Unit 10 · Nature and Propagation of Light

STUDY NOTES

WHAT NEB'S GRADE 12 EXAM ASKS

- **CDC's grid (2078):** Waves and Optics (Units 6–13 together): 15 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** nothing from this unit; its wavefronts and wavelets are the tools of Units 11–13
- **MCQ (1 mark)**
  - what Newton's theory can't explain (interference, diffraction)
  - where corpuscles go faster (the denser medium: wrong)
  - what disproved Newton (light slower in water, Foucault 1850)
  - Young's fringes support the wave theory
  - why Huygens alone can't explain straight-line travel
  - the new wavefront: the forward envelope
- **Short (5 marks, in parts)**
  - wavefront and its kinds; rays perpendicular to it
  - state Huygens' principle; construct a new wavefront
  - straight-line travel; wave vs particle theory
  - phase; points of one wavefront; phase difference
  - backward wavelets and why they aren't seen
  - prove reflection and refraction by Huygens' construction
  - limitations of Huygens' theory; why wavefronts never cross

Key terms

Corpuscular theory (Newton, 1704): light a stream of tiny material particles, faster in a denser medium.

Wave theory (Huygens, 1678): light a wave in the ether, slower in a denser medium.

Dual nature: light shows wave properties (interference, diffraction, polarization) and particle ones (photons).

Phase: the stage a vibration has reached, an angle; in $a\sin(\omega t - kx)$, $\omega t - kx$.

Wavefront: a surface joining all points of a wave in the same phase.

Ray: the direction a wave travels; perpendicular to the wavefronts.

Spherical / plane / cylindrical wavefront: from a point source / far from a source / from a line source.

Wavelet: a secondary wave sent out from a point on a wavefront.

Huygens' principle: every point of a wavefront is a source of secondary wavelets at the wave's speed; the new wavefront is their forward **envelope**.

Obliquity factor: $K(\theta) = \frac{1}{2}(1 + \cos\theta)$, 1 ahead and 0 backwards.

Refraction: change of direction at a slant into another medium, because the speed changes.

Formulas

$\phi = \frac{2\pi}{\lambda}x$	x path difference **Use:** phase difference
$\text{radius} = c\,\Delta t$	wave speed × time **Use:** a wavelet
$K(\theta) = \frac{1}{2}(1 + \cos\theta)$	0 at $\theta = 180°$ **Use:** obliquity factor
$i = r$	congruent triangles **Use:** reflection
$\frac{\sin i}{\sin r} = \frac{c}{v} = \mu$	v in the second medium **Use:** Snell's law
$v = c/\mu$	water 2.26×10^8, glass 2×10^8 m/s **Use:** speed in a medium

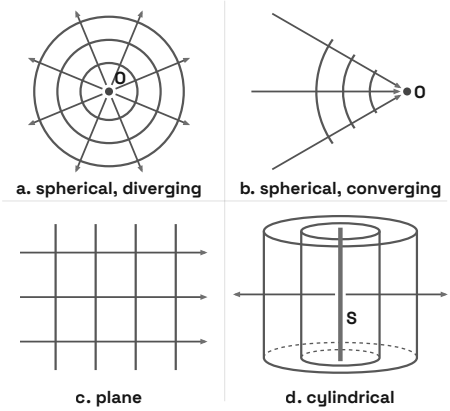
Two theories

	Newton	Huygens
light is	particles	a wave in the ether
straight lines	easily	only roughly
reflection, refraction	yes	yes
speed in water	**faster** (wrong)	**slower** (right)
interference, diffraction	no	yes, once Young and Fresnel added interference
photoelectric effect	not known	no (needs photons)

- Young's two slits (exam answers: 1801): bright and dark bands, only waves do that
- Fresnel (1818) diffraction; Maxwell (1865) EM wave, no ether; Planck (1900), Einstein (1905) photons
- polarization: light's vibrations are across its travel

Wavefronts

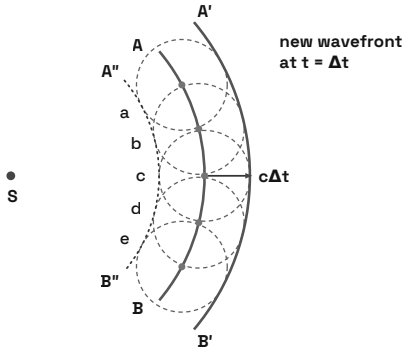
- phase falls behind 2π per wavelength along the wave; in phase add, out of phase cancel
- a wave's crests are wavefronts, λ apart; rays $\perp$ wavefronts



Point source: spherical, diverging; after a convex lens: converging; far away: plane; slit: cylindrical.

