

PHYSICS • CLASS 12

CHAPTER 10

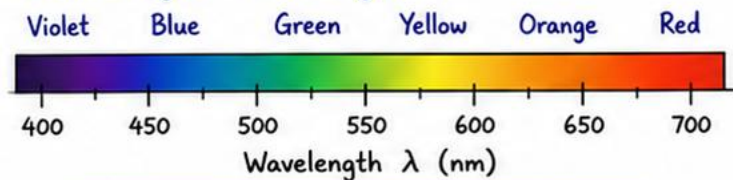
Wave Optics

CHAPTER NOTES



Wave optics describes light when its wavelength matters.

Visible light wavelengths:



Yellow light: $\lambda \approx 0.6 \mu\text{m} = 600 \text{ nm}$

Ray optics is the $\lambda \rightarrow 0$ approximation and works when apertures and objects are much larger than λ (i.e., $D \gg \lambda$, $a \gg \lambda$).

1. Wavefronts and Huygens Principle

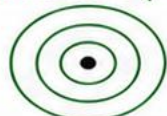
- Wavefront: surface of constant phase.
- Plane wavefronts: flat, parallel.
- Spherical wavefronts: curvature from a point source.

Plane wave



(front view)

Spherical wave (point source)



(in 2D cross-section)

3. Interference

- Superposition of coherent waves gives reinforcement or cancellation.
- Double-slit (equal slits, screen far away)



d = slit separation
 Δ = path difference

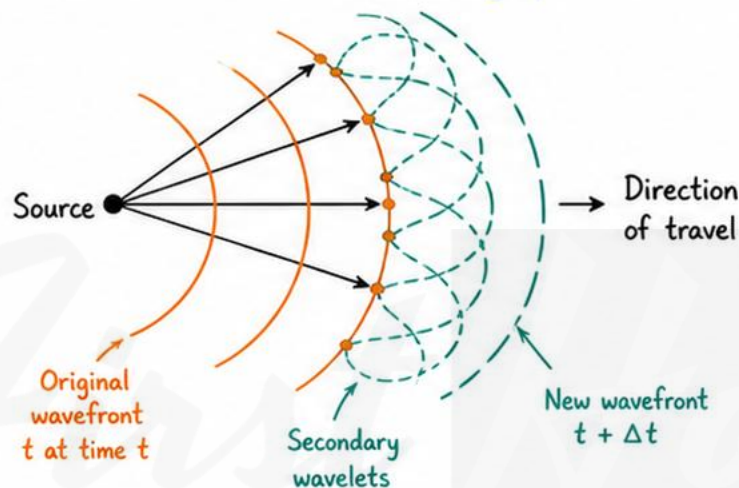
Bright (max)
Dark (min)

Maxima (bright):
 $\Delta = d \sin \theta = m \lambda$
 $m = 0, \pm 1, \pm 2, \dots$

Minima (dark):
 $\Delta = (m + \frac{1}{2}) \lambda$

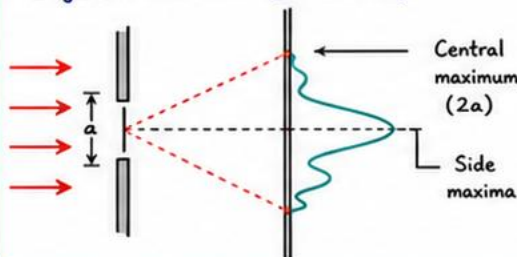
WAVE OPTICS

Huygens Principle: Every point on a wavefront acts as a source of secondary spherical wavelets.



4. Diffraction

- Bending and spreading of light when it passes through an aperture or around an edge.
- Single-slit diffraction (slit width a)

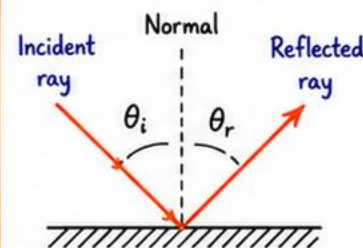


Minima (dark):
 $a \sin \theta = m \lambda$
 $m = \pm 1, \pm 2, \dots$

Angular width of central maximum:
 $\approx \frac{2\lambda}{a}$ (radians)

