2023 VCE Physics EP Curriculum Map

Unit 1: How is energy useful to society?

Area of Study 1: How are heat and light explained?

Content Descriptor/s	EP Lessons in ***1.1.1. Electromagnetic radiation***
1.1.1.1. identify all electromagnetic waves as transverse waves travelling at the same speed, *c*, in a vacuum as distinct from mechanical waves that require a medium to propagate **1.1.1.2.** identify the amplitude, wavelength, period and frequency of waves **1.1.1.3.** calculate the wavelength, frequency, period and speed of travel of waves using: $\lambda = v/f = vT$ **1.1.1.4.** explain the wavelength of a wave as a result of the velocity (determined by the medium through which it travels) and the frequency (determined by the source) **1.1.1.5.** describe electromagnetic radiation emitted from the Sun as mainly ultraviolet, visible and infrared **1.1.1.6.** compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and compare the different uses each has in society **1.1.1.7.** investigate and analyse theoretically and practically the behaviour of waves including: - refraction using Snell's Law: $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ and $n_1 v_1 = n_2 v_2$; - total internal reflection and critical angle including applications: $n_1 \sin(\theta_c) = n_2 \sin(90°)$; **1.1.1.8.** investigate and explain theoretically and practically colour dispersion in prisms and lenses with reference to refraction of the components of white light as they pass from one medium to another **1.1.1.9.** explain the formation of optical phenomena: rainbows; mirages **1.1.1.10.** investigate light transmission through optical fibres for communication	• Electromagnetic Wave Model • Wave Graphs • Wave Speed • You, Me and UV • The Electromagnetic Spectrum • Introduction to Snell's Law • Colour • Reflection and Refraction • Total Internal Reflection *Lab Activity: Optical Fibres* • Optical Fibres • Risk Assessment (in RiskAssess) • Student Worksheet PDF • Teacher Guide PDF • Laboratory Technician Guide PDF • Editable Documents - Word (.docx)

Content Descriptor/s	EP Lessons in ***1.1.2. Thermal energy***
1.1.2.1. convert between Celsius and kelvin scales **1.1.2.2.** describe how an increase in temperature corresponds to an increase in thermal energy (kinetic and potential energy of the atoms) of a system: - distinguish between conduction, convection and radiation with reference to heat transfers within and between systems; - explain why cooling results from evaporation using a simple kinetic energy model **1.1.2.3.** investigate and analyse theoretically and practically the energy required to: - raise the temperature of a substance: $Q = mc\Delta T$; - change the state of a substance: $Q = mL$	• Temperature • Particle Model (Revision) • Heat Transfer • Conduction • Convection • Radiation • Specific Heat Capacity • Thermal Equilibrium

Content Descriptor/s	**EP Lessons in *1.1.3. Interaction of thermal energy and electromagnetic radiation***
1.1.2.7. apply concepts of energy transfer, energy transformation, temperature change and change of state to climate change and global warming.	• Climate • Weather • Climate and Weather • Ocean Currents • El Niño and La Niña • The Greenhouse Effect • The Enhanced Greenhouse Effect • Human Influences on Climate • Evidence for Climate Change • Computer Modelling and the Environment

Area of Study 2: How is energy from the nucleus utilised?

