Scheme of work

AS Physics 7407

v1.1

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 AS Physics 7407.

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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# 3.1 Measurements and their errors

**Introduction**

Content in this section is a continuing study for a student of physics. A working knowledge of the specified fundamental (base) units of measurement is vital. Likewise, practical work in the subject needs to be underpinned by an awareness of the nature of measurement errors and of their numerical treatment. The ability to carry through reasonable estimations is a skill that is required throughout the course and beyond.

## 3.1.1 Use of SI units and their prefixes

Prior knowledge: Units and equations from GCSE eg force, kinetic energy and potential energy. SI prefixes, k, c, m.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| To recognise that a system of measurement depends on the selection of several base units. To recall the base units of the SI system.To name and use standard prefixes.To be able to convert between different units for the same quantity. | 3.0hours | * Students know that base units are needed in a system of measurement.
* Students demonstrate that they can convert between different units of the same quantity, eg J and eV, J and kW h.

  | Use of dimensional analysis to predict relationships between quantities eg the speed of a wave, *v*, in water in terms of depth, *d*, and *g*MS0.1MS0.2MS2.2 | Exampro.SAMs AS and A-level Q on same topic | <http://www.npl.co.uk/educate-explore/> |

## 3.1.2 Limitation of physical measurements

Prior knowledge: The importance of the number of significant figures quoted for a quantity.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills s** | **Assessment Opportunities** | **Resources** |
| To recognise the terms: precision, repeatability, reproducibility, and accuracy.To be able to estimate absolute uncertainties and to calculate fractional and percentage uncertainties.To be able to combine absolute and percentage uncertainties.To be able to use error bars on graphs. | 4.0 hours | * Students explain the difference between precision and accuracy.
* Students explain the difference between repeatability and reproducibility.
* Students can estimate uncertainties in measurements
* Students are able to calculate percentage uncertainties from absolute uncertainties.
* Students are able to combine absolute and percentage uncertainties.
* Students can use error bars on graphs to estimate uncertainties in gradients and intercepts.
 | Practical: investigate the relationship between time period and length for a pendulum. Give students the opportunity to estimate uncertainties in the measurement of length and time.MS1,1MS1.5MS3.4PS2.1PS2.2PS2.3PS3.1PS3.3 |  | <https://www.youtube.com/watch?v=1dTn2pt5PuA> |

## 3.1.3 Estimation of Physical Quantities

Use of standard form.

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| **Learning objective/** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment Opportunities** | **Resources** |
| To understand and to use orders of magnitude.To derive estimates using knowledge of physics. | 1 hour | Students are able to make order of magnitude estimates. | Students participate in group learning by designing their own order of magnitude estimates.MS1.4PS1.2Extend to estimates outside physics eg estimate how many piano tuners there are in Chicago. |  | <http://physics.info/orders-magnitude/problems.shtml><http://powersof10.com/film> |

# 3.2 Particles and radiation

**Unit description**

Content in this section introduces students both to fundamental properties of matter, and to electromagnetic radiation and quantum phenomena. Through a study of these topics students become aware of the way new ideas develop and evolve in physics. They will appreciate the importance of international collaboration in the development of new experiments and theories in this area of fundamental research.

## 3.2.1 Particles

**3.2.1.1 Constituents of the atom**

Prior knowledge: GCSE Dual Award Science; Simple atomic model, Isotopes.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Simple model of the atom, including the proton, neutron and electron. Charge and mass of the proton, neutron and electron in SI units and relative units.Specific charge of the proton and the electron, and of nuclei and ions.Proton number *Z*, nucleon number *A*, nuclide notation.Students should be familiar with the $$ notation.Meaning of isotopes and the use of isotopic data. | 0.5 weeks | * Describe a model of the atom including protons, neutrons and electrons.
* Identify the charge and mass of the proton, neutron and electron in SI and relative units.
* Define specific charge and calculate the specific charges of the proton and the electron and of nuclei and ions.
* Identify the unit of specific charge.
* Define proton number and nucleon number and recognise nuclear notation.
* Explain the meaning of isotopes.
* Analyse isotopic data.
 | **Learning activities:*** GCSE baseline assessment.
* Present pictures of atomic models and ask students to identify the neutrons, protons and electrons.
* Compare the charges and masses of protons, neutrons and electrons in SI and relative units.
* Introduce specific charge and practice calculations involving the specific charges of protons and electrons and of nuclei and ions.
* Review atomic number and nucleon number and practice using nuclide notation.
* Review isotopes and practise analysing isotopic data to deduce neutron number.

**Skills developed by learning activities:**AO1: Demonstration of knowledge of simple models of the atom.PS2.2: Present masses in SI and relative units.MS2.3: Substitute numerical values into algebraic equations to calculate specific charge.MS2.4: Solve algebraic equations involving masses and charges of nuclei and ions.AO2: Demonstrate knowledge and understanding isotopes and analyse isotope data. | Past exam paper materials:PHYA1 May 2013 Q1PHYA1 January 2013 Q1(a)PHYA1 June 2012 Q2(a)PHYA1 June 2012 Q2(b)PHYA1 May 2014 Q2(a)(i), (ii) and (iii) | <http://phet.colorado.edu/en/simulation/build-an-atom>**Rich questions:**Why was specific charge important in the discovery of the electron by J.J. Thomson? |

**3.2.1.2 Stable and unstable nuclei**

Prior knowledge: GCSE Dual Award Science;unstable nuclei

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The strong nuclear force; its role in keeping the nucleus stable; short-range attraction up to approximately 3 fm, very-short range repulsion closer than approximately 0.5 fm.Unstable nuclei; alpha and beta decay.Equations for alpha decay, *β*- decay including the need for the neutrino.The existence of the neutrino was hypothesised to account for conservation of energy in beta decay. | 1.0weeks | * Describe the strong nuclear force and its role in keeping the nucleus stable.
* Recognise that the strong nuclear force has a short range attraction and a very short range repulsion.
* Associate distance below 0.5 fm with repulsion and between 0.5 and 3.0 fm with attraction.
* Describe alpha decay and beta decay.
* Illustrate alpha beta decay using equations.
* Deduce why the neutrino is necessary in beta decay.
 | **Learning activities:*** Show the graph of the variation of the strong nuclear force with distance.
* Discuss the key features of the graph, contrasting it with the electromagnetic interaction between two point charges.
* Explain what is meant by unstable nuclei and contrast alpha and beta decay.
* Demonstrate alpha and beta tracks in a cloud chamber.
* Demonstrate the difference in absorption properties of alpha and beta.
* Practise writing equations to represent alpha and beta decay.
* Compare the energy of alpha particles with beta particles and discuss why this led to the existence of neutrinos being hypothesised.

**Skills developed by learning activities:**AO1**:** Demonstration of knowledge of strong nuclear force. AO2: Apply knowledge and understanding of scientific ideas, processes, techniques and procedures when handling quantitative data.AO2: Apply knowledge and understanding of alpha and beta decay to analyse and complete equations representing the decay.MS0.2: Recognise and use the distances associated with the strong nuclear force in standard form.ATl: Use of ionising radiation, including detectors. | Past exam paper materials:PHYA1 May 2013 Q2(b)(i)PHYA1 May 2013 Q2(a)(iv)PHYA1 May 2011 Q2PHYA1 May 2010 Q2(b) and (c) SAM 013 | <http://www.walter-fendt.de/ph14e/decayseries.htm>**Rich question**:Identify a radioactive decay series and analyse the types of decay taking place that lead to the series. |

**3.2.1.3 Particles, antiparticles and photons**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| For every type of particle, there is a corresponding antiparticle.Knowledge of particle antiparticle pairs and a comparison of their properties.The photon model of electromagnetic radiation.The energy of photons.The mechanisms of annihilation of matter and antimatter and pair production. | 0.5 weeks | * Recall that every particle has a corresponding antiparticle.
* Contrast the properties of particles and antiparticles.
* Give examples of particle antiparticle pairs.
* Describe the photon model of electromagnetic

radiation.* Calculate the energy of photons from wavelength and frequency.
* Describe the processes of annihilation and pair production.
 | **Learning activity:*** Show table which compares properties of particles and antiparticles
* Highlight similarities (rest mass) and differences (quantum numbers)
* Introduce the photon as a particle of light whose energy depends on frequency.
* Calculations involving photon energy using both frequencies and wavelengths.
* Look at examples of annihilation of matter and antimatter.
* Calculations linking the frequencies of photons produced in the annihilation of matter and antimatter.
* Look at examples of pair production.
* Calculations on the energy of photons necessary for pair production.

