Topic 1: Measurement and uncertainties

1.1 Measurements - Understandings:

- Fundamental and derived SI units
- Scientific notation and metric multipliers
- Significant figures
- Orders of magnitude
- Estimation

Applications and skills:

- Using SI units in the correct format for all required measurements, final answers to calculations and presentation of raw and processed data
- Using scientific notation and metric multipliers
- Quoting and comparing ratios, values and approximations to the nearest order of magnitude
- Estimating quantities to an appropriate number of significant figures

1.2 Uncertainties and errors - Understandings:

- Random and systematic errors
- Absolute, fractional and percentage uncertainties
- Error bars
- Uncertainty of gradient and intercepts

Applications and skills:

- Explaining how random and systematic errors can be identified and reduced
- Collecting data that include absolute and/or fractional uncertainties and stating these as an uncertainty range (expressed as: best estimate ± uncertainty range)
- Propagating uncertainties through calculations involving addition, subtraction, multiplication, division and raising to a power
- Determining the uncertainty in gradients and intercepts

1.3 Vectors and scalars - Understandings:

- Vector and scalar quantities
- Combination and resolution of vectors – navigation, surveying

Applications and skills:

- Solving vector problems graphically and algebraically

Topic 2: Mechanics

2.1 Motion - Understandings:

- Distance and displacement
- Speed and velocity
- Acceleration
- Graphs describing motion
- Equations of motion for uniform acceleration
- Projectile motion - ballistics
- Fluid resistance and terminal speed – diving, parachuting

Applications and skills:

- Determining instantaneous and average values for velocity, speed and acceleration
- Solving problems using equations of motion for uniform acceleration
- Sketching and interpreting motion graphs
- Determining the acceleration of free-fall experimentally

- Analysing projectile motion, including the resolution of vertical and horizontal components of acceleration, velocity and displacement
- Qualitatively describing the effect of fluid resistance on falling objects or projectiles, including reaching terminal speed

2.2 Forces - Understandings:
- Objects as point particles
- Free-body diagrams
- Translational equilibrium
- Newton's laws of motion
- Solid friction

Applications and skills:
- Representing forces as vectors
- Sketching and interpreting free-body diagrams
- Describing the consequences of Newton's first law for translational equilibrium
- Using Newton's second law quantitatively and qualitatively
- Identifying force pairs in the context of Newton's third law
- Solving problems involving forces and determining resultant force
- Describing solid friction (static and dynamic) by coefficients of friction

Utilization: Construction, Biomechanics

2.3 Work, Energy and Power - Understandings:
- Kinetic energy
- Gravitational potential energy
- Elastic potential energy
- Work done as energy transfer
- Power as rate of energy transfer
- Principle of conservation of energy
- Efficiency

Applications and skills:
- Discussing the conservation of total energy within energy transformations
- Sketching and interpreting force–distance graphs
- Determining work done including cases where a resistive force acts
- Solving problems involving power
- Quantitatively describing efficiency in energy transfers

2.4 Momentum and Impulse - Understandings:
- Newton's second law expressed in terms of rate of change of momentum
- Impulse and force–time graphs
- Conservation of linear momentum
- Elastic collisions, inelastic collisions and explosions

Applications and skills:
- Applying conservation of momentum in simple isolated systems including (but not limited to) collisions, explosions, or water jets
- Using Newton's second law quantitatively and qualitatively in cases where mass is not constant
- Sketching and interpreting force–time graphs
- Determining impulse in various contexts including (but not limited to) car safety and sports
- Qualitatively and quantitatively comparing situations involving elastic collisions, inelastic collisions and explosions

Utilization: Jet engines and rockets, Particle theory and collisions

Topic 3: Thermal physics

3.1 – Thermal concepts - Understandings:

- Molecular theory of solids, liquids and gases
- Temperature and absolute temperature
- Internal energy
- Specific heat capacity
- Phase change
- Specific latent heat

Applications and skills:

- Describing temperature change in terms of internal energy
- Using Kelvin and Celsius temperature scales and converting between them
- Applying the calorimetric techniques of specific heat capacity or specific latent heat experimentally
- Describing phase change in terms of molecular behaviour
- Sketching and interpreting phase change graphs
- Calculating energy changes involving specific heat capacity and specific latent heat of fusion and vaporization

Utilization

Pressure gauges, barometers and manometers

3.2 – Modelling a gas - Understandings:

- Pressure
- Equation of state for an ideal gas
- Kinetic model of an ideal gas
- Mole, molar mass and the Avogadro constant
- Differences between real and ideal gases

Applications and skills:

- Solving problems using the equation of state for an ideal gas and gas laws
- Sketching and interpreting changes of state of an ideal gas on pressure–volume, pressure–temperature and volume–temperature diagrams
- Investigating at least one gas law experimentally

