Topic 4: Waves

15 hours

Essential idea: A study of oscillations underpins many areas of physics with simple harmonic motion (shm), a fundamental oscillation that appears in various natural phenomena.

4.1 – Oscillations

Nature of science:

Models: Oscillations play a great part in our lives, from the tides to the motion of the swinging pendulum that once governed our perception of time. General principles govern this area of physics, from water waves in the deep ocean or the oscillations of a car suspension system. This introduction to the topic reminds us that not all oscillations are isochronous. However, the simple harmonic oscillator is of great importance to physicists because all periodic oscillations can be described through the mathematics of simple harmonic motion. (1.10)

Understandings:

- Simple harmonic oscillations
- Time period, frequency, amplitude, displacement and phase difference
- Conditions for simple harmonic motion

Applications and skills:

- Qualitatively describing the energy changes taking place during one cycle of an oscillation
- Sketching and interpreting graphs of simple harmonic motion examples

International-mindedness:

- Oscillations are used to define the time systems on which nations agree so that the world can be kept in synchronization. This impacts most areas of our lives including the provision of electricity, travel and location-determining devices and all microelectronics.

Theory of knowledge:

- The harmonic oscillator is a paradigm for modelling where a simple equation is used to describe a complex phenomenon. How do scientists know when a simple model is not detailed enough for their requirements?

4.1 – Oscillations	
Guidance: • Graphs describing simple harmonic motion should include displacement–time, velocity–time, acceleration–time and acceleration–displacement • Students are expected to understand the significance of the negative sign in the relationship: $a \propto -x$ **Data booklet reference:** • $T = \frac{1}{f}$	**Utilization:** • Isochronous oscillations can be used to measure time • Many systems can approximate simple harmonic motion: mass on a spring, fluid in U-tube, models of icebergs oscillating vertically in the ocean, and motion of a sphere rolling in a concave mirror • Simple harmonic motion is frequently found in the context of mechanics (see *Physics* topic 2) **Aims:** • **Aim 6:** experiments could include (but are not limited to): mass on a spring; simple pendulum; motion on a curved air track • **Aim 7:** IT skills can be used to model the simple harmonic motion defining equation; this gives valuable insight into the meaning of the equation itself

Essential idea: There are many forms of waves available to be studied. A common characteristic of all travelling waves is that they carry energy, but generally the medium through which they travel will not be permanently disturbed.

4.2 – Travelling waves

Nature of science:

Patterns, trends and discrepancies: Scientists have discovered common features of wave motion through careful observations of the natural world, looking for patterns, trends and discrepancies and asking further questions based on these findings. (3.1)

Understandings:

- Travelling waves
- Wavelength, frequency, period and wave speed
- Transverse and longitudinal waves
- The nature of electromagnetic waves
- The nature of sound waves

Applications and skills:

- Explaining the motion of particles of a medium when a wave passes through it for both transverse and longitudinal cases
- Sketching and interpreting displacement–distance graphs and displacement–time graphs for transverse and longitudinal waves
- Solving problems involving wave speed, frequency and wavelength
- Investigating the speed of sound experimentally

Guidance:

- Students will be expected to derive $c = f\lambda$
- Students should be aware of the order of magnitude of the wavelengths of radio, microwave, infra-red, visible, ultraviolet, X-ray and gamma rays

Data booklet reference:

- $c = f\lambda$

International-mindedness:

- Electromagnetic waves are used extensively for national and international communication

Theory of knowledge:

- Scientists often transfer their perception of tangible and visible concepts to explain similar non-visible concepts, such as in wave theory. How do scientists explain concepts that have no tangible or visible quality?

Utilization:

- Communication using both sound (locally) and electromagnetic waves (near and far) involve wave theory
- Emission spectra are analysed by comparison to the electromagnetic wave spectrum (see *Chemistry* topic *2* and *Physics* sub-topic *12.1*)
- Sight (see *Biology* sub-topic *A.2*)

Aims:

- **Aim 2:** there is a common body of knowledge and techniques involved in wave theory that is applicable across many areas of physics
- **Aim 4:** there are opportunities for the analysis of data to arrive at some of the models in this section from first principles
- **Aim 6:** experiments could include (but are not limited to): speed of waves in different media; detection of electromagnetic waves from various sources; use of echo methods (or similar) for determining wave speed, wavelength, distance, or medium elasticity and/or density

Essential idea: All waves can be described by the same sets of mathematical ideas. Detailed knowledge of one area leads to the possibility of prediction in another.

4.3 – Wave characteristics

Nature of science:

Imagination: It is speculated that polarization had been utilized by the Vikings through their use of Iceland Spar over 1300 years ago for navigation (prior to the introduction of the magnetic compass). Scientists across Europe in the 17th–19th centuries continued to contribute to wave theory by building on the theories and models proposed as our understanding developed. (1.4)

Understandings:

- Wavefronts and rays
- Amplitude and intensity
- Superposition
- Polarization

Applications and skills:

- Sketching and interpreting diagrams involving wavefronts and rays
- Solving problems involving amplitude, intensity and the inverse square law
- Sketching and interpreting the superposition of pulses and waves
- Describing methods of polarization
- Sketching and interpreting diagrams illustrating polarized, reflected and transmitted beams
- Solving problems involving Malus's law

Guidance:

- Students will be expected to calculate the resultant of two waves or pulses both graphically and algebraically
- Methods of polarization will be restricted to the use of polarizing filters and reflection from a non-metallic plane surface

Data booklet reference:

- $I \propto A^2$
- $I \propto x^{-2}$
- $I = I_0 \cos^2 \theta$

Theory of knowledge:

- Wavefronts and rays are visualizations that help our understanding of reality, characteristic of modelling in the physical sciences. How does the methodology used in the natural sciences differ from the methodology used in the human sciences?
- How much detail does a model need to contain to accurately represent reality?

