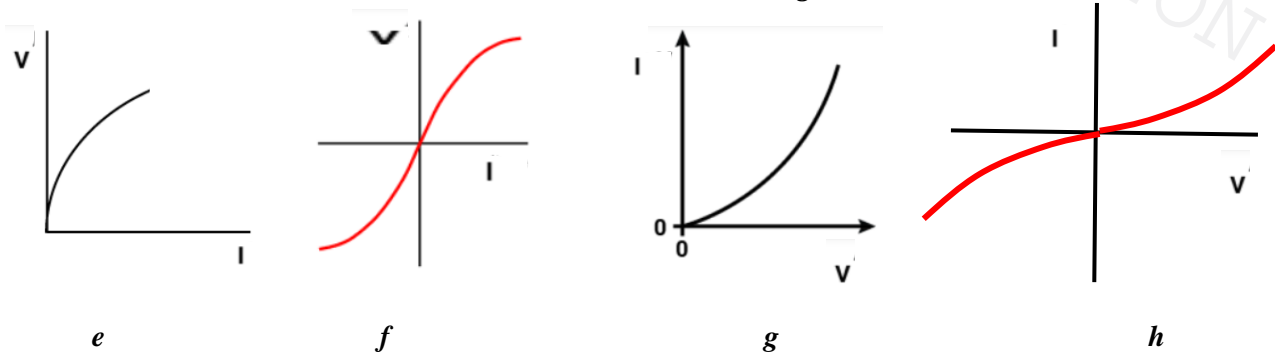


Increase in temperature of thermistor causing number of electrons to increase. So rate of flow of charge that is current through the thermistor is increased which means resistance has decreased.

Graph of Thermistor:

Since the resistance of the thermistor decreases with temperature.

- V-I graph is a curve with **decreasing gradient**. It is because the gradient of V-I graph is the resistance. (graphs e, and f)
- I-V graph is a curve with **increasing gradient**. It is because $\frac{1}{\text{gradient}}$ is the resistance. (graphs g, and h)



Resistance-temperature graph of thermistor:

The resistance of thermistor changes so it does not obey Ohm's Law.

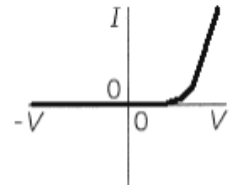
Diode:



Diode is a semi-conductor. It allows current to flow in one direction.

- If **anode of the diode** is connected to **positive terminal/high potential** the diode is in **forward bias** it allows current to pass through.
- If **anode of the diode** is connected to **negative terminal/low potential** the diode is in **reverse bias** it does not allow current to pass through.

If forward voltage is gradually increased there is no or little current passes through the diode. At voltage greater than threshold voltage current increase sharply.



The resistance of diode changes so it does not obey Ohm's Law.

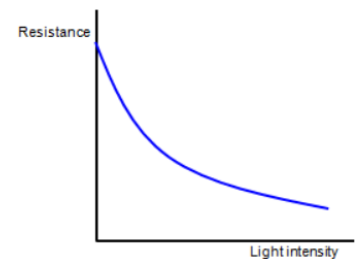
Light Dependent Resistor (LDR):

LDR is also a semi-conductor. Its resistance decreases with increase in light intensity.



Increase in the light intensity causing number of electrons to increase. So rate of flow of charge that is current through the LDR is increased which means resistance has decreased.

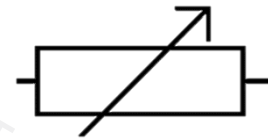
Resistance-light intensity graph of LDR:



The resistance of LDR changes so it does not obey Ohm's Law.

Variable Resistor:

A variable resistor is a resistor whose value can be changed.



Resistivity

Resistivity:

Other than temperature, **resistance** of a conductor depends upon **dimension/size (Length and area)** of the conductor.

Effect of length, L:

Length increases – resistance increases. The longer the piece of wire the more collisions the electrons will have.

Effect of Area, A:

Area increases – resistance decreases. The wider the piece of wire the more gaps there are between the ions.

$$R \propto l \text{ and } R \propto \frac{1}{A}$$

Combining the above relation we can have;

$R = \rho \frac{l}{A}$, where ρ is called **resistivity** of the material, *which depends upon the material of the conductor*.

Each metal has its own value of resistivity for each temperature. For example, at room temperature the resistivity of copper is $1.7 \times 10^{-8} \Omega\text{m}$ and for carbon is $3 \times 10^{-5} \Omega\text{m}$.

The resistivity can be found by using; $\rho = R \frac{A}{l}$

If $l = 1\text{m}$ and $A = 1\text{m}^2$ then $\rho = R$.

“Resistance of 1m^3 of conductor is called resistivity”.

Resistivity is measured in ohm meter, Ωm

Drift Speed and Transport Equation

Drift Speed:

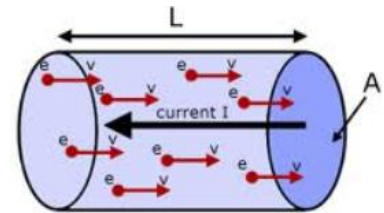
Drift velocity is the average velocity attained by charged particles, such as electrons, in a material due to an electric field.

Drift speed v through a conductor of length l and area of cross section A is given by;

$$v = \frac{I}{nAq}$$

Where I is the current, and n is the charge density (number of electrons per unit volume).

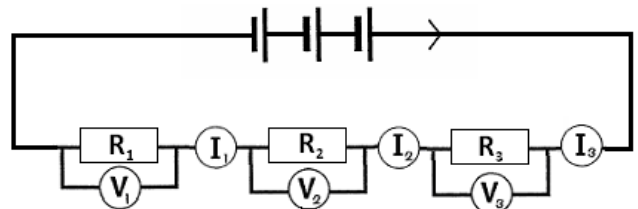
The SI unit of n is m^{-3} .



Series and parallel circuits

Series circuit:

Components are connected in one loop so that there is only one path available for current. I.e. in each component current remains the same.



- The total current of the circuit is the same at each point in the circuit. $I_{TOTAL} = I_1 = I_2 = I_3$
- Voltage/p.d across each component is different as per resistance of the component. Higher the resistance more the p.d across the component is.
- The total voltage of the circuit is equal to the sum of the p.d.s across each component. $V_{TOTAL} = V_1 + V_2 + V_3$
- The total resistance of the circuit is equal to the sum of the resistance of each resistor. I.e. the total resistance is greater than the greatest resistance present in the circuit. $R_{TOTAL} = R_1 + R_2 + R_3$

Parallel circuit:

Components are connected in separate loop so that current have more than one path.

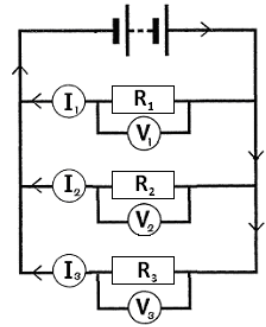
- Voltage/p.d across each component is the same. I.e. for the simple circuit such as in the figure, the p.d across each component is equal to the p.d of the power supply. $V_{TOTAL} = V_1 = V_2 = V_3$

- The total current is equal to the sum of the currents through each resistor.

$$I_{TOTAL} = I_1 + I_2 + I_3$$

- Current in each component is different as per resistance of the component. Higher the resistance least the current is. The total resistance can be calculated using the equation:

$$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{I.e. the total resistance is less than the least resistance present in the circuit.}$$



Energy and Power

Power:

Any resistor in a circuit that has a voltage drop across it dissipates electrical power. This electrical power is converted into heat energy.

$$P = VI$$

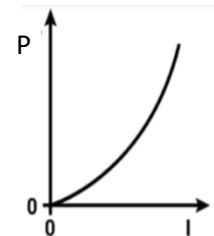
power is measured in watt, W

Power in terms of resistance:

- If current in a circuit stays the same (series circuit) the power across a component/resistor is proportional to the resistance.

$$P = I^2 R$$

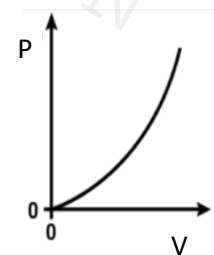
- A bulb of high resistance in series circuit dissipate more power so such bulb will be brightest.
- At constant resistance P-I graph is then a parabola.



- If voltage in a circuit is the same (parallel circuit) the power across a component/resistor is inversely proportional to the resistance.

$$P = \frac{V^2}{R}$$

- A bulb of low resistance in parallel circuit dissipate more power so such bulb will be brightest.
- At constant resistance P-V graph is then a parabola.



