Cambridge Assessment International Education

Scheme of Work

Cambridge International AS & A Level Physics 9702

For examination from 2016

Version 4.0

Cambridge Pathway

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Introduction

This scheme of work has been designed to support you in your teaching and lesson planning. Making full use of this scheme of work will help you to improve both your teaching and your learners' potential. It is important to have a scheme of work in place in order for you to guarantee that the syllabus is covered fully. You can choose what approach to take and you know the nature of your institution and the levels of ability of your learners. What follows is just one possible approach you could take and you should always check the syllabus for the content of your course.

Suggestions for independent study **(I)** and formative assessment **(F)** are also included. Opportunities for differentiation are indicated as **Extension activities**; there is the potential for differentiation by resource, grouping, expected level of outcome, and degree of support by teacher, throughout the scheme of work. Timings for activities and feedback are left to the judgment of the teacher, according to the level of the learners and size of the class. Length of time allocated to a task is another possible area for differentiation.

Key concepts

The key concepts on which the syllabus is built are set out below. These key concepts can help teachers think about how to approach each topic in order to encourage learners to make links between topics and develop a deep overall understanding of the subject. As a teacher, you will refer to these concepts again and again to help unify the subject and make sense of it. If mastered, learners can use the concepts to solve problems or to understand unfamiliar subject-related material.

KC1 – Models of physical systems
Physics is the science that seeks to understand the behaviour of the universe. The development of models of physical systems is central to physics. Models simplify, explain and predict how physical systems behave.

KC2 – Testing predication against evidence
Physical models are usually based on prior observations, and their predictions are tested to check that they are consistent with the behaviour of the real world. This testing requires evidence, often obtained from experiments.

KC3 – Mathematics as a language and problem-solving tool
Mathematics is integral to physics, as it is the language that is used to express physical principles and models. It is also a tool to analyse theoretical models, solve quantitative problems and produce predictions.

KC4 – Matter, energy and waves
Everything in the universe comprises matter and/or energy. Waves are a key mechanism for the transfer of energy and are essential to many modern applications of physics.

KC5 – Forces and fields
The way that matter and energy interact is through forces and fields. The behaviour of the universe is governed by fundamental forces that act over different length scales and magnitudes. These include the gravitational force and the electromagnetic force.

The key concepts are listed under the relevant syllabus reference, those in **bold** are where the coverage of the learning objective makes a significant contribution to the key concept.

Guided learning hours

Guided learning hours give an indication of the amount of contact time teachers need to have with learners to deliver a particular course. Our syllabuses are designed around 180 hours for Cambridge International AS Level, and 360 hours for Cambridge International A Level. The number of hours may vary depending on local practice and your learners' previous experience of the subject. The table below give some guidance about how many hours are recommended for each topic.

Topic	Suggested teaching time (%)	Suggested teaching order
AS Level		
1. Skills for physics	It is recommended that this unit should take about 40 hours / 11% of the course.	1.1.a, 1.1.b, 1.2.a, 1.2.b, 1.2.c, 1.2.d, 1.2.e, 1.4.a, 1.4.b, 1.4.c, 2.1.a, 2.1.b, 2.1.c, 2.2.a, 2.2.b, 2.2.c
2. Motion	It is recommended that this unit should take about 29 hours / 8% of the course.	3.1.a, 3.1.b, 3.1.d, 3.1.e, 3.1.c, 3.1.f, 3.1.g, 3.1.h, 3.1.i, 4.1.a, 4.1.b, 4.1.c, 4.1.d, 4.1.e, 4.2.a, 4.2.b, 5.1.a, 17.1.a, 17.1.b, 17.2.a, 17.2.b, 17.2.c, 4.3.a, 4.3.b, 4.3.c, 4.3.d
3. Forces, work and materials	It is recommended that this unit should take about 40 hours / 11% of the course.	5.1.b, 5.1.c, 5.1.d, 5.2.a, 5.2.b, 5.2.c, 5.3.a, 5.3.b, 5.3.c, 5.4.a, 5.4.b, 5.4.c, 5.4.d, 6.1.a, 6.2.a, 6.2.b, 6.2.c, 6.2.d, 6.3.a, 6.3.b, 6.3.c, 6.3.d, 6.3.e, 6.3.f, 6.4.a, 6.4.b, 9.1.a, 9.1.b, 9.1.c, 9.1.d, 9.2.a, 9.2.b, 9.2.c
4. Waves	It is recommended that this unit should take about 29 hours / 8% of the course.	14.1.a, 14.1.b, 14.1.c, 14.1.d, 14.1.e, 14.1.f, 14.2.a, 14.2.b, 14.3.a, 14.4.a, 14.4.b, 14.4.c, 14.5.a, 15.1.a, 15.1.b, 15.1.c, 14.3.b, 15.3.a, 15.3.b, 15.3.c, 15.3.d, 15.2.a, 15.2.b, 15.4.a, 15.4.b
5. Electrical circuits	It is recommended that this unit should take about 29 hours / 8% of the course.	20.1.a, 20.1.b, 19.1.a, 19.1.b, 19.1.c, 19.1.d, 19.1.e, 19.3.a, 19.3.e, 19.2.a, 19.2.b, 19.3.d, 19.3.b, 19.3.c, 19.2.c, 20.2.a, 20.2.b, 20.2.c, 20.2.d, 20.2.e, 20.2.f, 20.2.g, 20.1.c, 20.1.d, 20.1.e, 20.3.a, 20.3.b
6. Particle physics	It is recommended that this unit should take about 13 hours / 4% of the course.	26.1.a, 26.1.b, 26.1.c, 26.1.d, 26.1.e, 26.1.f, 26.1.g, 26.1.h, 26.2.a, 26.2.b, 26.2.c, 26.2.d, 26.2.e, 26.2.f

Topic	Suggested teaching time (%)	Suggested teaching order
A Level		
7. Further mechanics	It is recommended that this unit should take about 36 hours / 10% of the course.	7.1.a, 7.1.b, 7.1.c, 7.2.a, 7.2.b, 7.2.c, 13.1.a, 13.1.b, 13.1.c, 13.1.d, 13.1.e, 13.1.f, 13.1.g, 13.2.a, 13.3.a, 13.3.b, 13.3.c, 13.3.d, 14.6.a, 14.6.b, 14.6.c, 14.6.d, 8.1.a, 8.2.a, 8.2.b, 8.2.c, 8.3.a, 8.3.b, 8.3.c, 8.4.a, 8.4.b
8. Thermodynamics	It is recommended that this unit should take about 36 hours / 10% of the course.	11.1.a, 11.1.b, 11.2.a, 11.2.b, 11.2.c, 11.3.a, 12.1.a, 12.1.b, 12.1.c, 12.2.a, 12.2.b, 12.2.c, 1.2.a, 1.3.a, 1.3.b, 10.1.a, 10.2.a, 10.2.b, 10.2.c, 10.3.a, 10.3.b
9. Electricity and electronics	It is recommended that this unit should take about 40 hours / 11% of the course.	17.3.a, 17.3.b, 17.4.a, 17.5.a, 17.5.b, 17.5.c, 17.5.d, 18.1.a, 18.1.b, 18.1.c, 18.1.d, 18.2.a, 18.2.b, 21.1.a, 21.2.a, 21.2.b, 21.2.c, 21.2.d, 21.2.e, 21.3.a, 21.3.b, 21.3.c, 21.3.d, 19.4.a, 19.4.b, 19.4.c, 19.4.d, 19.4.e, 20.3.c, 20.3.d, 16.1.a, 16.2.a, 16.2.b, 16.2.c, 16.2.d, 16.2.e, 16.3.a, 16.3.b, 16.3.c, 16.4.a, 16.4.b, 16.5.a, 16.5.b
10. Electromagnetism	It is recommended that this unit should take about 40 hours / 11% of the course.	22.1.a, 22.1.b, 22.2.a, 22.2.b, 22.2.c, 22.2.d, 22.3.a, 22.3.b, 2.1.a, 22.3.c, 22.3.d, 22.3.e, 22.3.f, 23.1.a, 23.1.b, 23.1.c, 23.1.d, 23.1.e, 23.1.f, 24.1.a, 24.1.b, 24.1.c, 24.1.d, 24.2.a, 24.2.b, 24.3.a, 24.4.a, 24.4.b, 24.4.c, 24.4.d
11. Quantum physics	It is recommended that this unit should take about 18 hours / 5% of the course.	25.1.a, 25.1.b, 25.2.a, 25.2.b, 25.2.c, 25.2.d, 25.2.e, 25.3.a, 25.3.b, 25.4.a, 25.4.b, 25.4.c, 25.5.a, 25.5.b, 25.5.c, 25.5.d, 25.6.a, 25.6.b, 25.6.c, 25.6.d, 25.6.e, 25.6.f, 25.6.g
12. Nuclear physics	It is recommended that this unit should take about 10 hours / 3% of the course.	26.3.a, 26.3.b, 26.3.c, 26.3.d, 26.3.e, 26.3.f, 26.3.f, 26.4.a, 26.4.b, 26.4.c, 26.4.d, 26.4.e, 26.4.f

Resources

The up-to-date resource list for this syllabus, including textbooks endorsed by Cambridge International, is listed at www.cambridgeinternational.org
Endorsed textbooks have been written to be closely aligned to the syllabus they support, and have been through a detailed quality assurance process. As such, all textbooks endorsed by Cambridge International for this syllabus are the ideal resource to be used alongside this scheme of work as they cover each learning objective.

School Support Hub

The School Support Hub www.cambridgeinternational.org/support is a secure online resource bank and community forum for Cambridge teachers, where you can download specimen and past question papers, mark schemes and other resources. We also offer online and face-to-face training; details of forthcoming training opportunities are posted online. This scheme of work is available as PDF and an editable version in Microsoft Word format; both are available on the School Support Hub at www.cambridgeinternational.org/support If you're unable to use Microsoft Word you can download Open Office free of charge from www.openoffice.org

Websites

This scheme of work includes website links providing direct access to internet resources. Cambridge Assessment International Education is not responsible for the accuracy or content of information contained in these sites. The inclusion of a link to an external website should not be understood to be an endorsement of that website or the site's owners (or their products/services).

The website pages referenced in this scheme of work were selected when the scheme of work was produced. Other aspects of the sites were not checked and only the particular resources are recommended.

How to get the most out of this scheme of work – integrating syllabus content, skills and teaching strategies

We have written this scheme of work for the Cambridge International AS & A Level Physics (9702) syllabus and it provides some ideas and suggestions of how to cover the content of the syllabus. We have designed the following features to help guide you through your course.

Learning objectives help your learners by making it clear the knowledge they are trying to build. Pass these on to your learners by expressing them as 'We are learning to / about…'.

Suggested teaching activities give you lots of ideas about how you can present learners with new information without teacher talk or videos. Try more active methods which get your learners motivated and practising new skills.

Syllabus ref. and key concepts	Learning objectives	Suggested teaching activities
KC1 / **KC3** 3.1.d	Determine velocity using the gradient of a displacement-time	• Revise how to calculate gradient. Provide some easy examples to start with. • **Extension activity:** Draw graphs or use prepared graphs from which to calculate velocity from the gradient. Include curved graphs. **(I)** **Note:** It is important that learners can recognise the shape of displacement-time graphs for objects which are: • stationary • moving with constant speed/velocity • accelerating. These may be combined in different sections of the same graph. Reminders may be needed for some learners about how to measure the gradient of a straight line ($\Delta s/\Delta t$) and the gradient of a curve by drawing a tangent at the point in question. They need to distinguish between distance-time g (gradient represents the speed) and displacement-time graphs (gradient represents the velocity). They must be qui clear about the physics of why the gradient can be used in this way. http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_06/Mechanics_Page_6.htm

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

Extension activities provide your abler learners with further challenge beyond the basic content of the course. Innovation and independent learning are the basis of these activities.

Independent study (I) gives your learners the opportunity to develop their own ideas and understanding with direct input from you.

Past Papers, Specimen Papers and **Mark Schemes** are available for you to download at: www.cambridgeinternational.org/support

Using these resources with your learners allows you to check their progress and give them confidence and understanding.

Formative assessment (F) is on-going assessment which informs you about the progress of your learners. Don't forget to leave time to review what your learners have learnt, you could try question and answer, tests, quizzes, 'mind maps', or 'concept maps'. These kinds of activities can be found in the scheme of work.

1: Skills for physics

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC3 1.1a	Understand that all physical quantities consist of a numerical magnitude and a unit.	• Discuss why quantities need a unit. • Learners make a list of quantities with which they are familiar, including units and symbols for both the quantities and units. This could be done as a card-sort activity. **Note:** • Units are essential in order to convey the scale of a measurement (for example, if the length of an elastic cord is measured, a magnitude of 30 would not be of any use without knowing whether the unit of the measurement was m, cm or mm). Also quantities must have the correct units for equations which link them, and represent physical laws, to make scientific sense. • Learners should be strongly encouraged to become accustomed to using the index notation, rather than the solidus notation, for units expressed as a quotient**.**
KC1 / KC3 1.1b	Make reasonable estimates of physical quantities included within the syllabus.	• Estimate quantities such as: ○ Height of bench/table ○ Length of room or width of pencil end/pencil lead ○ Volume of room/volume of water in a cup/volume of water in an Olympic sized swimming pool and in a bath ○ Mass of a person/mass of a nail/mass of a cruise liner ○ Time between heartbeats/period of a pendulum ○ Electric current in a cooker element ○ Force on a tennis ball when served ○ Acceleration of a jet plane when taking off.
KC1 / KC3 1.2.a (AS Level only)	Recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K).	• Learners should carry out an internet or textbook search to find out what the base units are and how these five units are defined. **Note:** • The SI (Système Internationale) system is founded on six base quantities. Learners should recognise that their units are fundamental and cannot be expressed in terms of any other unit. • The mol will be introduced later. http://physics.nist.gov/cuu/Units/

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

KC1 / KC3
1.2.b
	Express derived units as products or quotients of the SI base units and use the named units listed in this syllabus as appropriate.	• Introduce the concept of derived units by describing them as a combination of one or more base units. The base units may be multiplied together or divided by one another, but never added or subtracted.
		• With guidance learners explore the idea of compound units. Examples might include the units of frequency (s^{-1}), speed ($m\ s^{-1}$), acceleration ($m\ s^{-2}$), force ($kg\ m\ s^{-2}$), energy ($kg\ m^2\ s^{-2}$), power ($kg\ m^2\ s^{-3}$) and potential difference ($kg\ m^2\ s^{-3}\ A^{-1}$).
		• **Extension activity:** Learners should express the units of some derived quantities in terms of base units, for example using a prepared worksheet. **(I)**
		
		Note:
		• The importance of the notation for units needs to be emphasised. In particular, two points should be noted by learners:
		  ○ Care must be taken to use upper case and lower case letters correctly
		  ○ A gap should never be shown between a prefix and the unit to which it refers (e.g. milligrams must be written mg and not m g).
		
		Occasionally, a physical quantity (such as tensile strain) has no units. This might be because it is the ratio of two other quantities which both have the same unit. In cases like these, learners should be discouraged from giving the unit as ‘1’, and from using ‘1’ as a representation of a unit when checking to see whether an equation is homogeneous. It should be stated clearly, when necessary, that the quantity has ‘no units’.

KC1 / KC3 1.2.c	Use SI base units to check the homogeneity of physical equations.	• Learners practise verifying the homogeneity of equations such as $P = Fv$, i.e. showing that both sides have the same base units. In addition, learners should consider equations such as $W = ½mv^2 + mgh$, where *each term* must be shown to have the same base units. **(I)** http://www.s-cool.co.uk/a-level/physics/units-quantities-and-measurements/revise-it/homogenous-equations
KC1 / KC3 1.2.d	Use the following prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T).	• Learners draw up a table to include the prefixes, their abbreviation and how many powers of ten they represent. **(I)** • Prepared sheet of exercises converting between prefixes. **(I)** • Look at measuring instruments, such as timers, milliammeters or metre rules, with calibrations in multiples or submultiples of the base unit. **Note:** • It is vital that learners become thoroughly conversant with these prefixes and the powers of ten they represent as early as possible in the course. They will be used so often when solving problems that a fluent working knowledge is essential. They need to be confident in converting from one form to

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		the other (for example, expressing 62 μA as 6.2×10^{-5} A), and in handling numbers expressed in standard form when using a calculator. • Where prefixes are not used, learners should be strongly encouraged to write very large or very small numbers in standard form, rather than writing out all the zeros. Errors can very easily occur in the positioning of decimal points, or in counting the number of zeros, if standard form is not used. http://www.s-cool.co.uk/a-level/physics/units-quantities-and-measurements/revise-it/units-and-prefixes
KC1 / KC3 1.2.e	Show an understanding of and use the conventions for labelling graph axes and table columns as set out in the ASE publication *Signs, Symbols and Systematics* (*The ASE Companion to 16–19 Science*, 2000).	• Practise plotting graphs to include appropriate scales, axes labels and lines of best fit. **(I)** **Note:** • The conventions used for labelling columns of data in tables and on graph axes should be understood by learners. These conventions include the use of the style where the symbol for the quantity is shown in italics, followed by a solidus, followed by the unit in normal type, for example, a/m s^{-2}. The data items in the table, or along the graph axis, are then shown just as numbers, the unit should not be given every time. • Examples where a power of ten is also included, such as $t/10^2$ s, meaning that every item in the data column or on the graph axis has been divided by 100, also need to be examined and practised. • Alternatively make sure you cover these ideas as and when the learners undertake practical work. **Practical booklets** 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
KC1 / KC3 1.4.a	Distinguish between scalar and vector quantities and give examples of each.	• Discuss the meaning of the terms scalar and vector. Discuss with reference to distance and displacement, speed and velocity. • Learners list several quantities and include whether they are scalar or vector. **(I)** http://www.tap.iop.org/mechanics/static/201/page_46240.html http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_01/Mechanics_page_1.htm
KC1 / KC3 1.4.b	Add and subtract coplanar vectors.	• Brainstorm what the word 'resultant' means. • Exercises adding parallel and antiparallel vectors. **(I)** • A visual approach to adding vectors using a vector triangle or a parallelogram of forces. Possibly card arrows, lengths of string. • Prepared exercises to calculate the resultant of two vectors by sketch and calculation as well as by scale drawing. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Experiment to verify the idea of using a vector triangle to find a resultant, making use of three newton meters, chalk, thin string and paper. http://www.s-cool.co.uk/a-level/physics/vectors-and-scalars-and-linear-motion/revise-it/vectors-and-scalars-whats-the-differ
KC1 / KC3 1.4.c	Represent a vector as two perpendicular components.	• Experiment to see how the force to pull a block depends on the angle to the horizontal, using a wooden block, string, protractor and newton meter. • Discuss the results to draw out how much of the force is actually acting horizontally. • Exercises to calculate the perpendicular component of a number of vectors. Include displacements, velocities and forces. **(I)** • Examples to find the resultant of many vectors by first representing each vector as two perpendicular components. **Note:** • Present the idea of resolving a single vector into two components (usually, though not necessarily, perpendicular) as the opposite process to finding the resultant of two or more vectors. It is a useful means of solving certain kinds of problem, and plenty of practice exercises will ensure that the trigonometry of the process is well understood and learners can carry out the mathematical procedures with ease**.** The ratios for sin θ, cos θ and tan θ for right-angled triangles will need revision, as will the use of Pythagoras' Theorem. • Throughout the course, there are cases where both of two perpendicular components of a vector quantity serve a particular purpose and need to be considered separately. An example is the Earth's magnetic field, where it is often more convenient to make use of only the horizontal component when considering the e.m.f. induced in a conductor (for example, the wings of an aircraft) moving through it. The recurrent nature of this type of physical situation will need to be frequently reinforced with leaners as the course proceeds. http://www.s-cool.co.uk/a-level/physics/vectors-and-scalars-and-linear-motion/revise-it/resolving-vectors-into-components http://www.physicsclassroom.com/Class/vectors/U3L3b.cfm
KC1 / **KC2** / KC3 2.1.a (AS Level only)	Use techniques for the measurement of length, volume, angle, mass, time, temperature and	• A circus of experiments to practise the use of different measuring techniques and instruments. **(I)** Experiments might include ○ measuring the length of a pendulum, the thickness of a wire and the internal and external diameters of a measuring cylinder.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	electrical quantities appropriate to the ranges of magnitude implied by the relevant parts of the syllabus. In particular, candidates should be able to: • measure lengths using a ruler, calipers and micrometer • measure weight and hence mass using balances • measure an angle using a protractor • measure time intervals using clocks, stopwatches and the calibrated time-base of a cathode-ray oscilloscope (c.r.o.) • measure temperature using a thermometer • use ammeters and voltmeters with appropriate scales • use a galvanometer in null methods • use a cathode-ray oscilloscope (c.r.o.).	○ finding the mass of 145 cm^3 of water and finding the weight of a brick ○ measure the angles of incidence and reflection when using a plane mirror with a beam of light ○ find the period of oscillation of a simple pendulum, where the technique of counting multiple oscillations is necessary. The count must be started at ‘0’ rather than ‘1’ ○ plotting of the cooling curve for two different liquids (this would be a good opportunity to introduce the use of a digital temperature sensor, although revision of the use of a liquid-in-glass thermometer will also be necessary). ○ set up circuits and make measurements using digital and analogue meters with a variety of ranges. ○ magnitudes of direct and alternating voltages can be measured, as well as the frequency of an unknown alternating potential difference. **Note:** • It is important that learners realise that this is just an introduction to the very large variety of measurement techniques available to scientists. They need to be aware of the variety of means of measurement they will need to carry out. Throughout the course, these techniques will need to be revised and practised as appropriate. • You may want to demonstrate some techniques, but learners will need to practise themselves. This can be achieved by introducing practical work on a topic-by-topic basis, or as a more wide-ranging ‘circus’ of experiments where this is possible. • At all stages, learners should be encouraged to think about and write down the accuracy of their measurements. • The meaning of ‘parallax error’ needs to be made clear to learners; they can easily demonstrate it using a ruler and set square. • You can initiate discussion with learners on how we might measure very small distances, such as the thickness of a sheet of paper or the diameter of a length of fine wire. This will lead to the introduction of digital calipers and the micrometer. This would be a good point to introduce ‘zero error’ as a source of inaccuracy which needs to be avoided when making measurements. • You will need to revise the use of the spring balance (newton meter), top-pan balance and level balance with learners. • Learners will need to be reminded of the correct use of a protractor and of a stopwatch or digital timer, and the need for repeat readings. • The use of the c.r.o. to find the time interval between sending a sound pulse and its reflection being received could be studied and learners will need to revise the use of the time-base to do this. They could be challenged to find the speed of sound from such measurements.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• You'll need to revise the correct ways to connect ammeters and voltmeters in circuits. Learners set up circuits and make measurements using digital and analogue meters with a variety of ranges. Multimeters could also be used, but these should not be considered as a universal substitute for the individual types of meter. • Demonstrate the concept of a 'null' point until learners make a study of the p.d. along a current-carrying wire in potentiometer experiments (Unit 11). They should understand it as a 'balance' point, not as a position where there is literally no electrical activity. • The method of operation of the c.r.o. will need to be revised/ introduced. • The Y-plate sensitivity and the variation possible in the X-plate time-base setting need to be understood, and how they work together to give a sinusoidal trace for an alternating Y-input. **Practical booklets** 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 http://www.nuffieldfoundation.org/practical-physics http://www.upscale.utoronto.ca/PVB/Harrison/Micrometer/Flash/MicSimulation.html http://www.tap.iop.org/electricity/emf/122/page_46061.html http://www.best-microcontroller-projects.com/how-to-use-an-oscilloscope.html http://www.virtual-oscilloscope.com/
KC2 2.1.b	Use both analogue scales and digital displays.	• Learners look at a variety of scales, both analogues and digital. Discuss the advantages and disadvantages of each. **Note:** • It is important that learners have some experience of analogue meters and scales as well as digital ones, and are familiar with the skills needed to accurately read from them, e.g. liquid-in-glass thermometers and analogue ammeters and voltmeters. **Practical booklets** 4, 7
KC1 / **KC2** / KC3 2.1.c	Use calibration curves.	• Look at calibration curve as explained in Sang p.482. • **Extension activity:** Experiment with a length of narrow-bore glass tube with a coloured liquid in the lower part. Place it in a water bath and plot a calibration curve of the length of the coloured liquid column against the temperature (measured on an external sensor, perhaps). Measure unknown temperatures using the length of the coloured liquid in combination with the calibration curve. **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• It is necessary for learners to appreciate the stages in the process of calibrating a measuring instrument. All measuring instruments use a physical quantity which varies with what is being measured and a calibration curve has to be set up as a link between the two.
KC2 2.2.a	Understand and explain the effects of systematic errors (including zero errors) and random errors in measurements.	• Prepared examples showing different types of error displayed visually, in a graph or in a results table. Learners decide which type of error is which. **Note:** • Learners should understand that *random* errors are errors of judgement, which can cause the measurement to be either too large or too small. They can be reduced by repeating a measurement several times and taking an average. *Systematic* errors, e.g. zero errors, are all in the same direction, consistently similar, and arise from faults in equipment or sometimes from poor technique when taking the measurements. They can be eliminated by recalibration of the instrument or by improving the technique being used. • In all practical work, learners should be encouraged to identify as many sources of both types of error as they can. http://www.physics.umd.edu/courses/Phys276/Hill/Information/Notes/ErrorAnalysis.html
KC2 2.2.b	Understand the distinction between precision and accuracy.	• **Extension activity:** Prepared results table resources so that learners can investigate the difference between precision and accuracy. Include varying numbers of significant figures and a comparison with expected values. **Note:** • Learners should understand that *precise* results are all very similar, and are clustered closely round an average. Precision is reflected in how the results are recorded. If a time is recorded as 12s, it implies that it was only measured to the nearest second, whereas 12.0 s suggests a precision of 0.1 s. Learners must be careful to give figures in data tables to the appropriate precision, and all tabulated values of a particular quantity to the same precision. • *Accurate* results are close to the true value of the quantity. Learners must be careful not to confuse accuracy with precision. Measurements can be precise, without being accurate! http://www.haystack.mit.edu/edu/pcr/Data/pdf/Worksheet-Accuracy%20and%20Precision-Final.pdf
KC2 2.2.c	Assess the uncertainty in a derived quantity by simple addition of	• Look at a range of various measuring instruments to work out their absolute uncertainty. Then take measurements and calculate percentage uncertainty.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	absolute, fractional or percentage uncertainties (a rigorous statistical treatment in not required).	• Prepared exercises to practise these ideas. **Note:** • Uncertainties in calculated quantities can be found by adding individual uncertainties, and these can be expressed in any one of three ways. Learners will need to practise estimating the absolute uncertainties of measurements that they make in the course of experiments and expressing them as fractional or percentage uncertainties. Final results should be given to an appropriate n

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

2: Motion

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC3 3.1.a	Define and use distance, displacement, speed, velocity and acceleration.	• Question sheet (and mark scheme) prepared by you with many examples to practise using these definitions. **(I)** • **Extension activity:** Examples to draw out the difference between distance and displacement, speed and velocity. Look at the example of an object travelling at constant speed in a circle to help here. **(I)**
KC1 / KC3 3.1.b	Use graphical methods to represent distance, displacement, speed, velocity and acceleration.	• Experimental work using a motion sensor with a data-logger to generate data. Hand draw or use the computer to plot the various motion graphs. • Give learners examples of graphs and ask them to explain the motion shown. • Provide sets of displacement, velocity and acceleration graphs and ask the learners to put them into relevant groups of three showing the same motion. • The two suggested webpages show the different graphical representations which can be made for the data. • Revision of good practice for graph plotting with some learners where necessary. Questions using data tables showing one of these quantities varying with time would give these learners the opportunity to practise this. http://www.tap.iop.org/mechanics/kinematics/205/page_46316.html http://www.s-cool.co.uk/a-level/physics/vectors-and-scalars-and-linear-motion/revise-it/the-basics-of-linear-motion-and-disp
KC1 / **KC3** 3.1.d	Determine velocity using the gradient of a displacement-time graph.	• Revise how to calculate gradient. Provide some easy examples to start with. • **Extension activity:** Draw graphs or use prepared graphs from which to calculate velocity from the gradient. Include curved graphs. **(I)** **Note:** It is important that learners can recognise the shape of displacement-time graphs for objects which are: • stationary • moving with constant speed/velocity • accelerating. These may be combined in different sections of the same graph**.**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Reminders may be needed for some learners about how to measure the gradient of a straight line ($\Delta s/\Delta t$) and the gradient of a curve by drawing a tangent at the point in question. They need to distinguish between distance-time graphs (gradient represents the speed) and displacement-time graphs (gradient represents the velocity). They must be quite clear about the physics of why the gradient can be used in this way. http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_06/Mechanics_Page_6.htm
KC1 / **KC3** 3.1.e	Determine acceleration using the gradient of a velocity-time graph.	• Experiment with a trolley on a sloping runway with light gates or ticker timers to determine velocity and/or acceleration. They should plot suitable graphs from the results of the experiment and practise using the graphs to find other quantities. • Worksheet (and mark scheme) prepared by you with example graphs to practise finding acceleration. **(I)** **Note:** Learners will need to recognise the shapes of velocity-time graph sections for objects which are: • stationary • moving with constant speed/velocity • accelerating. Learners must practise and appreciate that displacement-time and velocity-time graphs which look the same shape, represent completely different kinds of motion. Learners need to distinguish between speed-time graphs and velocity-time graphs.
KC1 / **KC3** 3.1.c	Determine displacement from the area under a velocity-time graph.	• **Extension activity:** Use previous velocity-time graphs (LO 3.1.e) to find displacement from the area under the line. Include curved lines and either count the squares or divide into a series of trapeziums. **(I)** **Note:** The idea of representing a physical quantity by a graphical area may be new to some learners. You will need to explain how this comes about and emphasise that it is a method of working out another quantity which will be encountered in several other areas of the course, for example when finding the work done in stretching a wire in Unit 7. Emphasise that learners must use the scales on the axes. http://www.physicslab.co.uk/skater.htm

