Introduction

This is a learning as well as an exam preparation video.

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Chapter 10: Wave Optics

Chapter 10: Wave Optics

Introduction

Wave optics also called Physical optics deals with the study of various phenomena such as polarization, diffraction, interference, and other occurrences where ray approximation of geometric optics cannot be done. Thus, the section of optics that deals with the behaviour of light and its wave characteristics is said to be wave optics.

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Wave Front:

The locus of all those particles which are vibrating in the same phase at any instant is called wave front. Thus, wave front is a surface having same phase of vibrating particles at any instant at every point on it.

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Wave Front:

These are three types:

- Spherical wavefront
- Cylindrical wavefront
- Plane wavefront

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Models of Light:

Corpuscular model:

According to this model, a luminous body emits a stream of particles in all directions. The particles are assumed to be very-very tiny. It explained the laws of reflection and refraction of light at an interface using concepts of elastic collisions and momentum conservation. Although this law could explain reflection and refraction, this law could not satisfactorily explain phenomenon like interference, polarization, and diffraction. In 1637, Descartes gave the corpuscular model of light.

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Models of Light:

Wave model:

The wave theory of light was first put forward by Christian Huygen in 1678. On the basis of his wave theory, Huygen explained satisfactorily the phenomenon of reflection, refraction and total internal reflection.

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Huygens's Principle:

Huygens's principle is a geometrical construction, which can be used to obtain new position of a wave front at a later time from its given position at any instant. Or we can quote that this principle gives a method gives an idea about how light spreads out in the medium.

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Huygens's Principle:

It is developed on the following assumptions:

- All the points on a given or primary wave front acts as a source of secondary wavelets, which sends out disturbance in all directions in a similar manner as the primary light source.
- The new position of the wave front at any instant (called secondary wave front) is the envelope of the secondary wavelets at that instant.

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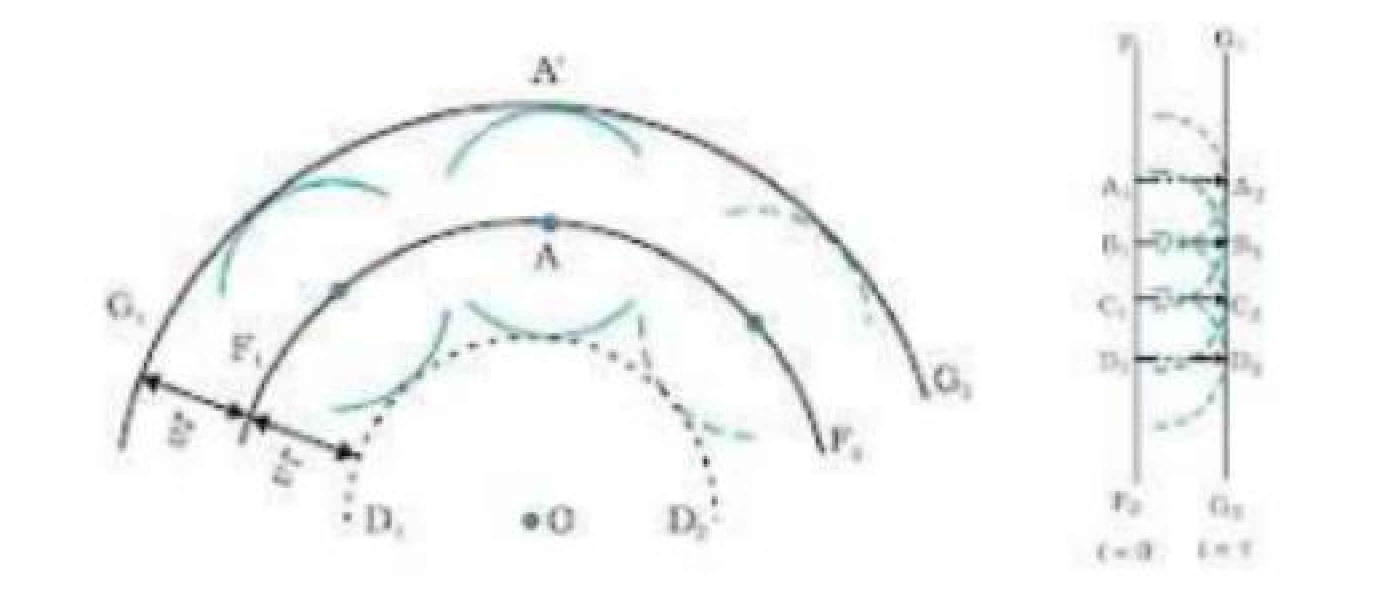
Huygens's Principle:

These two assumptions are known as Huygens principle or Huygens' construction.



