Teaching ideas for Option C: Imaging

This topic may be the easiest of the options to deliver to students. There are clear links with the earlier work that students have done on waves (from Topic **4**: Waves and the additional HL Topic **9**: Wave phenomena), although this topic concentrates much more on the way in which waves are shown to propagate (i.e. using both ray diagrams and wavefront diagrams) and how we use them to produce images.

Some useful points to consider are:

- There is going to be a large amount of drawing of diagrams for students to be able to reproduce. Lessons will have to ensure that students are properly prepared for this aspect of learning about producing an image.
- This topic will lend itself very well to Theory of knowledge (TOK) discussions about the nature of our sense of sight and how dependent most people are on it. It will also require consideration of how images are interpreted by those trained in what to look for.
- There may be good opportunities in this topic to use, or make, contacts with outside organisations such as hospitals or astronomy societies. When students are able to see a variety of different images produced in different ways and using different parts of the electromagnetic spectrum (or sound) the impact of how important they are helps their motivation to learn. Hospitals are particularly good for this, because they may be able to offer examples of microscopic images and images from endoscopic observations, as well as X-ray images, ultrasound images, magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) images. The latter examples will be very useful for students who are taking the HL course.
- There are two required experiments in this topic: investigating an optical compound microscope and investigating an optical refracting telescope (see the ‘Applications and skills’ section of the IB Physics guide). You should ensure that these investigations are performed by students; the expectation is that questions based on these investigations will appear in the Paper 3 examination.

Ideas for teaching the topic

- A good start to this topic is to look at lenses and what they do to waves. It is worth thinking that a lens introduces curvature to a plane wave front; this will help students to understand how to draw a wavefront diagram.
- If students can use a piece of white card, on which their images appear, it will be easy to get them to recognise that an image that can appear on a screen is a real image, and therefore images that do not appear on a screen are virtual.
- The classical way of showing the rays passing through a thin lens is important for students to be able to reproduce. So, it is a good idea to spend plenty of time getting students to do this. Concentrating on parallel incident rays at first and then moving to more complicated curved wavefronts is the right way to proceed. Once students can draw a ray diagram for one lens, then two lenses can be used. This will lead to how a simple refracting telescope works and an optical microscope.
- Using diverging lenses will introduce the idea of a focal point that is on the other side of the lens, i.e. on the same side as the object. This will be a useful idea for students to use later.
- Once students have mastered the optics of thin lenses, introduce the mirror as another way of changing the shape of the wavefront. A good idea would be start with plane mirrors and then move to curved mirrors, see the paragraph about mirrors in the practical activities section below.

- The optics of astronomical telescopes can be taught using ray diagrams. Both refracting telescopes (using two lenses) and reflecting telescopes (using one or two mirrors and a lens) can be easily shown with a carefully drawn ray diagram. Students should be able to reproduce these. In the case of reflecting telescopes, students are only required to deal with Newtonian and Cassegrain reflectors.
- The ideas used by radio telescopes are transferrable from ideas used in reflecting telescopes. The important points to stress here are: longer wavelength waves require a bigger aperture to collect the waves; the ratio of wavelength to aperture size makes the resolution of a radio telescope poor unless an array of radio telescopes (an interferometer) with a very large effective aperture size is used; radio waves are not prone to atmospheric absorption, nor are they affected by poor weather; astronomical objects usually have completely different images when viewed in visible and in radio wavelengths, leading to obtaining a better overall picture of the object and its behaviour.
- Subtopic **C.3**: Fibre optics is about the use of total internal reflection in optic fibres. It is crucial that students can understand this important phenomenon. Ray diagrams and practical demonstrations will help to illustrate the ideas here. Thinking of an optic fibre as a waveguide is a good idea. It will be important for students to appreciate, and to make calculations on, the way in which energy from the wave is attenuated by its propagation along a waveguide; the syllabus states that the term 'waveguide dispersion' will be used in examinations and that this also refers to 'modal dispersion'.
- The additional HL material concentrates on medical uses of imaging. Importantly, and interestingly, these images are produced from radiation that originates both outside and inside a patient's body. Any contact with a local hospital will be useful if a trip for students to see medical uses of imaging is likely to be possible.

Practical activities

- If the teaching begins with investigating lenses, then a combination of practical work, looking at what happens to rays of light as they pass through lenses, and drawing of ray and wavefront diagrams will be an excellent introduction to this topic. A ray box, or a 12 V partially shielded light bulb with a small slit (or three slits) placed in front, can be used to produce some thin rays of light. If these rays are incident on a selection of thin lenses, then students can draw on some paper placed underneath their experiment where the rays go. It would be good to start with parallel rays incident along the principal axis and then students can investigate what happens when the angle of incidence is changed. This should allow students to find out empirically the relationship between the focal length of the lens and its power in dioptres. This links well with aim 6 of the group 4 aims in the IB Physics guide.
- In getting students to draw ray diagrams, it is worth producing a sheet with a principal axis drawn horizontally on a landscape-orientated page. A thin converging lens can be drawn in the centre with the centre of the lens on the principal axis. If the principal axis is then marked in units of the focal length of the lens, f_o, (either side of the lens), then students can investigate what happens to the image formation of an object that is placed: more than $2f_o$ from the lens, at $2f_o$, between $2f_o$ and f_o, at f_o and at less than f_o from the lens. This is an excellent exercise for students and will show the existence of a virtual image when the object is less that f_o away from the lens, the basic optics behind a microscope. Students will also be able to find out how the size of the image is magnified from the size of the object.
- Students should repeat the exercise above using diverging lenses.
- Colleagues in the biology department might allow students to investigate the action of a simple compound microscope. If this is not possible it is a difficult investigation for students to do, although it is not impossible because it can be done by drawing careful ray diagrams. Either way, students must be able to show that they have done this.

