Teaching ideas for Topic 4: Waves

It is quite a challenge to teach this unit in the suggested time of 15 hours, so it is important to be carefully selective about what you do and how much time you spend doing it. The overall idea is that students should be able to recognise the many ways in which knowledge and understanding of waves helps us, as humans, to explain so many physical phenomena.

If you are following the HL physics course, then you may find it sensible to teach the additional HL Topic **9**: Wave phenomena at the same time as this topic. The two topics fit together well, but this does mean that students find themselves learning the same kind of physics for quite a long time.

Some useful points to consider are:

- So many different physical systems oscillate that an overall idea of how they oscillate and what the important features of oscillations are is vital if we, as physics students, want to appreciate the role they play in our lives. Although this section of the topic examines only oscillations that have a constant time period (i.e. isochronous oscillations), many of the principles that apply can be used to describe other non-constant time period oscillations. This section of the topic allows for good investigative work, particularly with masses on springs and with simple pendulums.
- In Subtopic **4.2**: Travelling waves, it is likely that students will have met many of the ideas before. However, it is well worth working through all the important terms with them. This section also includes another of the required experiments (see 'Applications and skills' section of the IB Physics guide): measuring the speed of sound experimentally.
- Many students find Subtopic **4.3**: Wave characteristics interesting, particularly the polarisation aspect and its uses. Ideas about amplitude, intensity and superposition form the basis of work to be done in the next section about interference and diffraction.
- There is a lot of important work to be done in Subtopic **4.4**: Wave behaviour, and it is worth spending sufficient time, where available, on the ideas in this part of the topic.
- Once students have mastered the idea of superposition, Subtopic **4.5**: Standing waves is relatively easy to deliver. It will also provide good opportunity for demonstrations of various kinds of standing waves; students usually enjoy these.

Ideas for teaching the topic

- A very good way of starting the work on simple harmonic motion (SHM) and oscillations is to get students investigating the oscillations of a mass on a spring. Some useful relationships can come out of this, which can then be analysed using free-body force diagrams. It should not be too difficult to derive the concept that the restoring force is proportional to the displacement from the equilibrium position – something that students should use as a definition for SHM. Once this important idea is dealt with, students can examine other kinds of oscillation (for example, simple pendulums and a ball rolling up and down on a curved track) and see how the idea applies. Introducing angular frequency, ω, at this point will set the idea that SHM oscillations take the form of the (second order differential) equation $a = -\omega^2 x$. The importance of the minus sign is something students should appreciate. It is also important for students to become familiar with graphs of displacement–time, velocity–time and acceleration–displacement. This links directly with aim 6 in the group 4 aims in the IB Physics guide.
- Many teachers would cover Subtopic **4.2** by demonstrating waves on a slinky spring. This is an effective way of getting across the visual learning that students can do, observing the waves travelling along the slinky, as well as reinforcing the terms used. It is also good for showing the difference between transverse and longitudinal waves.

- Students should appreciate what a sound wave is, and its need for a medium to travel through (‘In space, no-one can hear you scream’ was a phrase used once to advertise a feature film), so that they can perform a simple experiment to find the speed of the sound wave.
- It is good here too to show students examples of each of the kinds of electromagnetic (em) waves in the em spectrum; students can then consider the important features of each kind of wave: approximate wavelength, how they are formed, how they are detected, what uses they have, possible dangers etc. This links directly with aims 2, 4 and 6 in the group 4 aims in the IB Physics guide.
- The way that waves behave forms a foundation on which students can build substantial understanding of more complex ideas involving wave applications. So this part of the topic is worthy of considerable care and focus. Students might start with drawing ray diagrams (they may be familiar with this approach already) and using these to explore reflection and refraction. This will allow students to work through ideas of refractive index, Snell’s law, critical angle and total internal reflection. Moving from ray diagrams to diagrams of wave fronts poses more of a problem, but with care, students will cope with this.
- After this, it might be a good idea to do some experimental work with diffraction and interference. It would be good, if equipment is available, to provide as many examples of diffraction of waves as possible, for example: water waves passing through a gap in a barrier (or around the edge of one), sound waves diffracting through a door (this might seem silly, but it strongly reinforces the idea that if the wavelength of the wave is about the same size as the gap then the waves diffract as much as they can), light waves diffracting through a small slit and microwaves diffracting through gaps in metal sheets. Later, these ideas can be extended to show superposition if more than one source is used. This links directly with aim 6 in the group 4 aims in the IB Physics guide.
- It is worthwhile working through the classical derivation of the path difference for waves through a single slit, as this will allow students to appreciate the classical ideas that Huygens proposed. The single-slit diffraction pattern can then be used as an envelope for the double-slit pattern. Students should be able to use the ideas of path difference and the conditions for constructive and destructive interference to explain patterns observed by waves passing through one or two slits. This links directly with aim 1 in the group 4 aims in the IB Physics guide.
- Now is a good time to introduce the idea of polarisation. Some simple sheets of Polaroid are all that is needed for some impressive demonstrations. It is important for students to appreciate that polarisation occurs with transverse waves only and that it can occur because of transmission through media (such as Polaroid or sugar–water mix) or because of reflection from a plane surface. Students might like to consider what their Polaroid sunglasses actually do! This links directly with aim 6 in the group 4 aims in the IB Physics guide.
- The last part of this topic deals with standing waves. In the laboratory, standing waves are easy to demonstrate with rubber chords stretched over a pulley with a mass keeping them in tension. But you may find that YouTube videos are so much more impressive for students. Examples of Kundt’s tube and Ruben’s flame tube are good to illustrate the variation of amplitude in a standing wave. If access to a church organ is possible, it is worth taking students to see one in operation and to check whether the pipes are open at both ends, or closed at one end – this will allow them to consider the family of possible standing waves that can occur in the pipe.