**Skills developed by learning activities:**AO1**:** Demonstration of knowledge of matter and antimatter.AO2: Apply knowledge and understanding of the factors affecting the energy of photons.MS2.3: Substitute numerical values into algebraic equations to calculate energies of photons using frequency and wavelength.MS2.2, 2.4: Solve algebraic equations to calculate energy of photons from frequency and wavelength.AO1**:** Demonstration of knowledge of the process of pair production.MS2.3: Substitute numerical values into algebraic equations to calculate the frequencies of photons required for pair production.AO1**:** Demonstration of knowledge of the process of annihilation.MS2.4: Solve algebraic equations to calculate the frequency of the photons released during annihilation. | PHYA1 January 2013 Q2PHYA1 May 2013 Q4(b) | QED – Richard Feynman**Rich question:**How is annihilation of matter and antimatter used in forming a PET scan? |

**3.2.1.4 Particle interactions**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The four fundamental interactions.The fundamental interactions in terms of exchange particles.The weak interaction.Diagrams to represent the fundamental interactions.  | 0.5 weeks | * Name the four fundamental interactions.
* Describe the fundamental interactions in terms of exchange particles.
* Identify the virtual photon as the exchange particle in the electromagnetic interaction.
* Distinguish between β- and β+ decay identifying them both as examples of the weak interaction.
* Analyse electron capture and electron positron collisions as examples of the weak interaction and identify the appropriate exchange particle (W+ or W-) in each case.
* Draw simple diagrams to represent interactions.
 | **Learning activity:*** List the four fundamental forces together with the appropriate exchange particle.
* Give examples of the weak interaction and let students verifying that charge, lepton number and baryon number are conserved in these interactions.
* Practise the construction of simple Feynman diagrams. Emphasise the importance of the conservation laws at the points where lines in the diagrams meet.

**Skills developed by learning activities:**AO1:Demonstration of knowledge of the fundamental interactions.AO2:Apply knowledge and understanding of conservation laws in particle interactions.AO2: Apply knowledge and understanding in the importance of conservation laws when constructing Feynman diagrams. | PHYA1 June 2014 Q2(b)PHYA1 June 2013 Q2(a) and (b) | <http://hyperphysics.phy-astr.gsu.edu/hbase/forces/funfor.html><https://www.youtube.com/watch?v=3P-FGw5KUeo> |

**3.2.1.5 Classification of particles**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Hadrons are subject to the strong interaction.There are two classes of hadrons.Baryon number and its conservation.The proton as the only stable baryon.The pion as the exchange particle of the strong nuclear force.The decay of kaons into pions. Examples of leptons and their antiparticles.Lepton number and its conservation.The decay of muons into electrons.Strange particles and their production through the strong interaction and their decay through the weak interaction.Strangeness and its conservation in strong interactions.Strangeness does not have to be conserved in the weak interaction. | 1.0 week | * Associate hadrons with the strong interaction.
* Classify hadrons into baryons and mesons.
* Differentiate between baryons and mesons in terms of baryon number and are able to demonstrate baryon number conservation in interactions.
* Explain that the proton is the only stable hadron and that all other baryons eventually decay into protons.
* Identify the pion as the exchange particle of the strong nuclear force.
* Recognise and describe kaon decay.
* Identify leptons and how they can interact through the weak interaction.
* Identify the lepton numbers of electrons, muons and neutrinos and demonstrate lepton number conservation in examples of the weak interaction.
* Describe the decay of muons into electrons.
* Identify strange particles and describe their production and decay.
* Demonstrate the conservation of strangeness in strong interactions.
* Explain that strangeness does not have to be conserved in the weak interaction.
 | **Learning activity:*** Practise dividing particles into hadrons and leptons and then hadrons into baryon and mesons.
* Give examples of baryons and emphasise that the proton is the only stable baryon.
* Provide the opportunity to analyse baryon decay equations.
* Provide the opportunity to analyse the decay routes of the mesons such as the kaon.
* Give practise at identifying possible decays of mesons and baryons by applying conservation laws.
* Provide a list of leptons with associated lepton numbers and use this to analyse lepton interactions through the weak interaction.
* Give examples of strange particles and demonstrate how strangeness is conserved in the strong interaction but does not have to be in the weak interaction.

**Skills developed by learning activities:**AO1: Demonstration of knowledge of the classification of hadrons, baryons and mesons.AO2: Apply knowledge and understanding of how decay equations can be analysed to predict if they can occur.AO1: Demonstration of knowledge of leptons.AO1: Demonstration of knowledge of the classification of strange particles.AO2: Apply knowledge and understanding of how strangeness does not have to be conserved in the weak interaction. | SAM 1PHYA1 May 2013 Q3(a)PHYA1 May 2014 Q1PHYA1 May 2012 Q3 | <http://www.particleadventure.org/quarks_leptons.html>**Rich questions:**What is the Higg’s boson and why is it so important to the standard model? |

**3.2.1.6 Quarks and antiquarks**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Properties of quarks and antiquarks.Combinations of quarks and antiquarks required for baryons, antibaryons and mesons. | 0.5 weeks | * Recognise charge, baryon number and strangeness as properties of quarks and antiquarks.
* Analyse the quark structure of protons, neutrons, antiprotons, antineutrons, pions and kaons.
 | **Learning activity:*** Provide a table of properties of quarks and antiquarks.
* Provide the opportunity to deduce the quark structure of a wide range of particles.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of quark and antiquark properties.AO2: Apply knowledge and understanding of quark properties to deduce quark structures. | PHYA1 May 2014 Q1PHYA1 May 2012 Q1(a)PHYA1 Jan 2013 Q3(a) | <http://sciencepark.etacude.com/particle/introduction.php><http://hyperphysics.phy-astr.gsu.edu/hbase/particles/quark.html><http://hyperphysics.phy-astr.gsu.edu/hbase/particles/meson.html> |

**3.2.1.7 Applications of conservation laws**

Prior knowledge: Conservation of energy

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Change of quark nature in β- and β+ decay.Application of conservation laws for charge, baryon number, lepton number and strangeness for particle interactions.Conservation of energy and momentum in interactions. | 0.5 weeks | * Identify the change in quark character in β- and β+ decay.
* Apply the conservation laws for charge, baryon number, lepton number and strangeness for particle interactions.
* Recall that momentum and energy are conserved in interactions.
 | **Learning activity:*** Demonstrate beta minus decay using a radioactive source. Distinguish between beta minus and beta plus decay.
* Provide a list of decay equations and ask students to identify which are possible decays by applying conservation laws.
* Provide incomplete decay equations and ask students to the missing particles.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of beta plus and beta minus decay.AO2: Apply knowledge and understanding of conservation laws to analyse decay equations. | PHYA1 May 2014 Q1(c)PHYA1 May 2012 Q1(b) | <http://hyperphysics.phy-astr.gsu.edu/hbase/particles/parint.html> |