- Both spherical and chromatic aberration can be demonstrated by drawing ray diagrams. Students should appreciate that when the rays do not focus at a single point, then aberration is occurring.
- Students may have used plane mirrors before, and these would be very helpful in getting students to reproduce ray and wavefront diagrams. They are crucial in allowing students to understand the idea of a virtual image. Teachers might like to ask students to look at things through a mirror, make a note of what they see and then translate this into a ray diagram and a wavefront diagram. They will find this more difficult than might be expected, but it is important for them to do. Leonardo da Vinci's mirror writing might inspire some students to persevere with this approach.
- Converging and diverging mirrors will be the next thing for students to investigate practically. If ray boxes are available, using these will make conducting the investigation simple. If curved mirrors are not available, this is best done using ray diagrams and curves on paper to represent the mirrors.
- Students can make their own examples of astronomical refracting telescopes, using two lenses, one for the object lens and one for the eyepiece lens. If they have been shown the ray diagram for two lenses, students should be able to see where their lenses have to be placed in order for them to produce an image of a distant object. It may be helpful if you have some lens holders that can be clipped on to a long piece of wood, such as a metre ruler. This will satisfy the required experiment about refracting telescopes for this topic.
- If you are lucky enough to have an observatory, or access to one, then students will gain excellent experience from looking at the images that are available from a refracting or reflecting telescope. There are also lots of really exciting images of astronomical objects available on various websites, such as http://hubblesite.org/.This site has an extensive collection of really useful material, from how the telescope works to deep field images of distant galaxies. This links nicely with aims 3 and 5 of the group 4 aims.
- There is a virtual MRI scanner available on the following website: http://www.healthcare.philips.com/main/products/mri/clinical-cases/index.html?origin=7_global_en_dstreamccm_google___10_1_1&pcrid=37431772700|plid|. Students might enjoy looking at some examples of MRI scans.
- Please see the available practical notes for further ideas.

ICT

- Ray diagrams for a range of different optical instruments are to be found on a number of websites. The National STEM centre in the UK is an excellent source of useful material: http://www.nationalstemcentre.org.uk/ *Optical Instruments and Ray Diagrams* is a good pdf document that looks at ray diagrams in telescopes and in a microscope.
- The following website is also very good, and the ray diagrams are perhaps easier to understand: http://www.physchem.co.za/OB11-wav/instruments.htm.
- Websites that display colourful and inspiring images of astronomical objects are fairly numerous, but the site mentioned above http://hubblesite.org/ is excellent.
- The ever popular How Stuff Works website is good for providing useful information about fibre optic cables: http://computer.howstuffworks.com/fiber-optic.htm.

Common problems

- It is expected that students will find difficulty with constructing ray and wavefront diagrams to show what happens to waves when they pass through lenses and when they are reflected by mirrors. Lots of practice is necessary to embed this.

- The critical angle between two refracting media is a concept that students frequently find difficult. A common problem is identifying clearly which medium is which and which way the wave is travelling. It is vital to get students to see that total internal reflection occurs only when waves are incident on a boundary between two media where the medium on the far side has a smaller refractive index.
- The concept of attenuation as the combined effect of absorption and scattering is a useful idea in physics, but it is an idea that students often find difficult. It may be a good idea to begin with how a beam of light is attenuated as it passes through the air and then gradually change the medium to explore how differing media affect the two factors that contribute to attenuation. Try to remember that any electromagnetic wave also obeys an inverse-square law of intensity with distance, even without any attenuation.

Theory of knowledge (TOK)

- The well-used question with any image is: How do I know that what someone else is looking at is the same thing I am looking at? After all, two people looking at an object from different directions may well see two completely different things, simply because the object is not a regular or isotropic shape. This brings out interesting discussions about the nature of perception and the quotation 'You look, but you do not observe' can be seen to be relevant not only to observations in science but also in all areas of people's lives.
- This has been mentioned elsewhere, but it is worth pointing out again: as this topic is about imaging, it is important to stress how the interpretation, as well as the perception, of the image affects what is learnt from it.
- If we accept that any kind of perception and interpretation is intrinsically human, will it ever be possible for a computer to do this job for us? Students might see this leading to discussions of the Turing problem or how it is that Deep Blue was able to beat an international Grand Master at chess.

International-mindedness

- A great deal of communication between different countries on different continents is accomplished with under-sea cables. This would not happen without international collaboration.
- The huge array system of radio telescopes in Australia provides it with an effectively enormous aperture. If radio telescopes across the globe were to be used as a global interferometer, this would give an even better resolution to images and allow a better understanding of different cultures of the groups of scientists involved.
- International medical organisations rely on the international-mindedness of doctors and nurses to provide medical care almost anywhere in the world where it is required.