OXFORD
INTERNATIONAL
AQA EXAMINATIONS

INTERNATIONAL A-LEVEL PHYSICS

(9630)

Outline Schemes of Work

For teaching from September 2016 onwards
For A2 exams in June 2018 onwards

Introduction
This Scheme of Work has been prepared by teachers for teachers. We hope you will find it a useful starting point for producing your own schemes.

The Scheme of Work is designed to be a flexible medium term plan for the teaching of content and development of the skills that will be assessed. It covers the needs of the specification for the International A2 units of Physics 9630.

The teaching of investigative and practical skills is embedded within the specification. We are producing a Practical Handbook that provides further guidance on this. There are also opportunities in this scheme of work, such as the inclusion of rich questions.

We have provided links to some resources. These are illustrative and in no way an exhaustive list. We would encourage teachers to make use of any existing resources, as well as resources provided by Oxford International AQA Examinations and new textbooks written to support the specification. Please note there maybe access restrictions to certain websites from certain countries.

The majority of the prior knowledge listed in this scheme of work will come from the AS units of the course. Where GCSE prior knowledge is referred to, this comprises knowledge from the current double science (ie Core and Additional Science) International GCSE specifications. Students who studied the separate International Science GCSE courses will have this knowledge but may also have been introduced to other topics which are relevant to the International A-level content. Topics only found in separate sciences are not included in the prior knowledge section.

We know that teaching times vary from school to school. In this scheme of work we have made the assumption that it will be taught over about 30 weeks with 4½ to 5 hours of contact time per week. Teachers will need to fine tune the timings to suite their own students and the time available. It could also be taught by one teacher or by more than teacher with topics being taught concurrently.

The **assessment opportunities** column details AQA past paper questions that have been mapped to this new Oxford International AQA qualification and are available through the international Exampro from early 2016. Of course there are also Sample Assessment Materials for download at oxfordaqaexams.org.uk/9630

Scheme of work

3.6 Circular and periodic motion

3.6.3 Circular Motion

Prior knowledge: Vectors and Scalars. Linear motion. Newton's Laws of motion.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Motion in a circular path at constant speed implies there is an acceleration and requires a centripetal force. Magnitude of angular speed $\omega = v / r = 2\pi f$ Radian measure of angle. Direction of angular velocity will not be considered.	1 week	Understand and explain why circular motion is an accelerated motion and needs a centripetal force. Recall and use equations $\omega = v / r = 2\pi f$, $a = v^2/r = \omega^2 r$, $F = mv^2/r = m\omega^2 r$, to solve circular motion problems.	Discussion and demonstration of circular motion, for example stone/bucket of water on a string, helium balloon in car. Student experiment: Verification of the centripetal force experiment with a whirling bung. Rehearse circular motion problems (including use of radians) from Institute of Physics (IOP).	Exampro QSP.4A.06 QBS04.4.02	Rich Question: What forces do you experience when travelling round a corner at constant speed? Helium Balloon in a car video clip. Verification of the centripetal force experiment with a whirling bung – schoolphysics.co.uk

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Centripetal acceleration $a = v^2/r = \omega^2 r$ The derivation of the centripetal acceleration formula will not be examined. Centripetal force $F = mv^2/r = m\omega^2 r$		Use radian as a measure of angle and convert between radians and degrees. Identify and calculate centripetal forces in contexts such as a mass whirled on a string and a car rounding a bend.	**Skill developed by learning activities:** Mathematical skills: Understand the relationship between degrees and radians and translate from one to the other in circular motion problems. Practical skills: Use methods to increase accuracy of measurements, such as timing over multiple rotations in circular motion experiment.		Circular motion problems from IOP

3.6.4 Simple Harmonic Motion (SHM) – Part 1

Prior knowledge: Uniform linear motion and motion graphs. *F* = *ma*

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Analysis of characteristics of simple harmonic motion (SHM). Condition for SHM: $a = -\omega^2 x$ $x = A\cos(\omega t)$ and $v = \pm\omega\sqrt{A^2 - x^2}$ Graphical representations linking the variations of x, v and a with time. Appreciation that the *v* - *t* graph is derived from the gradient of the *x* - *t* graph and that the *a* - *t* graph is derived from the gradient of the *v* - *t* graph.	1 week	Recall the condition for SHM : $a \propto -x$ Solve problems using the equations of SHM : $x = A\cos(\omega t)$ and $v = \pm\omega\sqrt{A^2 - x^2}$ $v_{max} = \omega A$ $a_{max} = \omega^2 A$ Recognise and use the concept of the gradient of the *x* - *t* graph leading to the *v* - *t* graph, and the gradient of the *v* - *t* graph leading to the *a* - *t* for SHM.	Students observe examples of SHM (IOP observing oscillations). They describe the characteristics observed, e.g. velocity is maximum at centre; period is independent of amplitude; need for a restoring force directed to the centre of the motion. Give the condition for SHM as $a \propto -x$ Discuss relationship between x, v, and a using observations and an animation such as that provided by University of New South Wales. Students use motion sensors and/or spread sheets to plot v - t and x - t graphs for SHM. Students should use the relationship between x, v and a graphs when explaining and processing the results of this work.	Exampro QBW05.5.04 QW12.4A.06 QS11.4A.07 QW11.4A.04 QW11.4A.05 QSP.4A.08	Rich Question: What characteristics do oscillating systems share? IOP observing oscillations SHM animation University of New South Wales. Nuffield Foundation investigating SHM

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Maximum speed $v_{max} = \omega A$ Maximum acceleration $a_{max} = \omega^2 A$			Use Exampro questions to rehearse problem solving using SHM equations and knowledge and understanding of graphs. **Skill developed by learning activities:** Demonstrate knowledge and understanding of conditions for SHM by investigating different examples of oscillations. Analyse and interpret data to reach conclusions on the relationship between x, v and a in a system executing SHM Mathematical skills: Apply the concepts underlying calculus by finding the velocity/acceleration from *x* - *t* / *v* - *t* graphs of SHM. Practical skills: Use ICT such as computer modelling, or data logger to collect data, or use of software to process data on SHM experiments.		