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Maxwell's Electromagnetic Wave Theory:

- Light waves are electromagnetic waves which do not require a material medium for their propagation.
- Due to transverse nature, light wave undergo polarization.
- The velocity of electromagnetic wave in vacuum is $c = \frac{1}{\mu_0 \varepsilon_0}$
- The velocity of electromagnetic waves in medium is less than that of light, v < c v = $\frac{1}{\sqrt{\mu_0 \varepsilon_0 \varepsilon_r \mu_r}} = \frac{c}{\sqrt{\mu_0 \varepsilon_r}}$

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Maxwell's Electromagnetic Wave Theory:

- The velocity of electromagnetic waves in a medium depend upon the electric and magnetic properties of the medium.

  where, μ_o = absolute magnetic permeability and

  ε_o = absolute electrical permittivity of free space.

- It failed to explain the phenomenon of photoelectric effect, Compton effect and Raman effect.

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Max Planck's Quantum Theory:

- Light emits from a source in the form of packets of energy called quanta or photon.
- The energy of a photon is $E = hv$, where h is Planck's constant and v is the frequency of light.
- Quantum theory could explain photoelectric effect, Compton effect and Raman effect.
- Quantum theory failed to explain interference, diffraction and polarization of light.

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The Doppler's Effect:

When light producing source moves away from the observer the frequency as measured by the observer will be smaller than that is actually generated by the source. Astronomers call the increase in wavelength due to Doppler effect as red shift.

When observer moves towards the source or the source moves towards observer, then apparent wavelength decreases, and visible spectrum appear to be shifted towards shorter wavelength. Hence, we call this as blue shift.

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Coherent and Incoherent Sources of Light:

- **Coherent sources:**

Two sources of light which continuously emit light waves of same frequency (or wavelength) with a zero or constant phase difference between them, are called coherent sources.

Ex- LASER.

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Coherent and Incoherent Sources of Light:

Incoherent sources:

Two sources of light which do not emit light waves with a constant phase difference are called incoherent sources.

Ex- Two different light sources produce incoherent waves.

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Interference of Light Wave:

Interference is the phenomenon in which two waves superpose to form the resultant wave of the lower, higher or same amplitude. When the crest of one wave falls on the crest of another wave such that the amplitude is maximum then interference is called constructive interference.

When the crest of one wave falls on the trough of another wave such that the amplitude is minimum then interference is called destructive interference.