## 3.2.2 Electromagnetic radiation and quantum phenomena

**3.2.2.1 The photoelectric effect**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Description of the photoelectric effect.Explanation of threshold frequency in terms of the photon model.Explanation of work function and stopping potential.The photoelectric equation. | 1.0 week | * Describe the photoelectric effect.
* Recognise that the threshold frequency cannot be explained by the wave model of light and can deduce an explanation of threshold frequency in terms of the photon model.
* Explain the terms work function and stopping potential.
* Analyse the photoelectric effect using the photoelectric equation and calculate the maximum kinetic energy of emitted electrons.
* Deduce that the emitted electrons have a range of kinetic energies up to the maximum value calculated using the photoelectric equation.
 | **Learning activity:*** Demonstrate the photoelectric effect using a zinc plate on the cap of an electroscope and an ultraviolet light source.
* Discuss the predictions made by the wave theory of light and explain how the threshold frequency cannot be explained with this model. Explain that applying scientific method means that the theory of light needs to be changed to explain the experimental observations of the photoelectric effect.
* Outline the photon model of light and how this explains threshold frequency.
* Practise using the photoelectric equation to calculate the maximum kinetic energy of emitted electrons.
* Provide the opportunity to deduce the effect of changing the intensity of the incident light and the frequency of the incident light.
* Plot graphs of maximum kinetic energies of emitted electrons against frequency of incident light for different metal surfaces. Analyse the graph to find a value for the Planck constant, the threshold frequency and the work function.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of beta.AO2: Apply knowledge and understanding of the photoelectric effect both qualitatively and quantitatively.AO3: Analyse, interpret and evaluate scientific ideas and evidence to see why the wave model of light does not explain the photoelectric effect.MS0.2: Recognise expressions in decimal and standard form when applying the photoelectric equation.MS2.3: Substitute numerical values into the photoelectric equation.PS3.2: Process and analyse data from photoelectric experiments.MS2.4: Solve the photoelectric equation to determine maximum kinetic energies of electrons.MS3.2: Plot maximum kinetic energy against frequency of incident light.PS3.1: Plot and interpret graphs of maximum kinetic energy of emitted electrons against frequency of incident light.MS3.4: Determine the intercept and gradient of the maximum kinetic energy against frequency graph to find a value for Planck’s constant, threshold frequency and work function. | SAM 02PHYA1 May 2013 Q4PHYA1 May 2012 Q4 | <http://physics.info/photoelectric/><https://www.youtube.com/watch?v=0qKrOF-gJZ4><https://www.youtube.com/watch?v=kcSYV8bJox8> |

**3.2.2.2 Collisions of electrons with atoms**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Ionisation and excitation. Application in the fluorescent tube.The electron volt. | 0.5 weeks | * Describe the processes of excitation and ionisation
* Explain how excitation and ionisation apply in the fluorescent tube.
* Define the electron volt
* Convert energies from eV to J and vice versa.
 | **Learning activity:*** Show examples of line spectra with the use of discharge tubes and diffraction gratings or direct view spectroscopes.
* Examine the structure of the fluorescent tube.
* Practise calculations converting energy from joules to electron volts.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of nature of line spectra.AO1: Demonstration of knowledge and understanding of the structure of the fluorescent tube.AO2: Apply knowledge and understanding of the electron volt to perform calculations to convert energies in joules to electron volts.MS0.2: Recognise expressions in decimal and standard form when using energies in electron volts. | PHYA1 May 2014 Q4PHYA1 Jan 2013 Q4 | [http://astronomy.swin.edu.au/cosmos/S/Spectral+Line](http://astronomy.swin.edu.au/cosmos/S/Spectral%2BLine)<http://www.colorado.edu/physics/2000/quantumzone/><https://www.youtube.com/watch?v=QI50GBUJ48s>**Rich questions:**How are line spectra used to measure the rotational speeds of stars?How do line spectra provide evidence of the Big Bang? |

**3.2.2.3 Energy levels and photon emission**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Line spectra as evidence of discrete energy levels.Calculation of the frequency of emitted photons. | 0.5 weeks | * Demonstrate how line spectra implies discrete energy levels in atoms.
* Calculate the frequencies of emitted photons using the energies associated with different discrete energy levels.
 | **Learning activity:*** Contrast continuous spectra with line spectra and establish that line spectra are a consequence of discrete energy levels in atoms.
* Practise using the energy differences between levels to calculate frequencies and wavelengths of emitted photons.
* Analyse different energy level diagrams to predict the transitions responsible for a particular characteristic frequency.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of discrete energy levels and how these lead to line spectra.AO2: Apply knowledge and understanding of discrete energy levels and the energies associated with them to calculate frequencies and wavelengths of emitted photons.MS0.1, 0.2, 2.4: Solve the equation relating the energy differences between levels to the frequencies and wavelengths of emitted photons. | PHYA1 May 2014 Q4 | [http://hyperphysics.phy-astr.gsu.edu/hbase/hyde.html - c2](http://hyperphysics.phy-astr.gsu.edu/hbase/hyde.html%20-%20c2)<http://physics.nist.gov/PhysRefData/ASD/lines_form.html> |

**3.2.2.4 Wave-particle duality**

Prior knowledge: The diffraction of waves.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Electron diffraction as a demonstration that particles possess wave properties.The photoelectric effect as a demonstration that electromagnetic waves have a particulate nature. The de Broglie wavelength. | 0.5 weeks | * Identify that electron diffraction provides evidence of particles having wave properties.
* Analyse the photoelectric effect and deduce that it demonstrates the particulate nature of electromagnetic waves.
* Calculate the wavelength of a particle using the de Broglie equation.
* Explain how and why the amount of diffraction changes when the momentum of a particle is changed.
 | **Learning activity:*** Demonstrate electron diffraction and compare with diffraction of a laser through a single slit.
* Discuss the photoelectric effect and how it provides evidence of the dual nature of light.
* Practise calculations using the de Broglie equation.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of electron diffraction.PS1.2: Demonstration using electron diffraction tube.AO1: Demonstration of knowledge and understanding of the dual nature of light.AO2: Apply of knowledge and understanding of the de Broglie equation to calculate the de Broglie wavelength.MS1.1, 2.3: Use prefixes when expressing wavelength values. | PHYA1 May 2014 Q3 | [http://hyperphysics.phy-astr.gsu.edu/hbase/mod1.html - c1](http://hyperphysics.phy-astr.gsu.edu/hbase/mod1.html%20-%20c1)**Rich questions:**Is there experimental evidence for the diffraction of protons or neutrons?Why do electron microscopes have a much better resolving power than optical microscopes? |

# 3.3 Waves

**Introduction**

GCSE studies of wave phenomena are extended through a development of knowledge of the characteristics, properties, and applications of travelling and stationary waves. Topics treated include refraction, diffraction, superposition and interference.

## 3.3.1 Progressive and stationary waves

**3.3.1.1 Progressive waves**

Prior knowledge: Wave properties such as frequency, wavelength and amplitude.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Define the terms amplitude, frequency, period, wavelength, phase and phase difference.Use the equation *c= fλ* | 0.5 weeks | * Define the terms frequency, period, amplitude and wavelength of a wave.
* Explain what is meant by phase and phase difference.
* Use the equation *c= fλ* in calculations.
 | **Learning activity:*** Video transverse waves in a long heavy spring and use video analysis to measure the frequency and wavelength.
* Investigate the variation of the speed of a water wave with depth of water in a plastic tray.
* Measure the speed of sound in air.
* Use a spreadsheet to model the behaviour of a travelling wave using the full wave equation.
* Practise calculations to calculate frequencies, periods and wavelengths of waves.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of the terms amplitude, frequency, period, wavelength, phase and phase difference.AO2: Apply knowledge and understanding of the equation *c= fλ* to calculate wavelengths and frequencies.MS2.3: Substitute numerical values into the wave equation.MS4.5: Use sin in the modelling of a transverse wave.ATi: Generate and measure waves.PS3.2: Process and analyse data using a spreadsheet. | PHYA1 May 2013 Q6(d)PHYA1 Jan 2012 Q7 | <http://www.acs.psu.edu/drussell/demos/waves/wavemotion.html><http://www.animations.physics.unsw.edu.au/waves-sound/> |

