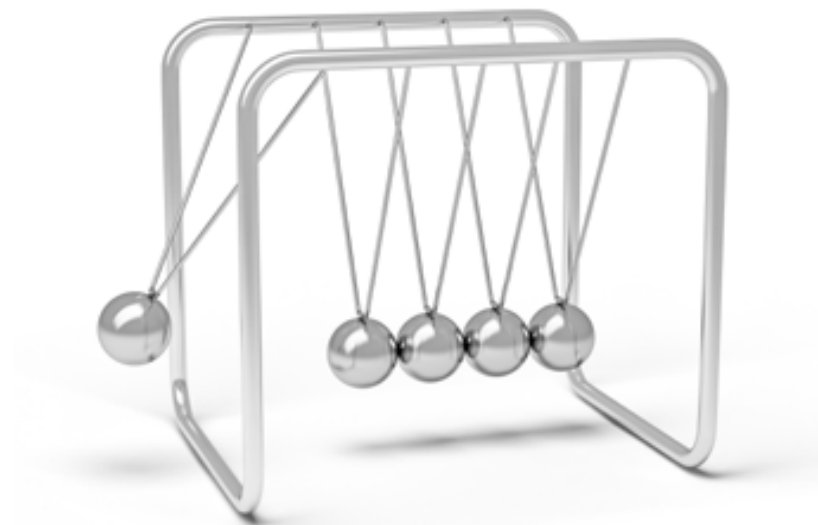


Scheme of Work

Cambridge International AS & A Level Physics 9702

For examination from 2022



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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 judgement 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 are highlighted as a separate item in the new syllabus. Reference to the key concepts is made throughout the scheme of work using the key shown below:

Key Concept 1 (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.

Key Concept 2 (KC2) – Testing predictions 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.

Key Concept 3 (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.

Key Concept 4 (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.

Key Concept 5 (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 with different magnitudes that interact over different distances. Physics involves study of these interactions across distances ranging from the very small (quantum and particle physics) to the very large (astronomy and cosmology).

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 (% of the course)	Suggested teaching order
1 Physical quantities and units	It is recommended that this unit should take about 5% of the AS level course.	1
2 Kinematics	It is recommended that this unit should take about 10% of the AS level course.	2
3 Dynamics	It is recommended that this unit should take about 12% of the AS level course.	3
4 Forces	It is recommended that this unit should take about 10% of the AS level course.	4
5 Work, energy and power	It is recommended that this unit should take about 5% of the AS level course.	5
4 Density and pressure & 6 Deformation of solids	It is recommended that this unit should take about 8% of the AS level course.	6
7 Waves & 8 Superposition	It is recommended that this unit should take about 20% of the AS level course.	7
9 Electricity & 10 D.C. circuits	It is recommended that this unit should take about 20% of the AS level course.	8
11 Particle physics & 23 Nuclear physics	It is recommended that this unit should take about 10% of the AS level course. It is recommended that this unit should take about 8% of the A level course.	9
12 Motion in a circle	It is recommended that this unit should take about 6% of the A level course.	10
13 Gravitational fields	It is recommended that this unit should take about 5% of the A level course.	13
14 Temperature, 15 Ideal gases & 16 Thermodynamics	It is recommended that this unit should take about 15% of the A level course.	12
17 Oscillations	It is recommended that this unit should take about 12% of the A level course.	11
18 Electric fields	It is recommended that this unit should take about 8% of the A level course.	15

Topic	Suggested teaching time (% of the course)	Suggested teaching order
19 Capacitance	It is recommended that this unit should take about 8% of the A level course.	14
20 Magnetic fields & 21 Alternating currents	It is recommended that this unit should take about 12% of the A level course.	16
22 Quantum physics	It is recommended that this unit should take about 8% of the A level course.	17
24 Medical physics	It is recommended that this unit should take about 8% of the A level course.	18
25 Astronomy and cosmology	It is recommended that this unit should take about 10% of the A level course.	19

Resources

You can find the endorsed resources to support Cambridge International AS & A Level Physics on the Published resources tab of the syllabus page on our [public website](#).

Endorsed textbooks have been written to be closely aligned to the syllabus they support, and have been through a detailed quality assurance process. 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. In addition to reading the syllabus, teachers should refer to the specimen assessment materials.

Test Maker is our new online service that makes it easy for teachers to create high-quality, customised test papers for their learners using Cambridge questions. Design a test for your whole class, or create individual tests for each learner. You can select questions depending on the level of difficulty and the assessment objectives they test. Test Maker is available from the School Support Hub www.cambridgeinternational.org/support

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 are 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.

www.falstad.com/mathphysics.html

www.khanacademy.org/science/physics

www.mathsisfun.com/physics/index.html

<https://phet.colorado.edu>

www.physicsclassroom.com

www.physicslab.co.uk

<https://sciencing.com>

<https://spark.iop.org>

www.stem.org.uk

<https://studynova.com/lecture/physics/>

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...'.
 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 (KC)	Learning objectives	Suggested teaching activities
	1.4.2 Add and subtract coplanar vectors. 1.4.3 Represent a vector as two perpendicular components.	<p>Demonstrate how to add vectors in the same direction and in the opposite direction, as well as how to draw appropriate diagrams. Learners should have seen simple examples of these at Cambridge IGCSE (or equivalent).</p> <p>Introduce how to add vectors graphically. Learners must establish an accurately draw angles. You can demonstrate the head to tail method of two vectors. Learners should practise adding and subtracting pairs of vectors (see mathwarehouse.com link).</p> <p>Introduce how to add vectors at right angles to each other mathematically using the Pythagorean theorem and trigonometry. Learners should practise finding the angle of the resultant vectors for any perpendicular vectors they have previously added. You could use online simulations or diagrams to visually demonstrate this.</p> <p>Set learners more questions for practice. (F)</p> <p>Introduce how to resolve a vector into vertical and horizontal components using trigonometry (see s-cool.co.uk link). You could again use online simulations or diagrams.</p> <p>Direct learners to practise resolving vectors into components. (F)</p> <p>Learners require different amounts of time to understand vectors so provide lots of examples of varying difficulty and be prepared to take the struggling learners through simpler examples step-by-step until they feel confident.</p> <p>Extension activity: Have harder questions for the stronger learners to work through.</p> <p>Learners can investigate the addition of vectors and their components further using the various simulations. (I)</p> <p>Head to tail and parallelogram methods to calculate a resultant vector: www.mathwarehouse.com/vectors/resultant-vector.php</p> <p>Vectors: www.mathsisfun.com/algebra/vectors.html</p> <p>Teacher notes and learner worksheets from the Institute of Physics (IoP) on scalars and vectors: https://spark.iop.org/episode-201-scalars-and-vectors</p> <p>Vector addition simulations:</p>

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

Formative assessment (F) is ongoing 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.

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.