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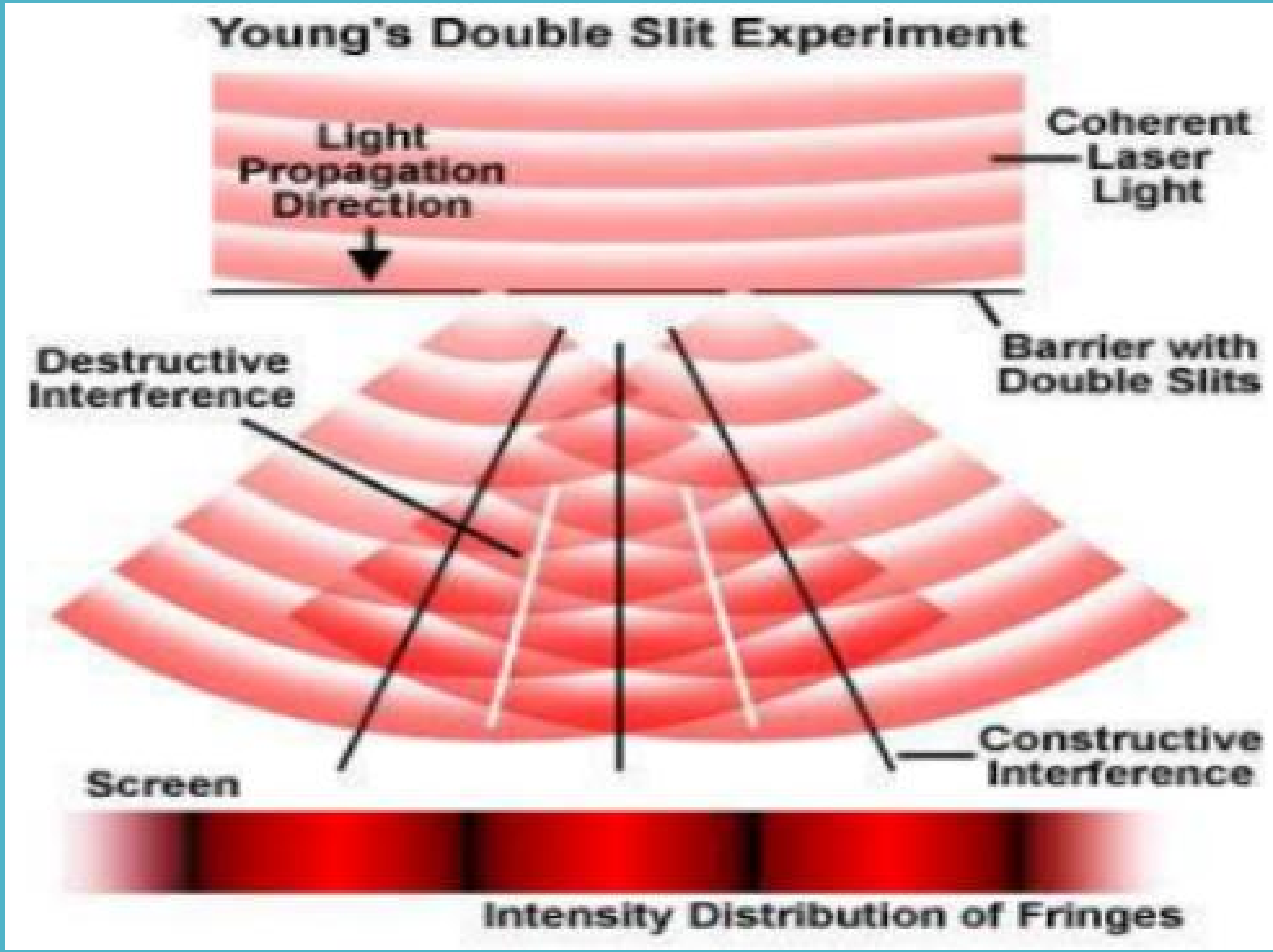
Interference of Light Wave:



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Interference of Light Wave:

Conditions for sustained interference:

- Two sources of light must be coherent.
- The frequencies (or wavelength) of the two waves should be equal.
- The light must be monochromatic.
- The amplitudes of the interfering waves must be equal or nearly equal.
- The two sources must be narrow.

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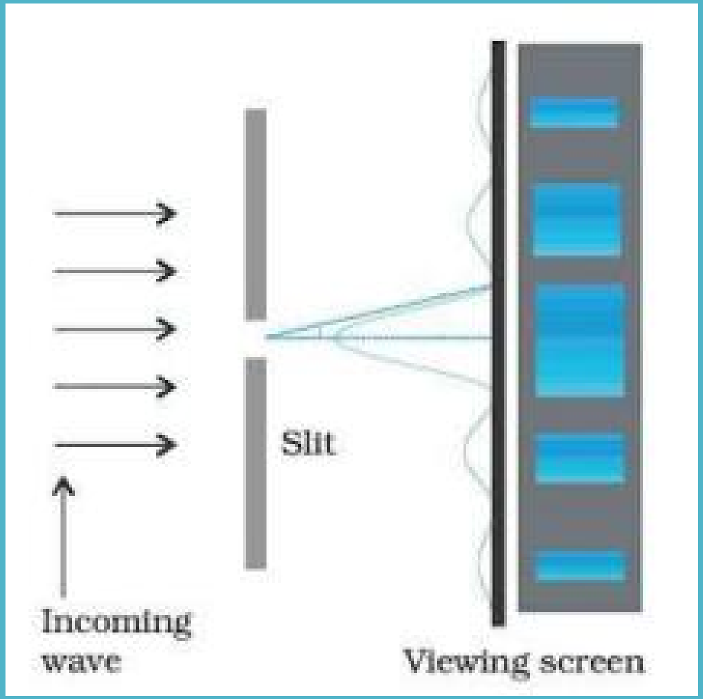
Diffraction

The phenomenon of bending of light around the corners of an obstacle is called the diffraction of light.



