Topic C.3

WAVE PHENOMENA

Every Formula, Trick & Trap on a Page
& IB-Style Quick Reference

Topics Covered	Exam Relevance
Refraction & wavefronts	P1 & P2 (SL + HL)
Snell's law & TIR	$\sin\theta_c = n_2/n_1$
Interference & Young's fringes	$s = \lambda D/d$
Single-slit diffraction (HL)	$\theta = \lambda/b$
Diffraction gratings (HL)	$n\lambda = d\sin\theta$

The Big Picture — How C.3 Fits Together

- **WAVE PHENOMENA** — what waves do at boundaries and slits
  - **Boundaries**: reflect & refract; f conserved
  - **Snell & TIR**: $n_1 \sin\theta_1 = n_2 \sin\theta_2$; $\sin\theta_c = n_2/n_1$
  - **Interference**: $\Delta d = n\lambda$ bright; $s = \lambda D/d$
  - **Single Slit (HL)**: $\theta = \lambda/b$ (minima)
  - **Gratings (HL)**: $n\lambda = d\sin\theta$ (maxima)

§1 — Wavefronts & Refraction SL/HL

Key Concepts

Wavefront: surface of equal phase. **Ray:** perpendicular to wavefront, direction of energy flow.

Plane waves $\Rightarrow$ parallel rays (distant source). **Point source** $\Rightarrow$ circular/spherical wavefronts, diverging rays.

At a Boundary

- **Reflection:** $\theta_i = \theta_r$ (from normal)
- **Refraction:** direction changes, frequency constant
- v changes $\Rightarrow \lambda$ changes; f unchanged

TRICK In a denser medium: wavefronts closer together (smaller λ), ray bends TOWARDS normal.

TRAP Never say frequency changes at a boundary — only speed and wavelength change!

§2 — Snell's Law & TIR SL/HL

Refractive Index

Definition: $n = \dfrac{c}{v}$

$n \geq 1$ always. Larger n = optically denser = slower speed.

Snell's Law

Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Equivalently: $\dfrac{n_1}{n_2} = \dfrac{\sin\theta_2}{\sin\theta_1} = \dfrac{v_2}{v_1} = \dfrac{\lambda_2}{\lambda_1}$

All angles from the **normal**.

Critical Angle & TIR

Critical angle: $\sin\theta_c = \dfrac{n_2}{n_1}$

$(n_1 > n_2)$

TIR conditions: (1) dense $\to$ less dense; (2) $\theta > \theta_c$

TRICK $n_Q = \sin\theta_{\text{air}} / \sin\theta_Q$ when light enters medium Q from air.

TRICK **Two ways for refraction:** angles $\to n_1 \sin\theta_1 = n_2 \sin\theta_2$; speeds/wavelengths $\to n_1/n_2 = v_2/v_1 = \lambda_2/\lambda_1$ (and $n = c/v$). f never changes.

TRAP TIR only from DENSER to LESS DENSE medium. Cannot happen going air $\to$ glass!

NOTE Application: optical fibres use TIR to transmit light along a bent path with negligible loss.

NOTE Measure n: ray-tracing a glass block ($n = \sin\theta_1 / \sin\theta_2$) or real/apparent depth ($n = \text{real}/\text{apparent}$).

FROM THE PHOTON QUESTION BANK

Set the refracted angle to $90°$ for the critical angle; across parallel layers intermediate indices cancel, so only the first & last media matter.

§3 — Superposition & Interference SL/HL

Superposition Principle

$y_{\text{total}} = y_1 + y_2$ (algebraic sum at each point)
Waves pass through each other unchanged.

Conditions for Stable Interference

Sources must be **coherent**: same frequency + constant phase difference.

Constructive: path diff $= n\lambda$ (bright fringe)
Destructive: path diff $= (n + \frac{1}{2})\lambda$ (dark fringe)
(Assumes sources in phase.)

