3.1 Unit 1 PHYA1 Particles, Quantum Phenomena and Electricity

This unit involves two contrasting topics in physics: particle physics and electricity. Through the study of these topics, students should gain an awareness of the on-going development of new ideas in physics and of the application of in-depth knowledge of well-established topics such as electricity. Particle physics introduces students to the fundamental properties and nature of matter, radiation and quantum phenomena. In contrast, the study of electricity in this module builds on and develops previous GCSE studies and provides opportunities for practical work and looks into important applications.

3.1.1 Particles and Radiation

- #### Constituents of the atom

  Proton, neutron, electron.

  Their charge and mass in SI units and relative units. Specific charge of nuclei and of ions. Atomic mass unit is not required.

  Proton number Z, nucleon number A, nuclide notation, isotopes

- #### Stable and unstable nuclei

  The strong nuclear force; its role in keeping the nucleus stable; short-range attraction to about 3 fm, very-short range repulsion below about 0.5 fm.

  Equations for alpha decay and β^- decay including the antineutrino.

- #### Particles, antiparticles and photons

  Candidates should know that for every type of particle, there is a corresponding antiparticle. They should know that the positron, the antiproton, the antineutron and the antineutrino are the antiparticles of the electron, the proton, the neutron and the neutrino, respectively.

  Comparison of particle and antiparticle masses, charge and rest energy in MeV

  Photon model of electromagnetic radiation, the Planck constant,

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

  Knowledge of annihilation and pair production processes and the respective energies involved. The use of $E = mc^2$ is not required in calculations.

- #### Particle interactions

  Concept of exchange particles to explain forces between elementary particles.

  The electromagnetic force; virtual photons as the exchange particle.

  The weak interaction limited β^-, β^+ decay, electron capture and electron-proton collisions; W^+ and W^- as the exchange particles.

  Simple Feynman diagrams to represent the above reactions or interactions in terms of particles going in and out and exchange particles.

- #### Classification of particles

  Hadrons: baryons (proton, neutron) and antibaryons (antiproton and antineutron) and mesons (pion, kaon).

  Hadrons are subject to the strong nuclear force.

  Candidates should know that the proton is the only stable baryon into which other baryons eventually decay; in particular, the decay of the neutron should be known.

  Leptons: electron, muon, neutrino (electron and muon types).

  Leptons are subject to the weak interaction.

  Candidates will be expected to know baryon numbers for the hadrons. Lepton numbers for the leptons will be given in the data booklet.

- ### Quarks and antiquarks

Up (u), down (d) and strange (s) quarks only.

Properties of quarks: charge, baryon number and strangeness.

Combinations of quarks and antiquarks required for baryons (proton and neutron only), antibaryons (antiproton and antineutron only) and mesons (pion and kaon) only.

Change of quark character in β^- and β^+ decay.

Application of the conservation laws for charge, baryon number, lepton number and strangeness to particle interactions. The necessary data will be provided in questions for particles outside those specified.

3.1.2 Electromagnetic Radiation and Quantum Phenomena

- ### The photoelectric effect

Work function ϕ, threshold frequency f_o, photoelectric equation $hf = \phi + E_k$; the stopping potential experiment is not required.

3

- ### Collisions of electrons with atoms

The electron volt.

Ionisation and excitation; understanding of ionisation and excitation in the fluorescent tube.

- ### Energy levels and photon emission

Line spectra (e.g. of atomic hydrogen) as evidence of transitions between discrete energy levels in atoms.

$hf = E_1 - E_2$

- ### Wave-particle duality

Candidates should know that electron diffraction suggests the wave nature of particles and the photoelectric effect suggests the particle nature of electromagnetic waves; details of particular methods of particle diffraction are not expected.

de Broglie wavelength $\lambda = \dfrac{h}{mv}$,

where mv is the momentum.

3.1.3 Current Electricity

- ### Charge, current and potential difference

Electric current as the rate of flow of charge; potential difference as work done per unit charge.

$$I = \frac{\Delta Q}{\Delta t} \text{ and } V = \frac{W}{Q}$$

Resistance is defined by $R = \dfrac{V}{I}$

- ### Current/voltage characteristics

For an ohmic conductor, a semiconductor diode and a filament lamp; candidates should have experience of the use of a current sensor and a voltage sensor with a data logger to capture data from which to determine $I - V$ curves.

Ohm's law as a special case where $I \propto V$

- ## Resistivity

$$\rho = \frac{RA}{L}$$

Description of the qualitative effect of temperature on the resistance of metal conductors and thermistors. Applications (e.g. temperature sensors).

Superconductivity as a property of certain materials which have zero resistivity at and below a critical temperature which depends on the material. Applications (e.g. very strong electromagnets, power cables).

- ## Circuits

Resistors in series; $R = R_1 + R_2 + R_3 + ...$

Resistors in parallel;

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

3

energy $E = I\,V\,t$, $P = IV$, $P = I^2R$; application, e.g. Understanding of high current requirement for a starter motor in a motor car.

Conservation of charge and energy in simple dc circuits.

The relationships between currents, voltages and resistances in series and parallel circuits, including cells in series and identical cells in parallel.

Questions will not be set which require the use of simultaneous equations to calculate currents or potential differences.

- ## Potential divider

The potential divider used to supply variable pd e.g. application as an audio 'volume' control.

Examples should include the use of variable resistors, thermistors and L.D.R.'s. The use of the potentiometer as a measuring instrument is not required.

- ## Electromotive force and internal resistance

$$\varepsilon = \frac{E}{Q} \qquad \varepsilon = I\,(R + r)$$

Applications; e.g. low internal resistance for a car battery.

- ## Alternating currents

Sinusoidal voltages and currents only; root mean square, peak and peak-to-peak values for sinusoidal waveforms only.

$$I_{rms} = \frac{I_0}{\sqrt{2}} \qquad V_{rms} = \frac{V_0}{\sqrt{2}}$$

Application to calculation of mains electricity peak and peak-to-peak voltage values.

- ## Oscilloscope

Use of an oscilloscope as a dc and ac voltmeter, to measure time intervals and frequencies and to display a.c. waveforms. No details of the structure of the instrument is required but familiarity with the operation of the controls is expected.