**3.3.1.2 Longitudinal and transverse waves**

Prior knowledge: The difference between transverse and longitudinal waves.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The nature of longitudinal and transverse waves.Electromagnetic waves as examples of transverse waves.Speed of electromagnetic waves.Polarisation as a feature of transverse waves.Applications of polarisers. | 1.0 weeks | * Distinguish between longitudinal and transverse waves.
* Recognise that electromagnetic waves are transverse and all examples of electromagnetic waves travel at the same speed in a vacuum.
* Describe the polarisation of transverse waves.
* Describe applications of polarisers.
 | **Learning activity:*** Use a slinky to demonstrate transverse and longitudinal waves.
* Give details of electromagnetic waves and identify their key properties.
* Demonstrate the polarisation of a transverse wave using a heavy spring and a vertical narrow gap.
* Demonstrate the polarisation of light using polarisation.
* Investigate how the transmitted intensity of light varies with the angle between the planes of polarisation of two polarisers.
* Research the uses of polarisers.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of longitudinal and transverse waves.AO1: Demonstration of knowledge and understanding electromagnetic waves and their properties.AO1: Demonstration of knowledge and understanding of the polarisation of transverse waves.ATj: Use a light source and polarisers to investigate polarisation.AO2: Apply knowledge and understanding of the polarisation to explain applications.AO3: Analyse, interpret and evaluate scientific information, ideas to identify applications of polarisation. | PHYA1 May 2013 Q6PHYA1 May 2014 Q7PHYA1 May 2012 Q7 | <http://science.hq.nasa.gov/kids/imagers/ems/waves2.html><http://missionscience.nasa.gov/ems/02_anatomy.html><http://hyperphysics.phy-astr.gsu.edu/hbase/waves/emwv.html><http://www.cyberphysics.co.uk/topics/light/polarisation.htm>**Rich questions:**How do we measure the speed of light?What affect does the motion of a light source have on the speed of light emitted from the source? What are the consequences of this? |

**3.3.1.3 Principle of superposition of waves and formation of stationary waves**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Stationary waves on strings.The meaning of nodes and antinodes in relation to standing waves.The equation for the frequency of the first harmonic for first harmonic.The formation of a stationary wave by two waves of the same frequency travelling in opposite directions.Graphical explanation for the formation of stationary waves.Examples of stationary waves including those formed on strings and those produced using sound waves or microwaves. | 1.5weeks | * Explain what is meant by a stationary wave.
* Define the terms node and antinode.
* Calculate the frequency of the first harmonic produced by a stationary wave on a string.
* Describe the formation of a stationary wave by two waves of the same frequency travelling in opposite directions.
* Use graphs to demonstrate the formation of standing waves.
* Describe the formation of standing waves produced by microwaves and sound waves.
 | **Learning activity:*** Investigate the variation of the frequency of stationary waves on a string with length, tension and mass per unit length.
* Practise calculations to determine the frequency of the first harmonic.
* Model the formation of stationary waves using a spreadsheet.
* Demonstrate examples of stationary waves using strings, sound waves and microwaves.

**Required practical**Investigation into the variation of the frequency of stationary waves on a string with length, tension and mass per unit length of the string.**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of standing waves including the meaning of nodes and antinodes.ATi: Generate and measure waves.MS2.3: Substitute numerical values into equation for frequency of first harmonic.AO2: Apply knowledge and understanding in calculations of the frequencies of the first harmonic.AO2: Apply knowledge and understanding of waves to explain the formation of standing waves.AO1: Demonstration of knowledge and understanding of different examples of stationary waves. | PHYA1 May 2014 Q7(d)PHYA1 Jan 2013 Q6PHYA1 May 2012 Q6PHYA1 Jan 2011 Q4 | <http://phet.colorado.edu/en/simulation/wave-on-a-string><https://www.youtube.com/watch?v=HpovwbPGEoo>**Rich question:**How are standing waves used in musical instruments? |

## 3.3.2 Refraction, diffraction and interference

**3.3.2.1 Interference**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Path difference and coherence.Demonstrate interference and diffraction using a laser as a source of monochromatic light.The Young’s double slit experiment. The equation for fringe spacing.Fringe spacing: $w=\frac{λD}{s}$Production of interference.The interference pattern produced by white light.Interference patterns produced by sound and electromagnetic waves.Appreciation of how knowledge and understanding of the nature of electromagnetic radiation has changed over time. | 2.0 weeks | * Explain the meaning of path difference and coherence.
* Describe the Young’s double slit experiment and calculate fringe spacing using data from the experiment.
* Distinguish between the fringe patterns produced by monochromatic and white light.
* Analyse different examples of the double slit experiment using both electromagnetic and sound waves.
* Explain how knowledge and understanding of the nature of electromagnetic radiation has changed over time.
 | **Learning activity:*** Demonstrate how path difference determines whether interference is constructive or destructive.
* Demonstrate with a laser the interference pattern produced by a double slit. Use measurements from the pattern to determine the wavelength of the laser light.
* Carry out the Young’s double slit experiment using an incandescent lamp and filters.
* Examine the interference produced by a white light source and identify the differences between this pattern and the pattern produced by monochromatic light.
* Demonstrate the interference of sound waves by using two loudspeakers connected to the same source.
* Investigate the historical development of the understanding of the nature of electromagnetic radiation has changed over time.

**Required practical**Investigation of interference effects to include the Young’s slit experiment and interference by a diffraction grating.**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of path difference and coherence.AO2: Apply knowledge and understanding of path difference to determine whether interference is constructive or destructive.ATj: Use light source or laser to investigate interference.MS2.2: Change the subject of the fringe separation equation to determine the wavelength of light.AO1: Demonstration of knowledge and understanding of the difference in the fringe pattern produced by monochromatic and white light sources.AO1: Demonstration of knowledge and understanding of examples of interference of sound waves.AO3: Analyse scientific information, ideas and evidence about the nature of light. | SAM Q3PHYA1 Jan 2013 Q7PHYA1 May 2011 Q7 | <http://www.physicsclassroom.com/class/light/Lesson-1/Two-Point-Source-Interference><https://www.youtube.com/watch?v=G-R8LGy-OVs> |

**3.3.2.2 Diffraction**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The appearance of the diffraction pattern from a single slit using monochromatic and white light.A qualitative treatment of the variation of the width of the central diffraction maximum and slit width.Using a plane diffraction grating with light at normal incidence.The derivation of the grating equation:$$dsinθ=nλ$$Applications of the diffraction grating. | 1.0 weeks | * Describe the diffraction patterns produced using a single slit with monochromatic light and contrast this with the pattern produced by white light.
* Discuss the effect on the width of the central maximum when the slit width is varied.
* Describe the use of the plane diffraction grating.
* Use the grating equation in calculations.
* Describe uses of the diffraction grating such as the analysis of spectra.
 | **Learning activity:*** Demonstrate the single slit diffraction pattern for white light and monochromatic light.
* Demonstrate the effect of changing slit width on the central maxima of the diffraction pattern.
* Investigate interference by a plane diffraction grating.
* Derive the equation for normal incidence on a plane diffraction grating.
* Use the diffraction grating equation to determine the wavelength of a light source.
* Practise calculations using the diffraction grating.
* Investigate applications of the diffraction grating.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of the main features of a single slit diffraction pattern.AO2: Apply knowledge and understanding of interference patterns to explain the diffraction pattern produced by a plane diffraction grating.PS3.2AO2: Apply knowledge and understanding of path difference to derive the diffraction grating equation.AO2: Apply knowledge and understanding of the diffraction grating equation in calculations.MS4.5: Use of sine in diffraction grating equation.AO3: Analyse scientific information to determine applications of the diffraction grating. | PHYA1 May 2014 Q6PHYA1 May 2013 Q7PHYA1 Jan 2012 Q5PHYA1 Jan 2011 Q3 | <http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/grating.html>**Rich question:**How does the spectrum from a diffraction grating differ from that produced by a prism? |