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

Past and specimen papers

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

1 Physical quantities and units

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
1.1 Physical quantities 1.2 SI units KC3	1.1.1 Understand that all physical quantities consist of a numerical magnitude and a unit. 1.1.2 Make reasonable estimates of physical quantities included within the syllabus. 1.2.1 Recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K). 1.2.2 Express derived units as products or quotients of the SI base units and use the derived units for quantities listed in this syllabus as appropriate. 1.2.3 Use SI base units to check the	<p>Discuss the importance of units. Why are units used? Why do physical quantities require a unit?</p> <p>Present the prefixes and their symbols for learners to order. This can be done as a simple card sort activity in small groups or as a class on the board.</p> <p>Go through the prefixes and their symbols in order, present the multiplication factor and introduce the importance of standard form (e.g. mega, M, is 1 000 000 or 10^6 in standard form). Learners should recall and 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) and tera (T).</p> <p>You can use interactive websites (see links) to give learners a sense of scale in the real world. (I)</p> <p>Test learners' understanding of the prefixes with simple examples both mathematical (such as conversions between km/h and m/s, cm and nm, s^{-1} to ps^{-1}, etc) and their meaning (e.g. can learners read a sentence with the prefixes added in? 'When the 10³ 10⁹bots attacked carrying 10¹²ball 10⁻³obes, it wasn't long before they 10⁻¹mated all 10⁻²ent life.' - 'When the KiloNanobots attacked carrying Teraball Miliobes, it wasn't long before they Decimated all Centient life.') (F)</p> <p>Ask learners what the base quantities might be. Introduce the SI base quantities and match their units.</p> <p>Set learners the task of simplifying derived units they know into SI base quantities e.g. the Newton is $kgms^{-2}$.</p> <p>Alternatively lay out a match up task of derived units and their SI base quantities.</p> <p>Pick some simple equations learners have learnt from Cambridge IGCSE Physics (or its equivalent) and direct them to check the homogeneity of the units e.g. momentum = mass x velocity. Momentum is measured in Ns or $kgms^{-1}$, the latter being the units for mass x velocity. A Newton is a $kgms^{-2}$ so $Ns = kgms^{-2}s = kgms^{-1}$. Therefore, the units are the same.</p> <p>Set learners more questions for practice. (F)</p> <p>Notes and questions:</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>homogeneity of physical equations</p> <p>1.2.4 Recall and use prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units.</p>	<p>www.s-cool.co.uk/a-level/physics/units-quantities-and-measurements</p> <p>Interactive websites showing the scale of the real world: www.nikon.com/about/sp/universscale/scale.htm https://scaleofuniverse.com</p>
<p>1.3 Errors and uncertainties</p> <p>KC3</p>	<p>1.3.1 Understand and explain the effects of systematic errors (including zero errors) and random errors in measurements.</p> <p>1.3.2 Understand the distinction between precision and accuracy.</p> <p>1.3.3 Assess the uncertainty in a derived quantity by simple addition of absolute or percentage uncertainties.</p>	<p>Discuss where errors come from. Pick an example like measuring a distance with a metre rule, the temperature of water using a thermometer, the time to walk across the room with a stopwatch, etc. Ask learners 'What is the error in your measurement? What does it depend on? What can you do to minimise the error?'</p> <p>Ask learners what they think the difference between a systematic error and a random error might be. A simple example of a systematic error is a zero error. This can happen when measuring a height from a desk with a 30 cm ruler and the measurer forgets that the ruler does not start at zero. This will introduce approximately +0.5 cm error for every measurement of the height. Another example of a zero error is forgetting to set a top pan balance to zero before taking a measurement of mass. Systematic parallax errors can be introduced by reading measurements at an angle, such as the temperature from a thermometer or the distance from a metre rule. Parallax errors can be avoided by reading measurements at eye level. An example of a random error is when a set of measurements are made, one may be read in error e.g. if all the readings, except one, are read at eye level.</p> <p>Discuss precision and accuracy. You could use the 'bull's-eye' analogy (see mathsisfun.com link below) to help explain the difference. A result may be accurate and not precise e.g. if the measured value is close to accepted value, but there is a lot of scatter on the graph and/or a large range in the repeated measurements. A result may be precise but not accurate e.g. if the measured value is very different to the accepted value, but the results are consistent then there is a small range and little scatter on the graph. A precise but inaccurate result may be due to systematic error.</p> <p>Introduce absolute and percentage uncertainty. Make use of examples when explaining these (see links below).</p> <p>Direct learners to think about what the absolute uncertainty would be in a measurement of distance using a 30 cm ruler, thickness using vernier callipers, time using a stopwatch, etc. It may be worth discussing human reaction time and its significance when taking measurements of time using a stopwatch versus automated electronic timers.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Demonstrate how to calculate absolute and percentage uncertainty for a derived quantity. For example, using $F = ma$, the percentage uncertainty in F is the sum of the percentage uncertainty in m and the percentage uncertainty in a. Why use the percentage uncertainty when adding the uncertainties, rather than the absolute uncertainty?</p> <p>Direct learners to practise the identification and calculation of uncertainties through a simple measurement circus. Measurements can include: the time for one pendulum swing, the rebound height of a tennis ball, the thickness of a sheet of A4 paper, the length of a piece of A4 piece of paper, etc. Learners should think about which measurement instrument should be used; preferably one that will introduce the smallest absolute uncertainty. They should also consider how to use repeated measurements to improve the absolute uncertainty of their measurement e.g. when timing a pendulum swing it will be more accurate to time for 20 swings, rather than one.</p> <p>Set learners questions on errors and uncertainties for practice. (F)</p> <p>Learners can also practise the addition of uncertainties. They can find the density of a block of material by measuring mass and volume. They should carefully consider the absolute uncertainties and calculate the percentage uncertainties. They can then add the percentage uncertainties of mass and volume to find the percentage uncertainty in the density. They should express their final answer of density with the absolute uncertainty. (I)</p> <p>Bull's-eye analogy of precision and accuracy: www.mathsisfun.com/accuracy-precision.html</p> <p>Absolute and percentage uncertainty notes and examples: https://sciencing.com/how-to-calculate-uncertainty-13710219.html www.bellevuecollege.edu/physics/resources/measure-sigfigsintro/f-uncert-percent/</p> <p>Absolute and percentage uncertainty video explanation: https://studynova.com/lecture/physics/measurement-and-uncertainty/absolute-fractional-percentage-uncertainty/</p>
1.4 Scalars and vectors KC3	1.4.1 Understand the difference between scalar and vector quantities and give examples of scalar and vector quantities	<p>Direct learners to sort the following quantities into scalars and vectors: displacement, distance, speed, velocity, acceleration, volume, mass, momentum, force, work done, energy, temperature, torque, charge, voltage and frequency.</p> <p>Discuss the difference between work done and momentum as an example of two similar equations with the same units, but they have different meanings and one is a scalar, while the other is a vector.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>included in the syllabus.</p> <p>1.4.2 Add and subtract coplanar vectors.</p> <p>1.4.3 Represent a vector as two perpendicular components.</p>	<p>Define scalar and vector and ensure learners have clear examples for each.</p> <p>Demonstrate how to add vectors in the same direction and in the opposite direction, as well as how to draw appropriate diagrams. Learners should have seen simple examples of these at Cambridge IGCSE (or equivalent).</p> <p>Introduce how to add vectors graphically. Learners must establish an appropriate scale and use a protractor to accurately draw angles. You can demonstrate the head to tail method or the parallelogram method for the addition of two vectors. Learners should practise adding and subtracting pairs of vectors graphically (see mathwarehouse.com link).</p> <p>Introduce how to add vectors at right angles to each other mathematically using Pythagoras' theorem. Remind learners of sine, cosine and tangent functions for finding the angle of the resultant vector. Learners can now check the resultant vectors for any perpendicular vectors they have previously added graphically with this mathematical method. You could use online simulations or diagrams to visually demonstrate this.</p> <p>Set learners more questions for practice. (F)</p> <p>Introduce how to resolve a vector into vertical and horizontal components using trigonometry (see s-cool.co.uk link). You could again use online simulations or diagrams.</p> <p>Direct learners to practise resolving vectors into components. (F)</p> <p>Learners require different amounts of time to understand vectors so provide lots of examples of varying difficulty and be prepared to take the struggling learners through simpler examples step-by-step until they feel confident.</p> <p>Extension activity: Have harder questions for the stronger learners to work through.</p> <p>Learners can investigate the addition of vectors and their components further using the various simulations. (I)</p> <p>Head to tail and parallelogram methods to calculate a resultant vector: www.mathwarehouse.com/vectors/resultant-vector.php</p> <p>Vectors: www.mathsisfun.com/algebra/vectors.html</p> <p>Teacher notes and learner worksheets from the Institute of Physics (IoP) on scalars and vectors:</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>https://spark.iop.org/episode-201-scalars-and-vectors</p> <p>Vector addition simulations: https://phet.colorado.edu/en/simulation/vector-addition www.physicsclassroom.com/Physics-Interactives/Vectors-and-Projectiles/Vector-Addition/Vector-Addition-Interactive www.falstad.com/dotproduct/</p> <p>Resolving vectors into components: www.s-cool.co.uk/a-level/physics/vectors-and-scalars-and-linear-motion/revise-it/resolving-vectors-into-components www.physicsclassroom.com/Class/vectors/u3l1e.cfm</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