Energy:

Energy in an electric circuit can be calculated by;

$$E = VIt$$

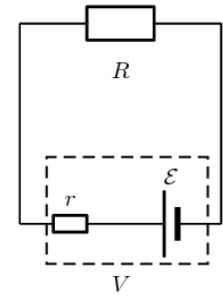
EMF and Internal Resistance

Electromotive force (EMF):

Charges/electrons gain energy from power supply so they can move along the circuit.

“Amount of energy transferred to one coulomb/per unit of charge is called EMF”

Ideally a cell transfers energy to charge, the charge then transfers same amount of energy to the component/resistor in the circuit. (Voltage = EMF).



In reality, there is a small resistance in every cell/power source. *The small resistance of cell is called internal resistance of the cell, denoted by r.*

The internal resistance causes some amount of received energy to lose within the cell. **The lost energy is called lost volt V_r .**

The output voltage is always less than the EMF (E).

$$E = V + Ir; \quad \text{where } Ir \text{ is the lost volt.}$$

EMF is measured in joule, J

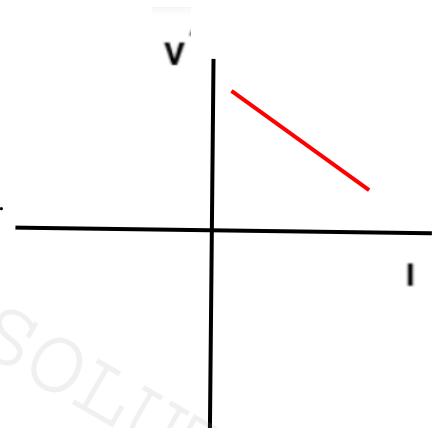
V-I graph to calculate EMF and internal resistance:

The equation $E = V + Ir$ can be rewritten as $V = -rI + E$.

V-I graph is a straight line with negative gradient.

- The **gradient** of the line gives the **internal resistance (r)** of the cell.
- The **y-intercept** gives **EMF** of the cell.

Gradient = -r, y-intercept = EMF



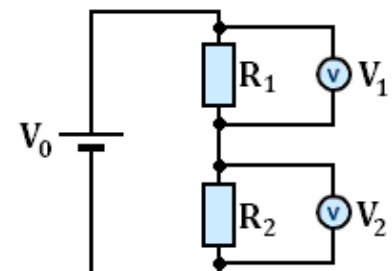
Potential Divider and Kirchhoff's Laws

Potential divider circuit:

A circuit with two resistance in series connected with a cell of negligible internal resistance is called simple potential divider.

Voltage of the source V_0 (EMF) is divided between the two resistances such that ratio between the voltages is same as the ratio between the two resistances.

$$\frac{V_1}{V_2} = \frac{R_1}{R_2} \quad \frac{V_1}{V_0} = \frac{R_1}{R_1 + R_2}$$



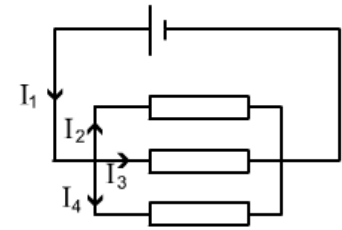
If one of the resistance in the circuit is changed then so the corresponding voltage.

Kirchhoff's first Laws:

Electric charge is conserved in all circuits, all the charge that arrives at a point must leave it. OR

Total current arriving at a junction is equal to the total current leaving the junction.

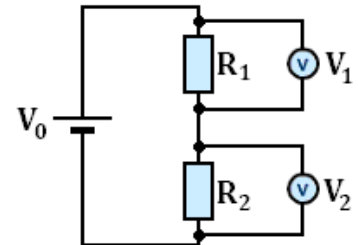
In the diagram we can say that: $I_1 = I_2 + I_3 + I_4$



Kirchhoff's second Laws:

Energy is conserved in all circuits, for any complete circuit the sum of the emfs is equal to the sum of the potential differences.

In the diagram we can say that: $V_0 = V_1 + V_2$



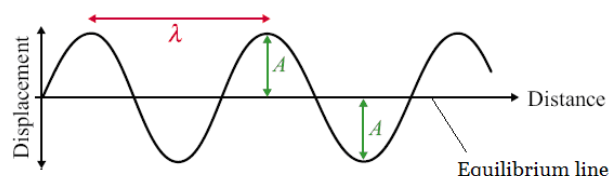
NATURAL SCIENCE SOLUTION

Wave Motion

Wave:

Energy can be transferred in different ways, if it transfers in the form of *oscillation* we call this wave. All waves are caused by oscillations.

Energy is transferred without transferring matter.



Waves are classified as,

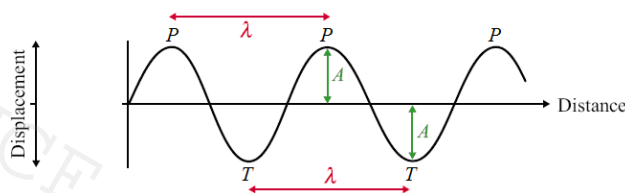
1. **Mechanical waves:** Waves which require medium/particles to travel (such as water waves, waves in spring or string, sound waves).
2. **Electromagnetic waves:** Waves which do not require medium/particles to travel (electromagnetic spectrum such as light wave, x-rays etc.).

The waves can be progressive or standing/stationary.

1. **Progressive wave:** Wave that can move or travel from one point to another (such as water wave, sound waves). **Energy is transferred through progressive wave.**
2. **Stationary wave:** Wave that does not move or travel. It only oscillates at one position (wave in stretched elastic band, waves in organ pipes etc.). **Energy is not transferred through standing/stationary wave.**

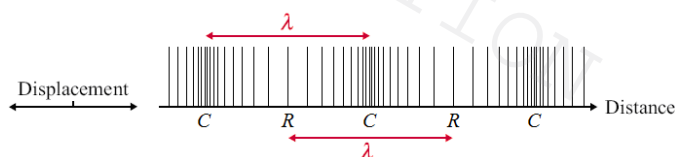
The progressive waves further classified as,

1. **Transverse wave:** In transverse wave, the oscillations are perpendicular to the direction of propagation. It consists of crest/peak and trough. The position where the particles are displaced above the equilibrium position we call a peak (P) and below we call a trough (T).



Examples: Water wave, wave in string, electromagnetic waves

2. **Longitudinal wave:** In longitudinal wave, the oscillations are parallel to the direction of propagation. It consists of Compression and rarefaction. The position where the particles are close together we call a compression (C) and position where the particles spread we call a rarefaction (R).



Examples: Sound waves

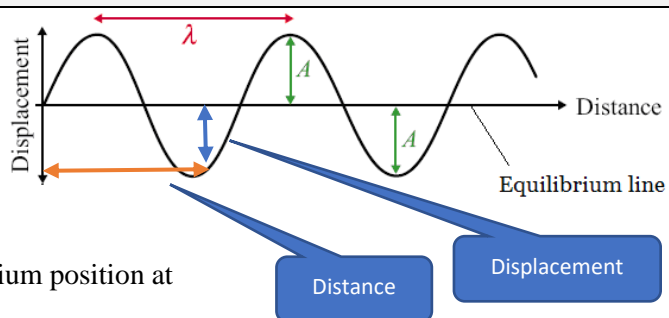
Important terms/Wave characteristics

Distance:

Position of a particle measured along *X-axis* from origin at time *t*. (**It is measured in terms of wave length, λ**).

Displacement:

Position of a particle measured along *Y-axis* from equilibrium position at time *t*.

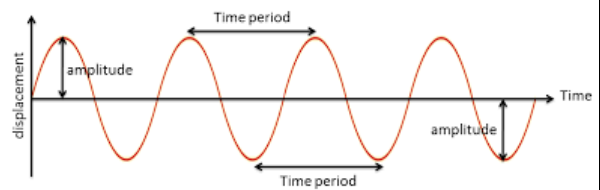


Amplitude:

Maximum displacement (A) from the equilibrium. I.e. distance of crest or trough from the equilibrium position.

Time period/period of a wave (T):

Time to complete one wave/one cycle of wave. (*It is measured in s*).



Frequency (f):

Number of waves/cycles per unit time. (*It is measured in hertz, Hz = s⁻¹*)

Frequency and time period can be related as follows; $f = \frac{1}{T}$ OR $T = \frac{1}{f}$

Wavelength (λ):

Wavelength can be defined in many ways. (*It is in fact length of one wave*)

For transvers wave: “The distance between two successive crests/peaks or troughs”.

For longitudinal wave: “The distance between two successive compressions or rarefactions”.

