Module 8: From the Universe to the Atom

NSW HSC Physics Year 12

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Module Overview

This module explores the origins of the Universe and elements through cosmology and nucleosynthesis, then traces the development of atomic models from Thomson to the quantum mechanical model.

Indicative Hours: 60 hours (combined with Depth Study)

Related Outcomes:

- **PH12-6** solves scientific problems using primary and secondary data, critical thinking skills and scientific processes
- **PH12-7** communicates scientific understanding using suitable language and terminology
- **PH12-15** explains and analyses the evidence supporting the relationship between astronomical events and nucleosynthesis, and the development of the current atomic model

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Inquiry Questions

1. **What evidence is there for the origins of the elements?**
2. **How is it known that atoms are made up of protons, neutrons and electrons?**
3. **How is it known that classical physics cannot explain the properties of the atom?**
4. **How can the energy of the atomic nucleus be harnessed?**

Key Concepts

8.1 Origins of the Elements

> **Learning Focus**
>
> Investigate cosmological evidence for the Big Bang and stellar nucleosynthesis.

Content:

- Investigate the transformation of radiation into matter after the Big Bang
- Analyse Hubble's evidence for the expanding Universe
- Apply mass-energy equivalence to stellar nuclear reactions
- Compare emission, absorption, and black body spectra
- Use stellar spectra to classify stars
- Analyse the Hertzsprung-Russell diagram

Key Concepts:

Feature	Description
Hubble's Law	$v = H_0 d$ (velocity distance)
Redshift	Evidence for expansion
CMB	Cosmic Microwave Background - remnant radiation
H-R Diagram	Luminosity vs temperature classification

Nucleosynthesis Processes:

- **Proton-proton chain**: Main sequence stars (like Sun) - H → He
- **CNO cycle**: Hotter main sequence stars - H → He catalysed by C, N, O
- **Triple-alpha process**: Red giants - He → C
- **Supernova nucleosynthesis**: Elements heavier than iron

8.2 Structure of the Atom

> **i** Learning Focus
>
> Investigate experimental evidence for subatomic particles and the nuclear model.

Content:

- Investigate cathode ray experiments
- Analyse Thomson's charge-to-mass experiment
- Evaluate Millikan's oil drop experiment
- Investigate the Geiger-Marsden (gold foil) experiment
- Assess Rutherford's nuclear model
- Understand Chadwick's discovery of the neutron

Key Historical Experiments:

Experiment	Scientist	Discovery
Cathode rays	Crookes, Perrin	Electrons as particles
Charge/mass ratio	Thomson	q/m for electron
Oil drop	Millikan	Quantised electron charge
Gold foil	Geiger-Marsden	Nuclear model
Neutron discovery	Chadwick	Neutral nuclear particle

8.3 Quantum Mechanical Nature of the Atom

> **i** Learning Focus
>
> Trace the development from Bohr's model to quantum mechanics.

Content:

- Assess limitations of Rutherford and Bohr models
- Investigate hydrogen line emission spectra (Balmer series)
- Relate quantised energy levels to spectral lines
- Investigate de Broglie's matter waves

- Analyse Schrödinger's contribution to the atomic model

Key Formulas:

Quantity	Formula
Photon energy	$E = hf = \frac{hc}{\lambda}$
Rydberg formula	$\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$
de Broglie wavelength	$\lambda = \frac{h}{mv} = \frac{h}{p}$
Bohr energy levels	$E_n = \frac{-13.6}{n^2}$ eV

Rydberg constant: $R = 1.097 \times 10^{7}\ \text{m}^{\ 1}$

8.4 Properties of the Nucleus

> **Learning Focus**
>
> Analyse radioactive decay, nuclear fission, and nuclear fusion.

Content:

- Analyse alpha, beta, and gamma radiation properties
- Apply half-life and decay constant relationships
- Model nuclear fission and chain reactions
- Analyse mass-energy conservation in nuclear reactions
- Account for energy release in nuclear fusion

Key Formulas:

Quantity	Formula
Radioactive decay	$N_t = N_0 e^{-\lambda t}$
Decay constant	$\lambda = \frac{\ln 2}{t_{1/2}}$
Mass defect energy	$E = \Delta m \cdot c^2$
Activity	$A = \lambda N$
Half-life relation	$N_t = N_0 \left(\frac{1}{2}\right)^{t/t_{1/2}}$

Radiation Properties:

Type	Nature	Penetration	Ionising	Deflection
Alpha ( )	^{2}He nucleus	Paper stops	High	Positive
Beta ( )	Electron	mm Al stops	Medium	Negative
Gamma ( )	EM radiation	cm Pb reduces	Low	None

Working Scientifically

Practical Investigations

1. **Spectroscopy**
   - Observe emission spectra from discharge tubes
   - Identify elements from characteristic spectral lines
   - Compare continuous and line spectra
2. **Half-Life Simulation**
   - Model radioactive decay using dice or coins
   - Graph decay curves and determine half-life
   - Compare with theoretical predictions
3. **Historical Experiments Analysis**
   - Research and present on key atomic structure experiments
   - Evaluate evidence and conclusions from each

HSC Exam Coverage

This module features prominently in extended response questions:

- Big Bang and nucleosynthesis evidence (5-7 marks)
- Atomic model development (6-8 marks)
- Spectral analysis calculations (4-6 marks)
- Nuclear physics calculations (5-7 marks)

Practice Resources

- Module 8 Quiz
- Universe to Atom Worksheet
- Past HSC Questions - Module 8

Key Definitions

Big Bang The cosmological model describing the origin of the Universe from an extremely hot, dense state.

Nucleosynthesis The process of creating new atomic nuclei from pre-existing nucleons (protons and neutrons).

Hertzsprung-Russell Diagram A graph plotting stellar luminosity against surface temperature used to classify stars.

Main Sequence The band on the H-R diagram where stars spend most of their lifetime fusing hydrogen.

Balmer Series The series of hydrogen emission lines in the visible spectrum.

de Broglie Wavelength The wavelength associated with a moving particle due to wave-particle duality.

Half-Life The time required for half of a radioactive sample to decay.

Decay Constant The probability per unit time that a nucleus will decay.

Mass Defect The difference between the mass of a nucleus and the sum of its individual nucleons.

Binding Energy The energy required to completely separate a nucleus into its constituent nucleons.

Nuclear Fission The splitting of a heavy nucleus into lighter nuclei with release of energy.

Nuclear Fusion The combining of light nuclei to form a heavier nucleus with release of energy.