4. WAVES

4.1 OSCILLATIONS

SIMPLE HARMONIC OSCILLATIONS

Oscillations refer to back & forth motion
↳ are periodic
↳ A period is the time taken to complete one full oscillation.

Amplitude is the maximum displacement from the equilibrium position.

For a system to oscillate, it is necessary to have a restoring force.
↳ a force that brings the system back towards its equilibrium position when it is displaced.

SIMPLE HARMONIC MOTION (SHM)

↳ a special periodic oscillation
↳ defining property:
↳ Acceleration is proportional & opposite to the displacement, & therefore, so is the restoring force.

$$a \propto -x$$

↳ the period & amplitude are constant.
↳ the period is independent of the amplitude.
↳ the displacement, velocity & acceleration are sine or cosine functions of ~~time~~ time.
↳ there is fixed equilibrium position.

Frequency is the number of oscillations per second.

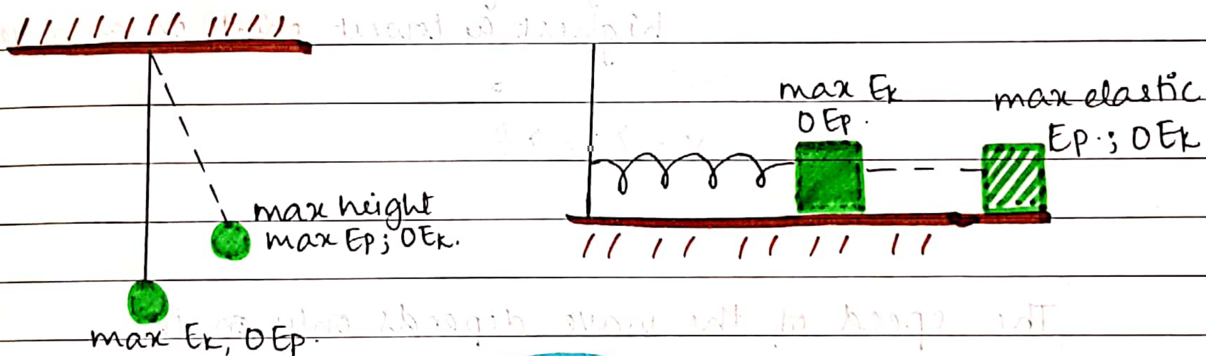
$$f = \frac{1}{T}$$

Phase Difference between two curves is the amount by which one curve is shifted forward relative to another curve.

In terms of angle φ, the phase difference is:

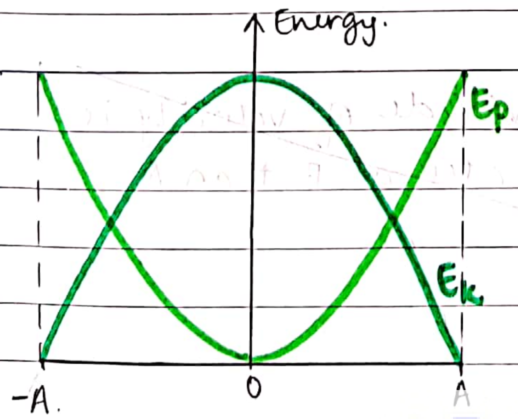
$$\varphi = \frac{\text{shift}}{T} \times 360^\circ$$

ENERGY IN SIMPLE HARMONIC MOTION.



$$E = E_p + E_k$$

In absence of frictional & other resistance forces, this total energy is conserved & so E is constant.



$$(E_k)_{max} = (E_p)_{max} = E$$

4.2 TRAVELLING WAVES

A wave is a disturbance that travels in a medium (vacuum in case of electromagnetic waves) transferring energy & momentum from one place to another.

The direction of propogation of the wave is the direction of energy transfer.

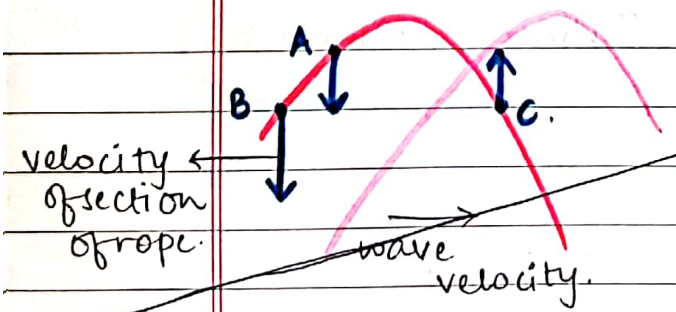
There is no large-scale motion of the medium itself as the wave passes through it.