Content Descriptor/s	EP Lessons in ***1.2.1. Radiation from the nucleus***
1.2.1.1. explain nuclear stability with reference to the forces in the nucleus including electrostatic forces, the strong nuclear force and the weak nuclear force **1.2.1.2.** model radioactive decay as random decay with a particular half-life, including mathematical modelling with reference to whole half-lives **1.2.1.3.** describe the properties of α, β^-, β^+ and γ radiation **1.2.1.4.** explain nuclear transformations using decay equations involving α, β^-, β^+ and γ radiation **1.2.1.6.** explain the effects of α, β and γ radiation on humans, including: - different capacities to cause cell damage; - short- and long-term effects of low and high doses; - ionising impacts of radioactive sources outside and inside the body; - calculations of absorbed dose (gray), equivalent dose (sievert) and effective dose (sievert) **1.2.1.7.** evaluate the use of medical radioisotopes in therapy including the effects on healthy and damaged tissues and cells	• Nuclear Model (Revision) • Nuclear Forces • Radioactive Decay • Balancing Nuclear Equations • Half-Life • Introduction to Radiation • Introduction to Alpha, Beta and Gamma Radiation • Effects of Radiation on Humans • Types of Radiation 1 • Types of Radiation 2 • Nuclear Medicine
Content Descriptor/s	**EP Lessons in *1.2.2. Nuclear energy***
1.2.2.1. explain, qualitatively, nuclear energy as energy resulting from the conversion of mass **1.2.2.2.** explain fission chain reactions including: - the effect of mass and shape on criticality; - neutron absorption and moderation **1.2.2.3.** compare the processes of nuclear fusion and nuclear fission **1.2.2.4.** explain, using a binding energy curve, why both fusion and fission are reactions that release energy **1.2.2.5.** investigate the viability of nuclear energy as an energy source for Australia.	• Energy • Mass-Energy Equivalence • Nuclear Fission • Nuclear Fusion • Transmutation and Decay • Nuclear Fuel as a Resource • Nuclear Power Plants

Area of Study 3: How can electricity be used to transfer energy?

Content Descriptor/s	EP Lessons in ***1.3.1. Concepts used to model electricity***
1.3.1.1. apply concepts of charge (*Q*), electric current (*I*), potential difference (*V*), energy (*E*) and power (*P*), in electric circuits **1.3.1.2.** analyse and evaluate different analogies used to describe electric current and potential difference **1.3.1.3.** investigate and analyse theoretically and practically electric circuits using the relationships: - $I = Q/t$, $V = E/Q$, $P = E/t = VI$ **1.3.1.4.** justify the use of selected meters (ammeter, voltmeter, multimeter) in circuits **1.3.1.5.** apply the kilowatt-hour (kW h) as a unit of energy	• Electricity and Charge • Potential • Current • Power • Electrical Potential Energy and Work • Potential Difference • Circuit Properties • Measuring Electricity
Content Descriptor/s	**EP Lessons in *1.3.2. Circuit electricity***
1.3.2.1. model resistance in series and parallel circuits using: - current versus potential difference (*I*–*V*) graphs; - resistance as the potential difference to current ratio, including *R* = constant for ohmic devices; - equivalent resistance in arrangements in - series: $R_{equivalent} = R_1 + R_2 + ... + R_n$ and - parallel: $1/R_{equivalent} = 1/R_1 + 1/R_2 + ... + 1/R_n$ **1.3.2.2.** calculate and analyse the equivalent resistance of circuits comprising parallel and series resistance **1.3.2.3.** analyse circuits comprising voltage dividers **1.3.2.4.** model household (AC) electrical systems as simple direct current (DC) circuits	• Resistance • Ohm's Law • Kirchhoff's Current Law • Kirchhoff's Voltage Law • Circuits • Circuit Analysis • Parallel Circuits and Total Resistance • Total Circuit Properties of Parallel Circuits • Combination Circuits and Voltage Dividers
Content Descriptor/s	**EP Lessons in *1.3.3. Using electricity***
1.3.3.1. investigate and apply theoretically and practically concepts of current, resistance, potential difference (voltage drop) and power to the operation of electronic circuits comprising resistors, light bulbs, diodes, thermistors, light dependent resistors (LDRs), light-emitting diodes (LEDs) and potentiometers (quantitative analysis restricted to use of $I = V/R$ and $P = VI$) **1.3.3.2.** investigate practically the operation of simple circuits containing resistors, variable resistors, diodes and other non-ohmic devices **1.3.3.3.** describe energy transfers and transformations with reference to resistors, light bulbs, diodes, thermistors, light dependent resistors (LDRs), light-emitting diodes (LEDs) and potentiometers in common devices	• Diodes, Variable Resistors and Transducers

Content Descriptor/s	EP Lessons in ***1.3.4. Electrical safety in the home***
1.3.4.1. model household electricity connections as a simple DC circuit comprising fuses, switches, circuit breakers, loads and earth **1.3.4.2.** compare the operation of safety devices including fuses, circuit breakers and residual current devices (RCDs) **1.3.4.3.** describe the causes, effects and first aid treatment of electric shock and identify the approximate danger thresholds for current and duration.	• The Power Grid and You • Household Circuits and Electrical Safety

Unit 2: How does physics help us to understand the world?

