MA99 EDUCATION

Waves: Summary 02

NSW PHYSICS 11-12 SYLLABUS 2025 FOR HSC 2028 AND LATER

1. Key ideas

- **A wave carries energy, not matter.** Particles oscillate about fixed positions. Transverse: across the direction of energy transfer (rope, water ripples, light). Longitudinal: along it (sound), with compressions and rarefactions.
- **Every wave obeys $f = \frac{1}{T}$ and $v = f\lambda$.** The medium sets v; the source sets f. In a new medium f stays the same and λ changes with v.
- **Two graphs, one shape.** Displacement-time (one particle) gives T; displacement-distance (the whole wave) gives λ. Read the horizontal axis first.
- **Aboriginal Peoples read water depth from waves.** Slower, shorter waves mean shallow water; faster, longer waves mean deep water (NESA). With f fixed, slower means shorter by $v = f\lambda$.
- **Mechanical waves need a medium; light does not.** Sound passes energy by collisions between particles. Light is an electromagnetic wave: an accelerating charge makes electric and magnetic fields that regenerate each other and travel at $c = 3.00 \times 10^8$ m/s in a vacuum.
- **Across the electromagnetic spectrum,** radio to gamma, frequency and photon energy rise and wavelength falls: $c = f\lambda$ and $E = hf$. Each region's use follows from a property.
- **Inverse square law:** a point source spreads its power over $4\pi r^2$, so $I \propto \frac{1}{r^2}$. Double the distance, a quarter of the intensity.
- **Reflection:** $i = r$, from the normal. A plane mirror image is virtual, upright, the same size and as far behind as the object is in front.
- **Refraction** is caused by a change of speed. Slower (higher n): towards the normal. Faster (lower n): away. Total internal reflection needs higher n to lower n and an angle above θ_c.
- **Diffraction** is greatest when the gap or obstacle is about one wavelength. **Superposition** adds displacements algebraically; in phase gives constructive interference, opposite phase destructive.
- **Interference patterns** have fixed maxima (path difference $0, \lambda, 2\lambda$) and minima (path difference $\frac{1}{2}\lambda, 1\frac{1}{2}\lambda$).
- **Standing waves on a string fixed at both ends:** nodes at both ends, a whole number of half wavelengths, $\lambda_n = \frac{2L}{n}$ and $f_n = \frac{nv}{2L}$.
- **Frequency shift phenomenon:** relative motion of source and observer changes the frequency received. Approaching: higher (blueshift for light). Separating: lower (redshift).

> If you remember one sentence, make it this: the source sets the frequency, the medium sets the speed, and the wavelength does what it must.

2. Formulae, as on NESA's sheet

FORMULA	QUANTITIES AND UNITS	USE IT WHEN
$f = \frac{1}{T}$	f in Hz, T in s	You have one and need the other
$v = f\lambda$	v in m/s, λ in m	Any wave; $c = f\lambda$ for light in a vacuum
$E = hf$	E in J, $h = 6.626 \times 10^{-34}$ J s	Photon energy of electromagnetic radiation
$I \propto \frac{1}{r^2}$, $I_1 r_1^2 = I_2 r_2^2$	I in W/m² or lux, r in m	Intensity at a new distance from a point source
$n_x = \frac{c}{v_x}$	n has no unit	Speed of light in a medium

FORMULA	QUANTITIES AND UNITS	USE IT WHEN
$n_1 \sin\theta_1 = n_2 \sin\theta_2$	angles from the normal	Angle of refraction at a boundary
$\sin\theta_c = \frac{n_2}{n_1}$	$n_1 > n_2$	Critical angle for total internal reflection
$f' = f\frac{(v_{\text{wave}} + v_{\text{observer}})}{(v_{\text{wave}} - v_{\text{source}})}$	towards is positive for both	Frequency shift for sound

Not on the sheet, but derived from it. Standing waves: $L = n\frac{\lambda}{2}$, so $\lambda_n = \frac{2L}{n}$, then $f_n = \frac{v}{\lambda_n}$. Speed ratio at a boundary: $\frac{v_1}{v_2} = \frac{n_2}{n_1}$. **Data sheet values:** $c = 3.00 \times 10^8$ m/s; speed of sound in air 340 m/s; $h = 6.626 \times 10^{-34}$ J s.

frequency and energy rising, wavelength falling →

	Radio	Microwave	Infrared	Visible	Ultraviolet	X ray	Gamma
typical λ	100 m	1 cm	10 μm	500 nm	100 nm	0.1 nm	1 pm
f = c ÷ λ	3×10^6 Hz	3×10^{10} Hz	3×10^{13} Hz	6×10^{14} Hz	3×10^{15} Hz	3×10^{18} Hz	3×10^{20} Hz
E = hf	2.0×10^{-27} J	2.0×10^{-23} J	2.0×10^{-20} J	4.0×10^{-19} J	2.0×10^{-18} J	2.0×10^{-15} J	2.0×10^{-13} J

All travel at c = 3.00×10^8 m/s in a vacuum. Each step left to right multiplies f and E by the same factor that divides λ.
Boundaries between regions are not sharp; the values shown are typical members of each region, not limits.

Figure 1 · The electromagnetic spectrum with a typical λ, f and photon energy for each region. Source: MA99 Education.