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / **KC3** 3.1.f	Derive, from the definitions of velocity and acceleration, equations that represent uniformly accelerated motion in a straight line.	• Learners should derive the equation $v = u + at$ from the definition of constant acceleration. **(I)** • They use average speed to derive $s = (u + v)t/2$. **(I)** • **Extension activity:** They can derive the equation $s = ut + ½at^2$ from combining the first two. **(I)** • **Extension activity:** The equation $v^2 = u^2 + 2as$ can be derived by combining the first and third equations or the first and second equations. This is more difficult algebraically and its derivation could be set as a challenge to abler learners. **(I)** **Note:** Some initial discussion will be necessary as to why these equations are necessary and the physical circumstances in which they are valid. You will need to emphasise that these equations can only be used in situations of where the acceleration is *constant*. http://www.tap.iop.org/mechanics/kinematics/206/page_46322.html http://www.s-cool.co.uk/a-level/physics/equations-of-motion/revise-it/equations-of-motion
KC1 / **KC3** 3.1.g	Solve problems using equations that represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance.	• Worksheet (and mark scheme) prepared by you in two levels to practise using the equations for uniform acceleration. **(I)** **Note:** • It is often helpful for learners when they are new to these equations if they make a list of the known and required quantities at the start of a question. They can then more easily decide which equation to use. • When they are solving questions involving free fall, you can remind them that the acceleration of free fall (g) at the Earth's surface is $9.81\,m\,s^{-2}$ (they should be discouraged from using the approximate value of $10\,m\,s^{-2}$). When a question is about an object being projected upwards, they will need to remember to take g as negative, as they should whenever there is a deceleration involved. **Practical booklet** 3
KC2 3.1.h	Describe an experiment to determine the acceleration of free fall using a falling body.	• **Extension activity:** Experiment with a ball bearing and timer to measure the time taken to fall different heights. Plot the appropriate graph and find g from the gradient. • The suggested webpage has a link to a worksheet which explains how g can be measured experimentally. **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Learners should be aware that this determination can be carried out in several ways. If appropriate timing devices are available, they can carry out the experiment using the direct method of timing the fall of an object through a measured height and using $s = ½gt^2$. Alternatively, *g* can be found using a simple pendulum. Learners should be able to describe at least one of these experiments clearly and in detail, including how the result is calculated. **Practical booklet** 3 http://www.tap.iop.org/mechanics/kinematics/206/page_46322.html
KC1 / **KC3** 3.1.i	Describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.	• **Extension activity:** Demonstrations or video clips of experiments such as ‘monkey and hunter’ or ‘pearls in air’. Discuss how to analyse such a problem. • **Extension activity:** Look at a vertical drop alongside a horizontal projection to look at the similarities and differences. • Plot some projectile trajectories on graph paper to make it easier to visualise the parabolic shape. • Prepared question sheet in two levels to practise solving many examples. **(I)** **Note:** • This will require learners to resolve vectors into two perpendicular components, as initially covered in Unit 1. This is the projectile idea and they will need to consider the vertical and horizontal components of the velocity separately, with the horizontal component being taken as constant in the absence of air resistance and the vertical component being subject to the acceleration of free fall. The overall trajectory of a projectile is in the shape of a parabola. • In projectile questions, learners need to be careful to use a consistent sign convention. The upwards direction is generally taken as positive, so that the initial velocity will be positive (but the initial acceleration is negative). Quantities which learners should be able to find for a projectile include the maximum height reached, the horizontal range of the motion, the angle of projection and the time taken to reach the ground again after projection. • Learners do not need to learn specific variations of the equations of motion for (maximum) range and height. http://www.nationalstemcentre.org.uk/elibrary/resource/2084/monkey-and-hunter Monkey and hunter experiment http://sciencedemo.org/2014/01/pearls-in-air/ Pearls in air experiment http://www.tap.iop.org/mechanics/kinematics/207/page_46332.html Projectile motion is discussed with links to experimental activities. http://www.s-cool.co.uk/a-level/physics/equations-of-motion.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.s-cool.co.uk/a-level/physics/vectors-and-scalars-and-linear-motion/revise-it/resolving-vectors-into-components http://www.physicslab.co.uk/shoot.htm
KC1 / KC5 4.1.a	Understand that mass is the property of a body that resists change in motion.	• 'Why is it harder to stop a fully loaded minibus than one with only the driver in?' Discuss what mass is and write down a formal definition. • Demonstrations to show how it is more difficult to move a heavier mass, e.g. 0.5 kg, 1 kg, 2 kg masses pulled with a thin thread. • Demonstrate the trick of a coin on a piece of card over a beaker, and pulling a mass horizontally with a thin thread. A greater acceleration requires a larger force, the coin is left behind, the thread snaps (it does not when pulled more slowly). The inertia of the coin / mass means a force is needed to move them. This also leads to $F = ma$. • Learners answer worksheet (and mark scheme) prepared by you or from the textbook. **(I)** **Note:** • Start by asking 'What is mass?' and hopefully someone will give the answer, 'a measure of inertia', if they have come across that idea somewhere. Or ask the group to write their own answer to the same question. The 'inertia' idea leads to the idea of the resistance of an object to changes in its state of rest or uniform motion. The everyday experiences of learners will lead them to the conclusion that it is more difficult to bring about changes in movement to objects with larger mass.
KC1 / KC3 / KC5 4.1.b	Recall the relationship $F = ma$ and solve problems using it, appreciating that acceleration and resultant force are always in the same direction.	• Experiments to verify the relation between force and acceleration could include the use of trolleys on a runway being pulled by a falling weight, ticker timers and tape, elastic bands, linear air tracks or motion sensors and data loggers. • **Extension activity:** Analyse results to show the relationship between force and acceleration and the relationship between mass and acceleration. **(I)** • Worksheet (and mark scheme) prepared by you in two levels to apply the formula. **(I)** **Note:** • The idea should be established with learners that a force is needed to bring about **any** change in the motion of a moving object, perhaps in answer to the question 'what causes an acceleration?' The relationship $F = ma$ is a mathematical expression of Newton's second law, and a simplified form of this is 'for a body of constant mass, the acceleration produced is directly proportional to the force applied to it', as long as the direction of the acceleration is in the direction of the applied force. • It may be necessary to emphasise that F stands for resultant force.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• This would be a good time to revise the mathematical meaning of the phrase 'is proportional to' when applied to two physical quantities and to ensure that they have all completely dismissed the idea that such quantities are equal in some way. **Practical booklet** 3 http://www.physicslab.co.uk/newton.htm
KC3 / KC5 4.1.c	Define and use linear momentum as the product of mass and velocity.	• Discuss what learners understand by the term momentum. Follow with a formal definition. • Worksheet (and mark scheme) prepared by you applying the formula. **(I)** • **Extension activity:** For abler learners include direction change to reinforce how to subtract vectors to find the change in momentum. **(I)** • Learners show that the units N s and kg m s^{-1} are the same.
KC1 / KC3 / KC5 4.1.d	Define and use force as rate of change of momentum.	• Develop the relationship *Force = change of momentum / time taken* from $F = ma$. Apply the new formula with a worksheet (and mark scheme) prepared by you. • Learners discuss everyday consequences of this and asked to explain a particular example in writing, using the correct scientific vocabulary, such as the reason why eggs are less likely to break if dropped when packed in thick cardboard boxes, or the reasons why modern cars have crumple zones. **(I)** • Experiment to build a car crumple zone attached to a dynamics trolley (release from a set height on a ramp) or to build an 'egg box'. • **Extension activity:** Look at the area under a force-time graph. What does it represent? Introduce impulse. Discuss with reference to, for example, the force on a tennis ball during a serve. **Note:** • There should be plenty of practice questions to solve, including those where the concept of impulse is introduced, and those which illustrate the use of rocket motors to supply a constant force, as well as questions making use of the more conventional 'rapid' collisions. • Learners must appreciate that in the vast majority of real collisions, the force applied to an object to change its momentum is not constant, but varies from minimum to maximum, and back to minimum again, over the course of the collision. http://www.tap.iop.org/mechanics/momentum/221/page_46450.html http://www.tap.iop.org/mechanics/wep/215/page_46398.html http://www.tap.iop.org/mechanics/momentum/222/page_46460.html

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.s-cool.co.uk/a-level/physics/momentum-and-impulse/revise-it/impulse
KC1 / KC5 4.1.e	State and apply each of Newton's laws of motion.	• Discuss Newton's laws by looking at some pictures chosen to illustrate each law. Write formal definitions of the laws. • Investigate some examples of each, for example the situation of an object at rest, an object accelerating, two objects exerting equal and opposite forces on each other. **Note:** You will need to make sure that learners can quote each of these laws, using the correct language, and are aware of the physical circumstances where each can be applied. These laws need to become second nature to learners. They should know that: • The first law describes the situation where two or more forces act on a single object, causing its motion not to change if the resultant is zero • The second law states that resultant force is *directly proportional* to the rate of change of momentum. It is only because of the way the Newton is defined which enables the proportional relationship stated in the law to be replaced by 'equals' • The third law is best stated thus: If object A exerts a force on object B, then object B will exert an equal but opposite force on body A. In contrast to the first law, this refers to the forces acting on a pair of objects not necessarily in contact with one another. The statement 'action and reaction are equal and opposite' which is seen occasionally should be strongly avoided. • It is worthwhile looking at some examples of the third law, for example the Moon orbiting around the Earth, how car tyres work. http://www.tap.iop.org/mechanics/newton/210/page_46364.html http://www.s-cool.co.uk/a-level/physics/forces/revise-it/newtons-laws http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_02/Mechanics_Page_2.htm
KC1 / KC5 4.2.a	Describe and use the concept of weight as the effect of a gravitational field on a mass and recall that the weight of a body	• Discuss 'What is mass?' and 'What is weight?' • Draw up a table to show the differences between mass and weight. • Worksheet (and mark scheme) prepared by you to apply $W = mg$. Include different values of 'g' on different planets / moons. **(I)** **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	is equal to the product of its mass and the acceleration of free fall.	• They will probably have met the relationship $W = mg$ before; learners should realise that this is an example of $F = ma$ applied to the particular situation of free fall acceleration, which is the same for all falling objects near the Earth's surface, regardless of the object's mass, if air resistance is not considered.
KC1 / KC5 4.2.b	Describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance.	• Practical work to investigate the motion of a small weight falling with a paper or polythene parachute. • Time a paper cone of different base area by increasing the overlap (constant mass) to see how the terminal velocity depends on the area. • Time increasing numbers of paper cake cases to see how terminal velocity depends on mass. • Demonstrations could include a ball bearing falling through a viscous liquid such as glycerol, or the 'guinea and feather' experiment if the apparatus is available or watch on YouTube. • **Extension activity:** Draw sketch velocity-time graphs to show a body reaching terminal velocity. Learner to explain in terms of forces and draw force diagrams at each key stage in the fall. • **Extension activity:** Abler learners could develop this to look at what happens to a skydiver who then opens a parachute and reaches a new, slower terminal velocity. **Note:** Learners must understand the following ideas: • The forces acting on a falling object are weight and air resistance • Air resistance increases with speed, while the weight stays the same • As speed increases, the resultant force decreases, so the acceleration decreases • When the speed is reached where the air resistance is equal and opposite to the weight, the acceleration is zero, and the object falls with *terminal velocity.* • The magnitude of the terminal velocity depends on the nature of the falling object and the density of the medium. http://www.tap.iop.org/mechanics/drag/209/page_46353.html http://www.grc.nasa.gov/WWW/K-12/airplane/termv.html http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_07/Mechanics_Page_7.htm http://www.youtube.com/watch?v=zXDZWKmRxI0 Guinea and feather experiment
KC1 / KC3 / **KC5** 5.1.a	Describe the forces on a mass in a uniform gravitational field and on a	• Ask learners what they think an electric field is. • Ask learners to describe what happens when a mass is released from rest in a gravitational field. Then ask them to do the same for a charged particle released from rest in an electric field.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	charge in a uniform electric field.	• Learners study the relevant sections in a textbook on gravitational fields and electric fields and answer relevant questions. **(I)** **Note:** • You need to be sure that learners understand that uniform gravitational fields lead to forces on other masses which are always attractive, constant (regardless of the speed of movement of the mass), and equal to *mg.* Uniform electric fields lead to forces on other charged particles which can be either attractive or repulsive. These forces, too, are constant and are equal to *Eq*. • Learners should also appreciate that a uniform gravitational field is an approximation which can be realistically applied near the surface of a very large spherical object such as a planet or moon. However, uniform electric fields can easily be set up in a laboratory by applying a potential difference between two parallel conducting plates. http://www.physicslab.co.uk/forces.htm
KC5 17.1.a	Understand the concept of an electric field as an example of a field of force and define electric field strength as force per unit positive charge acting on a stationary point charge.	• Discuss: What do electric fields exert forces on? What do gravitational fields exert forces on? • Learners draw up a table of the similarities and the differences between gravitational and electric fields. They can begin this by comparing the definitions of electric and gravitational field strengths, noting the similarity; the symbols used (*E* and *g* respectively) must also be made clear. Remind learners of the vector nature of *E* and *g*. **Note:** • Before starting work on electric fields, revise learners' previous knowledge of static electricity, charged particles and the concept of discharging by connecting to earth**.** A practical demonstration to remind them of the principles illustrated with the Van der Graaf generator and the experiments associated with it would make an enjoyable and constructive introduction to the work to follow on electric fields. http://www.s-cool.co.uk/a-level/physics/current-charge-and-voltage/revise-it/the-basics-and-the-conservation-of-charge http://www.physicslab.co.uk/pfield.htm
KC1 / KC5 17.1.b	Represent an electric field by means of field lines.	• Learners predict and draw the shape of the electric field around a point charge and between two parallel plates. • **Extension activity:** Expand to include attracting and repelling charges, a pint charge and a flat plate. **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Draw out the ideas of radial and uniform fields, the field lines reaching the surface of the object at 90°. Go through the need for an arrow on the field line to show the direction of the force on a positive charge. Learners should be aware of radial and uniform fields. You could expand this to cover gravitational fields too. http://www.physicsclassroom.com/Class/estatics/u8l4c.cfm http://www.s-cool.co.uk/a-level/physics/electric-fields-and-forces/revise-it/electric-field-strength-e
KC1 / KC3 / KC5 17.2.a	Recall and use $$E = \frac{\Delta V}{\Delta d}$$ to calculate the field strength of the uniform field between charged parallel plates in terms of potential difference and separation.	• Learners derive this expression. Having established the definition of electric field strength as $$E = \frac{F}{Q}$$ (compare this to the definition of gravitational field strength, *g*). Hint that they need to think about the work done by the field in moving a charge *Q* from the positive to the negative plate (distance *d*). They will also need to recall the definition of potential difference which they will not have met since GCSE / O Level. • Learners show the two units are identical: that $N\ C^{-1}$ is equivalent to $V\ m^{-1}$ and also the equivalence of $N\ kg^{-1}$ and $m\ s^{-2}$ in the gravitational case. • Worksheet (and mark scheme) of practice examples prepared by you. **(I)** http://www.tap.iop.org/fields/electrical/409/page_46894.html http://www.physicslab.co.uk/Efield.htm
KC3 / KC5 17.2.b	Calculate the forces on charges in uniform electric fields.	• Worksheet (and mark scheme) prepared by you of practice questions including examples where learners have to rearrange the defining equation for electric field strength to the form $F = EQ$. **(I)**
KC1 / KC5 17.2.c	Describe the effect of a uniform electric field on the motion of charged particles.	• Provide learners with two diagrams: a mass falling in a gravitational field and a charged particle projected horizontally into a vertical electric field. Ask them to come up with similarities and differences. • Discuss the forces and hence motion on the charged particle both horizontally and vertically. **Note:** • Remind learners of the effect on a mass of being in a state of free fall in a uniform gravitational field. By comparison, they should be able to envisage a similar motion of a 'falling' charged particle in a

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		uniform electric field; acceleration under a constant force, and perhaps reaching terminal velocity if falling through air. • Another situation requiring study is the case of a beam of charged particles entering the region between plates at right angles to the field between the plates. Learners should look back at their work on projectiles in gravitational fields and remind themselves of the idea of dividing the motion into components which are perpendicular and parallel to the field. The outcome in the electrical case is similar; a parabolic path with constant speed perpendicular to the field and accelerated motion parallel to it. http://www.physicslab.co.uk/qpaths.htm http://www.antonine-education.co.uk/Pages/Physics_4/Fields/FLD_04/Fields_4.htm
KC1 / KC5 4.3.a	State the principle of conservation of momentum.	• Introduce this law by looking at some real examples, for example snooker ball collisions, Newton's cradle, car crashes. When one body loses momentum, the other one gains it. • **Extension activity:** Experimental verification using a linear air track with timers and light gates, colliding trolleys and motion sensors. • **Extension activity:** Abler learners can derive the law, starting from Newton's Third Law of Motion. **Note:** • The law needs to be stated by learners in terms of a collision and a 'closed' system where no external forces are acting. They must appreciate that, in reality, there is nearly always an external force, such as friction, which can make it appear as though the law is not being adhered to. http://www.s-cool.co.uk/a-level/physics/momentum-and-impulse/revise-it/principle-of-the-conservation-of-momentum http://www.physicslab.co.uk/bump.htm http://www.physicsclassroom.com/class/momentum/u4l2b.cfm
KC1 / KC3 / KC5 4.3.b	Apply the principle of conservation of momentum to solve simple problems, including elastic and inelastic interactions between bodies in both one and two dimensions	• Demonstrate and then discuss different types of collision, e.g. equal mass, bodies coalescing, explosions. Define elastic and inelastic collisions. • Worksheet (and mark scheme) prepared by you on two levels to apply the law to calculations of many types. **(I)** **Note:** • The difference between elastic and inelastic collisions will need to be established, and it should be recognised by learners that nearly all real-life collisions are inelastic to a lesser or greater extent

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	(knowledge of the concept of coefficient of restitution is not required).	because some of the kinetic energy of the colliding objects is almost always transformed into other forms. A distinction should be made between *totally* inelastic and *partially* inelastic collisions. http://www.tap.iop.org/mechanics/momentum/220/page_46435.html http://www.tap.iop.org/mechanics/momentum/221/page_46450.html
KC1 / KC3 / KC5 4.3.c	Recognise that, for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation.	• Discuss what relative speed is and practise some basic examples. • **Extension activity:** Abler learners derive this from conservation of momentum and conservation of kinetic energy. • **Extension activity:** Worksheet (and mark scheme) prepared by you of examples to apply this relationship. **(I)** **Note:** • Emphasise that this relationship is for elastic collisions only. http://www.s-cool.co.uk/a-level/physics/momentum-and-impulse/revise-it/types-of-collisions http://hyperphysics.phy-astr.gsu.edu/hbase/colsta.html
KC1 / KC2 / KC3 / KC5 4.3.d	Understand that, while momentum of a system is always conserved in interactions between bodies, some change in kinetic energy may take place.	• Practical work with the air track or colliding trolleys to see how much kinetic energy is lost in the collision. Can changes be made to increase or decrease the loss? • Examples where the KE is calculated before and after the collision. **(I)** • Worksheet (and mark scheme) prepared by you. **(I)** **Note:** • Learners should consider, in a variety of collisions, the conservation of momentum (always conserved), total energy (always conserved) and kinetic energy (not conserved except in elastic collisions). Although some collisions (such as the bouncing of a ping-pong ball) may appear to be elastic, careful measurement would show that this is not the case. • There are some mathematical traps learners can fall into here, with subtracting velocities before squaring them. You may need to show the difference results with the correct and incorrect approaches.

Past and specimen papers

Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

3: Forces, work and materials

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

KC1 / **KC5**
5.1.b
	Understand the origin of the upthrust acting on a body in a fluid.	• Experiment to measure the upthrust on a metal weight and other objects when immersed in water in a measuring cylinder.
		• Learners should analyse several upthrust situations:
		  ○ An empty, sealed water bottle is held so that it is completely immersed in water
		  ○ A ship floating on the sea
		  ○ A hot air balloon rising upwards
		  ○ A falling brick
		  ○ A submarine remaining at a fixed distance below the surface of the sea
		The relative sizes of the forces should be considered by learners for each of these.
		
		Note:
		At the start, it is a good idea to make sure that learners appreciate that a fluid can be either a gas or a liquid, and that any object immersed in a fluid experiences an upward force called *upthrust*. They should be careful not to confuse this force with *thrust*, which is the name often given to the force supplied to a rocket by its engine. The origin of upthrust forces should be discussed with learners in terms of the pressure difference of the fluid on the upper and lower surfaces of the object.

KC5
5.1.c
	Show a qualitative understanding of frictional forces and viscous forces including air resistance (no treatment of the coefficients of friction and viscosity is required).	• Discuss situations when friction is a problem and conversely when it is essential. **(W) (Basic)**
		• Learners should consider these situations:
		  ○ The brakes of a bicycle causing speed to be reduced when travelling downhill
		  ○ Pushing a large box across i) a very rough floor, ii) a smooth floor
		  ○ Walking or running i) normally, ii) on a very slippery surface
		  ○ A ball bearing falling through a very viscous liquid
		  ○ The factors affecting the terminal velocity of a free falling object
		  ○ Imagine a world where friction didn't exist!
		In each case, they should analyse the part played by friction or viscous forces and write down the reasons why friction or viscosity is important, and whether it is a problem or a necessity. **(P) (Basic)**
		
		Note:
		You will need to establish that learners understand friction as a force which opposes the motion of two surfaces over one another, and always acts along a surface in the direction opposite to movement (attempted or actual movement), never at an angle to the surface. They should understand viscous forces (or drag forces) as a particular case of friction when an object moves through a fluid.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Practical booklet 3
KC1 / KC5 5.1.d	Understand that the weight of a body may be taken as acting at a single point known as its centre of gravity.	• Experiment to find the centre of gravity of an oddly shaped piece of cardboard, using a plumb-line, stand and clamp, cork and supporting pin. Test the centre of gravity by seeing whether the card will balance when supported on the end of a pin placed at that point. **(I)** **Note:** • Learners should recognise that although all parts of the card possess weight, some problems can be solved more easily by assuming that all the weight acts downwards from this particular point. • Learners should also be aware of where the centre of gravity is for shapes with uniform weight distribution, such as circles, squares, rectangles and triangles. **Practical booklet** 6 http://www.s-cool.co.uk/a-level/physics/moments-couples-and-equilibrium/revise-it/centre-of-gravity-and-centre-of-mass
KC1 / KC2 / KC5 5.2.a	Define and apply the moment of a force.	• Discuss in pairs the occasions when they have applied a force to something which resulted in a turning motion today, and make a list. The suggestions could be brought together to make a longer group list. Examples could include turning on a tap, or opening or closing a door. • Demonstrate that the turning effect depends on both the magnitude of the force applied and the distance of its point of application from the pivot with a simple experiment using a newton meter to open a door at different distance from the pivot. An alternative is to rotate a retort stand from lying down to horizontal. Calculate the moment at each distance to show it is the same. • Worksheet (and mark scheme) prepared by you with many examples, including where the force is not applied perpendicularly so that trigonometry needs to be used. **(I)** **Practical booklet** 1 http://www.tap.iop.org/mechanics/static/203/page_46264.html
KC3 / KC5 5.2.b	Understand that a couple is a pair of forces that tends to produce rotation only.	• **Extension activity:** Discuss how, for example, a screwdriver or bicycle handle bars work. Two forces of equal size in opposite directions. • Show a picture of an object with a couple acting on it. Discuss if is it in equilibrium.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• **Extension activity:** Examine the differences between the moment of a single force and the moment produced by a couple. http://www.s-cool.co.uk/a-level/physics/moments-couples-and-equilibrium/revise-it/couples
KC3 / KC5 5.2.c	Define and apply the torque of a couple.	• Illustrate the torque of a couple by taking moments for a body with a couple acting on it about a number of places, for example where one force acts, on the line joining the two forces, along the same line but outside of the object entirely. Show that the torque is always the same. • Worksheet (and mark scheme) prepared by you of examples to practise the idea of the torque of a couple. **(I)** **Note:** • As mentioned for learning objective 5.2.b, there needs to be a clear distinction made between the case of a single turning force which has a *moment* about a pivot, and a couple, which always consists of two forces, equal and opposite, which produce a *torque.* • Torque (of a couple) should be defined carefully, and learners should ensure they are using the correct wording.
KC1 / KC3 / KC5 5.3.a	State and apply the principle of moments.	• Experiment to verify the principle of moments using a metre rule pivoted at the centre and various weights suspended from it on either side**.** • Experiment to investigate how the support forces for a metre rule suspended on two newton meters changes as the load changes position between them. This can be analysed to find the unknown weight of the load by using a formula derived from taking moments about one support and the gradient of the graph. • Worksheet (and mark scheme) prepared by you in two levels to practise all ideas linked to moments. **(I)** **Practical booklet** 1 http://www.s-cool.co.uk/a-level/physics/moments-couples-and-equilibrium/revise-it/the-principle-of-moments http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_03/Mechanics_Page_3.htm
KC1 / KC3 / KC5 5.3.b	Understand that, when there is no resultant force and no resultant torque, a system is in equilibrium.	• Discuss what learners understand by equilibrium. • Worksheet (and mark scheme) prepared by you of pictures with forces to analyse to see if the object is in equilibrium or not.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Note: Learners need to arrive at the conclusion that equilibrium describes a situation where there is no resultant force in any direction *and* no resultant torque about any point. Only then can we say that the system is in equilibrium; the word is used only for this specific situation. http://www.tap.iop.org/mechanics/static/202/page_46254.html http://www.s-cool.co.uk/a-level/physics/moments-couples-and-equilibrium/revise-it/equilibrium-conditions
KC1 / KC3 5.3.c	Use a vector triangle to represent coplanar forces in equilibrium.	• Recap the idea of a vector triangle. Check learners know what 'coplanar' means. • **Extension activity:** Demonstration of the use of a vector triangle can be set up using three weights and two pulleys, with a board placed immediately behind the threads suspending the weights, on which the directions of the threads can be marked to enable measurement of the relevant angles. • Practise drawing and solving problems from vector triangles, for example. **(I)** http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_02/Mechanics_Page_2.htm
KC1 / KC3 5.4.a	Define and use density.	• Brainstorm what 'density' means in a scientific context. • Learners research the density of given objects, or try to find the range of densities in the universe, or look at how the density of liquids and gases can change with temperature and pressure. • Practise applying the density equation to problems. **(I)** • You could use a displacement of water method to find the density of some irregular solids. http://www.s-cool.co.uk/a-level/physics/stress-and-strain/revise-it/density http://www.antonine-education.co.uk/Pages/Physics_2/Solid_Materials/MAT_01/materials_page_1.htm

KC1 / KC3 / KC5
5.4.b
	Define and use pressure.	• Learners asked to explain
		  ○ why it is easy to push a drawing pin into a cork board, but very difficult to push the unsharpened end of a pencil into the same board
		  ○ why it would be very uncomfortable to pick up a heavy case using a single piece of string, but much less painful to use a much thicker handle.
		• Experiment to measure their pressure when standing on the ground. Find their weight in newtons, and draw round their feet while standing on a sheet of graph paper. Find the area by counting squares, and convert to square metres; a good opportunity to practise converting square units.
		
		http://www.s-cool.co.uk/a-level/physics/forces/revise-it/pressure

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC3 / KC5 5.4.c	Derive, from the definitions of pressure and density, the equation $\Delta p = \rho g \Delta h$.	• Given the two definitions, challenge learners to carry out this derivation. You could give them a hint about considering the weight of a column of liquid at distance *h* below the surface.
KC1 / KC3 / KC5 5.4.d	Use the equation $\Delta p = \rho g \Delta h$.	• Practise using this relationship, noting that it is used for calculating the pressure at a certain depth in a fluid of density ρ. **(I)**
KC1 / **KC4** 6.1.a	Give examples of energy in different forms, its conversion and conservation, and apply the principle of conservation of energy to simple examples.	• Use pictures to reinforce the important types of energy and straightforward conversions, e.g. in the generation and distribution of electrical energy. • Learners to show that the unit of energy, the joule is the same as the N m. **(I)** http://www.s-cool.co.uk/a-level/physics/work-energy-and-efficiency
KC1 / **KC4** 6.2.a	Understand the concept of work in terms of the product of a force and displacement in the direction of the force.	• Brainstorm what the word '*work*' means. Point out to learners that the word is used in a variety of often vague ways in everyday speech but has a very specific meaning in physics. • Worksheet (and mark scheme) prepared by you to show use of the formula. Include examples where the force needs to be resolved to be in the same direction as the distance. **(I)** • Work through examples from the three webpages given. **(I)** **Note:** • Although force and displacement are vector quantities, work is a scalar and therefore has no direction • The unit of work can be expressed as N m, which is the same unit as that for the moment of a turning force, so confusion needs to be avoided • Work can also be described as the amount of energy transferred or transformed, although this is not a formal definition. • Distinguish between work done by a force (positive work) and work done on a on a force (negative work). http://www.tap.iop.org/mechanics/wep/215/page_46398.html http://www.tap.iop.org/mechanics/wep/214/page_46390.html http://www.tap.iop.org/mechanics/wep/216/page_46406.html

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC3 / **KC4** 6.2b	Calculate the work done in a number of situations including the work done by a gas that is expanding against a constant external pressure: $W = p\Delta V$.	• Derive the equation $W = p\Delta V$ and use it in exercises, noting that when a gas expands, work is done *by* the gas; if it contracts, then another agency must be doing work *on* the gas. • Worksheet (and mark scheme) prepared by you in two levels applying this in different situations. **(I)** • Learners read and make note of when work is and is not done from examples in textbook. **Note:** • Ensure that W, p and ΔV are all in the correct units when carrying out calculations using this formula.
KC1 / KC3 / KC4 6.2c	Recall and understand that the efficiency of a system is the ratio of useful energy output from the system to the total energy input.	• Learners construct Sankey diagrams and use them to illustrate a particular energy transformation. Compare CFL energy saving bulbs with incandescent bulbs and LEDs. **(I)** • Use the efficiency relationship to solve problems and work out efficiency from Sankey diagrams. **(I)** **Note:** Learners need to appreciate the following: • In nearly all energy changes, some of the input energy is converted to heat energy which is dissipated into the surroundings (i.e. 'wasted'). • It is incorrect to refer to energy being 'lost' or 'used up' as heat, because the principle of conservation of energy states that energy is never destroyed. • Efficiency of a device or system is calculated as *useful* work done / *total* energy input. • Efficiency can be expressed as a ratio (must be less than 1) or a percentage (less than 100%). • Energy cannot be created, so efficiency can never be greater than 100%. • Energy transfers can be best represented pictorially using Sankey Diagrams. Some practice in drawing and using them will probably be necessary. **Practical booklet** 5 http://www.tap.iop.org/mechanics/wep/217/page_46414.html http://www.physicslab.co.uk/work.htm http://www.cyberphysics.co.uk/general_pages/sankey/sankey.htm http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_11/Mechanics_Page_11.htm
KC1 / KC3 / KC4 6.2d	Show an appreciation for the implications of energy losses in practical devices and use the concept of	• Carry out an experiment to determine the efficiency of an electric motor using a joulemeter (or ammeter and voltmeter), a low voltage motor, thread and pulley, weights, a stop clock or timer and a meter rule. • Worksheet (and mark scheme) prepared by you or from textbook. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	efficiency to solve problems.	**Practical booklet** 5
KC3 6.3a	Derive, from the equations of motion, the formula for kinetic energy $E_K = ½mv^2$.	• **Extension activity:** Learners can derive this relationship using $v^2 = u^2 + 2as$ and $F = ma$, but may need assistance. • Reinforce ideas from Unit 1 concerning the homogeneity of equations.
KC3 6.3b	Recall and apply the formula $E_K = ½mv^2$.	• Worksheet (and mark scheme) prepared by you in two levels so learners practise using the relationship to find the translational kinetic energy of a variety of moving objects, or the mass or the speed. **(I)** **Note:** • Those whose mathematical skills are not so strong may need to be warned against squaring *m* as well as *v*.
KC1 / KC4 **6.3c**	Distinguish between gravitational potential energy and elastic potential energy.	• Brainstorm what potential means. Have some prepared pictures to pick out those which show potential energy. Draw out the differences between GPE and EPE. • Learners should study the two main sections of the suggested webpage and use the 'Check your Understanding' section. **(I)** **Note:** • There are many ways in which energy may be stored, and learners should appreciate the situations where each arises. For example, elastic potential energy is stored in objects which have had their shape changed elastically, and gravitational potential energy is stored in objects which have been moved away from the source of a gravitational field. Learners should be aware of other frequently encountered kinds of potential energy, most notably electrical PE (for example in batteries) and chemical PE (in fuels and food). http://www.physicsclassroom.com/Class/energy/u5l1b.cfm
KC1 / KC3 / KC4 / KC5 6.3d	Understand and use the relationship between force and potential energy in a uniform field to solve problems.	• Prepare examples on this. Explore the link between GPE and work done. **(I)** • Plot ΔE_P against Δh for an object near the Earth's surface, using a table of appropriate data (pre-prepared). Repeat using similar data for an object on the moon. Note that these graphs are straight lines, and answer the question 'what does the gradient represent?' **(I)** **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Learners should develop an understanding that, for any object to increase its potential energy in any of the forms discussed in the previous section, work must be done on it by a force. In the case of a mass in a uniform gravitational field, its gravitational potential energy can be increased by an external force which does work on the mass by lifting it to a greater height in the field. • Having established that the gradient represents the gravitational force on the object (above), learners will be in a position to appreciate that a steeper gradient (i.e. a more rapid rate of increase of GPE with height) is associated with a larger gravitational force (i.e. larger weight). http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_12/Mechanics_page_12.htm
KC3 6.3e	Derive, from the defining equation $W = Fs$, the formula $\Delta E_P = mg\Delta h$ for potential energy changes near the Earth's surface.	• Learners derive the formula for gravitational potential energy. • Discuss what the 'Δ' means and why it is important.
KC1 / **KC3** / KC4 / KC5 6.3f	Recall and use the formula $\Delta E_P = mg\Delta h$ for potential energy changes near the Earth's surface.	• Worksheet (and mark scheme) prepared by you to practise using this formula. Practise rearranging the formula. Include examples from different planets. **(I)** • **Extension activity:** Apply conservation of energy to objects in freefall, $\frac{1}{2}mv^2 = mgh$. Calculate height or speed or other quantity in the equation. **(I)** • **Extension activity:** Discuss how air resistance alters this relationship and how to include its effect in the conservation of energy equation. • Worksheet (and mark scheme) prepared by you to practise these conservation ideas. **(I)** **Note:** • At this stage, it would be a good idea if you directed learners' attention towards the particular case of the energy conversions taking place for an object in free fall. If air resistance is ignored, the loss in gravitational potential energy can be equated to the gain in kinetic energy at any point in the fall. They should also give the *reasons* for the changes (e.g. GPE decreases because of the reduction in height, and the kinetic energy increases due to the greater speed of fall). With air resistance, mention must be made of some GPE being converted to thermal energy, since work is done against the air resistance force; the loss in GPE is then equal to the gain in kinetic energy + the gain in thermal energy. • When learners complete practice questions and exercises using this relationship, they should always include the Δ symbols when quoting the equation. They should also note carefully that the

