C Wave behavior

Lesson 1

Topic	**C.3 Wave phenomena**
Lesson	**Water waves**
Level	SL and HL
Duration	1 hour
Lesson context	The wave model has already been established, including transfer of energy, characteristics of waves, distinguishing features of transverse and longitudinal waves, and examples such as the EM spectrum and sound. This is the first lesson on wave phenomena. Although the textbook for this section provides a definition of Snell's law, this will be revisited more extensively in the next lesson. Likewise, a quantitative treatment of single-slit diffraction will follow in the later HL-only lessons.
Students should understand	• that waves traveling in two and three dimensions can be described through the concepts of wavefronts and rays • wave behavior at boundaries in terms of reflection, refraction and transmission • wave diffraction around a body and through an aperture • wavefront-ray diagrams showing refraction and diffraction.
Potential misconceptions	The idea of light traveling at a constant speed might make it difficult for students to appreciate how refraction emerges from light taking the path of shortest time.
Plan for how students will acquire knowledge, understanding and skills	• Read pages 309–315, which include sketches of wavefronts and rays for incident, reflected, and transmitted waves. • Attempt Exercise questions 1–2 on page 313 and Exercise question 3 on page 315.
Activities	• Practice questions 7, 18, 19, and 20 on pages 330–335
Links to IB concepts (e.g. NOS, TOK)	Diagrams can be simplified representations of reality (in this case wavefronts in place of many wavelets) and yet still be useful in describing observed phenomena (like diffraction, reflection and refraction).
Key questions to check for understanding	Linking Question: What evidence is there that particles possess wave-like properties such as wavelength? (NOS)
Additional resources for support/extension	Students investigate how the speed of water waves varies with depth, perhaps using a ripple tank or by creating a disturbance in a plastic tray. Encourage video analysis.

Lesson 2

Topic	**C.3 Wave phenomena**
Lesson	**Light, refractive index and Snell's law**
Level	SL and HL
Duration	2 hours
Lesson context	Students will by now have a qualitative understanding of reflection and refraction from their study of water waves. In this lesson, the priority shifts to gaining a quantitative understanding.
Students should understand	• Snell's law, critical angle and total internal reflection • Snell's law as given by $\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$ where n is the refractive index and θ is the angle between the normal and the ray.
Potential misconceptions	Students might struggle to define the various presentations of Snell's law equation. They will need to consider refractive indices, speeds and angles. Some students might find it helpful to recall that 'sine' of an angle is a ratio of lengths.
Plan for how students will acquire knowledge, understanding and skills	• Read pages 316–318. • Attempt Exercise questions 4–8 on page 317 and Exercise question 9 on page 319.
Activities	• Lab skills PDF: Measuring the refractive index of a glass block • Simulation: Bending light • Practice questions: 2, 4, 5, 6, and 14 on pages 327–332
Links to IB concepts (e.g. NOS, TOK)	There are global applications resulting from total internal reflection: it can be found in reflective road safety and prismatic optical devices, optical fiber communications, medicine and decorative lighting.
Key questions to check for understanding	Guiding Question: What is the explanation for observations of wave behaviors at a boundary between different media?
Additional resources for support/extension	It can be fun to commence this lesson by picking an 'invisible' test tube out of glycerol, perhaps even referencing Wells' *The Invisible Man*. Students investigate how the refractive index varies for different wavelengths of light and, accordingly, how dispersion occurs. They might also find it interesting to find out how the eye perceives brightness and color.

