Teaching ideas for Topic 9: Wave phenomena (HL)

This is an additional HL topic that adds the mathematics of SHM to what students cover in the core (Topic **4**: Waves). In addition, this topic explores much more deeply the physics of single-slit diffraction, double-slit interference and interference patterns from diffraction gratings, as well as from thin films. Students also cover important work on the concept of resolution and on the Doppler effect for moving observers and for moving sources. This makes this topic another demanding one time-wise, although if it is being taught alongside Topic **4**, the overlap between the two topics allows some flexibility in time.

Some useful points to consider are:

- The initial work that students do with Topic **4** on oscillations is explored further with mathematics. These are important ideas for students to cover.
- Students will need to become familiar with the single-slit diffraction pattern – and the classical derivation of this. Using Huygens' secondary wavelet sources will provide a strong understanding of the way to find the position of the first minimum of the diffraction pattern.
- The double-slit interference pattern, as a pattern housed within the single slit diffraction envelope, extends students, understanding of the behaviour of waves.
- Optical effects, such as the interference patterns produced by thin films, will allow students to link their ideas of path difference, conditions for constructive and destructive interference and refraction to explain interesting and often colourful observations. The use of thin films as anti-reflective coatings on various optical instruments is an obvious application to consider.
- Resolution has many applications, from its use in astronomy to optical imaging in medicine and micro-photography. This is a strong selling point for teaching this concept to students.
- Examples of the Doppler effect are used to provide information on the expansion of the universe, on meteorological conditions and on the flow rate of blood in humans and animals. Although sometimes found by students to be a difficult idea to understand, it forms a strong foundation for understanding the importance of Hubble's law in modern views of cosmology.

Ideas for teaching the topic

- If you began teaching Topic **4** with exploring oscillations of a mass on a spring, then a good idea is to ask students how they can predict where the mass will be at any time. This will lead to modelling the motion of the mass mathematically. You might help students formulate ideas by holding the oscillating mass and then by walking sideways. Students will observe that the mass makes a sine wave path as you walk along. This will be a strong hint for students to apply their knowledge of a sine wave to the motion of the mass. Pay attention to boundary conditions (i.e. where is the mass when the clock says zero?). Using a spreadsheet is particularly helpful here. This links directly with aim 4 of the group 4 aims.
- Differentiating the graph of position against time will lead students to the graph of velocity against time, and further differentiation produces acceleration. You can do this graphically, or, for more able students, it can be done using simple calculus. It is good at this point to relate what students notice from the graphs to what you may have achieved earlier with Topic **4**: that acceleration against time is a similar relationship to that of position against time, but it is **negative**.
- Energy considerations, especially the way that potential energy and kinetic energy transfer between each other, can then be done using the equations for position and velocity. Students should be able to see that in the absence of frictional or damping forces the total energy of the harmonic oscillator remains constant.

- Students should also be able to show how the equation for simple harmonic motion (i.e. that $a = -\omega^2 x$) also applies to a simple pendulum oscillating with a small amplitude. This links directly to aim 6 in the group 4 aims in the IB Physics guide.
- Students can investigate single-slit diffraction nicely if you have a variable-width slit and a laser light source. If a commercially made variable-width slit is not available, it is quite easy to make one using two sharp edges (such as model knife blades, or razor blades) that can be positioned close to each other. It is also becoming easier and easier to buy lasers with different wavelength outputs, but make sure that their output power is less than about 5 mW, otherwise there are possible health and safety issues involved with students using them in experiments. It is worth focusing attention on the nature of the intensity pattern produced on a screen, the position of the first minimum and the relative intensity of successive maxima as you move outwards from the central maximum of the diffraction pattern.
- 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 the patterns observed by waves passing through one, two or many slits. Diffraction gratings with a range of how many slits there are per millimetre will be useful pieces of equipment here. Also, an old CD or DVD disc can be used very effectively as a reflection grating (see below).
- The path difference method is vital if you are to explain the patterns observed with light passing through thin films.
- The classical idea of resolution, as outlined by the Rayleigh criterion, will give students a good idea of how good our eyes are at night-time and in the daytime compared to other animals, how big the apertures of telescopes have to be (both optical and radio) and how the aperture sizes have to be related to the wavelength of the radiation being collected, how big pixels in digital images need to be to produce visually sharp images and a host of other applications.
- There is lots of scope for demonstrating the Doppler effect. It is important, however, that students can draw wavefront diagrams to explain how this wave phenomenon occurs. Its applications are vital to many areas of research and have been instrumental in helping scientists produce ways of measuring relative motion.