Wave length (λ) → the length of a complete oscillation.
Crest & Trough → highest & lowest point on a wave.

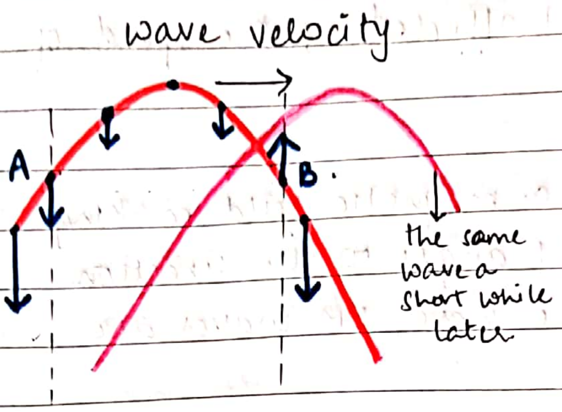
$$v = \frac{\lambda}{T} = \lambda f$$

The speed of the wave depends only on the properties of the medium & not on how it is produced.

TRANSVERSE WAVES:
↳ displacement is perpendicular to the direction of energy transfer.



Magnitude of velocity is greater at B than A.

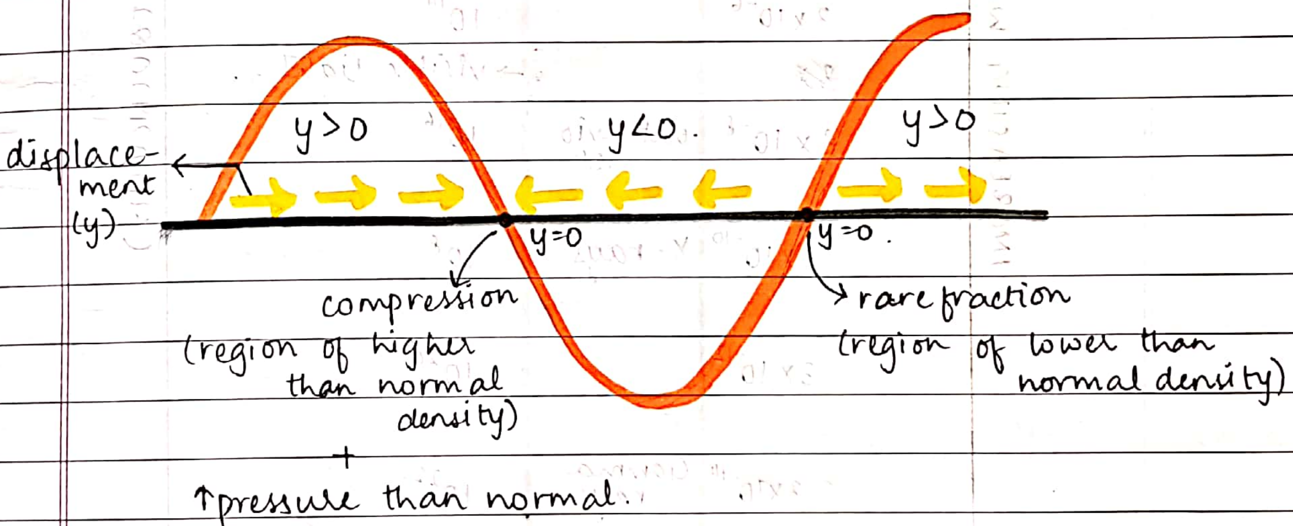


Arrows of different lengths show different magnitudes of velocity.
Velocities in SHM are not constant.

At B, the velocity is downwards & it has the same magnitude as A. However here it (the arrow) shows that as the wave moves ~~upwards~~ forwards the points on the wave move vertically upwards.

LONGITUDNAL WAVES:

↳ Displacement is parallel to the direction of energy transfer

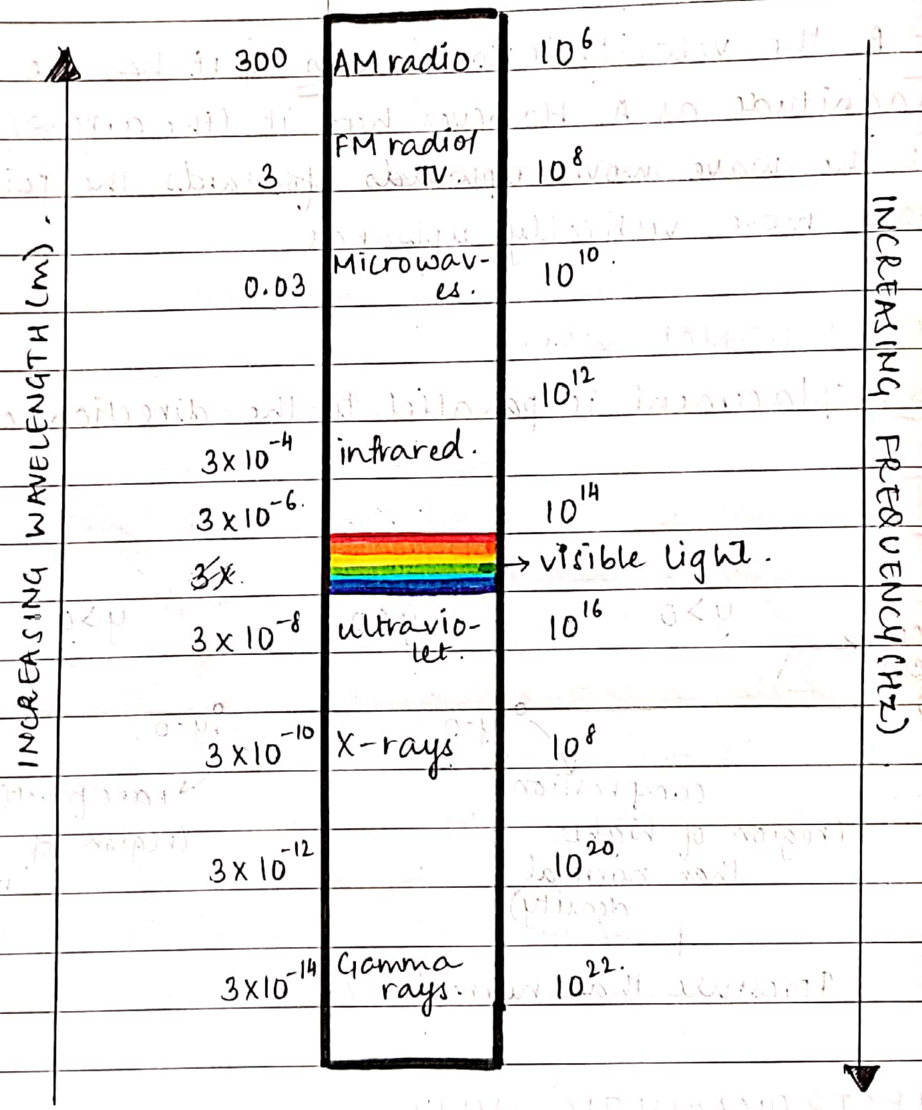


ELECTROMAGNETIC WAVES

Oscillating electric feild produces an oscillating magnetic feild such that the two are at right angles to each other & both propogate in space at the speed of light. ($3 \times 10^8 \, ms^{-1}$).

The speed of light is not affected by the speed of its source.

Since both, the electric & magnetic feild making up the EM wave are right angles to the direction of energy transfer of the wave, EM waves are transverse.



4.3 WAVE CHARACTERISTICS

WAVE FRONTS & RAYS

A wavefront is a surface through crests of a wave. It is normal to the direction of energy transfer. All points on a wave front have 0 phase difference.

Lines in the direction of energy transfer of the wave (& hence normal to the wavefronts) are called rays.

A source that emits waves in all directions is called a point source.

AMPLITUDE & INTENSITY

A wave carries energy. The rate at which the energy is carried is the power (P) of the wave.

When some of this power is incident on an area A, the intensity is given by:

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

In case of a point source, $I = \frac{P}{4\pi r^2}$ → area of a sphere.

