Scheme of work

A-level Physics 7408

## v1.2

Introduction

This draft 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; it is available in Word for ease of editing.

The Scheme of Work 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 second year of A-level Physics 7408.

The teaching of investigative and practical skills is embedded within the specification. We have produced 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 [AQA](http://www.aqa.org.uk/subjects/science/as-and-a-level/biology-7401-7402/supporting-resources/teaching-resources) and new textbooks written to support the specification.

GCSE prior knowledge comprises knowledge from the 2011 Core and Additional Science AQA GCSE specifications. Students who studied the separate science GCSE courses will have this knowledge but may also have been introduced to other topics which are relevant to the 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.

**Assessment opportunities** detail past questions that can be used with students as teacher- or pupil self- assessments of your students’ knowledge and understanding. You may also use [Exampro](http://exampro.co.uk/scienceafl/) and the specimen assessment materials that are available via our [website](http://www.aqa.org.uk/subjects/science/as-and-a-level/biology-7401-7402/supporting-resources/specimen-papers-and-mark-schemes).

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## 3.6 Further mechanics and thermal physics

3.6.1 Periodic motion

3.6.1.1 Circular motion

Prior knowledge: Vectors and Scalars. Linear motion. Newton’s laws of motion.

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| **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  *ω = v / r = 2πf*  Radian measure of angle.  Direction of angular velocity will not be considered.  Centripetal acceleration *a = v2/r = ω2r*  The derivation of the centripetal acceleration formula will not be examined.  Centripetal force  *F* = *mv2*/r= *m*ω2*r* | 1 week | Understand and explain why circular motion is an accelerated motion and needs a centripetal force.  Recall and use equations  *ω = v / r= 2π f, a = v2/r = ω2r, F = mv2/r= mω2r,* to solve circular motion problems.  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. | 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 IOP.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of circular motion as an accelerated motion.  AO2: Apply knowledge and understanding of forces to identify and calculate centripetal forces.  MS4.7: Understand the relationship between degrees and radians and translate from one to the other in circular motion problems.  ATc: Use methods to increase accuracy of measurements, such as timing over multiple rotations in circular motion experiment. | 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.](https://www.youtube.com/watch?v=XXpURFYgR2E)  [Verification of the centripetal force experiment with a whirling bung – schoolphysics.co.uk](http://www.schoolphysics.co.uk/age14-16/Mechanics/Circular%20motion/experiments/Whirling_bung.doc)  [Circular motion problems from IOP](http://www.tap.iop.org/mechanics/circular/225/page_46483.html) |

3.6.1.2 Simple harmonic motion (SHM)

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

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| **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 ∝ − x*  Defining equation:  and  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.  Maximum speed  Maximum acceleration | 1 week | Recall the condition for SHM : *a* ∝ − *x*  Solve problems using the equations of SHM :  and  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 eg 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 ∝ − 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 spreadsheets to plot v – t and x – graphs for SHM. Students should use the relationship between x, v and a graphs when explaining and processing the results of this work.  Use Exampro questions to rehearse problem solving using SHM equations and knowledge and understanding of graphs.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of conditions for SHM by investigating different examples of oscillations.  AO3: Analyse and interpret data from to reach conclusions on the relationship between *x, v* and *a* in a system executing SHM.  MS3.9: Apply the concepts underlying calculus by finding the velocity/acceleration from *x –t / v – t* graphs of SHM.  ATk: Use ICT such as computer modelling, or data logger to collect data, or use of software to process data on SHM experiments. | Exampro  QBW05.5.04  QW124A06  QS11.4A.07  QW11.4A.04  QW11.4A.05  QSP.4A.08 | **Rich questions:**  What characteristics do oscillating systems share?  [IOP observing oscillations](http://www.tap.iop.org/vibration/shm/301/page_46554.html)  [SHM animation University of New South Wales.](http://www.animations.physics.unsw.edu.au/jw/SHM.htm)  [Nuffield Foundation investigating SHM](http://tap.iop.org/vibration/shm/303/page_46578.html) |

3.6.1.3 Simple harmonic systems

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

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Study of mass-spring system:  Study of simple pendulum:  Questions may involve other harmonic oscillators  (Eg liquid in U-tube) but full information will be provided in questions where necessary.  Variation of *Ek , Ep* , and total energy with both displacement and time.  Effects of damping on oscillations.  **Required practical 7:** Investigation into simple harmonic motion using a mass–spring system and a simple pendulum. | 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.  Recognise other harmonic oscillators and apply knowledge and understanding of mass-spring and pendulum to solve problems in different contexts.  Describe the energy changes that take place in SHM and sketch graphs of variation of *Ek*, *Ep* and total energy with displacement and time.  Describe the effects of damping on oscillations including sketching appropriate graphs of damped systems. | 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 using a 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.  Students observe damped systems such as water in a U-tube or a damped spring. Different degrees of damping illustrated practically or with a simulator.  **Skills developed by learning activities:**  AO2: Apply knowledge and understanding of scientific ideas to derive the equations for the mass spring and pendulum systems.  AO3: Analyse and interpret data from to reach conclusions on the relationship between variables in oscillating systems.  **MS 4.6 / AT b, c**  Students should recognise the use of the small-angle approximation in the derivation of the time period for examples of approximate SHM. | Exampro  QS13.4A.09  QW11.4A.07  QS13.4.03  QBS04.4.03 | **Rich questions:**  How should a suspension system work to give the smoothest possible ride?  [Mass-spring resources from IOP](http://tap.iop.org/vibration/shm/303/page_46578.html)  [Pendulum resources from IOP](http://tap.iop.org/vibration/shm/304/page_46587.html)  [Nothing Nerdy Energy simulation](http://nothingnerdy.wikispaces.com/4.2+ENERGY+CHANGES+DURING+SHM)  [Practical investigation of damped motion from school physics.co.uk](http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=4&cad=rja&uact=8&ved=0CDQQFjAD&url=http%3A%2F%2Fwww.schoolphysics.co.uk%2Fage16-19%2FMechanics%2FSimple%2520harmonic%2520motion%2Fexperiments%2Fdamped_simple_harmonic_motion.doc&ei=Dnz2U5DKL8ap0AX_oIHYDw&usg=AFQjCNGUAJeyII1wPO5RzO03acqWr_qxjA&bvm=bv.73373277,d.bGE)  [Damped motion simulator](http://ngsir.netfirms.com/englishhtm/Damped.htm)  [Water in a U-tube ISA June 2012](http://filestore.aqa.org.uk/subjects/AQA-PHY6T-Q12-W-JUN12-TS.PDF) |
| Extension |  |  | A step method using a spread sheet to model SHM and damped SHM.  The exponential decay of a damped system investigated mathematically. |  |  |

3.6.1.4 Forced vibrations and resonance

Prior knowledge: Simple Harmonic motion.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Qualitative treatment of free and forced vibrations.  Resonance and the effects of damping on the sharpness of resonance.  Examples of these effects in mechanical systems and situations involving stationary waves. | 0.5 weeks | Recognise free and forced vibrations and describe the difference between them.  Sketch a typical frequency response curve for a forced vibration to show the sharpness of response and the effect of damping. | Demonstration and discussion of Barton’s pendulum.  Student experiments on resonance from IOP (hacksaw blade, book on string etc.). Students report back to group on one of the experiments.  Students investigate the effect of damping on resonance curves using a simulation from PHET.  Student experiment: Determination of the Speed of Sound using resonance of an air column.  Resonance case studies: car suspension system questions and resources from IOP; Tacoma bridge disaster; shattering a glass with your voice.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of resonance.  AO3: Analyse and interpret data to reach conclusions on the relationship between variables in oscillating systems.  ATk: Use ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data. | Exampro  QSP.4A.10  [Antonine education questions on vibrations.](http://www.antonine-education.co.uk/Pages/Physics_4/Further_Mechanics/FMC_05/FMech_Page_5.htm) | **Rich question:**  Is it possible to shatter a glass with your voice alone?  [Scientific American Article– Fact or Fiction Opera Singer breaking a glass](http://www.scientificamerican.com/article/fact-or-fiction-opera-singer-can-shatter-glass/)  [Mythbuster Shattering a glass with your voice from YouTube](https://www.youtube.com/watch?v=IZD8ffPwXRo)  [Student experiments on resonance from IOP](http://tap.iop.org/vibration/simple_harmonic_motion/page_39848.html)  [PHET resonance simulation](http://phet.colorado.edu/en/simulation/resonance)  [Determining the speed of sound using an air column](http://www.physics1.howard.edu/undergraduate/Labs/GenLab1/10-resonance.pdf)  [Car suspension systems and Tacoma bridge from IOP](https://www.google.co.uk/?gfe_rd=cr&ei=6nX3U8WCF8qKOsXygOAB&gws_rd=ssl#q=tAP+resonance)  [Tacoma Bridge Disaster video from YouTube](https://www.youtube.com/watch?v=j-zczJXSxnw) |

3.6.2 Thermal physics

3.6.2.1 Thermal energy transfer

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

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Calculations involving transfer of energy.  For a change of temperature:  *Q = mcΔθ*  Where *c* is specific heat capacity.  Calculations including continuous flow.  For a change of state *Q* = *ml* where *l* is the specific latent heat. | 1.5 weeks | Recall the definition of specific heat capacity and specific latent.  Understand and apply the equation *Q = mcΔθ* to solve thermal energy transfer problems including in continuous flow.  Understand and apply the equation *Q* = *ml* to solve thermal energy transfer problems where there is a change of state. | 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.  Demonstration and discussion of changes of state without temperature change eg 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.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of specific heat and specific latent heat.  AO2: Apply knowledge and understanding of scientific ideas to solve problems involving transfer of thermal energy.  **MS 1.5 / PS 2.3 / AT a, b, d, f**  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.  **PS 1.1, 4.1 / AT k**  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. | Exampro  QS13.5.03  QS12501  QAS03.2.01 | **Rich questions:**  You can put out a candle with moist fingers (800 °C) but putting your hand in boiling water is very dangerous (100 °C). Explain.  [Fire proof balloon demonstration and notes.](http://www.chem.purdue.edu/bcce/the_fireproof_balloon.pdf)  [Measuring Heat Capacity from IOP](http://tap.iop.org/energy/thermal/607/page_47500.html)  [Measuring Latent heat of ice from IOP](http://tap.iop.org/energy/thermal/608/page_47512.html)  [Specific Heat and Latent heat questions from Cyberphysics.co.uk](http://www.cyberphysics.co.uk/pdfs/A2/shc_SOLN.pdf?vm=r&s=1) |

3.6.2.2 Ideal gases

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

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| **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* Δ *V*  Avogadro constant *N*A, molar gas constant *R* , Boltzmann  constant *k* .  Molar mass and molecular mass.  **Required practical 8:** Investigation of Boyle's law (constant temperature) and Charles’s law (constant pressure) for a gas. | 1.5 weeks | 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* Δ *V*  Understand and use the terms: Avogadro constant, molar mass, molecular mass.  Use the gas law equations *Work done* = *p* Δ *V* to solve problems on the behaviour of gases. | 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 *oC* 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, NA*, *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* Δ *V* .  Rehearsal of calculations using IOP and www.s-cool.co.uk questions.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the Ideal Gas equation.  AO3: Analyse and interpret data from gas law experiments to find a value for absolute zero and evaluate this value.  MS3.12: Sketch the relationship modelled by *y* = *k*/*x*, when dealing with an ideal gas. | Exampro  QS13.5.04  QS12504 | **Rich questions:**  What is the best scale for measuring temperature?  [Boyle’s Law and Charles Law investigations from CLEAPPS](http://www.cleapss.org.uk/attachments/article/0/Gas%20Laws.pdf?Conferences/ASE%202013/) and an alternative for [Boyles Law from Flinn Scientific](https://www.youtube.com/watch?v=vSFVMJQ4J7U)  [IOP questions on Ideal Gases.](http://tap.iop.org/energy/kinetic/602/page_47437.html)  [www.s-cool.co.uk examination style questions](http://www.s-cool.co.uk/a-level/physics/kinetic-theory/test-it/exam-style-questions) |

3.6.2.3 Molecular kinetic theory model

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

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| **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.  Assumptions leading to    including derivation of the equation and calculations.  A simple algebraic approach involving conservation of momentum is required.  Appreciation that for an ideal gas internal energy is kinetic energy of the atoms.  Use of average molecular kinetic energy  Appreciation of how knowledge and understanding of the behaviour of gas has changed over time. | 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.  Know the assumptions of the kinetic theory and the derivation of  Use the equations of the kinetic theory to solve problems.  Describe how knowledge and understanding of gaseous behaviour has changed over time. | 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 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.  Question practice using examination questions from Cyberphysics.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of Brownian motion and the development of kinetic theory.  AO2: Apply knowledge and understanding of mechanics to derive the kinetic theory equations. | Exampro  QAW03.2.04  QBS04.4.01  QBSOB6.4.06  SAMs Paper 2 Q 3 | **Rich questions:**  Suggest and explain conditions under which the kinetic theory would fail to describe the behaviour of a gas?  [YouTube video clip of Brownian motion](https://www.youtube.com/watch?v=2Vdjin734gE)  [Brownian motion simulator](http://labs.minutelabs.io/Brownian-Motion/)  [Cyberphysics Kinetic theory examination style questions.](http://www.cyberphysics.co.uk/Q&A/KS5/KineticTheory/questions.html) |

## 3.7 Fields and their consequences

3.7.1 Fields

Prior knowledge: Electric and gravitational fields.

