3.5 Unit 5 PHA5A-5D Nuclear Physics, Thermal Physics and an Optional Topic

This unit consists of two sections. The first part of Section A 'Nuclear and Thermal Physics' looks at the characteristics of the nucleus, the properties of unstable nuclei and how energy is obtained from the nucleus. In the second part of Section A, the thermal properties of materials and the properties and nature of gases are studied in depth.

Section B offers an opportunity to study one of the following optional topics to gain deeper understanding and awareness of a selected branch of physics:

A Astronomy and cosmology

B Medical Physics

C Applied Physics

D Turning Points in Physics.

Nuclear and Thermal Physics

3.5.1 Radioactivity

- **Evidence for the nucleus**

  Qualitative study of Rutherford scattering.

- **α, β and γ radiation**

  Their properties and experimental identification using simple absorption experiments; applications e.g. to relative hazards of exposure to humans.

  The inverse square law for γ radiation, $I = \frac{k}{x^2}$

  including its experimental verification; applications, e.g. to safe handling of radioactive sources.

  Background radiation; examples of its origins and experimental elimination from calculations.

- **Radioactive decay**

  Random nature of radioactive decay; constant decay probability of a given nucleus;

  $$\frac{\Delta N}{\Delta t} = -\lambda N, \quad N = N_0 e^{-\lambda t}$$

  Use of activity $A = \lambda N$

  Half life, $T_{1/2} = \frac{\ln 2}{\lambda}$; determination from

  graphical decay data including decay curves and log graphs; applications e.g. relevance to storage of radioactive waste, radioactive dating.

- **Nuclear instability**

  Graph of N against Z for stable nuclei.

  Possible decay modes of unstable nuclei including α, β^+, β^- and electron capture.

  Changes of N and Z caused by radioactive decay and representation in simple decay equations.

  Existence of nuclear excited states; γ ray emission; application e.g. use of technetium-99m as a γ source in medical diagnosis.

- ### Nuclear radius

Estimate of radius from closest approach of alpha particles and determination of radius from electron diffraction; knowledge of typical values.

Dependence of radius on nucleon number

$$R = r_0 A^{1/3}$$

derived from experimental data.

Calculation of nuclear density.

3.5.2 Nuclear Energy

- ### Mass and energy

Appreciation that $E = mc^2$ applies to all energy changes.

Simple calculations on mass difference and binding energy.

Atomic mass unit, u; conversion of units;

$$1 \text{ u} = 931.3 \text{ MeV}$$

Graph of average binding energy per nucleon against nucleon number.

Fission and fusion processes.

Simple calculations from nuclear masses of energy released in fission and fusion reactions.

- ### Induced fission

Induced fission by thermal neutrons; possibility of a chain reaction; critical mass.

The functions of the moderator, the control rods and the coolant in a thermal nuclear reactor; factors affecting the choice of materials for the moderator, the control rods and the coolant and examples of materials used; details of particular reactors are not required.

- ### Safety aspects

Fuel used, shielding, emergency shut-down.

Production, handling and storage of radioactive waste materials.

3.5.3 Thermal Physics

- ### Thermal energy

Calculations involving change of energy.

For a change of temperature; $Q = mc\Delta T$, where c is specific heat capacity.

For a change of state; $Q = m\,l$, where l is specific latent heat.

- ### Ideal gases

Gas laws as experimental relationships between p, V, T and mass.

Concept of absolute zero of temperature.

Ideal gas equation as $pV = nRT$ for n moles and as $pV = NkT$ for N molecules.

Avogadro constant N_A, molar gas constant R, Boltzmann constant k.

Molar mass and molecular mass.

- **Molecular kinetic theory model**

  Explanation of relationships between p, V and T in terms of a simple molecular model.

  Assumptions leading to and derivation of

  $$pV = \frac{1}{3} N m (c_{rms})^2$$

  Average molecular kinetic energy

  $$\frac{1}{2} m (c_{rms})^2 = \frac{3}{2} kT = \frac{3RT}{2 N_A}$$