Inverse square law relationship : $I \propto x^{-2}$

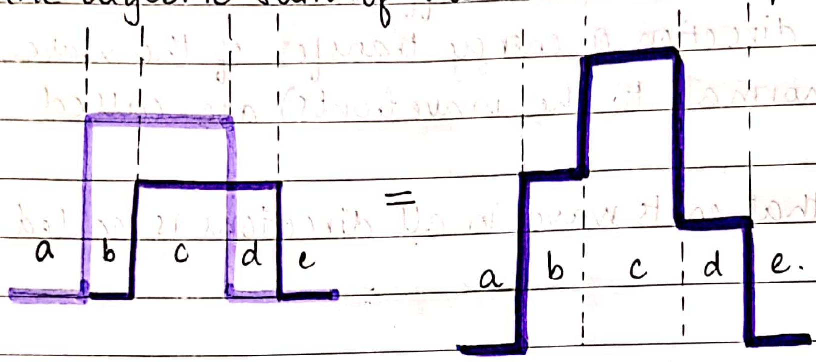
Also,

$$\cancel{I \propto Area^2}$$

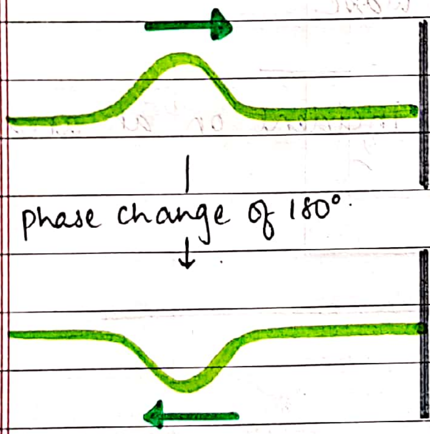
$$I \propto Amplitude^2$$

THE PRINCIPLE OF SUPERPOSITION.

When two or more waves of the same type arrive at a given point in space at the same time, the displacement of the medium at that point is the algebric sum of the individual displacements



REFLECTION OF PULSES



When the pulse in the rope hits the fixed end, the rope attempts to move the fixed end upward by an upward force.

The wall exerts an equal & opposite force. Therefore, the reflected pulse is inverted.

If the end of the rope is free to move, there is no phase change or inversion of the wave.

POLARISATION

In visible light:

→ an electric & magnetic feild are perpendicular to each other.

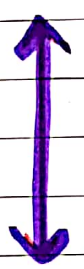
→ direction of propogation is normal to both feilds.

An electromagnetic wave is said to be plane polarised if the electric field oscillates on the same plane.
If the electric feild oscillates on a vertical plane then the light is vertically polarised.

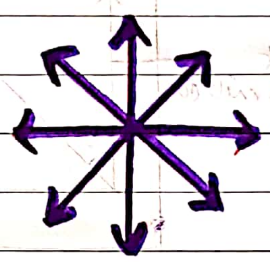
Individual emitters of light emit polarised light waves.

But in a collection of emitters, the plane of polarisation of one emitter is different from another's

Therefore, a given ray of light would consist of a huge number of differently polarised waves. So this light is unpolarised.
Eg- light from a light bulb



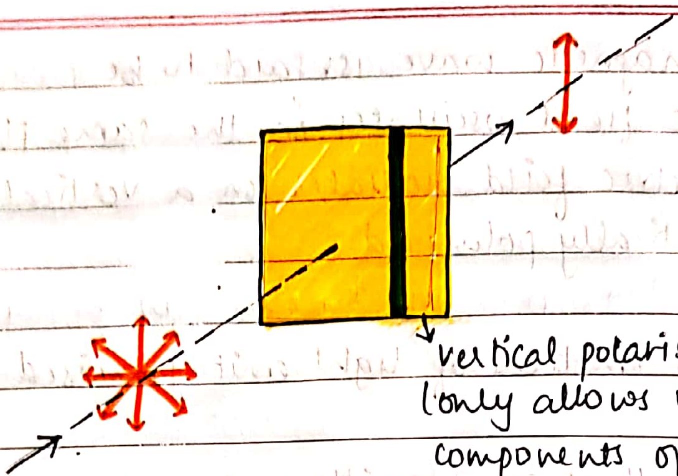
Electric feild of a polarised light



Electric feild of unpolarised light.

Both waves are propogating at right angles to the electric feild i.e into the page.

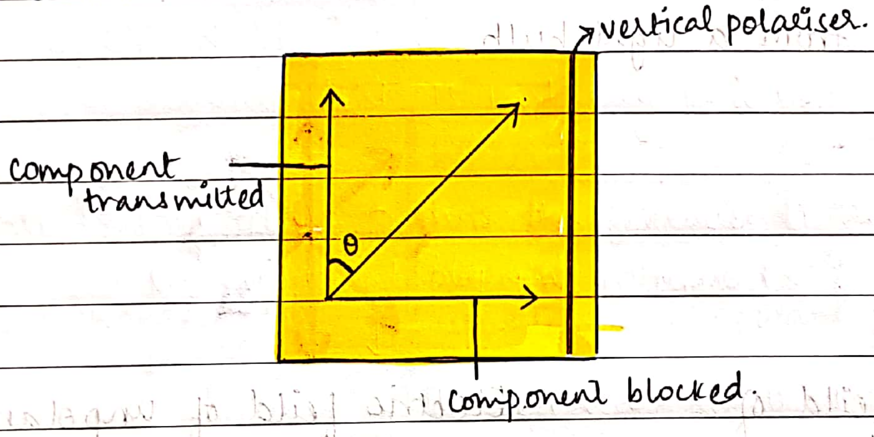
Unpolarised light can be polarised by passing it through a polariser.
↳ sheet with a material whose molecular structure is such that only a specific orientation of electric feild can go through it.



vertical polariser (only allows vertical components of the electric feild to pass through).

