Topic 7: Atomic, nuclear and particle physics

14 hours

Essential idea: In the microscopic world energy is discrete.

7.1 – Discrete energy and radioactivity	
Nature of science: Accidental discovery: Radioactivity was discovered by accident when Becquerel developed photographic film that had accidentally been exposed to radiation from radioactive rocks. The marks on the photographic film seen by Becquerel probably would not lead to anything further for most people. What Becquerel did was to correlate the presence of the marks with the presence of the radioactive rocks and investigate the situation further. (1.4)	
Understandings: • Discrete energy and discrete energy levels • Transitions between energy levels • Radioactive decay • Fundamental forces and their properties • Alpha particles, beta particles and gamma rays • Half-life • Absorption characteristics of decay particles • Isotopes • Background radiation	**International-mindedness:** • The geopolitics of the past 60+ years have been greatly influenced by the existence of nuclear weapons **Theory of knowledge:** • The role of luck/serendipity in successful scientific discovery is almost inevitably accompanied by a scientifically curious mind that will pursue the outcome of the "lucky" event. To what extent might scientific discoveries that have been described as being the result of luck actually be better described as being the result of reason or intuition?

7.1 – Discrete energy and radioactivity

Applications and skills:

- Describing the emission and absorption spectrum of common gases
- Solving problems involving atomic spectra, including calculating the wavelength of photons emitted during atomic transitions
- Completing decay equations for alpha and beta decay
- Determining the half-life of a nuclide from a decay curve
- Investigating half-life experimentally (or by simulation)

Guidance:

- Students will be required to solve problems on radioactive decay involving only integral numbers of half-lives
- Students will be expected to include the neutrino and antineutrino in beta decay equations

Data booklet reference:

- $E = hf$
- $\lambda = \frac{hc}{E}$

Utilization:

- Knowledge of radioactivity, radioactive substances and the radioactive decay law are crucial in modern nuclear medicine
- How to deal with the radioactive output of nuclear decay is important in the debate over nuclear power stations (see *Physics* sub-topic *8.1*)
- Carbon dating is used in providing evidence for evolution (see *Biology* sub-topic *5.1*)
- Exponential functions (see *Mathematical studies SL* sub-topic *6.4*; *Mathematics HL* sub-topic *2.4*)

Aims:

- **Aim 8:** the use of radioactive materials poses environmental dangers that must be addressed at all stages of research
- **Aim 9:** the use of radioactive materials requires the development of safe experimental practices and methods for handling radioactive materials

Essential idea: Energy can be released in nuclear decays and reactions as a result of the relationship between mass and energy.

7.2 – Nuclear reactions

Nature of science:

Patterns, trends and discrepancies: Graphs of binding energy per nucleon and of neutron number versus proton number reveal unmistakable patterns. This allows scientists to make predictions of isotope characteristics based on these graphs. (3.1)

Understandings:

- The unified atomic mass unit
- Mass defect and nuclear binding energy
- Nuclear fission and nuclear fusion

Applications and skills:

- Solving problems involving mass defect and binding energy
- Solving problems involving the energy released in radioactive decay, nuclear fission and nuclear fusion
- Sketching and interpreting the general shape of the curve of average binding energy per nucleon against nucleon number

Theory of knowledge:

- The acceptance that mass and energy are equivalent was a major paradigm shift in physics. How have other paradigm shifts changed the direction of science? Have there been similar paradigm shifts in other areas of knowledge?

Utilization:

- Our understanding of the energetics of the nucleus has led to ways to produce electricity from nuclei but also to the development of very destructive weapons
- The chemistry of nuclear reactions (see *Chemistry* option sub-topics *C.3* and *C.7*)

7.2 – Nuclear reactions	
Guidance: • Students must be able to calculate changes in terms of mass or binding energy • Binding energy may be defined in terms of energy required to completely separate the nucleons or the energy released when a nucleus is formed from its nucleons **Data booklet reference:** • $\Delta E = \Delta m\, c^2$	**Aims:** • **Aim 5:** some of the issues raised by the use of nuclear power transcend national boundaries and require the collaboration of scientists from many different nations • **Aim 8:** the development of nuclear power and nuclear weapons raises very serious moral and ethical questions: who should be allowed to possess nuclear power and nuclear weapons and who should make these decisions? There also serious environmental issues associated with the nuclear waste of nuclear power plants.

Essential idea: It is believed that all the matter around us is made up of fundamental particles called quarks and leptons. It is known that matter has a hierarchical structure with quarks making up nucleons, nucleons making up nuclei, nuclei and electrons making up atoms and atoms making up molecules. In this hierarchical structure, the smallest scale is seen for quarks and leptons (10^{-18}m).

7.3 – The structure of matter

Nature of science:

Predictions: Our present understanding of matter is called the Standard Model, consisting of six quarks and six leptons. Quarks were postulated on a completely mathematical basis in order to explain patterns in properties of particles. (1.9)

Collaboration: It was much later that large-scale collaborative experimentation led to the discovery of the predicted fundamental particles. (4.3)

Understandings:

- Quarks, leptons and their antiparticles
- Hadrons, baryons and mesons
- The conservation laws of charge, baryon number, lepton number and strangeness
- The nature and range of the strong nuclear force, weak nuclear force and electromagnetic force
- Exchange particles
- Feynman diagrams
- Confinement
- The Higgs boson

Applications and skills:

- Describing the Rutherford-Geiger-Marsden experiment that led to the discovery of the nucleus
- Applying conservation laws in particle reactions
- Describing protons and neutrons in terms of quarks
- Comparing the interaction strengths of the fundamental forces, including gravity
- Describing the mediation of the fundamental forces through exchange particles

International-mindedness:

- Research into particle physics requires ever-increasing funding, leading to debates in governments and international research organizations on the fair allocation of precious financial resources

Theory of knowledge:

- Does the belief in the existence of fundamental particles mean that it is justifiable to see physics as being more important than other areas of knowledge?

Utilization:

- An understanding of particle physics is needed to determine the final fate of the universe (see *Physics* option sub-topics *D.3* and *D.4*)

Aims:

- **Aim 1:** the research that deals with the fundamental structure of matter is international in nature and is a challenging and stimulating adventure for those who take part
- **Aim 4:** particle physics involves the analysis and evaluation of very large amounts of data
- **Aim 6:** students could investigate the scattering angle of alpha particles as a function of the aiming error, or the minimum distance of approach as a function of the initial kinetic energy of the alpha particle

7.3 – The structure of matter

- Sketching and interpreting simple Feynman diagrams
- Describing why free quarks are not observed

Guidance:

- A qualitative description of the standard model is required

Data booklet reference:

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$
All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1				

Charge	Leptons		
–1	e	μ	τ
0	υ_e	υ_μ	υ_τ
All leptons have a lepton number of 1 and antileptons have a lepton number of –1			

	Gravitational	Weak	Electromagnetic	Strong
Particles experiencing	All	Quarks, leptons	Charged	Quarks, gluons
Par ticles mediating	Graviton	W^+, W^-, Z^0	γ	Gluons

- **Aim 8:** scientific and government organizations are asked if the funding for particle physics research could be spent on other research or social needs