2 Kinematics

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
2.1 Equations of motion KC1 KC3	2.1.1 Define and use distance, displacement, speed, velocity and acceleration. 2.1.2 Use graphical methods to represent distance, displacement, speed, velocity and acceleration. 2.1.3 Determine displacement from the area under a velocity–time graph. 2.1.4 Determine velocity using the gradient of a displacement–time graph. 2.1.5 Determine acceleration using the gradient of a velocity–time graph.	<p>Start with questions to establish what learners recall from Cambridge IGCSE (or equivalent). What is the difference between distance and displacement and can they provide a good example? Discuss running laps around an athletics track or the difference between a rambling walk versus a direct route. What is the difference between speed and velocity? Can you give an example of when velocity changes but speed does not? Discuss the example of travelling in a circle: the velocity changes due to the changing direction but the speed remains constant. How can acceleration be calculated? Discuss why acceleration depends on velocity, referring back to their understanding of vectors.</p> <p>Introduce simple example calculations to recap equations for velocity and acceleration as learnt at IGCSE.</p> <p>Give learners displacement–time graphs to match up with the appropriate description. Examples can include an object moving at constant velocity, an object that is accelerating, an object stationary over a period of time, etc.</p> <p>Discuss any differences that would be seen with a set of distance–time graphs. Highlight the important difference that distance–time graphs can never have negative gradients or a negative y-axis.</p> <p>Give learners displacement–time graphs to interpret and describe.</p> <p>Give learners descriptions to draw. This works particularly well on mini-whiteboards as a group interactive task so that learners can compare and discuss what they've drawn. Examples can include a distance–time graph to show a person walking backwards, a displacement–time graph to show a person walking backwards, a displacement–time graph to show a person repeatedly jumping up and down, a distance–time graph to show a person walking in a circle, a displacement–time graph to show a person walking in a circle, etc. These should stimulate learners' questions over how direction cannot be shown on a distance–time graph, how acceleration and constant velocity are respectively represented and the importance of establishing where 'zero' is.</p> <p>Recap with learners how the gradient of a displacement–time graph is velocity.</p> <p>Recap with learners how the gradient of a velocity–time graph is acceleration, and the area under the line is the displacement. Learners can practise the calculation of these on simple examples.</p> <p>Introduce how to find the gradient of a curve. Learners should be familiar with the concept of a tangent to a curve from Cambridge IGCSE Maths (or equivalent).</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Set learners questions on motion graphs for practice. (F)</p> <p>Learners can investigate motion and motion graphs further using The Moving Man simulation (see link below). (I)</p> <p>The basics of linear motion and displacement and velocity–time graphs: www.s-cool.co.uk/a-level/physics/vectors-and-scalars-and-linear-motion/revise-it/the-basics-of-linear-motion-and-disp</p> <p>The Moving Man simulation that plots motion: https://phet.colorado.edu/en/simulation/legacy/moving-man</p> <p>Teacher notes and learner worksheets from the IoP on describing motion: https://spark.iop.org/episode-205-describing-motion</p>
<p>2.1 Equations of motion</p> <p>KC1</p> <p>KC3</p>	<p>2.1.6 Derive, from the definitions of velocity and acceleration, equations that represent uniformly accelerated motion in a straight line.</p> <p>2.1.7 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.</p>	<p>Introduce 'suvat' as the symbols for displacement, initial velocity, final velocity, acceleration and time.</p> <p>Derive three equations of motion (also known as suvat equations) from a velocity–time graph showing an object starting at an initial velocity, u, and undergoing a constant acceleration, a, for period of time, t, until reaching a final velocity, v. The area under the line is equal to the displacement, s. Derive the final equation of motion by combining two of the equations to find an equation without time, t (see s-cool.co.uk link).</p> <p>Demonstrate how to apply the equations of motion to simple examples. Encourage learners to draw simple diagrams, identify which variables they know, identify which variable they want to know and select the appropriate equation of motion.</p> <p>Discuss when to use equations of motion. Emphasise that they can only be used when there is a constant acceleration.</p> <p>Discuss how there may be additional clues in a question e.g. an object starts at rest ($u=0$), an object comes to a stop ($v=0$), constant velocity ($a=0$), etc.</p> <p>Set learners more questions for practice. (F)</p> <p>Equations of motion: www.s-cool.co.uk/a-level/physics/equations-of-motion/revise-it/equations-of-motion https://studynova.com/lecture/physics/mechanics/uniformly-accelerated-motion/</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		Teacher notes and learner worksheets from the IoP on uniform acceleration: https://spark.iop.org/episode-206-uniform-and-non-uniform-acceleration
2.1 Equations of motion KC1 KC2 KC3	2.1.8 Describe an experiment to determine the acceleration of free fall using a falling object.	Introduce free fall as the motion of bodies falling in a uniform gravitational field without air resistance. In this scenario the acceleration is due to gravity and is equal to 9.81ms^{-2} . Set learners questions about objects in free fall that can be solved using the equations of motion. (F) Discuss how it can be proved that an object is undergoing free fall. <div style="border: 1px solid black; padding: 2px;">Resource Plus</div> <div style="border: 1px solid black; padding: 2px;">Carry out the <i>Acceleration of free fall</i> experiment referring to the Teaching Pack for lesson plans and resources.</div> If not already covered, discuss and carry out alternative methods for finding the acceleration of free fall e.g. light gates and datalogger and/or electromagnet triggered timer.
2.1 Equations of motion KC1 KC2 KC3	2.1.9 Describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.	How does a package fall from a plane if dropped while the plane flies with a constant velocity? Discuss the possible trajectories and encourage learners to consider the forces acting, ignoring air resistance. Introduce projectile motion through a video clip such as the bus jump in the movie <i>Speed</i> or the jump from a crane in the movie <i>Skyscraper</i> . Discuss the realities of such a jump. Learners can estimate values of initial velocity and displacement to work out whether the jumper would survive. Lay out the key principles of projectile motion and take learners through examples before setting questions. Remind learners that the horizontal and vertical components of velocity are independent of each other. The horizontal component of velocity does not change as no forces act in this direction, so velocity = displacement / time can be used. The vertical component of velocity changes due to the force of gravity, so the equations of motion can be applied using $g = 9.81\text{ms}^{-2}$. Encourage learners to draw diagrams to visualise the problem and aid with answering questions. Demonstrate the separation of horizontal and vertical components of velocity using a wheelie chair and a ball. Ask a learner to throw the ball vertically upwards while sitting on the chair. The chair can be pushed horizontally while the learner repeats the throw, causing the ball to move in a parabolic path. Demonstrate projectile motion with the Monkey and the Hunter demonstration (see stem.org monkey link). Ask learners before the demonstration: should the monkey stay or should it drop?