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| **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.  Students should recognise that a force field can be represented as a vector, the direction of which must be determined by inspection.  Force fields arise from the interaction of mass, of static charge, and between moving charges.  Similarities and differences between gravitational and electrostatic forces:  Similarities: Both have inverse-square force laws that have many characteristics in common, eg use of field lines, use of potential concept, equipotential surfaces etc.  Differences: masses always attract, but charges may attract or repel |  |  | Content covered in subsequent sections within 3.7 |  |  |

3.7.2 Gravitational fields

3.7.2.1 Newton’s law

Prior knowledge: Basic forces including gravity. Vectors

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| **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.  Magnitude of force between point masses:  where *G* is the gravitational constant. | 0.5 weeks | Understand that gravity is a force that acts between all matter, is always attractive and is a vector quantity.  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 eg two golf balls a metre apart, the Moon and the Earth.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of Newton’s Law of gravitation.  MS1.4: Make order of magnitude calculations for gravitational forces between objects. | [Questions from IOP on Newton’s Law of Gravitation](http://tap.iop.org/fields/gravity/401/page_46813.html) | **Rich question:**  What is the Newton’s third law reaction force to your weight? |

#### 3.7.2.2 Gravitational field strength

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

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Representation of a gravitational field by gravitational field lines.  *g* as force per unit mass as defined by  Magnitude of *g* in a radial field given by | 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, | 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  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the concept of gravitational fields.  AO2: Apply knowledge and understanding of gravitational field strength to solve problems in different contexts. | Exampro  QS13.4A.13  QS124A13  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](http://tap.iop.org/fields/gravity/402/page_46820.html) |
| Extension |  |  | [Apollo 11 mission data analysis from IOP](http://tap.iop.org/fields/gravity/402/page_46820.html) |  |  |

3.7.2.3 Gravitational potential

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

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| **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.  Understanding of gravitational potential difference.  Work done in moving mass *m* given by  Equipotential surfaces.  Idea that no work is done when moving along an equipotential surface.  *V* in a radial field given by  Significance of the negative sign.  Graphical representations of variations of *g* and *V* with *r*.  *V* related to *g* by:  *Δ V* from area under graph of *g* against *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 and apply the concept that potential difference along an equipotential line is zero.  Use the equations.  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  and the concept that *ΔV* is foundfrom area under graph of *g* against *r*. | 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 led to 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.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the concept of gravitational potential when solving problems.  MS3.8, 3.9: Students use graphical representations to investigate relationships between *v*, *r* and *g*. | Exampro  QAW05.4B.03  QW13.4.01 | **Rich questions:**  What is the best choice for the zero point of reference for potential energy?  [TAP resources](http://tap.iop.org/fields/gravity/404/page_46842.html) |

#### 3.7.2.4 Orbits of planets and satellites

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

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| **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; derivation of;  *T*2 ∝ *r*3  Energy considerations for an orbiting satellite.  Total energy of an orbiting satellite.  Escape velocity.  Synchronous orbits.  Use of satellites in low orbits and geostationary orbits, to include plane and radius of geostationary orbit. | 0.5 weeks | Students can derive;  *T*2 ∝ *r*3  Describe the energy considerations for an orbiting satellite and provided with structure solve problems.  Describe the meaning of the term escape velocity and given appropriate data calculate escape velocities.  Describe Synchronous orbits and the use of satellites in low orbits and geostationary orbits, including plane and radius of geostationary orbit. | Students supported through derivation of *T*2 ∝ *r*3  Students prepare notes on the energy considerations for a satellite using online tutorial information eg Lisa Volkening.  Discuss the concept of escape velocity and students rehearse problem solving using resources from the Beacon Learning Centre.  Students observe different types of orbit using J-track. Students choose satellites and research their use, relating this to the observed orbit.  Rehearse problem solving using Exampro questions.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of satellites and their orbits when relating observed orbits to uses.  AO2: 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 questions:**  Is it better to launch a rocket from the poles or the equator?  [Energy of orbits by Lisa Volkening](http://www.youtube.com/watch?v=ZuFpSZEnvY8)  [Escape Velocity Resources from the Beacon Learning Centre](http://www.beaconlearningcenter.com/documents/1483_01.pdf)  [J-track](http://science.nasa.gov/realtime/jtrack/3d/JTrack3D.html/) |

3.7.3 Electric fields

3.7.3.1 – 3.7.3.2 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.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Force between point charges in a vacuum:  Permittivity of free space, *ε0.*  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.  Representation of electric fields by electric field lines.  Electric field strength.  *E* as force per unit charge defined by  *E* = *F / Q*  Magnitude of *E* in a uniform field given by *E = V / d*  Derivation from work done moving charge between plates:  *Fd* = *Q∆V*  Trajectory of moving charged particle entering a uniform electric field initially at right angles.  Magnitude of *E* in a radial field given by | 0.5 weeks | Understand the meaning of ε0 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  *E = F / Q* and  *E* = *V / d*  to solve electric field problems.  Derive *Fd = Q∆V*  Sketch and describe the trajectory of a moving charged particle entering a uniform electric field initially at right angle. | Discuss similarities of the equations for electric and gravitational fields.  Discussion of forces between point charges and Coulomb’s law including ε0. Students rehearse calculation of electric forces between point charges.  Demonstration of electric field lines with oil and semolina. Students sketch electric field lines and equipotential lines.  Student experiment: equipotential lines with conducting paper.  Define electric field strength and derivation of *Fd* = *Q∆V*  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.  **Skills developed by learning activities:**  AO2: 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.  ATf: 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. | Exampro  QS124B02  QW11.4B.04 | **Rich questions:**  Design an experiment to confirm the Coulomb law.  [Electric field lines with oil and semolina from IOP.](http://tap.iop.org/fields/electrical/406/page_46863.html)  [Antonine Education Electric Field questions](http://www.antonine-education.co.uk/Pages/Physics_4/Fields/FLD_04/Fields_4.htm)  [Electron deflection demonstration from Nuffield Foundation](http://www.nuffieldfoundation.org/practical-physics/deflecting-electron-beam) |
| Extension |  |  | Students calculate *e/m* from electron deflection tube data. |  |  |

3.7.3.3 Electric potential

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| **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  *Δ W = Q Δ V*  Equipotential surfaces.  No work done moving charge along an equipotential surface.  Magnitude of *V* in a radial field given by    Graphical representations of variations of *E* and *V* with *r*.  *V* related to *E* by  *E = Δ V / Δ r*  Δ *V* from the area under graph of *E* against *r*. | 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.  Use the equation  Sketch and use graphs showing the variations of E and V with r.  Recognise and use the relationships *E* = Δ *V /* Δ *r* and Δ *V* is the area under graph of *E* against *r*. | 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.  **Skills developed by learning activities:**  AO2: 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.  ATf: 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.  MS3.8: Δ *V* from the area under graph of *E* against *r* and be able to calculate it or estimate it by graphical methods as appropriate. | Exampro  QW12.4B.01 | **Rich questions:**  PHET electric fields activity [1](http://phet-downloads.colorado.edu/files/activities/3464/Electric%20Potential%20Activity.pdf) and [2](http://phet-downloads.colorado.edu/files/activities/3464/Electric%20Potential%20Activity.pdf)  [Equipotential lines student experiments from IOP](http://tap.iop.org/fields/electrical/406/page_46863.html)  [s-cool questions](http://www.s-cool.co.uk/a-level/physics/electric-potential/test-it/exam-style-questions)  [IOP resources and questions](http://tap.iop.org/fields/electrical/408/page_46882.html) |

3.7.4 Capacitance

3.7.4.1 – 3.7.4.3 Capacitance, Parallel plate capacitor and Energy stored by a capacitor

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

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| **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*ε0εr/*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* = ½*CV*2 = ½ *Q*2 */ C* | 1.5 weeks | Define capacitance.  Use the equations,  *C* = *A*ε0εr/*d ,*  *E* = ½ *QV* = ½ *CV*2  = ½ *Q*2 */ C*  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.  Find and interpret the area under a graph of charge against PD | 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.  **Skills developed by learning activities:**  AO2: Apply knowledge and understanding of capacitors to solve problems in a variety of contexts.  ATf: 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.  ATg: design, construct and check circuits using DC power supplies, cells, and a range of circuit components. | Exampro  QS11.4B.03  QW11.4A.17  QAS04.4A.05  SAMs Paper 2 Q2 | **Rich question:**  What features are desirable in the design of a capacitor?  [Super-Capacitor and capacitors in everyday life from IOP](http://tap.iop.org/electricity/capacitors/125/page_46154.html)  [Student experiments : Investigating Q and V for a capacitor and investigating a parallel plate capacitor](http://tap.iop.org/electricity/capacitors/126/page_46162.html)  [Student experiment : energy stored in a capacitor](http://www.schoolphysics.co.uk/age16-19/Electricity%20and%20magnetism/Electrostatics/text/Capacitor_energy_stored/index.html) |

3.7.4.4 Capacitor charge and discharge

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| **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.  Time to halve, *T*½ = 0.69*RC*  Quantitative treatment of capacitor discharge,  Use of the corresponding equations for *V* and *I*.  Quantitative treatment of capacitor charge,  **Required practical 9:** Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant, *RC* . | 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.  Solve problems including the use of the equations :  *T*½ = 0.69*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.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of capacitor discharge by sketching graphs of Q, V and I against time.  ATk: Use ICT in the form of computer modelling of capacitor discharge. | Exampro  QAS05.4B.03  QAW04.4B.04 | **Rich questions:**  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.](http://tap.iop.org/electricity/capacitors/129/page_46197.html)  [Capacitor problems from scool](http://www.s-cool.co.uk/a-level/physics/capacitors/test-it/exam-style-questions) |

### 3.7.5 Magnetic fields

3.7.5.1 Magnetic flux density

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

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| **Learning objective/** | **Time taken** | **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.  **Required practical 10:** Investigate how the force on a wire varies with flux density, current and length of wire using a top pan balance | 1 week | 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 Flemings 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.  **Skills developed by learning activities:**  AO2: Apply knowledge and understanding to predict direction of motion of a spinning motor.  MS4.2: Visualise and represent 2D and 3D forms including two-dimensional representations of 3D  objects.  ATf: The construction of dc circuits with correct polarity. | Exampro  QAS03.4B.03  QS124A20 | [Kicking wire simulation](http://www.walter-fendt.de/ph14e/lorentzforce.htm)  [Force on Conductors in Magnetic Field Questions from IOP](http://tap.iop.org/fields/electromagnetism/412/page_46925.html)  **Rich questions:**  How can we change electrical energy into kinetic energy?  How can we quantify the strength of a magnetic field? |

3.7.5.2 Moving charges in a magnetic field

Prior knowledge: Circular motion and centripetal forces.

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| **Learning objective/** | **Time taken** | **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.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of forces on charged particles in magnetic fields.  AO2: Apply knowledge and understanding to explain machines that use magnetic forces to guide the motion of charged particles.  MS4.2: Visualise and represent 2D and 3D forms including two dimensional representations of 3D objects. | Exampro  QAS04.4B.02  QS13.4B.03 | **Rich questions:**  Show this [Cyclotron applet](http://www.phy.ntnu.edu.tw/oldjava/cyclotron/cyclotron.html)  How can the movement of charged particles be controlled?  What are the applications of controlling the movement of charged particles |
| Extension |  |  | Experiment to measure e/m.  [Cyclotron teaching resources from Triumpf](http://www.triumf.ca/home/for-media/publicationsgallery/videos/e-m-and-circular-motion) |  |  |

3.7.5.3 Magnetic flux and flux linkage

Prior knowledge: Basic magnetism and electromagnetism.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Magnetic flux defined by *ϕ = BA* where *B* is normal to *A*.  Flux linkage as *N* ϕ 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  *Nϕ = BANcosθ*  **Required practical 11:** Investigate, using a search coil and oscilloscope, the effect on magnetic flux linkage of varying the angle between a search coil and magnetic field direction. | 1 week | Be able to define flux and flux linkage.  Use the relationships  *ϕ* = *BA*  and  *Nϕ = BANcosθ*  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.  Required practical 11.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of magnetic flux.  MS0.6: Use calculators to handle sin *x* , cos *x* , tan *x* when *x* is expressed in degrees or radians  MS4.5: Use sin, cos and tan in physical problems  ATa: Use appropriate analogue apparatus to record a range of measurements and to interpolate between scale markings.  ATh: Use signal generator and oscilloscope, including volts/division and time-base. | Exampro    QAW04.4B.03 | [Sketching flux patterns exercises from IOP](http://tap.iop.org/fields/electromagnetism/414/file_46956.doc)  [Flux linkage animation](http://phys23p.sl.psu.edu/phys_anim/EM/embeder3.20100.html)  [Antonine Education Flux linkage calculations](http://www.antonine-education.co.uk/Pages/Physics_4/Magnetism/MAG_04/Mag_field_4.htm) |

3.7.5.4 Electromagnetic induction

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

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| **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  *ε= N Δ ϕ / Δ t*  Applications such as a straight conductor moving in a magnetic field.  emf induced in a coil rotating uniformly in a magnetic field: | 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.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of how changing flux linkage produces an emf.  AO2: Apply knowledge and understanding of scientific ideas to explain electromagnetic braking.  MS2.1: Understand and use the symbols:  =, <, <<, >>, >, ∝, ≈, Δ  MS3.5: Calculate rate of change from a graph showing a linear relationship. | 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](http://tap.iop.org/fields/electromagnetism/414/page_46948.html)  [ED Tether information from Earth Observation Portal](https://directory.eoportal.org/web/eoportal/satellite-missions/s/space-tethers) |
| Extension |  |  | Investigate the motion of a pendulum damped by electromagnetic braking or other Eddy current brake. |  | [Example of an Eddy current brake investigation](http://www.rose-hulman.edu/~moloney/Ph425/0143-0807_33_3_697EddyCurrentBrake.pdf) |

3.7.5.5 Alternating currents

Prior knowledge: The difference between ac and dc signals.

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| **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.  Application to the calculation of mains electricity peak and peak-to-peak voltage values.  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. | 0.5 weeks | Know the meaning of the terms root mean square and peak-to-peak value.  Use the equations  to calculate root mean square values or peak values.  Use of an oscilloscope to display dc and ac voltage signals and find rms and 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.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of rms and peak values.  AO3: Analyse and interpret data from oscilloscope display to find rms and peak values.  MS3.1: Translate information between graphical, numerical and algebraic forms.  ATh: Use signal generator and oscilloscope, including volts/division and time-base. | Exampro  QS13.15 | **Rich question:**  What range of voltage does the mains supply?  [Use and questions on an oscilloscope from the IOP](http://tap.iop.org/electricity/emf/122/page_46061.html)  [AC questions and resources from IOP](http://tap.iop.org/electricity/emf/123/page_46066.html) |
| Extension |  |  |  |  | [Example of an Eddy current brake investigation](http://www.rose-hulman.edu/~moloney/Ph425/0143-0807_33_3_697EddyCurrentBrake.pdf) |

3.7.5.6 The operation of a transformer

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

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The transformer equation:  Transformer efficiency  Production of eddy currents.  Causes of inefficiencies in a transformer.  Transmission of electrical power at high voltage including calculations of power loss in transmission lines. | 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.  Use electrical power equations to calculate power losses in transmission lines. | Demonstrate the construction and operation of a transformer. Students sketch the parts of a transformer and explain it 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 Antonin website.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of construction and operation of a transformer.  AO3: Analyse, interpret and evaluate data from building transformer practical.  MS0.3: Use ratios in transformer problems.  PS2.3: Evaluate results of transformer experiment and draw conclusions about efficiency. | Exampro  QS13.4A.25  QW13.4A.24 | **Rich question:**  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](https://www.youtube.com/watch?v=ZjwzpoCiF8A)  [Antonine Education : transformers](http://www.antonine-education.co.uk/Pages/Physics_4/Magnetism/MAG_07/Mag_field_7.htm) |