3. How to answer the question

TASK	RECIPE
Wave from a graph	Read the axis. Time axis: one cycle is T, then $f = \frac{1}{T}$. Distance axis: one cycle is λ. Then $v = f\lambda$. Amplitude is rest line to crest.
Longitudinal displacement graph	Compression where the graph crosses zero going down; rarefaction where it crosses going up. Peaks are not compressions.
Inverse square	Ratio of distances, squared, flipped: $I_2 = I_1(\frac{r_1}{r_2})^2$. Further means dimmer: check.
Spectrum calculation	Convert prefixes (nm = 10^{-9} m, MHz = 10^6 Hz). $f = \frac{c}{\lambda}$, then $E = hf$.
Refraction	Angles from the normal, calculator in degrees. $\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$. Check: into higher n, smaller angle.
Total internal reflection	Check $n_1 > n_2$. $\theta_c = \sin^{-1}(\frac{n_2}{n_1})$. TIR only if the angle of incidence is larger.
Plane mirror diagram	Image as far behind. Line from eye to image locates the reflection point. Real rays solid with arrows, virtual rays dashed.
Two sources	$\lambda = \frac{v}{f}$. Path difference ÷ λ. Whole number: maximum. Odd half: minimum.
Standing wave on a string	Count loops n. $\lambda = \frac{2L}{n}$. $v = f\lambda$. Nodes = $n + 1$, antinodes = n.
Frequency shift (sound)	Decide up or down first. Towards is positive for both velocities. Substitute and check direction.

4. Numbers worth knowing

QUANTITY	VALUE
Speed of light in a vacuum, c	3.00×10^8 m/s
Speed of sound: air, water, steel	about 340 m/s, 1500 m/s, 5000 m/s or more
Visible light	about 400 nm (violet) to 700 nm (red)

QUANTITY	VALUE
Refractive index: water, perspex, crown glass, diamond	1.33, 1.49, 1.52, 2.42
Critical angle: water, glass (n = 1.50), diamond, each to air	48.8°, 41.8°, 24.4°
Inverse square: 2r, 3r, 10r	I ÷ 4, I ÷ 9, I ÷ 100
Sound level: +10 dB, +6 dB	10 times, about 4 times the intensity
Gundungurra mirror flash	Southern Highlands to Blue Mountains (NESA); Bowral to Katoomba is about 85 km

5. The eight investigations in one table

INVESTIGATION	METHOD IN ONE LINE	ANALYSIS	MAIN UNCERTAINTY
Particle oscillation (slinky)	Tape a coil; send transverse and longitudinal pulses; time pulses	Tape returns to its start; v = distance ÷ mean time	Reaction time: repeat, average, or video
Wavelength, frequency, pitch, loudness	Two microphones on an oscilloscope; move one until traces realign	λ against $\frac{1}{f}$: straight line, gradient = v	Judging alignment; echoes
Frequency, amplitude, energy of sound	Sound level meter as amplitude doubles; rice on a speaker as f rises	+6 dB per doubling: about 4 times the energy (A^2)	±1 dB meter; background noise
Light intensity and distance	Light sensor at measured distances from a small bulb, dark room	I against $\frac{1}{r^2}$: straight line; Ir^2 constant	Bulb is not a point; reflections
Refraction between 2 media	Ray box and block; ripple tank with a shallow region	Bends towards the normal entering the slower medium	Wide rays; marking positions
Refractive index (accuracy)	Semicircular block, ray to the centre of the flat face, 7 angles	$\sin i$ against $\sin r$: gradient = n; percentage error	±0.5° worst at small angles
Spectacles	Model eye (lens and screen); add diverging or converging lenses; secondary sources	Which lens moves the focus onto the retina, and why	Reliability of secondary data
Diffraction	Ripple tank, gaps and obstacles of different widths	Spreading greatest at gap about λ	Qualitative judgement; wall reflections

6. Common errors

The errors to avoid

1. Amplitude measured crest to trough. It is rest to crest.
2. Reading period from a displacement-distance graph, or wavelength from a displacement-time graph.
3. Calling the peaks of a longitudinal displacement graph compressions.
4. Changing the frequency when a wave enters a new medium.
5. “Louder sounds travel faster.” Same medium, same speed.
6. Halving, not quartering, the intensity when the distance doubles.
7. Angles measured from the surface, or the calculator in radians.
8. Total internal reflection from low n into high n: impossible.
9. One loop of a standing wave as one wavelength. It is half.
10. Signs in the frequency shift formula giving a lower note from an approaching source.
11. Saying the moving source emits a different frequency. The observer receives one.

7. Checklist

- [ ] A wave has T = 5.0 ms and λ = 0.68 m. Find v. (136 m/s)
- [ ] Find the wavelength of 95.3 MHz radio waves. (3.15 m)
- [ ] Find the photon energy of 400 nm light. (4.97×10^{-19} J)
- [ ] A lamp gives 360 lux at 1.5 m. Find the intensity at 4.5 m. (40 lux)
- [ ] Light goes from glass (1.50) into water (1.33) at 30°. Find the angle of refraction. (34.3°)
- [ ] Find the critical angle for diamond (2.42) in water (1.33). (33.3°)
- [ ] A 0.90 m string fixed at both ends carries waves at 180 m/s. Find f_1 and f_3. (100 Hz, 300 Hz)
- [ ] A 600 Hz source moves away from you at 30 m/s; v = 340 m/s. Find f'. (551 Hz)
- [ ] Explain, in three sentences, how a sound wave transfers energy through air.
- [ ] Explain why a converging lens corrects long sight.

Stuck on one? Topic Notes 2.4 to 2.6 (the first two), 3.7 and 3.9 (photons, intensity), 4.4 to 4.6 (refraction), 5.6 and 5.7 (strings, frequency shift), 3.2 and 4.9 (the explanations).

About this resource

MA99 EDUCATION

Scope

NSW Physics, Year 11. Written to the NSW Physics 11-12 Syllabus 2025, Waves, for students sitting the HSC in 2028 and later years. Written to the new syllabus, taught in Year 11 from 2027. Every value in a worked example was recomputed from its inputs before printing; contexts are invented unless a source is named.

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