In general: “Distance between two such successive points on a wave which are in the same phase of motion.”

Wave speed (v):

The speed of a wave can be calculated by the following equation; $v = f \lambda$.

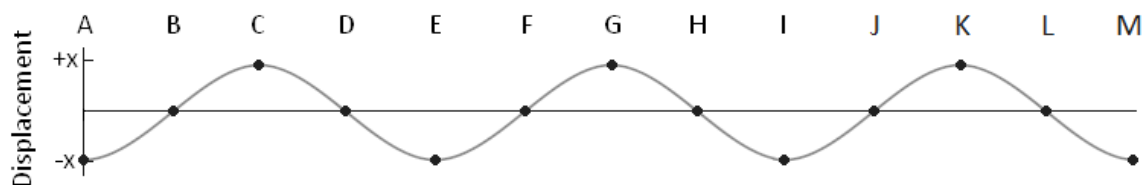
- For an electromagnetic wave the speed is represented by c. Which is same for all electromagnetic waves ($c = 3 \times 10^8 \text{ ms}^{-1}$). This speed generally known as speed of light.
- The wave speed is now can be written as; $c = f \lambda$.

Phase of motion:

The stage of an oscillation at given instant. *It is generally measured in terms of angle (degree or radian)*.

- The difference between the phases of two particles or two waves is called phase difference.

Observe the positions of particles A to M and their phase.



	B	C	D	E	F	G	H	I	J	K	L	M
Phase Difference from A (radians)	$\frac{1}{2}\pi$	1π	$1\frac{1}{2}\pi$	2π	$2\frac{1}{2}\pi$	3π	$3\frac{1}{2}\pi$	4π	$4\frac{1}{2}\pi$	5π	$5\frac{1}{2}\pi$	6π
Phase Difference from A (degrees)	90	180	270	360	450	540	630	720	810	900	990	1080

➤ *If phase difference between two waves is 0° or 360° , the waves are called in phase.*

➤ *If phase difference between two waves is 180° , the waves are called out of phase or antiphase.*

Path difference:

It is difference between the distances travelled by two waves. (*It is measured in terms of λ*)

- If two waves or beams of light are reaching simultaneously at a point, they might take different paths to reach the point.

	B	C	D	E	F	G	H	I	J	K	L	M
Path Difference from A	$\frac{1}{4}\lambda$	$\frac{1}{2}\lambda$	$\frac{3}{4}\lambda$	1λ	$1\frac{1}{4}\lambda$	$1\frac{1}{2}\lambda$	$1\frac{3}{4}\lambda$	2λ	$2\frac{1}{4}\lambda$	$2\frac{1}{2}\lambda$	$2\frac{3}{4}\lambda$	3λ

So two waves leaving A with one making it to C and the other to I will have a path difference of $1\frac{1}{2}\lambda$.

Superposition/Interference of waves

Superposition:

When two waves meet at a point the displacement of the resultant wave is the sum of individual displacements. *It is called principle of superposition.*

Coherent waves:

Waves of same frequency and period are called coherent waves. **OR** if there is constant phase difference between two waves, the waves are called coherent.

- In case of beam of light we use coherent beams of light.

In order to get coherent beams of light, a single beam of light is split into two beams.

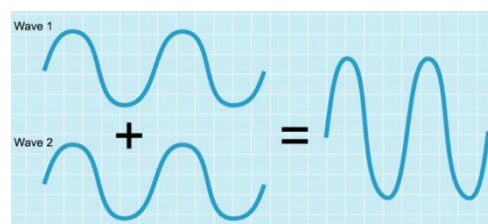
Interference of waves:

When two coherent waves interact or superpose, They either reinforce each other or cancel out each other.

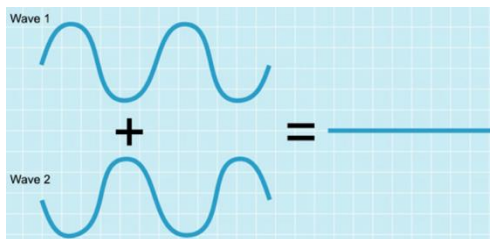
- If waves reinforce each other than the resultant wave is greater than the interacting waves this is called *constructive interference*.
- If waves cancel out each other than the resultant wave is smaller or no wave is produced this is called *destructive interference*.

Conditions for Interference:

- When two coherent waves interact or superpose such that crest of one wave falls upon crest of the other wave or trough of one wave falls upon trough of the other wave. The result is a larger wave (*constructive interference*).
- It happens if path difference between the two waves is equal to $n\lambda$ and waves are in phase.



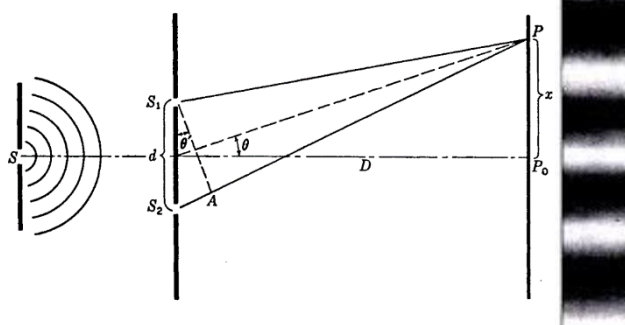
- When two coherent waves interact or superpose such that crest of one wave falls upon trough of the other. No wave is produced (**destructive interference**).
- It happens if path difference between the two waves is equal to $(n + \frac{1}{2})\lambda$ and waves are out of phase or antiphase.



Young's double slits experiment

Setup:

- In order to get coherent beams of light, a monochromatic beam of light from a source (s) passes through from two slit S_1 and S_2 to divide further into two beams.
- The two beams are then made to meet at a point P on the screen.
- Alternate bright and dark bands are observed on the screen.



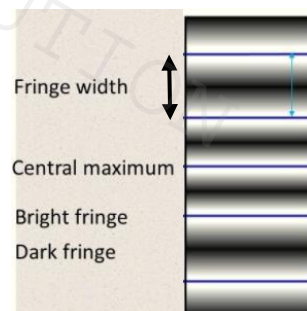
- * *The position where path difference is $n\lambda$ and waves are in phase we observed bright bands.*
- * *The position where path difference is $(n + \frac{1}{2})\lambda$ and waves are out of phase we observed dark bands*
- * *There always be a bright band at the centre of the screen, because the path difference is zero.*
- *From the above figure the path difference $S_2A = d\sin\theta$*

Fringe width/spacing/Separation:

Distance between two consecutive bright or dark bands is called fringe width Δx

Fringe width Δx , Source Separation d , Distance to Screen D , and Wavelength λ are related as follows;

$$\Delta x = \frac{\lambda D}{d}$$



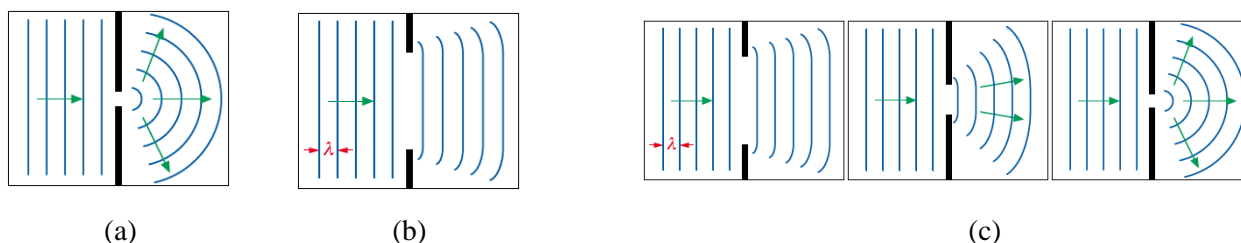
1. *If wavelength is increased the fringe width becomes wider.*
2. *If the screen is moved away from the slits the fringe width becomes wider.*
3. *If the slits distance is reduced the fringe width becomes wider.*

Diffraction and Diffraction grating

Diffraction of wave:

Spreading of wave when passes through a gap/slit or an obstacle is called diffraction.
Diffraction depends upon the wavelength and the gap size.

- Diffraction will be maximum if wavelength and the gap size are the same (fig-a).
- Diffraction will be Minimum if wavelength is smaller than the gap size (fig-b).

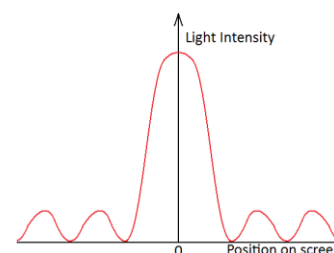


Observe the change in amount of diffraction with the gap size (fig-c).