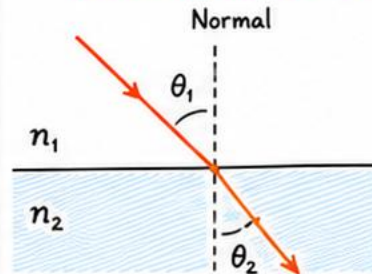
2. Reflection and Refraction

Reflection (law)



$$\theta_i = \theta_r$$

Refraction (Snell's law)

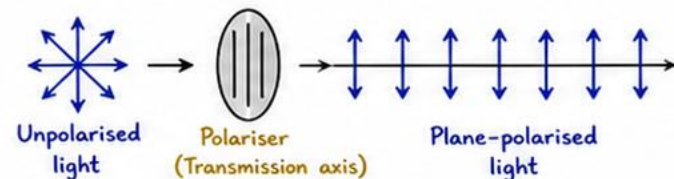


$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

n = refractive index, c = speed of light in vacuum

5. Polarisation

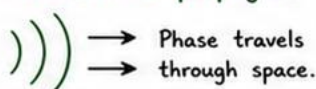
- Transverse nature of light: electric field oscillates perpendicular to direction of travel.
- Polariser transmits one plane of vibration.



$\vec{E}$ oscillates $\perp$ to direction of propagation.
Light is a transverse wave.

CONCEPT CHAIN

Wavefronts propagate



Amplitudes superpose



Intensity patterns appear

$$I \propto |E|^2$$

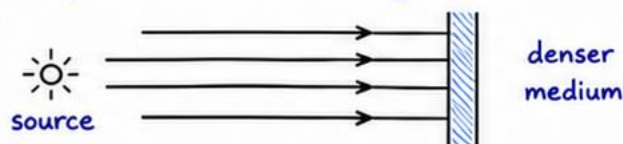
Polarisation reveals transverse light



WHY LIGHT IS A WAVE

① 17th Century: Newton's Corpuscular Picture

- Newton proposed that light is made of tiny particles (corpuscles) emitted by sources.
- Corpuscles move in straight lines.



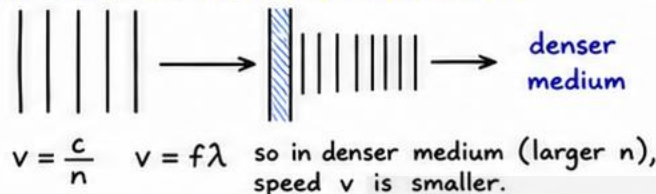
- This explains rectilinear propagation, reflection and refraction qualitatively.
- But the corpuscular model predicted that light should travel FASTER in a denser medium. (Incorrect.)

Newton's theory could not explain why light slows down in denser media.

② 18th–19th Centuries: Wave Ideas and Proofs

(a) Huygens' Wave Picture (1678)

- Light spreads as waves. In a denser medium, waves interact more and move slower.



(b) Young's Double-Slit Interference (1801)

- Two coherent light waves superpose to give bright and dark fringes.



(c) Foucault's Measurement (1850)

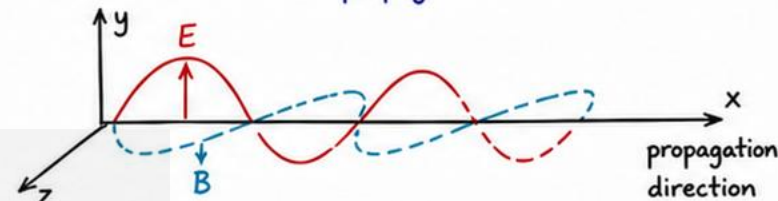
- Measured speed of light in water and glass. Found it is LOWER than in air or vacuum.

Wave picture predicts and experiments confirm lower speed in denser media.

③ 19th–20th Centuries: Electromagnetic and Quantum

(a) Maxwell's Electromagnetic Wave (1860s)

- Light is an electromagnetic wave—oscillating electric and magnetic fields, perpendicular to each other and to the direction of propagation.



