Core topics

15 hours

Essential idea: The progress of a wave can be modelled via the ray or the wavefront. The change in wave speed when moving between media changes the shape of the wave.

C.1 – Introduction to imaging

Nature of science:

Deductive logic: The use of virtual images is essential for our analysis of lenses and mirrors. (1.6)

Understandings:

- Thin lenses
- Converging and diverging lenses
- Converging and diverging mirrors
- Ray diagrams
- Real and virtual images
- Linear and angular magnification
- Spherical and chromatic aberrations

Applications and skills:

- Describing how a curved transparent interface modifies the shape of an incident wavefront
- Identifying the principal axis, focal point and focal length of a simple converging or diverging lens on a scaled diagram
- Solving problems involving not more than two lenses by constructing scaled ray diagrams

International-mindedness:

- Optics is an ancient study encompassing development made in the early Greco-Roman and medieval Islamic worlds

Theory of knowledge:

- Could sign convention, using the symbols of positive and negative, emotionally influence scientists?

Utilization:

- Microscopes and telescopes
- Eyeglasses and contact lenses

Aims:

- **Aim 3:** the theories of optics, originating with human curiosity of our own senses, continue to be of great value in leading to new and useful technology
- **Aim 6:** experiments could include (but are not limited to): magnification determination using an optical bench; investigating real and virtual images formed by lenses; observing aberrations

C.1 – Introduction to imaging

- Solving problems involving not more than two curved mirrors by constructing scaled ray diagrams
- Solving problems involving the thin lens equation, linear magnification and angular magnification
- Explaining spherical and chromatic aberrations and describing ways to reduce their effects on images

Guidance:

- Students should treat the passage of light through lenses from the standpoint of both rays and wavefronts
- Curved mirrors are limited to spherical and parabolic converging mirrors and spherical diverging mirrors
- Only thin lenses are to be considered in this topic
- The lens-maker's formula is not required
- Sign convention used in examinations will be based on real being positive (the "real-is-positive" convention)

Data booklet reference:

- $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$
- $P = \frac{1}{f}$
- $m = \frac{h_i}{h_o} = -\frac{v}{u}$
- $M = \frac{\theta_i}{\theta_o}$
- $M_{\text{near point}} = \frac{D}{f} + 1;\ M_{\text{infinity}} = \frac{D}{f}$

Essential idea: Optical microscopes and telescopes utilize similar physical properties of lenses and mirrors. Analysis of the universe is performed both optically and by using radio telescopes to investigate different regions of the electromagnetic spectrum.

C.2 – Imaging instrumentation

Nature of science:

Improved instrumentation: The optical telescope has been in use for over 500 years. It has enabled humankind to observe and hypothesize about the universe. More recently, radio telescopes have been developed to investigate the electromagnetic radiation beyond the visible region. Telescopes (both visual and radio) are now placed away from the Earth's surface to avoid the image degradation caused by the atmosphere, while corrective optics are used to enhance images collected at the Earth's surface. Many satellites have been launched with sensors capable of recording vast amounts of data in the infrared, ultraviolet, X-ray and other electromagnetic spectrum ranges. (1.8)

Understandings:

- Optical compound microscopes
- Simple optical astronomical refracting telescopes
- Simple optical astronomical reflecting telescopes
- Single-dish radio telescopes
- Radio interferometry telescopes
- Satellite-borne telescopes

Applications and skills:

- Constructing and interpreting ray diagrams of optical compound microscopes at normal adjustment
- Solving problems involving the angular magnification and resolution of optical compound microscopes
- Investigating the optical compound microscope experimentally
- Constructing or completing ray diagrams of simple optical astronomical refracting telescopes at normal adjustment

International-mindedness:

- The use of the radio interferometry telescope crosses cultures with collaboration between scientists from many countries to produce arrays of interferometers that span the continents

Theory of knowledge:

- However advanced the technology, microscopes and telescopes always involve sense perception. Can technology be used effectively to extend or correct our senses?

Utilization:

- Cell observation (see *Biology* sub-topic *1.2*)
- The information that the astronomical telescopes gather continues to allow us to improve our understanding of the universe
- Resolution is covered for other sources in *Physics* sub-topic *9.4*

C.2 – Imaging instrumentation	
• Solving problems involving the angular magnification of simple optical astronomical telescopes • Investigating the performance of a simple optical astronomical refracting telescope experimentally • Describing the comparative performance of Earth-based telescopes and satellite-borne telescopes **Guidance:** • Simple optical astronomical reflecting telescope design is limited to Newtonian and Cassegrain mounting • Radio interferometer telescopes should be approximated as a dish of diameter equal to the maximum separation of the antennae • Radio interferometry telescopes refer to array telescopes **Data booklet reference:** • $M = \frac{f_o}{f_e}$	**Aims:** • **Aim 3:** images from microscopes and telescopes both in the school laboratory and obtained via the internet enable students to apply their knowledge of these techniques • **Aim 5:** research astronomy and astrophysics is an example of the need for collaboration between teams of scientists from different countries and continents • **Aim 6:** local amateur or professional astronomical organizations can be useful for arranging demonstrations of the night sky

Essential idea: Total internal reflection allows light or infrared radiation to travel along a transparent fibre. However, the performance of a fibre can be degraded by dispersion and attenuation effects.