* **There is no change in frequency, wavelength, and speed of wave.**

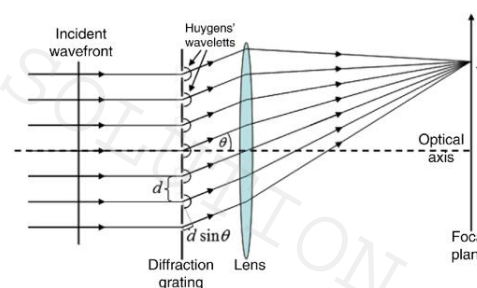
Diffraction pattern:

- The diffraction pattern from light being shone through a single slit.
- There is a central maximum that is twice as wide as the others and by far the brightest.
- The outer fringes are dimmer and of equal width.
- If we use three, four or more slits the interference maxima become brighter, narrower and further apart.



Diffraction grating:

- A diffraction grating is a series of narrow, parallel slits. They usually have around 500 slits per mm.
- When light shines on the diffraction grating several bright sharp lines can be seen as shown in the diagram to the right.



The zero-order maximum (n=0)

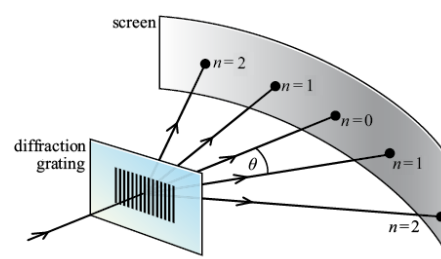
- There is no path difference between neighbouring waves. They arrive in phase and interfere constructively.

The first-order maximum (n=1)

- There is a path difference of 1 wavelength between neighbouring waves. They arrive in phase and interfere constructively.

The second-order maximum (n=2)

- There is a path difference of 2 wavelengths between neighbouring waves. They arrive in phase and interfere constructively.



Between the maxima:

- The path difference is not a whole number of wavelengths so the waves arrive out of phase and interfere destructively.

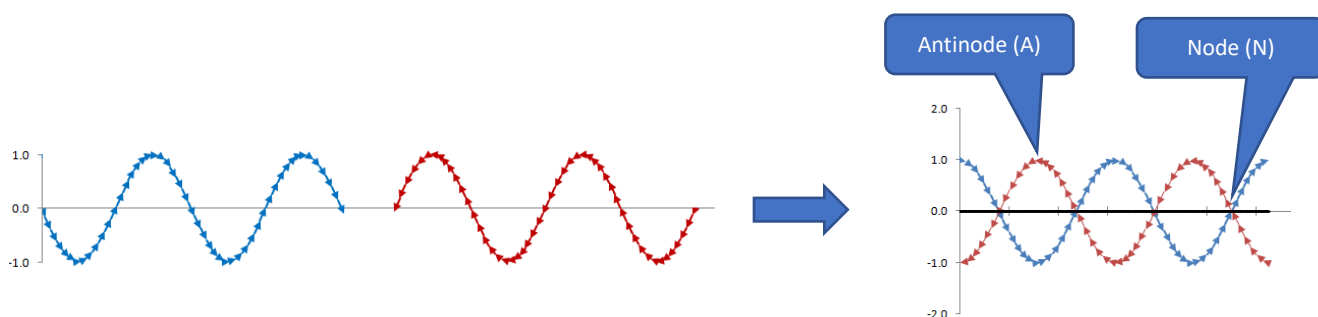
For the *n*th order the opposite side of the triangle becomes $n\lambda$, making the equation:

$$d \sin \theta = n\lambda$$

Stationary Waves/Standing Waves

Stationary Waves:

Two coherent waves *moving in opposite direction* interact or superpose give pattern of nodes and antinodes called stationary waves.



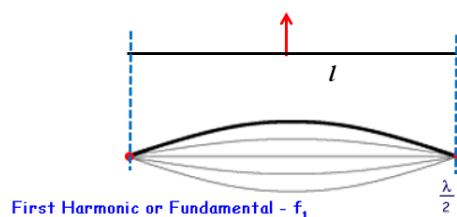
- * **Point of max displacement is called Antinodes.**
- * **Point of min displacement is called Nodes.**
- * **As the wave is not moving energy is not transferred b/w two points. All particles oscillates around mean position**

Harmonics, Mode, and Overtone in String:

Stationary waves consists of various **Modes of Vibrations** called **Harmonics and Overtones**:

The simplest stationary wave is produced when a string of length l fixed at both end is plucked from the centre.

- **This mode of vibration is fundamental loop or first harmonic of frequency f_1 .**
- The length and the wavelength can be related as follows; $l = \frac{\lambda}{2}$



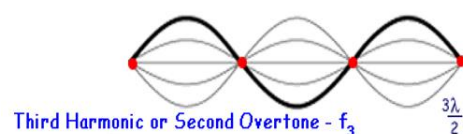
If the string is plucked from other positions, other mode of vibrations can be obtained.

- **This mode of vibration is second harmonic or first overtone of frequency f_2 .**
- The length and the wavelength can be related as follows; $l = \lambda$



- **This mode of vibration is third harmonic or second overtone of frequency f_3 .**
- The length and the wavelength can be related as follows;

$$l = \frac{3\lambda}{2}$$



The frequency of modes of vibration can be found by using the formula;

$$f_n = n f_1$$

Where, $n = 2, 3, 4, \dots$

- * **For a given length of string the velocity of stationary waves remains same.**

Organ Pipe/Air Column:

An organ pipe/air column is a sound-producing element that resonates at a specific pitch when pressurized air (commonly referred to as wind) is driven through it. Each pipe is tuned to a specific note of the musical scale.



Harmonics, Mode, and Overtone in Organ Pipes/Air Columns:

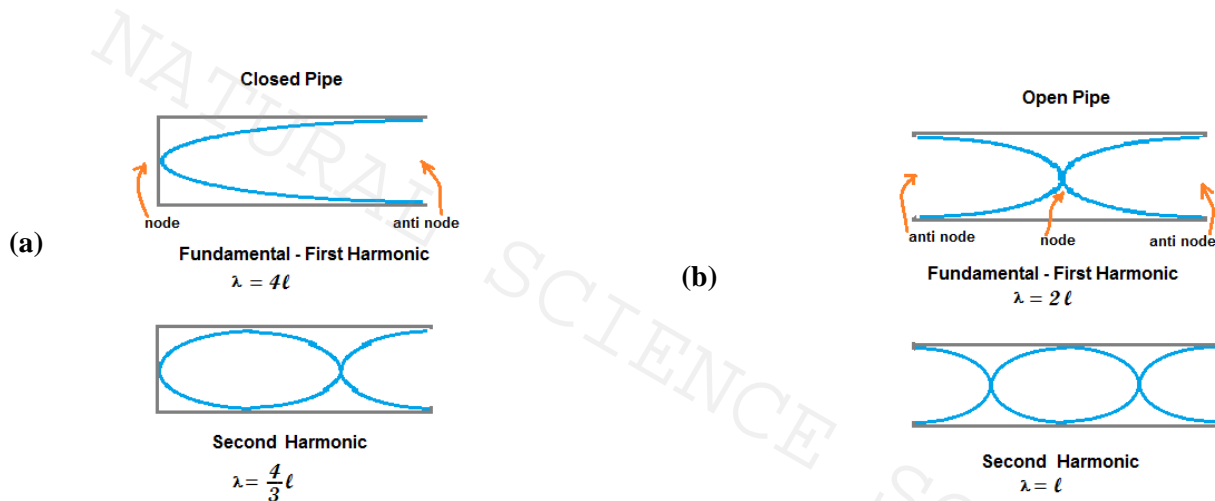
There are two types of organ pipes:

1. Open ended pipe:

The pipe is closed at one end. *Depending upon length* stationary wave is produced at *particular frequency* when pressurized air is driven through it (**figure-a**).

2. Closed ended:

The pipe is open at both the end. *Depending upon length* stationary wave is produced at *particular frequency* when pressurized air is driven through it (**figure-b**).