Utilization

Verification of gas laws; calculation of the Avogadro constant

Topic 4: Waves

4.1 – Oscillations - Understandings:

- Simple harmonic oscillations
- Time period, frequency, amplitude, displacement and phase difference
- Conditions for simple harmonic motion

Applications and skills:

- Qualitatively describing the energy changes taking place during one cycle of an oscillation
- Sketching and interpreting graphs of simple harmonic motion examples
- Isochronous oscillations can be used to measure time
- Many systems can approximate simple harmonic motion: mass on a spring, fluid in U-tube, models of icebergs oscillating vertically in the ocean, and motion of a sphere rolling in a concave mirror

4.2 – Travelling waves - Understandings:

- Travelling waves
- Wavelength, frequency, period and wave speed
- Transverse and longitudinal waves
- The nature of electromagnetic waves
- The nature of sound waves

Applications and skills:

- Explaining the motion of particles of a medium when a wave passes through it for both transverse and longitudinal cases
- Sketching and interpreting displacement–distance graphs and displacement–time graphs for transverse and longitudinal waves
- Solving problems involving wave speed, frequency and wavelength
- Investigating the speed of sound experimentally

4.3 – Wave characteristics - Understandings:

- Wavefronts and rays
- Amplitude and intensity
- Superposition
- Polarization

Applications and skills:

- Sketching and interpreting diagrams involving wavefronts and rays
- Solving problems involving amplitude, intensity and the inverse square law
- Sketching and interpreting the superposition of pulses and waves
- Describing methods of polarization
- Sketching and interpreting diagrams illustrating polarized, reflected and transmitted beams
- Solving problems involving Malus's law
- A number of modern technologies, such as LCD displays, rely on polarization for their operation

4.4 – Wave behaviour - Understandings:

- Reflection and refraction
- Snell's law, critical angle and total internal reflection
- Diffraction through a single-slit and around objects
- Interference patterns
- Double-slit interference
- Path difference

Applications and skills:

- Sketching and interpreting incident, reflected and transmitted waves at boundaries between media
- Solving problems involving reflection at a plane interface
- Solving problems involving Snell's law, critical angle and total internal reflection
- Determining refractive index experimentally
- Qualitatively describing the diffraction pattern formed when plane waves are incident normally on a single-slit
- Quantitatively describing double-slit interference intensity patterns
- A satellite footprint on Earth is governed by the diffraction at the dish on the satellite
- Applications of the refraction and reflection of light range from the simple plane mirror through the medical endoscope and beyond. Many of these applications have enabled us to improve and extend our sense of vision.
- The simple idea of the cancellation of two coherent light rays reflecting from two surfaces leads to data storage in compact discs and their successors
- The physical explanation of the rainbow involves refraction and total internal reflection. The bright and dark bands inside the rainbow, supernumeraries, can be explained only by the wave nature of light and diffraction.

4.5 – Standing waves - Understandings:

- The nature of standing waves
- Boundary conditions
- Nodes and antinodes

Applications and skills:

- Describing the nature and formation of standing waves in terms of superposition
- Distinguishing between standing and travelling waves
- Observing, sketching and interpreting standing wave patterns in strings and pipes
- Solving problems involving the frequency of a harmonic, length of the standing wave and the speed of the wave
  Musical instruments

Topic 5: Electricity and magnetism

<u>5.1 – Electric fields - Understandings:</u>

- Charge
- Electric field
- Coulomb's law
- Electric current
- Direct current (dc)
- Potential difference

Applications and skills:

- Identifying two forms of charge and the direction of the forces between them
- Solving problems involving electric fields and Coulomb's law
- Calculating work done in an electric field in both joules and electronvolts
- Identifying sign and nature of charge carriers in a metal
- Identifying drift speed of charge carriers
- Solving problems using the drift speed equation
- Solving problems involving current, potential difference and charge
- Students will be expected to apply Coulomb's law for a range of permittivity values

<u>5.2 – Heating effect of electric currents - Understandings:</u>

- Circuit diagrams
- Kirchhoff's circuit laws
- Heating effect of current and its consequences
- Resistance expressed as ratio of p.d. to current.
- Ohm's law
- Resistivity
- Power dissipation

Applications and skills:

- Drawing and interpreting circuit diagrams
- Identifying ohmic and non-ohmic conductors through a consideration of the *V/I* characteristic graph
- Solving problems involving potential difference, current, charge, Kirchhoff's circuit laws, power, resistance and resistivity
- Investigating combinations of resistors in parallel and series circuits
- Describing ideal and non-ideal ammeters and voltmeters
- Describing practical uses of potential divider circuits, including the advantages of a potential divider over a series resistor in controlling a simple circuit
- Investigating one or more of the factors that affect resistance experimentally

Guidance:

- The filament lamp should be described as a non-ohmic device; a metal wire at a constant temperature is an ohmic device