~~MAU~~

MALUS'S LAW



θ is the angle between E_0 (Electric feild) & the transmission axis of the polariser.

Vertical

$E = E_0 \cos\theta$

~~Horizontal.~~

~~$E = E_0 \sin\theta$~~

⋆ Electric feild strength is a vector quantity.

classmate

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Page

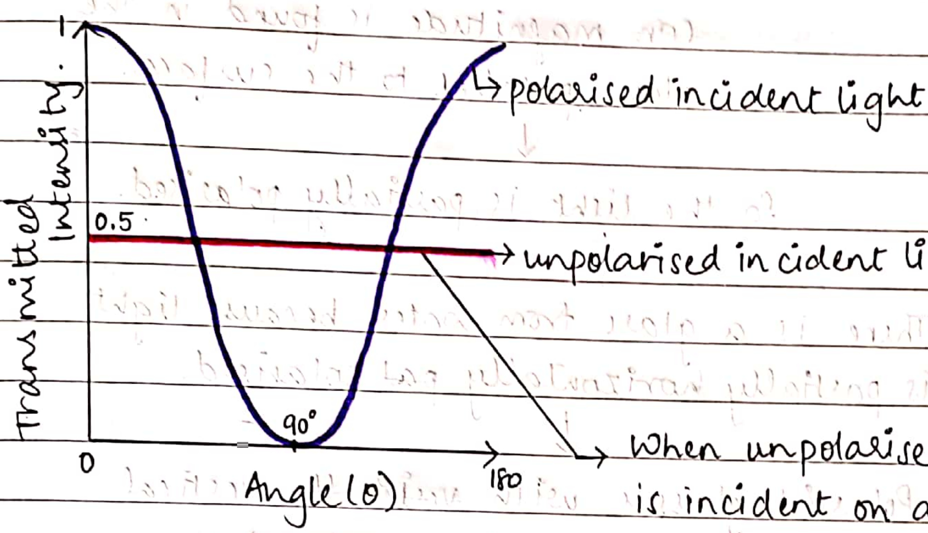
$$I = KE^2$$

$$I = K(E_0 \cos\theta)^2 = (KE_0^2)\cos^2\theta = I_0 \cos^2\theta$$

I_0 ↓ incident intensity.

$$I = I_0 \cos^2\theta$$

Malus's law.



When unpolarised light is incident on a polariser, very many angles of θ are involved & so, we take the average of $\cos^2\theta$ i.e is 0.5.

If there are two polarisers, with their transmission axes at right angles, passing no light emerges.

So the transmitted intensity is half of the incident intensity.

POLARISATION BY REFLECTION.

Another way of obtaining polarised light is through reflection from non-metallic surface.

When ~~unpolirr~~ unpolarised light reflects off a non-metallic surface, the reflected ray is partially polarised.

↳ the reflected ray has varios components of the electric feild of unequal magnitude.
The component with the greatest ~~con~~ magnitude is found in the plane parallel to the surface.

↓

So the light is partially polarised.

There is a glare from water because light is partially horizontally ~~pa~~ polarised.

↓

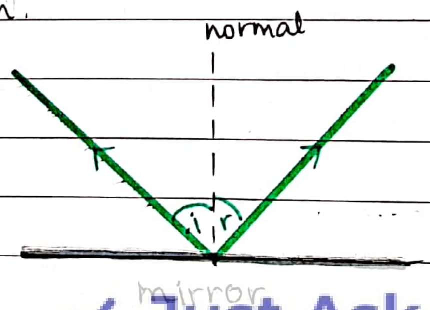
Polaroid glasses with ~~verticall~~ vertical transmission axes reduces this glare.

4.4 WAVE BEHAVIOR

REFLECTION

Laws of Reflection:

→ The angle of incidence is equal to the angle of reflection.



→ The reflected ray, incident ray & the normal should be on the same plane. This plane is called the plane of incidence.

→ The plane should be sufficiently smooth.
↓
$\lambda_i >$ any irregularities of the surface.

→ The wave-length of the incident & the reflected ray is the same

REFRACTION & SNELL'S LAW.