Practical activities

- Investigative work with masses on springs is a good way to begin. Students should investigate how the time period depends on three factors, amplitude, mass and spring constant, although it would be good to let the students decide for themselves what their independent variables are going to be. There is good scope for all aspects of laboratory reporting here, from designing investigations to analysing data and graphing processed data to evaluating the limits and weaknesses of methods.

- Students can move to investigating other oscillations after this, applying what they have learnt about SHM. Water in a U-tube, a simple pendulum, a water molecule vibrating and a small ball rolling inside a glass bowl are all possible examples, although time available might restrict this.
- Perhaps the easiest way of measuring the speed of sound in air is to do the experiment outside. If it is possible to have two groups of students a good distance apart (say 300 m or so), then if one group makes a loud sound and at the same time waves a flag, the other group can start a stopwatch when they see the flag and stop it when they hear the sound. Although this experiment has a large uncertainty in time (due to human timing and reaction speed), it produces surprisingly good values for the speed of sound in air. If there is a large building from which you can get a substantial echo, this is also a good venue for doing the experiment – it may also allow for a longer time period (and hence smaller fractional error in timing). This will fulfil the required experiment for the practical scheme of work (PSOW4).
- A selection of examples of the use of em waves is a good way of highlighting the important features of the em spectrum and the various waves in it. A radio receiver, microwave transmitter and receiver (or mobile phone), a Leslie cube filled with hot water, some coloured lights, an ultraviolet lamp and some fluorescent material, and a gamma radioactive source will make a good selection for students to look at and think about.
- The slinky spring and a water ripple tank are the two most-used pieces of equipment for demonstrating wave properties. Together these will show all the necessary features of waves that students need to understand.
- With the slinky, a simple demonstration of transverse and longitudinal waves can be done – this can then be extended to getting students to understand that the speed at which the waves move along the spring depends on the tension in the spring and the mass per unit length of the spring. It is easy to change these (although you have to do both at the same time) and show students how to make waves travel faster or slower. It is also good to show that longitudinal and transverse waves will both travel at the same speed along the slinky – reinforcing the idea that it is the medium itself that dictates how fast the waves travel through it. Superposition of waves can also be shown with the slinky: send two pulses along the spring, allowing one pulse to be reflected from the other end of the spring so that the two pulses superpose. Students can easily see the effects of constructive and destructive superposition.
- With the water ripple tank, the visual aspect of seeing the wavefronts is a good way for students to observe the behaviour of waves. Reflection and refraction can be shown using small blocks as mirrors and using water of varying depth. Students should observe the wavefronts and see what happens to the wavelength as the wave is refracted, reinforcing the idea of waves changing speed. Both single-slit diffraction and double-slit interference can also be shown with the ripple tank, and students can then translate what they see into wavefront diagrams for greater clarity.
- Double slit interference patterns are shown to good effect using a double slit slide (a black photo slide with two very narrow and parallel lines etched into it) and a laser. Project the laser onto a whiteboard some distance away (say 5 or 10 m if possible) in a darkened room and the interference pattern should be nicely observed. Students can then make suitable measurements of fringe spacing and distance from laser to screen together with knowledge of the wavelength of the laser light to find the separation of the two slits. This is a powerful method of making measurements of small distances and leads students to think about how small distances are measured accurately in industry. The double-slit pattern is also nicely shown using two hi-fi speakers attached to a signal generator. Students can then walk past the two speakers and listen to where the sound is loud and quiet, showing the maxima and minima of the interference pattern. By making suitable measurements, students can confirm the effectiveness of the equation given in the data booklet $s = \lambda D/d$.