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		equation is only applicable near the surface of a planet or moon, where the strength of the gravitational field may be taken as constant. **Practical booklet 5** http://www.physicsclassroom.com/Class/energy/u5l2a.cfm
KC3 6.4a		• Discuss what power means, where the word is used in everyday life, its specific use in physics. Power is a scalar quantity. Define power as work done per unit time. • Learners should investigate the link between the watt and the joule. • Practical work to measure personal power when walking up stairs. • Derive *power* = *force* × *velocity* for a force moving at constant velocity, for example a car travelling at constant velocity doing work against air resistance. • Worksheet (and mark scheme) prepared by you on these ideas. **(I)** **Note:** • Learners need to be careful not to use confusing language when describing the power in physical situations. It is common in everyday language to refer to a strong person as 'powerful' but in physics, force and power are not the same. Large forces may be exerted in some situations with no resulting movement, in which case no work is done and the power is zero. An example is the force which a large building exerts on its foundations. http://www.tap.iop.org/mechanics/wep/218/page_46422.html http://www.antonine-education.co.uk/Pages/Physics_2/Mechanics/MEC_10/Mechanics_Page_10.htm
KC1 / KC3 / KC4 6.4b	Solve problems using the relationships $P = W/t$ and $P = Fv$.	• Worksheet (and mark scheme) prepared by you using these formulae. Include examples where the power is given in MW, kW and mW. **(I)** **Note:** • Learners should recognise that the equations for *electrical* power (where electrical energy is being converted to other forms) are not the same as these; they will be dealt with in Units 10 and 11.
KC1 / KC5 9.1a	Appreciate that deformation is caused by a force and that, in one dimension, the	• Learners look at a mass on a spring and discuss the terms load, extension and deformation. Then look at a wire and a metal cylinder. Will these materials show deformation? Discussion should lead to the conclusion that a force applied to any solid body produces some deformation, even if it is very small. • Discuss tensile and compressive load with reference to a compressible spring.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	deformation can be tensile or compressive.	
KC2 / KC3 / KC5 9.1b	Describe the behaviour of springs in terms of load, extension, elastic limit, Hooke's law and the spring constant (i.e. force per unit extension).	• Experiment to investigate how the extension of a spring depends on the load applied. Equipment required: suitable spring, weights, rule or scale, support, data table for force-extension graph where the elastic limit has been exceeded. • Plot a load extension graph; find the gradient which is the spring constant. **(I)** • Discuss Hooke's law and the elastic limit. Perhaps use an expendable spring and further practical work to investigate what happens to the shape of the graph or use provided data to do the same. **Note:** • You may need to specify the maximum load which should be applied, to ensure that the springs used are not stretched beyond the elastic limit! • Check that learners are plotting the *total* extension for each point, and not just the increase in length from one reading to the next. • The *spring constant* is sometimes called the *force constant* or *stiffness* for that particular spring**.** • This might be a good opportunity to revise the mathematical ideas of proportionality between variables and the role of the constant of proportionality. • Learners need to appreciate that beyond the elastic limit the graph is no longer a straight line. • Additional experiments could be carried out using two identical springs, firstly in series and secondly in parallel, and the new spring constants compared with the value for the single spring. **Practical booklet** 1 http://www.tap.iop.org/mechanics/materials/227/page_46508.html http://www.s-cool.co.uk/a-level/physics/deformation-of-solids/revise-it/hookes-law
KC1 / KC3 / KC5 9.1c	Define and use the terms stress, strain and the Young modulus.	• Discuss how spring constant varies for a spring of the same material but with different dimensions. Lead on to introduce stress, strain and the Young modulus and how this is a material constant. • Worksheet (and mark scheme) prepared by you to use these three formulae. **(I)** • Learners research the value of the Young modulus for some well-known materials. **Note:** • Stress should be labelled as tensile or compressive, and the units can be N m^{-2} or Pa. • Strain should also be labelled as tensile or compressive, and learners need to be clear that this is a ratio with no units.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Strain can be expressed as a decimal or as a percentage. • The Young modulus can only be applied when Hooke's law is obeyed. • The Young modulus is better than the spring constant for finding unknown extensions because it is a constant for a particular material which does not vary from specimen to specimen. • Units of the Young modulus are: Pa or N m^{-2} (the same as for stress). • Make sure learners become familiar with the sizes of the numbers for stress, strain and the Young modulus. • Draw attention to pitfalls in calculating, for example cross section area of a wire: diameter to radius, mm to m. http://www.tap.iop.org/mechanics/materials/228/page_46520.html http://www.antonine-education.co.uk/Pages/Physics_2/Solid_Materials/MAT_01/materials_page_1.htm http://www.s-cool.co.uk/a-level/physics/stress-and-strain
KC2 / KC5 9.1d	Describe an experiment to determine the Young modulus of a metal in the form of a wire.	• Experiment to measure the Young modulus. Plot a stress strain graph (or force extension), find the Young modulus. Compare with the data book value. **(I)** **Note:** • Copper is a good metal to use for this because it produces relatively large extensions on either side of the elastic limit. • Learners should wear eye protection in case the wire snaps, and they should consider why it is better to use a thin wire and a long length. • Look at the Searle's experiment method if you do not have the apparatus available. http://physicsnet.co.uk/a-level-physics-as-a2/materials/young-modulus/
KC1 / KC5 9.2a	Distinguish between elastic and plastic deformation of a material.	• Show graphs for the different types of deformation. Identify what elastic and plastic deformation are and identify how different material behave. • Brief experimental work with rubber bands and strips of plastic bag. • Learners construct a table to compare the different deformation graphs. **Note:** • It is important for learners to realise that the results of an experiment such as this can be represented either on a force-extension graph, or (better) on a stress-strain graph, from which the Young modulus of the material can be found directly. They need to note carefully which kind they are dealing with when approaching a graphical problem. The shape of these graphs varies greatly

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		from material to material; for example, the shape for a brittle material will be very different from that for a ductile material, and so will the extent of the elastic and plastic sections. http://www.tap.iop.org/mechanics/materials/229/page_46534.html
KC1 / KC3 / KC4 / KC5 9.2b	Understand that the area under the force-extension graph represents the work done.	• Analyse the units of force and extension to show that the area under the graph has the unit of the joule. • Worksheet (and mark scheme) prepared by you using this relationship. Include non-linear graphs. **(I)** **Note:** • The idea from Unit 1 of finding another quantity from the area under a graph line may need revision. • Learners need to appreciate that since the stretching force is variable, the area is given by $W = ½Fe$, where F is the *maximum* force applied and e is the extension, the equivalent calculation would then be: *Work done = average force × total extension produced* • This relationship only applies when the force-extension graph is linear, but the work done in deforming is still given by the area under the line if the graph is curved. • Learners should be able to show that the equation $W = ½Fe$ can be used in a different form: Since $F = kx$ (Hooke's law) then $W = ½(kx)x$ so $W = ½kx^2$ Where $x = e$ = extension; either symbol can be used. k is the spring constant (or force constant or stiffness) for that sample of material. http://www.s-cool.co.uk/a-level/physics/deformation-of-solids/revise-it/energy-in-deformations
KC1 / KC3 / KC4 / KC4 9.2c	Deduce the strain energy in a deformed material from the area under the force-extension graph.	• Introduce using the example of a bow and arrow: the elastic is strained by the force applied by the archer. When released, the stored energy is transferred to the arrow in the form of kinetic energy. • Practice questions using a worksheet (and mark scheme) prepared by you, or from a textbook, to enable learners to gain confidence in using this concept. **Note:** • Learners must develop an appreciation of the idea of strain energy, or elastic potential energy, and realise that the work done by the deforming force is equal to the strain energy stored in a deformed object. The strained object can then do work on something as it returns to its original shape when the force is removed.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.tap.iop.org/mechanics/materials/229/page_46534.html

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

4: Waves

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / **KC4** 14.1a	Describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks.	• Discuss waves on the sea; demonstrate waves in ropes and slinky springs. • You can demonstrate the ripple tank as a piece of apparatus in which waves can be seen and analysed visually and in more detail. **Note:** • Learners need to understand from this initial work that waves are a means of transferring energy by vibrations (or oscillations) without permanent displacement of the medium (this word will probably need explaining) if there is one. http://www.tap.iop.org/vibration/progressive/309/page_46635.html http://www.physicslab.co.uk/twave.htm

KC1 / KC4
14.1b
	Understand and use the terms, displacement, amplitude, phase difference, period, frequency, wavelength and speed.	• Group work looking at displacement distance and displacement time graphs of waves. Label as relevant. Define the other wave terms.
		• Work out the phase difference between two waves on some prepared examples.
		Note:
		• A sinusoidal wave can be demonstrated on the screen of a c.r.o. and the use of the term 'sinusoidal' can be linked to the shape, which they may or may not have met previously, both in a mathematical and a physical context. You will need to make it clear that this is not the only shape (or 'profile') it is possible for waves to have; square waves and triangular (or 'saw-tooth') waves can be generated from many signal generators. It should be emphasised, however, that the sinusoidal shape is by far the most common in nature, and that many waves possess this profile.
		• The meaning and definition of these terms must be clear to learners:
		  ○ Displacement *x* and amplitude *A* (make sure they understand clearly the distinction between these two terms as there is a frequent tendency to confuse them)
		  ○ Frequency *f* and period *T*, linked by the relationship
		$$f = \frac{1}{T}$$
		  ○ Wavelength λ and the concept of a 'wavefront' (easily demonstrated in a ripple tank)
		  ○ Speed of the wave in the medium *v* (or *c* in the case of electromagnetic radiation in a vacuum)
		  ○ Phase difference/phase angle between two points on a wave and between two continuous waves

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• The concepts of phase difference and phase angle will require additional work. Although not strictly required for AS Level, an introduction could be given to measuring angles in radians. At this stage, learners can think of radians as another unit for angles (it will be defined at another point in the course). http://www.tap.iop.org/vibration/progressive/310/page_46654.html http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/wavplt.html http://whatis.techtarget.com/definition/phase http://www.antonine-education.co.uk/Pages/Physics_2/Waves/WAV_01/Waves_Page_1.htm
KC3 / KC4 14.1c	Deduce, from the definitions of speed, frequency and wavelength, the wave equation $v = f\lambda$.	• A worksheet prepared by you to help learners through this derivation. Ask for the definition of speed at the start, then wavelength, time period and finally frequency. A successful group could feedback to the others. http://www.tap.iop.org/vibration/progressive/311/page_46661.html
KC3 / KC4 14.1d	Recall and use the equation $v = f\lambda$.	• Worksheet (and mark scheme) prepared by you with plenty of practice examples. These should include cases where the wavelength is given in cm or nm, for example, needing conversion, and the frequency is given in kHz, MHz or GHz. **(I)**
KC1 / **KC4** 14.1e	Understand that energy is transferred by a progressive wave.	• Experiment to observe how particles in a wave oscillate only and do not move along with the wave. For example, tape or ribbon on a turn of the slinky spring or tied to the rope. **Note:** • The term 'progressive' as applied to a wave will need clarification; a distinction should be made between this and a 'stationary' wave, which will be discussed later. This would be an opportunity for you to reinforce the idea that a wave transfers energy, but not matter. The word 'propagation' as applied to a wave's transfer of energy could be introduced to learners at this point.
KC1 / KC3 / KC4 14.1f	Recall and use the relationship *intensity* $\propto$ (*amplitude*)^2.	• Brainstorm ideas on what 'intensity' means. The discussion should lead to the conclusion that it is the power incident on a surface per unit area, in W m^{-2}. • **Extension activity:** Learners need to practise using this relationship and they should develop an appreciation of the meaning of 'wave intensity' as power per unit area. **(I)** **Note:** • Learners will be able to understand from everyday experience that the intensity of any wave decreases as distance from the source increases. You can demonstrate this by considering with

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		them a suitable diagram showing that the intensity is in fact proportional to $1/x^2$. This could be the opportunity for a first introduction to the idea of an 'inverse-square' law. • Take care not to confuse the relationship between intensity and amplitude ($I \propto A^2$) with an 'inverse-square' relationship ($I \propto 1/x^2$). http://hyperphysics.phy-astr.gsu.edu/hbase/forces/isq.html
KC1 / **KC4** 14.2a	Compare transverse and longitudinal waves.	• Learners build a table to compare and contrast transverse and longitudinal waves, including key words and giving examples of each. • Demonstrate the difference between both types of wave using a slinky. http://www.tap.iop.org/vibration/progressive/309/page_46635.html http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html http://www.antonine-education.co.uk/Pages/Physics_2/Waves/WAV_02/Waves_Page_2.htm
KC1 / **KC4** 14.2b	Analyse and interpret graphical representations of transverse and longitudinal waves.	• Discuss how both transverse and longitudinal wave can be represented graphically. Draw out that the *x*-axis can be either time or distance. Gather ideas for what the *y*-axis could represent. • Look at prepared graphical examples to work out amplitude, time period, frequency, wavelength, wave speed etc. **(I)** • Worksheet (and mark scheme) prepared by you or from a textbook. **(I)** **Note:** Transverse waves: • Displacement (y-axis) against distance or time (x-axis). Learners must take care to note which quantity is plotted on the horizontal axis before analysing Longitudinal waves: • Displacement at a point is represented in terms of compressions and rarefactions, along the direction of travel • Alternatives would be to plot the pressure difference from the normal against either distance or time http://www.tap.iop.org/vibration/progressive/310/page_46654.html http://www.s-cool.co.uk/a-level/physics/progressive-waves/revise-it/progressive-waves
KC2 / KC3 / KC4 14.3a	Determine the frequency of sound using a	• Demonstrate how the c.r.o. can be used to show waveforms and how to take relevant measurements to determine the frequency of sound.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	calibrated cathode-ray oscilloscope (c.r.o.).	• If apparatus is available learners use the c.r.o. with a signal generator or source of sound (e.g. a tuning fork or a signal generator connected to a loudspeaker) oscilloscope and a microphone to gather their own data. • **Extension activity:** Use the interactive online oscilloscope and a worksheet prepared by you so learners can work out the frequency of the signal provided. **(I)** http://www.tap.iop.org/electricity/emf/122/page_46061.html http://www.doctronics.co.uk/scope.htm http://www.virtual-oscilloscope.com/
KC1 / **KC4** 14.4a	Understand that when a source of waves moves relative to a stationary observer, there is a change in observed frequency.	• Show a video clip of the Doppler effect and discuss why the pitch of the note changes. Link pitch to frequency. This could also be linked to 'red-shift' at this stage. **Note:** Learners will have experienced the Doppler effect with sound, e.g. the siren of an emergency vehicle approaches and then recedes. A discussion of this, along with a video to demonstrate the effect, will enable you to establish with them that the change in pitch is due to a change in the frequency heard. http://www.youtube.com/watch?v=Djz_rtnXSfY http://www.youtube.com/watch?v=h4OnBYrbCjY
KC3 / **KC4** 14.4b	Use the expression $f_o = \frac{f_s v}{(v \pm v_s)}$ for the observed frequency when a source of sound waves moves relative to a stationary observer.	• Learners must use practice examples to ensure they have the correct understanding of the symbols f_o, v, v_s and f_s. **(I)** • Complete the self-assessment questions on the physicslab.org webpage. **(I)** **Note:** The idea of a frequency change can be further investigated by using the relationship. The derivation is quite lengthy, but learners can understand the reasons behind the expression by drawing diagrams showing a bunching of (circular) wavefronts ahead of a moving source, leading to a shorter wavelength, and hence higher pitch, on approach, and a stretched wavelength behind, leading to a lower pitched note heard from a receding source. http://dev.physicslab.org/Document.aspx?doctype=5&filename=WavesSound_DopplerPractice.xml http://www.astronomynotes.com/light/s10.htm
KC1 / **KC4** 14.4c	Appreciate that Doppler shift is observed with all	• Learners research other applications of the Doppler effect, for example red-shift, radar, ultrasound measurement of blood flow and give brief presentations to the class.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	waves, including sound and light.	http://www.tap.iop.org/astronomy/astrophysics/702/page_47545.html http://www.tap.iop.org/astronomy/cosmology/704/page_47564.html
KC1 / KC3 / KC4 14.5a	State that all electromagnetic waves travel with the same speed in free space and recall the orders of magnitude of the wavelengths of the principal radiations from radio waves to γ-rays.	• Discuss and draw what an electromagnetic wave is. **(I)** • Learners research the properties common to all parts of the electromagnetic spectrum. • Learners can be given a region of the electromagnetic spectrum and asked to give a presentation to the rest of the group. These presentations must include details of the wavelength and frequency ranges for that region. **Note:** Learners should already be familiar with the idea that all electromagnetic waves travel at the same speed in a vacuum; you can also discuss with them how the speed varies when the waves are passing through a medium. The variation of the speed of sound in gases and solids could also be examined to provide contrast between the behaviour of these and electromagnetic waves. This would be a good opportunity to revise the order of the types of radiation in the electromagnetic spectrum, and for learners to examine the idea of an order of magnitude, if they are not already familiar with the concept. The corresponding frequencies can be found as a practice exercise, using $v = f\lambda$. http://www.tap.iop.org/vibration/em/314/page_46695.html http://www.s-cool.co.uk/a-level/physics/electro-magnetic-waves
KC1 / **KC4** 15.1a	Explain and use the principle of superposition in simple applications.	• Discuss what learners think will happen when two single wave pulses, travelling in opposite directions, meet on a rope. They should first consider a 'peak meets peak' situation and then 'peak meets trough'. • Practical work with a slinky spring or rope: send pulses simultaneously from both ends. Observe carefully what is seen when the pulses cross, as well as afterwards. • **Extension activity:** Learners draw two waves of given dimensions on the same axes, then they use the principle of superposition to add them together. Square waves are the most straightforward. **(I)** **Note:** • Learners may be surprised to find that, after meeting briefly as they cross over, the pulses continue along the rope, after reinforcement or cancellation. • The principle of superposition should be understood as an explanation of these observations, and learners should bear in mind: ○ The principle illustrates the vector nature of displacement

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• The energy of the pulses remains unchanged after superposition, which is why they continue even after momentary cancellation http://www.tap.iop.org/vibration/superpostion/320/page_46742.html http://www.s-cool.co.uk/a-level/physics/diffraction/revise-it/diffraction-interference-and-superposition http://www.antonine-education.co.uk/Pages/Physics_2/Waves/WAV_03/Waves_Page_3.htm
KC1 / KC2 / KC4 15.1b	Show an understanding of experiments that demonstrate stationary waves using microwaves, stretched strings and air columns.	• Practical work to set up a stationary wave. One person at either end, or tie one end to a door handle (for example). Adjust the frequency until a set of loops is seen, characteristic of a stationary wave. • Demonstrate the stationary waves indicated and discuss the conditions needed for the formation of a stationary wave. Measurements could be taken and used later to find the wavelength. http://www.tap.iop.org/vibration/superpostion/324/page_46786.html http://www.s-cool.co.uk/a-level/physics/progressive-waves/revise-it/fundamental-waves-on-strings http://www.s-cool.co.uk/a-level/physics/progressive-waves/revise-it/standing-waves-in-pipes
KC1 / KC3 / KC4 15.1c	Explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes.	• Construct, on graph paper, 'snapshots' of the relative positions of the two waves at several stages of overlap, and use the principle of superposition to find the resultant disturbance in each case. Identify nodes and antinodes and observe that they do not move. • Complete a worksheet (with mark scheme) prepared by you in two levels on stationary waves and the wave speed equation. **Note:** • The basic condition for the formation of a stationary wave needs to be clear. Waves of the same frequency must be travelling in opposite directions along the same path. http://www.s-cool.co.uk/a-level/physics/progressive-waves/revise-it/standing-waves http://www.physicslab.co.uk/swave.htm
KC2 / KC3 / KC4 14.3b	Determine the wavelength of sound using stationary waves.	• Experiment using an air column to measure the frequency of sound. This can be extended to the speed of sound in air and then corrected to the expected value at 0 °C. Equipment: source of sound (e.g. a signal generator connected to a loudspeaker), reflecting sheet or board, microphone connected to a c.r.o. or a sensitive meter. **Note:** • This experiment can be done either in groups if sufficient equipment is available, or as a demonstration. There are several possible methods, including the use of a resonance tube or

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Kundt's tube, but this method, which uses the direct reflection of a sound wave from a sheet or board, is relatively simple to set up, and it is straightforward to find the wavelength from the observations, particularly if a c.r.o. is used.
KC1 / KC3 / KC4 15.3a	Understand the terms interference and coherence.	• Demonstrate or show a video of a ripple tank. • **Extension activity:** Learners use a prepared diagram showing two sets of overlapping semi-circular wavefronts (solid = peak, dotted = trough) and the principle of superposition to understand the formation of the interference pattern. **(I)** • **Extension activity:** Use the concept of path difference to solve problems with sound waves. **(I)** • **Extension activity:** Discuss what would happen if the phase difference is not zero and then if the phase difference changes in order to understand the term coherence. • Watch a video on YouTube to see the effect of ripple tank sources being in phase as well as out of phase and one having a different frequency. (Also includes changing the separation of the sources which is useful later). http://www.tap.iop.org/vibration/superpostion/321/page_46750.html http://www.antonine-education.co.uk/Pages/Physics_2/Waves/WAV_07/Waves_Page_7.htm http://www.youtube.com/watch?v=J_xd9hUZ2AY
KC2 / **KC4** 15.3b	Show an understanding of experiments that demonstrate two-source interference using water ripples, light and microwaves.	• Discuss and list the conditions needed for a two source interference pattern. • Ask what is needed to show two source interference with light. Talk through the original experiment, and then show how easy it is to do now using a laser. • Make notes on the experimental set up and approximate distances for interference with water ripples, light and microwaves. **(I)** **Note:** • The ripple tank demonstration and an understanding by learners of the nature of the interference pattern can lead to the question 'can we obtain this sort of pattern using other waves?' • Laser pens are available in various colours and can be used in a number of light experiments so the learners can do practical work themselves. http://www.tap.iop.org/vibration/superpostion/321/page_46750.html http://www.s-cool.co.uk/a-level/physics/diffraction/revise-it/youngs-double-slit-experiment http://www.physicslab.co.uk/ripple.htm

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

KC1 / **KC4**
15.3c
	Understand the conditions required if two-source interference fringes are to be observed.	• Discuss and list the conditions needed for a two source interference pattern.
		Note:
		• Learners need to appreciate the following:
		  ○ Coherence is essential
		  ○ The slit width must be appropriate for the beams to overlap sufficiently and they must be a suitable distance apart
		  ○ Sufficient distance must be arranged between the sources and place of observation
		• In the case of light, the following difficulties are encountered:
		  ○ The slits have to be very narrow and very close
		  ○ For a reasonable fringe width, the distance from the sources to the screen must be more than 1m
		  ○ A single monochromatic light source must be used (the word 'monochromatic' should be explained if necessary)
		• When explaining coherence in solutions to questions, learners must be careful to use the correct terminology. It should *not* be explained as 'same frequency/amplitude/wavelength' or similar. A common mistake is to use the phrase '*same* phase difference' which is meaningless!
		
		http://www.physicslab.co.uk/doubleslit.htm

KC3 / KC4 15.3d	Recall and solve problems using the equation $\lambda = \frac{ax}{D}$ for double-slit interference using light.	• Derive the equation, making the units of the quantities clear. • Use an interactive program or different colour laser pens and slits of different widths to show the effect of changing any variable in the equation. Link to the equation. • Worksheet (and mark scheme) prepared by you in two levels to practise the application of this formula. **(I)** • Experiment to find the wavelength of the light from a laser pen. Alter *D*, measure *x*. http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/slits.html http://www.physicslab.co.uk/doubleslit.htm
KC1 / **KC4** 15.2a	Explain the meaning of the term diffraction.	• Demonstration or video on diffraction of water waves (using a ripple tank). Change the width of the gap and if possible the wavelength. • One of the group stands outside an open door, against the adjacent wall. Others inside the room should then speak *quietly*. The person standing outside can hear perfectly. The door opening is similar in width to the wavelengths of sound produced in normal speech, and acts as a diffraction aperture.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Discuss the link between aperture width and amount of diffraction. http://www.tap.iop.org/vibration/superpostion/323/page_46776.html http://www.physicslab.co.uk/ripple.htm
KC1 / KC2 / KC4 15.2b	Show an understanding of experiments that demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap.	• Show diffraction with other waves, for example laser light and microwaves. If possible show the effect of changing wavelength and aperture width.
KC3 / KC4 15.4a	Recall and solve problems using the formula $d \sin \theta = n\lambda$.	• Derive the formula for abler learners. • Worksheet (and mark scheme) prepared by you in two levels using the formula. **(I)** • Show the difference between the single slit diffraction pattern and a multiple-source diffraction pattern. **Note:** • Diffraction can be observed with any kind of wave, given the right conditions. • Learners should understand the meaning of the term 'grating element' as well as observe the effect of the grating on a beam of light. The width of the observed pattern will need to be linked to the grating element. Learners could examine a diffraction grating under a microscope in order to observe the fine, closely-spaced lines. • Learners must understand the idea of the *order* of a diffracted maximum, with the use of diagrams to see the way in which the different orders are produced. • They should understand that spectra produced when white light is diffracted are different from those produced by refraction in the following respects: ○ More than one spectrum is produced • Longer wavelengths are diffracted through greater angles than shorter wavelengths (whereas longer wavelengths are refracted less) http://www.antonine-education.co.uk/Pages/Physics_2/Waves/WAV_08/waves_page_8.htm
KC2 / **KC4** 15.4b	Describe the use of a diffraction grating to	• Experiment with laser light to determine the wavelength of the laser.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	determine the wavelength of light (the structure and use of the spectrometer are not included).	• Learners research different diffraction patterns and line emission spectra (although this will be covered in more detail later). **(I)** http://www.tap.iop.org/vibration/superpostion/322/page_46765.html http://academia.hixie.ch/bath/laser/home.html

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

5: Electrical circuits

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 20.1a	Recall and use appropriate circuit symbols as set out in the ASE publication *Signs, symbols and Systematics* (example circuit symbols are given in Syllabus Section 5.5).	• Discuss the need for circuit diagrams and revise the conventions used to generate world-wide consistency in the production of these diagrams. • Complete a table to show the names and symbols of all the components they will meet. This could be done with a 'card match' activity. • Provide a sheet of symbols based on *Signs, Symbols and Systematics* for learners to be familiar with.
KC1 20.1b	Draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters and/or any other type of component referred to in the syllabus.	• One learner describes a circuit verbally while the others draw it. • In pairs practise setting up circuits, including wiring ammeters and voltmeters correctly as well as other polarised components. Include series and parallel wiring. You could emphasis the correct use of red and black wires. **Practical booklet** 4 http://www.tap.iop.org/electricity/current/101/page_45881.html
KC1 19.1a	Understand that electric current is a flow of charge carriers.	• Discuss 'What is electric current?' • What is a charge? What is a charge carrier? Come up with examples, e.g. ions as well as electrons. • Demonstrate with electrolysis, e.g. potassium permanganate crystal soaked in ammonium hydroxide on filter paper. **Note:** The term 'charge carriers' may need clarification. Charge should be understood as a property possessed by some (but not all) atomic particles; it is found as two types (positive and negative) which 'neutralise' one another if brought together in equal quantities. Particles must be charged and be moving if they are to contribute to an electric current; so a stream of neutrons would *not* give rise to a current. http://www.tap.iop.org/electricity/current/102/page_45896.html http://www.tap.iop.org/electricity/current/104/page_45912.html http://www.tap.iop.org/electricity/current/103/page_45905.html

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 19.1b	Understand that the charge on charge carriers is quantised.	• Discussion based around how much charge is there on an electron? An ion? Learners find the elementary charge, *e*, on the formula sheet. • **Extension activity:** Worksheet (and mark scheme) prepared by you with the charge on various particles and learners show that charge is quantised. **(I)**
KC1 19.1c	Define the coulomb.	• Learners introduced to the coulomb and asked to express it in base units. • How many electrons in one coulomb? **Note:** It should be recognised by learners that the idea of a current of 1A flowing past a point in 1 s is used to define the *coulomb*, not the ampere. You can remind them that, since the ampere is a base unit, it cannot be defined in terms of any other unit. http://www.tap.iop.org/electricity/current/102/page_45896.html
KC1 / KC3 19.1d	Recall and use $Q = It$.	• Worksheet (and mark scheme) prepared by you on $Q = It$ for a variety of charge carriers. Include conversion of units, e.g. mA, and use of powers of ten and standard form. **(I)** **Note:** • This relationship comes directly from the definition of the coulomb, and practice examples will need to be given. **(I)**
KC1 / KC3 19.1e	Derive and use, for a current-carrying conductor, the expression $I = Anvq$, where n is the number density of charge carriers.	• **Extension activity:** Abler learners can have a go at deriving the equation; otherwise go through this with the class. • Worksheet (and mark scheme) prepared by you using this formula. Make sure that all aspects are fully covered, including giving diameter instead of area. Practise converting from mm^2 to m^2. **(I)** • Use previous data from the drift of potassium permanganate ions demonstration, or do this demonstration now, to find the drift velocity of the ions. **Note:** Learners can be asked to derive this equation for themselves, but they will need to clarify some ideas first: • Free charge carriers move randomly at high speeds (of the order of 10^5 m s^{-1}). Under the influence of a voltage, they will *also* gradually progress along the conductor (at the order of 10^{-4} m s^{-1}). This is the drift velocity. • Learners should note carefully the very large difference between the rapid random motion of charge carriers and the drift velocity • The number density is the number of charge carriers per unit volume