Velocity of light in all other media < Velocity of light in vacuum ($c = 3 \times 10^8 \, ms^{-1}$)

Refraction is the travel of light from one medium to another where it has different speed.

Usually, when a ray of light strikes the boundry ~~of~~ between 2 mediums, there is both, reflection & refraction.

SNELL'S LAW relates the sines of the angles of incidence & refraction to the wave speeds in the two media. This form of law applies to all waves.

$$\boxed{\frac{n_1}{n_2} = \frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1} = \frac{\lambda_2}{\lambda_1}}$$

Since, the speed of light in vacuum is the greatest, the refractive index of any other medium is always >1.

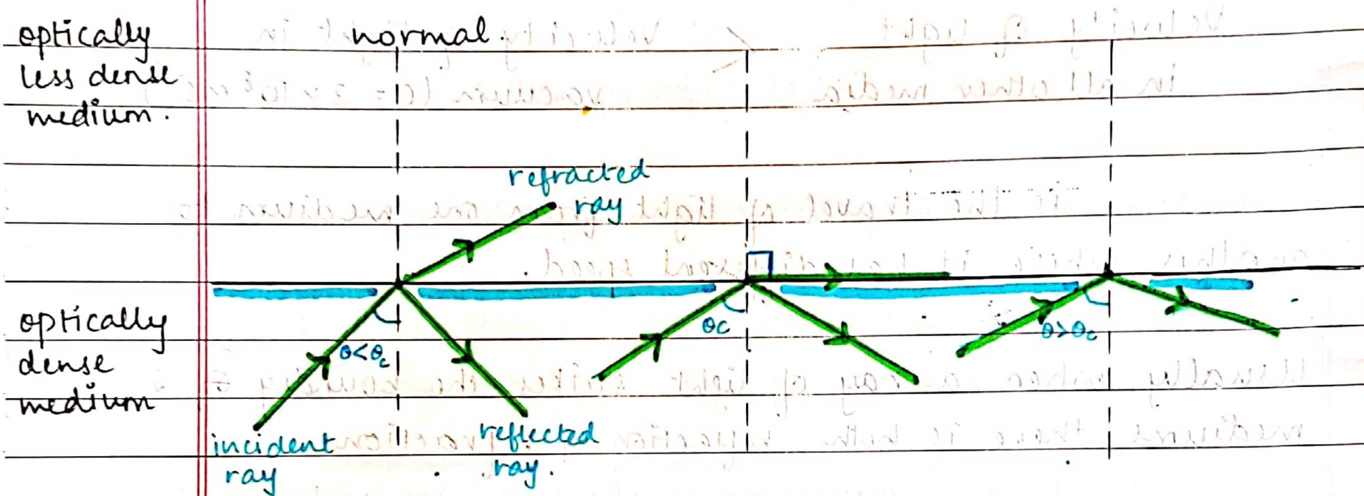
$$n_{vacuum} = 1$$

TOTAL INTERNAL REFLECTION :

↳ occurs when a wave moves from an optically dense medium to a less dense medium.

↳ as the angle of incidence increases, the angle of refraction reaches 90°

The angle of incidence for which the angle of refraction becomes 90° is called the critical angle. Total internal reflection occurs when the $\angle i >$ critical angle.



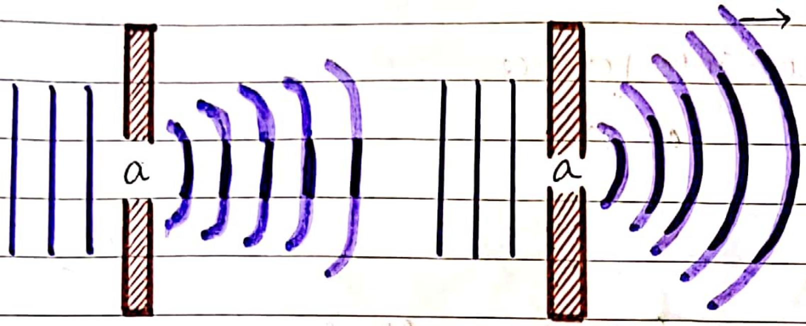
The refractive index does not depend on wavelengths. So wave~~lengths~~ with same $\angle i$ but different wavelength are refracted at different angles. This phenomenon is called dispersion.

Application of Total internal reflection

↳ propogation of digital signals carrying information in optical fibres.

DIFFRACTION.

↳ Spreading of a wave as it goes past an obstacle or through an aperture.