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Difference between Diffraction and Interference:

S. No.	Interference	Diffraction
1.	Interference may be defined as waves emerging from two different sources, producing different wavefronts.	Diffraction, on the other hand, can be termed as secondary waves that emerge from the different parts of the same wave.

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Difference between Diffraction and Interference:

S. No.	Interference	Diffraction
2.	The intensity of all the points on maxima is of similar intensity in interference.	In diffraction, there is a variance of the intensity of positions.

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Difference between Diffraction and Interference:

S. No.	Interference	Diffraction
3.	It is absolutely dark in the region of minimum intensity, in the case of interference.	We see a variance in the intensity of interference in diffraction.

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Difference between Diffraction and Interference:

S. No.	Interference	Diffraction
4.	The width of the fringes in interference is equal in interference.	The width of the fringes is not equal in interference.

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Difference between Diffraction and Interference:

S. No.	Interference	Diffraction
5.	The sources are referred to as interference sources if the number of sources is as few as two sources.	If the number of sources is more than to the sources are referred to as diffraction sources.

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Polarization:

If the vibrations of a wave are present in just one direction in a plane perpendicular to the direction of propagation, the wave is said to be polarized or plane polarised. The phenomenon of restricting the oscillations of a wave to just one direction in the transverse plane is called polarization of waves.

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Malus' Law:

It states that the intensity of plane-polarized light that passes through an analyzer varies directly with the square of the cosine of the angle between the plane of the polarizer and the transmission axes of the analyzer.

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

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Polarizer:

A device that polarizes the unpolarized light passed through it is called a polarizer.

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Optical Activity:

When plane polarized light passes through a certain substances, the plane of polarization of the light is rotated about the direction of propagation of light through a certain angle.

This phenomenon is called optical activity or optical rotation and the substances opticall active.

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Brewster's Law:

According to Brewster's law, when an unpolarized light is incident on a transparent substance surface, it experiences maximum plan polarization at the angle of incidence whose tangent is the refractive index of the substance for the wavelength.

$n = \tan i$ (where, i = incident angle)

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Double Refraction:

When unpolarized light is incident on a calcite or quartz crystal it splits up into two refracted rays. one of which follows laws of refraction. called ordinary ray (O-ray) and other do not follow laws of refraction. called extraordinary ray (E-ray). This phenomenon is called double refraction.

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Dichroism:

Few double refracting crystals have a property of absorbing one of the two refracted rays and allowing the other to emerge out. This property of crystal is called dichroism.

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Polaroid:

It is a polarizing film mounted between two glass plates. It is used to produce polarized light.

A polaroid is used to avoid glare of light in spectacles.

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Uses of Polaroid:

- Polaroids are used in sunglasses. They protect the eyes from glare.

- The polaroid's are used in window panes of a train and especially of an aero plane. They help to control the light entering through the window.

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Uses of Polaroid:

- The windshield of an automobile is made of polaroid. Such a mind shield protects the eyes of the driver of the automobile from the dazzling light of the approaching vehicles.
- The pictures taken by a stereoscopic camera. When seen with the help of polarized spectacles, create three-dimensional effect.

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Nicol Prism:

A Nicol prism is an optical device which is used for producing plane polarised light and analyzing light the same.

The Nicol prism consists of two calcite crystal cut at 68° with its principal axis joined by a glue called Canada balsam.

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Validity of Ray Optics:

By diffraction of light travels, a parallel beam of light travels up to distances as large as few meters can be broadened.

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Fresnel Distance:

The minimum distance a beam of light can travel before its deviation from straight line path becomes significant/ noticeable is known as Fresnel distance.

$$Z_F = \frac{a^2}{\lambda}$$

As the wavelength of light is very small, the deviation will be also very small, and light can be assumed as travelling in a straight line.

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Fresnel Distance:

So, we can neglect broadening of beam due to diffraction up to distances as large as a few meters, i.e., we can assume that light travels along straight lines and ray optics can be taken as a limiting case of wave optics.

Therefore, Ray optics can be considered as a limiting case of wave optics.

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Resolving Power:

If two point objects are close to each other, images diffraction patterns of those objects will also be close and overlap each other.