C.3 – Fibre optics	
Nature of science: Applied science: Advances in communication links using fibre optics have led to a global network of optical fibres that has transformed global communications by voice, video and data. (1.2)	
Understandings: • Structure of optic fibres • Step-index fibres and graded-index fibres • Total internal reflection and critical angle • Waveguide and material dispersion in optic fibres • Attenuation and the decibel (dB) scale **Applications and skills:** • Solving problems involving total internal reflection and critical angle in the context of fibre optics • Describing how waveguide and material dispersion can lead to attenuation and how this can be accounted for • Solving problems involving attenuation • Describing the advantages of fibre optics over twisted pair and coaxial cables	**International-mindedness:** • The under-sea optic fibres are a vital part of the communication between continents **Utilization:** • Will a communication limit be reached as we cannot move information faster than the speed of light? **Aims:** • **Aim 1:** this is a global technology that embraces and drives increases in communication speeds • **Aim 9:** the dispersion effects illustrate the inherent limitations that can be part of a technology

C.3 – Fibre optics	
Guidance: • Quantitative descriptions of attenuation are required and include attenuation per unit length • The term *waveguide dispersion* will be used in examinations. Waveguide dispersion is sometimes known as *modal dispersion*. **Data booklet reference:** • $n = \frac{1}{\sin c}$ • $\text{attenuation} = 10 \log \frac{I}{I_0}$	

Additional higher level option topics

10 hours

Essential idea: The body can be imaged using radiation generated from both outside and inside. Imaging has enabled medical practitioners to improve diagnosis with fewer invasive procedures.

C.4 – Medical imaging

Nature of science:

Risk analysis: The doctor's role is to minimize patient risk in medical diagnosis and procedures based on an assessment of the overall benefit to the patient. Arguments involving probability are used in considering the attenuation of radiation transmitted through the body. (4.8)

Understandings:

- Detection and recording of X-ray images in medical contexts
- Generation and detection of ultrasound in medical contexts
- Medical imaging techniques (magnetic resonance imaging) involving nuclear magnetic resonance (NMR)

Applications and skills:

- Explaining features of X-ray imaging, including attenuation coefficient, half-value thickness, linear/mass absorption coefficients and techniques for improvements of sharpness and contrast
- Solving X-ray attenuation problems
- Solving problems involving ultrasound acoustic impedance, speed of ultrasound through tissue and air and relative intensity levels

International-mindedness:

- There is constant dialogue between research clinicians in different countries to communicate new methods and treatments for the good of patients everywhere
- Organizations such as *Médecins Sans Frontières* provide valuable medical skills in parts of the world where medical help is required

Theory of knowledge:

- "It's not what you look at that matters, it's what you see." – Henry David Thoreau. To what extent do you agree with this comment on the impact of factors such as expectation on perception?

Utilization:

- Scanning the human brain (see *Biology* sub-topic *A.4*)

C.4 – Medical imaging	
• Explaining features of medical ultrasound techniques, including choice of frequency, use of gel and the difference between A and B scans • Explaining the use of gradient fields in NMR • Explaining the origin of the relaxation of proton spin and consequent emission of signal in NMR • Discussing the advantages and disadvantages of ultrasound and NMR scanning methods, including a simple assessment of risk in these medical procedures **Guidance:** • Students will be expected to compute final beam intensity after passage through multiple layers of tissue. Only parallel plane interfaces will be treated. **Data booklet reference:** • $L_I = 10 \log \frac{I_1}{I_0}$ • $I = I_0 e^{-\mu x}$ • $\mu x_{\frac{1}{2}} = \ln 2$ • $Z = \rho c$	**Aims**: • **Aim 4:** there are many opportunities for students to analyse and evaluate scientific information • **Aim 8:** the social impact of these scientific techniques for the benefit of humankind cannot be over-emphasized • **Aim 10:** medicine and physics meet in the hi-tech world of scanning and treatment. Modern doctors rely on technology that arises from developments in the physical sciences.