Area of Study 1: How is motion understood?

Content Descriptor/s	EP Lessons in ***2.1.1. Concepts used to model motion***
2.1.1.1. identify parameters of motion as vectors or scalars **2.1.1.2.** analyse graphically, numerically and algebraically, straight-line motion under constant acceleration: $v = u + at$, $v^2 = u^2 + 2as$, $s = 1/2\,(u + v)t$, $s = ut + 1/2(at^2)$, $s = vt - 1/2(at^2)$ **2.1.1.4.** apply concepts of momentum to linear motion: p = mv	• Distance and Time • Displacement • Displacement and Compass Directions • Speed • Velocity • Acceleration • Using the Acceleration Formula to Calculate Final Velocity • Using the Acceleration Formula to Calculate Initial Velocity • Using the Acceleration Formula to Calculate Time • Kinematic Equations • Calculating Displacement • Momentum

Content Descriptor/s	EP Lessons in ***2.1.2. Forces and motion***
2.1.2.1. explain changes in momentum as being caused by a net force: $\Delta p = F_{net}\,\Delta t$ **2.1.2.2.** model the force due to gravity, F_g, as the force of gravity acting at the centre of mass of a body, $F_{\text{on body by Earth}} = mg$, where *g* is the gravitational field strength (9.8 N kg^{-1} near the surface of Earth) **2.1.2.3.** model forces as vectors acting at the point of application (with magnitude and direction), labelling these forces using the convention 'force on A by B' or $F_{\text{on A by B}} = -F_{\text{on B by A}}$ **2.1.2.5.** apply the vector model of forces, including vector addition and components of forces, to readily observable forces including the force due to gravity, friction and normal forces	• Conservation of Momentum • Gravitational Fields • Centre of Mass • Work Done by Gravitational Fields • Free Body Diagrams • Forces in Two Dimensions • Forces on an Angle • Projectiles

Content Descriptor/s	EP Lessons in ***2.1.3. Energy and motion***
2.1.3.1. apply the concept of work done by a force using: - work done = force × displacement: $W = Fs\cos\theta$, where force is constant; - work done = area under force vs distance graph **2.1.3.2.** investigate and analyse theoretically and practically Hooke's Law for an ideal spring: $F = -kx$, where x is extension **2.1.3.3.** analyse and model mechanical energy transfers and transformations using energy conservation: - changes in gravitational potential energy near Earth's surface: $E_g = mg\Delta h$; - elastic potential energy in ideal springs: $E_s = 1/2\ kx^2$; - kinetic energy: $E_k = 1/2mv^2$ **2.1.3.4.** analyse rate of energy transfer using power: $P = E/t$ **2.1.3.5.** calculate the efficiency of an energy transfer system: η="useful energy out" /"total energy in" **2.1.3.6.** analyse impulse in an isolated system (for collisions between objects moving in a straight line): $F\Delta t= m\Delta v$ **2.1.3.7.** investigate and analyse theoretically and practically momentum conservation in one dimension	• Hooke's Law • Mechanical Energy and Springs • Energy Transfer • Impulse • Conservation of Momentum

Content Descriptor/s	EP Lessons in ***2.1.4. Equilibrium***
2.1.4.1. calculate torque, $\tau = r\perp F$ **2.1.4.2.** analyse translational and rotational forces (torques) in simple structures in translational and rotational equilibrium	• Torque • Torque from Force at an Angle • Net Torque • Equilibrium

Content Descriptor/s	EP Lessons in ***2.1.5. Application of motion***
2.1.5.1. investigate the application of motion concepts through a case study, for example, through motion in sport, vehicle safety, a device or a structure.	• Momentum • Impulse • Conservation of Momentum • Friction • Uniform Circular Motion • Circular Motion on Banked Curves • Vertical Circular Motion

Area of Study 2 (Supporting Resources):

Options: How does physics inform contemporary issues and applications in society?