5.3 – Electric cells - Understandings:

- Cells
- Internal resistance
- Secondary cells
- Terminal potential difference
- Emf

  Applications and skills:

- Investigating practical electric cells (both primary and secondary)
- Describing the discharge characteristic of a simple cell (variation of terminal potential difference with time)
- Identifying the direction of current flow required to recharge a cell
- Determining internal resistance experimentally
- Solving problems involving emf, internal resistance and other electrical quantities**:**
- Students should recognize that the terminal potential difference of a typical practical electric cell loses its initial value quickly, has a stable and constant value for most of its lifetime, followed by a rapid decrease to zero as the cell discharges completely

5.4 – Magnetic effects of electric currents - Understandings:

- Magnetic fields
- Magnetic force

  Applications and skills:

- Determining the direction of force on a charge moving in a magnetic field
- Determining the direction of force on a current-carrying conductor in a magnetic field
- Sketching and interpreting magnetic field patterns: long straight conductors, solenoids, and bar magnets
- Determining the direction of the magnetic field based on current direction
- Solving problems involving magnetic forces, fields, current and charges

Topic 6: Circular motion and gravitation

6.1 – Circular motion - Understandings:
- Period, frequency, angular displacement and angular velocity
- Centripetal force
- Centripetal acceleration

Applications and skills:
- Identifying the forces providing the centripetal forces such as tension, friction, gravitational, electrical, or magnetic
- Solving problems involving centripetal force, centripetal acceleration, period, frequency, angular displacement, linear speed and angular velocity
- Qualitatively and quantitatively describing examples of circular motion including cases of vertical and horizontal circular motion**:**
- Banking will be considered qualitatively only

Utilization:
- Motion of charged particles in magnetic fields (see Physics sub-topic 5.4)
- Mass spectrometry (see Chemistry sub-topics2.1 and 11.3)
- Playground and amusement park rides often use the principles of circular motion in their design
- mass on a string; observation and quantification of loop-the-loop experiences; friction of a mass on a turntable

6.2 – Newton's law of gravitation - Understandings:
- Newton's law of gravitation
- Gravitational field strength

Applications and skills:
- Describing the relationship between gravitational force and centripetal force
- Applying Newton's law of gravitation to the motion of an object in circular orbit around a point mass
- Solving problems involving gravitational force, gravitational field strength, orbital speed and orbital period
- Determining the resultant gravitational field strength due to two bodies
- motion of satellites, planets, moons and entire galaxies
- Comparison to Coulomb's law

Topic 7: Atomic, nuclear and particle physics

7.1 – Discrete energy and radioactivity - 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

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 including neutrino production
- Determining the half-life of a nuclide from a decay curve
- Investigating half-life experimentally (or by simulation)

7.2 – Nuclear reactions - 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

7.3 – The structure of matter - 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
- Sketching and interpreting simple Feynman diagrams
- Describing why free quarks are not observed

Topic 8: Energy production

8.1 – Energy sources - Understandings:
- Specific energy and energy density of fuel sources
- Sankey diagrams
- Primary energy sources
- Electricity as a secondary and versatile form of energy
- Renewable and non-renewable energy sources

Applications and skills:
- Solving specific energy J kg^{-1} and energy density J m^{-3} problems
- Sketching and interpreting Sankey diagrams
- Describing the basic features of fossil fuel power stations, nuclear power stations, wind generators, pumped storage hydroelectric systems and solar power cells
- Solving problems relevant to energy transformations in the context of these generating systems
- Discussing safety issues and risks associated with the production of nuclear power
- Describing the differences between photovoltaic cells and solar heating panels

8.2 – Thermal energy transfer - Understandings:
- Conduction, convection and thermal radiation
- Black-body radiation
- Albedo and emissivity
- The solar constant
- The greenhouse effect
- Energy balance in the Earth surface–atmosphere system

Applications and skills:
- Sketching and interpreting graphs showing the variation of intensity with wavelength for bodies emitting thermal radiation at different temperatures
- Solving problems involving the Stefan–Boltzmann law and Wien's displacement law
- Describing the effects of the Earth's atmosphere on the mean surface temperature
- Solving problems involving albedo, emissivity, solar constant and the Earth's average temperature
- Greenhouse gases CH_4, H_2O, CO_2 and N_2O have both natural and man-made origins.
- Earth's albedo varies daily and is dependent on season (cloud formations) and latitude. The global annual mean albedo will be taken to be 0.3 (30%) for Earth.

