

## Topic 12: Quantum and nuclear physics

16 hours

**Essential idea:** The microscopic quantum world offers a range of phenomena, the interpretation and explanation of which require new ideas and concepts not found in the classical world.

### 12.1 – The interaction of matter with radiation

#### Nature of science:

Observations: Much of the work towards a quantum theory of atoms was guided by the need to explain the observed patterns in atomic spectra. The first quantum model of matter is the Bohr model for hydrogen. (1.8)

Paradigm shift: The acceptance of the wave–particle duality paradox for light and particles required scientists in many fields to view research from new perspectives. (2.3)

#### Understandings:

- Photons
- The photoelectric effect
- Matter waves
- Pair production and pair annihilation
- Quantization of angular momentum in the Bohr model for hydrogen
- The wave function
- The uncertainty principle for energy and time and position and momentum
- Tunnelling, potential barrier and factors affecting tunnelling probability

#### Theory of knowledge:

- The duality of matter and tunnelling are cases where the laws of classical physics are violated. To what extent have advances in technology enabled paradigm shifts in science?

#### Utilization:

- The electron microscope and the tunnelling electron microscope rely on the findings from studies in quantum physics
- Probability is treated in a mathematical sense in *Mathematical studies SL* sub-topics 3.6–3.7

## 12.1 – The interaction of matter with radiation

### Applications and skills:

- Discussing the photoelectric effect experiment and explaining which features of the experiment cannot be explained by the classical wave theory of light
- Solving photoelectric problems both graphically and algebraically
- Discussing experimental evidence for matter waves, including an experiment in which the wave nature of electrons is evident
- Stating order of magnitude estimates from the uncertainty principle

### Guidance:

- The order of magnitude estimates from the uncertainty principle may include (but is not limited to) estimates of the energy of the ground state of an atom, the impossibility of an electron existing within a nucleus, and the lifetime of an electron in an excited energy state
- Tunnelling to be treated qualitatively using the idea of continuity of wave functions

### Data booklet reference:

- $E = hf$
- $E_{\max} = hf - \Phi$
- $E = -\frac{13.6}{n^2} eV$
- $mvr = \frac{nh}{2\pi}$
- $P(r) = |\Psi|^2 \Delta V$
- $\Delta x \Delta p \geq \frac{h}{4\pi}$
- $\Delta E \Delta t \geq \frac{h}{4\pi}$

### Aims:

- **Aim 1:** study of quantum phenomena introduces students to an exciting new world that is not experienced at the macroscopic level. The study of tunneling is a novel phenomenon not observed in macroscopic physics.
- **Aim 6:** the photoelectric effect can be investigated using LEDs
- **Aim 9:** the Bohr model is very successful with hydrogen but not of any use for other elements

**Essential idea:** The idea of discreteness that we met in the atomic world continues to exist in the nuclear world as well.

## 12.2 – Nuclear physics

### Nature of science:

Theoretical advances and inspiration: Progress in atomic, nuclear and particle physics often came from theoretical advances and strokes of inspiration.

Advances in instrumentation: New ways of detecting subatomic particles due to advances in electronic technology were also crucial.

Modern computing power: Finally, the analysis of the data gathered in modern particle detectors in particle accelerator experiments would be impossible without modern computing power. (1.8)

### Understandings:

- Rutherford scattering and nuclear radius
- Nuclear energy levels
- The neutrino
- The law of radioactive decay and the decay constant

### Applications and skills:

- Describing a scattering experiment including location of minimum intensity for the diffracted particles based on their de Broglie wavelength
- Explaining deviations from Rutherford scattering in high energy experiments
- Describing experimental evidence for nuclear energy levels
- Solving problems involving the radioactive decay law for arbitrary time intervals
- Explaining the methods for measuring short and long half-lives

### Theory of knowledge:

- Much of the knowledge about subatomic particles is based on the models one uses to interpret the data from experiments. How can we be sure that we are discovering an “independent truth” not influenced by our models? Is there such a thing as a single truth?

### Utilization:

- Knowledge of radioactivity, radioactive substances and the radioactive decay law are crucial in modern nuclear medicine (see *Physics* option sub-topic C.4)

### Aims:

- **Aim 2:** detection of the neutrino demonstrates the continuing growing body of knowledge scientists are gathering in this area of study

## 12.2 – Nuclear physics

### Guidance:

- Students should be aware that nuclear densities are approximately the same for all nuclei and that the only macroscopic objects with the same density as nuclei are neutron stars
- The small angle approximation is usually not appropriate to use to determine the location of the minimum intensity

### Data booklet reference:

- $R = R_0 A^{1/3}$
- $N = N_0 e^{-\lambda t}$
- $A = \lambda N_0 e^{-\lambda t}$
- $\sin \theta \approx \frac{\lambda}{D}$