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Demonstrate projectile motion with the Pearls of Water demonstration (see stem.org pearls link). Learners can then collect data on the path of the water using the shadows of the droplets on a screen and measure the distance between each droplet. The horizontal distances should be largely constant. The vertical distances and the frequency of the strobe can be used to find the initial velocity, final velocity and acceleration due to gravity.</p> <p>This method of using a strobe to 'freeze' the water droplets in midair was also used in the movie <i>Now You See Me 2</i> to 'stop' the rain.</p> <p>Learners can investigate projectile motion further using various simulations. (I)</p> <p>Projectile motion simulation: https://phet.colorado.edu/en/simulation/projectile-motion www.physicslab.co.uk/shoot.htm</p> <p>Teacher notes and learner worksheets from the IoP on projectile motion: https://spark.iop.org/episode-207-projectile-motion</p> <p>Monkey and Hunter demonstration: www.stem.org.uk/resources/elibrary/resource/27021/monkey-and-hunter</p> <p>Pearls of Water demonstration: www.stem.org.uk/resources/elibrary/resource/34375/pearls-water</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

3 Dynamics

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
3.1 Momentum and Newton's laws of motion KC1 KC2 KC3 KC5	3.1.1 Understand that mass is the property of an object that resists change in motion. 3.1.2 Recall $F = ma$ and solve problems using it, understanding that acceleration and resultant force are always in the same direction. 3.1.3 Define and use linear momentum as the product of mass and velocity. 3.1.4 Define and use force as rate of change of momentum. 3.1.5 State and apply each of Newton's laws of motion. 3.1.6 Describe and use the concept of weight as the effect of a gravitational field	<p>Introduce Newton's first law. Learners may remember this from Cambridge IGCSE (or equivalent).</p> <p>Discuss inertia and its relationship to mass. Discuss how a truck has more inertia than a car: a truck is harder to get moving and harder to stop.</p> <p>Demonstrate the coin drop. Place a coin on top of a piece of thick square cardboard that covers the top of a glass. Flick the cardboard hard with your finger to remove the cardboard. The coin will drop straight into the glass. Describe and link to Newton's first law.</p> <p>Discuss examples of scenarios where an object travels at a constant velocity due to the resultant forces being zero: a rocket through space, a lift moving between floors, a car rolling down a hill such that its weight component parallel to the road is equal to the friction against its motion, etc.</p> <p>Introduce Newton's second law. Learners may remember this from Cambridge IGCSE in the format of $F = ma$.</p> <p>Define the unit of the Newton. Define Newton's second law as the rate of change of momentum. Learners may remember how to define momentum from IGCSE.</p> <p>Link $F = ma$ to $W = mg$. Learners may be able to explain this.</p> <p>Demonstrate the guinea and feather drop (see practicalphysics.org guinea link). All objects have the same acceleration of free fall (ignore air resistance). Show the Apollo 15 hammer-feather drop (see moon.nasa.gov link). Professor Brian Cox did a similar demonstration in the world's largest vacuum chamber for the BBC (search for 'Brian Cox visits the world's biggest vacuum' or use the link below).</p> <p>Set learners more questions on $F = ma$ for practice. (F)</p> <p>Investigate $F = ma$ using a trolley and ramp set up (see practicalphysics.org second law link). This can be done using light gates and a datalogger or by using a stopwatch and equations of motion. Learners can use this to practise their calculation and analysis of errors.</p> <p>Introduce Newton's third law. Learners may remember this from IGCSE. It is highly likely they will recall the inaccurate version regarding 'action and reaction'. Clarify the law and its wording so that it clearly refers to bodies</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>on a mass and recall that the weight of a body is equal to the product of its mass and the acceleration of free fall.</p>	<p>experiencing forces. Break it down so that learners understand that the forces are equal in magnitude, opposite in direction and of the same type. Introduce force pairs.</p> <p>Use a lift to demonstrate the force on a person as a lift starts to move and as it slows to a stop. One learner can stand on a balance (in either kilograms or Newtons) and observe how their mass (or weight) changes as the lift accelerates and decelerates. Learners should be able to explain what they are seeing.</p> <p>Use two skateboards or pairs of roller skates to demonstrate equal and opposite forces on two people as they push off from each other. They do not have to both push; as long as one person pushes and the other keeps their arms firm, both will move away. This also works on ice skates due to the low friction.</p> <p>Discuss apparently paradoxical examples e.g. if there are equal and opposite forces between the Sun and the Earth, why do we orbit the Sun and not the other way around? Why does a rock fall to the Earth and not the Earth to the rock? Would the Earth move if a lot of people jumped together in one place? How does a swimmer move when they push the side of a swimming pool? How does a bat or racket cause a ball to move? In each case the two forces are equal and opposite, but according to $F = ma$ the difference in masses produce different amounts of acceleration.</p> <p>Demonstrate a simple use of force pairs using a balloon: jet propulsion. Also used by rockets, animals such as squid and octopuses, aeroplanes and EVA (extra vehicular activity) jetpacks.</p> <p>Identify and discuss the force pairs on a book placed on a table (see tap.iop link).</p> <p>Discuss how two magnets, one stronger than the other, pull each other with equal force (see tap.iop link).</p> <p>Demonstrate equal and opposite forces using a newton meter and a top pan balance.</p> <p>Discuss how a horse can pull a carriage when the force on the carriage is equal and opposite to the force on the horse. Repeat the idea of the difference in masses producing different accelerations for equal forces.</p> <p>Set learners more questions for practice. (F)</p> <p>Learners can investigate forces and motion further using various simulations. (I)</p> <p>Forces and Newton's laws: https://studynova.com/lecture/physics/mechanics/forces-and-newtons-laws/ www.mathsisfun.com/physics/force.html www.s-cool.co.uk/a-level/physics/forces</p> <p>Guinea and feather demonstration:</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>https://youtu.be/E43-CfukEgs</p> <p>The Apollo 15 Hammer-Feather Drop: https://moon.nasa.gov/resources/331/the-apollo-15-hammer-feather-drop/</p> <p>Forces and Motion simulations: https://phet.colorado.edu/en/simulation/forces-and-motion-basics https://phet.colorado.edu/en/simulation/legacy/forces-and-motion</p> <p>Teacher notes and learner worksheets from the IoP on Newton's laws: https://spark.iop.org/newtons-laws-motion</p>