EP Lessons in *2.2.01.1. The physics of climate change*

- Energy Efficient Houses
- Heating Systems
- Carbon Capture
- Carbon Footprints
- Cars of the Future

EP Lessons in *2.2.02.1. The physics of nuclear fusion and fission reactions*

- Elementary Particles
- The Standard Model
- The Fundamental Forces
- Conservation Laws
- Reaction Diagrams

EP Lessons in *2.2.03.1. The physics of flight*

- Friction
- Projectile Motion
- Projectile Calculations
- Springs and Pendula
- Kinematics of SHM
- Phasor Diagrams
- Energy in SHM
- Damped and Driven Systems

EP Lessons in *2.2.06.1. The physics of medical radiation*

- What is Radioactivity?
- X-rays
- Radioactivity in Medicine
- Effects of Radiation on Humans
- Marie Curie and Radioactivity

EP Lessons in *2.2.07.1. The physics of the use of electricity in the human body*

- The Cells of the Nervous System
- The Central Nervous System
- Electrical Signalling in the Nervous System
- Chemical Signalling in the Nervous System
- Bionic Ears
- Potential
- Potential Difference
- Current

EP Lessons in *2.2.08.1. The physics of human vision*

- The Eye
- Bionic Eyes
- Polarisation of Light

Lab Activity: Eye Dissection

- Eye Dissection
- Risk Assessment (in RiskAssess)
- Student Worksheet PDF
- Teacher Guide PDF
- Laboratory Technician Guide PDF
- Editable Documents - Word (.docx)

EP Lessons in ***2.2.09.1. The physics of photography***	EP Lessons in ***2.2.010.1. The physics of sound production and music***
• Making a Pinhole Camera • The History of Lenses • Lenses • Curved Mirrors • Plane Mirrors and Reflection • Drawing Ray Diagrams • Telescopes	• Sound Waves • Sound Formation • Standing Waves in Strings • Standing Waves in Pipes *Lab Activity: Musical Bottles* • Musical Bottles • Risk Assessment (in RiskAssess) • Student Worksheet PDF • Lab Report Material PDF • Teacher Guide PDF • Laboratory Technician Guide PDF • Editable Documents - Word (.docx)
EP Lessons in ***2.2.012.1. The physics of using AC electricity to charge a DC device***	EP Lessons in ***2.2.013.1. The physics of stars***
• Alternating Current • Energy and Power • Transformers • Phasor Diagrams • Reactance • Impedance • Resonance • Diodes, Variable Resistors and Transducers • Capacitance • Equivalent Capacitance and Energy Storage • Charging and Discharging	• The Big Bang Theory I • The Big Bang Theory II • Properties of Stars • Radar Ranging • Parallax and Distances Between Stars • Distances to Stars and Parsecs • Red Shift • Red Shift and the Expanding Universe • The Solar System and Beyond • The Life Cycle of Stars • Nuclear Fusion • Reading Hertzsprung-Russell Diagrams • Calculating Distance to Stars • Black Holes • End of the Universe
EP Lessons in ***2.2.014.1. The physics of life beyond the Solar System***	EP Lessons in ***2.2.016.1. The physics of particle accelerators***
• Cosmic Background Radiation	• Particle Accelerators

Unit 3: How do fields explain motion and electricity?

Area of Study 1: How do physicists explain motion in two dimensions?