## 3.8 Nuclear physics

3.8.1 Radioactivity

3.8.1.1 Rutherford scattering

Prior knowledge: Nuclear model of the atom. Properties of alpha radiation. Coulomb’s Law. Momentum.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Qualitative study of Rutherford scattering.  Appreciation of how knowledge and understanding of the structure of the nucleus has changed over time. | 0.5 weeks | Describe the results of the Rutherford scattering experiment and explain how they lead to the nuclear model of the atom.  Understand that the model of the atom has changed over time. | Investigate Rutherford Scattering results using a simulation.  Demonstrate how the results of the experiment lead to the idea of very small relatively massive positive nucleus. Colliding balls of different masses and the Chinese hat analogies are helpful.  Students research models of the atom and construct a timeline to show how it has changed.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of Rutherford Scattering experiment.  AO3: Analyse and interpret data from Rutherford Scattering experiment to draw a conclusion. |  | **Rich questions:**  What evidence do we have for atomic structure?  Is the nuclear model of the atom viable?  [Colliding Balls and Chinese hat analogies from IOP](http://tap.iop.org/atoms/rutherford/521/page_47197.html)  [Rutherford Scattering simulation from PHET](http://phet.colorado.edu/en/simulation/rutherford-scattering) |

3.8.1.2 α, β and γ radiation

Prior knowledge: Nuclear model of the atom. Nature of α, B and γ radiation. Sources of background radiation.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Their properties and experimental identification using simple absorption experiments; applications eg to relative hazards of exposure to humans.  Applications also include thickness measurements of aluminium foil paper and steel.  Inverse-square law for γ radiation:  Experimental verification of inverse-square law.  Applications, eg to safe handling of radioactive sources.  Background radiation; examples of its origins and experimental elimination from calculations.  Appreciation of balance between risk and benefits in the uses of radiation in medicine.  **Required practical 12:** Investigation of the inverse-square law for gamma radiation. | 0.5 weeks | Recall the properties of α, β and γ radiation.  Describe a simple absorption experiment that could be used to identify the different types of radiation including correction for background radiation.  Apply knowledge and understanding of properties of radiation and inverse square law to explain safe handling of radioactive sources and applications in industry and medicine. To include evaluation of the balance of risks and benefits of applications.  Use the inverse square law to calculate distances and intensities.  Describe an experiment to confirm the inverse square law including correction for background radiation. | Demonstrate background radiation and the penetration properties of α, β and γ radiation. Students apply knowledge of the nature of the radiations to explain observations. Students record count data, correct for background radiation and make conclusions on nature of radiation from different sources.  Demonstrate inverse square law or use a computer simulation. Students ideally collect their own data and should process the data independently correcting for background radiation. As a minimum - measure background count rate and one count rate with a source in place taking all necessary precautions to satisfy ATj.  Case study and/or presentations on applications of radiation in medicine and industry to consolidate knowledge and understanding.  **Skills developed by learning activities:**  AO2: Apply knowledge and understanding of the properties of radiation in medicine and industry.  AO3: Analyse, interpret and evaluate data from absorption and inverse-square law experiments to:   * make judgements and reach conclusions * develop and refine practical design and procedures.   ATk: Use ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data.  ATl: Use ionising radiation, including detectors. | Exampro  QS13.5.05  QS12503 | **Rich questions:**  What is the nature of radiation?  Which is the most dangerous type of radiation?  Full body scans for asymptomatic people: a good or a bad thing?  [Radiation lab simulation](http://radiation-lab.software.informer.com/) |

3.8.1.3 Radioactive decay

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

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| **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;  Use of activity,  Modelling with constant decay probability.  Questions may be set which require students to use:  Questions may also involve use of molar mass or the Avogadro constant.  Half-life equation:  Determination of half-life from graphical decay data including decay curves and log graphs.  Applications eg relevance to storage of radioactive waste, radioactive dating, etc. | 1 week | Recognise and understand the random nature of radioactive decay.  Use the equations    to solve radioactive decay problems in a variety of contexts.  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. | 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.  Summarise and evaluate the safety considerations in dealing with the short and long term storage of radioactive waste OR the evidence for the age of the Earth from radioactive dating of rocks.  **Skills developed by learning activities:**  AO2: Apply knowledge and understanding of radioactive decay to the storage of radioactive waste and radioactive dating.  AO3: Analyse, interpret and evaluate data on radioactive decay to make judgements and reach conclusions.  MS1.3: Understand simple probability in radioactive decay.  MS2.1: Understand and use the symbols: ∝, Δ.  MS3.1: Translate information between graphical, numerical and algebraic forms when dealing with radioactive decay. | Exampro  QAS04.5.01  QAW03.5.01  SAMs Paper 2 Q 4 | **Rich question:**  How long do we have to wait until a radioactive source is safe?  [Radioactive Decay questions from scool](http://www.s-cool.co.uk/a-level/physics/radioactive-decay-equations/test-it/exam-style-questions)  [Half-life of protactinium experiment from the IOP](http://tap.iop.org/atoms/radioactivity/514/page_47129.html)  [Modelling radioactive decay with dice](http://web.mst.edu/~tbone/subjects/tbone/dicedata.pdf)  [Article on storage of Radioactive waste from World Nuclear Association](http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/) |
| Extension |  |  | Students consider parallels between the mathematics of radioactive decay, capacitor discharge and damped harmonic motion. |  |  |

3.8.1.4 Nuclear instability

Prior knowledge: Atomic notation. Nature of α, B and γ radiation.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Graph of *N* against *Z* for stable nuclei.  Possible decay modes of unstable nuclei including *α, β+, β−* and electron capture.  Changes in *N* and *Z* caused by radioactive decay and representation in simple decay equations.  Questions may use nuclear energy level diagrams.  Existence of nuclear excited states; γ ray emission; application eg use of technetium-99m as a γ source in medical diagnosis. | 1 week | Sketch the graph of *N* against *Z* for stable nuclei.  Identify and explain regions of the graph that correspond to possible decay modes,  Generate and/or complete simple decay equations.  Describe the existence of nuclear excited states and applications. | Discussion of nuclear stability graph.  In a peer discussion group students allocate decay processes to correct regions of stability graph and explain.  Rehearsal of decay equations.  Read and summarise article on nuclear excited states and technetium-99m in medicine.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of decay processes. | Exampro  QAW04.5.01  QAS03.5.01 | **Rich question:**  What aspects of radioactive decay are predictable?  [Decay processes from IOP](http://tap.iop.org/atoms/radioactivity/512/page_47107.html)  [Article on Nuclear excited states and technetium-99m](http://www.laradioactivite.com/en/site/pages/Technetium_99.htm) |

3.8.1.5 Nuclear radius

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

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| **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.  Students will need to be familiar with the Coulomb equation for the closest approach estimate.  Dependence of radius on nucleon number:  *R* = *R*0*A*1/3 derived from experimental data.  Interpretation of equation as evidence for constant density of nuclear material.  Calculation of nuclear density.  Students should be familiar with the graph of intensity against angle for electron diffraction by a nucleus. | 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* = *R*0*A*1/3 to relate the radius of different nuclei to nucleon number.  Given appropriate data calculate nuclear densities.  Recall the order of magnitude radius for the nucleus. | 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 eg 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 spreadsheet 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.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the size of the nucleus and evidence for this.  AO2: Apply knowledge and understanding of Coulomb’s Law and diffraction to calculate nuclear radii.  MS1.4: Make order of magnitude calculations in determining nuclear densities. | Exampro  QS12505  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](http://tap.iop.org/atoms/rutherford/522/page_47210.html) |
| Extension |  |  | Data from the Rutherford Scattering experiment can be used for deeper mathematical modelling. |  | [IOP data from Rutherford Scattering Experiment and analysis activity.](http://tap.iop.org/atoms/rutherford/521/page_47197.html) |

3.8.1.6 Mass and energy

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

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Appreciation that  *E* = *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.  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.  Appreciation that knowledge of the physics of nuclear energy allows society to use science to inform decision making. | 0.5 weeks | Understand that  *E* = *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.  Sketch the graph of average binding energy per nucleon against nucleon number and explain regions where fission and fusion will release energy. | 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.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of binding energy, fission and fusion.  AO2: Apply knowledge and understanding to calculate the energy released in nuclear fission and fusion.  MS0.1: Recognise and make use of appropriate units (*eV, MeV* and *J*) in binding energy calculations.  MS3.1: Translate information between graphical and numerical form with binding energy graph. | Exampro  QS115.01  QS115.03 | **Rich question:**  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](https://www.youtube.com/watch?v=yTkojROg-t8)  [Mass difference and binding energy calculations from IOP](http://tap.iop.org/atoms/stability/525/page_47241.html)  [Mass and Energy exam standard questions from Cyberphysics](http://www.cyberphysics.co.uk/Q&A/KS5/Nuclear/fusion/fusion.html) |

#### 3.8.1.7 Induced fission

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

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| **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.  Factors affecting the choice of materials for the moderator, control rods and coolant. Examples of materials used for these functions. | 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.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of nuclear fission, fusion and the construction of a nuclear power station. | Exampro  QS13.05.02  QS10.05.02 | **Rich question:**  What is a critical mass?  Is nuclear energy the answer to our energy needs?  [Bang Goes the Theory Nuclear Power Station](https://www.youtube.com/watch?v=MGj_aJz7cTs)  [Introductory clip](https://www.youtube.com/watch?v=MGj_aJz7cTs)  Fission and Fusion  [Nuclear Reactor Card loop game](http://www.tes.co.uk/teaching-resource/Nuclear-Fission-Reactor-Loop-game-6196870/)  [CyberPhysics nuclear physics questions](http://www.cyberphysics.co.uk/Q&A/KS5/Nuclear/Critical%20Mass/critical.html)  [Extended Writing task Nuclear Energy on TES resources](http://www.tes.co.uk/teaching-resource/A-Level-Physics-Extended-Writing-Tasks-6368020/) |

3.8.1.8 Safety aspects

Prior knowledge: Nuclear Power stations. Nature of Radiation.

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| **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 Do we need Nuclear Power debate.  In triads, one student prepares a short argument for nuclear power, another against and the third evaluates the two arguments.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of nuclear safety.  AO3: 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](https://www.youtube.com/watch?v=1TxJxUbs2L4)  [TED Nuclear Power Debate](https://www.youtube.com/watch?v=UK8ccWSZkic) |

## 3.9 Astrophysics

3.9.1 Telescopes

3.9.1.1 – 3.9.1.2 Astronomical telescope consisting of two converging lenses and Reflecting telescope

Prior knowledge: Refraction, ray diagrams and behaviour of converging and diverging lenses, Law of Reflection, ray diagrams for convex mirror.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Ray diagram to show the image formation in normal adjustment.  Angular magnification in normal adjustment.  *M* = *angle subtended by image at eye / angle subtended by object at unaided eye*  Focal lengths of the lenses.  Cassegrain arrangement using a parabolic concave primary mirror and convex secondary mirror.  Ray diagram to show path of rays through the telescope up to the eyepiece.  Relative merits of reflectors and refractors including a qualitative treatment of spherical and chromatic aberration. | 1 week | Recall and understand the term normal adjustment.  Draw ray diagram to show image formation in normal adjustment.  Recall and use the concept of angular magnification.  Solve problems involving angular magnification.  Recall and sketch the Cassegrain arrangement including ray diagram to the eyepiece.  Describe and discuss merits of reflectors and refractors including spherical and chromatic aberration. | Revise properties of lenses using PhET geometric optics simulator.  Students construct a simple astronomical telescope using two lenses. Students sketch ray diagrams of arrangement in normal adjustment. This knowledge is consolidated through use of a simulation such as the Walter-Fendt applet.  Discussion of angular magnification and rehearsal of calculations.  Students research Cassegrain arrangement and write a short report discussing the merits of reflectors and refractors including spherical and chromatic aberration.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of spherical and chromatic aberration. | Exampro  QS10.5A.01  QAS03.5.02  SAMs Astrophysics Q1 | **Rich question:**  [PhETGeometric optics simulator](https://phet.colorado.edu/en/simulation/geometric-optics)    [Making an astronomical telescope from the Nuffield Foundation.](http://www.nuffieldfoundation.org/practical-physics/making-telescope)  [Astronomical telescope applet from Walter-Fendt.](http://www.walter-fendt.de/ph14e/refractor.htm) |

3.9.1.3 – 3.9.1.4 Single dish radio telescopes, U-V, I-R, and X-ray telescopes, and Advantages of large diameter telescopes

Prior knowledge: Radians. Diffraction.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Similarities and differences of radio telescopes compared to optical telescopes. Discussion should include structure, positioning and use, together with comparisons of resolving and collecting powers.  Minimum angular resolution of telescope.  Rayleigh criterion,  θ ≈ λ / *D*  Collecting power is proportional to *diameter*2.  Students should be familiar with the rad as the unit of angle.  Comparison of the eye and CCD as detectors in terms of quantum efficiency, resolution, and convenience of use.  No knowledge of the structure of the CCD is required. | 1 week | Describe the similarities and differences of radio telescopes compared to optical telescope including structure, positioning and use, together with comparisons of resolving and collecting powers.  Use the concept of minimum angular resolution.  Solve problems using the Rayleigh criterion θ ≈ λ / *D* .  Use the concept of collecting power being proportional to diameter2 .  Use the rad to solve problems.  Compare the eye and CCD in terms of quantum efficiency, resolution, and convenience of use. | Student’s research well known optical and radio telescopes looking for the similarities and differences. Group discussion should lead to structure, positioning and use, together with comparisons of resolving and collecting powers (collecting power should be defined for students during this discussion).  Students complete the angular resolution activity.  Discussion and definition of the Rayleigh Criterion.  Students research CCDs and the term quantum efficiency. Discussion to compare CCDs and the eye in terms of quantum efficiency, resolution, and convenience of use.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of angular resolution and the Rayleigh Criterion.  MS4.7: Understand the relationship between degrees and radians and translate from one to the other when solving angular resolution problems. | Exampro  QS13.5A.13  QSP.5A.03  QS11.5A.01  SAMs Astrophysics Q | **Rich question:**  Given the choice: optical or radio telescopes? Explain your decision.  [Angular resolution activity](http://mintaka.sdsu.edu/projectastro/Galileoscope/Angular-resolution-activity-Blanco.pdf)  [CCD simulator from University of Nebraska](http://astro.unl.edu/classaction/animations/telescopes/buckets.html) |

3.9.2 Classification of Stars

3.9.2.1 – 3.9.2.2 Classification by luminosity and Absolute magnitude, M

Prior knowledge: Radians. Diffraction.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Apparent magnitude, *m*.  The Hipparcos scale.  Dimmest visible stars have a magnitude of 6.  Relation between brightness and apparent magnitude. Difference of 1 on magnitude scale is equal to an intensity ratio of 2.51.  Brightness is a subjective scale of measurement.  Parsec and light year.  Definition of *M* , relation to *m* : | 1 week | Understand and describe the concept of apparent magnitude, the Hipparcos scale and the relation to brightness.  Appreciate that a difference of 1 on the magnitude scale is equal to an intensity of 2.56  Understand that brightness is subjective.  Define the parsec and light year and absolute magnitude.  Solve problems using the relationship | From an image of the stars students design a system for rating brightness. Discussion of apparent magnitude and Hipparcos scale.  Discussion of the scale of the universe and the need for light years and parsecs to measure immense distances. The YouTube clip Powers of Ten is used to support this discussion.  Define the light year and parsec.  Students complete Constellations and Stellar Distances from Real World Learning Objects.  Discussion and definition of absolute magnitude supported by resource and questions from Victoria Museum (Activity 16).  Rehearsal of calculations using past paper questions.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of apparent and absolute magnitude.  MS0.5: Use calculators to find and use power and logarithmic functions when calculating astronomical distances and absolute magnitude. | Exampro  QAW03.5.05 | **Rich question:**  How can we measure the distance to a star?  [YouTube clip : Powers of Ten](http://www.youtube.com/watch?v=0fKBhvDjuy0)  [Real World Learning Objects : Constellations and Stellar distances](http://www.ciese.org/pathways/rwlo/search.php?filter=science&secondary_id=1)  [Parallax and apparent/absolute magnitude activities from Victoria Museum.](http://museumvictoria.com.au/pages/7573/the-stars-student-activities-11-20.pdf) |