3.6.4 Simple harmonic motion

Prior knowledge: Uniform linear. Newton's Laws. $F = ma$. Small angle approximation.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Derivation of formulae for the period of a mass-spring system and a simple pendulum. $T = 2\pi\sqrt{\frac{m}{k}}$ $T = 2\pi\sqrt{\frac{l}{g}}$ Variation of *Ek* , *Ep* , and total energy with both displacement and time. Total energy of the oscillator = $\frac{1}{2}m\omega^2A^2$	1.5 weeks	Given appropriate structure and support students should be able to derive the equations for mass-spring and simple pendulum. Use the mass-spring and pendulum equations to solve SHM problems. Describe the energy changes that take place in SHM and sketch graphs of variation of E_k, E_p and total energy with displacement and time.	With support students derive the equations for the mass-spring system and pendulum. Rehearse mass-spring, pendulum and other harmonic oscillator problem solving using Exampro questions. **Required practical investigation:** mass-spring and pendulum system. Students confirm mathematical relationships between variables, for period and mass in the mass-spring system. Students compare the form of the mass-spring and pendulum systems. Discuss the energy changes that occur during SHM using the Nothing Nerdy simulation.	Exampro QS13.4A.09 QW11.4A.07 QS13.4.03 QBS04.4.03	Rich Question: How should a suspension system work to give the smoothest possible ride? Mass-spring resources from IOP Pendulum resources from IOP Nothing Nerdy Energy simulation Water in a U-tube ISA June 2012

Required practical 5: Investigation into simple harmonic motion using a mass–spring system and a simple pendulum.			**Skill developed by learning activities:** Apply knowledge and understanding of scientific ideas to derive the equations for the mass spring and pendulum systems. Analyse and interpret data from to reach conclusions on the relationship between variables in oscillating systems. Students should recognise the use of the small-angle approximation in the derivation of the time period for examples of approximate SHM		
Extension			A step method using a spread sheet to model SHM.		

3.7 Gravitational fields and satellites

3.7.2 Newton's gravitational law

Prior knowledge: Basic forces including gravity.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Gravity as a universal attractive force acting between all matter. Force between point masses: $F = \frac{Gm_1m_2}{r^2}$ where *G* is the gravitational constant.	0.5 weeks	Understand that gravity is a force that acts between all matter, is always attractive. Calculate the force between masses using Newton's Law of gravitation.	Students brainstorm gravity. Discussion of gravity and weight leading to Newton's Law of gravitation. Students use Newton's Law of gravitation to estimate the force between different objects, e.g. two golf balls a metre apart, the Moon and the Earth. **Skill developed by learning activities:** Mathematical skills: Make order of magnitude calculations for gravitational forces between objects.	Questions from IOP on Newton's Law of Gravitation	Rich Question: What is the Newton's 3rd Law reaction force to your weight?

3.7.3 Gravitational field strength:

Prior knowledge: Contact and non-contact forces. Magnetic field diagrams.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
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 as defined by $g = \frac{F}{m}$ Magnitude of *g* in a radial field given by $g = \frac{GM}{r^2}$	0.5 weeks	Understand and describe the concept of a force field. Sketch gravitational fields around objects and near the surface of the Earth. Recall the definition of gravitational field strength and use the gravitational field strength equations, $g = \frac{F}{m}$ $g = \frac{GM}{r^2}$	Discuss contact and non-contact forces as an introduction to the concept of a force field. Demonstration of magnetic field pattern around a bar magnet with iron filings. Students plot field lines with a compass. Discuss how field line model can be used to draw gravitational fields. Students draw gravitational fields around masses and close to the surface of the Earth. Apollo 11 mission data analysis from IOP. Definition of gravitational field strength and rehearsal of calculations using *g* = F / m and *g* = GM/r^2	Exampro QS13.4A.13 QS12.4A.13 QS10.4B.01	Rich Questions: How does the gravitational field around a star change as it evolves through its life cycle? Gravitational field strength calculations from the IOP

			Skills developed by learning activities: Demonstrate knowledge and understanding of the concept of gravitational fields. Apply knowledge and understanding of gravitational field strength to solve problems in different contexts.		
Extension			Apollo 11 mission data analysis from IOP		

3.7.4 Gravitational potential

Prior knowledge: Work. Potential difference. Gravitational potential energy (*GPE = mgh*)

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Understanding of definition of gravitational potential, including zero value at infinity and potential difference. Work done in moving mass *m* given by $\Delta W = m\Delta V$ Equipotential surfaces: appreciation that no work is done when moving along an equipotential surface. Gravitational potential *V* in a radial field given by $V = -\frac{GM}{r}$	0.5 weeks	Define gravitational potential. Recall and understand zero value at infinity. Understand and apply the concept of potential difference including through calculations. Draw equipotential surfaces on field line diagrams and understand apply the concept that potential difference along an equipotential line is zero.	Discuss changes in gravitational potential energy at the surface of Earth and beyond. Relate these changes to the concept of work. Students sketch graphs to show the variation of g and V with r. Students recognise need for a zero value of potential at infinity. Significance of area under *g -r* graph and gradient of *V-r* graph. Discuss similarities of contour maps and equipotential surfaces. Rehearse calculations and problem solving using Exampro questions.	Exampro QAW05.4B.03 QW13.4.01	Rich Question: What is the best choice for the zero point of reference for potential energy? TAP resources

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Graphical representations of variations of *g* and *V* with *r*. *V* related to *g* by: $g = -\frac{\Delta V}{\Delta r}$		Use the equations $\Delta W = m\Delta V$ $V = -\frac{GM}{r}$ $g = -\frac{\Delta V}{\Delta r}$ to solve problems. Understand the significance of the negative sign. Sketch and interpret graphs to show the variation of *g* and *V* with *r*. Recall and use the relationship $V = -\frac{GM}{r}$	**Skill developed by learning activities:** Demonstrate knowledge and understanding of the concept of gravitational potential when solving problems. Mathematical skills: Students use graphical representations to investigate relationships between *v*, *r* and *g*.		

3.7.5 Orbits of planets and satellites

Prior knowledge: Circular motion. Centripetal force. Gravitational forces and potential.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Orbital period and speed related to radius of circular orbit. Energy considerations for an orbiting satellite.	0.5 weeks	Describe the energy considerations for an orbiting satellite and provided with structure solve problems.	Students prepare notes on the energy considerations for a satellite using online tutorial information, e.g. Lisa Volkinen. Rehearse problem solving using Exampro questions. **Skill developed by learning activities:** Demonstrate knowledge and understanding of satellites and their orbits when relating observed orbits to uses. Apply knowledge and understanding of gravitational potential when explaining energy considerations in the orbit of satellites.	Exampro QAS03.4B.02 QAW06.4B.04 SAMs Paper 2 Q6	Rich Question: Is it better to launch a rocket from the poles or the equator? Energy of orbits by Lisa Volkinen Escape Velocity Resources from the Beacon Learning Centre J-track

3.8 Electric fields and Capacitance

3.8.1 and 3.8.2 Coulomb's law and Electric field strength

Prior knowledge: Non-contact forces. Concept of a force field. Use of field lines to represent a force field. Work. Circular motion and centripetal force.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Force between point charges in a vacuum: $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ where ε_0 is the permittivity of free space. Appreciation that air can be treated as a vacuum when calculating force between charges. For a charged sphere, charge may be considered to be at the centre.	0.5 weeks	Understand the meaning of ε_0 and that air can approximately be treated as a vacuum. Use electric field lines to sketch electric field patterns. Define electric field strength. Use the equations $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$	Discuss similarities of the equations for electric and gravitational fields. Discussion of forces between point charges and Coulomb law including ε_0. Students rehearse calculation of electric forces between point charges. Students calculate and then compare the electric and gravitational forces in a hydrogen atom. Demonstration of electric field lines with oil and semolina. Students sketch electric field lines and equipotential lines. Student experiment: equipotential lines with conducting paper.	Exampro QS12.4B.02 QW11.4B.04	Rich Questions: Design an experiment to confirm the Coulomb law. Is the gravitational or electric force the dominant force in the universe? Electric field lines with oil and semolina from IOP. Antonine Education Electric Field questions