**3.3.2.3 Refraction at a plane surface**

Prior knowledge: The refraction of light.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Defining refractive index in terms of wave speed in different media.Snell’s law of refraction at a boundary:$$n\_{1}\sin(θ\_{1})=n\_{2}\sin(θ\_{2})$$Total internal reflection $$\sin(θ\_{c})=\frac{n\_{1}}{n\_{2}}$$Step index optic fibres including the function of the cladding.Material and modal dispersion and the consequences of pulse broadening and absorption. | 1.0 weeks | * Define refractive index in terms wave speed in different media.
* Recall that the refractive index of air is approximately 1.
* Use Snell’s law to calculate angles when light crosses a boundary between two media,
* Describe total internal reflection and distinguish this from partial reflection.
* Calculate critical angles using refractive indices.
* Describe the step index optic fibre.
* Understand the principles and consequences of pulse broadening and absorption.
 | **Learning activity:*** Define refractive index and practice calculations calculating refractive indices from wave speeds.
* Define Snell’s law.
* Practise calculations using Snell’s law.
* Use Snell’s law to determine the refractive index of a rectangular glass block.
* Demonstrate total internal reflection and show the meaning of the critical angle.
* Determine the critical angle of the material in a semi-circular block.
* Practise calculations involving the critical angle and the refractive indices of the materials either side of the boundary.
* Demonstrate optic fibres, pointing out the importance of cladding.
* Define material and modal dispersion and point out the consequences of pulse broadening and absorption.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of refractive index and its relationship to wave speed.AO1: Demonstration of knowledge and understanding of Snell’s law.AO2: Apply knowledge and understanding of Snell’s law in calculations.MS0.6, 4.5: Use of sine.MS4.1: Use of angles (incidence and refraction).MS2.4: Solve algebraic equations to determine angles of refraction.MS3.2 and 3.4: Plot graph to determine refractive index.AO1: Demonstration of knowledge and understanding of total internal reflection and critical angle.AO2: Apply knowledge and understanding in calculations involving the critical angle.MS4.5: Use of sine.MS2.4: Solve algebraic equations to determine critical angles.AO1: Demonstration of knowledge and understanding of optic fibres and the importance of cladding.AO1: Demonstration of knowledge and understanding of material and modal dispersion.PS1.2: Apply scientific knowledge to explain the consequences of pulse broadening and absorption. | PHYA1 May 2014 Q5PHYA1 May 2013 Q5PHYA1 Jan 2013 Q5PHYA1 May 2012 Q4PHYA1 Jan 2012 Q6PHYA1 May 2011 Q5 | <http://www.learnerstv.com/animation/animation.php?ani=102&cat=physics><http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/refr.html><https://www.youtube.com/watch?v=0MwMkBET_5I> |

# 3.4 Mechanics and materials

**Introduction**

Vectors and their treatment are introduced by development of the student’s knowledge and understanding of forces, energy and momentum. The section continues with a study of materials considered in terms of their bulk properties and tensile strength. As with earlier topics, this section and also the following section Electricity would provide a good starting point for students who prefer to begin by consolidating work.

## 3.4.1 Forces, energy and momentum

**3.4.1.1 Scalars and vectors**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The nature of scalar and vector quantities.Addition of vectors by calculation or scale drawing.The resolution of vectors into two components.The conditions for equilibrium for two or three coplanar forces acting at a point. | 0.5 weeks | * Students can distinguish between scalar and vector quantities including velocity/speed, mass, force/weight, acceleration, displacement/distance.
* Students can add two vectors by constructing an appropriate scale drawing.
* Calculate the sum of two vectors.
* Resolve a vector into two perpendicular components.
* Recognise the conditions for two or three coplanar forces acting at a point to be in equilibrium.
* Apply the conditions for equilibrium in the context of an object at rest or moving at constant velocity.
 | **Learning activity:*** Provide a list of scalar and vector quantities.
* Investigate the parallelogram law for combining vectors using three masses, string and pulleys.
* Practise calculations combining vectors using vector triangles.
* Practical investigation into resolving forces using a fan cart or rolling cars done a slope at various angles.
* Construct free body diagrams to show equilibrium when two or three coplanar forces act at a point.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of vector and scalar quantities.AO2: Apply knowledge and understanding of how vectors can be combined.AO2: Apply knowledge and understanding of how vectors can be resolved.MS0.6: Use of calculators to handle sin and cosine when resolving vectors.MS4.2: 2D representation of coplanar forces.MS4.5: Use of sin and cos in problems involving the resolution of vectors. | PHYA1 Jan 2013 Q2PHYA1 Jan 2012 Q1PHYA1 May 2012 Q1 | <http://ed.ted.com/lessons/football-physics-scalars-and-vectors-michelle-buchanan> |

**3.4.1.2 Moments**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Definition of the moment of a force about a point.A couple as a pair of equal and opposite coplanar forces. The equation for the moment of a couple.The principle of moments.The centre of mass and its position in a uniform regular solid. | 0.5 weeks | * Define and calculate the moment of a force.
* Describe a couple and calculate the moment of a couple.
* State the principle of moments.
* Apply and use the principle to analyse the forces acting on a body in equilibrium.
* Explain what is meant by the centre of mass.
 | **Learning activity:*** Explain what is meant by the moment of a force and a couple.
* Practise calculations of moments of a force.
* Calculations involving couples produced by coplanar forces.
* Experimental investigation of the principle of moments.
* Give examples of centre of mass of regular solids.
* Determine the centre of gravity and hence the centre of mass by using pieces of card and a plumb line.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of the moment of a force and a couple.AO2: Apply knowledge and understanding of the moment equation by using in calculations.AO2: Apply knowledge and understanding of the principle of moments in calculations.MS2.2, 2.3: Use algebraic equations for moments, couples and the principle of moments. | PHYA1 May 2014 Q3PHYA1 Jan 2013 Q3PHYA1 May 2012 Q3PHYA1 Jan 2012 Q3PHYA1 May 2011 Q4 | <http://www.schoolphysics.co.uk/age16-19/Mechanics/Statics/text/Equilibrium_/index.html>**Rich question:**Are the centre of mass and centre of gravity of a body always in the same position? |

**3.4.1.3 Motion along a straight line**

Prior knowledge: Motion graphs, the acceleration due to gravity.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Definitions of displacement, speed, velocity, acceleration.Representation by graphical methods of uniform and non-uniform acceleration.Significance of areas of velocity – time and acceleration – time graphs and gradients of displacement – time and velocity – time graphs.The equations for uniform acceleration.$$v=u+at$$$$s=\left(\frac{u+v}{t}\right)t$$$$s=ut+\frac{1}{2}at^{2}$$$$v^{2}=u^{2}+2as$$The acceleration due to gravity*, g*. | 1.5 weeks | * Define displacement, speed, velocity and acceleration.
* Distinguish between velocity and speed.
* Calculate velocities and accelerations.
* Calculate both instantaneous and average velocities.
* Draw graphs to represent motion.
* Recognise the significance of the areas of velocity – time and acceleration – time graphs.
* Recognise the significance of the gradients of displacement – time and velocity – time graphs.
* Recall the equations of uniform acceleration and can apply them in calculations. Involving motion in straight lines.
* Analyse experiments to determine the acceleration due to gravity using a graphical method
 | **Learning activity:*** Practise calculations using the definitions of displacement, speed, velocity and acceleration.
* Use light gates to obtain data from a trolley rolling down a slope or a glider on an air track to generate displacement time and velocity time graphs.
* Practise plotting and analysing motion graphs.
* Highlight the link between displacement time, velocity time and acceleration time graphs.
* Practise calculations using the equations of uniform acceleration.
* Practical to determine *g* using a free fall method.