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Greater cross-sectional area allows more room for charge carriers so leads to more current. A common misconception among learners is that when a light, for example, is switched on, electrons somehow rush round to the lamp at a very high speed, hence it illuminates instantaneously. It should be discussed that the magnitude of the drift velocity shows that this is quite clearly not the case. They should regard the connecting wires as being already 'full' and switching on merely starts the slow flow, rather like turning on a tap to start water flowing. http://www.tap.iop.org/electricity/current/104/page_45912.html http://www.s-cool.co.uk/a-level/physics/current-charge-and-voltage/revise-it/drift-velocity
KC1 / KC2 19.3a	Define resistance and the ohm.	• Experiment to plot the *I*-*V* characteristic of a fixed resistor. Find the resistance from the gradient. Equipment: fixed resistors, d.c. power source, ammeter, voltmeter, variable resistor, connecting wires. • Worksheet (and mark scheme) prepared by you to use the resistance formula. Include units, graphs and unit conversions. **(I)** **Note:** In previous work, learners will probably have come to think of electrical resistance as something within a conductor which acts to reduce the current flowing through it. This is a reasonable physical concept, but they now need to appreciate that resistance is *defined* as the ratio of the potential difference across the conductor to the current flowing through it. They should define the unit of resistance, the ohm, at the same time. http://www.tap.iop.org/electricity/resistance/108/page_45955.html
KC1 / KC3 19.3e	Recall and use $R = \frac{\rho l}{A}$	• Experimental work measuring the resistance of wires of different cross-sectional area and length. Deduce the relationships between resistance and cross-sectional area and length and hence the formula. Introduce the formula and resistivity as the constant of proportionality. Equipment: different lengths of resistance wire with the same cross-sectional area; wires with various cross-sectional area, all the same length; DC power source, ammeter, voltmeter. • Learners deduce the units for resistivity. **(I)** • **Extension activity:** Worksheet (and mark scheme) prepared by you to apply the new formula. Include examples where the units need to be converted to standard and also where the cross-sectional area needs to be calculated from the diameter. **(I)** **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Learners should recognise that resistivity is a quantity applicable to a particular material, independent of its length or cross-sectional area. • You could also look at how the resistance of a fixed length and cross-sectional area of wire depends on the material. **Practical booklet** 4 http://www.tap.iop.org/electricity/resistance/112/page_45984.html
KC1 19.2a	Define potential difference and the volt.	• Discuss what causes charge carriers to drift along a conductor, forming an electric current. Where does the electrical energy come from in a circuit? Potential difference as the charge carriers gaining energy. http://www.tap.iop.org/electricity/current/105/page_45920.html
KC1 / KC3 19.2b	Recall and use $V = \frac{W}{Q}$.	• Worksheet (and mark scheme) prepared by you applying this formula. Also include ideas of resistance, resistivity, charge and current to challenge abler learners. **(I)** **Note:** This relationship comes directly from the definition of the potential difference and the volt, and practice examples will need to be given. When solving electrical problems of any type, learners should be strongly discouraged from making any sort of statement which implies that p.d. or voltage *passes through* a device. They should always talk about a potential difference *across the ends* of the device
KC1 19.3d	State Ohm's law.	• Research Ohm's law and find out the conditions when it does and does not apply. • Worksheet (and mark scheme) prepared by you of graphs to decide if a conductor obeys Ohm's Law. **(I)** http://www.tap.iop.org/electricity/resistance/108/page_45955.html
KC3 19.3b	Recall and use $V = IR$.	• Worksheet (and mark scheme) prepared by you applying this formula. Also include ideas of potential difference, resistivity, charge and current to challenge abler learners. **(I)** **Practical booklet** 4

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

KC1 / KC2 / KC3
19.3c
	Sketch and discuss the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp.	• Practical work to investigate the I-V characteristics of other components including a filament lamp, a diode, a fixed resistor. Requires a d.c. power source, ammeter, voltmeter, variable resistor, connecting wires. Include positive and negative p.d.s. Find the resistance at various potential differences. Show this is not the same as the gradient.
		    ○ Learners can use the three items in turn. Set up a suitable circuit, take readings of the current through the item and potential difference across it as the p.d. of the circuit is varied.
		    ○ They should compare and *explain* the different characteristics obtained, plotting both forward and reverse voltages in each case.
		    ○ The shape of each should be noted carefully.
		• Worksheet (and mark scheme) prepared by you of graphs to identify different conductors and to relate to Ohm's Law. **(I)**
		
		http://www.tap.iop.org/electricity/resistance/109/page_45962.html
		http://www.s-cool.co.uk/a-level/physics/resistance/revise-it/voltage-current-graphs

KC3 19.2c	Recall and use $P = VI$ and $P = I^2R$.	• Recap what power means and discuss how it can be applied to electrical circuits. • Learners derive the formula for electrical power from the definition of power and the definition of potential difference. • Learners use $V = IR$ to substitute into the power formula to reach $P = I^2R$. • Practical work on the power of a lamp. • Worksheet (and mark scheme) prepared by you using the electrical power formula. **(I)** **Note:** The equation $V = IR$ can also be substituted into $P = IV$ to arrive at the alternative forms $P = I^2R$ and $P = \frac{V^2}{R}$ They should note that $P = I^2R$ shows that, for a given resistor, the power dissipated depends on the square of the current. So, for example, if the current is doubled, the power given out will be four times as great. http://www.tap.iop.org/electricity/current/106/page_45925.html http://www.tap.iop.org/electricity/circuits/115/page_46018.html http://www.tap.iop.org/electricity/circuits/116/page_46023.html
KC1 / KC2 20.2a		• Practical work to show that the sum of the currents into a junction is equal to the sum of the currents out of a junction. Requires: circuit boards, lamps or resistors, ammeters, DC power source, wires.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Apply this idea to some circuits with junctions on a worksheet (with mark scheme) prepared by you. **(I)** **Note:** • Experiments such as this are also useful in establishing that charge is not 'used up' while going around a circuit. The analogy of flowing water helps with the understanding of this. Kirchhoff's first law can then be introduced and seen in the context of charge conservation. http://www.tap.iop.org/electricity/circuits/117/page_46028.html http://www.s-cool.co.uk/a-level/physics/kirchoffs-laws-and-potential-dividers/revise-it/kirchoffs-first-and-second-laws
KC1 / KC2 20.2b	Recall Kirchhoff's second law and appreciate the link to conservation of energy.	• Discuss the principle of conservation of energy. Look at circuit diagrams to discuss where the energy is supplied and where it is used. Lead on to Kirchhoff's second law. • Discuss the need to distinguish between energy supply and energy use to introduce e.m.f. • Practical work to measure p.d.s and e.m.f.s to verify this law, using circuit boards, lamps or resistors, ammeters, voltmeters DC power source, wires. A worksheet giving learners some appropriate circuits to set up will also be necessary.
KC3 20.2c	Derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series.	• **Extension activity:** Learners should write out this derivation, showing all stages in the working, starting with a statement of Kirchhoff's second law. **(I)** **Note:** • This is a very well-known relationship which learners may be tempted to dismiss as obvious; however, you need to make clear that it arises as a direct consequence of Kirchhoff's second law. It is worth going through the derivation, using the law as the starting point; this will help learners to appreciate the significance of the second law used in practice. http://www.tap.iop.org/electricity/circuits/114/page_46010.html
KC3 20.2d	Solve problems using the formula for the combined resistance of two or more resistors in series.	• Worksheet (and mark scheme) prepared by you or from a textbook with a variety of problems which make use of this relationship. **(I)** **Practical booklet** 4

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC3 20.2e	Derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in parallel.	• Learners should write out this derivation, showing all stages in the working, starting with a statement of Kirchhoff's second law. **(I)** • **Extension activity:** Learners carry out this derivation in groups, with final agreement on what the relationship should be decided as a result of feedback and group discussions. **Note:** • Learners may have used this relationship in the past, but are unlikely to be as familiar with its use as the one for resistors in series. The derivation can this time begin from Kirchhoff's first law, and an application of Ohm's law will lead to the correct relationship. http://www.tap.iop.org/electricity/circuits/114/page_46010.html
KC3 20.2f	Solve problems using the formula for the combined resistance of two or more resistors in parallel.	• Worksheet (and mark scheme) prepared by you or from a textbook with a variety of problems which make use of this relationship. **(I)** • Calculate the total resistance of 2, 3, 4, etc., identical resistors in parallel to show how the total resistance is ½, ⅓, ¼, etc. • **Extension activity:** Ask learners to devise resistor networks to have required combined resistances. **(I)**
KC1 / KC3 20.2g	Apply Kirchhoff's laws to solve simple circuit problems.	• Worksheet (and mark scheme) prepared by you in two levels which contain combinations of resistors in series and parallel so learners can apply the formulae for series and parallel resistors as well as Kirchhoff's Laws. **(I)** http://www.s-cool.co.uk/a-level/physics/resistance/revise-it/combinations-of-resistors
KC1 / KC3 20.1c	Define electromotive force (e.m.f.) in terms of the energy transferred by a source in driving unit charge round a complete circuit.	• Recap what is happening to the charge carriers when there is a potential difference across a component. Discuss whether this idea can be applied to a cell/battery/power supply. Introduce the concept of e.m.f. as the charge carriers gaining energy. **Note:** The physics surrounding the definition of potential difference in Unit 10 should be revisited, and learners should be asked to consider the energy transfers taking place in both a battery and cell and in an external circuit item such as a resistor or lamp**.** These are the main ideas which need to emerge: • In a battery, chemical energy is transformed into electrical energy • In an external component, electrical energy is transformed into other forms

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		The difference forms the basis for the distinction between electromotive force (this term will need to be introduced) and potential difference. Both definitions should be linked to the relationship already used in Unit 10: $$V = \frac{W}{Q}$$ • Learners must understand that both are measured in volts. http://www.tap.iop.org/electricity/emf/120/page_46095.html
KC1 20.1d	Distinguish between e.m.f. and potential difference (p.d.) in terms of energy considerations.	• Discuss the need to distinguish between the supply of energy to the charge carriers and the use of energy from the charge carriers as before. • Learners must write definitions, correctly worded, for both potential difference and electromotive force, and develop an appreciation of the different circumstances where each is used. **Note:** • It may take some practice and increased familiarity for learners to become confident in using these two sets of initials in the correct contexts. After defining both in terms of energy transfer per unit charge, it may be helpful for a discussion to clarify that they should *never* refer to the e.m.f. of, say, a resistor, and that it would be equally mistaken to talk about the p.d. of a battery (as will be seen in the following section, this can vary).
KC1 / KC2 / KC3 20.1e	Understand the effects of the internal resistance of a source of e.m.f. on the terminal potential difference.	• Brief practical work to show the reading on a voltmeter connected across a cell on open circuit and on load. Discuss the implications of the results. **(I)** • Experiment to investigate the reading on a voltmeter connected across the terminals of a battery, while the current it is delivering to an external circuit is steadily increased. • **Extension activity:** Apply Kirchhoff's Second Law and Ohm's Law to write the formula for the circuit $= V - Ir$. Plot a graph to find the e.m.f. and the internal resistance. **(I)** • **Extension activity:** Worksheet (and mark scheme) prepared by you to practise finding internal resistance and other quantities. **(I)** **Note:** Discussion of the results will be needed to establish the following points: • The voltmeter is measuring the p.d. which the battery is supplying to the external circuit • This quantity reduces as the current being delivered to the external circuit by the battery increases. It is known as the 'terminal p.d.'

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• All batteries have some 'internal resistance' (due to the chemicals within it) which the current has to pass through in addition to passing through the external resistance • A greater proportion of the battery's e.m.f. is used in driving the current through its own internal resistance for larger currents. This does not form part of the voltmeter reading. • The situation can be represented by Ohm's law in the form: $E = I(R + r)$ • The e.m.f. is the terminal p.d. when the cell is on 'open circuit', i.e. not delivering any current • The internal resistance reduces the power the battery can deliver to the external circuit because some heat energy is dissipated inside it • Internal resistance is ignored in some problems involving sources of e.m.f. but in circuit diagrams including batteries which do have internal resistance, the circuit symbol is amended http://www.tap.iop.org/electricity/emf/121/page_46054.html http://www.s-cool.co.uk/a-level/physics/resistance/revise-it/internal-resistance-emf-and-potential-difference http://www.physicslab.co.uk/emfandpd.htm
KC2 / KC3 20.3a	Understand the principle of a potential divider circuit as a source of variable p.d.	• Experiment to connect two resistors in series with a battery (they can try pairs of resistors which are the same and pairs which are different) and measure the potential difference across each, as well as measuring the e.m.f. of the source. They should be able to establish, after discussion and some thought, that in each case, $\frac{V_1}{V_2} = \frac{R_1}{R_2}$. • Develop results to realise that, by choosing resistors in a particular ratio, the e.m.f. can be divided into two parts with any values, subject to the condition that $V_1 + V_2$ is equal to the e.m.f. of the battery. A potential difference of any value between 0 V and the e.m.f. can thus be obtained. http://www.tap.iop.org/electricity/circuits/118/page_46038.html http://www.s-cool.co.uk/a-level/physics/kirchoffs-laws-and-potential-dividers/revise-it/potential-dividers
KC3 20.3b	Recall and solve problems using the principle of the potentiometer as a means of comparing potential differences.	• Experiment with a continuous length of suitable resistance wire, to discover that by using a sliding contact with a voltmeter it is possible to obtain an output voltage which varies continuously from 0 V to up to the terminal p.d. of the battery. • Experiment to find the 'balance position' when comparing an unknown p.d. with a known p.d. • Reinforce through the solution of suitable problems prepared by you or from a textbook. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Note: The experiment should lead to learners understanding the potentiometer relationship: $V_{\mathrm{OUT}} = \frac{VR_1}{(R_1 + R_2)}$ • The potentiometer wire would normally be assumed to have uniform cross-sectional area, which means that the p.d. obtained is proportional to the length of the wire. http://www.s-cool.co.uk/a-level/physics/kirchoffs-laws-and-potential-dividers/revise-it/using-potential-dividers-to-find-emf

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

6: Particle physics

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

KC4 / KC5
26.1a
	Infer from the results of the α-particle scattering experiment the existence and small size of the nucleus.	• Learners research previous models of the atom and produce a time line showing significant changes. **(I)**
		• Learners research the alpha particle scattering experiment, focussing on apparatus, results and conclusions.
		• Learners draw the paths of alpha particles that are far from the nucleus, near to the nucleus and a head on collision with the nucleus. **(I)**
		• **Extension activity:** Learners watch a YouTube video summarising the set-up used and compile a list of the principle observations and the resulting conclusions about the structure of the atom.
		
		Note:
		• The results of the experiment:
		  ○ The majority of α-particles were undeviated
		  ○ A few were deviated by small angles (< 10°)
		  ○ Even fewer (a *very* small proportion) were deviated by large angles (> 90°).
		• Learners must appreciate how these results led to the following conclusions
		  ○ Most of the mass and charge is concentrated in a very small nucleus
		  ○ The nucleus is very much smaller than the whole atom, and so most of the atom is empty space
		• The conclusions were not finalised until several years after the experiments were carried out.
		
		http://www.tap.iop.org/atoms/rutherford/521/page_47197.html
		http://www.tap.iop.org/atoms/rutherford/522/page_47210.html
		http://www.s-cool.co.uk/a-level/physics/atomic-structure/revise-it/rutherford-alpha-particle-scattering-experiment
		http://www.physicslab.co.uk/nucleus.htm
		http://www.youtube.com/watch?v=dNp-vP17asI

KC4 26.1b	Describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons.	• Provide learners with an unlabelled diagram of an atom on which they add arrows to indicate protons, neutrons and electrons. **(I)** **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Learners will almost certainly have a picture of the basic structure of atoms from previous work, but some revision of the charges, relative masses and interactions between the particles would be useful, since the following sections rely on a thorough understanding of these ideas. http://www.s-cool.co.uk/a-level/physics/atomic-structure/revise-it/particles-in-the-atom
KC4 26.1c	Distinguish between nucleon number and proton number.	• Provide learners with diagrams of different atomic nuclei then find the nucleon number and the proton number for each one. **(I)** • Complete a table with blanks to work out A, Z, number of protons, electrons, neutrons. **(I)** **Note:** Revise the concept of an element, and reinforce the concept of the proton number defining the element, although the nucleon number can vary. Ensure learners make the distinction between a nucleus, a nucleon and a nuclide, and use each term in the correct context.
KC4 26.1d	Understand that an element can exist in various isotopic forms, each with a different number of neutrons.	• Ask learners to explain to you what an isotope is**.** • Use different coloured beads to represent protons and neutrons and ask learners to build a nucleus. • Learners draw out the nuclei of the three known isotopes of carbon, with the correct numbers of protons and neutrons in each. **(I)** **Note:** Many learners in the group will be familiar with the concept that an element can have different isotopes. However, there will be no harm in revisiting the topic, to make sure that they are all familiar with the concept. http://www.s-cool.co.uk/a-level/physics/atomic-structure/revise-it/isotopes http://www2.glos.ac.uk/gdn/origins/life/carbon.htm
26.1e	Use the usual notation for the representation of nuclides.	• Questions which require learners to indicate a variety of isotopes of different elements using both notations, for example isotopes of carbon, oxygen and potassium. **(I)** **Note:** The 'nuclide notation' of the form ${}^{A}_{Z}X$ should be revised, but learners must also be prepared to see nuclides identified using the form neon-20 or neon-22, for example. In this notation, the proton number is not given (but as it is fixed for any given element, it can be found easily). http://preparatorychemistry.com/Bishop_Isotope_Notation.htm

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC4 / KC5 26.1f	Appreciate that nucleon number, proton number, and mass-energy are all conserved in nuclear processes.	• Provide a worksheet for learners to compose some simple nuclear equations, using the nuclide notation, to promote understanding of the need for nucleon number and proton number to be conserved.
KC4 / KC5 26.1g	Show an understanding of the nature and properties of α-, β- and γ-radiations (both β^- and β^+ are included).	• Learners construct a table to compare these nuclear radiations with respect to: ○ Particle or wave? ○ Composition of particle or wave ○ Mass of particle ○ Charge on particle ○ Energy of particle or wave (use of energies in eV and MeV is required) ○ Speed of particle or wave at emission ○ Ionising ability and the reasons for differences ○ Range in various materials ○ Penetration power and the reasons for differences ○ Changes to nucleus as a result of emission. **(I)** • Discuss the concept of anti-matter. The idea that every particle has its corresponding anti-particle is definitely worth considering at this stage. You could refer to PET scans as real-life use of antimatter. **Note:** • Learners will probably have carried out work on the three types of nuclear radiation previously, but revision and clarification of their ideas will undoubtedly be necessary. Ensure that they classify these radiations correctly as '*nuclear radiation*' (sometimes referred to as '*ionising radiation*') and discuss the random and spontaneous nature of the emissions. • Learners will need to appreciate the differences between β^- and β^+ particles. They have probably only recognised β-particles as negatively charged electrons previously, discuss how it is possible for a positively charged particle, which is in every other sense identical to an electron, to exist. Learners will need to understand the mechanisms by which both β^- and β^+ particles are emitted, and they should link them to the changes which occur in the parent nuclei. http://www.tap.iop.org/atoms/radioactivity/510/page_47087.html http://www.s-cool.co.uk/a-level/physics/radioactivity http://www.tap.iop.org/atoms/radioactivity/511/page_47096.html http://www.physicslab.co.uk/decay.htm http://www.youtube.com/watch?v=oFdR_yMKOCw http://www.s-cool.co.uk/a-level/physics/matter-and-antimatter

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC4 26.1h	State that (electron) antineutrinos and (electron) neutrinos are produced during β^- and β^+ decay.	• Learners research the discovery of neutrinos. • Learners construct decay equations for both types of β decay, ensuring they obey the conservation laws. **Note:** • Learners will have appreciated from the considerations of the speeds of emission of different types of nuclear radiation that, whereas α-particles are all emitted at the same speed, β-particles of both types are emitted with a range of speeds. Discuss the concept of the neutrino (and its anti-matter equivalent). Diagrams involving conservation of momentum is one way of demonstrating how these particles give rise to the varied emission speeds of both kinds of β-particles.
KC4 26.2a	Appreciate that protons and neutrons are not fundamental particles since they consist of quarks.	• Discuss what a fundamental particle is, and the concept of quarks. • Classify various particles, to include neutrons, protons and electrons as to whether they are fundamental or not. **Note:** The question of whether protons and neutrons really are fundamental or whether they contain other, yet smaller, particles had been a scientific puzzle which was not answered until the 1960s. http://www.youtube.com/watch?v=V0KjXsGRvoA
KC4 26.2b	Describe a simple quark model of hadrons in terms of up, down and strange quarks and their respective antiquarks.	• Learners research the evidence for quarks. • Learners complete a table summarising the nature of up, down and strange quarks. • Learners research hadrons, baryons and mesons, including names and number of quarks. • **Extension activity:** For abler learners discuss 'how do nucleons stay together in a nucleus' and introduce the strong nuclear force. **Note:** You could continue the discussion of the previous section in terms of the discovery during the mid-twentieth century of many more sub-atomic particles than had previously been known, and how attempts to classify them into groups with particular characteristics have proved difficult. See online resource for learning objective 26.2.a. http://hyperphysics.phy-astr.gsu.edu/hbase/particles/quark.html http://www.tap.iop.org/atoms/stability/524/page_47230.html http://www.tap.iop.org/atoms/particles/533/page_47319.html

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.s-cool.co.uk/a-level/physics/particle-classification-and-interactions/revise-it/the-quark-model-of-hadrons
KC4 26.2c	Describe protons and neutrons in terms of a simple quark model.	• Learners draw pictures or complete a table to summarise the quark structure of protons and neutrons. Show how the mass and charge add to give those of protons and neutrons. **(I)** • Discuss the stability of protons and neutrons both inside and outside the nucleus. Draw out the link to both types of β decay. **Note:** The only two stable baryons are protons (uud) and neutrons (udd), although an isolated neutron only lasts for about 15 minutes as they are only stable when *inside* a nucleus. All other hadrons, consisting of other combinations of quarks and antiquarks, decay in tiny fractions of a second. Learners must appreciate that this is a new way of thinking about nucleons; previously they will have considered them as solid, indivisible particles and this is a very different picture which may take them by surprise. http://www.tap.iop.org/atoms/quarks/540/page_47397.html
KC4 / KC5 26.2d	Appreciate that there is a weak interaction between quarks, giving rise to β-decay.	• Learners research the four fundamental forces. In four groups they could present their findings on each force. **Note:** The weak nuclear force needs to be thought of as the force responsible for β-decay, because it is an interaction which exists between the different quarks within a proton or neutron. Occasionally the weak interaction gives rise to changes in the nature of one or more of the quarks, and this change is what causes the emission of either an electron or a positron, accompanied by a neutrino or antineutrino respectively. The probability of these changes is low, which explains why some nuclides decay slowly. http://www.youtube.com/watch?v=cnL_nwmCLpY
KC4 / KC5 26.2e	Describe β^- and β^+ decay in terms of a simple quark model.	• Learners draw diagrams and write explanations of the changes which occur inside a nucleus during β^- and β^+ decay at the quark level. Include decay equations in terms of quarks. **(I)** **Note:** Before the quark model can be discussed, learners must have a clear picture of the changes to nucleons which occur when β^- and β^+ particles are emitted. This can be reinforced by considering the conservation of proton and nucleon number when such an event happens. Then, they need to think about what changes would be needed to the quarks inside to produce the observed emissions while conserving charge and

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		mass-energy. There are some good online illustrations and animations which show the steps in the process, giving a visual observation of what is going on. http://www.particleadventure.org/npe.html
KC4 26.2f	Appreciate that electrons and neutrinos are leptons.	• Start with a question such as 'what is a muon? • Learners research leptons, including a list of names and properties such as mass, charge. **Note:** Discuss with learners that leptons are a class of particles which are considered to be truly fundamental, i.e. they cannot be broken down to anything smaller. Examples are electrons (and positrons), neutrinos and muons. http://www.tap.iop.org/atoms/particles/534/page_47331.html

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

7: Further mechanics

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC2 / **KC3** 7.1a	Define the radian and express angular displacement in radians.	• Practise converting degrees into radians and vice versa. Complete a table with some gaps. **(I)** • Use the formula $s = r\theta$ and practise the idea of angular displacement by using some prepared examples. **(I)** **Note:** • Learners need to become completely confident with using simple cases such as 180° = π rad and 90° = $\pi/2$ rad, etc. These will crop up frequently in future work on related topics. • Learners may not have come across radians before, except as a label on a calculator button. You can introduce it simply as an alternative unit for measuring angles which is far more convenient than using degrees when considering the motion of objects moving in a circular path. http://www.tap.iop.org/mechanics/circular/225/page_46483.html
KC1 / KC2 / **KC3** 7.1b	Understand and use the concept of angular speed to solve problems.	• Practise using the relation $\omega = \theta/t$ and the more general form of this, $\omega = 2\pi/T$ to solve problems. Use familiar examples, such as the three hands on a clock, the rotation of the Earth. **(I)** **Note:** • Learners will develop an understanding of this by recalling that linear speed is defined as 'linear displacement/time' and substituting the word 'angular' for 'linear' in this expression. You will need to ensure that learners distinguish between the use of *t* to represent time in general, and *T* to represent the period of an object in circular motion.
KC1 / KC2 / **KC3** 7.1c	Recall and use $v = r\omega$ to solve problems.	• Worksheet (and mark scheme) prepared by you with examples using this relationship. Perhaps develop from the angular speeds found in 7.1.b to find their linear speed. **(I)** **Note:** Learners must note that parts of a rotating object at different radii have *different* linear speeds, but the *same* angular speed.
KC1 / KC2 / KC3 7.2a	Describe qualitatively motion in a curved path due to a perpendicular force, and understand the	• Discuss the difference between speed and velocity, the changing velocity and hence the need for an acceleration. Use a vector triangle to show the direction of the acceleration. • Learners should answer the first five questions on (http://www.antonine-education.co.uk). **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	centripetal acceleration in the case of uniform motion in a circle.	**Note:** In order for you to ensure that learners have a clear understanding of the concept of centripetal acceleration, it will be instructive at this stage to revise Newton's laws of motion. The 1st law, in particular, tells us that for any moving object to deviate from straight line motion, there must be an unbalanced force in a direction which is different from the direction of travel of the object. In the particular case of uniform circular motion, this force is perpendicular to the direction of motion, constant and directed towards the centre of the circle in which the object is moving. The acceleration produced by the force in this case is due entirely to the steady change in direction of the velocity, not the change in its magnitude. http://www.physicsclassroom.com/class/circles/Lesson-1/Mathematics-of-Circular-Motion http://www.tap.iop.org/mechanics/circular/225/page_46483.html http://www.antonine-education.co.uk/Pages/Physics_4/Further_Mechanics/FMC_03/Fmech_page_3.htm
KC1 / KC2 / **KC3** 7.2b	Recall and use the centripetal acceleration equations $a = r\omega^2$ and $a = \frac{v^2}{r}$.	• Worksheet (and mark scheme) prepared by you of examples in two levels to apply these relationships. **(I)** **Note:** These two relationships for centripetal acceleration do not need be derived, but a discussion with learners on how they are arrived at will promote better understanding, rather than simply quoting them. http://www.physicsclassroom.com/mmedia/circmot/ucm.cfm
KC1 / KC2 / KC3 / **KC5** 7.2c	Recall and use centripetal force equations $F = mr\omega^2$ and $F = \frac{mv^2}{r}$.	• Discuss that a resultant force is needed to cause an acceleration. Use Newton's second law. Discuss also the direction of the force. • Worksheet (and mark scheme) prepared by you that uses these and all previous examples. Make sure you have challenging examples too. **(I)** • Look at some pictures showing objects in circular motion. Discuss what provides the centripetal force. For example, gravitational attraction provides the centripetal force for an orbiting satellite. Look also at banked tracks and banking aircraft. • Experiment to show that *F* depends on ω and *r*. For example, whirling a small weight on the end of a string around in a circle, as shown on p.262 in Sang (Figure 18.7). • Discuss vertical circular motion. Draw on the forces, the centripetal force is the resultant of the forces acting. For example, tension in a string, where is the string most likely to break? Also analyse the forces on a car travelling over a humped back bridge. • Analyse the physics of weightlessness in reduced gravity aircraft, called the 'vomit comet'.