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Comparison of the magnitude of gravitational and electrostatic forces between subatomic particles. Representation of electric fields by electric field lines. Electric field strength. E as force per unit charge defined by $E = FQ$ Magnitude of E in a uniform field given by $E = V / d$ Derivation from work done moving charge between plates: $Fd = EQ$		$E = FQ$ and $E = V / d$ to solve electric field problems. Derive $Fd = EQ$ Sketch and describe the trajectory of a moving charged particle entering a uniform electric field initially at right angles.	Define electric field strength and derivation of $Fd = EQ$ Demonstration: Displacement of a charged polystyrene ball (coated with conducting paint) in field between parallel plates. Demonstration of trajectory of a moving charged particle in an electric field using electron deflection tube. Rehearsal of problem solving using Antonine Education questions. **Skill developed by learning activities:** Apply knowledge and understanding of electric fields and circular motion to describe and explain the trajectory of a charge particle in a uniform electric field. Practical skills: correctly construct circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components,		Electron deflection demonstration from Nuffield Foundation

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Trajectory of moving charged particle entering a uniform electric field initially at right angles. Magnitude of *E* in a radial field given by $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$			including those where polarity is important when plotting equipotential lines.		
Extension			Students calculate e/m from electron deflection tube data.		

3.8.3 Electric Potential

Prior knowledge: n/a

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
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 $\Delta W = Q \Delta V$ Equipotential surfaces. Appreciation that no work done moving charge along an equipotential surface.	0.5 weeks	Define absolute electric potential and explain the significance of the zero value at infinity. Understand and use the concept of potential difference. Sketch and use equipotential diagrams. Recognise and use the idea that no work is done by a moving charge on an equipotential surface.	Discussion of absolute potential including concept of work and significance of infinity. Use PhET electric fields simulation to investigate electric fields and electric potentials. Student experiment : Equipotential lines from IOP. Rehearsal of problem solving using s-cool questions and IOP questions. **Skill developed by learning activities:** Apply knowledge and understanding of electric fields and circular motion to describe and explain the trajectory of a charge particle in a uniform electric field.	Exampro QW12.4B.01	Rich Questions: PhET electric fields activity 1 and 2 Equipotential lines student experiments from IOP s-cool questions IOP resources and questions

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
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*. *V* related to *E* by $E = -\Delta V / \Delta r$ ΔV from the area under graph of *E* against *r*.		Use the equation $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ Sketch and use graphs showing the variations of E and V with r. Recognise and use the relationships $E = -\Delta V / \Delta r$ and ΔV is the area under graph of *E* against *r*.	Practical skills: Correctly construct circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important when plotting equipotential lines. Mathematical skills: ΔV from the area under graph of *E* against *r* and be able to calculate it or estimate it by graphical methods as appropriate.		

3.8.4 Capacitors

Prior knowledge: dc circuits, charge and potential difference, uniform electric field

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Definition of capacitance: $C = Q/V$ Dielectric action in a capacitor $C = A\varepsilon_0\varepsilon_r/d$ Relative permittivity and dielectric constant. Students should be able to describe the action of a simple polar molecule that rotates in the presence of an electric field. Interpretation of the area under a graph of charge against pd. $E = ½\ QV = ½CV^2 = ½\ Q^2C$	1.5 weeks	Define capacitance. Use the equations $C = A\varepsilon_0\varepsilon_r/d$, $E = ½\ QV = ½\ CV^2 = ½\ Q^2C$ to solve problems. Understand and use the terms relative permittivity and dielectric constant. Describe the action of a simple polar molecule that rotates in the presence of an electric field.	Demonstration of a 'super-capacitor' and capacitors in everyday life. Student experiment: Investigate the relationship between Q and V for a capacitor in order to define capacitance and the farad. Student experiment or demonstration: Use a reed switch or digital capacitance meter to investigate a parallel plate capacitor. Student experiment: Energy stored in a capacitor to lift a mass. Rehearse problems on capacitors using Exampro.	Exampro QS11.4B.03 QW11.4A.17 QAS04.4A.05 SAMs Paper 2 Q 2	Rich Question: What features are desirable in the design of a capacitor? Super-Capacitor and capacitors in everyday life from IOP Student experiments : Investigating Q and V for a capacitor and investigating a parallel plate capacitor Student experiment : energy stored in a capacitor

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
		Find and interpret the area under a graph of charge against potential difference.	**Skill developed by learning activities:** Apply knowledge and understanding of capacitors to solve problems in a variety of contexts. Practical skills: Correctly construct circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important when plotting equipotential lines. Practical skills: Design, construct and check circuits using DC power supplies, cells, and a range of circuit components.		

3.9 Electric fields and Capacitance

3.9.1 Capacitor charge and discharge

Prior knowledge: n/a

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Graphical representation of charging and discharging of capacitors through resistors. Corresponding graphs for *Q*, *V* and *I* against time for charging and discharging. Interpretation of gradients and areas under graphs where appropriate. Time constant *RC*. Calculation of time constants including their determination from graphical data.	0.5 weeks	Sketch graphs of *Q, V* and *I* against time to show charging and discharging of capacitors through different resistances. Find and interpret the area and gradient of graphs representing the discharge of capacitors. Recall the use the concept of Time Constant *RC*.	**Required practical:** Investigation of the charge and discharge of capacitors. Students use a spreadsheet to investigate how potential difference changes when a capacitor is charged and discharged. Discussion of *RC* to include dimensional analysis of unit as time and comparison to half-life. Rehearsal of problem solving using problems from IOP and s-cool.	Exampro QAS05.4B.03 QAW04.4B.04	Rich Question: Outline the similarities and differences between radioactive decay and capacitor charge and discharge. IOP charge and discharge of a capacitor experiment, spreadsheet modelling activity and other resources and questions. Capacitor problems from s-cool

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Time to halve, $T_{½}$ = ln2*RC* Quantitative treatment of capacitor discharge, $Q = Q_0 e^{-t/RC}$ Use of the corresponding equations for *V* and *I*. Quantitative treatment of capacitor charge, $Q = Q_{max}(1 - e^{-t/RC})$ **Required practical 6:** Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant, *RC*		Solve problems including the use of the equations : $T_{½}$ = 0.69*RC*, $Q = Q_0 e^{-t/RC}$ and $Q = Q_{max}(1 - e^{-t/RC})$	**Skill developed by learning activities:** Demonstrate knowledge and understanding of capacitor discharge by sketching graphs of *Q*, *V* and *I* against time. Practical skills: Use ICT in the form of computer modelling of capacitor discharge.		