<p>3.2 Non-uniform motion</p> <p>KC1</p> <p>KC2</p> <p>KC5</p>	<p>3.2.1 Show a qualitative understanding of frictional forces and viscous/drag forces including air resistance.</p> <p>3.2.2 Describe and explain qualitatively the motion of objects in a uniform gravitational field with air resistance.</p> <p>3.2.3 Understand that objects moving against a resistive force may reach a terminal (constant) velocity.</p>	<p>Introduce the topic through questioning e.g. what is the net force on an object falling through the air at constant velocity? Why does a piece of paper fall more slowly than a piece of chalk if the acceleration of gravity is the same?</p> <p>Set learners the task of drawing a series of force diagrams of a ball that it is thrown up and falls back down over several snapshots of time. Learners should identify that weight will be present in every diagram, acting down and unchanging, but drag changes with speed and acts opposite to the direction of motion. Most learners will draw an upwards force for the ball when it moves upwards, when what they are trying to express is the fact that the ball is moving upwards due to the force of the throw at the beginning. Highlight the difference between force and velocity. (F)</p> <p>Introduce terminal velocity by asking learners whether all objects have the same terminal velocity. Lead the discussion into variables that affect terminal velocity. Highlight the important concept of drag force increasing as speed increases. No treatment of the coefficients of friction and viscosity is required, but learners may enjoy discussing these variables qualitatively. Clarify that air resistance is drag force in air.</p> <p>Set learners the task of drawing a series of force diagrams of a parachutist falling from a plane and opening a parachute over several snapshots of time. Learners should consider both weight and air resistance, direction and size of both forces, motion before and after the parachute is opened and where terminal velocity occurs. Learners can also sketch a velocity–time graph of the motion. Videos and animations of parachutists may aid this, including extreme cases such as the record-breaking free fall parachute jump in 2012 (see guinnessworldrecords.com link). (F)</p> <p>Recap the criteria for an object to fall at terminal velocity and the variables that affect this.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Learners can carry out the quantitative task of timing the descent of an object over a fixed distance through a viscous liquid. Plasticine or silicone balls in translucent detergent work well.</p> <p>Learners can carry out the quantitative task of timing the descent of a paper parachute over different distances through air to assess when it reaches terminal velocity. Video recording and analysis of the results can be used, particularly in this case, as objects will fall quickly in air. The iPad app Vernier Video Physics works well. (I)</p> <p>You could give learners the qualitative task of designing, building and testing a parachute to safely protect the fall and landing of a raw egg.</p> <p>Learners can investigate terminal velocity further using the physicsclassroom.com link. (I)</p> <p>Complete toolkit on terminal velocity including interactive simulation and animations: www.physicsclassroom.com/Teacher-Toolkits/Terminal-Velocity/Terminal-Velocity-Complete-ToolKit</p> <p>Teacher notes and learner worksheets from the IoP on terminal velocity: https://spark.iop.org/episode-209-drag-air-resistance-terminal-velocity</p> <p>Record-breaking free fall parachute jump in 2012: www.guinnessworldrecords.com/news/60at60/2015/8/2012-highest-freefall-parachute-jump-392848</p>
<p>3.3 Linear momentum and its conservation</p> <p>KC2</p> <p>KC3</p>	<p>3.3.1 State the principle of conservation of momentum.</p> <p>3.3.2 Apply the principle of conservation of momentum to solve simple problems, including elastic and inelastic interactions between objects in both one and two dimensions.</p> <p>3.3.3 Recall that, for a perfectly elastic</p>	<p>Define impulse and relate back to Newton's second law of motion.</p> <p>Look at force–time graphs for impacts and relate to the change of momentum. Consider how a force–time graph for object A and object B and their forces relate to Newton's third law of motion.</p> <p>Introduce the principle of conservation of momentum.</p> <p>What is the force used to kick a football? Allow learners to come up with a plan to measure the change in momentum and the time of impact to calculate the force of impact (see spark.iop link).</p> <p>Remind learners of the principle of conservation of momentum. Ask learners whether they think the energy in a collision is conserved. The overall energy must be conserved but it may converted to different types, reducing the kinetic energy. A perfectly elastic collision is completely silent. Can learners suggest when this happens? A collision between molecules is a good example. A collision between billiard balls is not a good example because the balls make sound on impact.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>collision, the relative speed of approach is equal to the relative speed of separation.</p> <p>3.3.4 Understand that, while momentum of a system is always conserved in interactions between objects, some change in kinetic energy may take place.</p>	<p>Introduce examples of elastic and inelastic collisions such as a train and a truck, billiard balls, cars, etc. Calculate the change in velocity assuming momentum is constant and consider any changes in kinetic energy carefully.</p> <p>Set learners questions for practice. Learners should be able to apply the conservation of momentum to solve simple problems (knowledge of the concept of coefficient of restitution is not required). (F)</p> <p>Introduce explosions. These too conserve momentum, but the objects involved start with no momentum and no kinetic energy. Examples include an astronaut with a jet pack, using a fire extinguisher to power a small vehicle, a supernova. Video clips may aid this with scenes from movies <i>WALL-E</i> and <i>Gravity</i>, where in both cases the lead character uses a fire extinguisher to move through the vacuum of space.</p> <p>Demonstrate the transfer and conservation of momentum by dropping a tennis ball with a football below it such that the football's momentum is transferred to the tennis ball, causing it to shoot upwards quickly.</p> <p>Set learners more complicated questions for practice. (F)</p> <p>Learners can investigate the conservation of momentum further using the Collision Lab simulation. (I)</p> <p>Resource Plus</p> <p>Carry out the <i>Conservation of Momentum</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>Experiment notes from the IoP on the force used to kick a football: https://spark.iop.org/force-used-kick-football</p> <p>Collision Lab simulation: https://phet.colorado.edu/en/simulation/legacy/collision-lab</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