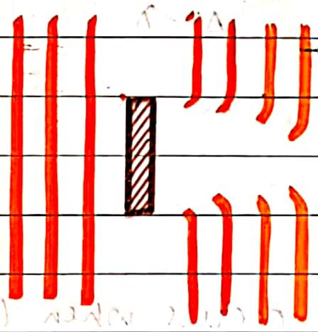
→ intensity of wavefronts decreases as we move to sides.

$\lambda < a$ = little diffraction

$\lambda > a$ = greater diffration.

Larger the wavelength, greater the effect.

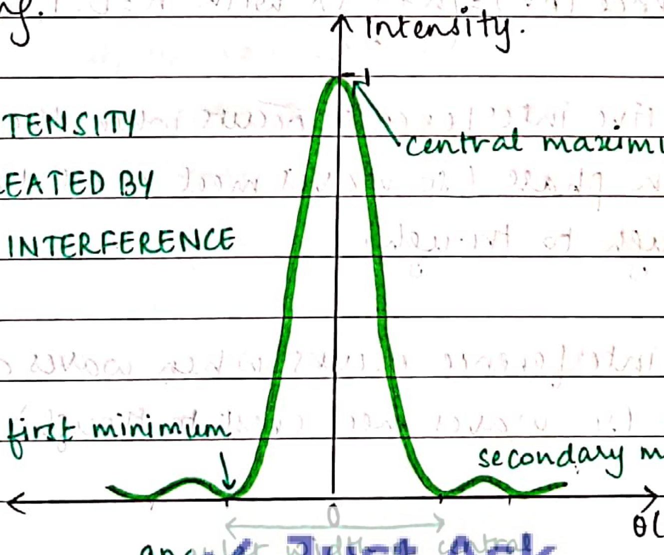
Diffraction around obstacles.



→ decreasing intensity

Diffraction explains why we cannot see be hear around corners. Sound diffracts arround an opening/ of op obstacle but light doesn't since its λ is very small compared to the opening.

COMPLEX INTENSITY PATTERNS CREATED BY SINGLE SLIT INTERFERENCE

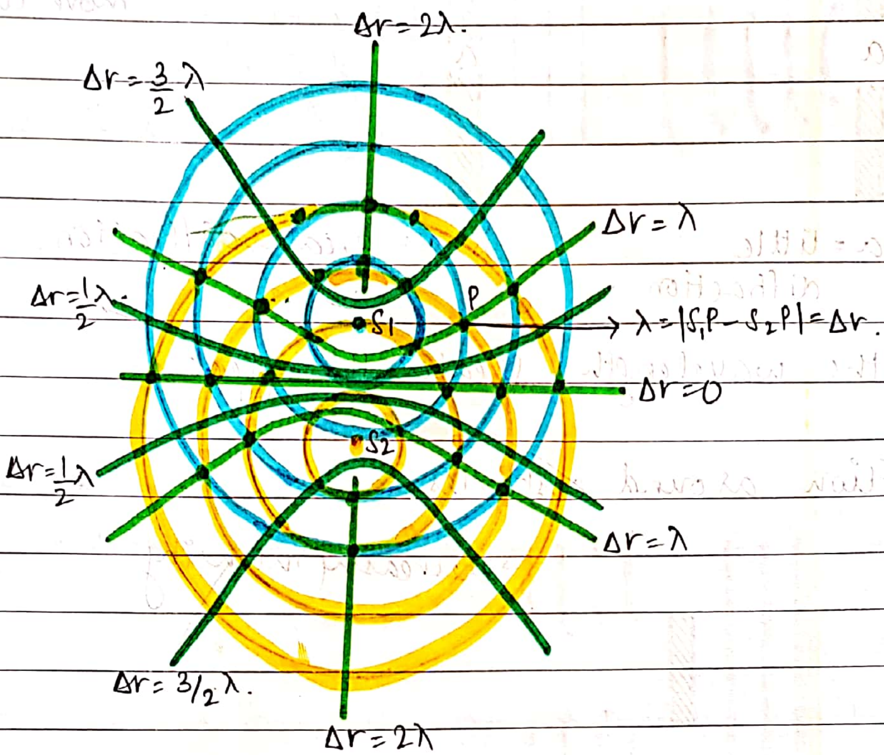


angular width central maximum

DOUBLE SOURCE INTERFERENCE:

The resulting pattern when 2 or more waves meet & superpose is called ~~sup~~ interference

All waves show interference.