3.9.2 Exponential changes in radioactivity

Prior knowledge: Simple understanding of probability. Random nature of radioactive decay. Activity and the Becquerel. Logarithms.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Random nature of radioactive decay; constant decay probability of a given nucleus; $$\frac{\Delta N}{\Delta t} = -\lambda N$$ $$N = N_o e^{-\lambda t}$$ Use of activity, $$A = \lambda N$$ Modelling with constant decay probability. Questions may be set which require students to use $$A = A_o e^{-\lambda t}$$	1 week	Recognise and understand the random nature of radioactive decay. Use the equations $$\frac{\Delta N}{\Delta t} = -\lambda N$$ $$N = N_o e^{-\lambda t}$$ $$A = \lambda N$$ $$T_{½} = \frac{\ln 2}{\lambda}$$ $$A = A_o e^{-\lambda t}$$ to solve radioactive decay problems in a variety of contexts.	Discussion of definition of the decay constant and activity. Modelling radioactive behaviour with dice. Rehearsal of radioactive decay equations. Find the half-life of protactinium or using gas mantle apparatus. **Skill developed by learning activities:** Apply knowledge and understanding of radioactive decay to the storage of radioactive waste and radioactive dating. Analyse, interpret and evaluate data on radioactive decay to make judgements and reach conclusions.	Exampro QAS04.05.01 SAMs Paper 2 Q 4	Rich Question: How long do we have to wait until a radioactive source is safe? Radioactive Decay questions from s-cool Half-life of protactinium experiment from the IOP Modelling radioactive decay with dice

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Questions may also involve use of molar mass or the Avogadro constant. Half-life equation: $T_{½} = \frac{\ln 2}{\lambda}$ Determination of half-life from graphical decay data including decay curves and log graphs.		Determination of half-life from graphical data. Apply knowledge and understanding of half-life to explain considerations such as the safe storage of radioactive waste and radioactive dating of rocks.	Mathematical skills: Understand simple probability in radioactive decay. Mathematical skills: Understand and use the symbols : $\propto$, Δ Mathematical skills: Translate information between graphical, numerical and algebraic forms when dealing with radioactive decay.		
Extension			Students consider parallels between the mathematics of radioactive decay, capacitor discharge and damped harmonic motion.		

3.10 Magnetic fields

3.10.1 Magnetic Flux Density

Prior knowledge: Construction of DC circuits, basic magnetism and electromagnetism.

Learning objective/	Time taken in weeks	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Force on a current-carrying wire in a magnetic field: *F* = *BIL* when field is perpendicular to current. Fleming's left hand rule. Magnetic flux density *B* and definition of the tesla.	1	Be able to predict the direction of a force on a current carrying wire. Use the equation *F*=*BIL* to calculate the force on a current carrying wire or magnetic flux density. Describe an investigation to investigate the relationship between magnetic flux density, current and length of a wire.	Demonstration of 'kicking wire' experiment. Students apply knowledge of magnetic fields and Fleming's left hand rule to explain and predict the direction of the force on the wire. Students construct dc motor kits from diagrams. Students explain using diagrams the operation of a dc motor. Students complete problems on forces on conductors in magnetic fields. Investigate the relationship between magnetic flux density, current and length of a wire.	Exampro QAS03.4B.03 QS12.4A.20	Kicking wire simulation Force on Conductors in Magnetic Field Questions from IOP Rich questions: How can we change electrical energy into kinetic energy? How can we quantify the strength of a magnetic field?

Learning objective/	Time taken in weeks	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
			Skill developed by learning activities: Apply knowledge and understanding to predict direction of motion of a spinning motor. Mathematical skills: Visualise and represent 2D and 3D forms including two dimensional representations of 3D. objects Practical skills: The construction of dc circuits with correct polarity.		

3.10.2 Moving charges in a magnetic field

Prior knowledge: Circular motion and centripetal forces.

Learning objective/	Time taken hours	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Force on charged particles moving in a magnetic field, $F = BQv$ when the field is perpendicular to velocity. Direction of force on positive and negative charged particles. Circular path of particles; application in devices such as the cyclotron.	1 week	Apply the equation $F = BQv$ to problems where a charge particle is moving in a magnetic field. Explain how the force on the charged particle leads to circular motion in devices such as the cyclotron.	Demonstration of fine beam tube. Students explain the deflection of the beam and use Fleming's left-hand rule to predict the direction of the curvature. Students research, present and peer assess talks on one of : mass spectrometer/a particle accelerator/ Cyclotron/Hall Probe. **Skill developed by learning activities:** Demonstrate knowledge and understanding of forces on charged particles in magnetic fields. Apply knowledge and understanding to explain machines that use magnetic forces to guide the motion of charged particles.	Exampro QAS04.4B.02 QS13.4B.03	Rich questions: Show this Cyclotron applet How can the movement of charged particles be controlled? What are the applications of controlling the movement of charged particles?

Learning objective/	Time taken hours	Learning Outcome	**Learning activity with opportunity to develop skills**	**Assessment opportunities**	Resources
			Mathematical skills: Visualise and represent 2D and 3D forms including two dimensional representations of 3D objects		
Extension			Experiment to measure e/m. Cyclotron teaching resources from Triumpf		

3.10.3 Magnetic flux and flux linkage

Prior knowledge: Basic magnetism and electromagnetism

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
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 $N\phi = BAN\cos\theta$	1 week	Be able to define flux and flux linkage. Use the relationships $\phi = BA$ and $N\phi = BAN\cos\theta$ to calculate flux linkage in common contexts such as a conductor dropped in a uniform magnetic field or a rectangular coil in an electric motor.	Students sketch magnetic flux patterns. Develop concept of flux linkage through sketching diagrams from a flux linkage animation. Practise calculating flux linkage in simple scenarios. Investigate the effect on magnetic flux density of varying the angle using a search coil and oscilloscope. **Skill developed by learning activities:** Demonstrate knowledge and understanding of magnetic flux. Mathematical skills: Use calculators to handle $\sin x$, $\cos x$, $\tan x$ when x is expressed in degrees or radians.	Exampro QAW04.4B.03	Sketching flux patterns exercises from IOP Flux linkage animation Antonine Education Flux linkage calculations

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
			Mathematical skills: Use sin, cos and tan in physical problems. Practical skills: Use appropriate analogue apparatus to record a range of measurements and to interpolate between scale markings. Practical skills: Use signal generator and oscilloscope, including volts/division and time-base.		