Content Descriptor/s	EP Lessons in ***3.1.1. Newton's laws of motion***
3.1.1.1. investigate and apply theoretically and practically Newton's three laws of motion in situations where two or more coplanar forces act along a straight line and in two dimensions **3.1.1.2.** investigate and analyse theoretically and practically the uniform circular motion of an object moving in a horizontal plane: ($F_{net}=mv^2/r$), including: - a vehicle moving around a circular road; - a vehicle moving around a banked track; - an object on the end of a string **3.1.1.3.** model natural and artificial satellite motion as uniform circular motion **3.1.1.4.** investigate and apply theoretically Newton's second law to circular motion in a vertical plane (forces at the highest and lowest positions only) **3.1.1.5.** investigate and analyse theoretically and practically the motion of projectiles near Earth's surface, including a qualitative description of the effects of air resistance **3.1.1.6.** investigate and apply theoretically and practically the laws of energy and momentum conservation in isolated systems in one dimension	• Newton's First Law • Newton's Second Law • Newton's Third Law • Uniform Circular Motion • Vertical Circular Motion • Circular Motion on Banked Curves • Satellite Motion • Projectile Motion • Conservation of Energy
Content Descriptor/s	**EP Lessons in *3.1.2. Relationships between force, energy and mass***
3.1.2.1. investigate and analyse theoretically and practically impulse in an isolated system for collisions between objects moving in a straight line: $F\Delta t = m\Delta v$ **3.1.2.2.** investigate and apply theoretically and practically the concept of work done by a force using: - work done = force × displacement; - work done = area under force vs distance graph (one dimensional only); **3.1.2.3.** analyse transformations of energy between kinetic energy, elastic potential energy, gravitational potential energy and energy dissipated to the environment (considered as a combination of heat, sound and deformation of material): - kinetic energy at low speeds: $E_k=1/2mv^2$; elastic and inelastic collisions with reference to conservation of kinetic energy; - elastic potential energy: area under force-distance graph including ideal springs obeying Hooke's Law: $E_s=1/2\ kx^2$; - gravitational potential energy: $E_g = mg\Delta h$ or from area under a force-distance graph and area under a field-distance graph multiplied by mass.	• Collisions • Momentum • Impulse • Work and Power • Hooke's Law • Mechanical Energy and Springs

Area of Study 2: How do things move without contact?

Content Descriptor/s	EP Lessons in ***3.2.1. Fields and interactions***
3.2.1.1. describe gravitation, magnetism and electricity using a field model **3.2.1.2.** investigate and compare theoretically and practically gravitational, magnetic and electric fields, including directions and shapes of fields, attractive and repulsive effects, and the existence of dipoles and monopoles **3.2.1.3.** investigate and compare theoretically and practically gravitational fields and electric fields about a point mass or charge (positive or negative) with reference to: - the direction of the field; - the shape of the field; - the use of the inverse square law to determine the magnitude of the field; - potential energy changes (qualitative) associated with a point mass or charge moving in the field **3.2.1.4.** investigate and apply theoretically and practically a field model to magnetic phenomena, including shapes and directions of fields produced by bar magnets, and by current-carrying wires, loops and solenoids **3.2.1.5.** identify fields as static or changing, and as uniform or non-uniform	• Introduction To Fields • Gravitational and Electric Fields • Magnetic Fields • Examples of Magnetic Fields (Solenoids) • Permanent Magnetic Fields • Magnetic Field of a Current-Carrying Wire

Content Descriptor/s	EP Lessons in ***3.2.2. Effects of fields***
3.2.2.1. analyse the use of an electric field to accelerate a charge, including: - electric field and electric force concepts: $E = k\,Q/r^2$ *and* $F = k\,q_1 q_2/r^2$; - potential energy changes in a uniform electric field: $W = {}_qV$, $E=V/d$; - the magnitude of the force on a charged particle due to a uniform electric field: $F = {}_qE$ **3.2.2.2.** analyse the use of a magnetic field to change the path of a charged particle, including: - the magnitude and direction of the force applied to an electron beam by a magnetic field: $F = qvB$, in cases where the directions of v and B are perpendicular or parallel; - the radius of the path followed by an electron in a magnetic field: $qvB = mv^2/r$, where $v << c$; **3.2.2.3.** analyse the use of gravitational fields to accelerate mass, including: - gravitational field and gravitational force concepts: $g = G\,M/r^2$ and $F_g = G\,m_1 m_2/r^2$; - potential energy changes in a uniform gravitational field: $E_g = mg\Delta h$	• Coulomb's Law for Two Charges • Force on a Charge in a Magnetic Field • Motion of Charges in a Magnetic Field • Electrical Potential Energy and Work • Newton's Law of Universal Gravitation • Gravitational Fields • Work Done by Gravitational Fields