<table>
<tr><th>Syllabus ref. and Key Concepts</th><th>Learning objectives</th><th>Suggested teaching activities</th></tr>
<tr><td></td><td></td><td>Demonstration (or learners can do it themselves) to swing a bucket containing some water in a vertical circle. Learners are given the task of explaining why the water does not fall out at the top of the swing if the bucket is rotating quickly enough.
Note:
If this were to be carried out under more controlled conditions, with a newton-meter attached, it would be possible to make approximate measurements showing that the centripetal force increases with greater angular velocity and smaller radius of circular motion.

http://www.tap.iop.org/mechanics/circular/224/page_46476.html
http://www.s-cool.co.uk/a-level/physics/circular-motion
http://www.physicsclassroom.com/class/circles/Lesson-2/Amusement-Park-Physics
http://www.antonine-education.co.uk/Pages/Physics_4/Further_Mechanics/FMC_04/FMech_Page_4.htm</td></tr>
<tr><td>KC1 / KC4
13.1a</td><td>Describe simple examples of free oscillations.</td><td>Watch a YouTube video or demonstrate a simple pendulum or an oscillating mass on a spring, for example.
Learners make a list of examples of oscillations they have come across (including musical ones and sounds) and recognise that free, or natural oscillations are those which are unconstrained by any external periodic force.
Note:
At the start, learners may have only vague ideas about what oscillations really are, and may simply be thinking of an oscillation as another word for a vibration.
Practical booklet 9

http://www.tap.iop.org/vibration/shm/301/page_46554.html</td></tr>
<tr><td>KC1 / KC4
13.1b</td><td>Investigate the motion of an oscillator using experimental and graphical methods.</td><td>Experiment with a motion sensor placed under a bouncing mass on a spring. Displacement, velocity and acceleration graphs can be produced and analysed.
Experiment with a tethered trolley and ticker tape. Produce a graph and analyse the motion for the first half of an oscillation.
Experiments to find g using a simple pendulum, or to determine the stiffness of a spring from an oscillating mass-spring system.
Analyse the graph as sinusoidal and revise the idea of the relationship between $\sin\theta$ and θ.
Practical booklet 9</td></tr>
</table>

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.tap.iop.org/electricity/emf/122/page_46061.html http://www.s-cool.co.uk/a-level/physics/simple-harmonic-motion-and-damping/revise-it/simple-harmonic-motion
KC1 / KC3 / **KC4** 13.1c	Understand and use the terms amplitude, period, frequency, angular frequency and phase difference and express the period in terms of both frequency and angular frequency.	• Give learners a list of these terms and ask them to define them and to link, where possible, to a graph. Also state the units of each quantity. • Worksheet (and mark scheme) prepared by you with questions to use the following relationships: $T = \frac{1}{f} \text{ and } T = \frac{2\pi}{\omega}$ **Note:** • Amplitude must not be confused with displacement. Learners need to recognise that it is the *maximum* displacement for the oscillation. The idea of phase difference between points may need revision. **Practical booklet** 9
KC1 / KC2 / KC3 / **KC4** 13.1d	Recognise and use the equation $a = -\omega^2 x$ as the defining equation of simple harmonic motion.	• Analysis of displacement and acceleration graphs will introduce the relationship $a \propto -x$. Deduce k as ω^2 using the mathematics of the equations for the more able learners. • Learners sketch a graph to show $a = -\omega^2 x$. **Note:** • S.H.M. has a reputation for being a difficult topic, so it would be a good idea to involve learners to as great an extent as possible in the establishment of the principles. Discussion and experimentation rather than just giving notes will help them to develop a better picture of the relevant physics. They will need to be clear from the outset that this is motion with variable acceleration, so the equations of motion used in Unit 3 cannot be applied. The varying quantities which they need to consider at different points in the motion are: ○ displacement from the equilibrium position ○ velocity ○ acceleration ○ the 'restoring' force, i.e. the force which, at all points, is attempting to 'restore' the oscillating object to the equilibrium position. • Learners should now use this equation to define S.H.M: ○ Acceleration is proportional to displacement from equilibrium ○ The acceleration is always directed towards the equilibrium position

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Learners should appreciate that the second defining point explains the minus sign, as the acceleration is always in the opposite direction to increasing displacement. You can invite learners to consider what the motion would be if the minus sign was not there; acceleration would simply increase in the same direction as increasing displacement, and we would never see the object again! **Practical booklet** 9 http://www.tap.iop.org/vibration/shm/302/page_46567.html http://www.physicslab.co.uk/shm.htm http://www.antonine-education.co.uk/Pages/Physics_4/Further_Mechanics/FMC_06/FMech_Page_6.htm http://www.tap.iop.org/vibration/shm/304/page_46587.html
KC3 / KC4 13.1e	Recall and use $x = x_0 \sin \omega t$ as a solution to the equation $a = -\omega^2 x$.	• For learners without the required calculus this equation can be built up from looking at the displacement time graphs already produced. • Worksheet (and mark scheme) prepared by you with examples to use this, emphasise the need for radians. Make sure some examples are graphical. **(I)** **Note:** • All angles ωt are in radians so learners need to ensure their calculators are set up correctly • The presence of a sine function in the equation agrees with any visual observations they made at an earlier stage (e.g. on a c.r.o.) of a sinusoidal displacement-time curve • Learners should take careful note of the fact that the same motion can be represented by $x = x_0 \cos \omega t$ as the cosine and sine curves are exactly the same basic shape; the difference lies in the point in the oscillation at which the motion is considered to begin. http://www.tap.iop.org/vibration/shm/302/page_46567.html http://www.s-cool.co.uk/a-level/physics/simple-harmonic-motion-and-damping/revise-it/calculations-and-examples-with-shm
KC3 / KC4 13.1f	Recognise and use the equations $v = v_0 \cos \omega t$ and $v = \pm\omega\sqrt{(x_0^2 - x^2)}$.	• Introduce learners to these two equations. Abler learners can be shown how to derive the relationship between velocity and displacement. Show the condition that when $x = 0$, the second equation reduces to $v = \omega x_0$. • **Extension activity:** Draw a velocity-displacement sketch graph. • Worksheet (and mark scheme) prepared by you to apply these formulae. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Note: • For correct use of the first formula they need to ensure their calculators are in radian mode.
KC3 / **KC4** 13.1g	Describe, with graphical illustrations, the changes in displacement, velocity and acceleration during simple harmonic motion.	• Learners draw sketch graphs for all the equations met so far. Alternatively provide learners with each graph and they match them, with reasons, to the correct equation. • Examine the links between the graphs using gradients. Draw linked graphs of displacement, velocity and acceleration with time directly underneath one another, in order to visualise the connections between them more visually. • Check that the graphs for displacement and acceleration are indeed proportional and in the opposite direction. **Note:** • Throughout the work on S.H.M. ask learners to consider the connection of S.H.M. with circular motion, using a demonstration of the movement of the shadow of an illuminated vertical object fixed to a turntable rotating with uniform circular motion. This will assist them in their efforts to understand the physics of S.H.M. • Remind learners several times that all angles in the sinusoidal relationships are in *radians.* http://physicsnet.co.uk/a-level-physics-as-a2/further-mechanics/simple-harmonic-motion-shm/ http://www.antonine-education.co.uk/Pages/Physics_4/Further_Mechanics/FMC_06/FMech_Page_6.htm

KC1 / **KC3** / KC4
13.2a
	Describe the interchange between kinetic and potential energy during simple harmonic motion.	• Apply the conservation of energy to an oscillating body. With no losses the total of the kinetic and potential energies is constant**.**
		• The following relationships need to be discussed and derived by learners:
		  ○ $E_K = \frac{1}{2}m\omega^2(x_0^2 - x^2)$
		  ○ $E_P = \frac{1}{2}m\omega^2x^2$
		  ○ $E_{TOTAL} = \frac{1}{2}m\omega^2x_0^2$.
		• **Extension activity:** Sketch energy-displacement graphs for the variation of both kinetic and potential energy on the same axes, and consider the significance of the point where the two graphs, both parabolic in shape, intersect.
		
		http://www.tap.iop.org/vibration/shm/305/page_46596.html

KC1 / KC2 / **KC4** 13.3a	Describe practical examples of damped	• Light damping:

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	oscillations with particular reference to the effects of the degree of damping and the importance of critical damping.	○ Illustrate damping, by setting up a mass on a spring as a demonstration, and ask members of the group to estimate the amplitude of oscillation. They should repeat their estimate after the system has been left to oscillate for a few seconds. ○ Discuss the reasons for the loss of energy. ○ Observe that the time period of the motion has not changed. • Show heavy damping by attaching a horizontal card to the bottom of the oscillating mass, or have the mass oscillating in water. Discuss the increase in damping as the loss of energy from the system is now occurring at a greater rate. • Learners to research what critical damping is and find some practical examples. • Draw displacement-time graphs for light, heavy and critical damping. **(I)** • Practical investigation into light damping, in which a long pendulum with a relatively long time period is set up (making the amplitude and period easier to measure). Repeatedly find the amplitude, say, every twenty swings for about 200 swings, and plot amplitude against time and find that: ○ The period is constant throughout • The decay of amplitude is an exponential process (this may need some additional work if learners are not yet familiar with the idea of an exponential decay process). http://www.tap.iop.org/vibration/shm/306/page_46606.html http://www.s-cool.co.uk/a-level/physics/simple-harmonic-motion-and-damping/revise-it/damping-natural-frequency-and-resonance http://www.antonine-education.co.uk/Pages/Physics_4/Further_Mechanics/FMC_05/FMech_5.htm
KC2 / KC4 13.3b	Describe practical examples of forced oscillations and resonance.	• Demonstrate the difference between a free and a forced oscillation using a simple mass-spring system. Then use a spring mechanically supported by a variable frequency oscillator to follow on to introduce resonance. • Demonstrate other examples of resonance, for example, a length of hacksaw blade attached to a variable frequency oscillator. Barton's pendulums can be shown. • Learners research examples of resonance, for example, the Tacoma Narrows Bridge, pushing a swing, the Millennium Footbridge in London. • Discuss resonance in terms of energy. The external force repeatedly does work on the system. **Note:** • It will be worthwhile drawing out the links here between stationary waves and resonance. http://www.tap.iop.org/vibration/shm/307/page_46612.html http://www.physicslab.co.uk/boom.htm

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.youtube.com/watch?v=j-zczJXSxnw http://www.youtube.com/watch?v=rRZT7xO5KN4
KC2 / KC4 13.3c	Describe graphically how the amplitude of a forced oscillation changes with frequency near to the natural frequency of the system, and understand qualitatively the factors that determine the frequency response and sharpness of the resonance.	• Demonstration or computer simulation to show how the amplitude of the oscillation depends upon the forcing frequency. • Investigate the resonance peak by using stiffer springs or by attaching cards of different areas to provide resistance to motion. Examine how the 'sharpness' of a resonance peak is influenced by factors such as the type of damping; the example of a speaker in a sound system gives a useful illustration of the idea. • **Extension activity:** Draw a graph showing all the results; the variation with frequency and with the addition of damping. http://www.physicslab.co.uk/Pull-it.htm
KC2 / KC4 13.3d	Show an appreciation that there are some circumstances in which resonance is useful and other circumstances in which resonance should be avoided.	• Research useful applications of resonance as well as when it is a problem. Learners give presentations to share their findings. Examples of uses include microwave ovens, musical instruments, tuning circuits. Examples of problems include buildings in earthquakes, bridges, loudspeakers. Learners feedback their findings.

KC1 / KC4
14.6a
	Explain the principles of the generation and detection of ultrasonic waves using piezo-electric transducers.	• Discuss and explain the nature of ultrasound.
		• Brainstorm uses of ultrasound, for example depth sounding, jewellery cleaning, medical uses.
		• **Extension activity:** Examine how an ultrasound transducer works.
		• **Extension activity:** Discuss how the transducer can both emit and receive ultrasound.
		
		Note:
		• Learners should note the following:
		  ○ The structure of a quartz crystal
		  ○ The link between distortion of the crystal when an alternating voltage is applied to it and production of ultrasound frequencies
		  ○ The idea of the applied alternating voltage being equal to the natural frequency of the crystal leading to resonance
		  ○ The transducer also acts as a receiver for reflected ultrasound

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		○ These devices can generate frequencies up to about 600 MHz. • You may need to remind learners of what a *transducer* is, if necessary, with possible reference to its use in a microphone. http://www.ob-ultrasound.net http://ozradonc.wikidot.com/principles-of-ultrasound
KC1 / KC4 14.6b	Explain the main principles behind the use of ultrasound to obtain diagnostic information about internal structures.	• Learners research how ultrasound scans build up images of inside the body. They write a concise but accurate account explaining the use of ultrasound waves to obtain diagnostic information about internal body structures, incorporating the points listed below. **Note:** Learners should be familiar with the following ideas: • Pulses of ultrasound are sent into the body under examination • These pulses are reflected from boundaries between media in the body • The same transducer both produces the initial pulse and detects the reflected pulse • The resulting voltage has to be processed and used to build up an image which is displayed • The time delay gives the depth of the boundary within the body • The reflected intensity gives information about the nature of the boundary. • Reflected signals within a pulse which are received later need to be amplified as they have travelled further and so are more attenuated (this term will need explanation) • High frequency ultrasound is able to resolve smaller structures http://www.mrcophth.com/commonultrasoundcases/principlesofultrasound.html
KC1 / KC3 / KC4 14.6c	Understand the meaning of specific acoustic impedance and its importance to the intensity reflection coefficient at a boundary.	• Calculate the specific acoustic impedance of relevant materials such as soft tissue, air and bone. **(I)** • **Extension activity:** Calculate the intensity reflection coefficient for pairs of media given relevant data. **(I)** • Discuss how the value of the intensity reflection coefficient relates to the amount of ultrasound reflected or transmitted. • **Extension activity:** Worksheet (and mark scheme) prepared by you to practise applying these formulae. **(I)** **Note:** • This quantity needs to be defined as $Z = \rho c$ and learners should appreciate that c is the speed of ultrasound *in the medium.*

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• The intensity reflection coefficient should be understood as a quantity applied to a particular boundary and they should know its definition as the ratio I_R/I, usually given the symbol α, where: $$\frac{I_R}{I} = \frac{(Z_2 - Z_1)^2}{(Z_2 - Z_1)^2}$$ • The value of α depends strongly on the difference between the values of Z on either side of the boundary. The closer they are to one another, the less reflection there will be. http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/Physics/reflectiontransmission.htm
KC3 / KC4 14.6d	Recall and solve problems by using the equation $I = I_0 e^{-\mu x}$ for the attenuation of ultrasound in matter.	• Worksheet (and mark scheme) prepared by you to apply the formula. **(I)** • Discussion of the similarities to other exponential decay functions, for example the attenuation of X-rays in matter. • Develop the equation into a straight line plot. Supply data so graphs can be plotted and the attenuation coefficient found. **Note:** Learners should appreciate that this relationship is very similar to the equivalent one for the attenuation of X-rays in matter. They should also know: • μ is a constant for a medium which needs to be defined • the exponential nature of this relationship.
KC1 / **KC5** 8.1a	Understand the concept of a gravitational field as an example of a field of force and define gravitational field strength as force per unit mass.	• Learners draw diagrams of both *radial* and *uniform* fields to understand the idea that a spherical object has a gravitational field which becomes weaker as the distance from the centre increases. The spacing of the lines of force indicates the relative strength. **(I)** • Discuss when the gravitational field of a planet can be described as uniform. • Research the value of g on the surface of other planets / moons. • Learners discuss whether everyday objects, such as their pen, have their own gravitational fields. **Note:** • Learners will probably only be familiar with the gravitational fields of large objects in space, such as the Earth, Moon and planets. These will usually have been considered as uniform, for example the gravitational field of the Moon is taken as 1.7 N kg^{-1}. • Learners could make a list of the similarities and differences between electric, magnetic and gravitational fields as an exercise to be carried out during the course of this unit, and also Units 4 and 21.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.tap.iop.org/fields/gravity/400/page_46809.html http://www.schoolphysics.co.uk/age14-16/Astronomy/text/Planetary_gravity/index.html http://www.s-cool.co.uk/a-level/physics/gravitational-fields-and-forces http://www.antonine-education.co.uk/Pages/Physics_4/Fields/FLD_01/Fields_1.htm
KC1 / **KC5** 8.2a	Understand that, for a point outside a uniform sphere, the mass of the sphere may be considered to be a point mass at its centre.	• Discuss with learners the idea of centre of mass and how this can be applied when analysing gravitational fields. Lead on to the concept of a point mass.
KC1 / **KC3** / KC5 8.2b	Recall and use Newton's law of gravitation in the form $F = \frac{Gm_1m_2}{r^2}$.	• Brainstorm with learners what the force between two bodies with mass depends upon. Introduce the full law. • Learners find the units of *G* by rearranging the equation. It is important that they do not confuse *G* with *g*. **(I)** • Research on inverse square laws, what they are and other inverse square laws that exist in nature. Learners report back their findings. • Worksheet (and mark scheme) prepared by you to practise applying the equation. Include some problems which explore related but less conventional phenomena, such as tides, black holes, or the forces between neighbouring galaxies. **(I)** **Note:** • It will be helpful for learners if you show how this law is deduced, rather than just quoting it to them. You need to emphasise the nature of *G* as a universal physical constant, with its value and units. • Note that learners need to know how to state the law in words as well as give the formula. • They should note that the negative sign (often omitted) is due to the attractive nature of the force. • They must understand that this equation is used to find the force between *point* masses with radial fields, or objects whose separation is *very much larger* than their radii. *W* = *mg* is only used to find the force on a small object in a field which is being considered as uniform. http://www.tap.iop.org/fields/gravity/401/page_46813.html http://www.physicslab.co.uk/gravity.htm

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

KC3 / **KC5**
8.2c
	Analyse circular orbits in inverse square law fields, including geostationary orbits, by relating the gravitational force to the centripetal acceleration it causes.	• Discuss 'what provides the centripetal force for an object in a circular orbit around a planet?'
		• Learners find out about all three of Kepler's laws and their relevance to planetary and satellite orbits, using textbooks or the internet.
		• Learners to show that $T^2 \propto r^3$, by using either $v = 2\pi r/T$ or $\omega = 2\pi/T$ in the centripetal force equation. **(I)**
		• Discuss what a geostationary orbit is. Ask the question 'why it is that TV satellite dishes have to be angled very carefully when they are being set up, after which they do not move?'
		• Learners calculate the height of a geostationary orbit, using Kepler's Third law. **(I)**
		• Worksheet (and mark scheme) prepared by you to practise numerical problems using Kepler's laws. **(I)**
		
		Note:
		• The features of a geostationary orbit will hopefully emerge:
		  ○ A geostationary satellite orbits once every 24 hours
		  ○ It follows an east-west path
		  ○ Its orbit is directly above the Equator
		• These features mean it *appears* stationary when viewed from the Earth (so the dishes will not need to 'track' the satellite)
		
		http://www.tap.iop.org/fields/gravity/403/page_46830.html
		http://www.antonine-education.co.uk/Pages/Physics_4/Fields/FLD_03/fields_page_3.htm
		http://www.jcsu.jesus.cam.ac.uk/~rpc25/notes/physics/gravitation/index.html

KC1 / **KC3** / KC5 8.3a	Derive, from Newton's law of gravitation and the definition of gravitational field strength, the equation $g = \frac{GM}{r^2}$ for the gravitational field strength of a point mass.	• Learners to derive this relationship, knowing that g is the force on unit mass (i.e. the force when m = 1 kg). **Note:** • Learners should note that the negative sign is a consequence of the force being attractive.
KC3 / **KC5** 8.3b	Recall and solve problems using the equation	• Using suitable data plot a graph of g against r, which will give a curve (which is *not* exponential), and then another graph of g versus $1/r^2$ (which will give a straight line). Learners to understand why these curves are on the negative side of the horizontal axis. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	$g = \frac{GM}{r^2}$ for the gravitational field strength of a point mass.	• Learners find the radius and mass of the Earth to verify the value we use for *g*. Calculate the variation in *g* from the deepest sea trench to the top of Everest. • **Extension activity:** Worksheet (and mark scheme) prepared by you of numerical problems. Reinforce the idea that this relationship is used to find the gravitational field strength at a distance *r* from the *centre* of a large mass. **(I)** http://www.tap.iop.org/fields/gravity/402/page_46820.html
KC5 8.3c	Show an appreciation that on the surface of the Earth *g* is approximately constant.	• Use units to show that $m\,s^{-2}$ and $N\,kg^{-1}$ are exactly the same. **(I)** • As a group discuss 'acceleration due to gravity' and 'gravitational field strength'. Use Newton's second law to show that $a = g$. • Solve examples using $W = mg$. **(I)** http://www.tap.iop.org/fields/gravity/402/page_46820.html
KC5 8.4a	Define potential at a point as the work done per unit mass in bringing a small test mass from infinity to the point.	• Discussion based around the basic idea of gravitational potential energy = *mgh* in a *uniform* field, before going on to discuss the potential energy of the mass in a *radial* field. • Discuss the idea of equipotential lines. Ask learners to compare them to the contour lines seen on a geographical map. • Learners should draw some equipotential lines round a representation of a spherical mass, noting that they are always perpendicular to the lines of gravitational force if they are drawn in on the same diagram. **(I)** • Discuss an arbitrary zero for potential energy. It is taken as infinity, so ask learners to explain how the potential energy depends upon the separation of two objects. **Note:** • The concept of *infinity* needs to be established. Infinity can mean many different distances in different physical circumstances, but in a gravitational context you should encourage learners to think of it as 'far enough from a mass for the gravitational force to be negligible'. • Introduce the idea of *potential* at a point in a gravitational field as distinct from the *potential energy* of a mass in the field. Learners give a written definition of gravitational potential using the correct form of words. They should always understand 'potential' as the potential energy of unit mass; its units are therefore $J\,kg^{-1}$. http://www.tap.iop.org/fields/gravity/404/page_46842.html http://www.antonine-education.co.uk/Pages/Physics_4/Fields/FLD_02/Fields_page_2.htm

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.s-cool.co.uk/a-level/physics/gravitational-potential-energy
KC3 / **KC5** 8.4b	Solve problems using the equation $\phi = -\frac{GM}{r}$ for the potential in the field of a point mass.	• Learners plot a graph of ϕ versus *r*, using suitable supplied data, and compare it with the one drawn previously for *g* versus r^2. They will be able to see that the two curves are different shapes (and neither of them is exponential). **(I)** • Practise the use of this equation in the form: • change of potential energy of mass m in the field of *M*: $\Delta E = GMm\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$ **(I)** • Practise the idea that the gravitational potential energy and the kinetic energy of a satellite are exchanged as the height above the centre changes with problems where, for example, the radius of an orbit changes. **(I)** **Note:** • This equation does not need to be derived, but learners must appreciate the significance of the negative sign and note carefully that this relationship is *not* an inverse-square one, but depends on 1/r. http://www.revisionworld.co.uk/a2-level-level-revision/physics/fields-0/gravitational-fields-0

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

8: Thermodynamics

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / **KC4** 11.1a	Appreciate that thermal energy is transferred from a region of higher temperature to a region of lower temperature.	• Discuss the difference between heat and temperature. • Learners draw up a table showing these differences. • Learners write down three pieces of evidence from everyday life which indicate that thermal energy always flows from high temperature to low temperature (but never the other way round). **Note:** Temperature needs to be understood as a scale of 'hotness' indicating the direction of flow of energy, and heat to be understood as a form of energy which can transfer between places at different temperatures. http://www.tutorvista.com/physics/animations/thermal-equilibrium-animation
KC1 / **KC4** 11.1b	Understand that regions of equal temperature are in thermal equilibrium.	• Discuss what learners understand by the term 'thermal equilibrium'. • Learners should watch the online animation and read the relevant section in a textbook. **Note:** Learners need to be aware that 'thermal equilibrium' is a 'dynamic' situation, where the transfer of heat energy between two objects (or regions) is actively going on in both directions at exactly the same rate. It would be wrong for them to say that there is no transfer of thermal energy between them, although they could say that there is no *net* transfer, unlike that between objects at different temperatures. http://www.tutorvista.com/physics/animations/thermal-equilibrium-animation

KC1 / KC2 / KC4
11.2a
	Understand that a physical property that varies with temperature may be used for the measurement of temperature and state examples of such properties.	• Demonstrate several thermometers, each making use of a different physical property which changes with temperature. Learners will need to understand in each case what physical property is being used as a measure of temperature. These could include:
		  ○ Volume of a liquid in a glass tube
		  ○ Resistance of a wire or thermistor
		  ○ Thermoelectric e.m.f.
		  ○ The pressure of a fixed mass of gas at constant volume
		  ○ The colour of an electrically heated wire.
		• Measure the temperature of a Bunsen flame using a thermocouple. This will require calibration and the understanding of the concept of fixed points.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Practical booklet 11 http://www.s-cool.co.uk/a-level/physics/temperature-and-thermal-properties/revise-it/introduction-to-temperature
KC1 / KC3 / KC4 11.2b	Understand that there is an absolute scale of temperature that does not depend on the property of any particular substance (i.e. the thermodynamic scale and the concept of absolute zero).	• Discuss with learners of how the concept of absolute zero arises. • **Extension activity:** Learners research what is meant by the 'triple point of water', find out its temperature and pressure and why it is *defined* to be 273.16K. **Note:** Learners will need to appreciate that the thermodynamic scale of temperature is different from other scales because it is not set up using a particular property of a particular substance. The fixed points are absolute zero and the triple point of water. These are defined in such a way as to make 1 kelvin exactly the same size as 1 degree on the Celsius scale.
KC3 / KC4 11.2c	Convert temperatures measured in kelvin to degrees Celsius and recall that T / K = T / °C + 273.15.	• Provide a table with gaps so learners can practise converting between Kelvin and degrees Celsius. **(I)** Learners come up with the basic formula used in the conversion. • Worksheet (and mark scheme) prepared by you or from a textbook. **(I)** **Note:** • Many in the teaching group will have met this relationship already. They should take careful note that the difference between the two scales is actually 273.15, although in problems, the relationship is often approximated to $t = T - 273$ where t is the temperature on the Celsius scale and T is the temperature on the thermodynamic scale.

KC1 / KC2 / **KC4**
11.3a
	Compare the relative advantages and disadvantages of thermistor and thermocouple thermometers as previously calibrated instruments.	• Learners undertake this as a research task, drawing up a table to compare the two devices. **(I)**
		• You will need to discuss with learners aspects of each type, such as:
		  ○ Range
		  ○ Thermal capacity
		  ○ Physical size
		  ○ Linearity of scale
		  ○ Sensitivity
		  ○ Possibilities for remote operation
		
		http://www.miniphysics.com/2011/07/thermometric-property.html

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC2 / KC4 12.1a	Explain, using a simple kinetic model for matter: • the structure of solids, liquids and gases • why melting and boiling take place without a change in temperature • why the specific latent heat of vaporisation is higher than the specific latent heat of fusion for the same substance • why a cooling effect accompanies evaporation.	• Discussion around the spacing, motion and arrangement of molecules in the three states of matter. • As a revision exercise give learners a selection of words, statements and pictures and they divide them into three sections, one for each state of matter. • Discuss what happens on a particle level when thermal energy is supplied to matter. Use the kinetic theory apparatus and / or a computer simulation. • **Extension activity:** Experiment using data logging equipment to measure the temperature of ice heated at a steady rate until all has turned to water vapour. Plot a graph of temperature against time. Explain each of the key sections. • Research the values of specific latent heat for some well-known substances. Offer an explanation of why the latent heat of vaporisation is always higher than the latent heat of fusion for the same substance. Discuss and feedback to the group by some learners. • Discuss 'why do we feel cold when wet?' and 'why is this increased when there is a breeze?' • Learners answer questions involving evaporation, for example from a worksheet (and mark scheme) prepared by you or a textbook. **Note:** • The mistake of referring to *gas* molecules as *vibrating* should be highlighted at an early stage. • 'Latent' means 'hidden' (because no temperature change can be seen to take place while the change of state is happening). • Learners must appreciate the differences between the processes of evaporation and boiling. http://www.chem.purdue.edu/gchelp/atoms/states.html http://www.harcourtschool.com/activity/states_of_matter/ http://www.tap.iop.org/energy/kinetic/603/page_47443.html
KC1 / KC2 / KC3 / KC4 12.1b	Define and use the concept of specific heat capacity, and identify the main principles of its determination by electrical methods.	• Experiment to measure the specific heat capacity of a solid in the form of a cylindrical block, and also for a liquid, using electrical heating**.** They may need assistance with calculating the electrical heat energy supplied if this has not been studied yet. Equipment: copper or aluminium calorimeter (for a liquid) or a cylindrical block with appropriate holes (for a solid); electrical heater, ammeter, voltmeter, thermometer, timer, balance. **(I)** • Experiment with a block of metal heated in a Bunsen flame, then plunged into water to find the temperature of the flame. **(I)** • Worksheet (and mark scheme) prepared by you in two levels to practise applying this formula. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Note: • This quantity, with its unit, should be defined and memorised and learners should note the correct form of words to use. It should be understood as a constant for a specific material, regardless of the mass involved. • Learners need to be familiar with the principles of the determination of the specific heat capacities of both a liquid and a solid. **Practical booklet** 10 http://www.chm.davidson.edu/vce/calorimetry/SpecificHeatCapacityOfCopper.html http://www.iun.edu/~cpanhd/C101webnotes/matter-and-energy/specificheat.html
KC1 / KC2 / KC3 / KC4 12.1c	Define and use the concept of specific latent heat, and identify the main principles of its determination by electrical methods.	• Worksheet (and mark scheme) prepared by you of questions to practise calculations with the formula. **(I)** • Experiment or demonstration to measure specific latent heat. The heating of melting ice in a funnel and the rate of loss of mass of a kettle containing boiling water provide adequate methods. http://www.tap.iop.org/energy/thermal/608/page_47512.html
KC1 / KC4 12.2a	Understand that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system.	• Discuss with learners the concept of internal energy. • Learners read about internal energy in textbook and develop a clear picture of what internal energy means in solids, liquids and gases. **(I)** **Note:** • Learners should have in mind a picture of the randomly vibrating molecules of a solid when describing internal energy, in order to appreciate the use of the important phrase ‘random distribution’. • The use of the word ‘system’ may also need some explanation; it is used simply so that the idea of internal energy can be applied to a wide range of objects and states of matter. It refers to the total energy associated with the molecules of the system, for example, the molecules in a sample of a certain material. • A visual image, e.g. a video, may help learners with comprehension of the concept. http://www.antonine-education.co.uk/Pages/Physics_5/Thermal_Physics/THE_01/Thermal_page_1.htm

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC4 12.2b	Relate a rise in temperature of a body to an increase in its internal energy.	• Learners build their own model, including pictures, to link changes in molecular movement, internal energy and temperature rise. • Link with a graph showing temperature against time for changes of state. • Worksheet (and mark scheme) prepared by you should be provided as well as past paper questions. **Note:** • Learners need to understand that a rise in temperature must mean that energy has been transferred to the object. This energy is transformed into increased potential and kinetic energies of the vibrating molecules (only increased kinetic energy in the case of a gas). http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/hques.html

KC1 / **KC3** / KC4
12.2c
	Recall and use the first law of thermodynamics $\Delta U = q + w$ expressed in terms of the increase in internal energy, the heating of the system (energy transferred <u>to</u> the system by heating) and the work done <u>on</u> the system.	• Worksheet (and mark scheme) prepared by you to practise this idea and its applications. **(I)**
		Note:
		• It is important that learners appreciate that the internal energy of a system can be increased by two means:
		  ○ Heat transfer to the object
		  ○ Work done on the object by an external agency (e.g. electrically)
		• Often, an increase in internal energy is due to a combination of these two causes. Both constitute an energy transfer to the object.
		• Learners should also note that, if work is done *by* the system (e.g. a gas expands against the pressure of the atmosphere), the internal energy will decrease, meaning the temperature will be lowered.
		
		http://www.s-cool.co.uk/a-level/physics/thermodynamics-and-ideal-gases/revise-it/the-first-law-of-thermaodynamics

KC1 / KC3 1.2a	Recall the following SI base quantities and their units: amount of substance (mol).	• Learners research what the mol is and how it is defined. http://physics.nist.gov/cuu/Units/