- * *There always be a node at closed end of the pipe*
- * *There always be an Antinode at the open end of the pipe*
- * *For the organ pipe/air columns the frequencies of higher notes can be found using;*

$$f_n = n f_1$$

Where, $n = 3, 5, 7, \dots$

	Standing Waves	Progressive Waves
Amplitude	Maximum at antinode and zero at nodes	The same for all parts of the wave
Frequency	All parts of the wave have the same frequency	All parts of the wave have the same frequency
Wavelength	Twice the distance between adjacent nodes	The distance between two adjacent peaks
Phase	All points between two adjacent nodes in phase	Points one wavelength apart in phase
Energy	No energy transfers	Energy transfers in the direction of the wave
Waveform	Does not move forward	Moves forwards

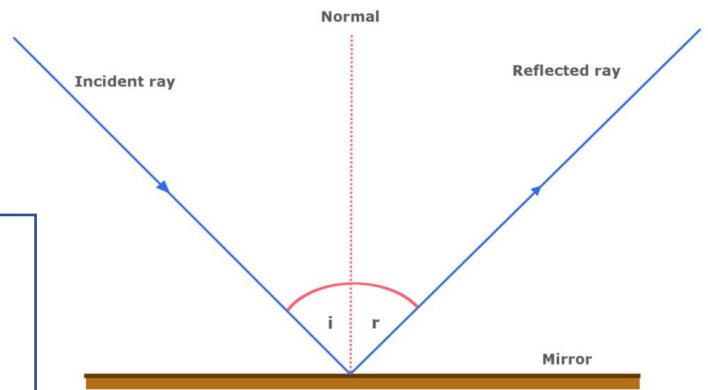
Reflection of light

Reflection of light:

Light bounces off a surface under certain conditions.

Angle of reflection = Angle of reflection.

Remember: All angles are measured from the normal.



Refraction of light

Refraction of light:

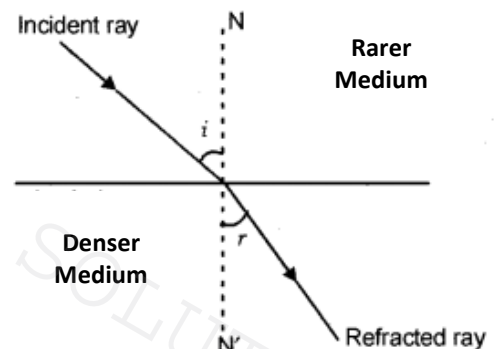
Transmission of light from one medium to another medium is called refraction of light. Refraction causes **change in speed and wavelength**. Refraction can also **change the direction** of transmission.

The changes depend upon the densities of the two mediums.

Refraction from rarer to denser medium:

- If light refracts from a less dense (rarer) medium to a high density (denser) medium, speed and wavelength decreases.
- If light arrives at an angle, the light moves closer to the normal.

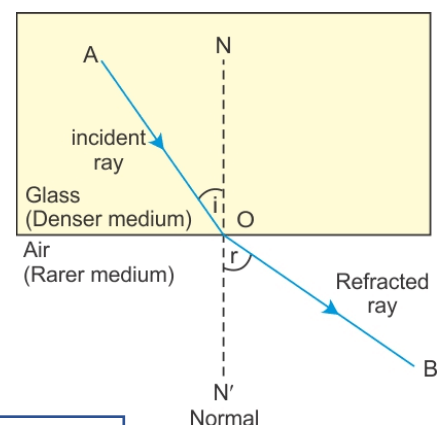
- *Speed decreases*
- *Wavelength decreases*
- *Frequency stays the same*
- *Refracted ray transmits towards the normal*
- *Angle r is less than angle i*



Refraction from denser to rarer medium:

- If light refracts from a high density (denser) medium to a less dense (rarer) medium, speed and wavelength increases.
- If light arrives at an angle, the light moves away from the normal.

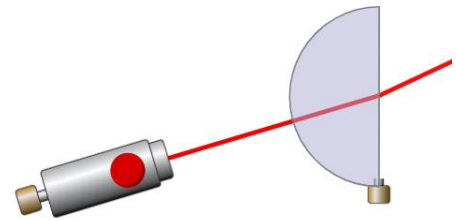
- *Speed increases*
- *Wavelength increases*
- *Frequency stays the same*
- *Refracted ray transmits away from normal*
- *Angle r is greater than angle i*



* **Remember: All angles are measured from the normal.**

If the incident ray arrives at right angle:

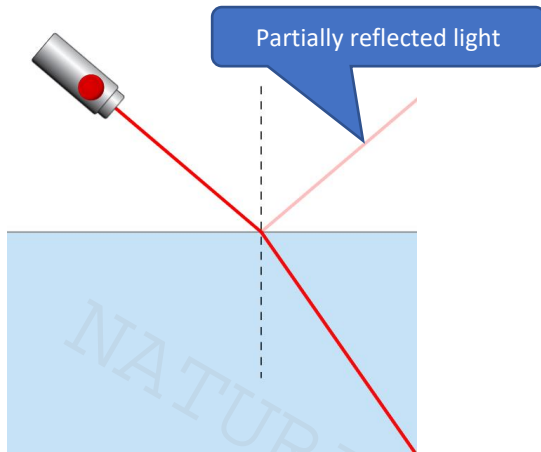
Speed and wavelength changes accordingly, but direction does not change. **Figure (a)**



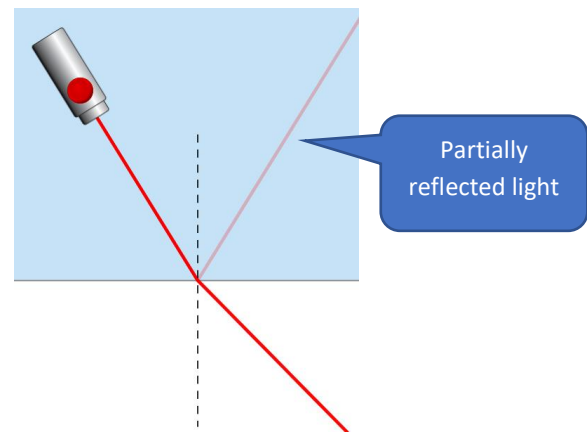
(a)

Remember:

In general when a beam of light refracts there is a partially reflected light at the same time. **Figure (b, and c)**



(b)



(c)

Refractive Index (n or μ):

It is a unit less quantity that describes change in speed, wavelength, and direction etc.

In general, “Ratio between $\sin i$ to $\sin r$ is called refractive index of the medium”.

Index of refraction from a rarer to a denser medium:

→ If a beam of light transmits/refracts from a **rarer** to a **denser** medium and the rarer medium is **vacuume** or **air**, the refractive index is define as;

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

where **n** is the refractive index of the **denser medium**. ($n > 1$)

The equation also known as **Snell's Law:**

Index of refraction from denser to rarer medium:

→ If a beam of light transmits/refracts from **denser to rarer** medium and the rarer medium is **vacuume** or **air** the refractive index is define as;

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

where **n** is the refractive index of the **denser medium**. ($n > 1$)

Index of refraction Intermis of Speed and wavelength:

Sometimes Speed **v** or wavelength **λ** is given to determine the refractive index.

Index of refraction If speeds are given:

→ If c be the speed of light in **vacuume/air** and v be the speed of light in a **denser medium**, the refractive index can be found by using the formula;

$$n = \frac{c}{v}, \text{ where } c = 3 \times 10^8 \text{ ms}^{-1}$$

where n is the refractive index of the **denser medium**. ($n > 1$)

Index of refraction If wavelengths are given:

→ If λ_0 be the wavelength of light in **vacuume/air** and λ be the wavelength of light in a **denser medium**, the refractive index can be found by using the formula;

$$n = \frac{\lambda_0}{\lambda}$$

where n is the refractive index of the **denser medium**. ($n > 1$)

Index of refraction (general case):

→ If a beam of light traveling in a **medium** of refractive index n_1 and incident at an angle θ_1 . The beam is then transmits/refracts at an angle of θ_2 in the second **medium** of refractive index n_2 .

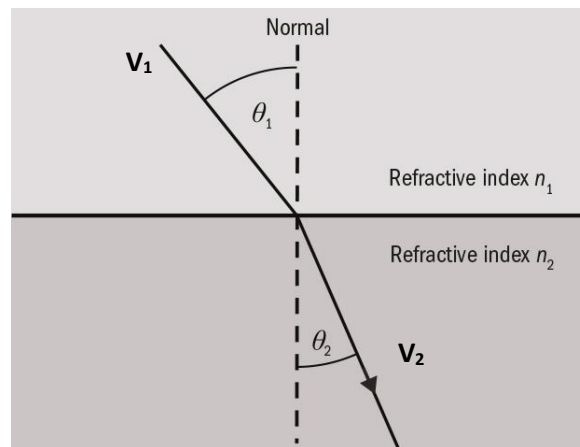
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

→ If a beam of light traveling at speed of v_1 in a **medium** of refractive index n_1 . The beam is then transmits/refracts at speed of v_2 in the second **medium** of refractive index n_2 .

$$n_1 v_1 = n_2 v_2$$

→ If λ_1 be the wavelength of light traveling in a **medium** of refractive index n_1 . λ_2 be the wavelength of light traveling in the second **medium** of refractive index n_2

$$n_1 \lambda_1 = n_2 \lambda_2$$



Critical Angle and Total Internal Reflection

Critical angle:

When light refracts **from high refractive index (denser) medium to low refractive index (rarer) medium** then there is an **incident angle** at which the **refracted ray transmits along the boundary**.

