3.4 Unit 4 PHYA4 Fields and Further Mechanics

This is the first A2 unit, building on the key ideas and knowledge covered in AS Physics. The first section advances the study of momentum and introduces circular and oscillatory motion and covers gravitation. Electric and magnetic fields are covered, together with basic electromagnetic induction. Electric fields leads into capacitors and how quickly they charge and discharge through a resistor. Magnetic fields leads into the generation and transmission of alternating current.

3.4.1 Further Mechanics

3

• Momentum concepts

Force as the rate of change of momentum

$$F = \frac{\Delta(mv)}{\Delta t}$$

Impulse $F\Delta t = \Delta(mv)$

Significance of area under a force-time graph.

Principle of conservation of linear momentum applied to problems in one dimension.

Elastic and inelastic collisions; explosions.

• Circular motion

Motion in a circular path at constant speed implies there is an acceleration and requires a centripetal force.

Angular speed $\omega = \frac{v}{r} = 2\pi f$

Centripetal acceleration $a = \frac{v^2}{r} = \omega^2 r$

Centripetal force $F = \frac{mv^2}{r} = m\omega^2 r$

The derivation of $a = v^2/r$ will not be examined.

• Simple harmonic motion

Characteristic features of simple harmonic motion.

Condition for shm: $a = -(2\pi f)^2 x$

$$x = A\cos 2\pi ft \quad \text{and} \quad v = \pm 2\pi f\sqrt{A^2 - x^2}$$

Graphical representations linking x, v, a and t.

Velocity as gradient of displacement-time graph.

Maximum speed = $2\pi fA$

Maximum acceleration = $(2\pi f)^2 A$

• Simple harmonic systems

Study of mass-spring system.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Study of simple pendulum.

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Variation of E_k, E_p and total energy with displacement, and with time.

- **Forced vibrations and resonance**

  Qualitative treatment of free and forced vibrations.

  Resonance and the effects of damping on the sharpness of resonance.

  Phase difference between driver and driven displacements.

  Examples of these effects in mechanical systems and stationary wave situations.

3.4.2 Gravitation

- **Newton's law**

  Gravity as a universal attractive force acting between all matter.

  Force between point masses

  $$F = \frac{Gm_1 m_2}{r^2},$$

  where G is the gravitational constant.

- **Gravitational field strength**

  Concept of a force field as a region in which a body experiences a force.

  Representation by gravitational field lines.

  g as force per unit mass defined by $g = \frac{F}{m}$

  Magnitude of g in a radial field given by $g = \frac{GM}{r^2}$

- **Gravitational potential**

  Understanding of the definition of gravitational potential, including zero value at infinity, and of gravitational potential difference.

  Work done in moving mass m given by

  $$\Delta W = m\,\Delta V$$

  Gravitational potential V in a radial field given by

  $$V = -\frac{GM}{r}$$

  Graphical representations of variations of g and V with r.

  V related to g by $g = -\frac{\Delta V}{\Delta r}$

- **Orbits of planets and satellites**

  Orbital period and speed related to radius of circular orbit.

  Energy considerations for an orbiting satellite.

  Significance of a geosynchronous orbit.

3.4.3 Electric Fields

- **Coulomb's law**

  Force between point charges in a vacuum

  $$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2},$$

  where ε_0 is the permittivity of free space.

- **Electric field strength**

  E as force per unit charge defined by $E = \frac{F}{Q}$

  Representation by electric field lines.

  Magnitude of E in a radial field given by

  $$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

  Magnitude of E in a uniform field given by

  $$E = \frac{V}{d}$$

- **Electric potential**

  Understanding of definition of absolute electric potential, including zero value at infinity, and of electric potential difference.

  Work done in moving charge Q given by

  $$\Delta W = Q\,\Delta V$$

  Magnitude of V in a radial field given by

  $$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

  Graphical representations of variations of E and V with r.

- **Comparison of electric and gravitational fields**

  Similarities; inverse square law fields having many characteristics in common.

  Differences; masses always attract but charges may attract or repel.

3

3.4.4 Capacitance

- **Capacitance**

  Definition of capacitance;

  $$C = \frac{Q}{V}$$

- **Energy stored by a capacitor**

  Derivation of $E = \frac{1}{2}QV$ and interpretation of area under a graph of charge against pd

  $$E = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \tfrac{1}{2}Q^2/C$$

- **Capacitor discharge**

  Graphical representation of charging and discharging of capacitors through resistors

  Time constant = RC

  Calculation of time constants including their determination from graphical data.

  Quantitative treatment of capacitor discharge

  $$Q = Q_o e^{-t/RC}$$

  Candidates should have experience of the use of a voltage sensor and datalogger to plot discharge curves for a capacitor.

3.4.5 Magnetic Fields

- ### Magnetic flux density

Force on a current-carrying wire in a magnetic field.
$F = B\,I\,l$, when field is perpendicular to current.
Fleming's left hand rule.
Magnetic flux density B and definition of the tesla.

- ### Moving charges in a magnetic field

Force on charged particles moving in a magnetic field.
$F = B\,Q\,v$, when the field is perpendicular to velocity.
Circular path of particles; application in devices such as the cyclotron.

- ### Magnetic flux and flux linkage

Magnetic flux defined by $\Phi = BA$, where B is normal to A.
Flux linkage as $N\Phi$, where N is the number of turns cutting the flux.
Flux and flux linkage passing through a rectangular coil rotated in a magnetic field:
flux linkage $N\Phi = BAN\cos\theta$ where θ is the angle between the normal to the plane of the coil and the magnetic field.

- ### Electromagnetic induction

Simple experimental phenomena.
Faraday's and Lenz's laws.
Magnitude of induced emf = rate of change of flux linkage = $N\dfrac{\Delta\phi}{\Delta t}$

Applications such as a moving straight conductor.
Emf induced in a coil rotating uniformly in a magnetic field:

$E = BAN\omega\sin\,\omega t$
The operation of a transformer;

The transformer equation = $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$

Transformer efficiency = $I_s\,V_s\,/\,I_p\,V_p$
Causes of inefficiency of a transformer.
Transmission of electrical power at high voltage.

3