3.10.4 Electromagnetic Induction

Prior knowledge: The relative motion of a conductor in a magnetic field induces an electric current.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Simple experimental phenomena. Faraday's and Lenz's Laws. Magnitude of induced emf = rate of change of flux linkage $= N \Delta \phi / \Delta t$ Applications such as a straight conductor moving in a magnetic field. emf induced in a coil rotating uniformly in a magnetic field: $\varepsilon = BAN\omega \sin \omega t$	1 week	Recognise situations in which electromagnetic induction will occur. Recall Faraday's and Lenz's Laws. Calculate the emf induced by electromagnetic induction in scenarios such as a straight conductor moving in a magnetic field or a coil rotating in a magnetic field.	Investigate the emf induced when a bar magnet falls through a coil. Calculations using Faraday's Law. Apply knowledge to calculate emf induced in airliner wing and case study ED Tethers. Apply Lenz's Law to explain electromagnetic braking. Practice questions on Faraday's and Lenz's Laws. **Skill developed by learning activities:** Demonstrate knowledge and understanding of how changing flux linkage produces an emf.	Exampro QAS06.4B.04 QW13.4B.05 QSP.4A.21 SAMs Paper 2 Q5	Rich Question: How is electricity made? Demonstrations, and questions from IOP ED Tether information from Earth Observation Portal

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
			Apply knowledge and understanding of scientific ideas to explain electromagnetic braking. Mathematical skills: Understand and use the symbols: =, <, <<, >>, >, ∝, ≈, Δ Mathematical skills: Calculate rate of change from a graph showing a linear relationship.		
Extension			Investigate the motion of a pendulum damped by electromagnetic braking or other Eddy current brake.		Example of an Eddy current brake investigation

3.10.5 Alternating Currents

Prior knowledge: The difference between ac and dc signals.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Sinusoidal voltages and currents only; root mean square, peak and peak-to-peak values for sinusoidal waveforms only. $$I_{rms} = \frac{I_0}{\sqrt{2}}$$ $$V_{rms} = \frac{V_0}{\sqrt{2}}$$ Application to the calculation of mains electricity peak and peak-to-peak voltage values.	0.5 weeks	Know the meaning of the terms root mean square and peak-to-peak (rms) value. Use the equations $$I_{rms} = \frac{I_0}{\sqrt{2}}$$ $$V_{rms} = \frac{V_0}{\sqrt{2}}$$ to calculate root mean square values or peak values.	Students to use an oscilloscope to compare dc and ac signals. Students should calculate peak to peak and rms values from experimental work. (compare calculated values with readings on digital or moving coil meters) Use oscilloscope to determine period of output from a signal generator(hence *f*). Practice questions on oscilloscope from IOP. **Skill developed by learning activities:** Demonstrate knowledge and understanding of rms and peak values.	Exampro QS12.1.05	Rich Question: What range of voltage does the mains supply? Use and questions on an oscilloscope from the IOP AC questions and resources from IOP

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Use of an oscilloscope as a dc and ac voltmeter, to measure time intervals and frequencies, and to display ac waveforms. No details of the structure of the instrument are required but familiarity with the operation of the controls is expected.		Use of an oscilloscope to display dc and ac voltage signals and find rms and peak values.	Analyse and interpret data from oscilloscope display to find rms and peak values. Mathematical skills: Translate information between graphical, numerical and algebraic forms. Practical skills: Use signal generator and oscilloscope, including volts/division and time-base.		
Extension					Example of an Eddy current brake investigation

3.10.6 Operation of a transformer

Prior knowledge: Electrical power = VI. Structure of a transformer : primary coil, secondary coil, laminated iron core. Use of transformers in National Grid.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
The transformer equation: $$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$ Transformer efficiency $$efficiency = \frac{I_s V_s}{I_p V_p}$$ Production of eddy currents. Causes of inefficiencies in a transformer.	0.5 weeks	Use the transformer and efficiency equations to solve problems related to structure and operation of transformers. Explain how Eddy currents form in transformers and how this leads to inefficiency. Describe the role of transformers in the transmission of power.	Demonstrate the construction and operation of a transformer. Students sketch the parts of a transformer and explain its operation using their knowledge of induction. Video resource available. Build transformers and check transformer and efficiency equation. Explain discrepancies using Eddy currents, copper losses and hysteresis (friction as molecular magnets flip). Calculation practice : Transformer equations using Antonine website. **Skill developed by learning activities:** Demonstrate knowledge and understanding of construction and operation of a transformer.	Exampro QS13.4A.25 QW13.4A.24	Rich Questions: What factors would need to be considered when designing a transformer? Why is the mains ac and not dc? Video : How Transformers work from Learn Engineering Antonine Education : transformers

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Transmission of electrical power at high voltage including calculations of power loss in transmission lines. **Required practical 7:** Investigation of the efficiency of a transformer.		Use electrical power equations to calculate power losses in transmission lines.	Analyse, interpret and evaluate data from building transformer practical. Mathematical skills: Use ratios in transformer problems. Practical skills: Evaluate results of transformer experiment and draw conclusions about efficiency.		

3.11 Thermal Physics

3.11.1 Energy transfer by heating and doing work

Prior knowledge: States of matter. Heat transfer mechanisms (conduction, convection and radiation). Basic kinetic theory.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Internal energy is the sum of the randomly distributed kinetic energies and potential energies of the particles in a body. The internal energy of a system is increased when energy is transferred to it by heating or when work is done on it (and vice versa).	1.5 weeks	Recall, understand and use the term internal energy and the equation for the first law of thermodynamics. Recall the definition of specific heat capacity and specific latent. Understand and apply the equation $Q = mc\Delta\theta$ to solve thermal energy transfer problems including in continuous flow.	Discuss simple examples of the application of the first law e.g. fire piston, bicycle pump, further examples of demonstrations can be found on the IOP website. Students to write first Law equations paying particular attention to sign conventions. Discuss the difference between temperature and heat. Demonstration of the 'Fire proof balloon' leading to concept and definition of specific heat capacity. Students measure the heat capacity of different substances using a variety of methods.	Exampro QAW00.3.07 QS13.5.03 QS12.5.01 QAS03.2.01	Rich Question: You can put out a candle with moist fingers (800^0C) but putting your hand in boiling water is very dangerous (100^0C). Explain. Fire piston video clip Demonstrations of 1st Law from IOP Fire proof balloon demonstration and notes. Measuring Heat Capacity from IOP

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
The first law of thermodynamics: $\Delta U = Q + W$ where Q is the energy input to the system by heating and W is the work done ON the system. Appreciation that during a change of state the potential energies of the particle ensemble are changing but not the kinetic energies. Calculations involving transfer of energy including continuous flow systems. For a change of		Understand and apply the equation $Q = ml$ to solve thermal energy transfer problems where there is a change of state.	Demonstration and discussion of changes of state without temperature change e.g. water boiling, stearic acid freezing. Students measure a specific latent heat, for example ice. Rehearsal of specific heat and latent heat examination questions from cyberphysics.co.uk **Skill developed by learning activities:** Demonstrate knowledge and understanding of specific heat and specific latent heat. Apply knowledge and understanding of scientific ideas to solve problems involving transfer of thermal energy.		Measuring Latent heat of ice from IOP Specific Heat and Latent heat questions from Cyberphysics.co.uk

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
temperature: $Q = mc\Delta\theta$ where *c* is specific heat capacity. For a change of state $Q = ml$ where *l* is the specific latent heat. **Required practical 8**: Determination of specific heat capacity by an electrical method.			Mathematical and practical skills: Investigate the factors that affect the change in temperature of a substance using an electrical method or the method of mixtures. Students should be able to identify random and systematic errors in the experiment and suggest ways to remove them. Practical skills: Investigate, with a data logger and temperature sensor, the change in temperature with time of a substance undergoing a phase change when energy is supplied at a constant rate.		