**Required practical**Determination of g by a free-fall method.**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding displacement, speed, velocity and acceleration.AO2: Apply knowledge and understanding of displacement, speed, velocity and acceleration in calculations.MS3.7: Distinguish between instantaneous velocity and average velocity.PS1.1: Solve motion problems in a practical context.AO1: Demonstration of knowledge and understanding of motion graphs.AO2: Apply knowledge and understanding in the analysis of motion graphs.MS3.5: Calculate rate of change from motion graphs showing a linear relationship.MS3.6: Draw and use the slope of a tangent to a curve in motion graphs.AO2: Apply knowledge and understanding of the equations for uniform acceleration.MS0.5: Use calculators to find powers.MS2.2: Change the subject of the equations of uniform acceleration.MS2.2, 2.3: Substitute into and solve equations for uniform acceleration.AO2: Apply knowledge and understanding of motion graphs and the equations of uniform acceleration to determine *g.*MS1.2: Find arithmetic means from data from the determination of *g.*MS3.9: Apply the concepts underlying calculus by solving equations involving rates of change in the experiment to determine *g.*ATd: Use stop watch or light gates in experiments investigating motion. | PHYA1 May 2013 Q2 and Q3PHYA1 May 2012 Q2PHYA1 Jan 2012 Q3(b)PHYA1 May 2011 Q1 and Q2PHYA1 Jan 2011 Q5 | <http://hyperphysics.phy-astr.gsu.edu/hbase/mechanics/motgraph.html><http://www.grc.nasa.gov/WWW/k-12/airplane/mofall.html>**Rich question:**What is the average velocity of a cyclist who cycles at a constant speed of 20 m s–1, around a circular track of circumference 400 m when they are a quarter of the way around the track? |

**3.4.1.4 Projectile motion**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Independent effect of motion in horizontal and vertical directions of a uniform gravitational field.A qualitative treatment of friction.Qualitative treatments of lift and drag forces.A qualitative treatment of the effects of air resistance on the trajectory of a projectile.The factors affecting the maximum speed of a vehicle. | 1.0 weeks | * Explain how the motion of a projectile can be analysed by treating its horizontal and vertical motion independently.
* Analyse the motion of a projectile by considering the effect of gravity on horizontal and vertical motion.
* Describe friction quantitatively.
* Explain the nature of lift and drag forces.
* Describe the effects of air resistance on the trajectory of a projectile.
* Explain why falling objects can reach a terminal speed.
* Discuss the factors that affect the maximum speed of a vehicle.
 | **Learning activity:*** Practise examples of projectile motion.
* Demonstrate the monkey and hunter experiment.
* Consider the effects of air resistance on the horizontal and vertical motion of a projectile.
* Experiment to investigate air resistance and terminal velocity using different numbers of stacked coffee filters or cupcake cases.
* Investigate the motion of different shaped objects through a tall column of viscous fluid.
* Outline the nature of lift and drag forces.
* Model the effects of air resistance on the motion of projectiles using a spreadsheet.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of projectile motion.AO2: Apply knowledge and understanding of the independence of horizontal and vertical motion when considering projectiles.MS0.6, 4.1, 4.2, 4.5: Use of sine and cos and 2D diagrams to represent projectile motion.PS2.1, 2.3: Evaluate results from the motion of an object through a fluid.AO3: Analyse, interpret and evaluate evidence from motion in a fluid experiments.AO1: Demonstration of knowledge and understanding of the nature of frictional forces.AO2: Apply knowledge and understanding of the effects of frictional forces on the motion of a projectile. | PHYA1 May 2014 Q2PHYA1 Jan 2011 Q2 | <http://phet.colorado.edu/sims/projectile-motion/projectile-motion_en.html><http://www.nationalstemcentre.org.uk/elibrary/resource/2084/monkey-and-hunter><http://www.instructables.com/id/MONKEY-HUNTER-PHYSICS/> |

**3.4.1.5 Newton’s laws of motion**

Prior knowledge: Force = mass ✕ acceleration

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Knowledge and application of the three laws of motion.Use of the equation; *F* = *ma* | 1.5 weeks | * Recall the three laws of motion and apply them in appropriate situations.
* Construct and use free-body diagrams.
* Use the equation linking force and acceleration in calculations.
* Recognise that the equation can only be used in situations where the mass is constant.
 | **Learning activity:*** Give examples of Newton’s first and second laws.
* Practise examples of free-body diagrams and relate these to Newton’s first and second laws.
* Investigate Newton’s second law using trollies or an air track.
* Practise examples using the equation *F=ma .*
* Investigate situations where mass is changing eg rocket motion.
* Model the motion of a rocket using a spreadsheet.
* Give examples of Newton’s third law.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of Newton’s laws of motion.AO2: Apply knowledge and understanding of Newton’s laws in practical situations.MS2.3: Substitute values into equation linking force, mass and acceleration.PS4.1, AT a,b,c: Knowledge and understanding of practical instruments needed to investigate Newton’s second law.AO3: Analyse, interpret and evaluate evidence from investigation of Newton’s second law.MS 4.1, 4.2: Use 2D representation of forces in a free-body diagram.ATk: Use ICT to model motion of rocket.AO2: AO1: Apply knowledge and understanding of situations involving Newton’s third law. | PHYA1 May 2013 Q1PHYA1 May 2011 Q3 | <http://hyperphysics.phy-astr.gsu.edu/hbase/newt.html>**Rich question:**How is the equation, *F=ma*, modified when mass is changing? |

**3.4.1.6 Momentum**

Prior knowledge: Safety features in cars such as crumple zones.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Define momentum.The conservation of linear momentum in one dimension.Force as rate of change of momentum.Define impulse and its relationship to the area under a force time graph.The relationship between impact forces and contact time.Distinguish between elastic an inelastic collisions.Apply the conservation of momentum to explosions. | 1.0 week | * Define momentum and recall the unit for momentum.
* Discuss the conservation of linear momentum and apply it in calculations involving collisions in one dimension.
* Relate force to rate of change of momentum.
* Define impulse.
* Deduce the effect on impact forces of contact times.
* Distinguish between elastic and inelastic collisions.
* Apply momentum conservation to explosions.
 | **Learning activity:*** Give the definition of momentum and state the principle of the conservation of momentum.
* Practise examples involving the conservation of momentum.
* Investigate momentum using colliding trollies or gliders on an air track.
* Link rate of change of momentum to Newton’s second law and demonstrate how this leads to *F=ma*
* Give examples of impulse and link this to the relationship between impact forces and contact time.
* Explain the difference between elastic and inelastic collisions and investigate inelastic collisions by dropping different balls from the same height and measuring the height of rebound.
* Practise examples using the conservation of momentum in explosions.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of momentum.AO2: Apply knowledge and understanding of the conservation of momentum in the analysis of collisions.PS2.3: Evaluate results from conservation of momentum experiments and draw conclusions.PS3.2: Process and analyse data from conservation of momentum experiments.AO1: Demonstration of knowledge and understanding of impulse.AO2: Apply knowledge and understanding impulse and relate this to the area under a force time graph.AO2: Apply knowledge and understanding of the relationship between impact force and contact time.AO1: Demonstration of knowledge and understanding elastic and inelastic collisions.MS2.2, 2.3: Substitute numerical values into a conservation of momentum equation and change the subject of the equation. | SAM Q4 | <http://hyperphysics.phy-astr.gsu.edu/hbase/elacol.html><http://hyperphysics.phy-astr.gsu.edu/hbase/inecol4.html><http://www.animations.physics.unsw.edu.au/jw/momentum.html>**Rich question:**Prove that an object of mass, *m*, must be stationary after an elastic collision with a stationary object also of mass *m.* |

**3.4.1.7 Work, energy and power**

Prior knowledge: Calculating work and power.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The relationship between energy transferred and work done.*W*=*Fs*cos*θ*Rate of doing work is equal to the rate of energy transfer$$P=\frac{∆W}{∆t}=Fv$$The significance of the area under a force displacement graph.Efficiency as the ratio of useful output power to input power. | 1.0 week | * Recognise that when work is done energy is transferred.
* Calculate the work done including situations where the force is not acting in the direction of displacement.
* Calculate the rate of doing work.
* Analyse situations in which the force acting is variable.
* Recall that the work done or energy transferred is equal to the area under a force displacement graph.
* Calculate efficiency as a ratio and as a percentage.
 | **Learning activity:*** Review the relationship between work and energy transfer from GCSE.
* Practise calculations for work done including situations where force and displacement do not act in the same direction.
* Derive the equation linking power, force and velocity.
* Construct force displacement graphs and work out the area under the graph.
* Investigate the power developed by the body by doing step ups or lifting masses.
* Define efficiency and practice calculations for efficiency in practical situations eg using pulley systems.
* Investigate the efficiency of an electric motor.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding the relationship between work done and energy transfer.AO2: Apply knowledge and understanding of work done using the appropriate equation.MS0.3: Use ratios, fractions and percentages in efficiency calculations.PS3.3: Consider precision and accuracy of data in efficiency experiments.PS4.1: Know and understand the use of a wide range of experimental and practical instruments, equipment and techniques in efficiency experiments. | PHYA1 Jan 2013 Q1PHYA1 Jan 2012 Q1 and Q2 | <http://hyperphysics.phy-astr.gsu.edu/hbase/work.html><https://phet.colorado.edu/en/simulations/category/physics/work-energy-and-power> |