Limit of resolution of the instrument is the minimum distance between two objects which can be seen separately by the object instrument.

$$\text{Resolving Power (R.P)} = \frac{1}{\text{Limit of Revolution}}$$

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Resolving power of Microscope:

$$\text{R.P. of microscope} = \frac{2\mu s}{\lambda}$$

Where D is the aperture of the telescope

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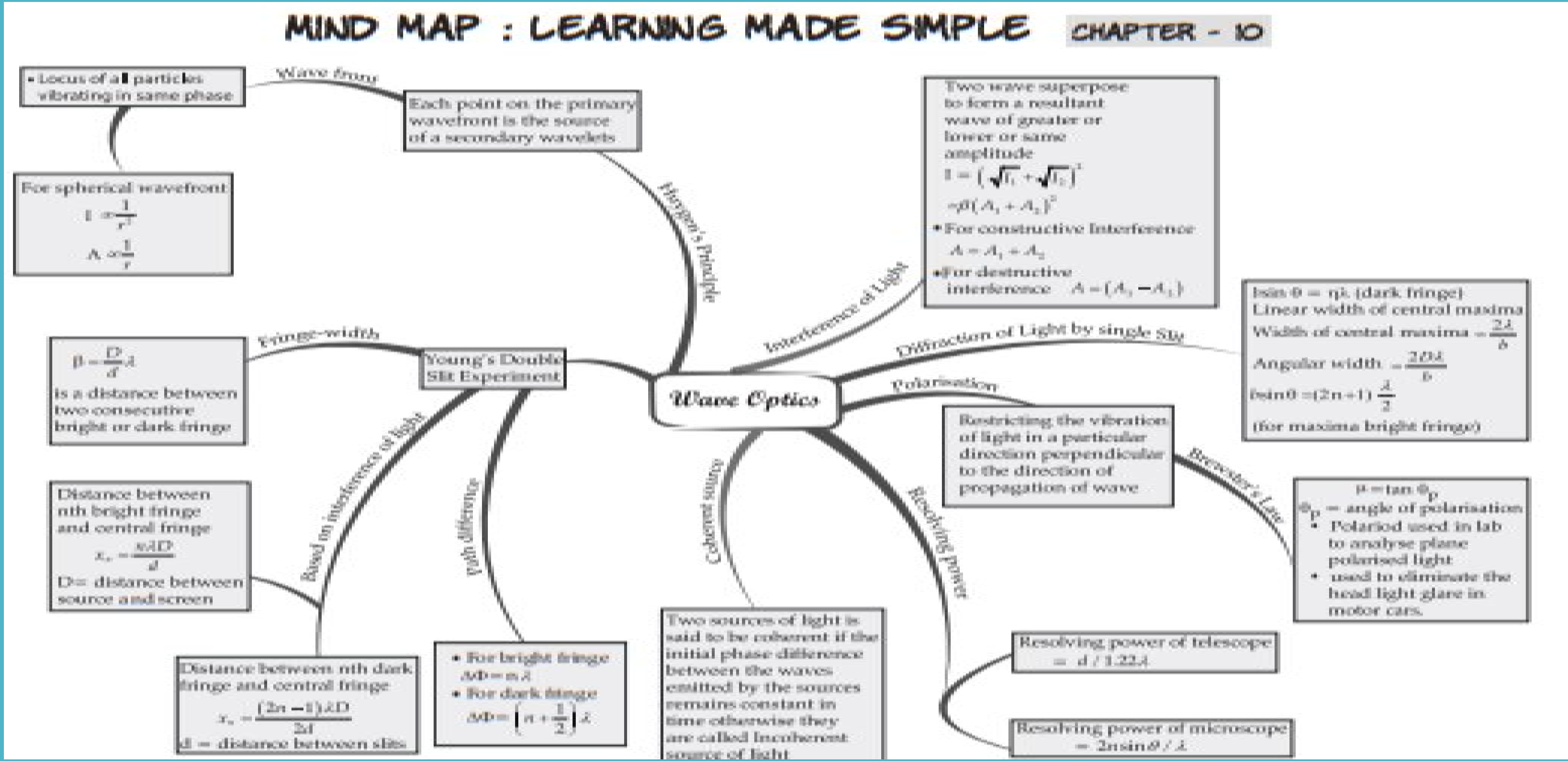

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