Lesson 3

Topic	**C.3 Wave phenomena**
Lesson	**Single-slit diffraction and modulation**
Level	HL ONLY
Duration	3 hours
Lesson context	This lesson is HL-only, but it is included at this stage because it can be advantageous for mixed or HL-only sets to appreciate diffraction from single slits before contemplating two or more slits. Modulation of double-slit patterns can be anticipated here ahead of their study.
Students should understand	• single-slit diffraction including intensity patterns as given by $\theta = \frac{\lambda}{b}$ where b is the slit width • that the single-slit pattern modulates the double slit interference pattern.
Potential misconceptions	Just as students might absentmindedly use the terms 'wavefront' and 'ray' interchangeably, similar issues might emerge with 'diffraction' and' interference'.
Plan for how students will acquire knowledge, understanding and skills	• Read pages 319–321 and 323, which include the impact of slit width on the intensity of the pattern for monochromatic light and rectangular slits. • Attempt Exercise questions 10 and 11 on page 321.
Activities	• Lab skills PDF: Interference of light using a single hair • Practice questions 12 and 16 on pages 331 and 334
Links to IB concepts (e.g. NOS, TOK)	The models for single-slit diffraction and double-slit interference can be combined to explain the pattern that is actually observed.
Key questions to check for understanding	Linking Question: What are the similarities and differences between single-slit diffraction and diffraction to study atomic structures (E.1)?
Additional resources for support/extension	Students explore the factor by which the equation for the angle is adjusted for circular apertures (and the applications of this). Resolution and the Rayleigh criterion would be interesting areas for extended inquiry.

Lesson 4

Topic	**C.3 Wave phenomena**
Lesson	**Double-slit interference**
Level	SL and HL
Duration	2 hours
Lesson context	The background to this lesson will depend on whether students are SL (in which case they will be aware of the paths taken by rays) or HL (where they will have seen path differences in practice when deriving the single-slit diffraction equation. Students might benefit from some reflection on the nature of progressive waves before embarking on stationary waves.
Students should understand	• superposition of waves and wave pulses • that double-source interference requires coherent sources • the condition for constructive interference as given by path difference $= n\lambda$ • the condition for destructive interference as given by path difference $= \left(n + \frac{1}{2}\right)\lambda$ • Young's double-slit interference as given by $s = \frac{\lambda D}{d}$ where s is the separation of fringes, d is the separation of the slits, and D is the distance from the slits to the screen.
Potential misconceptions	Students might find it difficult to understand the ideas of a vector sum and of particle displacement. Remind students of the wave model.
Plan for how students will acquire knowledge, understanding and skills	• Read pages 322–325, which include the interference and diffraction patterns produced at normal incidence. • Attempt Exercises questions 12 and 13 on page 323.
Activities	• Simulation: Ripple tank – wave interference • Practice questions 1, 3, 8, 9, 10, 11 and 15 on pages 326–332
Links to IB concepts (eg. NOS, TOK)	A simulation can be used to show how fringes are formed. This use of technology helps with the communication of ideas.

Key questions to check for understanding	Guiding Question: What happens when two waves meet at a point in space? Linking Question: What can an understanding of the results of Young's double-slit experiment reveal about the nature of light (C.2)?
Additional resources for support/extension	Teachers are likely to be familiar with the concept of thin film interference. Students research how iridescence is formed, perhaps even relating it to a particular species.

Lesson 5

Topic	**C.3 Wave phenomena**
Lesson	**Multiple-slit and diffraction grating interference**
Level	HL ONLY
Duration	3 hours
Lesson context	HL-only, and a natural follow-up from the double-slit concept that has just been concluded.
Students should understand	• interference patterns from multiple slits and diffraction gratings as given by $n\lambda = d\sin\theta$.
Potential misconceptions	Red light is diffracted through larger angles than violet light. However, it experiences less speed reduction during refraction. Students might struggle to separate the concepts of wavelength and speed.
Plan for how students will acquire knowledge, understanding and skills	Read pages 323–325, which include patterns for both white light and monochromatic wavelengths.
Activities	• Practice question 13 on page 322 and Practice question 17 on pages 334–335.
Links to IB concepts (e.g. NOS, TOK)	Now that the topic is concluded, students should refer to the Wave behavior theme discussion on page 265.
Key questions to check for understanding	Guiding Question: How is the behavior of waves passing through apertures represented?
Additional resources for support/extension	One application of diffraction gratings is in spectroscopy, which itself can be used to find out about the types of atoms from which light is emitted. There are many tests in physics in which the measured quantities tell us something about the material involved.