3.9.2.3 – 3.9.2.4 Classification by temperature, black-body radiation and Principles of the use of stellar spectral classes

Prior knowledge: Power, energy levels and spectra.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Stefan’s law and Wien’s displacement law.  General shape of black-body curves, use of Wien’s displacement law to estimate black-body temperature of sources.  Experimental verification is not required.  *λmaxT = constant = 2.9 × 10−3 m K*  Assumption that a star is a black body.  Inverse square law, assumptions in its application.  Use of Stefan’s law to compare the power output, temperature and size of stars.  *P = σAT4*  Description of the main spectral classes:  OBAFGKM  Temperature related to absorption spectra limited to Hydrogen Balmer absorption lines: requirement for atoms in an *n* = 2 state. | 1 week | Recognise and use Stefan’s law and Wien’s law.  Sketch black-body curves for bodies at different temperatures. Interpret black-body curves to estimate temperatures using Wien’s law.  Appreciate the reasons why a star can be considered as a black body.  Use of the inverse square law and understanding of the assumptions in its use.  Describe using qualitative and quantitative arguments how Stefan’s law can be used to compare the power output, temperature and size of stars.  Recall the main classes of stars including intrinsic colour, temperature and prominent absorption lines.  Describe how temperature is related to absorption spectra (Hydrogen Balmer) and appreciate the requirement for atoms in an *n* = 2 state. | Demonstration: filament bulb with increasing current. Students note the sequence of colour changes that occur in the visible light. Discussion of how these observations can be explained using Wien’s law and extension to finding the temperature of stars.  Students work through the Antonine Education tutorial on classification of stars.  Students learn the intrinsic colour, temperature and prominent absorption lines of the main classes. They create teaching resources, for example closing exercises; the group can share and practise.  Rehearsal of examination style questions.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of Wien’s and Stefan’s laws.  AO2: Apply knowledge and understanding of energy level diagrams to explain and interpret absorption spectra. | Exampro  QAW05.5.03  QAW03.5.04  SAMs Astrophysics Q2 | **Rich question:**  How do we measure the temperature of a star?  [Antonine Education tutorial on classification of stars](http://www.antonine-education.co.uk/Pages/Physics_5_Options/Astrophysics/AST_05/Astrophysics_5.htm) |

3.9.2.5 The Hertzsprung-Russell (HR) diagram

Prior knowledge: Life cycle of stars. Absolute magnitude. Spectral classes.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| General shape: main sequence, dwarfs and giants.  Axis scales range from –10 to +15 (absolute magnitude) and 50000 K to 2500 K (temperature) or OBAFGKM (spectral class).  Students should be familiar with the position of the Sun on the HR diagram.  Stellar evolution: path of a star similar to our Sun on the HR diagram from formation to white dwarf. | 0.5 weeks | Sketch and label the Hertzsprung-Russell diagram including values on the axes and positions of main sequence, dwarfs and giants.  Recall the position of the sun on the HR diagram.  Describe and explain the position of a star on the HR diagram from formation to white dwarf. | Introduction and discussion of HR diagram using European Space Agency clip.  Students construct an HR diagram from star data. For example the activity from Meridian Schools.  Discuss the position of a star on the HSD as it moves through its life cycle.  Consolidate learning with pin the star on the HR diagram game. Give students cards with information about stars. They must pin the star on a large HR diagram image (from a projector for example).  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the HSD | Exampro  QSP.5A.04  QAS04.5.04 | **Rich question:**  The Hertzsprung-Russell diagram can be thought of as the periodic table of the stars. In what ways is this true?  [European Space agency HR diagram clip](http://www.spacetelescope.org/videos/heic1017b/)  [Constructing a Hertzsprung-Russell diagram](http://www.mononagrove.org/faculty/J_Botella/hr.cfm) |
| Extension |  |  | Students estimate the age of a star cluster by plotting the colour and brightness of stars within it. Activity from the National Optical Astronomy Observatory. |  | [Jewel Box activity from National Optical Astronomy Observatory](http://www.noao.edu/education/jewels/instructions.html) |

3.9.2.6 Supernovae, neutron stars and black holes

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Defining properties: rapid increase in absolute magnitude of supernovae; composition and density of neutron stars; escape velocity > *c* for black holes.  Gamma ray bursts due to the collapse of supergiant stars to form neutron stars or black holes.  Comparison of energy output with total energy output of the Sun.  Use of type 1a supernovae as standard candles to determine distances.  Controversy concerning accelerating Universe and dark energy.  Students should be familiar with the light curve of typical type 1a supernovae.  Supermassive black holes at the centre of galaxies.  Calculation of the radius of the event horizon for a black hole, Schwarzschild radius (Rs), | 0.5 weeks | Recall and describe the defining properties of supernovae, neutron stars and black holes.  Recall and describe the origin of gamma ray bursts.  Describe the use of type 1a supernovae as standard candles to determine distance.  Appreciate and describe the controversy concerning accelerating Universe and dark energy.  Sketch the light curve for a typical type 1a supernovae.  Recall that supermassive black holes may be found at the centre of galaxies.  Use the Schwarzchild equation to calculate the radius of the event horizon for a black hole. | Within the structure of the learning outcomes students research one or more of supernovae, neutron stars and black holes.  Students create questions and solutions based on the learning outcomes for their chosen research area.  Students present research and questions for peer assessment. Students select the best work for a booklet that is reproduced and distributed.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of supernovae, neutrons stars and black holes. | Exampro  QAW05.5.05  QAS03.5.05  SAMs Astrophysics Q3 | **Rich question:**  What is the future of our sun? How is it different to that of a super massive star like Rigel or Betelgeuse? |

3.9.3 Cosmology

3.9.3.1 – 3.9.3.2 Doppler effect and Hubble’s law

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| and  for *v ≪ c* applied to optical and radio frequencies.  Calculations on binary stars viewed in the plane of orbit.  Galaxies and quasars.  Red shift *v* = *Hd* .  Simple interpretation as expansion of universe; estimation of age of universe, assuming *H* is constant.  Qualitative treatment of Big Bang theory including evidence from cosmological microwave background radiation, and relative abundance of hydrogen and helium. | 0.5 week | Understand and describe the Doppler effect.  Use the Doppler effect equations to carry out calculations. | Demonstration of Doppler effect using Doppler ball. European Space Agency video.  Practise of questions from IOP including for a binary system.  Demonstration of expansion of universe using dots on a balloon.  Students model the Hubble law with pieces of elastic (from IOP).  Discussion of how Hubble constant leads to an estimation of the age of the universe.  Students view video Stephen Hawking’s Universe - The Big Bang. Take notes on the evidence for the Big Bang in preparation for creating a piece of extended writing on this topic area.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the evidence for the Big Bang.  MS1.4: Make order of magnitude calculations when calculating distances or speeds of galaxies using the Hubble Law. | Exampro  QSP.5A.05  QAW04.5.05 | **Rich question:**  Did the universe really begin with a Big Bang?  [Doppler Effect video from the European Space Agency](http://www.esa.int/spaceinvideos/Videos/2014/07/Doppler_effect_-_classroom_demonstration_video_VP05)  [Practise of questions from IOP including for a binary system.](http://tap.iop.org/astronomy/astrophysics/702/page_47545.html)  [Modelling the Hubble law with elastic from the IOP.](http://tap.iop.org/astronomy/cosmology/704/page_47564.html)  [Stephens Hawking’s Universe – The Big Bang.](http://www.youtube.com/watch?v=vThyPbLOgOs) |

3.9.3.3 – 3.9.3.4 Quasars and Detection of exoplanets

Prior knowledge: Doppler effect. Red shift.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Quasars as the most distant measurable objects.  Discovery of quasars as bright radio sources.  Quasars show large optical red shifts; estimation involving distance and power output.  Formation of quasars from active supermassive black holes.  Difficulties in the direct detection of exoplanets.  Detection techniques will be limited to variation in Doppler shift (Radial velocity method) and the transit method.  Typical light curve. | 0.5 weeks | .  Describe the nature, discovery and formation of Quasars.  Understand the difficulties in detecting exoplanets and describe detection techniques limited to variation in Doppler shift (Radial velocity method) and the transit method.  Sketch and interpret typical light curves. | Students watch lecture from Professor Carolin Crawford on quasars. Draw out through discussion the required learning outcomes.  Exoplanet starter: Students watch Spaces 10 most amazing planets from Hybrid Librarian.  Students watch the video clip Exoplanets explained. Discussion of the difficulties in detecting exoplanets.  Students completing the Agent Exoplanet activity from Cardiff University.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the detection of exoplanets. | Exampro  QAS04.5.05 | **Rich question:**  How might it be possible to locate planets around stars other than the sun?  [Professor Carolin Crawford lecture on quasars.](http://www.youtube.com/watch?v=bagpxIzXow0)  [Space’s 10 most amazing planets video clip](http://www.youtube.com/watch?v=fJUmptj09GY)  [Exoplanets Explained video clip.](http://www.youtube.com/watch?v=zFPnOUSdMdc)  [Agent Exoplanet from Cardiff University.](http://blogs.cardiff.ac.uk/physicsoutreach/resources/agent-exoplanet/) |

## 3.10 Medical physics

3.10.1 Physics of the eye

3.10.1.1 – 3.10.1.2 Physics of vision and Defects of vision and their correction using lenses

Prior knowledge: Refraction, ray diagrams and behaviour of converging and diverging lenses.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The eye as an optical refracting system, including ray diagrams of image formation.  Sensitivity of the eye; spectral response as a photodetector.  Spatial resolution of the eye; explanation in terms of the behaviour of rods and cones.  Properties of converging and diverging lenses; principal focus, focal length and power,  *=+*  Myopia, hypermetropia, astigmatism.  Ray diagrams and calculations of powers (in dioptres) of correcting lenses for myopia and hypermetropia.  The format of prescriptions for astigmatism. | 1 week | Describe the role of refraction in the eye.  Draw ray diagrams to show image formation.  Describe the sensitivity of the eye and spectral response.  Explain the spatial resolution of the eye in terms of the behaviour and cones.  Recall the properties of converging and diverging lenses and sketch ray diagrams to show how light passes through.  Recall and use the terms principal focus, focal length and power.  Use the equations  *=+*  to solve problems related to lenses.  Understand and describe myopia, hypermetropia and astigmatism.  Draw ray diagrams and carry out calculations related to power of correcting lenses.  Know that the prescription for astigmatism includes a power and axis angle. | Discussion and research of the anatomy of the eye as a refracting system.  Students investigate converging and diverging lenses using software or real lenses.  Students investigate the response of the eye in different levels of light and spatial resolution. Students should try an eye test or complete a resolving power activity to support this learning. Colour perception test and colour blindness discussion.  Model eye to demonstrate behaviour of the eye and corrections to defects using flask.  Students produce a piece of extended writing on eye defects and their correction.  Rehearsal of examination questions.  **Skill developed by learning activities:**  AO2: Apply knowledge and understanding of lenses to explain the correction of defects in the eye. | Exampro  QS125B01  QS13.5B.01  SAMs Medical Physics Q1 | **Rich question:**  What are the similarities and differences between the eye and a digital camera?  [Animated eye from kscience.co.uk](http://www.kscience.co.uk/animations/eye.swf)  [Geometric optics simulator from PHET.](http://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html)  [The lens formula investigation from the Nuffield Foundation.](http://www.nuffieldfoundation.org/practical-physics/lens-formula)  [Resolving Power of the eye activity.](http://stokes.byu.edu/teaching_resources/resolve.html)  [Model eye demonstration with flask from Nuffield Foundation.](http://www.nuffieldfoundation.org/practical-physics/model-eye-demonstration-flask) |

3.10.2 Physics of the ear

3.10.2.1 – 3.10.2.3 Ear as a sound detection system and Sensitivity and frequency response, and Defects of hearing

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Simple structure of the ear, transmission processes.  Production and interpretation of equal loudness curves.  Human perception of relative intensity levels and the need for a logarithmic scale to reflect this.  Definition of intensity.  where the threshold of hearing  *I0 = 1 × 10−12 W m−2*  Measurement of sound intensity levels and the use of dB and dBA scales; relative intensity levels of sounds.  The effect on equal loudness curves and the changes experienced in terms of hearing loss due to injury resulting from exposure to excessive noise or deterioration with age (excluding physiological changes). | 0.5 weeks | Describe the structure of the ear and process of sound transmission.  Describe the production and interpretation equal loudness curves. | Demonstration and discussion of the ear using a model or interactive simulation such as that provided by Amplifon.  Range of hearing demonstration and discussion of production of equal loudness curves. Students should follow this up with the Equal Loudness activity from the University of New South Wales.  Discussion of need for logarithmic scale to reflect perception of relative intensity, the use of dB and dBA scales and rehearsal of calculations.  Students research the effect of excessive noise and age on the ear including effect on equal loudness curves to produce a piece of extended writing. Peer assessment of work.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of structure of the ear.  MS0.5: Use calculators to find and use logarithmic functions when calculating the intensity of sound.  MS2.5: Use logarithms in relation to quantities that range over several orders of magnitude when explaining the response of the ear. | Exampro  QS13.5B.02  QSP.5B.03  SAMs Medical Physics Q 2 | **Rich question:**  Why might the ear be most sensitive around the 3 KHz? How would our hearing experience be different if our hearing was equally sensitive across its entire range?  [Interactive ear by Amplifon](http://www.amplifon.co.uk/interactive-ear/index.html)  [Equal loudness curves activity from the University of New South Wales](http://newt.phys.unsw.edu.au/jw/hearing.html) |

3.10.3 Biological measurement

#### 3.10.3.1 Simple ECG machines and the normal ECG waveform

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Principles of operation for obtaining the ECG waveform; explanation of the characteristic shape of a normal ECG waveform. | 0.5 weeks | Describe the principle of operation for obtaining the ECG waveform.  Explain the shape of a normal ECG waveform. | Students research ECGs or view the video clip from Interactive Biology. Discuss and make notes.  Students should rehearse labelling and explaining the normal ECG waveform.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the ECG waveform. | Exampro  QS11.5B.04  QSP.5B.02 | [Video clip from Interactive Biology](http://www.youtube.com/watch?v=4vkbywows-o) |
| Extension |  |  | Students train themselves to read ECGs using Practical Clinical Skills online tutorials. |  | [Practical Clinical Skills online tutorials](http://www.practicalclinicalskills.com/ecg-interpretation.aspx) |