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC3 1.3a	Understand that the Avogadro constant N_A is the number of atoms in 0.012 kg of carbon-12.	• Learners research the Avogadro constant as the number of carbon atoms in exactly 12g of C-12.
KC1 / KC3 1.3b	Use molar quantities where one mole of any substance is the amount containing a number of particles equal to the Avogadro constant N_A.	• Basic questions working out the number of mols, the number of molecules or the mass of a substance. **(I)** **Note:** • The relationship between the number of moles of a substance present and the number of molecules in the form $n = N/N_A$ will need to be understood. • You will need to stress the difference between 'mass' in kg and 'amount of substance' in mol with learners. • A mole of a substance should also be considered as being equal to the relative atomic or molecular mass of the substance measured in grams (for example, one mole of Nitrogen, N_2, has a mass of about 28g.
KC1 / KC2 / KC3 / KC4 10.1a	Recall and solve problems using the equation of state for an ideal gas expressed as $pV = nRT$, where n = amount of substance (number of moles).	• Ask learners what they understand by the phrase 'ideal gas'. • Practical work or demonstrations to show the three gas laws. Extrapolate the line on the graph when doing the pressure law to find absolute zero. • Discuss how the gas laws lead to the concept of absolute zero. • Ask learners how all three gas laws can be combined, leading on to the equation of state for an ideal gas. • Worksheet (and mark scheme) prepared by you to practise applying the gas laws as well as the equation of state. **(I)** **Note:** • Learners should understand that the three gas laws can be combined to give an equation $\frac{pV}{T} = \text{constant}$ for a fixed mass of gas. • For *one mole* of any ideal gas, the value of pV / T is 8.31 J mol^{-1} K^{-1}. Learners should have some understanding of this quantity, its unit and its name, the *molar gas constant, R*. So the combined gas law may be written as $pV_m = RT$ where V_m is the volume of 1 mole of ideal gas at pressure p and thermodynamic temperature T. For n moles, $pV = nRT$, which is the ideal gas equation. • Learners must check carefully that all the quantities are given in the correct units, and be able to make conversions if they are not. For example, °C may need to be converted to K, and cm^3 to m^3.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.tap.iop.org/energy/kinetic/601/page_47422.html http://www.tap.iop.org/energy/kinetic/602/page_47437.html http://www.s-cool.co.uk/a-level/physics/kinetic-theory/revise-it/the-gas-laws http://www.physicslab.co.uk/gas.htm http://www.khanacademy.org/science/chemistry/ideal-gas-laws/v/ideal-gas-equation--pv-nrt
KC1 / **KC2** / KC4 10.2a	Infer from a Brownian motion experiment the evidence for the movement of molecules.	• Learners observe a Brownian motion demonstration as well as computer simulation. • Discuss the results and what they are evidence for. Leading on to a discussion with learners how this effect provides evidence for rapid, random molecular movement. • **Extension activity:** Ask learners to consider the effect on the observed motion of changes in temperature and particle size. http://www.tap.iop.org/energy/kinetic/601/page_47422.html
KC1 / KC4 10.2b	State the basic assumptions of the kinetic theory of gases.	• Learners research what the ideal gas assumptions are. • Discuss with learners what these assumptions mean and why they are important. **Note:** • These assumptions should be understood as enabling us to gain a simplified model of real gas behaviour. It needs to be appreciated that real gases deviate to some extent from the idealised behaviour, but more strongly so under conditions of high temperature or pressure. Learners need to commit the assumptions to memory. http://www.s-cool.co.uk/a-level/physics/kinetic-theory/revise-it/kinetic-theory-assumptions
KC1 / **KC3** / KC4 10.2c	Explain how molecular movement causes the pressure exerted by a gas and hence deduce the relationship $pV = \frac{1}{3}Nm\langle c^2\rangle$ where N = number of molecules. [A simple model considering one-	• Learners to construct a paragraph explaining how a gas exerts a pressure on the walls of its container. Ask some or all to share what they have written. • Expand the above paragraph with discussion on why the pressure increases with temperature. • With some key prompts, learners derive this relationship. • Provide data from which learners calculate the mean and the root mean square in order to show the difference. **(I)** • Worksheet (and mark scheme) prepared by you to apply this formula. **(I)** **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	dimensional collisions and then extending to three dimensions using $\frac{1}{3}<c^2>=<c_x^2>$ is sufficient.]	• Learners should develop an understanding of the stages in the derivation of $pV = \frac{1}{3}Nm<c^2>$ based on one molecule moving between opposite faces of a rectangular box. • Learners should take careful note of when kinetic theory assumptions are used in the course of the derivation. They should be aware that $$< c^2 > = \frac{c_1^2 + c_2^2 + c_3^2 + \cdots .... + c_N^2}{N}$$ • This quantity is known as the *mean square velocity* of the molecules. • Learners also need to understand that the square root of this quantity, called the *root mean square velocity* (r.m.s. velocity), is an approximation to, but not the same as, the average speed of the molecules and is of the same order of magnitude as the speed of sound in the gas. • Learners should *never* refer to $<c^2>$ as the 'mean speed squared' of the molecules, and the r.m.s. value must not be confused with the average molecular speed. • Learners should also be aware that the quantity Nm/V is the density of the gas. The relationship may therefore be written as: $p = \frac{1}{3}\rho<c^2>$ • They can rearrange this to $<c^2> = 3p/\rho$**.** This illustrates that the mean square speed can be found from two easily measurable quantities, the pressure and the density. It can then be used as an *estimate* of the average speed of the molecules, which would be very difficult to measure directly. However, it is *not the same* as the average velocity. http://www.tap.iop.org/energy/kinetic/603/page_47443.html
KC1 / **KC3** 10.3a	Recall that the Boltzmann constant k is given by the expression $k = \frac{R}{N_A}$.	• Learners to research the Boltzmann constant, and how it is defined. • Worksheet (and mark scheme) prepared by you to apply the two versions of the equation of state, so learners must choose which version to use. **(I)** **Note:** Learners need to realise that for 1 mole of gas, $N = N_A$, $n = 1$ and $R = N_A k$, where k is the Boltzmann constant. In this context, they can think of k as the molar gas constant per molecule. The ideal gas equation can therefore be written in this way: $pV = nRT = nN_AkT = NkT.$ • This version is easier to use in solving some problems.
KC1 / **KC3** / KC4 10.3b	Compare $pV = \frac{1}{3}Nm<c^2>$ with	• Learners come to this conclusion through comparison of the two formulae.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	pV = *NkT* and hence deduce that the average translational kinetic energy of a molecule is proportional to *T*.	• Look at how the KE and velocity of different gas molecules varies with their mass at fixed temperature through calculations. • Worksheet (and mark scheme) prepared by you to apply this new relationship as well as any other formulae from this unit. **(I)** http://www.tap.iop.org/energy/kinetic/602/page_47437.html http://www.s-cool.co.uk/a-level/physics/kinetic-theory/revise-it/boltzmann-constant-and-ek

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

9: Electricity and electronics

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC5 17.3a	Understand that, for any point outside a spherical conductor, the charge on the sphere may be considered to act as a point charge at its centre.	• Learners draw diagrams to illustrate the field around a spherical conductor and a point charge. **(I)** • Discuss how the field around the spherical conductor is the same as that around a point charge. **Note:** You will need to illustrate this idea to learners pictorially, enabling them to understand that the field surrounding the metal sphere is radial, just like that from a point charge. Since the charge is distributed evenly over the surface, the field will have the same strength as it would if all the charge was concentrated at the centre. They should also understand that the field strength *inside* a hollow charged sphere is zero. http://hyperphysics.phy-astr.gsu.edu/hbase/electric/potsph.html

KC1 / KC3 / KC5
17.3b
	Recall and use Coulomb's law in the form
	$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$
	for the force between two point charges in free space or air.
		• Brainstorm with learners what the force between two point charges depends upon and draw out the equation from the discussion.
		• Learners research ε_0, its meaning and its units.
		• By inspection of the formula learners establish which quantities are constant. Lead on to Coulomb's law in the form:
		$F = \frac{kQ_1 Q_2}{r^2}$
		• Learners find the units this constant must have and compare with the units of the gravitational constant, *G.* **(I)**
		• Learners compare the magnitudes of the two constants and discuss the consequences of the difference; the value of *k* being about twenty orders of magnitude larger than *G.*
		• Worksheet (and mark scheme) prepared by you of exercises to solve problems. **(I)**
		
		Note:
		• You can highlight the very close similarities between this law and Newton's law of gravitation (8.2.b) when deducing it; give an outline deduction rather than merely quote the formula.
		• Learners should make careful note of the following points:
		  ○ They must be able to state the law in words, using the correct terminology, as well as use the formula
		  ○ The law is appropriate for *point* charges, or cases where the separation is *very much larger* than the radii
		  ○ This is another example of an inverse-square law

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.tap.iop.org/fields/electrical/407/page_46874.html http://www.s-cool.co.uk/a-level/physics/electric-fields-and-forces/revise-it/forces-in-electric-fields http://www.antonine-education.co.uk/Pages/Physics_4/Fields/FLD_04/Fields_4.htm
KC1 / KC3 / KC5 17.4a	Recall and use $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for the field strength of a point charge in free space or air.	• Using suitable data plot a graph of *E* versus *r*, which will give a curve (which is *not* exponential), and then another graph of *E* versus 1/*r* (which will give a straight line). **(I)** • **Extension activity:** Learners derive this relationship, knowing that *E* is the force on unit charge (i.e. the force when Q = 1 C). • Worksheet (and mark scheme) prepared by you of questions for learners to practise using this relationship in the correct way. **(I)** **Note:** Learners should note carefully the idea that a negative charge gives an attractive field (the line is under the horizontal axis) but a positive charge gives rise to a repulsive field (the line is above the horizontal axis).
KC1 / KC4 / KC5 17.5a	Define potential at a point as work done per unit positive charge in bringing a small test charge from infinity to the point.	• Learners compare electric and gravitational potential. **Note:** • The negative sign of all gravitational potentials will not apply to electric potentials at points in a repulsive (positive) field. Learners must be careful to define electric potential in terms of unit *positive* charge. • Learners must recognise the following features as common to both electric and gravitational potential: 　○ The arbitrary zero of potential is taken as infinity 　○ Equipotential lines are an alternative way to represent fields • They should read the relevant section of a textbook and write out the definition of electric potential at a point using the correct wording. http://www.s-cool.co.uk/a-level/physics/electric-potential/revise-it/electric-potential-v
KC1 / KC3 / KC5 17.5b	State that the field strength of the field at a point is equal to the negative of potential gradient at that point.	• Discuss walking or running uphill and the concept of doing work. What is the effect of a steeper hill? Introduce the concept of increase of potential energy per unit distance. • Worksheet (and mark scheme) prepared by you of exercises where learners have to equate field strength to negative potential gradient. **(I)** **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Assist learners with their understanding of the concept of potential gradient by asking them to consider walking or running uphill. They are doing work to increase their gravitational potential energy; the steeper the hill, the greater is the increase of potential energy per unit distance. For unit mass, the ratio Δ(GPE)/Δd is the (gravitational) potential gradient, i.e. rate of change of potential with distance. Some discussion, with suitable illustrations, of 'potential wells' may be helpful to demonstrate the varying nature of potential gradient in a radial field. • In the electrical case for a uniform field, learners will be able to see that the potential energy of unit charge would change at a steady rate as it moved between one plate and the other. The potential gradient is therefore constant, and measured in J C^{-1} m^{-1} or V m^{-1}. They will have already noted that the units of E are also V m^{-1}, so they can therefore justify equating field strength with potential gradient. • One more important point: learners must note that the electric potential, by definition, increases from the negative to the positive plate. But the direction of the field is opposite to this. This is the reason why the relationship has the negative sign: E = – (potential gradient) http://www.tap.iop.org/fields/electrical/408/page_46882.html http://www.s-cool.co.uk/a-level/physics/electric-potential/revise-it/potential-gradient
KC1 / KC3 / KC4 / KC5 17.5c	Use the equation $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ for the potential in the field of a point charge.	• Learners draw a graph of V versus r and compared with that for E versus r^2, they will see that the two curves are different shapes (and neither of them are exponential). **(I)** • **Extension activity:** Learners practise using this relationship to solve problems involving electric potential in a radial field. **(I)** **Note:** • Learners will find, as with the graphs of E against r^2, that their V-r graph is below the horizontal axis for a negative (attractive) field, but above the horizontal axis for a positive (repulsive) field. • It is instructive for learners to compare the units of measurement for gravitational potential (J kg^{-1}) and electric potential (J C^{-1}). The closeness of the similarity is sometimes not recognised because the unit J C^{-1} is usually expressed as V but there is no equivalent abbreviation for J kg^{-1}. http://www.antonine-education.co.uk/Pages/Physics_4/Fields/FLD_05/Fields_5.htm
KC1 / KC3 17.5d	Recognise the analogy between certain qualitative and quantitative aspects of	• Learners check their own lists against those in a textbook or prepared by you. **(I)** **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	electric fields and gravitational fields.	This should have been accomplished by the end of the unit if learners have been keeping a record of similarities throughout. http://www.s-cool.co.uk/a-level/physics/a-comparison-of-electric-and-gravitational-fields http://www.tap.iop.org/fields/electrical/409/page_46894.html
KC1 / KC2 / KC3 18.1a	Define capacitance and the farad, as applied to both isolated conductors and to parallel plate capacitors.	• Experiment to charge a capacitor at constant current. Plot a graph of charge against p.d. • Evaluate the gradient and define it as capacitance. Introduce the units of capacitance. • Demonstrate the parallel plate capacitor. Ask learners what the charge on the plates depends upon. (Separation, overlap area, material between plates). Recognise that capacitors store energy in the form of separated charges. • Learners build their own capacitors using their choice of materials. See which one stores the most energy. **(I)** **Note:** • The idea of capacitance will probably be new to learners. A good starting point would be for you to ask them (perhaps with a reminder in the form of a demonstration and illustrations) to consider the charging of the dome of a Van der Graaf generator. They will readily be able to appreciate that the device acts a store of charge (and hence energy); but they need to recognise also that the potential of the dome is increasing as well (at this point, you can ask them to recall the definition of electrical potential they met in the previous unit). They can then acquire a mental picture of increasing difficulty in adding further charge as it builds up (learners should notice that this is a repulsive field so potential is increasing positively). • They need to end this discussion with the idea that the less rapidly potential increases as charge is added, the more charge can be 'stored'. Thus the conductor will be able to store more charge for less 'effort'. • Learners need to be aware that the farad is, in practice, an impractically large unit. The capacitance of real capacitors is usually expressed in μF, nF or pF. A capacitance of, for example, 10,000 μF is very large! **Practical booklet** 7 http://www.physicslab.co.uk/capacitance.htm http://www.youtube.com/watch?v=X707xxqB1Qc http://www.youtube.com/watch?v=gOwJLgjRtw8 http://www.tap.iop.org/electricity/capacitors/126/page_46162.html http://www.tap.iop.org/electricity/capacitors/125/page_46154.html

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.s-cool.co.uk/a-level/physics/capacitors/revise-it/how-capacitors-work
KC3 18.1b	Recall and use $C = \frac{Q}{V}$.	• Worksheet (and mark scheme) prepared by you of questions to apply the formula. Examples of both isolated conductors and parallel-plate capacitors should be included. **(I)** **Practical booklet** 7
KC1 / KC3 18.1c	Derive, using the formula $C = \frac{Q}{V}$, conservation of charge and the addition of potential differences, formulae for combined capacitance for capacitors in series and in parallel.	• Derive with learners the relationships below: Capacitors in series: $\frac{1}{C_{\mathrm{TOTAL}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$ Capacitors in parallel: $C_{\mathrm{TOTAL}} = C_1 + C_2 + C_3 + \cdots$ http://www.tap.iop.org/electricity/capacitors/127/page_46171.html http://www.s-cool.co.uk/a-level/physics/capacitors/revise-it/capacitors-in-series-and-parallel http://www.youtube.com/watch?v=vAfwte8-7d4
KC3 18.1d	Solve problems using the capacitance formulae for capacitors in series and in parallel.	• Worksheet (and mark scheme) prepared by you of examples to practise these relationships. Include combinations of series and parallel. **(I)** • Learners draw circuits of how they would put together a combination of capacitors of the same value to achieve the required values you ask for. **(I)**
KC1 / KC2 / KC3 18.2a	Deduce, from the area under a potential-charge graph, the equation $W = \frac{1}{2}QV$ and hence $W = \frac{1}{2}CV^2$.	• Discuss the movement of charge while a capacitor is charging. Draw out the idea that work needs to be done on the electrons by the power supply to move them off one plate and on to the other. Hence the capacitor stores energy. • Ask for the definition of p.d. With this and a graph of charge against p.d. ask learners to deduce how to calculate the energy stored on a capacitor. • Ask learners to come up with three different versions of the equation. • Experiments to discharge capacitors through various resistors. Establish it is an exponential process. **(I)** • Experiment with a capacitor discharging through a component to see how much charge it stores or use a coulombmeter. See IOP website. **(I)** **Note:**

<table>
<tr><th>Syllabus ref. and Key Concepts</th><th>Learning objectives</th><th>Suggested teaching activities</th></tr>
<tr><td></td><td></td><td>This charging process can be considered as a separation of positive and negative charges. At first, the energy required to do this is minimum, but as charging continues, more and more work must be done to add more charge against the repulsion of what is already there. Thus the potential of the plates increases, and the charging process becomes slower and slower; it ceases altogether when the potential difference between the plates is equal to the potential difference of the power supply.
Because the capacitor, when charged, has equal magnitudes of positive and negative charge on the plates, we can say that the total charge is zero. For this reason, learners should come to regard it as more correct to think of a capacitor as storing energy rather than charge.
Learners must be very careful not to miss the '½' factor when using these equations to solve problems; this is a very common mistake. They need to realise that W represents the energy which the charged capacitor is storing, and which is hence available for use on discharging.
Practical booklet 7

http://www.tap.iop.org/electricity/capacitors/128/page_46177.html
http://www.s-cool.co.uk/a-level/physics/capacitors/revise-it/charging-and-discharging
http://www.tap.iop.org/electricity/capacitors/129/page_46197.html</td></tr>
<tr><td>KC2 / KC3
18.2b</td><td>Show an understanding of the functions of capacitors in simple circuits.</td><td>Learners research the uses of capacitors and feedback their findings. (I)
Learners watch the YouTube and do research to find out about some common situations where capacitors are put to use in circuits. (I)
Note:
A relatively short look at the physical construction of capacitors, including the high-capacitance electrolytic type, is helpful in advance of examining their practical use for certain functions. These functions can include:
blocking of direct currents
smoothing of rectified alternating currents
time delays in electronic circuits
tuning circuits in radio receivers
http://www.physicslab.co.uk/crdischarge.htm
http://www.youtube.com/watch?v=QjpalQQ9YRk</td></tr>
</table>

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

KC1 / KC3
21.1a
	Recall the main properties of the ideal operational amplifier (op-amp).	• Learners research the main properties of operational amplifiers, understand the symbol and its connections and how it can be used in practical situations.
		
		Note:
		• The operational amplifier (op-amp) needs to be understood by learners as a relatively complicated piece of circuitry which has a number of uses, one of which is to amplify very small changes in the output voltage from a potential divider which incorporates a sensor of some kind.
		• You will need to reassure learners that they do *not* need to know details of the internal circuitry of an op-amp (which is an 'integrated circuit'). However, they must appreciate the following points:
		  ○ An op-amp has two inputs. These are the inverting input (the voltage here has the symbol V^{-}) and the non-inverting input (symbol V^{+}).
		  ○ The output, V_{OUT}, is proportional to the difference between V^{-} and V^{+}, so that: $V_{OUT} = A_0(V^{+} - V^{-})$.
		  ○ A_0 is called the open-loop gain of the op-amp (typically of the order of 10^5)
		  ○ An ideal op-amp has a number of properties (described in textbooks, e.g. Sang p.475). Real op-amps do deviate to some extent from the ideal.
		• Learners should be able to list these ideal properties.
		• The symbol for an op-amp must be known and used in circuit diagrams.
		
		http://www.electronics-tutorials.ws/opamp/opamp_1.html

KC3
21.2a
	Deduce, from the properties of an ideal operational amplifier, the use of an operational amplifier as a comparator.	• A possible experiment: op-amp in open loop mode as a comparator. Use with thermistor to monitor temperatures. The output may be monitored with a voltmeter or use of LEDs may be considered.
		• Learners read and make notes from textbooks and/or the internet.
		
		Note:
		• The comparator circuit is one that compares two inputs (e.g. two light intensities or two temperatures). Learners should study the use of an op-amp in this way.
		• You will need to discuss a number of points which learners will find are unfamiliar, in particular:
		  ○ The use of a dual power supply.
		  ○ The concept of a zero-volt line.
		  ○ Saturation of the op-amp when the difference between V^{+} and V^{-} is very small. The concept of saturation will need further work.
		• The circuit diagram for the use of an op-amp as a comparator.
		
		http://www.electronics-radio.com/articles/analogue_circuits/operational-amplifier-op-amp/comparator.php

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC3 21.2b	Understand the effects of negative feedback on the gain of an operational amplifier.	• Practical demonstration of feedback. Discuss the concept of feedback with reference to everyday examples. • Draw a flow diagram to illustrate feedback. **Note:** • The ways in which negative feedback (learners should appreciate the reason for the use of the term 'negative' in this context) impacts on the gain of the op-amp. The benefits of negative feedback include: ○ Increased bandwidth (the range of frequencies over which there is constant gain ○ Less distortion • Greater stability of operation (i.e. less affected by environmental changes)
KC3 21.2c	Recall the circuit diagrams for both the inverting and the non-inverting amplifier for single signal input.	• Learners spend time, with discussion and interaction with you, drawing the circuit diagrams for both types of amplifier, gaining an understanding of how each one works and in what context**.** They must understand the concept of *saturation*. **(I)** • Learners compare their circuit diagrams with those on the suggested webpages. **(I)** • Learners answer questions, e.g. from a worksheet (and mark scheme) prepared by you or from a textbook. **(I)** • Experiments to find the gain of both inverting and non-inverting amplifiers. **Note:** • The best approach for learning objectives 21.2.c, d, e is to teach them together – see LO 21.2.c; for example, learners will not find it possible to gain an understanding of the workings of an inverting amplifier without studying the concept of the virtual earth approximation. For these three learning objectives, it is acceptable to omit the power supplies from the relevant circuit diagrams, and it is assumed, when describing the working of both types of amplifier, that the op-amps are not saturated. http://www.electronics-tutorials.ws/opamp/opamp_8.html http://www.electronics-tutorials.ws/opamp/opamp_2.html http://www.electronics-tutorials.ws/opamp/opamp_3.html
KC1 / KC3 21.2d	Understand the virtual earth approximation and derive an expression for the gain of inverting amplifiers.	• Discuss and study the virtual earth approximation. • Ask learners to explain the significance of the minus sign. **Note:** • See LO 21.2.c.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Learners must appreciate that the gain of an inverting amplifier is given by the following relationship: $$\text{gain} = \frac{V_{\text{OUT}}}{V_{\text{IN}}} = -\frac{R_{\text{f}}}{R_{\text{IN}}}$$ • The negative sign shows that when the input voltage is positive, the output voltage is negative and vice versa. Learners should have an understanding of how the virtual earth approximation leads to this expression for the gain of an inverting amplifier. http://www.electronics-tutorials.ws/opamp/opamp_2.html
KC3 21.2e	Recall and use expressions for the voltage gain of inverting and of non-inverting amplifiers.	• Study the circuit diagram and the way of working of a non-inverting amplifier, leading learners towards an understanding of the following: $$\text{gain} = \frac{V_{\text{OUT}}}{V_{\text{IN}}} = 1 + \left(\frac{R_{\text{f}}}{R_1}\right)$$ • Learners should note carefully the difference between this and the corresponding formula for the gain of an inverting amplifier. • Learners use practice questions from a worksheet (and mark scheme) prepared by you or a textbook. **(I)** **Note:** • See LO 21.2.c. http://www.electronics-tutorials.ws/opamp/opamp_3.html
KC2 21.3a	Understand that an output device may be required to monitor the output of an op-amp circuit.	• Demonstrate how the voltage output of an op-amp is used to operate relays, LED warning lamps, digital meters, motors, and other output devices. • Learners investigate some output devices in their own experiments, depending on the availability of the relevant equipment.
KC2 21.3b	Understand the use of relays in electronic circuits.	• Demonstrate that the 20 mA output from an op-amp cannot operate an output device. Then show that with use of a relay the output device will work. • Draw circuit diagrams showing the use of a relay. **(I)** **Note:** Learners need to appreciate that a relay can be used as an electromagnetic switch for output devices requiring larger currents. They should note the following points:

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• A relay is a remote *switch*, and does *not control* the device in any way • It uses a small current or voltage to switch on or off a large current or voltage • It can be considered to isolate the op-amp from damagingly high currents or voltages • A diode is connected across the relay coil to prevent a damaging back e.m.f. when the relay current is switched off http://en.wikipedia.org/wiki/Relay

KC2 / KC3
21.3c
	Understand the use of light-emitting diodes (LEDs) as devices to indicate the state of the output of electronic circuits.	• Discuss LEDs, their uses, the available colours.
		• Demonstrate that an LED only emits light when forward biased.
		• Demonstrate the use of two LEDs in a circuit to distinguish between a positive and a negative output from an op-amp.
		• Study the summary of the use of the relay and the LED as output devices, with the reasons for the need to calibrate meters. Use textbooks. **(I)**
		
		Note:
		• Learners should be aware of the following points:
		  ○ LEDs can be used to indicate the state of an output, i.e. positive, negative or zero
		  ○ They only use a current of about 20 mA
		• A resistor must be used in series with an LED to prevent damage from currents which are higher than this.

KC2 / KC3 21.3d	Understand the need for calibration where digital or analogue meters are used as output devices.	• Experiment: thermistor circuit with the output as a voltmeter. A calibration curve will need to be plotted. This is revision of work from Unit 20. • Discuss the advantages and disadvantages of non-linear scales e.g. a fuel gauge. • Questions to allow learners to become fully confident in their understanding of the concept of calibration. Include cases of a meter being used as an output device, in conjunction with a non-linear calibration curve. **(I)** **Note:** • There may be a need to revise the idea of calibration at this point, and you could refer learners back to Unit 15, where there was discussion about the calibration of various kinds of thermometer. They should appreciate that the use of LEDs would be appropriate to monitor the output of an op-amp in cases where, for example, the only information required is whether the temperature is above or below a particular value. If actual values of temperature are needed a meter must be used, and it is essential to know exactly how the meter reading is varying with the changes in the temperature.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Learners may have carried out a calibration exercise when studying Unit 20. In learning objective 19.4.b an activity to develop a curve of resistance against temperature for a thermistor is suggested. This 'calibration curve' can then be used to change any other measurement of resistance into the corresponding temperature.
KC2 19.4a	Show an understanding of the change in resistance with light intensity of a light-dependent resistor (LDR).	• Experiment using illumination of varying intensity shone on to an LDR in the circuit. Monitor the resistance of the LDR. **(I)** • Learners devise their own circuit diagram for the above experiment. • Sketch the graph of resistance against light intensity, noting resistance falls non-linearly with illumination. **(I)** **Note:** • Learners should realise that such a circuit as in the experiment could be used to monitor light intensity levels. http://www.tap.iop.org/electricity/resistance/111/page_45979.html
KC2 19.4b	Sketch the temperature characteristic of a negative temperature coefficient thermistor.	• Experiment to investigate the temperature response of a thermistor. Plot a graph of resistance against temperature. Again the variation is non-linear. • **Extension activity:** Learners could research semiconductor materials in an attempt to try to explain why the thermistor behaves so differently to a piece of metal. http://www.tap.iop.org/electricity/resistance/110/page_45969.html
KC1 19.4c	Show an understanding of the action of a piezo-electric transducer and its application in a simple microphone.	• Learners can research what the piezo-electric effect is; find out some of its uses, as well as finding out which crystals behave in this way. Piezo-electric transducers will already have been met as part of the study of ultrasound generation/detection. http://www.wisegeek.org/what-is-a-piezoelectric-transducer.htm
KC1 19.4d	Describe the structure of a metal-wire strain gauge.	• Discuss what a strain gauge is, the factors that affect the resistance of a wire, and therefore how a piece of wire can be used to monitor small movements. • Learners research practical uses, such as monitoring cracks in buildings. • Learners research the structure of a strain gauge and draw their own diagram. **(I)** **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Learners will already have seen that the resistance of a piece of metal depends on its length and area of cross-section. If such a wire is compressed or stretched, its resistance will therefore change. This idea can be used to detect small movements in a variety of situations.
KC1 / KC3 19.4e	Relate extension of a strain gauge to change in resistance of the gauge.	• Challenge learners to be able to explain how the strain gauge works with reference to the resistivity formula for small changes in resistance. • Worksheet (and mark scheme) prepared by you of questions to apply this relationship. **(I)** **Note:** By considering the relationship $R = \frac{\rho l}{A}$ learners will be able to understand that it is simpler to make the approximation that the area of cross-section remains constant when the wire is stretched. If this is taken to be the case, they should verify that $\frac{\delta R}{R} = \frac{\delta L}{L}$ • However, if the fact that the area of cross-section decreases during stretching is taken into account, the relationship becomes: $\frac{\delta R}{R} = 2\frac{\delta L}{L}$
KC1 / KC3 20.3c	Understand that an electronic sensor consists of a sensing device and a circuit that provides an output that can be registered as a voltage.	• Learners can summarise the stages of electronic sensors in this way by drawing a flow chart: • Sensing device → Processing unit → Output device. **(I)** • Learners carry out an investigation using a thermocouple to measure a high temperature (e.g. a Bunsen burner flame) as a further illustration. **(I)** **Note:** • Learners will have encountered some physical properties of various materials which can be used in sensing devices. Examples include the resistance of an LDR (can be used in a light sensor), the resistance of a thermistor (used in a temperature sensor), piezo-electric e.m.f. (in a movement sensor) and changes in the resistance of a wire in a strain gauge which can be used to measure the strain experienced by a sample of material.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Learners must appreciate from experiments carried out at the time that the change in the property has to be interpreted by a calibrated output device, such as an indicator lamp or a digital meter, which usually makes use of a corresponding change in voltage. • Learners should think of the processing unit as an electronic circuit which transforms the change in physical property from the sensing device into a voltage which is indicated by the output device
KC2 / KC3 20.3d	Explain the use of thermistors, light-dependent resistors and strain gauges in potential dividers to provide a potential difference that is dependent on temperature, illumination and strain respectively.	• Demonstrations or group practicals to illustrate how a potential divider provides a means by which a change in an environmental condition can be converted into a change in potential difference. • Carry out an investigation where a potential divider is constructed incorporating a thermistor and a fixed resistor. As the thermistor's temperature is changed, the p.d. across it will vary too; this can be used to monitor the way in which temperature is varying.