Young's Double Slit

Path difference: $\Delta d = d\sin\theta = n\lambda$ (bright)

Fringe spacing: $s = \dfrac{\lambda D}{d}$

s = fringe spacing, λ = wavelength, D = slit-to-screen, d = slit separation.

$\uparrow \lambda \quad \uparrow s$
$\uparrow D \quad \uparrow s$
$\uparrow d \quad \downarrow s$

TRICK If all of λ, D, d are multiplied by the same factor k, fringe spacing s is unchanged!

TRICK **Bright or dark?** Path difference $\Delta d = n\lambda \Rightarrow$ constructive (bright); $\Delta d = (n+\frac{1}{2})\lambda \Rightarrow$ destructive (dark). Compute $\Delta d/\lambda$: whole $\to$ bright, “.5 o dark.

TRAP For constructive interference, path difference must equal a WHOLE number of wavelengths, NOT half-wavelengths.

FROM THE PHOTON QUESTION BANK
Compute Δd, divide by λ (whole $\to$ bright, “.5” $\to$ dark); intensity $\propto$ amplitude^2 so two equal coherent sources give $4I$ at a max, 0 at a min.

§4 — Single-Slit Diffraction — HL only

HL Only

1st minimum: $\theta = \dfrac{\lambda}{b}$

(b = slit width, θ in radians)
Central max width $= 2\lambda/b$ (on screen: $2\lambda D/b$).

Narrower slit $\Rightarrow$ wider, dimmer central max.
Wider slit $\Rightarrow$ narrower, brighter central max.
Missing orders: double-slit max n is absent when $n = kd/b$ (integer k).

Envelope Effect

Double-slit fine fringes (spacing $\approx \lambda/d$) are modulated by single-slit envelope (width $\approx \lambda/b$).

TRICK $n_{\text{missing}} = d/b$ for the first missing order. E.g. $d = 4b \Rightarrow n = 4$ missing.

TRICK **Same formula, opposite meaning:** $n\lambda = d\sin\theta$ = grating/double-slit *maxima* (d = slit separation); $n\lambda = b\sin\theta$ = single-slit *minima* (b = slit width).

§5 — Diffraction Gratings — HL only

HL Only

Grating equation: $n\lambda = d\sin\theta$

$d = 1/N$ (N = lines per metre), n = order.
Max order: $n_{\text{max}} = \lfloor d/\lambda \rfloor$
More slits $\Rightarrow$ **sharper**, brighter maxima.
Position of maxima: same as double slit.

Grating vs. Double Slit

Same d	$\Rightarrow$ same max positions
More slits	$\Rightarrow$ narrower, brighter peaks
More slits	$\Rightarrow$ more secondary minima

TRICK Convert lines/mm to grating spacing: 600 lines/mm $\Rightarrow d = 1/(600 \times 10^3)$ m $= 1.67\,\mu$m.

TRAP Maximum order is limited by $\sin\theta \le 1$. Always check $n\lambda \le d$.

NOTE White light through a grating disperses into spectra; violet (short λ) at smaller angles, red at larger angles in each order.

FROM THE PHOTON QUESTION BANK
Max order: set $\sin\theta = 1 \Rightarrow n_{\text{max}} = \lfloor d/\lambda \rfloor$; total maxima $= 2n_{\text{max}} + 1$ (incl. zero order); "angle between the two nth orders" $= 2\theta$, so halve first.

§6 — Formula Summary — SL/HL

All Key Equations

$n = c/v$	refractive index
$n_1\sin\theta_1 = n_2\sin\theta_2$	Snell's law
$\sin\theta_c = n_2/n_1$	critical angle
$\Delta d = n\lambda$	constructive
$\Delta d = (n+\frac{1}{2})\lambda$	destructive
$s = \lambda D/d$	Young's fringe spacing
$\theta = \lambda/b$	single-slit 1st min (HL)
$n\lambda = d\sin\theta$	diffraction grating (HL)
$d = 1/N$	grating spacing
$n_{\text{max}} = \lfloor d/\lambda \rfloor$	max grating order