3.10.4 Non-ionising imaging

3.10.4.1 Ultrasound imaging

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Reflection and transmission characteristics of sound waves at tissue boundaries, acoustic impedance, *Z*, and attenuation.  Advantages and disadvantages of ultrasound imaging in comparison with alternatives including safety issues and resolution.  Piezoelectric devices.  Principles of generation and detection of ultrasound pulses.  A-scans and B-scans.  Examples of applications.  Use of the equations  *Z* = ρ *c* and *I*r / *I*i  = [(*Z*2 − *Z*1) /( *Z*2 + *Z*1)]2 | 0.5 weeks | Understand and describe the reflection and transmission characteristics of sound waves at tissue boundaries including acoustic impedance, Z, and attenuation.  Recall and compare the advantages and disadvantages of ultrasound imaging to alternatives including safety and resolution arguments.  Describe the principles by which piezoelectric devices generate and detect ultrasound pulses.  Describe A-scans and B-scans and examples of application.  Use the equations  *Z* = ρ *c* and *I*r / *I*i  = [(*Z*2 − *Z*1) /( *Z*2 + *Z*1)]2 | Students watch the introductory video on Ultrasound scanning from the IOP.  Discussion and notes on reflection and transmission characteristics, acoustic impedance and attenuation.  Advantages and disadvantages can be left until other forms of imaging have been covered.  Students make a simple piezoelectric demonstration as explained by the Creative Learning Centre.  Discussion and notes on principles behind piezoelectric devices and the generation and detection of ultrasound pulses.  Students research and prepare notes on A-scans and B-scans including applications. These are peer assessed and collated in the group to form a revision pack. Students create questions on the contents for a group test.  Rehearsal of calculations using past examination papers.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of Ultrasound scanning including A-scans and B-scans. | Exampro  QS13.5B.03  QS125B04 | [Introductory video from IOP on Ultrasound scanning](http://www.nationalstemcentre.org.uk/elibrary/resource/7517/ultrasound)  [Piezo electric demonstration from the Creative Science Centre](http://www.creative-science.org.uk/piezo1.html) and [supporting video](http://vega.org.uk/video/programme/195) |

#### 3.10.4.2 – 3.10.4.3 Fibre Optics and endoscopy, and Magnetic resonance (MR) scanner

Prior knowledge: Refraction. Refractive index. Coherency.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Properties of fibre optics and applications in medical physics; including total internal reflection at the core–cladding interface.  Physical principles of the optical system of a flexible endoscope; the use of coherent and non-coherent fibre bundles; examples of use for internal imaging and related advantages.  Basic principles of MR scanner:   * cross-section of patient scanned using magnetic fields * protons initially aligned with spins parallel * spinning hydrogen nuclei (protons) precess about the magnetic field lines of a superconducting magnet * 'gradient' field coils used to scan cross-section, causing excitation and change of spin state in * successive small regions * protons excited during the scan emit radio frequency (RF) signals as they de-excite * RF signals detected and the resulting signals are processed by a computer to produce a visual image.   Students will not be asked about the production of magnetic fields used in an MR scanner, or about de-excitation relaxation times. | 1 week | Recall and describe properties and applications of optic fibres in medical physics including calculations on total internal reflection at core-cladding interface.  Understand the physical principles of the optical system of a flexible endoscope. Recall and describe use for internal imaging and related advantages.  Recall and describe the basic principles of the MR scanner as detailed in the learning objectives. | Demonstration and discussion of total internal reflection and optic fibre. Fibre optic video from the engineer guy.  Students use Inside story from IOP to perform a virtual colonoscopy.  Watch video clip explaining MR scanner from Lightbox Radiology Education.  Discussion and use of MR scanner resources and activities from IOP.  Students create card sorts to explain how MR scanner works.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of Endoscopy and MR scanning. | Exampro  QAS04.6.05  QS10.5B.04 | **Rich question:**  What happens to you when you undergo an MR scan?  [Fibre optic video from the engineerguy](http://www.youtube.com/watch?v=0MwMkBET_5I&list=PLwLbbNL-Qn4PoOch2MKLK2C8T4fW_aQyz)  [Inside story Colonoscopy from the IOP](http://www.insidestory.iop.org/insidestory_flash1.html)  [How MR scanners work from Lightbox Radiology Education](http://www.youtube.com/watch?v=Ok9ILIYzmaY)  [MR scanner resources from IOP](http://www.nationalstemcentre.org.uk/elibrary/resource/7522/magnetic-resonance-imaging-mri)  [MR Scanner simulaton from PHET](http://phet.colorado.edu/en/simulation/mri) |

3.10.5 X-ray imaging

#### 3.10.5.1 – 3.10.5.2 The physics of diagnostic X-rays and Image detection and enhancement

Prior knowledge: Photons. Spectra. Fluorescence.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Physical principles of the production of X-rays; maximum photon energy, energy spectrum; continuous spectrum and characteristic spectrum.  Rotating-anode X-ray tube; methods of controlling the beam intensity, the photon energy, the image sharpness and contrast, and the patient dose.  Flat panel (FTP) detector including X-ray scintillator, photodiode pixels, electronic scanning.  Advantages of FTP detector compared with photographic detection.  Contrast enhancement; use of X-ray opaque material as illustrated by the barium meal technique.  Photographic detection with intensifying screen and fluoroscopic image intensification; reasons for using these. | 1 week | Describe and understand the physical principles of the production of X-rays including maximum photon energy, energy spectrum, continuous spectrum and characteristics spectrum.  Describe and understand the Rotating-anode X-ray tube including methods of controlling the beam intensity, the photon energy, the image sharpness and contrast, and the patient dose.  Describe and understand FTP detectors including X-ray scintillator, photodiode pixels, electronic scanning.  Advantages of FTP detector compared with photographic detection.  Describe and understand contrast enhancement and photographic detection. | The basics of X-rays are introduced using the IOP X-ray imaging resources.  Students view the How X-ray tubes work video clip by Maido Merisalu.  Students made an information sheet/poster covering the learning outcomes for X-ray tubes.  Students study the patient information on contrast materials provided by Radiologyinfo.org. They write a short fact sheet to explain to a patient the principles of how this technique works.  Discussion of Upstate Medical University notes on Image Intensifiers leading to notes on learning objectives for FTP, intensifying screen and fluoroscopic mage intensification.  Rehearsal of examination questions.  **Skill developed by learning activities:**  AO2: Apply knowledge and understanding of photons in the production and detection of X-rays. | Exampro  QAS03.6.05  QAW03.6.05 | **Rich question:**  How is an x-ray image produced?  [IOP X-ray imaging](http://www.iop.org/education/teacher/resources/teaching-medical-physics/xray/page_56315.html)  [How X-ray tubes work video clip by Maido Merisalu](http://www.youtube.com/watch?v=TtQROz19wAE)  [Radiologyinfo.org – contrast materials.](http://www.radiologyinfo.org/en/safety/index.cfm?pg=sfty_contrast) |

#### 3.10.5.3 – 3.10.5.4 Absorption of X-rays and CT scanner

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Exponential attenuation.  Linear coefficient μ , mass attenuation coefficient μm, half-value thickness  *I* = *I*0 *e*−μ*x*  μ *m* = μ / ρ  Differential tissue absorption of X-rays excluding details of the absorption processes.  Basic principles of CT scanner:   * movement of X-ray tube * narrow, monochromatic X-ray beam * array of detectors * computer used to process the signals and produce a visual image.   Comparisons will be limited to advantages and disadvantages of image resolution, cost and safety issues. Students will not be asked about the construction or operation of the detectors. | 0.5 weeks | Use and understand the terms exponential attenuation, linear coefficient, mass attenuation coefficient and half-thickness.  Solve problems using the equations  *I* = *I*0 *e*−μ*x*  and  *μ m = μ / ρ*  Describe and understand differential tissue absorption of X-rays.  Recall and describe the basic principles of the CT scanner including comparison to other imaging techniques as detailed in the learning objectives. | Discussion of the terms exponential attenuation, linear coefficient, mass attenuation coefficient and half-thickness.  Rehearsal of problem solving using Antonine Education problems.  Students view the video on the history of CT scanning from Dr Klioze. Discussion and note taking on the key points defined by the learning outcomes.  **Skill developed by learning activities:**  MS0.5: Use calculators to find and use power, exponential and logarithmic functions when solving exponential attenuation problems. | Exampro  QS125B05  QAW04.6.05  QAW05.6.05 | **Rich question:**  How is a CT scan different to a standard X-ray image?  [Antonine Education X-ray resources and example problems.](http://www.antonine-education.co.uk/Pages/Physics_5_Options/Medical_Physics/MED_07/med_phys_7.htm)  [History of CT scanning video from Dr Klioze.](http://www.youtube.com/watch?v=9SUHgtREWQc) |

3.10.6 Radionuclide imaging and therapy

3.10.6.1 – 3.10.6.6 Imaging techniques, Half-life, Gamma camera, Use of high energy X-rays, Use of radioactive implants and Imaging comparisons

Prior knowledge: Gamma rays. Half-life. Anti-matter. Annihilation. Positrons.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Use of a gamma-emitting radioisotope as a tracer; technetium-99m, iodine-131 and indium-111 and their relevant properties.  The properties should include the radiation emitted, the half-life, the energy of the gamma radiation, the ability for it to be labelled with a compound with an affinity for a particular organ.  The Molybdenum-Technetium generator, its basic use and importance.  PET scans.  Physical, biological and effective half-lives;  =  definitions of each term.  Basic structure and workings of a photomultiplier tube and gamma camera.  External treatment using high-energy X-rays. Methods used to limit exposure to healthy cells.  Internal treatment using beta emitting implants.  Students will be required to make comparisons between imaging techniques.  Questions will be limited to consideration of image resolution, convenience and safety issues. | 1 week | Describe the use of isotopes as tracers including technetium-99m, iodine-131 and indium-111 and their relevant properties: the radiation emitted, the half-life, the energy of the gamma radiation, the ability for it to be labelled with a compound with an affinity for a particular organ.  Describe the use of the Molybdenum-Technetium generator and its importance.  Describe the basics of PET scans.  Understand and define the terms physical, biological and effective half-lives.  Solve problems using the equation. *1 / TE = 1TB+ 1/TP*  Describe and understand the basic structure and workings of a photomultiplier tube and gamma camera.  Describe external treatment using high-energy X-rays (including methods to limit exposure to healthy cells) and internal treatment using beta emitting implants.  Recall different imaging techniques and compare them in terms of: image resolution, convenience and safety issues. | Students research use of gamma emitting radioisotopes and their properties technetium-99m, iodine-131 and indium-111. Group discussion of findings.  Discussion of the gamma camera using the IOP resources.  Students view YouTube clip showing Molybdenum-Technetium generator and gamma camera / photomultiplier tube. Discussion and notes on learning outcomes.  Students view the video clip by NIBIB to understand the basics of PET scans.  Discussion of Physical, biological and effective half-lives leading to  =  and definitions of each term. From data tables students should rehearse suitable calculations, for example, a closing exercise from the table provided by Hyperphysics.  Students view the video clip from Cancerquest to understand external and internal treatments. Note that topic should be introduced with sensitivity.  Students construct a poster or information sheet comparing imaging techniques in terms of: image resolution, convenience and safety issues.  **Skill developed by learning activities:**  AO2: Apply knowledge and understanding of half-life to explain and calculate effective half-life. | SAMs Medical Physics Q3 | **Rich question:**  What is the best way to treat a cancer tumour?  [Gamma camera resources from the IOP](http://www.iop.org/education/teacher/resources/teaching-medical-physics/gamma/page_54689.html)  [YouTube clip : Molybdenum-Technetium generator and gamma camera / photomultiplier tube](http://www.youtube.com/watch?v=9GsrIARpTms)  [How a PET scan works by NIBIB](http://www.youtube.com/watch?v=GHLBcCv4rqk)  [Hyperphysics table of half-life data.](http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/biohalf.html)  [External and internal treatments videoclip from Cancer Quest](http://www.youtube.com/watch?v=qM6uxOaylaM) |

## 3.11 Engineering physics

3.11.1 Rotational dynamics

3.11.1.1 – 3.11.1.2 Concept of moment of inertia and Rotational kinetic energy

Prior knowledge: Circular motion.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| *I = mr2* for a point mass. *I* = Σ*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.  Factors affecting the energy storage capacity of a flywheel.  Use of flywheels in machines.  Use of flywheels for smoothing torque and speed, and for storing energy in vehicles, and in machines used for production processes. | 1 week | Recall, understand and use the equations *I* = *mr*2 and *I* = Σ*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 equation  Apply understanding of moment of inertia to explain the factors that affect the energy storage capacity of a flywheel.  Describe the use of flywheels in machines. | 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.  Student experiment: find the moment of inertia of a flywheel from schoolphysics.co.uk.  Students research the use of flywheels in machines to store energy. Write a short report for peer assessment.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of moment of inertia.  AO2: Apply knowledge and understanding of moment of inertia to explain the design of rotating objects. | Exampro  QSP.4A.06  QBS04.4.02 | **Rich question:**  Is a spoked or a solid wheel better for a racing bike?  [Student experiment : Moment of Inertia of flywheel from school physics.co.uk](http://www.google.co.uk/url?sa=t&rct=j&q=moment%20of%20intertia%20of%20a%20flywheel%20experiment&source=web&cd=4&cad=rja&uact=8&ved=0CDUQFjAD&url=http%3A%2F%2Fwww.schoolphysics.co.uk%2Fage16-19%2FMechanics%2FRotation%2520of%2520rigid%2520bodies%2Fexperiments%2Fmoment_of_inertia_of_a_flywheel.doc&ei=XWsXVP24O8GUaPCagNAC&usg=AFQjCNHrkHoX24ubCwQ5-YSudXRQTVtiiw&bvm=bv.75097201,d.d2s)  [Moment of inertia racing](https://www.youtube.com/watch?v=tcs93mPn91E) |
| Extension |  |  | Student experiment: find the moment of inertia of a flywheel. |  |  |

3.11.1.3 – 3.11.1.6 Rotational motion, Torque and angular acceleration, Angular momentum, and Work and power