$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 2.998 \times 10^8 \text{ m s}^{-1} \text{ (in vacuum)}$$

(b) Quantum Theory (20th Century)

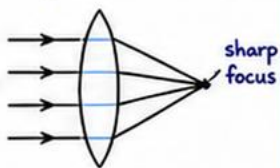
- Light also comes in quanta called photons with energy $E = hf$ and momentum $p = \frac{h}{\lambda}$.
- Photons do not remove the wave nature—interference and diffraction with single photons are observed.

Light is an electromagnetic wave that propagates in vacuum; it also exhibits particle (photon) nature.

RAY (GEOMETRICAL) AND WAVE (PHYSICAL) PICTURES COMPARED

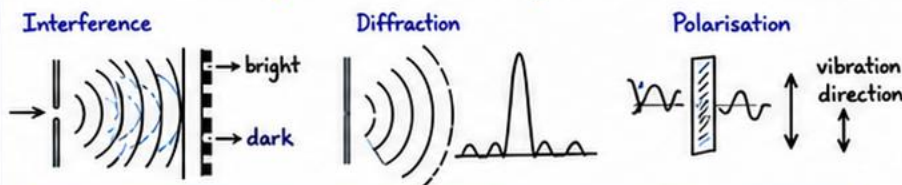
RAY (GEOMETRICAL OPTICS) EFFECTS

- Light travels in straight lines.
- Explains reflection, refraction, lenses, mirrors, sharp images.



Good when wavelength λ is much smaller than the size of objects or openings: $\lambda \ll \text{characteristic size}$.

WAVE (PHYSICAL OPTICS) EFFECTS



Important when λ is comparable to the size of openings, obstacles or structures.

WHY WAVE OPTICS MATTERS

- Many phenomena—interference, diffraction and polarisation—have no explanation in a purely corpuscular or ray picture.
- Wave optics explains when and why geometrical rays are a good approximation and when they fail.

Therefore, light is correctly described as a wave (electromagnetic) that can also behave as particles.

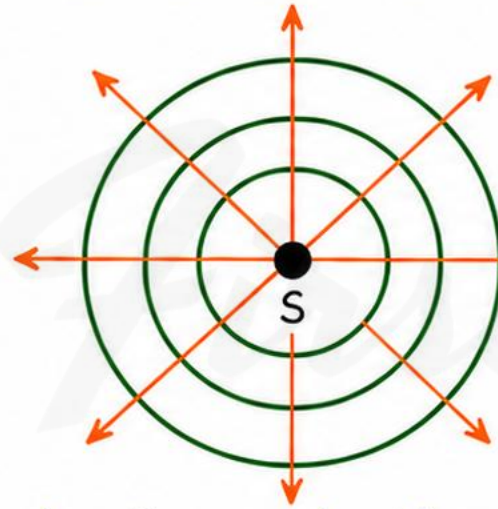
WAVEFRONTS & RAYS

- A wavefront is the locus of points having the same phase at an instant.
- Rays show the local energy propagation and are normal to wavefronts in an isotropic medium.

— = wavefront
 → = ray (energy direction)
 - - = normal to wavefront
 → = propagation direction
 v = speed (m s^{-1})

SPHERICAL WAVE (POINT SOURCE)

Concentric spherical wavefronts (shown as circular sections in 2D). Rays are radial and normal to wavefronts.



Later time →
larger radius

$$r = vt$$

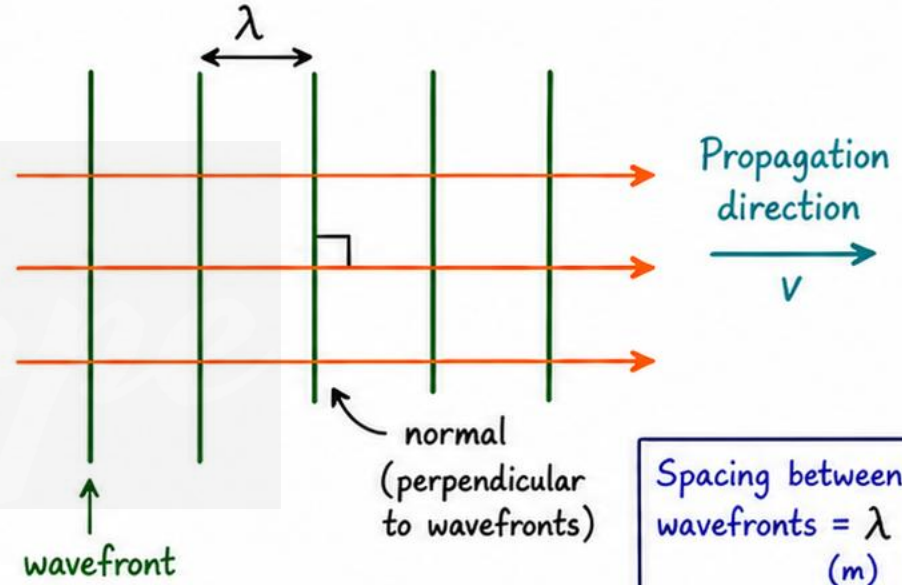
Radius increases
with time.