**3.4.1.8 Conservation of energy**

Prior knowledge: Energy is always conserved.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The principle of conservation of energy.Kinetic energy and gravitational potential energy.Quantitative and qualitative applications of energy conservation. | 0.5 weeks | * Recall the principle of the conservation of energy.
* Calculate kinetic and gravitational potential energy.
* Describe energy changes involving kinetic, gravitational potential energy and work done against friction.
 | **Learning activity:*** Review the principle of conservation of energy.
* Practise calculations using gravitational potential energy and kinetic energy.
* Investigate energy changes in a bouncing ball.
* Estimate the energy that can be derived from food consumption.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of the principle of conservation of energy.AO2: Apply knowledge and understanding of the formulae for gravitational potential energy and kinetic energy.Ata: Use analogue apparatus to measure heights and heights of rebound for a bouncing ball.MS0.4: Estimate energies derived from food consumption.MS2.2: Change the subject of equations calculating gravitational potential energy and kinetic energy. | PHYA1 Jan 2012 Q2PHYA1 Jan 2013 Q1PHYA1 May 2014 Q1 | <http://hyperphysics.phy-astr.gsu.edu/hbase/conser.html><http://www.nuffieldfoundation.org/node/1842> |

## 3.4.2 Materials

**3.4.2.1 Bulk properties of solids**

Prior knowledge: The definition of density. Investigation of Hooke’s law using springs.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The definition of density.Hooke’s law and the elastic limit.The force extension equation:$$F=k∆l$$Definitions of tensile stress and tensile strain.The meaning of breaking stress.Elastic strain energy$$energy stored= \frac{1}{2}F∆l$$Description of plastic behaviour, fracture and brittle behaviour related to force – extension graphs.Interpretation of stress – strain curves.Application of energy conservation to examples involving elastic strain energy and energy to deform.The transformation of spring energy to kinetic and gravitational potential energy.Appreciation of energy conservation issues in the context of ethical transport design. | 1.0 week | * Define density and do calculations using the density equation.
* State Hooke’s law and explain what is meant by the elastic limit.
* Apply the force extension equation and recognise that the constant, k, is known as the stiffness or the spring constant.
* Demonstrate that they recognise the meanings of tensile stress and tensile strain.
* Explain what breaking stress means.
* Calculate elastic strain energy.
* Recognise that the energy stored is equal to the area under a force – extension graph.
* Explain what is meant by plastic behaviour, fracture and brittle behaviour.
* Analyse stress – strain curves.
* Apply energy conservation to examples involving elastic strain energy and energy to deform.
* Analyse the energy changes taking place in an oscillating spring.
* Appreciate the importance of energy conservation in transport design.
 | **Learning activity:*** Practise calculations including those involving composite materials.
* Determine the density of different objects.
* Investigate the elastic behaviour of various materials such as metals in the form of wires and springs and rubber in the form of elastic bands.
* Review Hooke’s law and elastic limit.
* Give definitions of tensile stress and tensile strain and practice using both these quantities in calculations.
* Explain what is meant by elastic strain energy.
* Illustrate plastic behaviour, elastic behaviour, fracture and brittle behaviour using a variety of stress strain graphs for a variety of materials.
* Practise calculations involving energy conservation involving elastic strain energy and energy to deform.
* Describe the energy changes that take place when a mass is attached to a vibrating spring.
* Consider energy conservation issues in the context of ethical transport design.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of the meaning of density.AO2: Apply knowledge and understanding of density in calculations.MS0.3: Use of ratios in density calculations.MS4.3: Calculate volumes of regular solids.AO1: Demonstration of knowledge and understanding of Hooke’s Law and elastic limit.MS3.1: Translate information between graphical, numerical and algebraic form when investigating elastic behaviour.AO1: Demonstration of knowledge and understanding of tensile stress and tensile strain.MS3.8: Understand the significance of the area between the curve and the *x-axis* on a force extension graph.AO1: Demonstration of knowledge and understanding of plastic behaviour, fracture and brittle behaviour.AO2: Apply knowledge and understanding of plastic behaviour, fracture and brittle behaviour when relating them to force extension graphs.AO2: Apply knowledge and understanding in the interpretation of stress strain graphs.AO2: Apply knowledge and understanding in the description of the energy changes in masses attached to vibrating springs.AO3: Analyse, interpret and evaluate evidence when considering energy conservation in the context of ethical transport design.  | PHYA1 May 2013 Q4PHYA1 May 2012 Q5PHYA1 Jan 2012 Q4PHYA1 Jan 2011 Q1 | <https://depts.washington.edu/bonebio/ASBMRed/biomecha/bio.swf><http://www-tc.pbskids.org/zoom/printables/activities/pdfs/eggbungeejump.pdf> |

**3.4.2.2 The Young modulus**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The definition of the Young modulus.Experiment to determine the Young modulus using a stress – strain graph. | 0.5 week | * Define the Young modulus and use it in calculations.
* Describe a method to determine the Young modulus.
 | **Learning activity:*** Define the Young modulus and practice using this property in calculations.
* Carry out an experiment to determine the Young modulus of the metal in a wire.

**Required practical**Determination of the Young modulus by a simple method.**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of the Young modulus.AO2: Apply knowledge and understanding of the Young modulus in calculations.MS3.1: Translate information between graphical, numerical and algebraic form when investigating the Young modulus.MS4.3: Calculate cross sectional areas of wires.ATa: Use appropriate analogue apparatus in the Young modulus experiment.ATc: Use methods to increase accuracy in the Young modulus experiment.ATe: Use micrometer to measure the diameters of wires.PS2.2: Present data from the Young modulus experiment in appropriate ways.MS3.4: Determine the slope of a stress strain graph to find the Young modulus. | SAM Q6PHYA1 May 2014 Q4PHYA1 Jan 2013 Q4PHYA1 May 2011 Q6PHYA1 Jan 2011 Q6 | <https://www.tes.co.uk/teaching-resource/Young-Modulus-AS-Physics-6130086/><http://tap.iop.org/mechanics/materials/228/page_46520.html> |

# 3.5 Electricity

**Introduction**

This section builds on and develops earlier study of these phenomena from GCSE. It provides opportunities for the development of practical skills at an early stage in the course and lays the groundwork for later study of the many electrical applications that are important to society.

## 3.5.1 Current electricity

**3.5.1.1 Basics of electricity**

Prior knowledge: Electric current as a flow of charge. Definitions of current, potential difference and resistance.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Electric current is the rate of flow of charge.Potential difference is the work done per unit charge.The definition of resistance. | 0.5weeks | * Recognise that current is the rate of flow of charge.
* Recognise that potential difference is the work done per unit charge.
* Recognise the equation defining resistance and can apply it in calculations.
 | **Learning activity:*** Review current as a flow of charge and practice calculations.
* Review potential difference is the work done per unit charge and practice calculations.
* Practise resistance calculations.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of electric current, potential difference and resistance.AO2: Apply knowledge and understanding of electric current, potential difference and resistance. | PHYA1 May 2012 Q7PHYA1 Jan 2012 Q5(a) | <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elecur.html> |

