Topic 9: Wave phenomena

17 hours

Essential idea: The solution of the harmonic oscillator can be framed around the variation of kinetic and potential energy in the system.

9.1 – Simple harmonic motion

Nature of science:

Insights: The equation for simple harmonic motion (SHM) can be solved analytically and numerically. Physicists use such solutions to help them to visualize the behaviour of the oscillator. The use of the equations is very powerful as any oscillation can be described in terms of a combination of harmonic oscillators. Numerical modelling of oscillators is important in the design of electrical circuits. (1.11)

Understandings:

- The defining equation of SHM
- Energy changes

Applications and skills:

- Solving problems involving acceleration, velocity and displacement during simple harmonic motion, both graphically and algebraically
- Describing the interchange of kinetic and potential energy during simple harmonic motion
- Solving problems involving energy transfer during simple harmonic motion, both graphically and algebraically

Guidance

- Contexts for this sub-topic include the simple pendulum and a mass-spring system

Utilization:

- Fourier analysis allows us to describe all periodic oscillations in terms of simple harmonic oscillators. The mathematics of simple harmonic motion is crucial to any areas of science and technology where oscillations occur
- The interchange of energies in oscillation is important in electrical phenomena
- Quadratic functions (see *Mathematics HL* sub-topic *2.6*; *Mathematics SL* sub-topic *2.4*; *Mathematical studies SL* sub-topic *6.3*)
- Trigonometric functions (see *Mathematics SL* sub-topic *3.4*)

9.1 – Simple harmonic motion	
Data booklet reference: • $\omega = \frac{2\pi}{T}$ • $a = -\omega^2 x$ • $x = x_0 \sin \omega t;\ x = x_0 \cos \omega t$ • $v = \omega x_0 \cos \omega t;\ v = -\omega x_0 \sin \omega t$ • $v = \pm\omega\sqrt{\left(x_0^{\ 2} - x^2\right)}$ • $E_K = \frac{1}{2}m\omega^2\left(x_0^{\ 2} - x^2\right)$ • $E_T = \frac{1}{2}m\omega^2 x_0^{\ 2}$ • Pendulum: $T = 2\pi\sqrt{\frac{l}{g}}$ • Mass – spring: $T = 2\pi\sqrt{\frac{m}{k}}$	**Aims:** • **Aim 4:** students can use this topic to develop their ability to synthesize complex and diverse scientific information • **Aim 6:** experiments could include (but are not limited to): investigation of simple or torsional pendulums; measuring the vibrations of a tuning fork; further extensions of the experiments conducted in sub-topic 4.1. By using the force law, a student can, with iteration, determine the behaviour of an object under simple harmonic motion. The iterative approach (numerical solution), with given initial conditions, applies basic uniform acceleration equations in successive small time increments. At each increment, final values become the following initial conditions. • **Aim 7:** the observation of simple harmonic motion and the variables affected can be easily followed in computer simulations

Essential idea: Single-slit diffraction occurs when a wave is incident upon a slit of approximately the same size as the wavelength.

9.2 – Single-slit diffraction

Nature of science:

Development of theories: When light passes through an aperture the summation of all parts of the wave leads to an intensity pattern that is far removed from the geometrical shadow that simple theory predicts. (1.9)

Understandings:

- The nature of single-slit diffraction

Applications and skills:

- Describing the effect of slit width on the diffraction pattern
- Determining the position of first interference minimum
- Qualitatively describing single-slit diffraction patterns produced from white light and from a range of monochromatic light frequencies

Guidance:

- Only rectangular slits need to be considered
- Diffraction around an object (rather than through a slit) does not need to be considered in this sub-topic (see *Physics* sub-topic *4.4*)

Theory of knowledge:

- Are explanations in science different from explanations in other areas of knowledge such as history?

Utilization:

- X-ray diffraction is an important tool of the crystallographer and the material scientist

Aims:

- **Aim 2:** this topic provides a body of knowledge that characterizes the way that science is subject to modification with time
- **Aim 6:** experiments can be combined with those from sub-topics 4.4 and 9.3

9.2 – Single-slit diffraction	
• Students will be expected to be aware of the approximate ratios of successive intensity maxima for single-slit interference patterns • Calculations will be limited to a determination of the position of the first minimum for single-slit interference patterns using the approximation equation **Data booklet reference:** • $\theta = \frac{\lambda}{b}$	

Essential idea: Interference patterns from multiple slits and thin films produce accurately repeatable patterns.

9.3 – Interference

Nature of science:

Curiosity: Observed patterns of iridescence in animals, such as the shimmer of peacock feathers, led scientists to develop the theory of thin film interference. (1.5)

Serendipity: The first laboratory production of thin films was accidental. (1.5)

Understandings:

- Young's double-slit experiment
- Modulation of two-slit interference pattern by one-slit diffraction effect
- Multiple slit and diffraction grating interference patterns
- Thin film interference

Applications and skills:

- Qualitatively describing two-slit interference patterns, including modulation by one-slit diffraction effect
- Investigating Young's double-slit experimentally
- Sketching and interpreting intensity graphs of double-slit interference patterns
- Solving problems involving the diffraction grating equation
- Describing conditions necessary for constructive and destructive interference from thin films, including phase change at interface and effect of refractive index
- Solving problems involving interference from thin films

Theory of knowledge:

- Most two-slit interference descriptions can be made without reference to the one-slit modulation effect. To what level can scientists ignore parts of a model for simplicity and clarity?