$$v = \frac{dr}{dt}$$

Far from the source ($r \gg \lambda$), a small patch of a spherical wavefront is nearly plane.

PLANE WAVE

Equally spaced, parallel, plane wavefronts. Rays are parallel and normal to wavefronts.

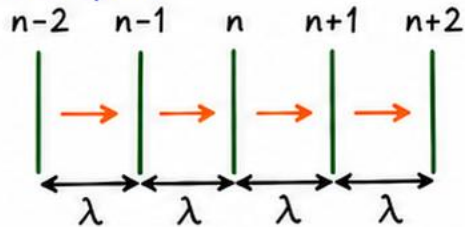


Spacing between
wavefronts = λ
(m)

PHASE & TIME

Successive wavefronts separated by λ are one period apart.

Phase of wave $\propto$ position of wavefront.
Adjacent wavefronts differ in phase by 2π radians.



In time T (one period), the wavefront advances by one spacing λ .

$$vT = \lambda$$

Hence,

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

where $f = \frac{1}{T}$ is frequency (Hz)
 v = speed (m s^{-1}), λ = wavelength (m),
 T = period (s)

Phase : in radians (rad)

λ : wavelength (m)

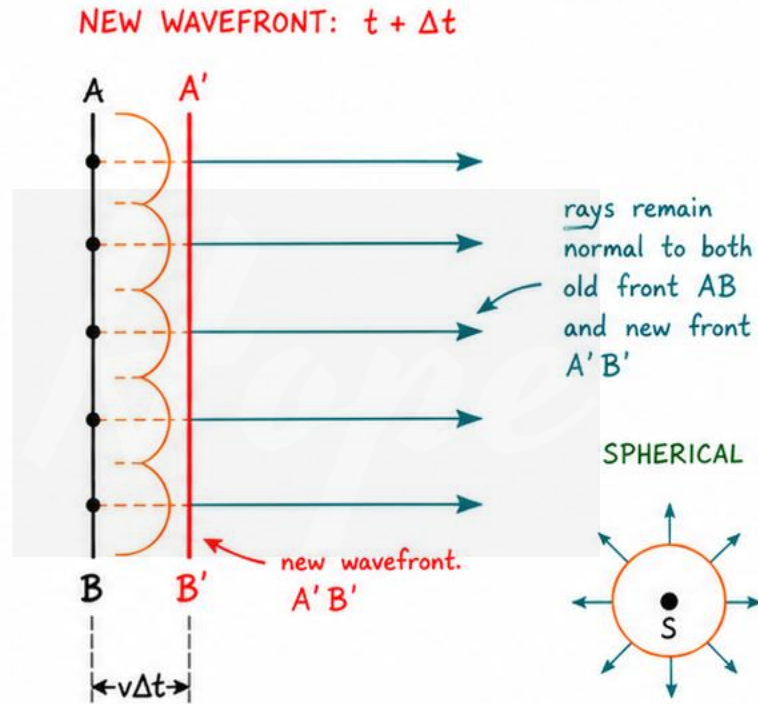
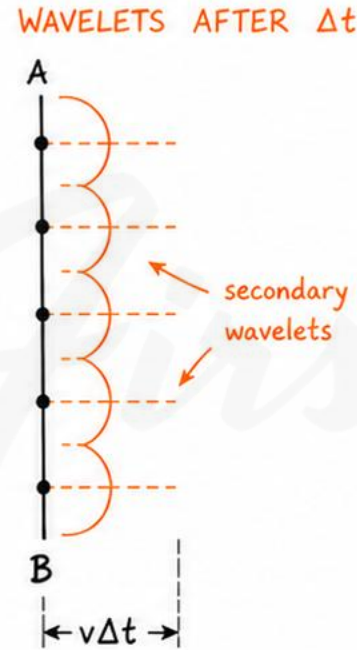
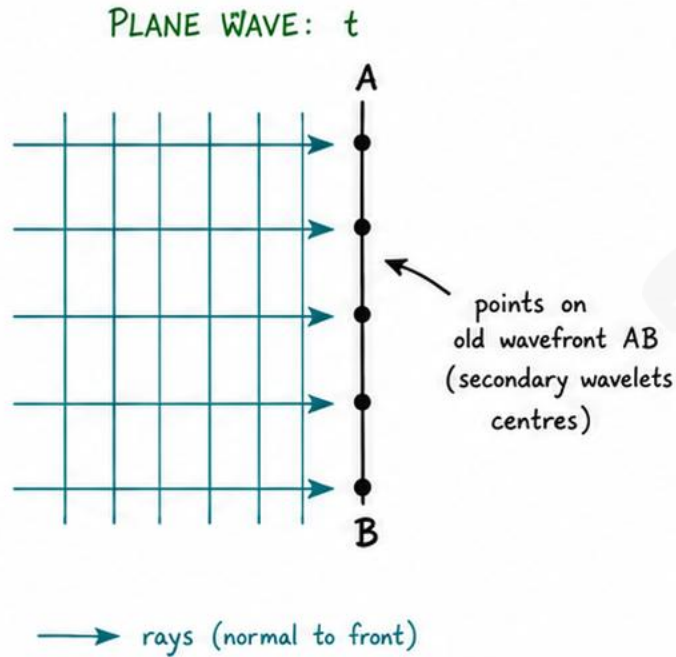
T : period (s)