3.11.2 Energy transfer by heating and doing work

Prior knowledge: States of matter. Heat transfer mechanisms (conduction, convection and radiation). Basic kinetic theory.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Rate of energy transfer by conduction = $\frac{kA\Delta\theta}{L}$ where *k* is the thermal conductivity. Use of *U* -values to calculate energy losses for parallel surfaces only. Rate of energy transfer = *UA* $\Delta\theta$ where $U = \frac{k}{L}$	**1.0 week**	Understand and use the relationship Rate of energy transfer by conduction = $\frac{kA\Delta\theta}{L}$ Understand and use U-value data to calculate energy losses. Understand and use the relationship: Rate of energy transfer = *UA* $\Delta\theta$ where $U = \frac{k}{L}$	Ask students to design an experiment to compare the ability of materials to transfer heat energy by conduction. Demonstrate Lee's Disc experiment and/or students use the Lee Disc experiment simulator. Discuss the use of U-values in engineering (for example building) with students. Students work through the example on Cyberphysics. **Skill developed by learning activities:** Demonstrate knowledge and understanding of U-values. Apply knowledge and understanding of scientific ideas to solve problems involving transfer of thermal energy.		Rich Question: How would you compare the ability of different materials to conduct heat? Lee's Disc experiment and simulator Cyberphysics U-Values

3.11.3 Ideal Gases

Prior knowledge: States of matter. Basic kinetic theory. *Work = force x distance*. Atomic notation.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Gas laws as experimental relationships between *p, V, T* and the mass of the gas. Concept of absolute zero of temperature. Ideal gas equation: $pV = nRT$ for *n* moles and $pV = NkT$ for *N* molecules. *Work done* = $p\,\Delta V$ Avogadro constant *NA* , molar gas constant *R* , Boltzmann constant *k.* Molar mass and molecular mass.	1.5 week	Recall the gas laws that give the relationships between *p*, *V* and *T* and the mass of a gas. Express these in words, algebraically and graphically. Understand the concept of absolute zero of temperature and how the gas laws lead to the existence of this temperature. Derive the equation *Work done* = $p\,\Delta V$	Students investigate Boyle's Law and Charles's Law. Students extrapolate their results to find absolute zero and evaluate the experiment. Discuss the Kelvin temperature scale and students practise converting between ^{o}C and K. Discussion of how to combine the gas law expressions to find the Ideal gas equation. Students to be familiar with all of the relevant terms: *N, k,* N_A, *R,* Molar Mass and molecular mass. Write a science dictionary entry for each. With support students derive the equation for the work done on/by a gas : *Work done* = $p\,\Delta V$ Rehearsal of calculations using IOP and www.s-cool.co.uk questions.	Exampro QS13.5.04 QS12.5.04	Rich Question: What is the best scale for measuring temperature? Boyle's Law and Charles's Law investigations from CLEAPPS and an alternative for Boyles Law from Flinn Scientific IOP questions on Ideal Gases. www.s-cool.co.uk examination style questions

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Required practical 9: Investigation of Boyle's law (constant temperature) and Charles's law (constant pressure) for a gas.		Understand and use the terms: Avogadro constant, molar mass, molecular mass. Use the gas law equation *Work done* = $p \Delta V$ to solve problems on the behaviour of gases.	**Skill developed by learning activities:** Demonstrate knowledge and understanding of the Ideal Gas equation. Analyse and interpret data from gas law experiments to find a value for absolute zero and evaluate this value. Mathematical skills: Sketch the relationship modelled by $y = k/x$, when dealing with an Ideal Gas.		

3.11.4 Kinetic Theory of Gases

Prior knowledge: Newton's Laws of motion. Momentum. Ideal Gas laws.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Brownian motion as evidence for existence of atoms. Explanation of relationships between *p*, *V* and *T* in terms of a simple molecular model. Students should understand that the gas laws are empirical in nature whereas the kinetic theory model arises from theory.	1 week	Describe Brownian motion and understand how it provides evidence for the existence of atoms. Explain relationships between *p*, *V* and *T* in terms of a simple molecular model. Understand that the gas laws are empirical in nature whereas the kinetic theory model arises from theory.	Observe Brownian motion through a microscope or a video clip. Students explain the observation and discussion of correct explanation using Brownian motion simulator. Demonstration: Kinetic theory model with ball bearings to demonstrate how particle collisions lead to the relationship *p*, *V* and *T*. Students rehearse explanations in writing. With support students discuss the assumptions and derivation of the kinetic theory. Students write a short essay on the development of the gas laws from an experimental and theoretical perspective. They peer assess work before handing in for marking.	Exampro QAW03.2.04 QBS04.4.01 QBSOB6.4.06 SAMs Paper 2 Q 3	Rich Question: Suggest and explain conditions under which the kinetic theory would fail to describe the behaviour of a gas. YouTube video clip of Brownian motion Brownian motion simulator Cyberphysics Kinetic theory examination style questions.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Assumptions leading to $pV = \frac{1}{3}N\,m\,(c_{rms})^2$ including derivation of the equation and calculations. A simple algebraic approach involving conservation of momentum is required. Use of average molecular kinetic energy $\frac{1}{2}m\,(c_{rms})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$		Know the assumptions of the kinetic theory and the derivation of $pV = \frac{1}{3}N\,m\,(c_{rms})^2$ Use the equations of the kinetic theory to solve problems. Describe how knowledge and understanding of gaseous behaviour has changed over time.	Question practice using examination questions from Cyberphysics. **Skill developed by learning activities:** Demonstrate knowledge and understanding of Brownian motion and the development of kinetic theory. Apply knowledge and understanding of mechanics to derive the kinetic theory equations.		