KC4
16.1a
	Appreciate that information may be carried by a number of different channels, including wire-pairs, coaxial cables, radio and microwave links, optic fibres.	• Learners (small groups) make a list of as many different forms of communication as they can think of (including historical ones such as smoke signals and fire beacons). Each group feeds back their suggestions and an overall list can be drawn up.
		• Learners research the nature, way of working and advantages and disadvantages of communication by:
		  ○ Wire pairs
		  ○ Coaxial cables
		  ○ Radio links of various frequencies
		  ○ Microwave links (e.g. with satellites)
		  ○ Optic fibres
		• A particular method can be given to each group, and a series of 'mini talks' arranged so that all group members have some knowledge about all the communication channels.
		
		http://en.wikipedia.org/wiki/File:Coaxial_cable_cutaway.svg
		http://www.jneuhaus.com/fccindex/spectrum.html
		http://computer.howstuffworks.com/fiber-optic2.htm
		http://wiki.answers.com/Q/What_is_microwave_and_satellite_communication?#slide=2

KC4 16.2a	Understand the term modulation and be able to	• Brainstorm the word modulation. • Learners research amplitude modulation and frequency modulation including its uses.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	distinguish between amplitude modulation (AM) and frequency modulation (FM).	• Learners draw and carefully annotate diagrams to explain amplitude modulation and frequency modulation. **(I)** **Note:** • You might need to start with some revision of the work on waves. • Learners will need to make a clear distinction between a carrier wave (high frequency) and the audio signal (at a typical sound frequency). • The idea of a 'piggy-back' would not be an unreasonable description, in order to convey the way in which this works. • Learners should understand *modulation* as a process where either the amplitude or the frequency of the carrier wave is altered by the information signal in order to 'carry' the information over far longer distances than would otherwise be possible. http://en.wikipedia.org/wiki/Amplitude_modulation http://www.youtube.com/watch?v=SmW4z76KgNQ http://www.youtube.com/watch?v=_5JyiFWLn-w
KC3 / KC4 16.2b	Recall that a carrier wave, amplitude modulated by a single audio frequency, is equivalent to the carrier wave frequency together with two sideband frequencies.	• Learners should investigate the representation of an amplitude modulated carrier wave as three separate frequencies: the carrier frequency f_s and two sidebands, which are at frequencies given by $f_c \pm f_a$. In addition, they should consider the factors which determine the relative amplitudes of the carrier and the two sidebands. • Introduce the concept of a frequency spectrum. This is essentially a graph of frequency against amplitude in the frequency range being considered.
KC3 / KC4 16.2c	Understand the term bandwidth.	• Investigate the shape of the frequency spectrum produced when the modulating signal is composed only of speech, and then when it is composed of music of different qualities. • Teach the term 'bandwidth' as the range of frequencies, equal to $2f_a$, occupied by the entire AM waveform.
KC4 16.2d	Recall the frequencies and wavelengths used in different channels of communication.	• As they progress through this unit, learners construct a data table listing the ranges of wavelengths and frequencies in each of the communication channels they encounter. **(I)** **Note:** • For every channel of communication, they study, learners should discover what range of frequencies and wavelengths are used, and the reasons for using that range. This relates to

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		learning objective 16.1.a, for example they should be aware that space waves used for satellite communication must have frequencies of over 30 MHz to avoid reflection by the ionosphere.
KC4 16.2e	Demonstrate an awareness of the relative advantages of AM and FM transmissions.	• Research to find the relative advantages and disadvantages of both AM and FM. **(I)** • Discussion to establish the main points, including considerations of interference, bandwidth, the number of stations which can share a waveband (range of wavelengths), attenuation, cost and complexity. http://www.diffen.com/difference/AM_vs_FM
KC4 16.3a	Recall the advantages of the transmission of data in digital form, compared with the transmission of data in analogue form.	• Learners research and draw analogue and digital signals. **(I)** • Discuss which forms of communication use which type of signal**.** • **Extension activity:** Learners construct a table to list and explain the advantages of digital transmission. **(I)** **Note:** • Learners should picture a digital signal as a series of 'highs' and 'lows' or '1s' and '0s' with no possible values in between those extremes. • Consideration of the reasons for recent changes from analogue to digital in TV and telephone systems can be used by learners to highlight the advantages of digital transmission. • They should note that digital signals *do* pick up noise and are attenuated just like analogue signals. The difference is that the digital version can be can be regenerated and the noise eliminated. • A *regenerator* should be considered as distinct from a *repeater amplifier*, which amplifies the noise as well as the signal. • Other advantages, such as the ability to attach extra bits to digital pulses to correct errors which might occur, should also be noted. http://www.differencebetween.net/technology/difference-between-analog-and-digital-transmission/ http://www.wikiforu.com/2012/09/digital-communication-advantages-over-analog.html
KC4 16.3b	Understand that the digital transmission of speech or music involves analogue-to-digital conversion (ADC) before transmission and digital-	• Demonstrate this with the use of a microphone, transmission system, optic fibre and loudspeaker. • **Extension activity:** Learners draw a block diagram of a digital transmission system. **(I)** **Note:** • Introduce the idea of a block diagram to represent the stages in a digital transmission system. The ADC and DAC are essential parts of such a system and learners need to appreciate the part they

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	to-analogue conversion (DAC) after reception.	play. The inner working of these devices is not essential but their role in modern systems must be understood, as well as the purpose of the parallel-to-serial and the serial-to-parallel converters.
KC3 / KC4 16.3c	Understand the effect of the sampling rate and the number of bits in each sample on the reproduction of an input signal.	• Give learners a voltage-time graph of an analogue signal. They take voltage samples at specified regular time intervals using 4-bit levels and they must understand why this would give 16 levels in all. Each sampled voltage should be given a binary number (they should note that, where the exact voltage does not coincide with a level, the nearest level *below* the actual voltage is taken. So 7.3 V would be sampled as 7 V). The 'recovered' signal can then be drawn as a series of 'steps'. • Repeat this, using the same analogue graph, but using twice the sampling frequency and 5-bit samples (allowing 32 levels). • Ask learners to look at their two sampled graphs and make some conclusions. ○ Increased sampling frequency reduces the 'step width'. ○ Increasing the number of bits in each sample reduces the 'step height' ○ The recovered signal is a more exact reproduction of the original signal ○ Less detail will be lost between samples. **Note:** • Before learners can understand this, they will need to look at and develop an understanding of the following ideas: ○ 'Sampling' of the analogue voltage output from, e.g., a microphone at regular time intervals ○ The representation of each sampled voltage by a binary number ○ The number of binary digits in each sample determines the number of sampling 'levels' possible ○ The terms 'bit', 'most significant bit' and 'least significant bit' • In real systems, sampling frequencies of the order of 44 kHz are used, with 8-bit samples. • Learners should have knowledge of Nyquist's rule. http://www.physicslab.co.uk/digitalsound.htm
KC3 / KC4 16.4a	Discuss the relative advantages and disadvantages of channels of communication in terms of available bandwidth, noise, crosslinking,	• Research these in small groups, using the internet, textbooks and other publications, followed by feedback to the group as a whole. **Note:** • Start with a short revision session to check that learners have the meaning of all the terms listed in this objective clearly defined and understood. They can then undertake a fairly comprehensive review, discussing and comparing the relative strengths and weaknesses of all the channels they have met in terms of these criteria.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	security, signal attenuation, repeaters and regeneration.	

KC4
16.4b
	Recall the relative merits of both geostationary and polar orbiting satellites for communicating information.	• Ask learners to tell you all they remember about geostationary satellites.
		• Learners draw up a table including the points below, as well as the relative merits of each type of satellite and the reasons for putting a satellite into that orbit. **(I)**
		• With diagrams discuss the uplink and downlink and what could happen when they overlap. Come to the conclusion the frequencies need to be different.
		
		Note:
		• Revise the reasons why TV relay satellites have to be in this kind of orbit.
		• The reasons why the uplink carrier frequency f_{up} is different from the downlink carrier frequency f_{down} should also be examined (and make sure the terms 'uplink' and 'downlink' are fully understood).
		• A study of *polar* orbits will enable the two kinds of orbit to be contrasted in the following respects:
		  ○ Height of orbit
		  ○ Period of orbit
		  ○ Orientation of orbit with respect to the Earth
		  ○ Coverage of Earth's surface
		  ○ Uses of satellites in the orbit
		• Why the type of orbit is best for the use?
		
		http://www-spof.gsfc.nasa.gov/Education/wlopolar.html
		http://searchmobilecomputing.techtarget.com/definition/geostationary-satellite

KC3 / KC4 16.5a	Understand and use signal attenuation expressed in dB and dB per unit length.	• Look at the power of the signal leaving Earth relative to the power arriving at a geostationary satellite. Calculate the ratio and introduce the idea of the logarithmic scale in order to provide more manageable numbers. • Learners research the terms 'attenuation' and 'signal-to-noise ratio'. • Learners read and make notes from textbook or internet. **Note:** • The most convenient unit for comparing power levels is the bel (B). Learners should define this as the ratio between two powers, using the relationship $\text{number of bels} = \log\left(\frac{P_1}{P_2}\right)$

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Rather than the bel, the ratio is usually expressed in decibels (dB) where 10 dB = 1 B. Learners should therefore appreciate that the relationship normally used is: $$\text{number of decibels} = 10\log\left(\frac{P_1}{P_2}\right)$$ • The use of the relationship in the form: $$\text{attenuation (in dB) per unit length} = \frac{1}{L}10\log\left(\frac{P_1}{P_2}\right)$$ should also be understood since this is an important feature of transmission lines, which of course vary in length. http://searchnetworking.techtarget.com/definition/attenuation
KC3 / KC4 16.5b	Recall and use the expression $number\ of\ dB = 10\ \lg\left(\frac{P_1}{P_2}\right)$ for the ratio of two powers.	• Worksheet (and mark scheme) prepared by you of problems and practice exercises in the use of this expression, so that they are confident about finding solutions to this type of question. **(I)** **Note:** • Revise, or even teach for the first time, the mathematical methodology for solving problems involving logarithmic relationships such as this. • Learners can be invited to recall work on the attenuation of ultrasound when travelling in a medium, covered in learning objective 14.6.d, which followed an exponential pattern. • They would have been introduced to *natural* logarithms (base *e*) at that time, but they must be fully aware that in this case, although the mathematical ideas are similar, the logarithms used here are *common* logarithms (base 10). There must be no confusion in the minds of learners between these different types of logarithm!

Past and specimen papers

Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

10: Electromagnetism

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

KC1 / KC5
22.1a
	Understand that a magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets.	• Discuss 'what is affected by a magnetic field?'
		• Simple investigation to attract metals other than iron or steel using a bar magnet. **(I)**
		• Experiment making an electromagnet and investigating the factors affecting its strength.
		• Demonstrate with iron filings or plotting compasses the magnetic fields around current carrying conductors.
		• Discuss whether this effect applies to all wires carrying currents.
		• **Extension activity:** Learners create a suitable table which they fill in throughout the unit, or use an extension of the one they constructed to compare gravitational, electric and magnetic fields. **(I)**
		
		Note:
		• The concept of a force field as a region of space in which a certain category of objects is influenced should be reinforced at the start of this unit. To assist in this you can remind learners about the background to gravitational fields and electric fields.
		• Discussion and simple demonstrations or experiments should establish the following at the outset:
		  ○ Iron and steel (the difference should be understood) are affected by magnetism
		  ○ There is no possibility of magnetising samples of most other metals
		  ○ Permanent magnets are made from steel and electromagnets from pure ('soft') iron
		  ○ A permanent magnet is the source of a magnetic field which exerts a force on other magnetic materials
		  ○ The idea of north and south poles and how they can't exist in isolation.
		
		Practical booklet 8
		
		http://solar-center.stanford.edu/magnetism/magneticfields.html
		http://www.ndt-ed.org/EducationResources/HighSchool/Magnetism/magneticfields.htm

KC1 / KC5 22.1b	Represent a magnetic field by field lines.	• Learners should plot experimentally the magnetic fields shown previously around a straight wire, a flat coil, an air-cored solenoid and an electromagnet (with iron core). See learning objective 22.4a in conjunction with this. **(I)** • Learners draw or are provided with diagrams of the magnetic fields, to ensure they have accurate versions to refer to. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Note: It is very likely that, at some previous stage of their scientific education, they will have drawn out the magnetic field of a bar magnet. Other magnetic fields can be revised or drawn out in simple practical activities, in particular the field pattern between the poles of a horseshoe magnet and between two bar magnets (firstly with like poles, then with opposite poles facing one another). http://www.tap.iop.org/fields/electromagnetism/411/page_46911.html
KC1 / KC2 / KC5 22.2a	Appreciate that a force might act on a current-carrying conductor placed in a magnetic field.	• Demonstrate the force on a current-carrying conductor in a magnetic field. • Discuss and show if possible the factors that alter the magnitude and direction of the force. • Learners apply Fleming's left-hand rule to a worksheet of examples prepared by you or in a textbook. **(I)** • **Extension activity:** Learners attempt to explain the origin of the catapult force after visualising the two magnetic fields involved and considering the spacing of the field lines. **Note:** • The conductor does not have to be perpendicular to the magnetic field for there to be a force; the size of the force varies with the sine of the angle between them (so the force is zero when the conductor is parallel to the field). However, the direction of the force is always perpendicular to the plane containing the field and the conductor. • The demonstrations and experiments serve to illustrate the three-dimensional nature of many magnetic effects. It would be sensible to warn learners at this stage that they will need to be prepared to 'think three dimensionally' and interpret three dimensional diagrams frequently. http://www.tap.iop.org/fields/electromagnetism/412/page_46925.html http://www.s-cool.co.uk/a-level/physics/forces-in-magnetic-fields/revise-it/the-motor-effect-and-flemings-left-hand-rule
KC3 / KC5 22.2b	Recall and solve problems using the equation $F = BIL\sin\theta$, with directions as interpreted by Fleming's left-hand rule.	• Experiment with a digital balance and a current in a clamped rod to show that the force is proportional to the current. • Worksheet (and mark scheme) prepared by you of questions to practise applying this formula. **(I)** **Note:** • It would be better for learners to see this equation deduced, rather than just seeing it quoted. You will need to include some explanation of the symbols, and it would probably be best to define the

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		quantity represented by the symbol *B* (magnetic flux density) and its unit, the tesla, at the same time. • The angle θ must be recognised as the angle between the magnetic field and the current direction. With three mutually perpendicular quantities to think about, there is room for confusion in learners' minds! • It would be preferable to cover learning objective 22.2.c beforehand, since an understanding of magnetic flux density and its unit will greatly assist learners in problem-solving when making use of this relationship.
KC1 / KC5 22.2c	Define magnetic flux density and the tesla.	• Learners research magnetic flux density and its unit. **(I)** **Note:** • These definitions need care and the wording used by learners must be correct. Magnetic flux density is defined by the equation: $$B = \frac{F}{Il}$$ • The word definition reflects this relationship and learners should include both in the list of similarities between force fields. *B* is comparable to the definitions of *E* (electric field strength) and *g* (gravitational field strength). • Encourage learners to use the phrase 'magnetic flux density', although magnetic field strength emphasises the links with the other two fields. • Learners should appreciate the values of some practical magnetic field strengths in real situations, e.g. the Earth's magnetic field. • A sense of scale can be given when they appreciate that a value of 1 T would be a *very* strong field (such as used in NMRI).
KC2 / KC3 / KC5 22.2d	Understand how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance.	• Experiment to use the current balance to find the magnetic flux density where apparatus permits. Effective current balances can be homemade. • Learners can make their own current balance using the method suggested on the Nuffield webpage. • Practice examples using the context of the current balance. You may need to revise the principle of moments. **(I)** **Note:** • This is one of several methods available for the measurement of magnetic flux densities. Learners should be aware of the following possibilities: ○ Using a current balance

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		○ Using a Hall probe ○ Using a search coil with alternating current ○ Observations of the force acting on a current-carrying conductor • Questions on the current balance should be given to learners to solve, but see learning objective 22.3.c for questions on the Hall effect. http://www.tap.iop.org/fields/electromagnetism/411/page_46911.html http://www.nuffieldfoundation.org/practical-physics/current-balance-0
KC1 / KC5 22.3a	Predict the direction of the force on a charge moving in a magnetic field.	• Firstly, discuss conventional current and electron flow. Then consider what happens when an electron or proton or other charged particle enters a magnetic field. • Using a diagram pose the problem of a charged particle entering at an angle. Learners to describe and explain the resulting helical path. They will need to consider two components of the velocity. • Practise using Fleming's left hand rule to find the direction of the force on a charge moving through a magnetic field in a variety of circumstances. Use a prepared sheet of diagram based examples. **(I)** http://www.tap.iop.org/fields/electromagnetism/413/page_46935.html
KC3 / KC5 22.3b	Recall and solve problems using $F = BQv \sin\theta$.	• Discuss with leaners how this formula arises form an analysis of $F = BIL \sin \theta$. • Worksheet (and mark scheme) prepared by you of examples for learners to apply this formula. **(I)** **Note:** You may want to cover learning objective 22.3.d beforehand, since an understanding of the deflection of charged particles in magnetic fields will greatly assist learners in problem-solving when making use of this relationship.
2.1a	use techniques for the measurement of length, volume, angle, mass, time, temperature and electrical quantities appropriate to the ranges of magnitude implied by the relevant parts of the syllabus. In particular, candidates should be able to:	• Practical work to use a Hall probe to investigate the magnetic field, for example, in and around a solenoid. • Practical work to construct a Hall probe. http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/hall.html

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	• use a calibrated Hall probe	
KC1 / KC3 / KC5 22.3c	Derive the expression $V_H = \frac{BI}{ntq}$ for the Hall voltage, where *t* = thickness.	• Discuss the structure of the Hall probe and ask learners to deduce how it works. • Discuss the nature and origin of the Hall effect. • Learners research the derivation of the equation for the Hall p.d. **(I)** • Discuss the need for calibration and introduce the expression given. • Worksheet (and mark scheme) prepared by you of examples to practise applying the formula. **(I)** **Note:** • Learners will need to become familiar with the term 'Hall slice' and appreciate that it is a thin, wide piece of semiconducting material. The slice is this shape and is made of this kind of material because the effect is most noticeable under those conditions. • Learners should note that the Hall effect is used in the determination of magnetic flux densities. Some details of how this could be carried out would be beneficial for learners as they become acquainted with the phenomenon. The device used in this way is called a 'Hall probe'. They should be very careful not to confuse this in answers to questions with 'flux-cutting' ideas. • The Hall effect is *not* an illustration of electromagnetic induction; there is no movement of the probe through the magnetic field whose flux density is being measured and no field lines are 'cut'. http://www.tap.iop.org/fields/electromagnetism/413/page_46935.html http://www.s-cool.co.uk/a-level/physics/forces-in-magnetic-fields/revise-it/the-hall-effect http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/hall.html
KC1 / KC5 22.3d	Describe and analyse qualitatively the deflection of beams of charged particles by uniform electric and uniform magnetic fields.	• Demonstrate the two types of deflection, if the apparatus is available. Otherwise use computer simulations. • Discuss the motion of a charged particle perpendicular to an electric field by using diagrams and showing that the motion is analysed in two perpendicular components, like a mass projected in a gravitational field. • Using diagrams discuss the force on the charged particle entering a magnetic field at right angles is always perpendicular to the velocity, hence circular motion results. • Take measurements from the fine beam tube deflecting the electron into a circle to find the specific charge of the electron. • Take measurements from the electron deflection tube with Helmholtz coils used to bring the beam back to horizontal in order to calculate the specific charge of the electron.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• For abler learners look at the structure of the cyclotron and discuss how it works. Apply relevant formulae for moving charged particles in a magnetic field and circular motion. http://www.s-cool.co.uk/a-level/physics/forces-in-magnetic-fields/revise-it/forces-on-charged-particles http://www.physicslab.co.uk/qpaths.htm http://www.youtube.com/watch?v=IGMzuKcSEAI
KC1 / KC3 / KC5 22.3e	Explain how electric and magnetic fields can be used in velocity selection.	• Learners draw a force diagram for an electron in suitably orientated electric and magnetic fields so that the beam is undeflected. • Use the formula for the forces to gain an expression for the velocity. Ask the learners to tell you what the velocity depends upon and discuss the significance of this. • Learners research the use of velocity selection, in particular the mass spectrometer. • Learners practise solving some quantitative problems using the velocity selection idea. They should derive the relationship $v = \frac{E}{B}$ for the selection of a particular velocity. **(I)** http://www.tap.iop.org/fields/electromagnetism/413/page_46935.html http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/maspec.html
KC3 / KC4 / KC5 22.3f	Explain the main principles of one method for the determination of v and $\frac{e}{m_e}$ for electrons.	• Learners consider the acceleration of the electrons by an electric field through a p.d. V and use the relationship • *Work done on electron = kinetic energy gained* or $eV = \frac{1}{2}m_e v^2$. **(I)** • Practise calculating the velocities of electrons in a beam using this relationship. They can also calculate speed from a circular orbit in a magnetic field of known flux density, or by using the velocity selector idea. **(I)** **Note:** • This ratio is the 'charge-to-mass ratio' and learners should be aware that, historically, this quantity was found before it became possible to find the mass separately. • Learners need to have knowledge of the way the ratio is calculated and to be able to give outline practical details of its determination. You can demonstrate the principles involved using the appropriate fine-beam tube. http://www.tap.iop.org/atoms/accelerators/518/page_47162.html

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC2 / KC5 22.4a	Sketch flux patterns due to a long straight wire, a flat circular coil and a long solenoid.	• By experiment or research learners draw out these flux patterns. They will require a three dimensional set-up and the use of a plotting compass will be found more convenient than using iron filings. Equipment: DC power source, long straight wire, flat circular coil and long solenoid with suitable cards placed appropriately for the plotting compass. **(I)** • Learners research and then discuss the direction of the magnetic field, using the right had rule as appropriate. • Learners research how the direction of the magnetic field is defined. Compare with electric and gravitational fields. **(I)** **Note:** • You may want to cover this learning objective at the same time as 22.1.a and 22.1.b • These magnetic flux patterns are best illustrated by demonstrations using iron filings or plotting compasses. The latter have the advantage that they show the directions of the fields; learners must be careful always to show the field directions when they draw these patterns. http://www.physicslab.co.uk/bfield.htm

KC1 / KC2 / KC5
22.4b
	Understand that the field due to a solenoid is influenced by the presence of a ferrous core.	• Practical work to see how an iron core can affect the strength of an electromagnet.
		• Learners compare the magnetic field of a bar magnet with the magnetic field of a solenoid.
		• Learners draw the magnetic field shape caused by a long current-carrying solenoid to discover that it is an exactly similar shape to that of a bar magnet. **(I)**
		Note:
		• Ensure that learners are confident with the meaning of the term ‘solenoid’.
		• Learners must appreciate that:
		  ○ A solenoid with no core acts as a weak electromagnet
		  ○ The addition of a ferrous (soft iron) core causes the magnetic field strength to increase markedly
		
		http://www.s-cool.co.uk/a-level/physics/magnetic-fields

KC1 / KC2 / KC5 22.4c	Explain the forces between current-carrying conductors and predict the direction of the forces.	• Show learners the experiments set up for this on a video (YouTube) or a picture. Challenge them to build the demonstration themselves. • Learners draw the magnetic field around the two wires with the current flowing the same way and then opposite ways. Ask them to use Fleming’s left hand rule to explain the attraction and repulsion that result.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Note: • The mutual nature of these forces must be emphasised. • The definition of the ampere can also be investigated as it is based on the physical situation of two parallel straight wires exerting a force on each other. http://www.tap.iop.org/fields/electromagnetism/412/page_46925.html http://www.s-cool.co.uk/a-level/physics/forces-in-magnetic-fields/revise-it/force-on-parallel-wires
KC1 / KC3 / KC5 22.4d	Describe and compare the forces on mass, charge and current in gravitational, electric and magnetic fields, as appropriate.	• Learners should have been working on a table showing this for some time. **(I)**

KC1 / KC4 / KC5
22.5a
	Explain the main principles behind the use of nuclear magnetic resonance imaging (NMRI) to obtain diagnostic information about internal structures.	• Watch a video or animation showing how NMRI works. Learners note the key details and the key terms.
		• Give learners a selection of sentences about how NMRI works and learners must order them logically.
		• Learners read the section in a textbook on this topic and answer questions. **(I)**
		• Learners try past paper questions as these will be descriptive rather than calculation based. **(I)**
		Note:
		• Learners will need to understand the meaning of the following:
		  ○ 'Spin' of atomic nuclei
		  ○ Precession of nuclei in a strong magnetic field
		  ○ Larmor frequency
		  ○ Relaxation time (there are two processes here)
		  ○ Hydrogen nuclei are the ones used in scans
		
		http://teaching.shu.ac.uk/hwb/chemistry/tutorials/molspec/nmr1.htm

KC1 / KC4 / KC5 22.5b	Understand the function of the non-uniform magnetic field, superimposed on the large constant magnetic	• Learners research the strength of the two magnetic fields involved including how much the variable one changes. Compare these values to other magnetic fields, such as the Earth's, or a horseshoe magnet. **Note:**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	field, in diagnosis using NMRI.	• The two magnetic fields are both important in NMRI and the function of each needs to make up an important part of the understanding by learners of this diagnostic technique: ○ A large (more than 1 T) constant, uniform magnetic field which gives all hydrogen nuclei the same Larmor frequency ○ The smaller, non-uniform ('gradient') field gives a different value of magnetic field at every point. ○ The combination of both fields allows hydrogen nuclei at a particular position in the body to be located and studied. • Learners must be careful to refer to hydrogen *nuclei*, not hydrogen atoms. http://en.wikipedia.org/wiki/Magnetic_resonance_imaging#External_links
KC1 / KC3 / KC5 23.1a	Define magnetic flux and the weber.	• Learners research the term magnetic flux and show how its unit, the weber, relates to the tesla. **Note:** • Learners should recall the concept of magnetic flux density from Unit 21 and they should be encouraged to develop a mental picture of this quantity in terms of a number of magnetic field lines in a region per unit area. This will lead easily to the relationship $B = \frac{\Phi}{A}$ • They can then define magnetic flux as the *total* number of magnetic field lines passing through a particular area. The definition can be represented by $\Phi = BA$. • The unit of magnetic flux is the weber, Wb, and they must define this in a similar way (the amount of magnetic flux with density 1 T passing through an area of 1 m^2). • Another point to note is that 1 T can be written as 1 Wb m^{-2}. http://www.tap.iop.org/fields/electromagnetism/414/page_46948.html
KC3 / KC5 23.1b	Recall and use $\Phi = BA$.	• Worksheet (and mark scheme) prepared by you of example questions to apply this relationship. Include examples where the magnetic flux density is not perpendicular to the area, the equation becomes $\Phi = BA\cos\theta$. **(I)** **Note:** • It is important for learners to try to solve a variety of problems making use of this relationship. However, since many questions involve the concept of flux linkage in conjunction with this formula, it would probably be best to cover the next learning objective (23.1.c) before giving learners a worksheet or using questions from textbooks.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.antonine-education.co.uk/Pages/Physics_4/Magnetism/MAG_04/Mag_field_4.htm
KC1 / KC3 / KC5 23.1c	Define magnetic flux linkage.	• Learners research the term *magnetic flux linkage*, including its unit. • Worksheet (and mark scheme) prepared by you or from textbook of example questions – see note in 23.1.b. **(I)** **Note:** • Learners should define magnetic flux linkage as the product of the number of turns and the total amount of magnetic flux. For a coil with N turns they should be able to show that: *Magnetic flux linkage* = $N\Phi = BAN \cos \theta$.
KC1 / KC2 / KC4 / KC5 23.1d	Infer from appropriate experiments on electromagnetic induction: • that a changing magnetic flux can induce an e.m.f. in a circuit • that the direction of the induced e.m.f. opposes the change producing it • the factors affecting the magnitude of the induced e.m.f.	• Demonstrations: ○ Moving a wire (with a sensitive voltmeter across the ends) between the poles of a horseshoe magnet ○ Moving a wire near to a magnet ○ Moving a magnet in and out of a coil ○ Moving a coil near to a magnet ○ Having two neighbouring coils, and switching an applied current on or off in one of them to induce an e.m.f. in the other coil ○ Putting a soft iron core into one of the coils to induce an e.m.f. in the other. • Demonstrate with a magnet and a coil that reversing the direction of the movement reverses the direction of the induced e.m.f. on the centre zero sensitive voltmeter. • Discuss through the attraction and repulsion of poles, force producing acceleration and the conservation of energy the idea that the induced e.m.f. opposes that change that made it. • Brainstorm what will affect the magnitude of the induced e.m.f. Demonstrate where possible and introduce the idea of 'rate of cutting of flux'. **Note:** • You will need to emphasise throughout these demonstrations that the induced e.m.f. only exists while the flux linkage is *changing.* This may or may not involve physical movement of one of the coils. • A clear distinction between the terms 'applied e.m.f.' and 'induced e.m.f.' must be made where necessary.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.tap.iop.org/fields/electromagnetism/414/page_46948.html http://www.s-cool.co.uk/a-level/physics/electromagnetic-induction/revise-it/flux-flux-linkage-and-how-do-you-induce-an-elect http://www.physicslab.co.uk/induce.htm http://www.antonine-education.co.uk/Pages/Physics_4/Magnetism/MAG_05/Mag_field_5.htm
KC3 / **KC5** 23.1e	Recall and solve problems using Faraday's law of electromagnetic induction and Lenz's law.	• Supply learners with problems to solve using both laws. Worksheet (and mark scheme) prepared by you or from textbook. **(I)** • Demonstrate with two long solenoids with one inside the other. The applied e.m.f. to the outer one and the induced e.m.f. in the inner one. Show these alternating e.m.f.s on a c.r.o. and discuss the two laws of electromagnetic induction through the gradient of the applied e.m.f. trace and the phase relationship. **Note:** The features of electromagnetic induction can be summarised by: • Faraday's law (refers to the magnitude of an induced e.m.f.) • Lenz's law (refers to the direction of the induced e.m.f.) http://www.s-cool.co.uk/a-level/physics/electromagnetic-induction/revise-it/faradays-law http://www.s-cool.co.uk/a-level/physics/lenzs-law

KC4 / **KC5**
23.1f
	Explain simple applications of electromagnetic induction.	• Demonstrate and discuss some applications of electromagnetic induction, e.g. turning a generator on and off load to feel the difference, dropping a magnet through a copper tube, braking a flywheel, magnet on a spring or pendulum type oscillation, the jumping ring demonstration.
		• Supply learners (small groups) with real life examples. Ask them to explain what is happening and present to the rest of the group/class. For example:
		  ○ e.m.f. induced in an aircraft wing in flight
		  ○ e.m.f. induced in a coil by changing flux
		  ○ opening or closing a metal window
		  ○ the transformer (studied in detail in unit 24)
		  ○ moving coil a.c. generator (theory of this not required)
		  ○ electromagnetic braking
		  ○ induction torch.