f : frequency ($\text{Hz} = \text{s}^{-1}$)

v : speed (m s^{-1})

HUYGENS PRINCIPLE

Huygens' principle states that every point on a wavefront acts as a source of secondary spherical wavelets that spread out with the same speed v as the wave. After a time Δt , the new wavefront is the forward tangent (envelope) to all the wavelets. Rays are everywhere normal (perpendicular) to the wavefronts.



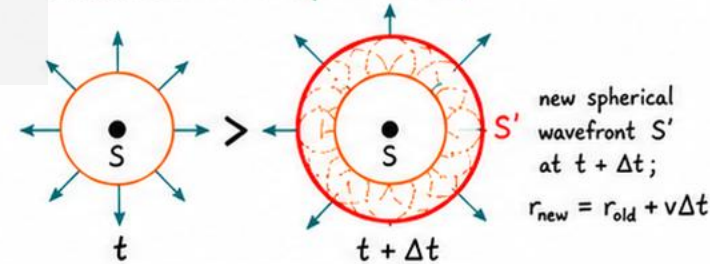
ADVANCE OF WAVEFRONT

In time Δt , the wavefront moves forward by a distance

$$\Delta x = v \Delta t$$

where v is the speed of the wave in the medium (isotropic here).

SPHERICAL WAVE (point source)



① Every point on a wavefront acts as a source of secondary disturbances (spherical wavelets) that spread out with the same speed v as the wave.

② After a time Δt , each wavelet has radius
 $r = v \Delta t$
 (in an isotropic medium where v is the same in all directions).

③ The new wavefront at $t + \Delta t$ is the forward envelope (common tangent surface/curve) to all the wavelets. Rays are everywhere perpendicular to the wavefronts.

④ Repeat the construction step by step to propagate the wave forward in time.

MODERN CAVEAT

Huygens' original principle assumed that backward wavelets cancel ("suppression of backward waves"). This was a heuristic idea, not a derivation. The complete Huygens-Fresnel theory introduces directional weighting (obliquity factor) and interference, which correctly predicts the direction and intensity of the resulting wave.

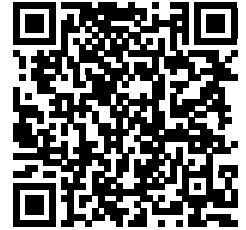


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