- a star's light at Earth: plane wavefronts
- all points of one wavefront are **in phase**

Huygens' principle



Wavelets of radius $c\Delta t$ from a–e on AB; forward envelope A′B′; backward A″B″ doesn't exist.

The construction

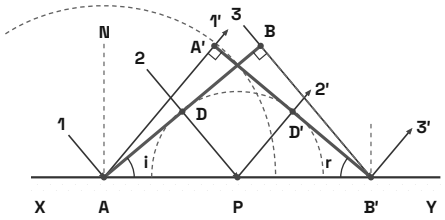
1. mark points on the wavefront
2. around each, a wavelet of radius $c\,\Delta t$
3. the surface touching them all ahead is the new wavefront
4. discard the backward envelope

- plane front $\rightarrow$ plane front $c\Delta t$ ahead: straight-line travel
- edges' wavelets spread into the shadow, but there they cancel except within a few wavelengths of the edge; light's $\lambda < 1\ \mu$m, so shadows look sharp; sound ($\lambda \approx 1$ m) bends round doors
- no backward wave: obliquity factor zero backwards (Fresnel, Kirchhoff 1882)
- two wavefronts of one wave never cross: a point would have two phases, travel two ways
- sound: each layer pushes the next; cool air near the ground at night tilts fronts down

Limitations of Huygens' theory

1. no reason given for leaving out backward wavelets
2. needed the ether (never found; Michelson–Morley 1887)
3. pulses with no wavelength: no interference, diffraction or colours alone
4. thought light longitudinal: no polarization
5. no wave theory explains the photoelectric effect or line spectra

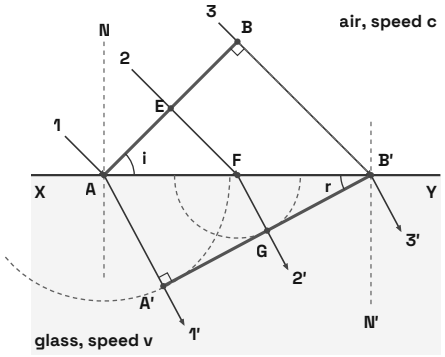
Reflection



A reaches the mirror first; while B goes to B′ (ct), A's wavelet grows to $AA' = ct$; tangent A′B′ is the reflected front.

1. $t = 0$: A at the mirror; B reaches B′ after t: $BB' = ct$
2. A's wavelet back in the same medium: $AA' = ct$
3. tangent from B′ to it: reflected front A′B′
4. $i = \angle BAB'$, $r = \angle A'B'A$ (front–surface angle = ray–normal angle)
5. triangles ABB′, B′A′A: right angles, common hypotenuse AB′, $BB' = AA'$ → congruent (RHS) → $i = r$
6. fronts and surface ⊥ the page → rays and normal in one plane

Refraction



Air into glass: while B goes ct, A's wavelet grows only vt; the front swings, the ray bends to the normal.

1. $BB' = ct$ in medium 1; A's wavelet in medium 2: $AA' = vt$
2. tangent from B′: refracted front A′B′
3. triangle ABB′: $\sin i = \frac{ct}{AB'}$; triangle AA′B′: $\sin r = \frac{vt}{AB'}$
4. divide: $\frac{\sin i}{\sin r} = \frac{c}{v} = \mu$, a constant: Snell's law
5. fronts and boundary ⊥ the page → one plane

- the end that enters first slows first: the front swings (marchers stepping onto mud)
- $\mu = 1.5$ → light 1.5 × slower in glass; water (1.33): 2.26×10^8 m/s
- frequency unchanged (set by the source); λ shrinks by μ
- glass to air with $\sin i > v/c$: no tangent possible → total internal reflection
- each colour its own speed → its own μ: dispersion

COMMON MISTAKES

✗ Newton's corpuscles were massless
✓ material particles.

✗ corpuscles go slower in water
✓ Newton needed them **faster**; measured slower.

✗ Huygens explained interference and diffraction alone
✓ only once Young and Fresnel added interference.

✗ a wavefront joins points at the same distance
✓ in the same **phase**.

✗ rays run along the wavefront
✓ **perpendicular** to it.

✗ refraction is a change of speed or intensity
✓ of **direction**, because the speed changes.

✗ light's frequency changes in glass
✓ its speed and wavelength do.