Utilization:

- Compact discs are a commercial example of the use of diffraction gratings
- Thin films are used to produce anti-reflection coatings

Aims:

- **Aim 4:** two scientific concepts (diffraction and interference) come together in this sub-topic, allowing students to analyse and synthesize a wider range of scientific information
- **Aim 6:** experiments could include (but are not limited to): observing the use of diffraction gratings in spectroscopes; analysis of thin soap films; sound wave and microwave interference pattern analysis
- **Aim 9:** the ray approach to the description of thin film interference is only an approximation. Students should recognize the limitations of such a visualization

9.3 – Interference	
Guidance: • Students should be introduced to interference patterns from a variety of coherent sources such as (but not limited to) electromagnetic waves, sound and simulated demonstrations • Diffraction grating patterns are restricted to those formed at normal incidence • The treatment of thin film interference is confined to parallel-sided films at normal incidence • The constructive interference and destructive interference formulae listed below and in the data booklet apply to specific cases of phase changes at interfaces and are not generally true **Data booklet reference:** • $n\lambda = d \sin \theta$ • Constructive interference: $2dn = \left(m + \frac{1}{2}\right)\lambda$ • Destructive interference: $2dn = m\lambda$	

Essential idea: Resolution places an absolute limit on the extent to which an optical or other system can separate images of objects.

9.4 – Resolution

Nature of science:

Improved technology: The Rayleigh criterion is the limit of resolution. Continuing advancement in technology such as large diameter dishes or lenses or the use of smaller wavelength lasers pushes the limits of what we can resolve. (1.8)

Understandings:

- The size of a diffracting aperture
- The resolution of simple monochromatic two-source systems

Applications and skills:

- Solving problems involving the Rayleigh criterion for light emitted by two sources diffracted at a single slit
- Resolvance of diffraction gratings

Guidance:

- Proof of the diffraction grating resolvance equation is not required

Data booklet reference:

- $\theta = 1.22\dfrac{\lambda}{b}$
- $R = \dfrac{\lambda}{\Delta\lambda} = mN$

International-mindedness:

- Satellite use for commercial and political purposes is dictated by the resolution capabilities of the satellite

Theory of knowledge:

- The resolution limits set by Dawes and Rayleigh are capable of being surpassed by the construction of high quality telescopes. Are we capable of breaking other limits of scientific knowledge with our advancing technology?

Utilization:

- An optical or other reception system must be able to resolve the intended images. This has implications for satellite transmissions, radio astronomy and many other applications in physics and technology (see *Physics* option *C*)
- Storage media such as compact discs (and their variants) and CCD sensors rely on resolution limits to store and reproduce media accurately

Aims:

- **Aim 3:** this sub-topic helps bridge the gap between wave theory and real-life applications
- **Aim 8:** the need for communication between national communities via satellites raises the awareness of the social and economic implications of technology

Essential idea: The Doppler effect describes the phenomenon of wavelength/frequency shift when relative motion occurs.

9.5 – Doppler effect

Nature of science:

Technology: Although originally based on physical observations of the pitch of fast moving sources of sound, the Doppler effect has an important role in many different areas such as evidence for the expansion of the universe and generating images used in weather reports and in medicine. (5.5)

Understandings:

- The Doppler effect for sound waves and light waves

Applications and skills:

- Sketching and interpreting the Doppler effect when there is relative motion between source and observer
- Describing situations where the Doppler effect can be utilized
- Solving problems involving the change in frequency or wavelength observed due to the Doppler effect to determine the velocity of the source/observer

Guidance:

- For electromagnetic waves, the approximate equation should be used for all calculations
- Situations to be discussed should include the use of Doppler effect in radars and in medical physics, and its significance for the red-shift in the light spectra of receding galaxies

Data booklet reference:

- Moving source: $f' = f\left(\frac{v}{v \pm u_s}\right)$
- Moving observer: $f' = f\left(\frac{v \pm u_0}{v}\right)$
- $\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$

International-mindedness:

- Radar usage is affected by the Doppler effect and must be considered for applications using this technology

Theory of knowledge:

- How important is sense perception in explaining scientific ideas such as the Doppler effect?

Utilization:

- Astronomy relies on the analysis of the Doppler effect when dealing with fast moving objects (see *Physics* option *D*)

Aims:

- **Aim 2:** the Doppler effect needs to be considered in various applications of technology that utilize wave theory
- **Aim 6:** spectral data and images of receding galaxies are available from professional astronomical observatories for analysis
- **Aim 7:** computer simulations of the Doppler effect allow students to visualize complex and mostly unobservable situations