Module 7: The Nature of Light

NSW HSC Physics Year 12

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Module Overview

This module examines the dual nature of light through wave and quantum models, and introduces Einstein's special theory of relativity. Students explore how 20th-century discoveries revolutionised our understanding of light, time, and space.

Indicative Hours: 60 hours (combined with Depth Study)

Related Outcomes:

- **PH12-7** communicates scientific understanding using suitable language and terminology
- **PH12-14** describes and analyses evidence for the properties of light and evaluates the implications of this evidence for modern theories of physics

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Inquiry Questions

1. **What is light?**
2. **What evidence supports the classical wave model of light and what predictions can be made using this model?**
3. **What evidence supports the particle model of light and what are the implications for the quantum model?**
4. **How does the behaviour of light affect concepts of time, space and matter?**

Key Concepts

7.1 Electromagnetic Spectrum

> ℹ Learning Focus
>
> Understand Maxwell's electromagnetic theory and the nature of electromagnetic radiation.

Content:

- Investigate Maxwell's unification of electricity and magnetism
- Describe production and propagation of electromagnetic waves
- Investigate historical and contemporary methods of measuring the speed of light
- Use spectroscopy to identify elements and analyse stellar properties

Key Concepts:

- Maxwell's equations predict electromagnetic waves travelling at $c = 3 \times 10^8$ m/s
- EM waves are self-propagating oscillating electric and magnetic fields
- Speed of light is now defined: $c = 299,792,458$ m/s exactly

7.2 Light: Wave Model

Learning Focus

Analyse evidence supporting the wave nature of light through diffraction, interference, and polarisation.

Content:

- Investigate diffraction of light qualitatively
- Analyse interference using double slits and diffraction gratings
- Compare Newton's particle model with Huygens' wave model
- Investigate polarisation and Malus' Law

Key Formulas:

Quantity	Formula
Double slit/diffraction grating	$d \sin\theta = m\lambda$
Path difference (bright fringe)	$\Delta x = m\lambda$
Malus' Law	$I = I_{\max} \cos^2\theta$

7.3 Light: Quantum Model

Learning Focus

Analyse evidence for the particle nature of light and the photoelectric effect.

Content:

- Analyse black body radiation and Wien's Law
- Investigate the photoelectric effect
- Apply photon model to explain observations that wave theory cannot
- Calculate photon energy and kinetic energy of photoelectrons

Key Formulas:

Quantity	Formula
Wien's displacement law	$\lambda_{\max} = \frac{b}{T}$ where $b = 2.898 \times 10^{-3}$ m · K
Photon energy	$E = hf = \frac{hc}{\lambda}$
Photoelectric effect	$K_{\max} = hf - \phi$
Threshold frequency	$f_0 = \frac{\phi}{h}$

Planck's constant: $h = 6.626 \times 10^{-34}$ J $\cdot$ s

7.4 Light and Special Relativity

> **Learning Focus**
>
> Apply Einstein's special relativity to analyse time dilation, length contraction, and mass-energy equivalence.

Content:

- Analyse Einstein's two postulates of special relativity
- Investigate evidence for time dilation and length contraction
- Apply relativistic formulas to muon observations, atomic clocks, particle accelerators
- Calculate relativistic momentum and mass-energy equivalence

Key Formulas:

Quantity	Formula
Lorentz factor	$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
Time dilation	$t = \gamma t_0 = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$
Length contraction	$l = \frac{l_0}{\gamma} = l_0\sqrt{1-\frac{v^2}{c^2}}$
Relativistic momentum	$p = \gamma m_0 v = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}}$
Mass-energy equivalence	$E = mc^2$
Total relativistic energy	$E = \gamma m_0 c^2$

Einstein's Postulates:

1. The laws of physics are the same in all inertial reference frames
2. The speed of light in a vacuum is constant (c) for all observers, regardless of motion

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Working Scientifically

Practical Investigations

1. **Double Slit Interference**
    - Measure wavelength of laser light using $d \sin \theta = m\lambda$
    - Observe interference pattern formation
2. **Diffraction Grating Spectroscopy**
    - Analyse spectra from discharge tubes
    - Identify elements from emission spectra
3. **Polarisation Investigation**
    - Verify Malus' Law using polarising filters
    - Demonstrate polarisation by reflection
4. **Speed of Light Methods**
    - Research historical measurements (Rømer, Fizeau, Michelson)
    - Understand modern definition and measurement

HSC Exam Coverage

This module is consistently assessed across all question types. Key areas:

- Wave interference calculations (4-5 marks)
- Photoelectric effect analysis (5-7 marks)
- Special relativity calculations and concepts (6-9 marks)
- Comparing wave and particle models (5-7 marks)

Practice Resources

- Module 7 Quiz
- Nature of Light Worksheet
- Past HSC Questions - Module 7

Key Definitions

Electromagnetic Spectrum The complete range of electromagnetic radiation from radio waves to gamma rays.

Diffraction The spreading of waves as they pass through an aperture or around an obstacle.

Interference The superposition of two or more waves resulting in a combined wave pattern.

Polarisation The restriction of wave oscillations to a single plane.

Photoelectric Effect The emission of electrons from a metal surface when illuminated by light above a threshold frequency.

Work Function The minimum energy required to remove an electron from a metal surface.

Time Dilation The slowing of time for a moving observer relative to a stationary observer.

Length Contraction The shortening of length in the direction of motion for a moving object.

Proper Time The time interval measured by an observer at rest relative to the events.

Proper Length The length measured by an observer at rest relative to the object.