Utilization:

- A number of modern technologies, such as LCD displays, rely on polarization for their operation

Aims:

- **Aim 3:** these universal behaviours of waves are applied in later sections of the course in more advanced topics, allowing students to generalize the various types of waves
- **Aim 6:** experiments could include (but are not limited to): observation of polarization under different conditions, including the use of microwaves; superposition of waves; representation of wave types using physical models (eg slinky demonstrations)
- **Aim 7:** use of computer modelling enables students to observe wave motion in three dimensions as well as being able to more accurately adjust wave characteristics in superposition demonstrations

Essential idea: Waves interact with media and each other in a number of ways that can be unexpected and useful.

4.4 – Wave behaviour

Nature of science:

Competing theories: The conflicting work of Huygens and Newton on their theories of light and the related debate between Fresnel, Arago and Poisson are demonstrations of two theories that were valid yet flawed and incomplete. This is an historical example of the progress of science that led to the acceptance of the duality of the nature of light. (1.9)

Understandings:

- Reflection and refraction
- Snell's law, critical angle and total internal reflection
- Diffraction through a single-slit and around objects
- Interference patterns
- Double-slit interference
- Path difference

Applications and skills:

- Sketching and interpreting incident, reflected and transmitted waves at boundaries between media
- Solving problems involving reflection at a plane interface
- Solving problems involving Snell's law, critical angle and total internal reflection
- Determining refractive index experimentally
- Qualitatively describing the diffraction pattern formed when plane waves are incident normally on a single-slit
- Quantitatively describing double-slit interference intensity patterns

International-mindedness:

- Characteristic wave behaviour has been used in many cultures throughout human history, often tying closely to myths and legends that formed the basis for early scientific studies

Theory of knowledge:

- Huygens and Newton proposed two competing theories of the behaviour of light. How does the scientific community decide between competing theories?

Utilization:

- A satellite footprint on Earth is governed by the diffraction at the dish on the satellite
- Applications of the refraction and reflection of light range from the simple plane mirror through the medical endoscope and beyond. Many of these applications have enabled us to improve and extend our sense of vision
- The simple idea of the cancellation of two coherent light rays reflecting from two surfaces leads to data storage in compact discs and their successors
- The physical explanation of the rainbow involves refraction and total internal reflection. The bright and dark bands inside the rainbow, supernumeraries, can be explained only by the wave nature of light and diffraction

4.4 – Wave behaviour	
Guidance: • Quantitative descriptions of refractive index are limited to light rays passing between two or more transparent media. If more than two media, only parallel interfaces will be considered • Students will not be expected to derive the double-slit equation • Students should have the opportunity to observe diffraction and interference patterns arising from more than one type of wave **Data booklet reference:** • $\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$ • $s = \frac{\lambda D}{d}$ • Constructive interference: path difference = $n\lambda$ • Destructive interference: path difference = $\left(n + \frac{1}{2}\right)\lambda$	**Aims:** • **Aim 1:** the historical aspects of this topic are still relevant science and provide valuable insight into the work of earlier scientists • **Aim 6:** experiments could include (but are not limited to): determination of refractive index and application of Snell's law; determining conditions under which total internal reflection may occur; examination of diffraction patterns through apertures and around obstacles; investigation of the double-slit experiment • **Aim 8:** the increasing use of digital data and its storage density has implications on individual privacy through the permanence of a digital footprint

Essential idea: When travelling waves meet they can superpose to form standing waves in which energy may not be transferred.

4.5 – Standing waves	
Nature of science: Common reasoning process: From the time of Pythagoras onwards the connections between the formation of standing waves on strings and in pipes have been modelled mathematically and linked to the observations of the oscillating systems. In the case of sound in air and light, the system can be visualized in order to recognize the underlying processes occurring in the standing waves. (1.6)	
Understandings: • The nature of standing waves • Boundary conditions • Nodes and antinodes **Applications and skills:** • Describing the nature and formation of standing waves in terms of superposition • Distinguishing between standing and travelling waves • Observing, sketching and interpreting standing wave patterns in strings and pipes • Solving problems involving the frequency of a harmonic, length of the standing wave and the speed of the wave **Guidance:** • Students will be expected to consider the formation of standing waves from the superposition of no more than two waves • Boundary conditions for strings are: two fixed boundaries; fixed and free boundary; two free boundaries	**International-mindedness:** • The art of music, which has its scientific basis in these ideas, is universal to all cultures, past and present. Many musical instruments rely heavily on the generation and manipulation of standing waves **Theory of knowledge:** • There are close links between standing waves in strings and Schrodinger's theory for the probability amplitude of electrons in the atom. Application to superstring theory requires standing wave patterns in 11 dimensions. What is the role of reason and imagination in enabling scientists to visualize scenarios that are beyond our physical capabilities? **Utilization:** • Students studying music should be encouraged to bring their own experiences of this art form to the physics classroom

4.5 – Standing waves	
• Boundary conditions for pipes are: two closed boundaries; closed and open boundary; two open boundaries • For standing waves in air, explanations will not be required in terms of pressure nodes and pressure antinodes • The lowest frequency mode of a standing wave is known as the first harmonic • The terms *fundamental* and *overtone* will not be used in examination questions	**Aims:** • **Aim 3:** students are able to both physically observe and qualitatively measure the locations of nodes and antinodes, following the investigative techniques of early scientists and musicians • **Aim 6:** experiments could include (but are not limited to): observation of standing wave patterns in physical objects (eg slinky springs); prediction of harmonic locations in an air tube in water; determining the frequency of tuning forks; observing or measuring vibrating violin/guitar strings • **Aim 8:** the international dimension of the application of standing waves is important in music