- If you can get some Polaroid sheets and an overhead projector, showing polarisation is easy. One good idea is to get a piece of plain glass and put two pieces of clear adhesive tape on it that overlap in the shape of a cross. (Clear adhesive tape rotates the plane of polarisation of light.) If the sheet of glass if then placed in between the two sheets of Polaroid, some interesting coloured effects can be seen. Students should be able to explain what they see in terms of planes of polarisation and the possible dispersive effect of the clear adhesive tape. Students that are also keen on art will see this as an interesting opportunity to produce original artwork using polarised light instead of other forms of colour. Viewing light that has been reflected from a plane surface (for example light coming through a window and reflecting off a bench) through a sheet of Polaroid will show students that reflection also causes partial plane polarisation. In a similar way, if there is lake nearby, take the students outside and let them use their Polaroid sunglasses (or use the sheets of Polaroid) to 'see' below the surface of the water, reminding them that they can do this because the partially plane polarised waves of light cannot pass through the Polaroid sheet if the sheet is correctly orientated. Students will also enjoy looking at stress patterns in plastic rulers and protractors using the Polaroid sheets.
- As mentioned earlier, standing waves are a very visual way of students learning about wave behaviour. Use a rubber cord stretched over a pulley with a vibrator at one end of the cord and a mass hanging over a pulley at the other. At special frequencies of vibration standing waves will occur. These can be investigated by changing the frequency of the vibrator and also by changing the tension and length of the cord. (Remember that changing the tension will change the speed at which the waves move along the cord and so the wavelength they will have for a given frequency of vibration.) The relationship between the wavelength of the waves and the length of the cord is what students need to understand, forming a set (mathematicians would call this family of wavelengths an **eigen set**) of values of possible wavelengths that will produce standing waves.
- Illustrating standing waves with the famous examples of Kundt's tube or Rubens' flame tube will require specialist equipment (although neither of these is difficult to make for yourself if you have workshop facilities). Failing this, there are good videos of both of these experiments available on YouTube, and students will find these interesting examples to look at. Making a drinking glass 'sing' is also something that students might like to consider.
- The obvious application of standing waves is to music. It may be useful to liaise with music departments or students with musical ability. Both stringed and wind instruments illustrate the ideas of standing waves very well. This part of the topic links very well with aims 3, 6 and 8 in the group 4 aims in the IB Physics guide.
- Please see the available practical notes for further ideas.

ICT

- There is good scope in this topic for the use of spreadsheets, such as Excel, to model waves. Superposition is a very good example of this; for example, ask students to see if they can combine (i.e. superpose) several sinusoidal waves to produce a square wave.
- As mentioned earlier, YouTube videos can be very useful for this topic. More adventurous students might like to video their own examples of standing waves and post their videos online; this also helps to support the international aspect of the IB.

Common problems

- The concept of path difference and its relationship with the phase of waves is an idea that many students find difficult at first. Using the idea of phase from a rotation around a circle will help students to realise the link between how far the wave has travelled and the phase of the wave.

- An idea to examine closely with students is the phenomenon of total internal reflection – particularly between two different media, neither of which are air. It is worth stressing that total internal reflection occurs when waves approach a boundary that separates a medium of high refractive index from a lower refractive index: students often get this wrong.
- The link between amplitude and intensity of a wave (i.e. that $I \propto A^2$) is something that students often forget when considering the effects of polarisation and of the intensity of interference patterns, and it is worth making a special point of this during lessons.

Theory of knowledge (TOK)

- Physicists use the model of SHM to help explain a whole range of different oscillations. This raises the questions: How do we know when a model is no longer good enough? What limitations do we impose on our models in order for us to use them to help our understanding? And perhaps the most obvious of questions: Why do we need to use models at all?
- The nature of science and the so-called 'scientific method' create an internationally recognised and accepted way of working. How does this way of knowing differ from the way in which knowledge is sought in other subjects? For example, does a historian follow a set of rules that are different to those followed by a physical scientist? After all, both subjects might be described as many-to-one mappings (or in the TOK language, deductive reasoning).
- During the history of scientific progress, light, for example, has been described using more than one model (the wave model, as proposed by Huygens, and the particle model, originally proposed by Newton). Does the use of more than one model, particularly if the two models appear to be contradictory, help or hinder our understanding of physics?
- Without the model of a standing wave, physicists find it hard to explain how an electron exists in an atom. (The classical model of an electron orbiting around the nucleus is flawed because an accelerating electron must emit em radiation, and this would mean that the electron loses energy and so would spiral inwards towards the nucleus.) Why, then, is this model still used so extensively in schools and colleges around the world?

International-mindedness

- Many different cultures have significant features that are linked to observations of wave or wave-like nature. This often creates legends and myths. Understanding the common features of wave behaviour may be a way of accessing understanding of other cultures and their histories.
- Much as mathematics forms a universal language for scientists, music is also an international collection of rules that everyone follows, and the production of music is the result of waves. Students might like to consider why some cultures have 'odd-sounding' wave combinations or why different kinds of music become 'trendy' in different cultures.