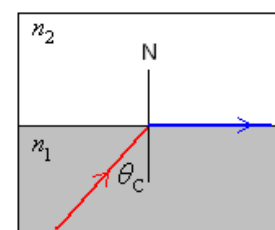
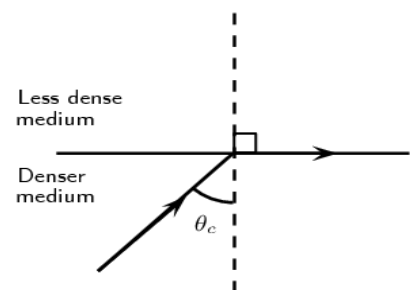
OR “The incident angle at which the refracted angle becomes 90° ”.

If the rarer (less dense) medium is air ($n \approx 1$) then at critical angle θ_c the refractive index n can be found by using;

$$\sin \theta_c = \frac{1}{n}$$

If the less dense medium is other than the air with refractive index n_2 then;

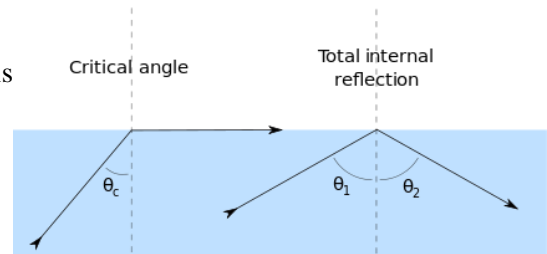
$$\sin \theta_c = \frac{n_2}{n_1}$$



Total Internal Reflection:

If incident angle is further increase than critical angle, all the light is reflected back. i.e. there will be no transmission.

$$\theta_1 > \theta_c$$



Remember:

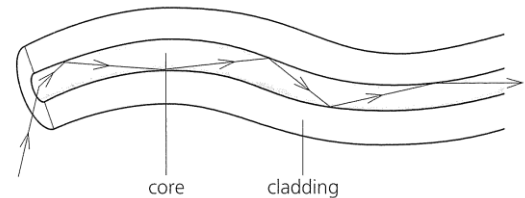
Critical angle and total internal reflection occurs only if refraction is from denser to rarer medium.

Optical Fibres/Fibre Optics:

An optical fibre is a thin piece of flexible glass. Light can travel through it due to total internal reflection. Their uses include:

Communication such as phone and TV signals:
they can carry more information than electricity in copper wires.

Medical endoscopes:
they allow us to see down them and are flexible so they don't cause injury to the patient.



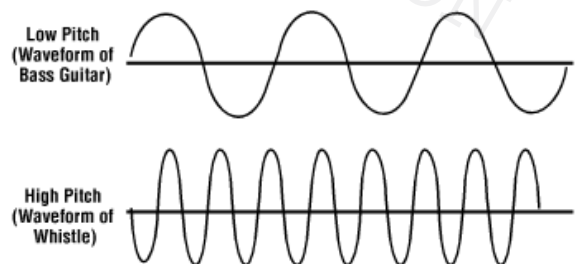
Sound Waves

Sound is produced due to **vibration/oscillation**. The vibrating body transfer energy to particles of a medium (air, fluid/liquid, or solid) the particles then vibrate/oscillate **parallel** to the wave direction in the form of **compression** and **rarefaction**.

Pitch of a sound:

Shrillness or **graveness** of a sound is called **pitch**. Pitch depends upon the frequency of the vibrating object.

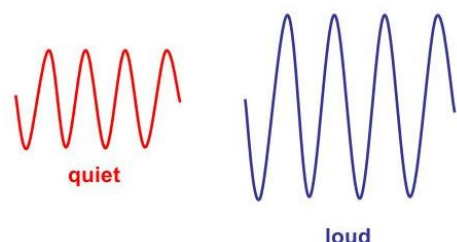
- ✓ Higher the frequency of vibration, higher the pitch is. The sound will be shrill.
- ✓ Lower the frequency of vibration, lower the pitch is. The sound will be grave.
- ✓ A bird produces high-pitched sound whereas roaring of a lion is a low-pitched sound.
- ✓ The voice of a woman has a higher pitch than that of a man.
- ✓ Healthy humans can hear from **20 Hz to 20,000 Hz**. This is called **audible** range.
- ✓ **Ultrasonic sound** has a frequency greater than 20,000 Hz.
- ✓ **Infrasonic sound** has a frequency below 20 Hz.



Loudness of a sound:

Loudness is human perception of intensity. Loudness depends upon the amplitude of vibration.

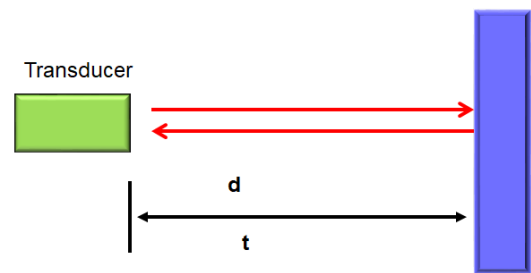
- ✓ Higher the amplitude of vibration, louder the sound is or vice versa.



Pulse and Echo:

High frequency sound waves can be used to detect objects and measure its distance using pulse and echo technique.

- ✓ A pulse of sound from a device called transducer is transmitted towards an object which is detected after reflection (echo).
- ✓ The time interval between the pulse and echo is measured.
- ✓ The formula $d = \frac{vt}{2}$ is used to determine the distance.



SONAR (Sound navigation and ranging):

- Finding the depth of sea.
- Presence of icebergs

RADAR (Radio detection and ranging):

- Used in airport to detect or to know the position of an aircraft

Polarisation

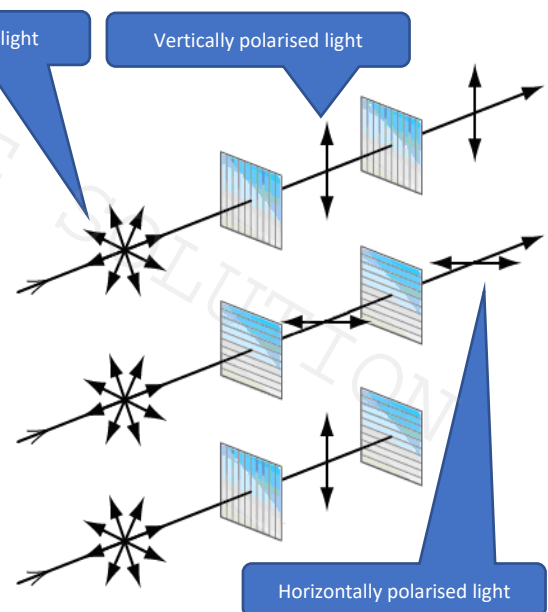
Polarisation:

Light emitting from a source *oscillates in many planes* such light is called **unpolarised light**.

Polarisation restricts the oscillations of a wave to one plane. In the diagrams the light is initially oscillating in all directions/in many planes.

A piece of Polaroid/filter only allows light to oscillate in one plane

- * In the top diagram the light passes through a vertical plane Polaroid and becomes vertically polarised. This can then pass through the second vertical Polaroid.
- * In the middle diagram the light becomes horizontally polarised.
- * In the bottom diagram the light becomes vertically polarised but this cannot pass through a horizontal plane Polaroid.



This is proof that the waves of the EM spectrum are transverse waves.

Polarisation exhibited by transverse waves. I.e. longitudinal waves such as sound waves cannot be polarised.

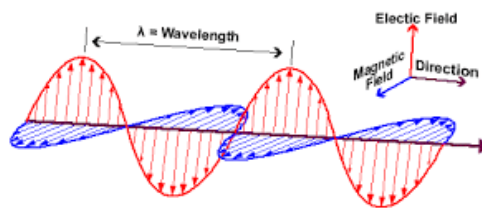
Applications:

TV aerials get the best reception when they point to the transmission source so they absorb the maximum amount of the radio waves.