(high intensity sound, bright light) ← Constructive Interference occurs when (Δr) path difference $= n\lambda$ with $n = 0, 1, 2, 3 \ldots$

(no sound & darkness) Destructive Interference occurs when the path difference $(\Delta r) = \left(n + \frac{1}{2}\right)\lambda$ with $n = 0, 1, 2, 3 \ldots$

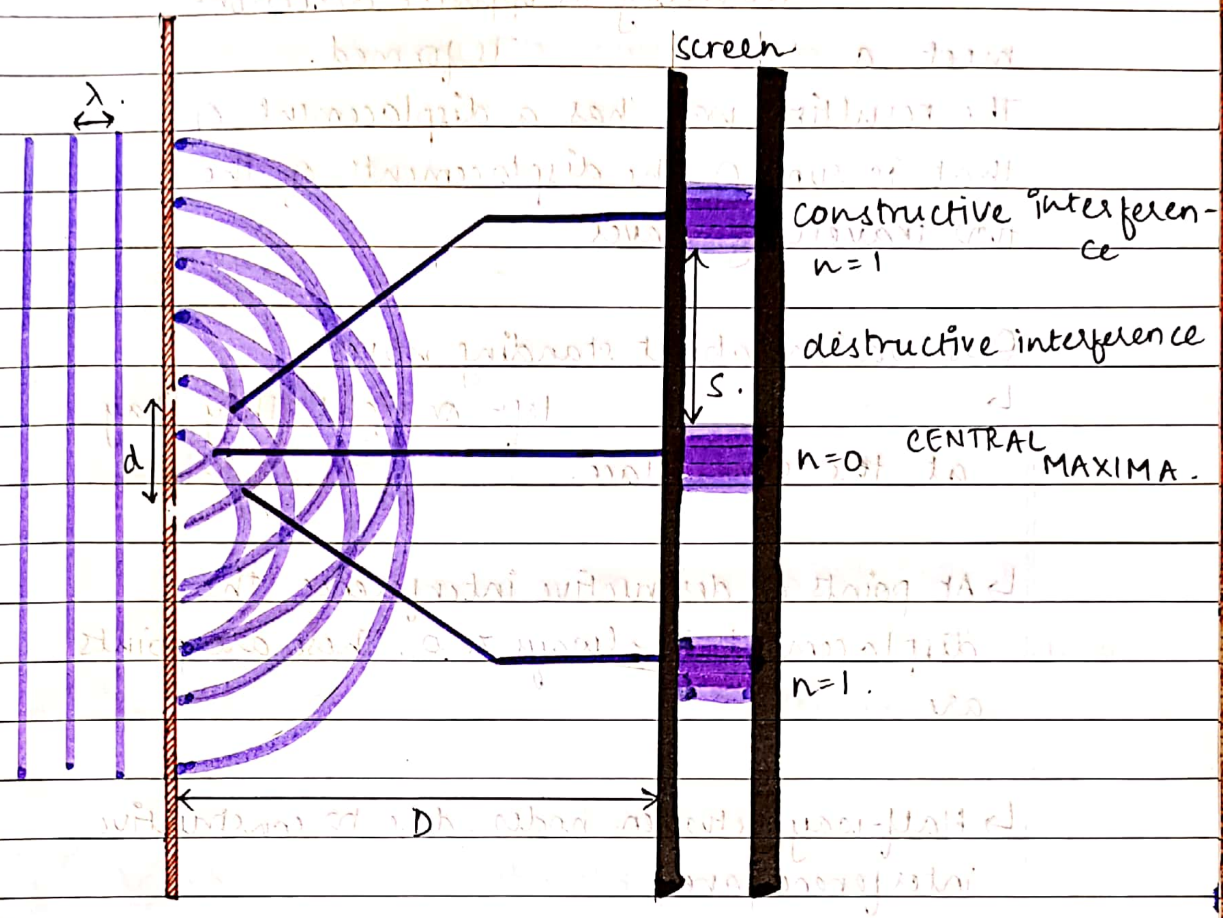
So constructive interference occurs when the waves are in phase (so waves meet crest to crest & trough to trough)

Destructive interference occurs when waves are out of phase (so waves meet crest to trough).

*If Δr is anything other than an integral or ½ integral multiple of λ, P will be some value between 0 & 2A (assuming the 2 waves have equal Amplitude)

If the phase difference is θ, add $\frac{\theta\lambda}{2\pi}$ to the path difference.

DOUBLE SLIT INTEFERENCE.



$$S = \frac{\lambda D}{d}$$

If the slit width is negligible, the peaks in intensity would have the same intensity magnitude.
If not, the secondary or tertiary maximas will have a lesser intensity than that of the central maxima.