4 Forces

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
4.1 Turning effects of forces KC2 KC5	4.1.1 Understand that the weight of a body may be taken as acting at a single point known as its centre of gravity. 4.1.2 Define and apply the moment of a force. 4.1.3 Understand that a couple is a pair of forces that acts to produce rotation only. 4.1.4 Define and apply the torque of a couple.	<p>Videos of rock balancing art (popularised by Michael Grab) are a fascinating starter. How is it that the rocks are stable? Learners can even try this themselves with small stones.</p> <p>Define the centre of gravity as the point where all of an object's weight appears to act.</p> <p>Learners can find the centre of gravity of an irregular 2D cardboard shape by suspending it from an optical pin and hanging a plumb line alongside. The centre of gravity of the shape will lie beneath the suspension point and the plumb line will show learners where to mark a line where this must be. Changing the suspension point should allow them to find another line. Where these cross is the centre of gravity.</p> <p>Learners can investigate their own centre of gravity. Without bending at the knees or waist, they can tip forwards while standing up, until they feel they are about to fall. When does this occur? Learners should identify that when their centre of gravity is not supported by their base (their feet), they become unstable and fall. How can the learners be more stable? They may take up a position with a wide stance and a lowered centre of gravity by bending their knees.</p> <p>Learners can investigate the centre of gravity of other objects. When do they tip over? How does adding mass to an object change its stability e.g. liquid in a wine glass or adding plasticine to a ruler.</p> <p>Show learners (pictures of) different-size wrenches and ask them which would be best for loosening a tight nut. Discuss the importance of a longer handle.</p> <p>Introduce the definition and equation for torque.</p> <p>Ask for two volunteers. Learners may want to declare themselves as the 'strongest' and 'weakest' in the class. Set the 'strongest' learner outside the door and explain that they must open the door, but can only place their hands on the door close to the hinge. The 'weakest' learner must try to stop them from coming in, but may use the handle, far away from the hinge. The 'strongest' learner will struggle to open the door because, despite their large force, the small distance from the hinge will decrease the turning effect and their ability to open the door.</p> <p>Introduce the definition of a couple and ask learners to show its relationship to torque. Clarify that a couple has two forces acting on an object that are parallel, in opposite directions, of equal size, but not along the same line of action. Learners should understand that couples produce rotation and cannot cause linear movement.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Set learners questions for practice. (F)</p> <p>Learners can investigate the turning effects of forces further using the Torque simulation. (I)</p> <p>Torque simulation: https://phet.colorado.edu/en/simulation/legacy/torque</p>
<p>4.2 Equilibrium of forces</p> <p>KC1</p> <p>KC2</p> <p>KC5</p>	<p>4.2.1 State and apply the principle of moments.</p> <p>4.2.2 Understand that, when there is no resultant force and no resultant torque, a system is in equilibrium.</p> <p>4.2.3 Use a vector triangle to represent coplanar forces in equilibrium.</p>	<p>Define equilibrium as when there is no resultant force and no resultant torque.</p> <p>Present various examples of objects in equilibrium: a car being towed at an angle by a truck, a picture hanging on a wall from two diagonal wires, a block on an inclined ramp, a shop sign supported by a cable and a rod, etc. Learners can identify forces and calculate missing values of forces. Simulations and demonstrations of these examples may aid understanding.</p> <p>Introduce the vector triangle and relate to the previous examples covered.</p> <p>Set up the demonstration of the washing line problem (see tap.iop 202 link) using two learners, a rope and a mass. If learners hold the rope at the same height, their force can be found by measuring the angle of the rope to the horizontal using a protractor and calculating the downwards gravitational force of the mass. Discuss whether the rope can ever be horizontal. Encourage learners to draw a vector triangle. Learners should conclude that this is impossible.</p> <p>Set up the experiment to find the centre of mass of a learner (see tap.iop 203 link) using a brick, scales and plank of wood. Take moments around the brick and calculate the missing value of distance.</p> <p>Learners can investigate the forces on a bridge (see tap.iop turning effects link) using masses and Newtonmeters.</p> <p>Set learners questions for practice. Learners may find questions with more than one pivot point particularly interesting and challenging. (F)</p> <p>Learners can investigate how a beam balances with more than one moment with the Balancing act simulation. (I)</p> <p>Resource Plus</p> <p>Carry out the <i>Investigating coplanar forces</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>The ramp simulation: https://phet.colorado.edu/en/simulation/legacy/the-ramp</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		Balancing act simulation: https://phet.colorado.edu/en/simulation/balancing-act Teacher notes and learner worksheets from the IoP on forces in equilibrium and turning effects: https://spark.iop.org/episode-202-forces-equilibrium https://spark.iop.org/episode-203-turning-effects
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

5 Work, energy and power

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
5.2 Gravitational potential energy and kinetic energy KC1 KC2 KC3 KC4	5.1.1 Understand the concept of work, and recall and use <i>work done = force x displacement</i> in the direction of the force. 5.2.1 Derive, using $W = Fs$, the formula $\Delta E_P = mg\Delta h$ for gravitational potential energy changes in a uniform gravitational field. 5.2.2 Recall and use the formula $\Delta E_P = mg\Delta h$ for gravitational potential energy changes in a uniform gravitational field. 5.2.3 Derive, using the equations of motion, the formula for kinetic energy $E_K = 1/2mv^2$. 5.2.4 Recall and use $E_K = 1/2mv^2$.	Estimate values of work done for everyday activities such as lifting a cookie to your mouth, walking up one flight of stairs, picking up your bag, a plane taking off, climbing Mount Everest, etc. Derive gravitational potential energy from work done. Learners can investigate the work done in raising a block up a ramp with friction by using a pulley and masses to provide the force. Learners can investigate the work done in raising a mass with a motor by calculating the electrical energy provided by the motor and the gravitational potential gained by the mass. Set learners questions for practice on work done and gravitational potential energy. Learners should be careful to consider the vertical distance moved. (F) Introduce kinetic energy. Challenge learners to derive this using their knowledge of work done and the equations of motion. Set learners questions for practice. (F) Learners can research information for calculations of the kinetic energy of everyday examples: a car on a motorway, Concord, Halley's comet, etc. Teacher notes and learner worksheets from the IoP on work done by a force: https://spark.iop.org/episode-214-work-done-force

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
5.1 Energy conservation KC1 KC2 KC3 KC4	5.1.2 Recall and apply the principle of conservation of energy. 5.1.3 Recall and understand that the efficiency of a system is the ratio of useful energy output from the system to the total energy input. 5.1.4 Use the concept of efficiency to solve problems.	<p>Introduce energy conservation and transfer through the example of a rollercoaster. Learners may enjoy watching a video to accompany this discussion.</p> <p>Consider everyday examples of energy transfer as covered at Cambridge IGCSE/O Level (or equivalent).</p> <p>Use the conservation of energy to solve free fall questions. Show that the equations of motion produce the same outcome through different equations.</p> <p>Learners can investigate the energy transfer and efficiency of a tennis ball as it falls and bounces on the ground. They can measure and compare the initial and rebound heights, calculate the change in gravitational energy and find an overall efficiency.</p> <p>Learners can investigate the energy changes and thus find the frictional force of a marble on a curved track. They can measure mass, height and time and assume that the initial gravitational potential energy converts to kinetic energy and work done against friction.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can investigate energy conservation with the Energy Skate Park simulations. (I)</p> <p>Teacher notes and learner worksheets from the IoP on conservation of energy: https://spark.iop.org/episode-217-conservation-energy</p> <p>Energy Skate Park simulations https://phet.colorado.edu/en/simulation/energy-skate-park-basics https://phet.colorado.edu/en/simulation/legacy/energy-skate-park</p>
5.1 Energy conservation KC2 KC3 KC4	5.1.5 Define power as work done per unit time. 5.1.6 Solve problems using $P = W / t$. 5.1.7 Derive $P = Fv$ and use it to solve problems.	<p>Ask learners to define power. They may remember this from Cambridge IGCSE (or equivalent).</p> <p>Derive $P = Fv$. Learners may be able to do this themselves.</p> <p>Discuss the efficiency of everyday items e.g. a light bulb, a hairdryer, etc.</p> <p>Learners can use the school's gym to find their power. They can perform simple exercises such as a goblet squat, press up or pull up to calculate their power using a stop watch and a metre rule. They will need to calculate the weight moved, the work done and the power. It is important the learners are supervised so that they perform these exercises safely. Alternatively learners can calculate their power when climbing a flight of stairs.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		Teacher notes and learner worksheets from the IoP on mechanical power: https://spark.iop.org/episode-218-mechanical-power Work, energy and power: https://studynova.com/lecture/physics/mechanics/work-energy-power/
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