Practical activities

- With an old CD or DVD disc, try reflecting laser light from its surface onto a screen. If you can position the disc so that the laser light is incident at 45° there will be a diffraction pattern produced on a screen with the central maximum where you would expect from a simple reflection. If students make measurements of the separation of the maxima on the screen and the screen-to-disc distance it is a simple calculation, using the idea that $s \sin \theta = \lambda$, to find the width of the tracks on the disc that are producing the diffraction grating interference pattern.
- You can make a good thin film interference pattern using a soap bubble toy. A larger version of this can be made using a fairly stiff wire that is shaped into a circle with the two ends of the wire wrapped around each other to form a handle. If you now dip the wire circle into a solution made of detergent, water and a little glycerol (or just use washing-up liquid and water) a thin film will remain in the circular space. Light shone through this will produce excellent interference fringes. If you use a colour filter in front of a white light source, monochromatic fringes can be investigated – and the beauty of these is that as the liquid flows towards the bottom of the wire circle and the thickness of the film increases, the separation of the fringes will change. White light, of course, will produce interesting visible spectra as interference fringes. This is another example of how light and physics experiments can produce interesting art.

- A nice way to illustrate the concept of resolution is to draw two, parallel, coloured lines on a piece of white paper. If one student moves away from another with the piece of paper, the student looking at the piece of paper can ask the other student to stop when the two lines appear to merge to form one. If measurements are now made to calculate the angle subtended by the two lines to the observer's eye, the Rayleigh criterion can be verified using the equation of $\theta = 1.22\ \lambda/b$. Students might like to investigate this in bright and dark conditions (where their pupil sizes will be different) and with lines drawn in different colours (to examine the effect of wavelength).
- There are several ways of demonstrating the Doppler effect; and some of these can be viewed on YouTube videos. The easiest, perhaps, is to put a small buzzer on the end of a piece of string. Turn on the buzzer and then swing it around in a large circle. Students will be able to hear the change in frequency (pitch) of the sound waves emitted by the buzzer, noting that when the buzzer is moving towards the observer the frequency of the sound is increased and when the buzzer moves away from the observer the frequency of the sound is decreased. Rotating the buzzer with different speeds should show different changes of frequency, leading students into the link between the speed of the buzzer and the frequency change observed. Students are likely to have experienced this phenomenon with emergency vehicles on roads. You can reproduce this if you can get someone to drive a car past your students while pressing the car's horn. It's fun, so why not do it?!
- These practical activities link very well with aims 3 and 6 in the group 4 aims in the IB Physics guide.
- Please see the available practical notes for further ideas.

ICT

- Although there are several examples of virtual experiments available on various university websites (such as the University of Colorado website (http://phet.colorado.edu), there is so much more benefit to students in actually doing these experiments and investigations for themselves that use of ICT does not need to play a significant role in this topic.
- For teachers who may not have good access to the kind of equipment required for these practical exercises, it is possible to illustrate much of what is mentioned here with the careful use of video.

Common problems

- Students frequently make mistakes when calculating the energy of a harmonic oscillator. Rather than relying on remembering equations, or reading them from the data booklet, students should be encouraged to consider where the equations come from and how they have been put together.
- Students confuse the equations for the single-slit diffraction pattern, the double-slit interference pattern and the diffraction grating pattern. It may help students to use the letter **b** to represent the width of a single slit, the letter **d** to represent the separation of two slits and the letter **s** to represent the separation of many slits. It is also important for students to remember that the equation for a single-slit diffraction pattern gives the angle at which the first minimum occurs, whereas the equation for the double-slit pattern gives the angle at which the first maximum occurs.
- When answering problems about resolution, students confuse the idea of the angle in the Rayleigh criterion. A good way to help students is to get them to find out what the actual angle is (i.e. the angle subtended by two objects at a distance from the observing aperture) and then compare this with what the Rayleigh criterion angle states. If the actual angle is greater than the Rayleigh criterion angle, then the two objects are resolved; if the two angles are the same, then the two objects are 'just resolved'; and when the actual angle is less than the Rayleigh criterion angle, then the two objects are not resolved. This means that in a

comparison between resolving powers, a system with the smallest Rayleigh criterion angle will have the greatest resolving power because it will allow more examples of real angles to occur that are greater than the Rayleigh criterion angle.

Theory of knowledge (TOK)

- The old physics syllabus included treatment of the double-slit interference pattern without requiring an understanding of the single-slit pattern. The double-slit pattern has to fit inside the single-slit pattern. So to what extent can scientists ignore some aspects of a model? Is ignoring complex aspects of a model necessary if a simple explanation is required?
- For much of scientific learning, the process is a deductive one. How important is it that knowledge of, for example, interference of thin films can be applied in an inductive way to a wide range of other situations? Is this a particular strength of this piece of knowledge, or is it just another example of a more general approach?
- Do other subjects allow both deductive and inductive processes to advance learning?

International-mindedness

- Modern-day astronomical research is a multinational collaboration that exploits all aspects of wave phenomena. International scientific groups utilise research facilities in many different countries at the same time. This strengthens our knowledge and understanding of different languages, customs and cultures.
- Modern aircraft tracking by civil aviation authorities requires extensive use of wave phenomena, including radar and applications of the Doppler effect. Without this international agreement and collaboration, international air travel would not be possible.