Electromagnetic waves and Nature of Light

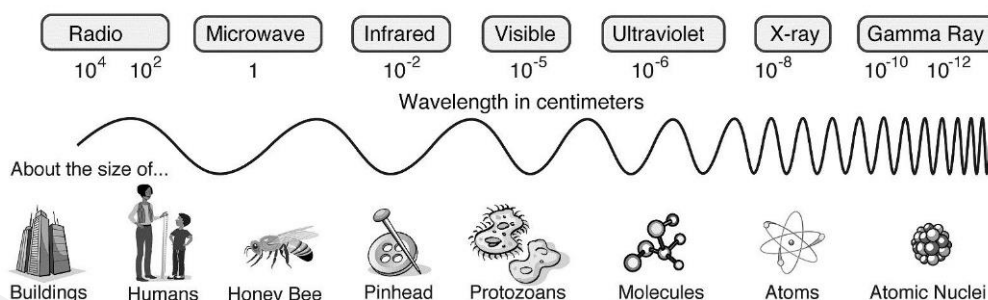
Electromagnetic waves (EMW):

Electromagnetic waves are the waves which do not need particles or medium to travel. They can travel through vacuum. In fact EMW consist of oscillating electric and magnetic fields.



For example: *Light wave (visible light), X-rays, Micro wave, etc.*

The electromagnetic waves are categorized in terms of wavelength and frequency.



* *Visible light from violet to red (VIBGYOR) wavelength ranges from 400nm – 700nm (n is nano = 10⁻⁹).*

Trends (*From Radio to Gamma ray*):

- * Wavelength decrease.
- * Frequency increases.
- * Energy increases.
- * Speed remains the same.

I. *Speed of all electromagnetic waves is the same, denoted by C.*

II. *The value of C is around 3X10⁸ ms⁻¹, called speed of light (C = 3X10⁸ ms⁻¹).*

Nature of light-A Debate (Wave or Particle):

- * Newton believed that light was a stream of particle, called corpuscular.
- * Using his particle model he showed how the properties of reflection and refraction could be explained.
- * In opposition C. Huygens proposed his wave theory of light. According to him, light is emitted as a series of waves in a medium he called “aether”.
- * By around 1700 A.D, there was good evidence to suggest that properties of light could be explained in term of a wave motion, but Newton rejected the idea.
- * For the about the next century particle theory of light was generally accepted.
- * In 1802 A.D, Young gave the evidence for wave nature of light.
- * In 1905 A.D, A. Einstein described the photo electric effect using particle model of light, and called the particle of light “**PHOTON**”

* *In fact light is an electromagnetic wave that also behaves as a particle.*

Conclusion: Light has dual nature.

Wave model of light:

- ✓ Since the *energy of a wave depends upon the intensity of the wave*, while *intensity depends upon the amplitude of the wave*.
- ✓ In case of light, *intensity depends upon the distance from the source*. I.e. In order to *increase the intensity or energy, the distance from the source is decreased*.

Photons:

A discrete energy packet of electromagnetic wave is called *a photon*. The energy of each photon depends upon the frequency of the radiation.

The energy of each photon is given by the equation: $E = hf$,

Where, f is the frequency of the electromagnetic wave and h is the Plank's constant.

$$h = 6.625 \times 10^{-34} \text{ Js}$$

Energy Levels, Spectrum, Excitation and Ionisation

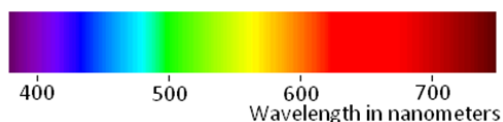
Light Spectrum:

Light coming from any source is analysed by using a diffraction grating to separate light into the colours that makes it up, called its spectrum. There are two types of spectrum.

Continuous Spectra:

Light coming from continuous source of light such as sunlight, candle light, bulb gives continuous spectra.

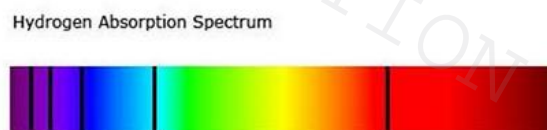
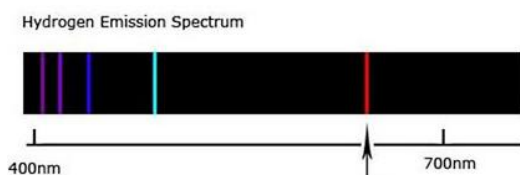
- ✓ In such spectrum there is no apparent breaks or gaps throughout its wavelength range.



Line Spectra:

Light coming from an atom or absorbed by an atom gives line spectra.

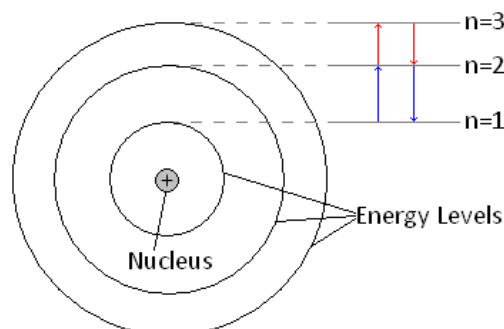
- ✓ If light is emitted from an atom we get emission spectrum (*colour bends in dark background*).
- ✓ If light is absorbed by an atom we get absorption spectrum (*dark bends in colour background*).



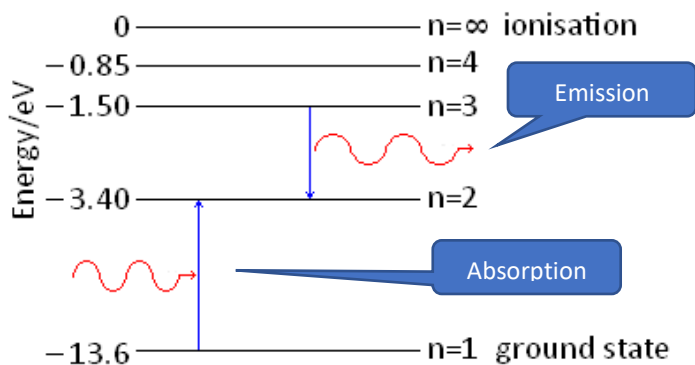
Bohr atomic model:

An atom consists of discrete energy levels called shells. An electron could only orbit the nucleus in certain 'allowed' energy levels. During orbit the electron neither releases nor absorbs energy.

- ✓ If electron absorbs energy/photon equal to the difference of two energy levels it jumps to the higher energy level the atom is said to be excited. This is the reason we get absorption spectrum.



- ✓ *The electron then jumps back to the ground state/low energy level by releasing the energy/photon. This is the reason we get emission spectrum.*
- ✓ *The change from one energy level to another is called a 'transition'.*
- ✓ *The released or absorbed energy is equal to the difference of the energies of the two levels. I.e. $\Delta E = E_2 - E_1 = hf$*
- ✓ *Only certain transitions are allowed in an atom, so during transition only certain frequencies are emitted by the atom.*



Excitation:

When an electron gains energy or absorb photon to move up one or more energy levels.

De-excitation:

When an electron gives out the energy or release photon to move back down to its original energy level.

Ionisation and free electron:

An electron can gain enough energy to be completely removed from the atom. The atom then becomes a positive ion.

- *Such emitted electron is called a free electron.*
- *Energy is given to free an electron, that's why energies of energy levels are negative.*

The Electronvolt, (eV):

The unit of energy joule (J) is too big to use on an atomic and nuclear scale, instead we use another unit called *electronvolt, represented by eV*.

One electronvolt is equal to the energy gained by an electron, when it is accelerated through a potential difference of 1 volt.

$$1\text{eV} = 1.6 \times 10^{-19}\text{J}.$$

Wave-Particle Duality and Electron Diffraction

De Broglie Hypothesis:

In 1923 *Louis de Broglie* put forward the idea that;

- **If a wave can behave like a particle than a particle can behave like a wave.**

A particle of mass, m travelling at velocity v , would have a wavelength given by:

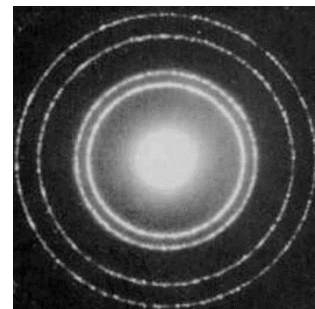
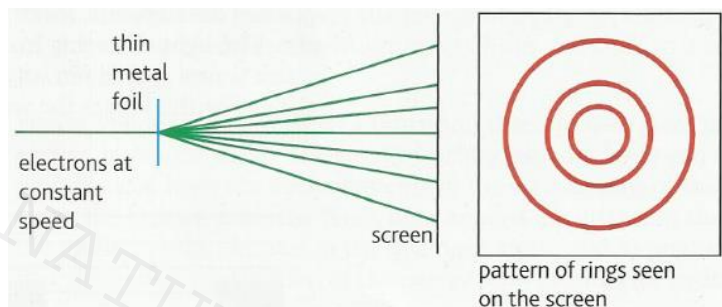
$$\lambda = \frac{h}{mv}, \text{ or } \lambda = \frac{h}{p}$$

Where, h is the Plank's constant and P is the momentum.