6 Density, pressure and deformation of solids

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
4.3 Density and pressure KC2 KC3 KC5	<p>4.3.1 Define and use density.</p> <p>4.3.2 Define and use pressure.</p> <p>4.3.3 Derive, from the definitions of pressure and density, the equation for hydrostatic pressure $\Delta p = \rho g \Delta h$.</p> <p>4.3.4 Use the equation $\Delta p = \rho g \Delta h$.</p> <p>4.3.5 Understand that the upthrust acting on an object in a fluid is due to a difference in hydrostatic pressure.</p> <p>4.3.6 Calculate the upthrust acting on an object in a fluid using the equation $F = \rho g V$ (Archimedes' principle).</p>	<p>Ask learners to define density. They may remember this from Cambridge IGCSE (or equivalent).</p> <p>Highlight the correct process for converting between g/cm^3 and kg/m^3. Learners may feel confident converting between g and kg, but they may get confused with cm^3 and m^3. Using multiple metre rules to make a physical metre cubed may help them to visualise and understand how squaring and cubing 1 m also squares and cubes 100 cm, producing a much larger number than they might expect.</p> <p>Learners can write their own simple methods for finding the density of a regular solid, a liquid and an irregular solid. Discuss how the methods change in each case.</p> <p>Learners can practise their practical skills by finding the density of aluminium foil. They will have to consider the best method that minimises errors in measurements. Is it better to have more foil? Do the Vernier callipers give measurements that can be considered precise? Should the learners fold the foil? Learners will likely find the biggest source of error is in the volume which depends on three separate measurements, with thickness (even when folded) being the biggest contributor of error.</p> <p>Learners can investigate how density relates to an object floating with the Buoyancy simulation. (I)</p> <p>Ask learners to define pressure. They may remember this from Cambridge IGCSE.</p> <p>Introduce the equation for hydrostatic pressure and derive this from pressure = force / area for a column of fluid with a certain height, density and cross-sectional area. This will prove that hydrostatic pressure does not depend on the area of the fluid.</p> <p>Demonstrate how pressure in a fluid is the same in all directions by using a plastic bag filled with water and poking small holes in it with a pin.</p> <p>Demonstrate how pressure in a fluid increases with depth by using a spouting can filled with water.</p> <p>Demonstrate examples of atmospheric pressure: a ruler largely covered by a piece of newspaper is hard to displace, suction cups can support significant force, a boiled egg can be sucked into a conical flask with a lighted splint, a heated can implodes when cooled suddenly, Magdeburg hemispheres support significant force, etc. These all help learners to understand the presence and strength of the air pressure around us.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Resource Plus</p> <p>Carry out the <i>Pressure and the imploding can</i> experiment referring to the Teaching Pack for lesson plans and resources. Note that the Teaching Pack and experiment video are available in Resource Plus for IGCSE/O Level Physics.</p> <p>Learners can feel how a mass on a string will feel lighter when placed into water. The mass does not float, but learners may be able to explain why it feels lighter. They are feeling the upthrust of the water which supports some of the mass's weight, but not enough to allow it to float.</p> <p>Derive upthrust by comparing the hydrostatic pressure on the top and bottom of a cuboid in a fluid. Introduce Archimedes' principle.</p> <p>Learners can predict whether an object will float and what fraction will be below the water using the relationship between upthrust and weight. Learners can then test their predictions and discuss any differences.</p> <p>Learners can calculate the fraction of an iceberg that sits hidden beneath the water. They should realise that the ratio of the mass below and above the water is the same as the ratio of the densities of ice and water.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can investigate pressure by working with the Under Pressure simulation. (I)</p> <p>Buoyancy simulation and Under Pressure simulation: https://phet.colorado.edu/en/simulation/legacy/buoyancy https://phet.colorado.edu/en/simulation/under-pressure</p> <p>Teacher notes from the IoP on imploding can demonstration: https://spark.iop.org/gas-pressure-rises-temperature</p>
<p>6.1 Stress and strain</p> <p>6.2 Elastic and plastic behaviour</p> <p>KC2</p> <p>KC3</p> <p>KC5</p>	<p>6.1.1 Understand that deformation is caused by tensile or compressive forces.</p> <p>6.1.2 Understand and use the terms load, extension, compression and limit of</p>	<p>Introduce the difference between a tensile force and compressive force (forces and deformations will be assumed to be in one dimension only). Learners may be able to give examples of each. Clarify that tensile forces produce extension and compressive forces produce compression.</p> <p>Use a photo of a well-known or local suspension bridge and ask learners to identify the tensile and compressive forces. The Clifton Suspension Bridge in Bristol, UK, and the Golden Gate Bridge in San Francisco, USA, are good examples.</p> <p>Learners can carry out an investigation into Hooke's law using a helical spring and masses. Clarify the difference between length and extension. Learners should plot a graph of their results, identify the limit of proportionality and</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>proportionality.</p> <p>6.1.3 Recall and use Hooke's law.</p> <p>6.1.4 Recall and use the formula for the spring constant $k = F / x$.</p> <p>6.2.1 Understand and use the terms elastic deformation, plastic deformation and elastic limit.</p> <p>6.2.2 Understand that the area under the force–extension graph represents the work done.</p> <p>6.2.3 Determine the elastic potential energy of a material deformed within its limit of proportionality from the area under the force–extension graph.</p> <p>6.2.4 Recall and use $E_P = 1/2Fx = 1/2 kx^2$ for a material deformed within its limit of proportionality.</p>	<p>find the spring constant, k. They can use the spring constant to make predictions for values of force that they did not measure.</p> <p>Extension activity: As an extension task, they can consider what happens to the spring constant if springs are placed in series or in parallel.</p> <p>Use a graph of force against extension to discuss the properties and differences between elastic and plastic deformation. Identify the elastic limit and link it to the limit of proportionality.</p> <p>Learners can investigate Hooke's law with the Hooke's law simulation. They can use the simulation to collect, plot and analyse results. (I)</p> <p>What happens if you drop a slinky (or large spring) extended due to its own weight? Learners should be able to present some different predictions. Learners can think about the forces acting on the spring. You could carry out the demonstration and make a video recording. and play back in slow motion (see youtube.com link). Discuss what happens again so that learners understand what they have just seen and why it happens.</p> <p>Discuss how a rubber band can store energy. Learners can make simple rubber band launchers (see instructables.com link).</p> <p>Ask learners how the elastic potential energy can be calculated. They may suggest calculating the work done in extending the rubber band. Consider that the force increases with extension so a constant force cannot be assumed. Suggest that learners consider Hooke's law and the graph of force and extension for a helical spring. They may link the area under the graph and the work done. Use this to derive the equation for elastic potential energy. Express elastic potential energy in terms of the spring constant also.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can investigate potential energy with the Hooke's law simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on Hooke's law: https://spark.iop.org/episode-227-hookes-law</p> <p>Hooke's law simulation: https://phet.colorado.edu/en/simulation/hookes-law</p> <p>Veritasium YouTube channel: Does a Falling Slinky Defy Gravity?: www.youtube.com/watch?v=uiyMuHuCFo4&list=PL16649CCE7EFA8B2F&index=21&t=0s</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		Rubber band launcher: www.instructables.com/id/Rubber-Band-Launcher-1/
6.1 Stress and strain KC2 KC5	6.1.5 Define and use the terms stress, strain and the Young modulus. 6.1.6 Describe an experiment to determine the Young modulus of a metal in the form of a wire.	<p>Define stress. Relate to pressure and identify that the units are the same.</p> <p>Define strain. Identify that as it is a ratio, strain has no units and may be quoted as a percentage or a decimal.</p> <p>Introduce stress–strain graphs. Learners can analyse the stress–strain graph of common materials like steel, glass and copper to identify the limits of proportionality, the region of elastic deformation, the region of plastic deformation and the properties that these materials have, such as being malleable or brittle.</p> <p>Discuss everyday items and the materials from which they are made. Consider an aeroplane: its tyres are made from rubber which deform elastically on landing and its wings are metal which deform very little.</p> <p>Introduce the Young modulus as the ratio of stress and strain. Identify that the Young modulus has the same units as stress, as strain is dimensionless. Derive the equation in terms of force and extension. Clarify that the Young modulus is much more useful than the spring constant because it describes a material, rather than one specific item like a steel helical spring of a certain length and diameter.</p> <p>Analyse stress–strain graphs. The gradient is equal to the Young modulus. The area is related to the work done, but is not equal to the work done due to the factors of original length and cross-sectional area.</p> <p>Set learners questions for practice. (F)</p> <p>Resource Plus</p> <p>Carry out the <i>The Young modulus</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>Teacher notes and learner worksheets from the IoP on stress–strain graphs and the Young modulus: https://spark.iop.org/episode-229-stress-strain-graphs https://spark.iop.org/episode-228-young-modulus</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