Content Descriptor/s	**EP Lessons in *3.2.3. Application of field concepts***
3.2.3.1. apply the concepts of force due to gravity and normal force including in relation to satellites in orbit where the orbits are assumed to be uniform and circular **3.2.3.2.** model satellite motion (artificial, Moon, planet) as uniform circular orbital motion: $a = v^2/ r =(4\pi^2 r)/T^2$ **3.2.3.3.** describe the interaction of two fields, allowing that electric charges, magnetic poles and current carrying conductors can either attract or repel, whereas masses only attract each other **3.2.3.4.** investigate and analyse theoretically and practically the force on a current carrying conductor due to an external magnetic field, $F = nIlB$, where the directions of I and B are either perpendicular or parallel to each other **3.2.3.5.** investigate and analyse theoretically and practically the operation of simple DC motors consisting of one coil, containing a number of loops of wire, which is free to rotate about an axis in a uniform magnetic field and including the use of a split ring commutator **3.2.3.6.** investigate, qualitatively, the effect of current, external magnetic field and the number of loops of wire on the torque of a simple motor **3.2.3.7.** model the acceleration of particles in a particle accelerator (including synchrotrons) as uniform circular motion (limited to linear acceleration by a uniform electric field and direction change by a uniform magnetic field).	• Kepler's Laws of Planetary Motion • Kepler's Second Law • Kepler's Third Law • Satellite Motion • Lenz's Law • Electromagnetic Induction in a Conductor • Electric Motors • Particle Accelerators

Area of Study 3: How are fields used in electricity generation?

Content Descriptor/s	EP Lessons in ***3.3.1. Generation of electricity***
3.3.1.1. calculate magnetic flux when the magnetic field is perpendicular to the area, and describe the qualitative effect of differing angles between the area and the field: $\Phi_B = B_\perp A$ **3.3.1.2.** investigate and analyse theoretically and practically the generation of electromotive force (emf) including AC voltage and calculations using induced emf: $\varepsilon = -N (\Delta \Phi B)/\Delta t$, with reference to: - rate of change of magnetic flux; - number of loops through which the flux passes; - direction of induced emf in a coil; **3.3.1.3.** explain the production of DC voltage in DC generators and AC voltage in alternators, including the use of split ring commutators and slip rings respectively	• Magnetic Flux • Properties of Inductors • Behaviour of Inductors • Faraday's Law • Electric Motors

Content Descriptor/s	EP Lessons in ***3.3.2. Transmission of electricity***
3.3.2.1. compare sinusoidal AC voltages produced as a result of the uniform rotation of a loop in a constant magnetic field with reference to frequency, period, amplitude, peak-to-peak voltage (V_{p-p}) and peak-to-peak current (I_{p-p}) **3.3.2.2.** compare alternating voltage expressed as the root-mean-square (rms) to a constant DC voltage developing the same power in a resistive component **3.3.2.3.** analyse transformer action with reference to electromagnetic induction for an ideal transformer: $N_1/N_2 = V_1/V_2 = I_2/I_1$ **3.3.2.4.** analyse the supply of power by considering transmission losses across transmission lines.	• Alternating Current • Transformers • Reactance • Impedance

Unit 4: How have creative ideas and investigation revolutionised thinking in physics?

Area of Study 1: How has understanding about the physical world changed?

Content Descriptor/s	EP Lessons in ***4.1.1. Light as a wave***
4.1.1.1. describe light as a transverse electromagnetic wave which is produced by the acceleration of charges, which in turn produces changing electric fields and associated changing magnetic fields **4.1.1.2.** identify that all electromagnetic waves travel at the same speed, c, in a vacuum **4.1.1.3.** explain the formation of a standing wave resulting from the superposition of a travelling wave and its reflection **4.1.1.4.** analyse the formation of standing waves (only those with nodes at both ends is required) **4.1.1.5.** investigate and explain theoretically and practically diffraction as the directional spread of various frequencies with reference to different gap width or obstacle size, including the qualitative effect of changing the λ/w ratio, and apply this to limitations of imaging using electromagnetic waves **4.1.1.6.** explain the results of Young's double slit experiment with reference to: - evidence for the wave-like nature of light; - constructive and destructive interference of coherent waves in terms of path differences: $n\lambda$ and $(n+1/2)\lambda$ respectively, where n = 0,1, 2,...; - effect of wavelength, distance of screen and slit separation on interference patterns: $\Delta x=\lambda L/d$ when $L>>d$	• Wave Frequency and Wavefronts • Wave Speed • The Electromagnetic Nature of Light • Wave Graphs • Phase of Waves • Two Source Interference of Waves • Standing Waves in Strings • Diffraction Around a Barrier • Huygens' Principle • Young's Double Slit Experiment • Multi-slit Diffraction