**3.5.1.2 Current-voltage characteristics**

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The current – voltage characteristics for an ohmic conductor, a semiconductor diode and a filament lamp.Ohm’s law as a special case where current is directly proportional to voltage under constant physical conditions. | 1.5 weeks | * Interpret current – voltage graphs and distinguish between the characteristics for an ohmic conductor, a semiconductor diode and a filament lamp.
* Recognise that Ohm’s law is a special case for a component with constant resistance.
 | **Learning activity:*** Investigate current – voltage graphs for an ohmic conductor, a semiconductor diode and a filament lamp.
* Give examples of current – voltage graphs and explain how they should be interpreted.
* Explain Ohm’s Law and outline why it is a special case.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of current-voltage characteristics of various components.AO2: Apply knowledge and understanding of current-voltage characteristics.MS3.2: Plot current voltage characteristics.PS3.1: Plot and interpret current-voltage graphs.ATb: Use digital meters.ATf: Construct and check circuits. |  | <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/ohmlaw.html> |

**3.5.1.3 Resistivity**

Prior knowledge: The definition of resistance.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Resistivity, $ρ=\frac{RA}{L}$Experiment to determine the resistivity of a wire.Description of the qualitative effect of temperature on the resistance of metal conductors.The effect of temperature on a negative temperature coefficient thermistor.Application of thermistors in temperature sensors.Superconductivity as a property of certain materials which have zero resistivity at or below the critical temperature.Applications of superconductors. | 1.5 weeks | * Define resistivity and use the resistivity equation in calculations.
* Describe an experiment to determine the resistivity of a wire.
* Describe the effect of temperature on the resistance of metal conductors.
* Describe the effect of temperature on a negative temperature coefficient thermistor.
* Describe application of thermistors including temperature sensors.
* Explain what is meant by a superconductor.
* Describe how superconductors can be used to produce strong magnetic fields and to reduce energy losses in the transmission of electric power.
 | **Learning activity:*** Define resistivity and practise using the definition in calculations.
* Determine the resistivity of the metal in a wire.
* Explain how temperature affects the resistance of metal conductors.
* Explain how temperature affects the resistance of a thermistor.
* Investigate applications of thermistors.
* Explain what is meant by superconductivity and explain the significance of critical temperature.
* Investigate some of the uses of superconductors.

**Required practical**Determination of resistivity of a wire using a micrometer, ammeter and voltmeter.**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of resistivity.AO2: Apply knowledge and understanding of resistivity in calculations.MS4.3: Calculate cross-sectional areas of wires.MS3.2: Plot a graph of voltage against current.ATe: Use micrometers to measure diameters of wires.ATb: Use multimeters.PS2.1: Apply scientific knowledge set in a practical context.PS4.1: Know and use a wide range of practical equipment to determine the resistivity of the metal in a wire.AO1: Demonstration of knowledge and understanding of effect of temperature on the resistance of metal conductors.AO1: Demonstration of knowledge and understanding of effect of temperature on a negative temperature coefficient thermistor.AO3: Analyse and interpret how thermistors are used in temperature sensors.AO1: Demonstration of knowledge and understanding of superconductivity.AO3: Analyse and interpret the applications of superconductors. | PHYA1 May 2014 Q6PHYA1 Jan 2013 Q7(a)PHYA1 Jan 2012 Q5(b) | <http://phet.colorado.edu/en/simulation/resistance-in-a-wire><http://hyperphysics.phy-astr.gsu.edu/hbase/electric/resis.html><https://teachers.web.cern.ch/teachers/archiv/HST2001/accelerators/superconductivity/superconductivity.htm> |

**3.5.1.4 Circuits**

Prior knowledge: Combining resistors in series. Energy and power in electric circuits.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| Combining resistors in series and in parallel.The relationship between currents, voltages and resistances in series and parallel circuits.Cells in series and identical cells in parallel.The energy and power equations:*E=VIt*$$P=VI=I^{2}R=\frac{V^{2}}{R}$$The conservation of charge and energy in dc circuits. | 1.5weeks | * Calculate the total resistance for combinations of series and parallel resistors.
* Analyse series and parallel circuits.
* Analyse circuits involving combinations of cells in series and identical cells in parallel.
* Calculate the energy and power in electric circuits.
* Explain how energy and charge are conserved in electric circuits.
 | **Learning activity:*** Explain how resistance in series and resistances in parallel combine.
* Explain why the total resistance of a parallel combination of resistors is always less than the smallest resistance resistor in the combination.
* Practise calculations involving series and parallel arrangements of components.
* Outline how the cells in series and in parallel combine.
* Review the power and energy equations and practise calculations involving these.
* Demonstrate how energy and charge are conserved in electric circuits.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of series and parallel electric circuits.AO2: Apply knowledge and understanding in the analysis of electric circuits.ATb, f: Construct circuits from a range of components.MS0.3: Use fractions when combining resistors in parallel.PS4.1: Know and understand how to use a wide range of experimental and practical instruments when investigating circuit.ATa,b,f,g: Construct circuits with various component configurations and measure currents and potential differences.AO1: Demonstration of knowledge and understanding of how cells combine in series and in parallel.AO2: Apply knowledge and understanding of the power equations and apply these in the analysis of electric circuits.MS2.3: Substitute numerical values into the power equations.MS2.2: Change the subject of the power equations.AO1: Demonstration of knowledge and understanding of the conservation of energy in electric circuits. | PHYA1 May 2014 Q5PHYA1 Jan 2013 Q6 and Q7(b)PHYA1 Jan 2012 Q6PHYA1 Jun 2012 Q6 | <http://www.tap.iop.org/electricity/circuits/index.html>**Rich question:**What is the resistance between A and B? |

**3.5.1.5 Potential divider**

Prior knowledge: The definition of resistance

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The potential divider used to supply constant or variable potential difference from a power supply.The use of variable resistors, light dependent resistors and thermistors in potential divider circuits. | 1.0 weeks | * Demonstrate that they understand how a potential divider can provide a constant or variable potential difference from a power supply.
* Describe how variable resistors, light dependent resistors and thermistors can be used in potential divider circuits.
 | **Learning activity:*** Investigate potential divider circuits.
* Investigate how sensors can be used in potential divider circuits.

**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of the potential divider.AO2: Apply knowledge and understanding of using potential dividers in sensing circuits.MS0.3: Use ratios and fractions when analysing potential divider circuits.MS2.3: Substitute numerical values into the potential divider equation.PS4.1: Know and understand how to use a wide range of experimental and practical instruments when investigating potential divider circuits.ATf, g: Correctly design, connect and check circuits. | SAM Q5PHYA1 May 2014 Q7PHYA1 May 2013 Q7PHYA1 May 2012 Q7 | <http://tap.iop.org/electricity/circuits/118/page_46038.html> |

**3.5.1.6 Electromotive force and internal resistance**

Prior knowledge: The definition of resistance.

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| **Learning objective** | **Time taken** | **Learning Outcome** | **Learning activity with opportunity to develop skills** | **Assessment opportunities** | **Resources** |
| The definition of emf.Circuit equation when cells have appreciable internal resistance.$$\in =I(R+r)$$Terminal pd. | 1.0 weeks | * Define emf with reference to cells.
* Understand and perform calculations for circuits in which the internal resistance of the supply is not negligible.
* Explain what is meant by terminal pd.
 | **Learning activity:*** Explain what is meant by emf, internal resistance and terminal pd.
* Practise calculations using the equation $\in =I(R+r)$
* Determine the internal resistance of a cell by measuring the terminal pd when the cell is connected to an external resistor with variable resistance.

**Required practical**Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of the cell with current in it.**Skills developed by learning activities:**AO1: Demonstration of knowledge and understanding of emf and internal resistance.AO2: Apply knowledge and understanding of emf and internal resistance in circuit calculations.MS3.1: Translate data from experiments to determine internal resistance into graphical form.MS3.3: Understand that the circuit equation including emf and internal resistance represents a linear relationship.MS3.4: Determine the intercept and slope of a linear graph.PS2.2: Present data from experiments to determine internal resistance in appropriate ways.PS3.1: Plot and interpret the graph from experiments to determine internal resistance.ATf: Correctly construct circuits for experiments to determine internal resistance. | PHYA1 May 2013 Q6PHYA1 Jan 2012 Q7 | <http://www.tap.iop.org/electricity/emf/index.html><http://www.nuffieldfoundation.org/practical-physics/internal-resistance-potato-cell>**Rich question:**Why is it important for car batteries to have very low internal resistances? |