3.12 Nuclear Energy

3.12.1 Radius of the nucleus

Prior knowledge: Nuclear model of the atom. Properties of alpha radiation. Coulomb's Law. Momentum. Wave particle duality - Electron Diffraction.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Estimate of radius from closest approach of alpha particles and determination of radius from electron diffraction. Knowledge of typical values for nuclear radius. Dependence of radius on nucleon number: $R = R0A^{1/3}$ derived from experimental data. Interpretation of equation as evidence for constant density of nuclear material.	0.5 weeks	Understand and describe how closest approach and electron diffraction give an estimate size for nuclear radius. Use the Coulomb Law to carry out closest approach calculations. Use the equation $R = R0A^{1/3}$ to relate the radius of different nuclei to nucleon number. Given appropriate data calculate nuclear densities.	Students estimate the order of magnitude size of the nucleus and the relative size of the nucleus relative to an atom. An analogy using everyday objects is useful, e.g. a small ball bearing for the nucleus. Students carry out closest approach and electron diffraction calculations to estimate the size of the nucleus. Use a spread sheet to calculate and plot a graph of the nuclear radius of a range of atoms. Students calculate the density of the proton/neutron and then for a number of different nuclei to appreciate how nuclear density remains constant.	Exampro QS12.5.05 QAW05.05.01	Rich Question: How do we know the size of an atom and the nucleus within? Closest approach and electron diffraction resources from IOP

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Calculation of nuclear density. Students should be familiar with the graph of intensity against angle for electron diffraction by a nucleus.		Recall the order of magnitude radius for the nucleus.	**Skill developed by learning activities:** Demonstrate knowledge and understanding of the size of the nucleus and evidence for this. Apply knowledge and understanding of Coulomb's Law and diffraction to calculate nuclear radii. Mathematical skills: Make order of magnitude calculations in determining nuclear densities.		
Extension			Data from the Rutherford Scattering experiment can be used for deeper mathematical modelling.		IOP data from Rutherford Scattering Experiment and analysis activity.

3.12.2 Mass and Energy

Prior knowledge: Atomic mass units and atomic notation. The electron volt and the mega electron volt. Nuclear equations.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Appreciation that $\Delta E = \Delta mc^2$ applies to all energy changes. Simple calculations involving mass difference and binding energy. Atomic mass unit, u. Conversion of units; 1 u = 931.5 MeV. Fission and fusion processes. Simple calculations from nuclear masses of energy released in fission and fusion reactions.	0.5 week	Understand that $\Delta E = \Delta mc^2$ applies to all energy changes. Define and understand the term binding energy. Calculate mass difference / binding energy using appropriate units including fission and fusion reactions. Describe fission and fusion processes including how knowledge of these processes informs energy supply choices.	Students calculate mass of an atom from the mass of its constituent nucleons and check for consistency with published values. Discussion of mass difference and binding energy. Students review the 'Fission and Fusion' video from the Science Channel. Rehearsal of mass difference and binding energy calculations from IOP resources and Cyberphysics. **Skill developed by learning activities:** Demonstrate knowledge and understanding binding energy, fission and fusion	Exampro QS1.15.01 QS1.15.03	Rich Questions: Is a mug of hot coffee more massive than a mug of cold coffee? Which element has the most stable nucleus? Fission and Fusion video from the Science Channel Mass difference and binding energy calculations from IOP Mass and Energy exam standard questions from Cyberphysics

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Graph of average binding energy per nucleon against nucleon number. Students may be expected to identify, on the plot, the regions where nuclei will release energy when undergoing fission/fusion.		Sketch the graph of average binding energy per nucleon against nucleon number and explain regions where fission and fusion will release energy.	Apply knowledge and understanding to calculate the energy released in nuclear fission and fusion. Mathematical skills: Recognise and make use of appropriate units (eV, MeV and J) in binding energy calculations. Mathematical skills: Translate information between graphical and numerical form with binding energy graph.		

3.8.1.7 Induced Fission

Prior knowledge: Atomic Structure. Nuclear equations. Elastic collisions.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Fission induced by thermal neutrons; possibility of a chain reaction; critical mass. The functions of the moderator, control rods, and coolant in a thermal nuclear reactor. Details of particular reactors are not required. Students should have studied a simple mechanical model of moderation by elastic collisions.	0.5 weeks	Describe the process of induced fission, chain reactions and the meaning of critical mass. Describe and explain the functions of the moderator (including use of a model of elastic collisions), control rods and coolant and the choice of material used for each.	'Bang Goes the Theory' Nuclear Reactors as preparation for extended writing task on Fission, Fusion and Nuclear Power. Extended writing on Nuclear Power stations, fission and fusion. Students should self and peer assess work before submission for marking. Nuclear Reactor Card loop game. CyberPhysics nuclear physics questions for consolidation and review of learning.	Exampro QS13.05.02 QS10.05.02	Rich Questions: What is a critical mass? Is nuclear energy the answer to our energy needs? Bang Goes the Theory Nuclear Power Station Introductory clip Fission and Fusion Nuclear Reactor Card loop game CyberPhysics nuclear physics questions Extended Writing task Nuclear Energy on TES resources

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Factors affecting the choice of materials for the moderator, control rods and coolant. Examples of materials used for these functions.			**Skill developed by learning activities:** Demonstrate knowledge and understanding of nuclear fission, fusion and the construction of a nuclear power station.		

3.12.4 Safety aspects nuclear reactors

Prior knowledge: Nuclear Power stations. Nature of Radiation.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Fuel used, remote handling of fuel, shielding, emergency shut-down. Production, remote handling, and storage of radioactive waste materials. Appreciation of balance between risk and benefits in the development of nuclear power.	0.5 weeks	Describe the safety considerations in nuclear power stations including the handling and storage of radioactive waste. Describe and evaluate the arguments for and against nuclear power.	Watch Nuclear Safety video and TED.com 'Do we need Nuclear Power?' debate. In trios one student prepares a short argument for nuclear power, another against and the third evaluates the two arguments. **Skill developed by learning activities:** Demonstrate knowledge and understanding of nuclear safety. Analyse, interpret and evaluate scientific information, ideas and evidence, including in relation to issues, to make judgements and reach conclusions on the development of nuclear power.	Exampro QAW06.4B.03	Nuclear Safety video clip from DW News – Tomorrow Today BBC video clip TED Nuclear Power Debate

3.12.4 Nuclear fusion

Prior knowledge: Electric potential, Boltzman constant, $\Delta E = \Delta mc^2$

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Knowledge of suitable nuclei for use in a fusion reactor. Estimation of kinetic energy of nuclei necessary for fusion to take place and of the temperature of the plasma. Energy release from fusion of two nuclei. Solar fusion cycle limited to the hydrogen cycle. Appreciation of the problems that have to be overcome to produce a practical nuclear reactor.	0.5 week	Recall suitable nuclei for a fusion reactor. Use ideas about electric potential to estimate the kinetic energy of the nuclei needed for fusion and the Boltzman constant to estimate the temperature of the plasma. Calculate the energy release from the fusion of two nuclei. Describe the solar fusion cycle (hydrogen cycle).	Introduce nuclear fusion with a fusion video clip. Students estimate the kinetic energy of the nuclei necessary for fusion using electric potential. Students use the Boltzman constant to estimate the energy of the plasma. Using data from the video clip students rehearse calculating energy release during fusion. Students work through the solar fusion cycle using Hyperphysics to produce a set of revision flashcards. Students research fusion reactors including the practical problems that need to be overcome. Students write a short essay on whether Fusion is a viable energy source in the next 50 years.		Rich Question: Why is nuclear fusion not a viable source of energy in the present day? Fusion video clip Hyperphysics : solar fusion

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
		Recall and explain the problems that have to be overcome to produce a practical nuclear reactor.	**Skill developed by learning activities:** Demonstrate knowledge and understanding of the hydrogen cycle.		