Prior knowledge: Equations of uniform motion, circular motion, torque, momentum, impulse.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Angular displacement, angular speed, angular velocity, angular acceleration.  ω = Δ θ / Δ *t* ,  α = Δ *ω* / Δ *t*  Representation by graphical methods of uniform and non-uniform angular acceleration.  Equations for uniform angular acceleration.  Students should be aware of the analogy between rotational and translational dynamics.  *T = F × r*  *T = Iα*  angular momentum = Iω  Conservation of angular momentum.  Angular impulse = change in angular momentum; *T* Δ *t* = Δ *I*ω where *T* is constant.  Applications may include examples from sport.  *W = Tθ ; P = Tω*  Awareness that frictional torque has to be taken into account in rotating machinery. | 2 weeks | Recall and use the terms: Angular displacement, angular speed, angular velocity, and angular acceleration.  Use the equations of rotational motion to solve problems.  Appreciate the analogy between rotational and translational dynamics.  Understand and use the terms torque and angular momentum.  Solve problems using the equations *T = F × r*  T = Iα and angular momentum = Iω  Understand and use the concept of conservation of angular momentum to solve problems.  Understand and use the concept Angular impulse = change in angular momentum.  Use the equations  *W = Tθ ; P = Tω* to solve problems.  Use the idea of frictional torque when solving problems. | Using an inspection method student’s use their knowledge of the equations of linear motion to find the equations of rotational motion.  Describe objects that are undergoing uniform and non-uniform angular acceleration and ask students to sketch graphs to represent this eg whirl an object attached to a string around a stick and allow the string to wind up; motion of a [particle in a cyclotron](http://www.phy.ntnu.edu.tw/oldjava/cyclotron/cyclotron.html); [spiral coin collector](http://www.youtube.com/watch?v=UdMIQOXzowQ)  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.  Discussion of frictional torque in rotating machinery.  Rehearsal of problem solving using exam pro questions.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of moment of inertia.  AO2: Apply knowledge and understanding of moment of inertia to explain the design of rotating objects. | Exampro  QS13.5C.02  QS10.5C.01  QAS03.7.03  SAMs Engineering Physics Q1 | **Rich questions:**  Try and spin yourself on a swivel chair without touching the ground (or another object). Why is this so difficult?  [Demonstrations of conservation of angular momentum from sfu](http://www.sfu.ca/~boal/120lecs/120lec24.pdf)  [Video of conservation of angular momentum from the table top explainer](http://www.youtube.com/watch?v=V3UsrfHa4MQ)  [Bang goes the theory angular momentum](https://www.youtube.com/watch?v=vk7Xzp5Cts8) |
| Extension |  |  | Students investigate and then explain how a clutch works. |  |  |

3.11.2 Thermodynamics and engines

3.11.2.1 – 3.11.2.3 First law of thermodynamics, Non-flow processes, and the p-V diagram

Prior knowledge: Conservation of energy, Work, Gas Laws.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Quantitative treatment of first law of thermodynamics,  *Q = Δ U + W*  where *Q* is energy transferred to the system by heating, Δ *U* is increase in internal energy and *W* is work done **by** the system.  Applications of first law of thermodynamics.  Isothermal, adiabatic, constant pressure and constant volume changes.  *pV* = *nRT*  adiabatic change :  *pV*γ = *constant*  isothermal change : *pV* = *constant*  at constant pressure *W* = *p*Δ*V*  Application of first law of thermodynamics to the above processes.  Representation of processes on *p–V* diagram.  Estimation of work done in terms of area below the graph.  Extension to cyclic processes: *work done per cycle = area of loop*  Expressions for work done are not required except for the constant pressure case, *W* = *p* Δ *V* | 1 week | Understand and apply the first law of thermodynamics equation including use of the equation.  *Q = Δ U + W*  Describe isothermal, adiabatic, constant volume and constant pressure changes. Interpret *p-V* graphs of these changes.  Solve problems using the equations:  *pV* = *nRT*  *pV*γ = *constant*  *pV* = *constant*  *W* = *p*Δ*V*  Appreciate that the area under a p-V graph is equal to the work done and find this quantity including for cyclic processes. | Discuss simple examples of the application of the first law eg 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 use of p-V diagrams to represent a cycle of changes in a graph. Students to interpret graphs identifying where isothermal, adiabatic, constant pressure and constant volume changes occur.  Case study of the Stirling Engine: students research the Stirling Engine and produce a report including p-V diagrams to show the cycle of changes the gas inside goes through and how to calculate work done during each cycle.  Rehearsal of solving problems using past examination questions.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of isothermal, adiabatic, constant volume and constant pressure changes.  MS3.8: Understand the physical  significance of the area between a curve and the x axis for a p-V graph as work done and be able to calculate it or estimate it by graphical methods as appropriate. | Exampro  QAS06.7.04  QS125C01  QS11.5C.03 | [Fire piston video clip](http://www.youtube.com/watch?v=1xbAVWBkGqI)  [Demonstrations of 1st Law from IOP](http://tap.iop.org/energy/thermal/605/page_47476.html)  [Animated Engines : Stirling Engine](http://www.animatedengines.com/stirling.html)  [myfordboy stirling engine](http://diystirlingengine.com/ltd-stirling-cycle-engine-tutorial/) |
| Extension |  |  | With support students build a Stirling Engine using plans such as those provided by myfordboy |  |  |

3.11.2.4 Engine cycles

Prior knowledge: Conservation of energy, efficiency, indicator diagrams.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Understanding of a four-stroke petrol engine cycle and a diesel engine cycle, and of the corresponding indicator diagrams.  Comparison with the theoretical diagrams for these cycles; use of indicator diagrams for predicting and measuring power and efficiency.  *input power* = *calorific value* × *fuel flow rate*  Indicated power as (*area of p*−*V loop)* × (*no. of cycles per second)* × (*no. of cylinders)*  Output or brake power:  *P* = *T*ω  *friction power* = *indicated power* – *brake power*  Engine efficiency; overall, thermal and mechanical efficiencies.  *Overall efficiency* = *brake power / input power*  *Thermal efficiency* = *indicated power / input power*  *Mechanical efficiency* = *brake power / indicated power*  A knowledge of engine constructional details is not required.  Questions may be set on other cycles, but they will be interpretative and all essential information will be given. | 1 week | Describe and understand the four-stroke petrol engine cycle and a diesel engine cycle, and sketch the corresponding indicator diagrams.  Describe and explain the differences between the real and theoretical diagrams for these cycles.  Interpret indicator diagrams to find power and efficiency.  Use the equations associated with engine cycles to solve problems. | Students use the internet to research four-stroke petrol engine cycle and a diesel engine cycle. Students peer assess work.  Students rehearse describing the engine cycle and sketching indicator diagrams under timed conditions.  Discussion of differences between theoretical and actual indicator diagrams.  Rehearsal of solving problems using past examination questions.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the four-stroke petrol engine cycle and a diesel engine cycle.  AO2: Apply knowledge and understanding of indicator diagrams to calculate power and efficiency. | Exampro  QS13.5C.03  QS125C04  QS10.5C.05  SAMs Engineering Physics Q3 | **Rich question:**  What are the advantages and disadvantages of petrol and diesel engines? |

3.11.2.5 – 3.11.2.6 Second Law and engines and Reversed heat engines

Prior knowledge: Conservation of energy, Efficiency, First Law of Thermodynamics.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Impossibility of an engine working only by the First Law.  Second Law of Thermodynamics expressed as the need for a heat engine to operate between a source and a sink.  *Efficiency*  =  *maximum theoretical efficiency*  =  Reasons for the lower efficiencies of practical engines.  Maximising use of *W* and *Q*H for example in combined heat and power schemes.  Basic principles and uses of heat pumps and refrigerators.  A knowledge of practical heat pumps or refrigerator cycles and devices is not required.  Coefficients of performance:   * refrigerator   *COPref = QC / w*  *= QC / (QH – QC) = TC / (TH – TC)*   * heat pump   *COP*hp = *Q*H / *w*  = *Q*H / (*Q*H − *Q*C)  = *T*H / (*T*H − *T*C) | 1 week | Appreciate how the first and second law apply to engines.  Recall and interpret diagrams to show heat and reverse heat engines.  Calculate the efficient and maximum theoretical efficiency of engines.  Understand and explain why engines do not achieve maximum theoretical efficiencies.  Understand the meaning of COP values.  Calculate COP values for reverse heat engines. | Discussion of the application of the first and second law to heat engines.  With guidance students derive the efficiency equation for a heat engine, heat pump and refrigerator.  Discussion of maximum theoretical efficiency, Coefficient of performance and reasons for energy losses in practical engines.  Students research a combined heat and power scheme. They should explain how it works, the benefits and attempt to draw a heat flow diagram.  Rehearsal of problems from past examination papers.  **Skill developed by learning activities:**  AO2: Apply knowledge and understanding to construct and interpret heat flow diagrams to for heat engines. | Exampro  QSP.5C.05  QS13.5C.04  SAMs Engineering Physics Q4 | **Rich question:**  In an ideal world what features would the most efficient heat engines have? |

## 3.12 Turning points in physics

3.12.1 The discovery of the electron

3.12.1.1 – 3.12.1.3 Cathode rays, Thermionic emission of electrons and Specific charge of the electron

Prior knowledge: Electric and Magnetic fields and electric potential. Electron energy levels.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Production of cathode rays in a discharge tube.  The principle of thermionic emission.  Work done on an electron accelerated through a pd *V ;*  *1/2mv2 = eV*  Determination of the specific charge of an electron, *e/me*  , by any one method.  Significance of Thomson’s determination of *e/me* .  .  Comparison with the specific charge of the hydrogen ion. | 1 week | Describe the production of cathode rays in a discharge tube.  Describe the principle of thermionic emission.  Understand that the energy of an electron accelerated through an electric field depends on the potential difference.  Calculate the work done on an accelerated electron using: 1/2*mv*2 = *eV*  Describe how the specific charge of an electron can be found.  Recall and understand the significance of Thomson’s determination of e/m for an electron.  Compare the specific charge of an electron and a hydrogen ion. | Students view the video clip Cathode rays and the discovery of the electron by High Voltage fun.  Demonstration and discussion of production of cathode rays in a discharge tube.  Demonstration of electron deflection tube leading to discussions of thermionic emission, work done on an electron as 1/2*mv*2 = *e*V and determination of the specific charge of an electron.  Discussion of the significance of Thomson’s determination of e/m.  Students calculate the specific charge of the hydrogen ion and compare to the value for an electron.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the cathode ray tube. | Exampro  QAS04.8.04  QS10.5D.01 | **Rich question:**  How do we ‘weigh’ the electron?  [Cathode rays and the discovery of the electron.](https://www.youtube.com/watch?v=CsjLYLW_3G0)  [Determination of e/m using balanced fields.](http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=3&cad=rja&uact=8&ved=0CDIQFjAC&url=http%3A%2F%2Fwww.liv.ac.uk%2F~iop%2FPTC%2FWorkshop%2520resources%2FDetermination%2520of%2520eOverM%2520balanced%2520fields%2520LPTC.doc&ei=dH5NVJLTLpSR7AbU0YDQAw&usg=AFQjCNGP9SluWHWtJe2fXgMZN61FgthyNw&sig2=x0nocJMLWNuBX8w-gZueWQ&bvm=bv.77880786,d.ZGU)  [Determination of e/m animation from McGraw-Hill](http://highered.mheducation.com/olcweb/cgi/pluginpop.cgi?it=swf::100%25::100%25::/sites/dl/free/0072512644/117354/01_Cathode_Ray_Tube.swf::Cathode%20Ray%20Tube) |

3.12.1.4 Principle of Milikan’s determination of the electronic charge, e

Prior knowledge: Electric fields.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Condition for holding a charged oil droplet, of charge *Q* , stationary between oppositely charged parallel plates.  *QV / d* = *mg*  Motion of a falling oil droplet with and without an electric field; terminal speed to determine the mass and the charge of the droplet.  Stokes’ Law for the viscous force on an oil droplet used to calculate the droplet radius.  *F* = 6πη*r*υ  Significance of Millikan’s results.  Quantisation of electric charge. | 0.5 weeks | Understand and explain the conditions for holding a charged oil droplet stationary in an electric field.  Understand and explain the procedure and measurements needed to find the electronic charge including use of the relationships:  *QV / d* = *mg*  *F* = 6πη*r*υ  Describe and explain the significance of Milikan’s results – quantisation of electric charge. | Demonstration and discussion of Milikan oil drop experiment using McGraw-Hill animation.  Students carry out a simulation of the Milikan oil drop experiment, for example the Teachscience.net simulation.  Discussion of the significance of the result of the experiment.  **Skill developed by learning activities:**  AO3: Analyse, interpret and evaluate scientific information, ideas and evidence, to make judgements and reach conclusions about the quantisation of charge in the Milikan oil drop experiment. | Exampro  QS11.5D.02  QS13.5D.01  SAMs Turning Points Q 1 | **Rich question:**  If the charge of an electron is quantised what other quantities in the universe share this behaviour?  [McGraw-Hill animation of the Milikan Oil drop experiment](http://highered.mheducation.com/olcweb/cgi/pluginpop.cgi?it=swf::100%25::100%25::/sites/dl/free/0072512644/117354/02_Millikan_Oil_Drop.swf::Milikan%20Oil%20Drop)  [Teachscience.net Milikan Oil Drop simulation](http://www.teachscience.net/2011/02/07/millikan-oil-drop-simulation/) |
| Extension |  |  | A discussion of Millikan’s data selection and the following controversy : <http://www.its.caltech.edu/~dg/MillikanII.pdf> |  |  |

3.12.2 Wave-particle duality

3.12.2.1 – 3.12.2.3 Newton’s corpuscular theory of light, Significance of Young’s double slits experiment and Electromagnetic waves

Prior knowledge: Diffraction. Superposition. Interference. Electric fields and Magnetic fields. Basic properties of electromagnetic waves.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Comparison with Huygens’ wave theory in general terms.  The reasons why Newton’s theory was preferred.  Explanation for fringes in general terms, no calculations are expected.  Delayed acceptance of Huygens’ wave theory of light.  Nature of electromagnetic waves.  Maxwell’s formula for the speed of electromagnetic waves in a vacuum,  c = 1/√ ε0μ0  where μ *o* is the permeability of free space and ε0 is the permittivity of free space.  Students should appreciate that ε0 relates to the electric field strength due to a charged object in free space and μ*o* relates to the magnetic flux density due to a current-carrying wire in free space.  Hertz’s discovery of radio waves including measurements of the speed of radio waves.  Fizeau’s determination of the speed of light and its implications. | 1 week | Describe and understand the key features of Newton’s corpuscular theory including explanation of reflection and refraction.  Comparison of Huygen’s wave theory.  Describe and appreciate the reasons why Newton’s theory was preferred.  Describe the nature of electromagnetic waves.  Appreciation that ε0 relates to the electric field strength due to a charged object in free space and μ*o* relates to the magnetic flux density due to a current-carrying wire in free space.  Describe and understand Hertz’s experiment to show the existence of and then measure the speed of electromagnetic waves. Understand the significance of this result.  Describe Fizeau’s determination of the speed of light and the implication of the result. | Students watch corpuscular theory video clip. Discussion of the reasons why this was preferred over Huygen’s wave theory.  Demonstration of Young’s double slit experiment or a simulation. Discussion of production of fringes and why the corpuscular theory cannot explain these.  Students view video clips on electromagnetic waves and their discovery by Maxwell and Hertz.  Discussion of Maxwell’s formula for the speed of electromagnetic waves and significance of the experimental determination of the speed of radio waves. Demonstration of standing waves with microwaves from IOP to reinforce details of the experiment.  Students view the TED talk fragment which details Fizeau’s determination of the speed of light and discuss the implications of this result at the time.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the evidence for the electromagnetic nature of light. | Exampro  QS13.5D.03  QS125D02  SAMs Turning Points Q3 | **Rich question:**  Is light a wave or a particle? What evidence do we have to inform our decision?  [Newton’s corpuscular theory video clip by elearnin](https://www.youtube.com/watch?v=uO2uyvf-E3k)g  [Double Slit experiment explained by Jim Al-Khalili](https://www.youtube.com/watch?v=A9tKncAdlHQ)  [PhET interference simulation](https://phet.colorado.edu/en/simulation/wave-interference)  [Discovery of Electromagnetic waves video clip](https://www.youtube.com/watch?v=dHhz-rQ5WWw)  [Notes on Hertz experiment to find the speed of radiowaves from Keelynet](http://www.keelynet.com/spider/b-103e.htm)  [Standing waves with microwaves from IOP](http://tap.iop.org/vibration/superpostion/324/file_46788.doc)  [TED talk: Fizeau’s determination of the speed of light.](https://www.youtube.com/watch?v=ScN-btW8ST8)  [Bang Goes the Theory finding the speed of light using a microwave oven.](http://www.bbc.co.uk/bang/handson/lightspeed.shtml) |
| Extension |  |  | Students find the speed of light using a microwave oven. |  |  |