Electron Diffraction:

Two years after de Broglie came up with his particle wavelengths and idea that electrons could diffract, Davisson and Germer proved this to happen.

- ✓ A narrow beam of electron is directed at a thin metal foil, composed of tiny crystalline regions in which atoms arranged in rows.
- ✓ These rows of atoms cause the electron in the beam to be diffracted.
- ✓ The electron pass through the metal foil and are diffracted in certain direction only.
- ✓ They form pattern of rings n a fluorescent screen.
- ✓ Each ring is due to electrons diffracted by the same amount from grains of different orientations, at the same angle to the incident beam.



- ✓ The speed of electrons can be increased by increasing of P.D b/w filament and metal foil.
- ✓ This make the diffraction rings smaller, because increase of speed makes the de Broglie wave length smaller.
- ✓ Less diffraction occurs and the ring becomes smaller.

Flux Radiation/Light Intensity

The amount energy falling on unit area per unit time.

$$\text{Intensity} = \frac{\text{Power}}{\text{Area}} \quad I = \frac{P}{A}$$

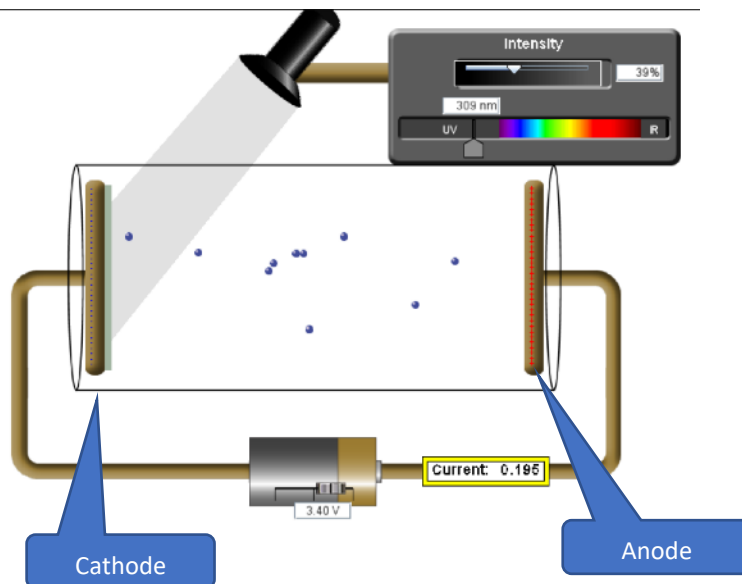
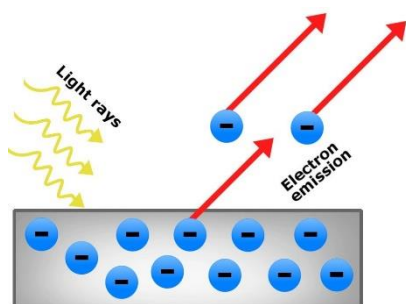
* *The SI unit of the intensity is Wm^{-2}*

Photoelectric Effect

Photoelectric effect:

When *light/electromagnetic wave is shone on a metal surface, electrons are emitted from the surface*. This phenomenon is called *photoelectric effect*.

- The emitted electrons are called *photoelectrons* and the current so obtained is called *photocurrent*.



Explanation using Wave model of light:

- ✓ As per wave model energy of a wave depends upon the intensity of the wave, so if light intensity is increased the **energy of the photoelectrons is also expected to increase** but it does not happen. Increasing intensity only causes current to increase but energy of the electrons remains the same.
- ✓ Energy of a wave takes some time to absorb, so **a time delay is expected in emission of electrons** but it does not happen. Electrons are emitted instantaneously.

(Increasing intensity means decreasing the distance of the light source from the metal).

Wave model failed to explain the observation of photoelectric effect.

Explanation using particle model of light/Einstein explanation:

Einstein used quantum theory of light and suggested that;

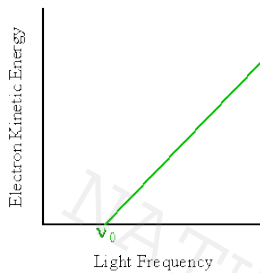
- Light consist of discrete energy packets **quanta** he called them as **photons**. I.e. a light source is emitting packets of energy.
- The photoelectric effect is **1-1 interaction** between incident photon and an electron.
- The incident photon must have **minimum frequency to emit an electron**. This frequency is called **threshold frequency (f_0)**.
- The incident photon **collides with one electron** in the metal, **giving its energy to the electron**, the electron uses that energy to come out from the metal surface.
- Since electrons are bounded within the metal therefor, **minimum energy is needed to emit an electron** from the metal. **This minimum energy is called work function (ϕ_0)** of the metal.
- The energy of the incident photon must be **greater than the work function** of the metal. It is because some of the **energy of the photon is used to break the bonds holding the electron in the metal (work function)** and the **rest of the energy is used by the electron to move away (kinetic energy)**.

$$hf = \phi_0 + E_k$$

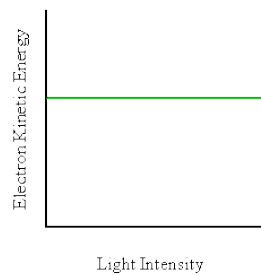
Where, ϕ_0 is the work function of the metal, that can be found by using $\phi_0 = hf_0$

Important Graphs:

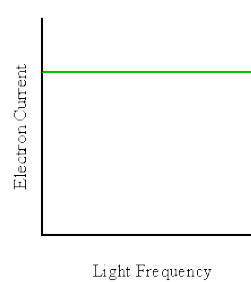
- **Kinetic energy of electron vs frequency of incident photon (fig: a):** The graph is a straight line with positive gradient not passing through origin. The *X-intercept* is **threshold frequency (f_0)**, *gradient* of the graph is **Planck's constant** and *Y-intercept* gives $-\phi_0$.
- **Kinetic energy of electron vs light intensity (fig: b):** The graph is a **horizontal line** showing **constant kinetic energy**.
- **Current vs Light frequency (fig: c):** The graph is a **horizontal line** showing **constant current**.
- **Current vs light intensity (fig: d):** The graph is a **straight line** with **positive gradient** passing through origin.



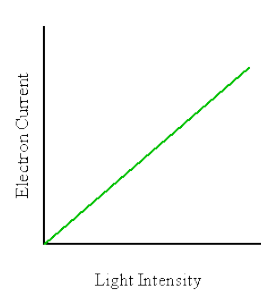
(a)



(b)



(c)



(d)

Important Note:

- * Increasing the intensity increases the number of photons the light source gives out each second not the energy of the photon. That's why increasing intensity causes an increase in current but not the energy of the electron.
- * Increasing the intensity just sends out more photons, all of which would still not have enough energy to release an electron.

Stopping voltage: In order to find the **maximum kinetic energy** of photoelectrons, the potential between the plates is reversed. The potential of the anode is gradually made negative until the ammeter shows no current. **That means even the electron of maximum energy is unable to reach the anode.**

The maximum energy of the electron can now be found by using; $E_k = V_0 e$

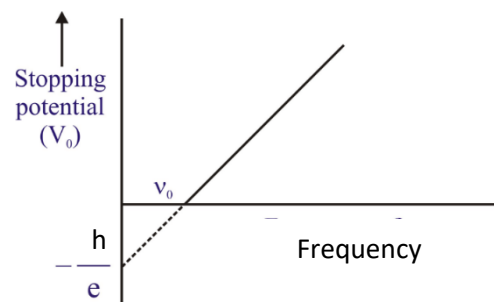
Where, V_0 is the **stopping potential** and e is the **charge of electron**.

The equation $hf = \phi_0 + E_k$ can be rewritten as;

$$hf = \phi_0 + V_0 e$$

The graph V_0 against frequency is a straight line with positive gradient not passing through origin. The *X-intercept* is **threshold frequency (f_0)**, *gradient* of the graph is $-\frac{h}{e}$ and *Y-intercept* gives;

$$-\frac{\phi_0}{e}$$



ALL THE BEST