3.13 Energy Sources

3.13.1 Rotational Motion

Prior knowledge: Circular motion.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
$I = mr^2$ for a point mass. $I = \Sigma mr^2$ for an extended object. Qualitative knowledge of the factors that affect the moment of inertia of a rotating object. Expressions for moment of inertia will be given where necessary. Angular displacement, angular speed, angular velocity and angular acceleration.	2 weeks	Recall, understand use the equations $I = mr^2$ and $I = \Sigma mr^2$ Apply knowledge of moment of inertia to explain the factors that affect the moment of inertia of a rotating object. Recall and use the terms : Angular displacement, angular speed, angular velocity, angular acceleration.	Discuss the meaning of point and extended objects. Students give examples. Discuss moment of inertia as the angular equivalent of mass. Moment of inertia demonstration with ruler and moment of inertia racing from YouTube. Student experiment : find the moment of inertia of a flywheel from schoolphysics.co.uk. Using an inspection method students use their knowledge of the equations of linear motion to find the equations of rotational motion.	Exampro QSP.4A.06 QBS04.4.02 QS13.5C.02 QS10.5C.01 QAS03.7.03 SAMs Engineering Physics Q1	Rich Questions: Is a spoked or a solid wheel better for a racing bike? Try and spin yourself on a swivel chair without touching the ground (or another object). Why is this so difficult? (Bang Goes the Theory video clip from BBC) Moment of inertia demonstration with rulers and moment of inertia racing from YouTube.

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Equations for uniform angular acceleration $\omega = \omega_0 + \alpha t$ $\theta = \frac{(\omega_0+\omega)}{2}t$ $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ $\omega^2 = \omega_0^2 + 2\alpha\theta$ Torque = $Fr = I\alpha$ Angular momentum $I\omega$ Conservation of angular momentum Rotational kinetic energy $E_{k(rot)} = \frac{1}{2}I\omega^2$ Work $W = T\theta$ and power = $T\omega$ Students should be aware of the analogy between rotational		Use the equations for uniform angular acceleration to solve problems. Appreciate the analogy between rotational and translational dynamics. Solve problems using the equations $T = Fr = I\alpha$ and angular momentum = $I\omega$ Understand and use the concept of conservation of angular momentum to solve problems. Use the equations $E_{k(rot)} = \frac{1}{2}I\omega^2$	Describe objects that are undergoing uniform and non-uniform angular acceleration and ask students to sketch graphs to represent this, e.g. whirl an object attached to a string around a stick and allow the string to wind up; motion of a particle in a cyclotron; spiral coin collector (on YouTube). Demonstration of angular acceleration with a flywheel. Rehearsal of problem solving using questions. Demonstration of angular momentum and conservation of angular momentum on rotating chair/platform/playground roundabout from sfu.ca Discussion of frictional torque in rotating machinery. Rehearsal of problem solving using Exampro questions.		Student experiment : Moment of Inertia of flywheel from school physics.co.uk Demonstrations of conservation of angular momentum from sfu Video of conservation of angular momentum from the table top explainer

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
and translational dynamics. .		Work $W = T\theta$ and power = $T\omega$ to solve problems. Appreciate the analogy between rotational and translational dynamics.	**Skill developed by learning activities:** Demonstrate knowledge and understanding of moment of inertia. Apply knowledge and understanding of moment of inertia to explain the design of rotating objects.		
Extension			Student experiment : find the moment of inertia of a flywheel.		

3.13.2 - Wind energy, Solar Energy, Hydroelectric power and pumped storage.

Prior knowledge: Energy, power, inverse square law

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Maximum power available from a wind turbine $E = \frac{1}{2}\pi r^2 \rho v^3$ where ρ is the density of air. Appreciation why all this energy cannot be used. Wind shadows determine arrangement of turbines in a wind farm. Environmental factors in the use of wind turbines. Intensity of energy from the Sun at the Earth's surface.	1 week	Use the equation $E = \frac{1}{2}\pi r^2 \rho v^3$ to solve problems related to max power available from a turbine. Understand and explain reasons why the maximum power available is not achieved including wind shadows and arrangement of turbines. Appreciate environmental factors in the use of wind turbines.	Issue students with the learning objectives and divide the objectives amongst the students. Students research their allocated area and produce a summary sheet of information and an examination style question with a mark scheme. Collate these resources and students should complete all of the questions and peer review the materials. Group discussion of key points to consolidate learning, Students carry out an investigation of the inverse square law using a light-dependent resistor (LDR) and a point source.	Student created examination questions.	Rich Question: What features would the most effective wind farm/solar array/hydroelectric energy solution have? Inverse Square Law experiment from the IOP

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Use of inverse square law to determine intensity at different distances from the Sun: $I = \frac{P}{4\pi r^2}$ *V-I* characteristic and maximum power for a solar cell. Arrangement of cells in solar arrays. Components of a hydroelectric power station: Turbine and generator. Transfer of gravitational potential energy to kinetic energy.		Use inverse square law to determine intensity of sun at different distances from the sun including at the Earth's surface. Recall the *V-I* characteristic and maximum power for a solar cell. Describe the arrangement of cells in a solar array. Describe the components in a hydroelectric power station (turbine and generator)	**Skill developed by learning activities:** Demonstrate knowledge and understanding of the arrangement of solar cells in an array. Apply knowledge and understanding to calculate the maximum power available from the flow of water through a turbine.		

Learning objective/	Time taken	Learning Outcome	Learning activity with opportunity to develop skills	Assessment opportunities	Resources
Maximum power available from flow of water through a turbine $E = \frac{1}{2}\pi r^2 \rho v^3$ where ρ is the density of water. Idea of base-power stations and back-up power stations. Principles of operation pumped storage systems. **Required Practical 10:** Investigation of the inverse square law for light using an LDR and a point source.		Understand the energy transfer of gravitational energy to kinetic and calculate the maximum power available using the equation $E = \frac{1}{2}\pi r^2 \rho v^3$ Describe base-power stations, back-up power stations and the principles of pumped storage systems.			
Extension			Students investigate and then explain how a clutch works.		