3.12.2.4 The discovery of photoelectricity

Prior knowledge: Electromagnetic waves. Photons. Photoelectric effect. Wave particle duality.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The ultraviolet catastrophe and black-body radiation.  Planck’s interpretation in terms of quanta.  The failure of classical wave theory to explain observations on photoelectricity.  Einstein’s explanation of photoelectricity and its significance in terms of the nature of electromagnetic radiation. | 0.5 weeks | Describe the ultraviolet catastrophe in terms of black body radiation.  Recall that Planck’s interpretation using quanta solved the ultraviolet catastrophe.  Understand and describe Einstein’s explanation of photoelectricity and it significance in demonstrating particle properties of electromagnetic radiation. | Demonstration of light from a filament lamp showing change of colour as it heats.  Explain the colour changes using Black Body Spectrum PHET simulation.  View Brief History of Quantum Mechanics video and discuss Ultraviolet Catastrophe and Einstein’s explanation of photoelectricity.  Demonstration of Photoelectric effect and TAP Photoelectric effect resources.  Students create a summary sheet describing the wave and particle models of electromagnetic radiation and the evidence for each. | Exampro  QAS06.8.02 | **Rich question:**  Is light a wave or a particle? How do we know?  [PHET simulation:](http://phet.colorado.edu/en/simulation/blackbody-spectrum)  [Black Body Spectrum.](http://phet.colorado.edu/en/simulation/blackbody-spectrum)  [Video Resource from Science Channel : A Brief History of Quantum Mechanics](https://www.youtube.com/watch?v=B7pACq_xWyw)  [TAP Photoelectric effect resources](https://tap.iop.org/atoms/quantum/502/page_47014.html) |

3.12.2.5 – 3.12.2.6 Wave-particle duality and Electron microscopes

Prior knowledge: Momentum. Interference. Diffraction.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| de Broglie’s hypothesis:  *p* = *h /* λ ;  λ = *h /* √2*meV*  Low-energy electron diffraction experiments; qualitative explanation of the effect of a change of electron speed on the diffraction pattern.  Estimate of anode voltage needed to produce wavelengths of the order of the size of the atom.  Principle of operation of the transmission electron microscope (TEM).  Principle of operation of the scanning tunnelling microscope (STM). | 1 week | Recall de Broglie’s hypothesis *p* = *h /* λ  Describe electron diffraction as evidence of the wave-like nature of the electron.  Explain, qualitatively, the changes in diffraction pattern observed when changing the speed of the electrons.  Solve problems using the equations:  *p* = *h /* λ ;  λ = *h /* √2*meV*  including estimating the voltage needed to produce wavelengths of the order of the size of an atom. | Students view the video clip on de Broglie’s hypothesis by Sixty Symbols.  To reinforce learning discussion of particle and wave model of the atom using PHET simulation.  Discussion of the de Broglie equation  *p* = *h /* λ leading to λ = *h /* √2*meV*  Rehearsal of problems including estimate of anode voltage needed to produce wavelengths of the order of the size of the atom.  Demonstration of electron diffraction. Discussion of how changing electron speed changes the diffraction pattern.  Students view the TEM and STM videoclips. Discussion of the principles of microscopes including magnetic lenses, resolution and quantum tunnelling. Further amplification of quantum tunnelling with discussion of the PHET quantum tunnelling simulation.  Students produce written reports on the TEM and STM to consolidate learning.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the TEM and STM | Exampro  QAS03.8.04  QAS06.8.04  SAMs Turning Points Q2 | **Rich question:**  What is the smallest object we can see?  [de Broglie hypothesis video clip by Sixty Symbols University of Notthingham](https://www.youtube.com/watch?v=JIGI-eXK0tg)  [Electron diffraction demonstration from Nuffield Foundation](http://www.nuffieldfoundation.org/practical-physics/electron-diffraction) and [STEM](http://www.nationalstemcentre.org.uk/elibrary/resource/2015/electron-diffraction-tube)  [Simulation of particle and de Broglie model of atom from PHET](https://phet.colorado.edu/en/simulation/hydrogen-atom)  [STM video clip](https://www.youtube.com/watch?v=wNEqRq6NyUw)  [PHET quantum tunnelling simulation](https://phet.colorado.edu/en/simulation/quantum-tunneling) |

3.12.3 Special relativity

3.12.3.1 – 3.12.3.2 The Michelson-Morley experiment and Einstein’s theory of special relativity

Prior knowledge: Interference.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Principle of the Michelson–Morley interferometer.  Outline of the experiment as a means of detecting absolute motion.  Significance of the failure to detect absolute motion.  The invariance of the speed of light.  The concept of an inertial frame of reference.  The two postulates of Einstein’s theory of special relativity:   * physical laws have the same form in all inertial frames * the speed of light in free space is invariant. | 1 week | Understand the principle of the Michelson–Morley experiment as an interferometer.  Describe and explain the experiment as a means of detecting absolute motion.  Describe and explain the significance of failure to detect absolute motion. | Students view the Michelson–Morley experiment video clip. Students prepare notes explaining the details of the interferometer and significance of the result leading to the invariance of the speed of light.  Discussion of the concept of an inertial frame of reference leading to Einstein’s two postulates.  Flipped lesson: students work through the self-study guide by vicphysics for homework. They bring questions to lesson time for discussion.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of Einstein’s two relativity postulates. | Exampro  QAS03.8.03  QS125D04  SAMs Turning Points Q4 | **Rich question:**  How fast does the light from a moving lamp travel at?  [The Michelson-Morley experiment video-clip.](https://www.youtube.com/watch?v=ZMdpyisUraY)  [Einstein’ Theory of Relativity video-clip including length correction and time dilation.](https://www.youtube.com/watch?v=ev9zrt__lec)  [Relativity supported self-study guide by vicphysics.org](http://www.vicphysics.org/documents/teachers/unit3/EinsteinRelEssentials2010.pdf) |
| Extension |  |  | Students perform a version of the Michelson-Morley experiment using microwaves.  Discussion of the refuted OPERA findings in which neutrinos travel faster than c. |  | [Link to example of Michelson-Morley experiment using microwaves](http://www4.wittenberg.edu/academics/phys/eag/P220/P220_Lab01uwave_S09.pdf) |

3.12.3.3 – 3.12.3.5 Time dilation, Length contraction, and Mass and energy

Prior knowledge:

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Proper time and time dilation as a consequence of special relativity.  Time dilation:  *t* = *to* √ (1 − *v*2 */ c*2)  Evidence for time dilation from muon decay.  Length of an object having a speed *v*  *l* = *lo* √ (1 − *v*2 */ c*2)  Equivalence of mass and energy, *E* = *mc*2 ; *E* = *moc*2 / √ (1 − *v*2 / *c*2)  Graphs of variation of mass and kinetic energy with speed.  Bertozzi’s experiment as direct evidence for the variation of kinetic energy with speed. | 1.5 weeks | Understand and use the terms proper time and time dilation.  Use the equation  *t* = *to* √ (1 − *v*2 */ c*2)  to solve problems.  Understand and use the term length contraction.  Use the equation  *l* = *lo* √ (1 − *v*2 */ c*2)  to solve problems.  Describe and interpret the results of Bertozzi’s experiment.  Understand and use the concept of the equivalence of mass and energy including sketching graphs of the variation of mass and kinetic energy with speed and calculations using  *E* = *mc*2 ; *E* = *moc*2 / √ (1 − *v*2 / *c*2) | Flipped classroom: students work through the self-study guide by vicphysics for homework. They bring questions to lesson time for discussion.  Consolidate knowledge and understanding with muon decay worked examples from Hyperphysics and the Einstein’s theory of relativity video-clip.  Students view the video on Bertozzi’s experiment. Discussion of the results leading to the equivalence of mass and energy  *E* = *mc*2; *E* = *moc*2 / √ (1 − *v*2 / *c*2).  Students sketch graphs of the variation of mass and kinetic energy with speed.  Question rehearsal using past examination questions.  **Skill developed by learning activities:**  AO2: Apply knowledge and understanding of length contraction / time dilation to explain the observed properties of muons. | Exampro  QS11.5.04  QAS05.8.04 | **Rich questions:**  Is it possible to time-travel?  Why is not possible to travel faster than the speed of light?  [Notes and worked examples of muon decay from hyperphysics](http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/muon.html)  [Einstein’s Theory of Relativity video-clip including length correction and time dilation.](https://www.youtube.com/watch?v=ev9zrt__lec)  [Relativity supported self-study guide by vicphysics.org](http://www.vicphysics.org/documents/teachers/unit3/EinsteinRelEssentials2010.pdf)  [Video-clip from Jefferson Lab Science series on Bertozzi’s experiment.](http://education.jlab.org/scienceseries/ultimate_speed.html) |
| Extension |  |  | Discussion of the twin paradox. |  |  |

## 3.13 Electronics

3.13.1 Discrete semiconductor devices

3.13.1.1 – 3.13.1.2 MOSFET and Zener diode

Prior knowledge: Current. Voltage. Diodes.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Simplified structure, behaviour and characteristics.  Drain, source and gate.  *VDS , VGS , IDSS , and Vth*  Use as a switch, use as a device with a very high input resistance.  Use in N-channel, enhancement mode only is required.  Characteristic curve showing zener breakdown voltage and typical minimum operating current.  Anode and cathode.  Use with a resistor as a constant voltage source.  Use to provide a reference voltage.  Use as a stabiliser is not required. | 0.5 weeks | Understand and describe in a simple way the structure, behaviour and characteristics of a MOSFET.  Recognise and use the concept of drain, source and gate and the symbols *V*DS , *V*GS , *I*DSS , and *V*th  Understand how the MOSFET can be used as switch. | Students view the video on MOSFETs from the University of Granada. Discussion and notes on the behaviour characteristics and use of the MOSFET as a switch.  Students investigate the switch behaviour of a MOSFET using Paul Falstad’s simulator.  Discussion of diodes including breakdown voltage and difference between Zener and standard diodes.  Students investigate the characteristic curve for a zener diode including breakdown voltage and minimum operating current.  Discussion of the characteristic curve and this leads to the zener being used with a resistor constant voltage source in reverse bias.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of zener diodes | SAMs Electronics Q1 | **Rich question:**  How is a zener diode different to a standard diode?  [Falstad’s simulator of MOSFET as a switch](http://www.falstad.com/circuit/e-nmosfet.html)  [Investigating the characteristics of a Zener diode from the University of Technology](http://www.uotechnology.edu.iq/dep-laserandoptoelec-eng/laboratory/2/electronic1/Zener%20diode%20Characteristics.pdf)  [Falstad’s simulator of a zener diode as a constant voltage source.](http://www.falstad.com/circuit/e-zenerref.html) |

3.13.1.3 – 3.13.1.4 Photodiode and Hall effect sensor

Prior knowledge: Current. Voltage. Diodes. Magnetic fields. Force on moving charge in a magnetic field – Lorentz force.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Characteristic curves and spectral response curves.  Use in photo-conductive mode as a detector in optical systems.  Use with scintillator to detect atomic particles.  Use as magnetic field sensor to monitor attitude.  Use in tachometer.  Principles of operation are not required. | 0.5 weeks | Sketch photodiode characteristics curve and spectral response curve.  Describe photodiode behaviour in photoconductive mode and use as a detector in optical systems.  Describe use of photodiode as a scintillator to detect atomic particles.  Understand and describe the Hall effect in use as magnetic field sensor to monitor attitude and in a tachometer. | Discussion of photo diode properties including characteristics curve, spectral response curve and use as a detector in optical systems.  Students investigate how photocurrent varies with applied reverse bias voltage and luminance.  Discussion of use of photodiode with scintillator to detect atomic particles.  Students view the video clip on the Hall effect from Sixty Symbols.  Discussion of how the Hall effect can be used as magnetic field sensor to monitor attitude and in a tachometer.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the Hall effect | Exampro | **Rich question:**  [Hall effect video clip from Sixty Symbols](http://www.youtube.com/watch?v=AcRCgyComEw) |
| Extension |  |  | Students plan and then build a Hall effect sensor. For example using the resource provided by Georgia Tech |  | [Hall effect project provided by Georgia tech](http://www.ece.gatech.edu/academics/outreach/step-up/lesson_plans/2013/HallEffect.pdf) |

3.13.2 Analogue and digital signals

3.13.2.1 Difference between analogue and digital signals

Prior knowledge: Basic understanding of analogue and digital signals.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Bits, bytes.  Analogue-to-digital conversion:   * sampling audio signals for transmission in digital form * conversion of analogue signals into digital data using two voltage levels * quantisation * sampling rate * effect of sampling rate and number of bits per sample on quality of conversion * advantages and disadvantages of digital sampling * process of recovery of original data from noisy signal * effect of noise in communication systems.   Pulse code modulation.  Students should appreciate the use of a variety of sensors to collect analogue data.  The ability to carry out binary arithmetic is not required. Knowledge of binary numbers 1 to 10 is adequate. | 0.5 weeks | Recall what a bit and a byte is.  Understand and describe the process of analogue to digital conversion including pulse code modulation, sampling, quantisation, quality, advantages and disadvantages, effect and process of recovery from noise.  Appreciation of the use of a variety of sensors in the collection of analogue data.  Recall and use the binary numbers for 1 to 10. | Discussion of the difference between analogue and digital information. Demonstrate SOS as a digital signal using morse code leading to difference between bits and bytes.  Students should learn the binary numbers from one to ten.  Students take simple block graphics and create binary codes to represent them. Discussion of how sampling rate and number of bits per sample effect quality. Discuss errors as noise.  Students study the Ethan Hein blog entry on analogue to digital conversion to deepen understanding including pulse modulation and sampling rate.  Students investigate a number of different data logging sensors (sound, temperature, motion etc.) to collect analogue data. The sampling rate can be varied (and made very low) to consolidate previous learning.  **Skills developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the process of analogue to digital conversion.  AO2: Apply knowledge and understanding to interpret steps in analogue to digital conversion. | Exampro | [Ethan Hein blog – analogue to digital conversion for audio signals tutorial](http://www.ethanhein.com/wp/2014/digital-audio-basics/) |