KC1 / KC3 24.1a	Understand and use the terms period, frequency,	• Brainstorm and discuss why electricity is generated as a.c.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	peak value and root-mean-square value as applied to an alternating current or voltage.	• Practical activity in groups (with worksheet giving instructions of how to investigate period, frequency, peak value and r.m.s. value), using a cathode-ray oscilloscope connected to a signal generator or variable a.c. source to establish the following: ○ The sinusoidal nature of the variation (although other variations are possible) ○ The existence of a steady frequency and time period (revision of these terms may be necessary from Units 8 and 9) ○ The meaning of the peak value. • Quickly recap these terms, possibly adding some others. Learners could match the key term with its definition. **(I)** • Discuss how the power of the alternating supply can be found since the value of the current is not constant. Lead on to the idea of the value d.c. current that would supply the same power and the concept of root mean square (already met in Unit 17). **Note:** • Discussions can focus on the relative ease of production on a very large scale compared to d.c., its ability to be sent economically over long distances, the essential role of transformers and the vast size of the electricity generating and distribution industries. http://www.s-cool.co.uk/a-level/physics/alternating-currents http://www.tap.iop.org/electricity/emf/123/page_46066.html
KC1 / KC3 24.1b	Deduce that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current.	• Ask learners to decide if the equations for d.c. circuits can apply to a.c. circuits. • Learners use the area under a sinusoidal power-time curve to deduce that the *mean* power is exactly half the *maximum* power (denoted by I_0^2R). This does not need to be proved mathematically, but they can use the fact that the power curve is also sinusoidal. **Note:** • You will need to ensure that learners understand that the same equations linking current, p.d. and power (e.g. $P = I^2R$) which they learnt in Unit 20 when studying d.c.circuits, apply with a.c. The difference is that the values are changing continuously, so only ‘instantaneous’ values can be considered. • They must also appreciate that the variation of power in the negative half of the cycle is exactly the same as that in the positive half. The direction of the current makes no difference. Learners should compare a power-time graph with that for current or voltage against time to illustrate this.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://www.tap.iop.org/electricity/emf/123/page_46066.html
KC1 / KC3 24.1c	Represent a sinusoidally alternating current or voltage by an equation of the form $x = x_0 \sin \omega t$.	• Discuss with learners the mathematical shape of the variation of the alternating current and p.d. Perhaps link to the ideas of the electrons performing SHM due to the applied p.d. • Worksheet (and mark scheme) prepared by you with example questions or from textbooks.
KC3 24.1d	Distinguish between r.m.s. and peak values and recall and solve problems using the relationship $I = \frac{I_0}{\sqrt{2}}$ for the sinusoidal case.	• Practice problems and questions, including examples where learners have to distinguish between peak and r.m.s. values, using the correct quantity as appropriate. **(I)** • Worksheet (and mark scheme) prepared by you or from textbooks. **(I)** • Although they do not need to prove mathematically that $$I_{\text{r.m.s.}} = \frac{I_0}{\sqrt{2}}$$ learners can look at how the name 'root-mean-square' comes about and the origin of the $\sqrt{2}$ factor. **(I)** • Learners could now mathematically show with equations that the mean power is half the peak power. http://www.tap.iop.org/electricity/emf/123/page_46066.html

KC1 / KC2 / KC3
24.2a
	Understand the principle of operation of a simple laminated iron-cored transformer and recall and solve problems using $\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$ for an ideal transformer.	• Learners research the structure of the transformer and become familiar with the names of its parts.
		• Demonstrate several basic electromagnetic induction experiments with a coil switched on and off next to another coil, linking the two with an iron core, then moving on to a.c. and the real transformer.
		• Use a transformer kit with a variety of turns in the primary and secondary to deduce the turns ratio formula.
		• Challenge learners to apply conservation of energy to an ideal transformer to come up with a relationship involving current.
		• Worksheet (and mark scheme) prepared by you of questions applying these new relationships or example questions of from textbooks. **(I)**
		
		Note:
		• The following concepts should be understood:
		  ○ The role of the iron core
		  ○ How a current in the primary coil gives rise to an induced e.m.f. in the secondary coil

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		○ The relationships between the number of turns, current and voltage in the primary and secondary coils ○ The connection between the primary (input) frequency and the secondary (output) frequency ○ The phase difference between the input and the output • Learners must be completely clear that there is no electrical connection between the primary and secondary coils. Energy is transferred entirely through the magnetisation of the iron core. • They should consider transformers as a *voltage* changing appliance. Although the associated current is also altered, their purpose is primarily to step the *voltage* up or down. http://www.tap.iop.org/fields/electromagnetism/416/page_46978.html http://www.s-cool.co.uk/a-level/physics/transformers-and-rectification/revise-it/transformers-and-the-turns-rule
KC1 24.2b	Understand the sources of energy loss in a practical transformer.	• Ask learners to come up with suggestions of how transformers lose energy. • Then ask learners to try to come up with ways in which these are reduced. **Note:** • Learners should understand that an *ideal* transformer is one where the input power is equal to the output power (i.e. $V_pI_p = V_sI_s$). In practice, though, there are always some energy losses between the primary coil and the secondary. • You can lead a discussion in which the reasons for the core being made of iron are established along with the purpose and nature of the laminations (learners should all have the opportunity to see a laminated core at close range). They should appreciate how eddy currents arise, why they cause energy losses in the transformer, and be aware of how the laminations reduce these losses (they do not, however, entirely *prevent* energy loss). • Such discussion should lead them to appreciate the following as the main sources of energy loss: ○ Flux losses from the iron core ○ Eddy currents in the core • They should also be aware that in modern transformers the energy losses are minimal (less than 1%). http://www.tap.iop.org/fields/electromagnetism/414/page_46948.html
KC1 / KC3 24.3a	Appreciate the practical and economic advantages of alternating current and	• Demonstrate a model transmission system both with and without the transformers to show how effective they are. Discuss where the energy loss occurs and why the use of transformers reduced this.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	of high voltages for the transmission of electrical energy.	• Calculation example working out the power loss due to heating in cables with high and low current to illustrate the need for high voltage transmission. • Discuss with learners where transformers are used in the home and why they are advantageous. • Research a 'switch-mode transformer'. **Note:** • You could draw learners' attention to the basic construction of the alternating current generator, and its relative ease of use in terms of straightforward technology on a very large scale. They should have an outline understanding of the working of a simple a.c. dynamo (which could be demonstrated as well) and this will need to be linked to the ideas of electromagnetic induction from Unit 22. http://www.tap.iop.org/fields/electromagnetism/416/page_46978.html http://science.howstuffworks.com/environmental/energy/power.htm http://www.antonine-education.co.uk/Pages/Physics_4/Magnetism/MAG_08/mag_field_page_8.htm
KC1 / KC2 24.4a	Distinguish graphically between half-wave and full-wave rectification.	• Demonstrate these waveforms on a c.r.o. • Discuss what 'rectification' means.
KC1 / KC2 24.4b	Explain the use of a single diode for the half-wave rectification of an alternating current.	• Ask learners to tell you what they remember about diodes. • Revisit the *I-V* characteristic for a diode. Ask learners to explain how the resistance of the diode changes. • Demonstrate half wave rectification on the c.r.o. Ask learners what has happed to the energy from the reverse half of the cycle. • Learners set up a circuit and observe the output across the load on a c.r.o. http://www.tap.iop.org/electricity/emf/122/page_46061.html http://www.s-cool.co.uk/a-level/physics/transformers-and-rectification/revise-it/rectification
KC1 / KC2 24.4c	Explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current.	• Construct a full-wave rectifier circuit using LEDs which would enable learners see the sequence in which the diodes conduct during rectification. • Draw and study the circuit of the bridge rectifier, exploring the orientation of the four diodes and how this orientation leads to the current direction through the load resistor during each half of the a.c. cycle.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC2 / KC3 24.4d	Analyse the effect of a single capacitor in smoothing, including the effect of the value of capacitance in relation to the load resistance.	• If possible, add a capacitor to the full-wave rectifier circuit above. • Look at c.r.o. traces for full-wave rectification and a smoothed output and note the ripple effect. Ask learners to tell you what could be changed to make the output smoother. Change the value of the capacitor and show there is still a 'ripple' effect. • Draw the smoothed output. **(I)**

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

11: Quantum physics

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC1 / KC4 25.1a	Appreciate the particulate nature of electromagnetic radiation.	• Ask learners what they think electromagnetic radiation is composed of. • Discuss the nature of electromagnetic waves, leading to a picture of oscillating perpendicular electric and magnetic fields. • Learners research the history of wave theory and particle theory, looking in particular at the work of Newton, Huygens, Einstein and Planck. • Set up a Geiger-Müller tube with a gamma source (or show a video of this). Learners listen to the irregular clicks, indicative of gamma rays behaving as particles. **Note:** Learners will have been using a wave picture to understand refraction, interference and diffraction, which are considered 'wave phenomena'. The existence of an alternative picture for the composition of electromagnetic radiation may surprise some learners, but they should review the evidence for it and come to accept that the two models coexist in the form of the 'wave-particle duality', which puzzled scientists for much of the twentieth century. http://www.s-cool.co.uk/a-level/physics/wave-particle-duality-and-electron-energy-levels/revise-it/wave-particle-duality http://www.youtube.com/watch?v=Q_h4IoPJXZw http://www.youtube.com/watch?v=5YW33tWPX34
KC1 / KC3 / KC4 25.1b	Recall and use $E = hf$.	• Ask learners what they understand by the terms: quantum, quanta, photon, photon energy. • Learners attempt simple problems involving the relationship $E = hf$; these should include examples where $E = \frac{hc}{\lambda}$ **(I)** **Note:** • Learners must appreciate that the energy of a single photon is proportional to its frequency and that Planck's constant is the link. • In combination with this, they should come to regard radiation as a 'series of pulses' in quantum situations.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://physics.about.com/od/lightoptics/f/photon.htm http://www.universetoday.com/74027/what-are-photons/
KC1 / KC4 25.2a	Understand that the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for a wave nature.	• Demonstrate the photoelectric effect using a zinc plate on a charged electroscope and irradiating it with ultra-violet light. • Explain the photoelectric effect with diagrams and/or a video. • **Extension activity:** Discuss how the observations of Einstein and Planck could not be explained satisfactorily using a wave-based analysis, whereas a quantum approach agreed in all respects with the evidence. **Note:** The reverse is true of interference and diffraction; the observations of these phenomena are perfectly explained by wave considerations. http://www.tap.iop.org/atoms/quantum/502/page_47014.html http://www.s-cool.co.uk/a-level/physics/quantum-physics http://www.physicslab.co.uk/photon.htm
KC1 / KC3 / KC4 25.2b	Recall the significance of threshold frequency.	• Practical to estimate the value of Planck's constant using the idea of threshold voltage using several LEDs emitting different colours. The wavelength emitted by each must be known or measured. This would be a good way to familiarise learners with the concept of a threshold voltage. **Note:** • Illustrate the concept of threshold frequency by reminding learners of the behaviour of an LED (see Unit 20) when in the forward direction; current does not flow (and no light is seen) until a minimum voltage is reached. This minimum voltage is the threshold voltage, the lowest voltage which gives a single electron enough energy to cause emission of a single photon; LEDs emitting shorter wavelengths have higher threshold voltages. • With the photoelectric effect the energy of a single photon in the incident light must be sufficient to release a single electron from the metal surface, leading to the 'threshold frequency'. http://www.tap.iop.org/atoms/quantum/501/page_47004.html
KC2 / KC4 25.2c	Explain photoelectric phenomena in terms of photon energy and work function energy.	• Ask learners to consider the photoelectric effect in terms of the photon energy, the work function energy and the kinetic energy of the released electron. They should apply the conservation of energy to the situation. • Learners research why some photoelectrons have less than the maximum kinetic energy.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Learners work through a textbook on this topic. • Learners should also define the term 'work function energy' and develop an understanding of this concept in terms of visualising electrons, including those at the surface, as inside a 'potential well'. http://www.tap.iop.org/atoms/quantum/502/page_47014.html
KC1 / KC4 25.2d	Explain why the maximum photoelectric energy is independent of intensity, whereas the photoelectric current is proportional to intensity.	• Brainstorm with learners the particle model explanation of more intense light. • Give learners these observations and ask them to explain using the particle model of light. **Note:** The term 'maximum photoelectric energy' must be understood as the maximum kinetic energy of emitted electrons from the metal surface, and 'photoelectric current' as the *rate* of emission.
KC3 / KC4 25.2e	Recall, use and explain the significance of $hf = \Phi + ½mv_{max}^2$.	• Worksheet (and mark scheme) prepared by you of exercises, in two levels, to use this relationship. **(I)** • Use past papers for formative assessment or homework. **Note:** Learners should now be able to understand how this equation arises if they have developed a clear picture of the quantum nature of the photoelectric effect.
KC1 / KC4 25.3a	Describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles.	• Ask learners to consider the question 'Can particles exhibit a wave nature?' • Learners revise diffraction and diffraction patters. Provide some diagrams / pictures, they explain what these show. • If possible, demonstrate the diffraction of electrons with an electron diffraction tube. If not use a video from the internet. • Explain to learners how the apparatus above works. Show the link between accelerating p.d. and diameter of diffraction ring. **)** • Ask learners whether an electron is therefore a particle or a wave. Discussion should conclude that moving electrons exhibit the properties of *both*. This was a puzzle for scientists over a long period of time. • You could also briefly discuss with learners the diffraction of other particles, such as neutrons. **Note:** You'll need to emphasise the conclusions: • Electrons show wave-like properties when they are *moving*

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• All things with mass (from other sub-atomic particles to large everyday masses) have an associated wavelength when moving • The wavelength is too small to be measured for masses which are much larger than those on an atomic order of magnitude. http://www.tap.iop.org/atoms/duality/506/page_47048.html http://www.tap.iop.org/atoms/xray/531/page_47309.html
KC3 / KC4 25.3b	Recall and use the relation for the de Broglie wavelength $\lambda = \frac{h}{p}$.	• Learners need to practise using the equation and suitable questions need to be supplied by you (with mark scheme). **(I)** • If an electron diffraction tube is available, you can demonstrate that increasing the voltage, and hence the speed of the electrons, causes the pattern of rings to change to a reduced radius. Learners should note that the equation $\lambda = 2d \sin \theta$ applies to electrons in exactly the same way as it does with wave diffraction, where *d* is the spacing of carbon atoms. **Note:** The de Broglie equation may be written $$\lambda = \frac{h}{mv}$$ Learners should appreciate that this should mean that faster electrons (or other particles with larger mass travelling at the same speed) will have shorter associated wavelengths. http://www.tap.iop.org/atoms/duality/507/page_47057.html
KC1 / KC4 25.4a	Show an understanding of the existence of discrete energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to spectral lines.	• Discuss with learners their pictures of electrons as they orbit the nucleus. Introduce the quantisation ideas of well-defined energy levels. A useful analogy is someone on a ladder; they can only be at certain heights above the ground, according to the positions of the rungs. It is not possible for them to be at any intermediate height. • Introduce the concept of measuring energy in electron volts, since they will be working with very small energies. Remind learners of the equation $W = qV$, then the conversion factor of 1.6×10^{-19} between eV and joules will be easy to grasp. Practice should be given in converting one to the other. **(I)** • Learners research and draw diagrams for the electron energy levels for some different atoms to show each is unique. **(I)** • Discuss what happens, in terms of energy, when electrons jump to a higher energy level, or fall to a lower energy level.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		• Show learners line emission and line absorption spectra and by discussion come to conclusions about the nature of the electron transitions for each. http://www.tap.iop.org/atoms/quantum/501/page_47004.html http://www.s-cool.co.uk/a-level/physics/wave-particle-duality-and-electron-energy-levels/revise-it/electron-energy-levels http://hyperphysics.phy-astr.gsu.edu/hbase/electric/ev.html http://dev.physicslab.org/Document.aspx?doctype=3&filename=AtomicNuclear_EnergyLevelDiagrams.xml
KC1 / KC4 25.4b	Distinguish between emission and absorption line spectra.	• Learners should understand the terms ionisation energy, ground state, line emission spectrum and line absorption spectrum. They could complete a worksheet with energy level diagrams given, where they are asked to draw possible transitions and find the frequencies of the emitted or absorbed photons. **(I)** • Demonstrate a real line spectrum. You can use a sodium lamp and a diffraction grating or glass prism, and it would be good to show them further examples to reinforce the idea that every element has a unique, characteristic spectrum. • Give learners a selection of line spectra and energy level diagrams and ask them to match them up. **Note:** • Learners should appreciate from the outset that line spectra are only seen in observation of *vapours*. They need to appreciate that absorption of light energy and its re-emission in all directions as electrons regain their lower energy positions produces an emission spectrum. • The emission and absorption spectrums for hydrogen (the simplest type of atom) should be studied and the correspondence between them regarding line frequencies should be noted carefully by learners. • The practical circumstances where an absorption spectrum (characteristic black lines superimposed on a continuous light spectrum) is produced must also be understood.
KC3 25.4c	Recall and solve problems using the relation $hf = E_1 - E_2$.	• Worksheet (and mark scheme) prepared by you of practice exercises to enable learners to gain confidence in its use to solve problems. **(I)**
KC1 / KC4 25.5a	Appreciate that, in a simple model of band theory, there are energy bands in solids.	• Learners research, make notes and draw diagrams of the model of energy bands in solids. To be done in conjunction with learning objective 25.5.b. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Note: • Learners must understand that this is an extension of the energy level model for isolated atoms, applied to a solid in which atoms are joined together. The previously discrete levels to spread into bands, within each of which there is a large number of energy levels which are close to one another, between certain limits. There are still distinct gaps between the bands. Learners need to develop a working knowledge of this model. http://hyperphysics.phy-astr.gsu.edu/hbase/solids/band.html http://www.doitpoms.ac.uk/tlplib/semiconductors/energy_band_intro.php
KC1 / KC4 25.5b	Understand the terms valence band, conduction band and forbidden band (band gap).	• Learners research the meaning of these terms. To be done in conjunction with learning objective 25.5.a. **Note:** These terms, which are applied to particular energy bands in solids, must be understood by learners in terms of differentiating between conductors and insulators. Diagrams and discussion will help learners to gain an insight into the band structures of both types of solid. http://madscientistchem.blogspot.co.uk/2006/09/conduction-and-band-theory.html
KC1 / KC4 25.5c	Use simple band theory to explain the temperature dependence of the resistance of metals and of intrinsic semiconductors.	• Learners to research online and use other resources to find out what differentiates a semiconductor from an insulator, and to explain this difference in terms of band theory. • The change of resistance with temperature of semiconductors and of metals can be investigated by different groups or pairs, with feedback to the whole group being given and questions asked in order to resolve uncertain points. Also include the term 'intrinsic' as a research task.
KC1 / KC4 25.5d	Use simple band theory to explain the dependence on light intensity of the resistance of an LDR.	• This can be included in the activity suggested for the previous learning objective, with the task of researching and explaining the reduction of resistance of an LDR as light intensity increases given to one pair or group. The results of the search will then need to be fed back to the rest of the group. **Note:** • Throughout the work on band theory, you will need to emphasise the importance of drawing clear diagrams to show how the theory accounts for the differences between various kinds of material.

<table>
<tr><th>Syllabus ref. and Key Concepts</th><th>Learning objectives</th><th>Suggested teaching activities</th></tr>
<tr><td>KC1 / KC4
25.6a</td><td>Explain the principles of the production of X-rays by electron bombardment of a metal target.</td><td>• Ask learners to find out the difference between X-rays and gamma rays. They also find out how X-rays are produced.
• Learners sketch a typical X-ray spectrum (intensity against wavelength or frequency) and to recognise the two distinct parts, each of which needs to be explained and identified. (I)

Note:
• Remind learners that X-rays are high frequency, short wavelength electromagnetic waves.
• They need to become accustomed to referring to these electrons, not by their speed, but by the p.d. they have been accelerated through, e.g. a 16 kV electron beam might be used in a particular case.
• The origins of both the continuous distribution of wavelengths and the sharp, characteristic peaks must be understood, and the reason for the abrupt cut-off at the short wavelength end. At this cut-off, the following relationship applies:
$$\mathrm{K.E.\ of\ electron} = eV = \frac{hc}{\lambda}$$
http://www.wikiradiography.com/page/Xray+Tube</td></tr>
<tr><td>KC4
25.6b</td><td>Describe the main features of a modern X-ray tube, including control of the intensity and hardness of the X-ray beam.</td><td>• Learners can be asked to sketch (or are provided with an outline of) a diagram of an X-ray tube and be aware of the following features, which should be labelled on their diagrams:
  ○ Heated filament (or hot cathode)
  ○ Large p.d. (20 kV → 100 kV)
  ○ Vacuum in tube
  ○ Cooled, rotating metal anode (they should explain why it has to be cooled)
  ○ X-ray window. (I)

Note:
The terms ‘tube current’ (which controls the intensity of the resulting X-ray beam) and ‘accelerating voltage’ (which controls the hardness) need to be appreciated. You will also need to ensure that learners understand the significance of the word ‘hardness’ as applied to the beam. The use of an aluminium filter across the window of the tube to absorb ‘soft’ X-ray photons should be discussed.</td></tr>
<tr><td>KC4
25.6c</td><td>Understand the use of X-rays in imaging internal body structures, including a simple analysis of the causes of sharpness and contrast in X-ray imaging.</td><td>• Learners can be shown some typical X-ray photographs of body structures taken in hospitals, and asked to discuss why this is referred to as a ‘shadow’ image. Various X-ray images can be found online.
• Learners research how sharpness and contrast can be maximised, and exposure minimised.</td></tr>
</table>

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities

		Note:
		• Learners will probably be aware of the use of X-rays to produce images of the bone structure, but they should realise that it is also possible to obtain images of other parts of the body in fine detail if there is sufficient difference between the absorbing properties of the organ under review and the surrounding tissues.
		• Learners must appreciate that the three main requirements of a high-quality X-ray image are:
		  ○ A high degree of sharpness (i.e. good definition of the edges or boundaries between body parts)
		  ○ Good contrast (i.e. a marked difference in the degree of blackening between neighbouring structures)
		• Minimum exposure to X-rays to gain the diagnosis required, since X-rays are harmful to cells.

KC3 / KC4 25.6d	Recall and solve problems by using the equation $I = I_0 e^{-\mu x}$ for the attenuation of X-rays in matter.	• Worksheet (and mark scheme) prepared by you of questions, perhaps with examples on both ultrasound and X-rays, to be given to learners. **(I)** **Note:** • In Unit 14, learners will have met an equation of very similar type concerning the attenuation of ultrasound in the medium through which it is passing. They will need to be reminded of this, and their attention drawn to the similarity between that equation and the one for the attenuation of x-rays. • If the work on ultrasound has not yet been covered, this would be a good opportunity to look at both simultaneously, and to reinforce this strong similarity; you will need to ensure, when they attempt problems, that they are able to deal with using natural logarithms and appreciate the exponential nature of the attenuation, and reinforce the term ‘attenuation’ if necessary.
KC4 25.6e	Understand the purpose of computed tomography or CT scanning.	• Learners make a list, with practical details, of the ways in which CT scanning differs from conventional X-ray photography and why it is more informative. **(I)** • Show X-ray images as well as CT images, and if possible a 3-D CT scan, to promote discussion. **Note:** The limitation of conventional X-ray images is that they are two-dimensional and therefore only show internal body structures as viewed from one particular angle. Learners should view CT scanning as an extension of this to give a three-dimensional image which can be rotated and hence viewed from all angles; this is basically achieved by taking many images (again using X-rays) from different angles and combining them. This greatly improves the ability of medical staff to make an accurate and informed diagnosis of health issues in patients.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		http://en.wikipedia.org/wiki/X-ray_computed_tomography
KC4 25.6f	Understand the principles of CT scanning.	• Using online resources and textbook references, learners should write a step-by-step account of the essential stages in the construction of a three-dimensional CT scan. **Note:** Learners will need to appreciate, through research and study, the following steps in the procedure: • A series of X-ray images taken from different angles are obtained for one thin ‘slice’ of the organ being investigated • All of these images are in the same plane • They are combined to give a complete image of that section or slice • More slices are imaged similarly • The images of successive slices are then combined • The result is a three dimensional image of the entire structure, which can be rotated and viewed from various angles • This takes a great deal of computing power • The procedure is also known as Computerised Axial Tomography (CAT) scanning. http://www.mashpedia.com/X-ray_computed_tomography
KC3 / KC4 25.6g	Understand how the image of an 8-voxel cube can be developed using CT scanning.	• Learners find out what a voxel is. • Learners work in small groups to discuss and study the procedures. • Practice questions should be given to the groups to help them gain confidence in understanding the way in which the image is constructed from data. A worksheet involving image construction will need to be provided. **(I)** **Note:** The concept of a voxel as a small cubic unit of a section or slice, and the analogy in three dimensions with a two-dimensional pixel in a flat image, will need some discussion and thought.

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

12: Nuclear physics

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC3 / KC4 / KC5 26.3a	Show an appreciation of the association between energy and mass as represented by $E = mc^2$ and recall and use this relationship.	• Ask learners if they have come across the equation $E = mc^2$. They will probably give a wide variety of contexts, not all of them scientific. • Considering a nucleus, for example helium, look at the mass of the nucleus and the total mass of all the constituent nucleons. • Revise the concept of an electron-volt as a unit of energy and work out the rest mass energy of various particles. • Worksheet (and mark scheme) prepared by you or from textbooks, with example questions. **(I)** • Worksheet (and mark scheme) prepared by you of example questions to practise applying this formula. **(I)** **Note:** • Learners should develop the concept that there is a difference, and that the mass of the separated nucleons is greater than the combined mass of the nucleus before separation. As each nucleon is lifted out of its 'potential well', work must be done to pull it away from the attraction of the strong nuclear force (this term may need revision). The consequent increase of potential energy is what increases the mass. • Learners will need to get used to the idea of expressing both masses and energies in this context in eV and MeV. It can equally be applied to masses too because mass and energy must be thought of as being interchangeable. As you progress through the unit, they should come to have a feeling for the quantities of energy and mass involved. http://www.youtube.com/watch?feature=player_embedded&v=AgwDNLBRqjQ http://www.youtube.com/watch?v=ogSTvmouXkM&feature=player_embedded
KC3 / KC4 26.3b	Understand the significance of the terms mass defect and mass excess in nuclear reactions.	• Learners look at examples, as described in 26.3.a, to explain these terms. • Learners show that 1 u is equivalent to about 931 MeV. • Problems to practise using the correct units in the correct context, and to gain confidence in the use of mass-energy equivalence. **(I)** http://www.youtube.com/watch?v=rXer6qidxQM http://www.curriculum-press.co.uk/

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC3 26.3c	Represent simple nuclear reactions by nuclear equations of the form $^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \rightarrow {}^{17}_{8}\text{O} + {}^{1}_{1}\text{H}$	• Give learners a selection of equations with some missing numbers to deduce. **(I)** **Note:** The notation and the need for conservation of proton and nucleon numbers will require revision and practice. http://www.s-cool.co.uk/a-level/physics/atomic-structure/revise-it/decay-equations http://www.tap.iop.org/atoms/radioactivity/512/page_47107.html
KC4 26.3d	Define and understand the terms mass defect and binding energy.	• Learners should memorise the definitions of mass defect and binding energy. **(I)** **Note:** • Learners must be able to define these terms, using the correct form of words, and understand binding energy as the work done or energy required to separate the nucleons in a nucleus far apart (or to infinity). They could also define this quantity as the energy given out when the nucleons come from being far apart to form the nucleus. Either definition is quite valid. Mass defect is defined as in 26.3.b. • You could constructively point out that 'infinity' in this context merely means far enough from the nucleus to be out of the influence of the strong nuclear force. This will actually be a very small distance. • It is important that learners talk about the *nucleons* in a *nucleus* when defining binding energy and mass defect. It is quite wrong to refer to the separation of atoms, isotopes, elements or nuclides in this context; the use of the right vocabulary is essential to give the correct meaning. http://www.tap.iop.org/atoms/stability/525/page_47241.html

KC3 / KC4
26.3e
	Sketch the variation of binding energy per nucleon with nucleon number.	• Ask learners what will happen to the binding energy when the number of nucleons in the nucleus increases.
		• Supply a table of data of binding energy for a number of nucleons. Learners work out the binding energy per nucleon. Discuss why this is more useful that the total binding energy.
		• Learners sketch the shape of binding energy per nucleon against *A.* Also look at textbook or internet examples noting the following points:
		  ○ Maximum B.E. per nucleon is at about nucleon number = 50.
		  ○ This is where the 'potential well' for every nucleon is deepest.
		
		• Either side of the maximum, the nuclei are less stable. **(I)**

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
KC4 / KC5 26.3f	Explain what is meant by nuclear fusion and nuclear fission.	• Divide the class into small groups, with some given the task to look into the fusion of light nuclei, and others asked to find out about the fission of large nuclei. Feedback between the 'fission' and the 'fusion' researchers will then be required. **Note:** • The two processes have similar names but are opposites of each other, so learners must be quite clear to spell the names correctly; even a slight misspelling could lead to confusion between them. • You will need to discuss with learners the nature of both processes and some discussion about the occurrence of both these processes in man-made and natural situations would be an advantage, and examples of both types of reaction should be discussed. http://www.tap.iop.org/atoms/fission/527/page_47258.html http://www.s-cool.co.uk/a-level/physics/nuclear-energy
KC4 26.3g	Explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission.	• Ask learners to locate those nuclei that undergo fusion and those which undergo fission on the graph from 26.3.e. and hence describe and also explain what is happening to the binding energy per nucleon. **(I)** **Note:** • Learners will need to understand that when a large nucleus disintegrates, the 'daughter' nuclei have lower nucleon number, and hence larger binding energy per nucleon. The release of energy in fission can then be explained in terms of the nucleons having reduced potential energy, or being deeper inside a potential well. In practical fission processes, the parent nucleus splits into two approximately equal halves, each of which has nucleon number larger than 50. • In a similar way, the release of energy in fusion reactions can be explained by learners. • An interesting discussion point would be to investigate the reasons behind the large amount of money which has been spent over more than 50 years in attempting to harness the process of nuclear fusion for the commercial generation of electricity. This has so far not proved to be possible, but experiments are still in progress. http://www.tap.iop.org/atoms/fission/528/page_47281.html http://hyperphysics.phy-astr.gsu.edu/Hbase/nucene/fusion.html
KC3 / KC4 26.4a	Infer the random nature of radioactive decay from the fluctuations in count rate.	• Learners listen to the count rate in a demonstration of background radiation and appreciate the random nature of the fluctuations. • Measure count rate, using background radiation over a period of some minutes.

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
		Note: At the outset, you will need to ensure that learners distinguish clearly between radioactive decay and fission or fusion. They will have carried out previous work on this subject, but you can expect their knowledge to be sketchy, and in all probability, a good deal of revision of all aspects of decay processes will be required, including the nature and properties of α-particles, β-particles and γ-rays. http://www.tap.iop.org/atoms/radioactivity/509/page_47071.html
KC4 26.4b	Show an appreciation of the spontaneous and random nature of nuclear decay.	• The random nature of radioactivity can best be appreciated by listening to the background count made audible. • The spontaneous and random nature of the emissions of alpha tracks in a cloud chamber (from a video clip) is demonstrated by the impossibility of predicting when a track will appear, and in what direction; learners should be encouraged to consider that if a particular nucleus could be selected, it would not be possible to indicate when it disintegrates. http://www.tap.iop.org/atoms/accelerators/519/page_47183.html http://www.youtube.com/watch?v=a9tl7O7AWhE
KC3 26.4c	Define the terms activity and decay constant and recall and solve problems using $A = \lambda N$.	• Learners research the terms count-rate and activity. • Learners research the link between the activity and the number of nuclei, and find out what the decay constant is. • Learners find the decay constant for a number of different nuclides, and discuss what larger and smaller values mean. • Practice questions on a worksheet making use of this relationship should be given. **(I)** **Note:** The decay constant should be defined as the probability that a particular nucleus will decay per unit time; learners could be asked to deduce that the units of the decay constant are s^{-1}. http://hyperphysics.phy-astr.gsu.edu/hbase/Nuclear/halfli2.html http://www.s-cool.co.uk/a-level/physics/radioactive-decay-equations
KC3 / KC4 26.4d	Infer and sketch the exponential nature of radioactive decay and solve problems using the relationship	• Practical to simulate radioactive decay (see online resources). This involves using a large number of small wooden cubes (at least 500), each with one face painted a particular colour. Dice would be a perfectly acceptable alternative. They should draw an appropriate graph using the results, and thus become familiar with the concept of exponential decay. **(I)** • Learners consider the relationship:

Syllabus ref. and Key Concepts	Learning objectives	Suggested teaching activities
	$x = x_0 e^{-\lambda t}$, where x could represent activity, number of undecayed nuclei or received count rate.	$$\frac{\Delta N}{\Delta t} = -\lambda N$$ **Extension activity:** Ask them to explain the negative sign. • More able learners can then be shown how $N = N_0 e^{-\lambda t}$ is a solution of the above. • Learners should be given a variety of problems to solve using this relationship, including examples where the equation appears in the form $A = A_0 e^{-\lambda t}$ or $X = X_0 e^{-\lambda t}$ where N is the number of undecayed nuclei, A is the activity and X is the received count rate. **(I)** **Note:** Learners will need to appreciate that there are a number of natural processes in which the magnitude of a physical quantity is proportional to the rate at which it is changing (e.g. the charge on a discharging capacitor, or the pressure in a leaking container of gas). http://www.nuffieldfoundation.org/practical-physics/simple-model-exponential-decay http://www.tap.iop.org/atoms/radioactivity/515/page_47139.html
KC3 / KC4 26.4e	Define half-life.	• Learners plot, or use a computer to do so, an exponential decay curve using data from the decay of nuclei. **(I)** • Use the above graph to find the half-life of the nuclide. **(I)** • Learners look up the half-life of some nuclides. They then find some practical applications and why their half-life is important, e.g. carbon dating, smoke alarm. http://www.tap.iop.org/atoms/radioactivity/514/page_47129.html http://www.tap.iop.org/atoms/radioactivity/509/page_47071.html
KC3 26.4f	Solve problems using the relation $\lambda = \frac{0.693}{t_{\frac{1}{2}}}$.	• From the understanding that after a time equal to one half-life the number of radioactive nuclei remaining has fallen to $0.5N_0$, learners should be able to deduce that, at that time, $$\frac{1}{2}N_0 = N_0 e^{-\lambda t_{½}}$$ From this, they can be asked to deduce the required relationship. **(I)** • A variety of problems should be given to learners to solve, so that they become confident in the context and use of this relationship. **(I)** http://www.tap.iop.org/atoms/radioactivity/516/page_47147.html

Past and specimen papers
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support **(F)**

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