AHL Topic 9: Wave phenomena

9.1 – Simple harmonic motion - **Understandings:**
- The defining equation of SHM
- Energy changes
  Applications and skills:
- Solving problems involving acceleration, velocity and displacement during simple harmonic motion, both graphically and algebraically
- Describing the interchange of kinetic and potential energy during simple harmonic motion
- Solving problems involving energy transfer during simple harmonic motion, both graphically and algebraically

  9.2 – Single-slit diffraction **Understandings:**
- The nature of single-slit diffraction
  Applications and skills:
- Describing the effect of slit width on the diffraction pattern
- Determining the position of first interference minimum
- Qualitatively describing single-slit diffraction patterns produced from white light and from a range of monochromatic light frequencies
  X-ray diffraction

  9.3 – Interference Understandings:
- Young's double-slit experiment
- Modulation of two-slit interference pattern by one-slit diffraction effect
- Multiple slit and diffraction grating interference patterns
- Thin film interference
  Applications and skills:
- Qualitatively describing two-slit interference patterns, including modulation by one-slit diffraction effect
- Investigating Young's double-slit experimentally
- Sketching and interpreting intensity graphs of double-slit interference patterns
- Solving problems involving the diffraction grating equation
- Describing conditions necessary for constructive and destructive interference from thin films, including phase change at interface and effect of refractive index
- Solving problems involving interference from thin films
- Compact discs are a commercial example of the use of diffraction gratings
- Thin films are used to produce anti-reflection coatings

  9.4 – Resolution Understandings**:**
- The size of a diffracting aperture
- The resolution of simple monochromatic two-source systems
  Applications and skills:
- Solving problems involving the Rayleigh criterion for light emitted by two sources diffracted at a single slit
- Resolvance of diffraction gratings

  9.5 – Doppler effect Understandings:
- The Doppler effect for sound waves and light waves
  Applications and skills:
- Sketching and interpreting the Doppler effect when there is relative motion between source and observer
- Describing situations where the Doppler effect can be utilized (red shift)

- Solving problems involving the change in frequency or wavelength observed due to the Doppler effect to determine the velocity of the source/observer

AHL Topic 10: Fields

10.1 – Describing fields **Understandings:**

- Gravitational fields
- Electrostatic fields
- Electric potential and gravitational potential
- Field lines
- Equipotential surfaces

Applications and skills:

- Representing sources of mass and charge, lines of electric and gravitational force, and field patterns using an appropriate symbolism
- Mapping fields using potential
- Describing the connection between equipotential surfaces and field lines

10.2 – Fields at work **Understandings:**

- Potential and potential energy
- Potential gradient
- Potential difference
- Escape speed
- Orbital motion, orbital speed and orbital energy
- Forces and inverse-square law behaviour

Applications and skills:

- Determining the potential energy of a point mass and the potential energy of a point charge
- Solving problems involving potential energy
- Determining the potential inside a charged sphere
- Solving problems involving the speed required for an object to go into orbit around a planet and for an object to escape the gravitational field of a planet
- Solving problems involving orbital energy of charged particles in circular orbital motion and masses in circular orbital motion
- Solving problems involving forces on charges and masses in radial and uniform fields
- Geostationary/polar satellites

AHL Topic 11: Electromagnetic induction

11.1 – Electromagnetic induction **Understandings:**

- Emf
- Magnetic flux and magnetic flux linkage
- Faraday's law of induction
- Lenz's law

Applications and skills:

- Describing the production of an induced emf by a changing magnetic flux and within a uniform magnetic field
- Solving problems involving magnetic flux, magnetic flux linkage and Faraday's law
- Explaining Lenz's law through the conservation of energy

11.2 – Power generation and transmission **Understandings:**

- Alternating current (ac) generators
- Average power and root mean square (rms) values of current and voltage
- Transformers

- Diode bridges
- Half-wave and full-wave rectification
  Applications and skills:
- Explaining the operation of a basic ac generator, including the effect of changing the generator frequency
- Solving problems involving the average power in an ac circuit
- Solving problems involving step-up and step-down transformers
- Describing the use of transformers in ac electrical power distribution
- Investigating a diode bridge rectification circuit experimentally
- Qualitatively describing the effect of adding a capacitor to a diode bridge rectification circuit why real transformers are not ideal (for example: flux leakage, joule heating, eddy current heating, magnetic hysteresis)

11.3 – Capacitance **Understandings:**
- Capacitance
- Dielectric materials
- Capacitors in series and parallel
- Resistor-capacitor (RC) series circuits
- Time constant
  Applications and skills:
- Describing the effect of different dielectric materials on capacitance
- Solving problems involving parallel-plate capacitors
- Investigating combinations of capacitors in series or parallel circuits
- Determining the energy stored in a charged capacitor
- Describing the nature of the exponential discharge of a capacitor
- Solving problems involving the discharge of a capacitor through a fixed resistor
- Solving problems involving the time constant of an RC circuit for charge, voltage and current

AHL Topic 12: Quantum and nuclear physics

12.1 – The interaction of matter with radiation **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
  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

12.2 – Nuclear physics **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