3.13.3 Analogue signal processing

3.13.3.1 LC resonance filters

Prior knowledge: Capacitance. Mass spring system. Resonance.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Resonant frequency,  *f*0 = 1 / (2 √ *LC)*  Only parallel resonance arrangements are required.  Analogy between LC circuit and mass–spring system.  Inductance as mass analogy.  Capacitance as spring analogy.  Derivation of the equation is not required.  Energy (voltage) response curve.  The response curve for current is not required.  *Q* factor, *Q* = *f* 0 / *f* B  *f* B is the bandwidth of the filter at the 50% energy points. | **0.5 weeks** | Describe the resonance of an LC circuit.  Use the equation  *f 0 = 1 / (2 √ LC)*  to calculate the resonant frequency of an LC circuit.  Describe and appreciate the analogy between an LC circuit and a mass-spring system.  Sketch the energy (voltage) response curve for an LC circuit.  Use the equation  *Q* = *f* 0 / *f* B  to calculate Q factor and recall that *f* B is the bandwidth of the filter at the 50% energy points. | Discussion of capacitors and inductors.  Students work through the LC circuit activity using the PHET simulator.  Students examine the PHET mass spring system simulator and deduce analogies to the LC circuit.  Discussion and definition of Q factor.  **Skill developed by learning activities:**  AO1: Demonstrate understanding of LC resonant filters. | SAMs Electronics Q4 | **Rich question:**  What are the analogies between an LC circuit and a mass-spring system?  [LC circuit activity using PHET simulator](http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=5&cad=rja&uact=8&ved=0CDkQFjAE&url=http%3A%2F%2Fphet.colorado.edu%2Ffiles%2Factivities%2F3572%2FLC%2520circuits%2520and%2520radio%2520tuners.docx&ei=3x1MVKXgM-iR7AbIo4CACQ&usg=AFQjCNH4CPnzvuBd2lAULaEJAF5mhPINzw&bvm=bv.77880786,d.ZGU) |

3.13.3.2 The ideal operational amplifier

Prior knowledge:

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Operation and characteristics of an ideal operational amplifier:  • power supply and signal connections  • infinite open-loop gain  • infinite input resistance.  Open-loop transfer function for a real operational amplifier;  *V* out = *A*OL (*V* + − *V* −) .  Use as a comparator.  The operational amplifier should be treated as an important system building block. | **0.5 weeks** | Recall the symbol, operation and characteristics of an ideal operational amplifier as defined in the learning objectives.  Recall the use open-loop transfer function for a real operational amplifier,  *V out = AOL (V + − V −) .*  Describe the use of an operational amplifier as a comparator.  Appreciate the importance of the operational amplifier as system building block. | Students deduce the simple behaviour of an operational amplifier from the Falstad simulation.  Students work through the Antonine education introduction to operational amplifiers including use as a comparator.  Students build example Op-Amp circuits on breadboard.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the characteristics of an ideal operational amplifier. | SAMs Electronics Q3 | [Falstad simulation of operational amplifier.](http://www.falstad.com/circuit/e-opamp.html)  [Antonine education introduction to operational amplifiers](http://www.antonine-education.co.uk/Pages/ELectronics_1/Electronic_Components/Op-amp/intro_8.htm)  [Example operational amplifier as a comparator circuit on breadboard](http://www.ece.rice.edu/~jdw/242_lab4/exp4.1.html) |

3.13.4 Operational amplifier in:

3.13.4.1 – 3.13.4.4 Inverting amplifier configuration, Non-inverting amplifier configuration, Summing amplifier configuration, Real operational amplifiers

Prior knowledge: Ohm’s Law. Current and Voltage in circuits. Potential divider.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Derivation of  *V* out / *V* in = − (*R*f / *R*in)  , calculations.  Meaning of virtual earth, virtual-earth analysis.  *V* out / *V*in =  1 + (*R*f  / *R*l)  Derivation is not required.  Difference amplifier configuration.  Derivation is not required.  Derivation is not required.  Limitations of real operational amplifiers.  Frequency response curve.  *gain* × *bandwidth* = *constant* for a given device. | 0.5 weeks | Recognise operational amplifier circuits in the following configurations: inverting, non-inverting, summing and difference.  Derive and use the relationship  *V* out / *V* in =  − (*R*f / *R*in)  or an operational amplifier in inverting configuration.  Understand the terms virtual earth and virtual-earth analysis.  Use the equations for a non-inverting amplifier and a summing amplifier to solve problems.  Recall the limitations of real operational amplifiers.  Sketch the frequency response curve.  Use the relationship gain x bandwidth = constant. | Students view the Falstad simulations to understand the basic behaviour of inverting, non-inverting, summing and difference configurations.  Detailed discussion and analysis of operational amplifiers in inverting, non-inverting, summing and difference configurations including derivation of  *V* out / *V* in = − (*R*f / *R*in) .  for the inverting configuration. Discussion should include virtual earth analysis and the meaning of virtual earth. Students work through the flash tutorial provided by Holbert of Arizona State University.  Discussion of the limitation of real operational amplifiers including the frequency response curve and the relationship *gain* × *bandwidth* = *constant .*  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of the characteristics of an ideal operational amplifier. | Exampro | **Rich question:**  What is the origin of the name operational amplifier?  [Falstad simulations.](http://www.falstad.com/circuit/e-index.html#amp-noninvert)  [Flash tutorial provided by Holbert of Arizona State University.](http://holbert.faculty.asu.edu/ece201/opamp.html) |

3.13.5 Digital signal processing

3.13.5.1 Combinational logic

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Use of Boolean algebra related to truth tables and logic gates.  = **not** *A*  *A* ∙ *B* = *A* **and** *B*  *A* + *B* = *A* **or** *B*  Identification and use of AND, NAND, OR, NOR, NOT and EOR gates in combination in logic circuits.  Construction and deduction of a logic circuit from a truth table.  The gates should be treated as building blocks. The internal structure or circuit of the gates is not required. | 0.5 weeks | Recall use  = **not** *A*  *A* ∙ *B* = *A* **and** *B*  *A* + *B* = *A* **or** *B*  Recall the symbols for behaviour of AND, NAND, OR, NOR, NOT and EOR gates in combination in logic circuits.  Be able to deduct and construct a logic circuit from a truth table. | Discussion and demonstration of AND, NAND, OR, NOR, NOT and EOR gate symbols and behaviour. This could be done with real components or a simulator such as that provided by SourceForge or Neuroproductions. Students should be challenged to complete simple logic gate projects.  Students construct truth tables for AND, NAND, OR, NOR, NOT and EOR gates.  Discussion of the relationships:  = **not** *A*  *A* ∙ *B* = *A* **and** *B*  *A* + *B* = *A* **or** *B*  Discussion and practise of the process of deducing a logic circuit from a truth table.  Students test their progress by working through the Antonine education resources and interactive questions.  **Skill developed by learning activities:**  AO2: Apply knowledge and understanding of Boolean algebra to deduce a logic circuit from a truth table. | Exampro | **Rich question:**  Suggested logic gate simulations:  [SourceForge](http://sourceforge.net/projects/gatesim/)  [Neuroproductions](http://www.neuroproductions.be/logic-lab/)  [Antonine education logic gate resources](http://www.antonine-education.co.uk/Pages/ELectronics_1/Digital_Systems/Logic_gates/Intro_9.htm) |

3.13.5.2 Sequential logic

Prior knowledge: Binary numbers 1 – 9. Logic gates.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Counting circuits:   * Binary counter * BCD counter * Johnson counter.   Inputs to the circuits, clock, reset, up/down.  Outputs from the circuits.  Modulo-*n* counter from basic counter with the logic driving a reset pin.  The gates should be treated as building blocks. The internal structure or circuit of the gates is not required. | 0.5 weeks | Recognise counting circuits and describe their behaviour.  Understand the output of the counters in terms of inputs, clock, reset, up/down. | Students view the counters and their operation in the Falstad simulations.  Discussion of the clock, reset, up/down and outputs of the circuits.  Discussion of how a Modulo – n counter can be constructed from a basic counter with the logic driving the reset pin.  Students build a counter circuit, for example the BCD counter detailed at technologystudent.com.  Students consolidate knowledge by writing a short report outlining and comparing the behaviour of the three counters and suggesting a use for each.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of counters. | Exampro | **Rich question:**  How does a machine count?  [Falstad simulations of counters](http://www.falstad.com/circuit/e-index.html#zenerref)  [BCD counter from technologystudent.com](http://www.technologystudent.com/elec1/count1.htm) |
| Extension |  |  | Students build a BCD counter using the Doctronics plan. |  | [Doctronics BCD counter](http://www.doctronics.co.uk/4510.htm#what) |

3.13.5.3 Astables

Prior knowledge: Capacitors.Time Constant RC.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The astable as an oscillator to provide a clock pulse.  Clock (pulse) rate (frequency), pulse width, period, duty cycle, mark-to-space ratio.  Variation of running frequency using an external *RC* network.  Knowledge of a particular circuit or a specific device (eg 555 chip) will not be required. | 0.5 weeks | Describe the behaviour of the astable and how it can provide a clock pulse.  Understand and use the terms: clock (pulse) rate (frequency), pulse width, period, duty cycle, mark-to-space ratio. | Students observe the behaviour of an astable using the Falstad simulator.  Students use the BBC Bitesize website and electronics-tutorials to find and understand the terms: clock (pulse) rate (frequency), pulse width, period, duty cycle, mark-to-space ratio.  Discussion of variation of running frequency using an external RC circuit.  Students gain experience of building astable circuits, for example from buildcircuit.com.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of astables. | Exampro | **Rich question:**  [Falstad simulation of an astable circuit.](http://www.falstad.com/circuit/e-multivib-a.html)  [Notes from website Electronics-tutorials](http://www.electronics-tutorials.ws/sequential/seq_3.html)  [BBC bitesize notes on astable](http://www.bbc.co.uk/schools/gcsebitesize/design/electronics/calculationsrev4.shtml)  [Astable circuits from buildcircuit.com](http://www.buildcircuit.com/astable-mode-of-555-timer/) |

3.13.6 Data communication systems

3.13.6.1 – 3.13.6.3 Principles of communication systems, Transmission media and Time-division multiplexing

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Communication systems, block diagram of 'real time' communication system.(see specification).  Only the purpose of each stage is required.  Transmission-path media: metal wire, optic fibre, electromagnetic (radio, microwave).  Ground wave, refraction and reflection of sky waves, diffraction of long-wavelength radiation around the Earth’s surface.  Satellite systems and typical transmission frequencies.  Students should recognise that up-links and down-links require different frequencies so that the receivers are not de-sensed.  Advantages and disadvantages of various transmission media. Students should consider data transmission rate, cost, and security issues.  Basic principles of time-division multiplexing. | 1 week | Recall and describe the purpose of each stage in a real time communication system.  Describe the transmission-path media of metal wires, optic fibres and electromagnetic waves (radio, microwave) including advantages and disadvantages of each in terms of data transmission rate, cost, and security issues.  Describe propagation by ground waves, sky waves.  Describe satellite transmissions including typical frequencies and understand why there is difference between up and down-links frequency.  Describe and understand the basic principles of time-division multiplexing. | Issue students with block diagram of real time communication system. Discuss each stage identifying purpose. Students make notes.  Students research one of the transmission-path media: metal wire, optic fibre, electromagnetic (radio, microwave). As part of this they should cover: Advantages and disadvantages, data transmission rate, cost, and security issues. Students present to the group and their work is peer assessed. Work is collated to form a resource for the group.  Discussion of ground and sky wave propagation, and satellite transmission including difference in up and down-link frequencies. (view video clips from 7activestudio and Tutorvista).  Discuss time-division multiplexing. In groups role-play time division multiplexing of images or a message cut into pieces.  **Skill developed by learning activities:**  AO1: Demonstrate knowledge and understanding of ground and sky waves in the propagation of electromagnetic waves. | SAMs Electronics Q4 | **Rich question:**  How are radio waves transmitted around the Earth?  [7activestudio propagation of electromagnetic waves](https://www.youtube.com/watch?v=r-shNhpBkhs)  [Satellite transmission from Tutorvista](https://www.youtube.com/watch?v=hXa3bTcIGPU)  [Time-division multiplexing notes from Hill Associates](http://hill2dot0.com/wiki/index.php?title=Time_Division_Multiplexing) |

3.13.6.4 Principles of communication systems and transmission media

Prior knowledge: Amplitude and frequency modulation (AM and FM) techniques.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Principles of modulation; bandwidth.  Carrier wave and information signal.  Details of modulation circuits for modulating a carrier signal with the information signal will not be required.  Graphical representation of both AM and FM modulated signals.  A detailed mathematical treatment is not required.  Students will be expected to identify the carrier frequency and the information frequency from a graph of the variation of signal voltage with time.  Bandwidth requirements of simple AM and FM:  *bandwidth = 2 f M for AM*  *bandwidth =*  *2 (Δ f + f M) for FM*  Data capacity of a channel.  Comparison of bandwidth availability for various media. | 0.5 weeks | Understand and describe the principles of AM and FM modulation.  Sketch graphs to represent AM and FM modulated signals and interpret these to find carrier and information frequency.  Use the relationships  *bandwidth = 2 f M for AM*  *bandwidth = 2 (Δ f + f M) for FM*  to calculate bandwidth for AM and FM signals.  Appreciate the concept of the data capacity of a channel.  Make comparisons of bandwidth availability for different media. | Discussion of modulation including bandwidth, carrier wave and information signal. Students write notes and sketch graphs to represent AM and FM modulated signals.  Rehearsal of distinguishing carrier and information frequencies from voltage time signals.  Discussion of bandwidth requirements for simple AM and FM and rehearsal of calculations using the equations.  *bandwidth = 2 f M for AM*  *bandwidth = 2 (Δ f + f M) for FM*  Discussion of data capacity of a channel and comparison of bandwidth availability for various media.  **Skill developed by learning activities:**  AO2: Apply knowledge and understanding to analyse modulated signals to deduce carrier and signal frequencies. | SAMs Electronics Q2 | **Rich question:**  [Amplitude modulation notes from Radio-electronics.com](http://www.radio-electronics.com/info/rf-technology-design/am-amplitude-modulation/what-is-am-tutorial.php)  [Frequency modulation notes from Radio-electronics.com](http://www.radio-electronics.com/info/rf-technology-design/fm-frequency-modulation/what-is-fm-tutorial.php) |