Content Descriptor/s	EP Lessons in ***4.1.2. Light as a particle***
4.1.2.1. apply the quantised energy of photons: $E = hf = hc/\lambda$ **4.1.2.2.** analyse the photoelectric effect with reference to: - evidence for the particle-like nature of light; - experimental data in the form of graphs of photocurrent versus electrode potential, and of kinetic energy of electrons versus frequency; - kinetic energy of emitted photoelectrons: $E_{k\,max} = hf - \phi$, using energy units of joule and electron-volt; - effects of intensity of incident irradiation on the emission of photoelectrons **4.1.2.3.** describe the limitation of the wave model of light in explaining experimental results related to the photoelectric effect	• Photons • The Photoelectric Effect

Content Descriptor/s	EP Lessons in ***4.1.4. Similarities between light and matter***
4.1.4.1. discuss the importance of the idea of quantisation in the development of knowledge about light and in explaining the nature of atoms **4.1.4.2.** compare the momentum of photons and of matter of the same wavelength including calculations using: $p = h/\lambda$ **4.1.4.3.** explain the production of atomic absorption and emission line spectra, including those from metal vapour lamps **4.1.4.4.** interpret spectra and calculate the energy of absorbed or emitted photons: $E = hf$ **4.1.4.5.** analyse the emission or absorption of a photon by an atom in terms of a change in the electron energy state of the atom, with the difference in the states' energies being equal to the photon energy: $E = hf = hc/\lambda$ **4.1.4.6.** describe the quantised states of the atom with reference to electrons forming standing waves, and explain this as evidence for the dual nature of matter **4.1.4.7.** interpret the single photon and the electron double slit experiment as evidence for the dual nature of light and matter	• Quantisation of Energy • Atomic Absorption Spectroscopy • Emission Spectra • Bohr's Model of the Hydrogen Atom • Young's Experiment

Content Descriptor/s	EP Lessons in ***4.1.5. Einstein's special theory of relativity***
4.1.5.1. describe the limitation of classical mechanics when considering motion approaching the speed of light **4.1.5.2.** describe Einstein's two postulates for his special theory of relativity that: - the laws of physics are the same in all inertial (non-accelerated) frames of reference; - the speed of light has a constant value for all observers regardless of their motion or the motion of the source **4.1.5.3.** interpret the null result of the Michelson-Morley experiment as evidence in support of Einstein's special theory of relativity **4.1.5.5.** describe proper time (t_0) as the time interval between two events in a reference frame where the two events occur at the same point in space **4.1.5.6.** describe proper length (L_0) as the length that is measured in the frame of reference in which objects are at rest **4.1.5.7.** model mathematically time dilation and length contraction at speeds approaching c using the equations: $t = \gamma t_0$ and $L = L_0/\gamma$ where $\gamma = 1/\sqrt{(1-v^2/c^2)}$^ **4.1.5.8.** explain and analyse examples of special relativity including that: - muons can reach Earth even though their half-lives would suggest that they should decay in the upper atmosphere; - particle accelerator lengths must be designed to take the effects of special relativity into account; - time signals from GPS satellites must be corrected for the effects of special relativity due to their orbital velocity	• Classical Relativity • Origins of Special Relativity • Einstein's Theory of Special Relativity • Time Dilation • Length Contraction • Evidence for Special Relativity: Muons

Content Descriptor/s	**EP Lessons in *4.1.6. Relationship between energy and mass***
4.1.6.1. interpret Einstein's prediction by showing that the total 'mass-energy' of an object is given by: $E_{tot} = E_k + E_0 = \gamma mc^2$ where $E_0 = mc^2$, and where kinetic energy can be calculated by: $E_k = (\gamma - 1)mc^2$ **4.1.6.2.** apply the energy-mass relationship to mass conversion in the Sun, to positron-electron annihilation and to nuclear transformations in particle accelerators (details of the particular nuclear processes are not required).	• Relativistic Mass and Momentum • Mass-Energy Equivalence • The Life Cycle of Stars • Nuclear Fusion • Particle Accelerators