7 Waves and superposition

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
7.1 Progressive waves KC2 KC4	<p>7.1.1 Describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks.</p> <p>7.1.2 Understand and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed.</p> <p>7.1.3 Understand the use of the time-base and y-gain of a cathode-ray oscilloscope (CRO) to determine frequency and amplitude.</p> <p>7.1.4 Derive, using the definitions of speed, frequency and wavelength, the wave equation $v = f\lambda$.</p> <p>7.1.5 Recall and use</p>	<p>Ask learners 'What is a wave?' They may be able to explain that a wave transfers energy, without transferring matter. Clarify that this is what a progressive wave does and that they will learn about another type of wave that stores energy later.</p> <p>Introduce longitudinal and transverse waves. Ask learners for examples of each. Ask learners what they all have in common. Define the key properties of waves. Diagrams and simulations may aid this.</p> <p>Mini-whiteboards can be used by learners to draw simple transverse waves. Ask them to draw two waves onto the board, with the second one having double the amplitude but half the frequency. Change other variables to test the learners' understanding. Ask learners whether they can label all of the following on one graph: wavelength, period, frequency, displacement and amplitude. Highlight the importance of labelling and reading graph axes. We can either show time on the x-axis (and therefore frequency and period can be labelled) or distance (and therefore wavelength can be labelled).</p> <p>Introduce phase difference and show plenty of visual examples to help with the explanation. Give physical examples of being 'in phase' such as two taps dripping at the same time, car indicators flashing in time or children jumping ropes together. Ask learners to think of examples of being 'in antiphase'. Relate a wavelength to a cycle, to 360 degrees, to 2π radian and ensure learners understand how to describe the phase difference between two waves.</p> <p>Using two clear sheets with a transverse wave drawn on each, move the sheets such that they start in phase from different positions and then meet. Changing the meeting point will change if they meet in phase or in antiphase. If they travel the same distance (so path difference = 0) their phase difference is zero and they are in phase. However, they may travel a different distance (and have a path difference that is non zero) and have no phase difference, as long as the path difference is a whole multiple of the wavelength. This visual demonstration may help learners to understand path and phase difference. Allow the learners to trial different scenarios.</p> <p>Test learners' understanding of phase difference by showing them diagrams of pairs of waves and asking them to identify the phase difference. They can use the mini-whiteboards to draw pairs of waves with specific phase differences. (F)</p> <p>Introduce the idea of phase difference to describe the difference between two points on one wave.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>$v = f\lambda$.</p> <p>7.1.6 Understand that energy is transferred by a progressive wave.</p> <p>7.1.7 Recall and use $intensity = power/area$ and $intensity \propto (amplitude)^2$ for a progressive wave.</p>	<p>Ask learners to find an equation that links wave speed, frequency and wavelength starting with the definition for speed. Remind them of the relationship between frequency and time period.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can find the frequency and amplitude of a sound wave using a microphone and cathode-ray oscilloscope. A signal generator and a loudspeaker can produce a sound wave of a specific and constant frequency and amplitude. Learners should be able to read the time-base and y-gain to determine the frequency and amplitude.</p> <p>Ask learners how they think a wave spreads out in a 3D space. How do they think this affects the intensity of the wave? Define intensity and show diagrams to highlight the spreading out of a wave's power through space. Cover the inverse square law. Use a displacement–time graph to identify that the gradient is the velocity and kinetic energy is proportional to the square of the velocity. A wave with double the amplitude produces a graph with double the gradient but four times the energy. Considering the definition for power and intensity, this gives the relationship $intensity \propto (amplitude)^2$ for a progressive wave.</p> <p>Learners can make waves by each acting as a 'particle' within the wave and moving their arms up and down around the equilibrium point of shoulder height. This can be used as a plenary task to test learners' understanding. Can they create a higher-frequency wave? Or perhaps a lower-amplitude one?</p> <p>Learners can investigate water waves in a ripple tank further using the Ripple tank simulation. Learners can also investigate progressive waves, like those travelling in a string, using the Travelling Waves simulation. (I)</p> <p>Progressive waves: www.s-cool.co.uk/a-level/physics/progressive-waves/revise-it/progressive-waves</p> <p>Properties of waves, intensity and amplitude: https://studynova.com/lecture/physics/waves/properties-of-waves/ https://studynova.com/lecture/physics/waves/intensity-and-amplitude/</p> <p>Teacher notes and learner worksheets from the IoP on progressive waves: https://spark.iop.org/collections/progressive-waves</p> <p>Ripple tank simulation and Travelling Waves simulation: www.falstad.com/ripple/ www.physicslab.co.uk/twave.htm</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
7.2 Transverse and longitudinal waves KC4	7.2.1 Compare transverse and longitudinal waves. 7.2.2 Analyse and interpret graphical representations of transverse and longitudinal waves.	<p>Ask learners to describe longitudinal and transverse waves and ask for examples of each. Encourage learners to make comparisons between the two types. Learners should realise that they have the same properties such as wavelength, frequency and amplitude. Concentrating on the movement of a single particle within a wave highlights the simple oscillation it undergoes, but with other particles in succession creates a wave through the particles. Simulations and diagrams may aid this explanation.</p> <p>Demonstrate transverse waves: water waves in a ripple tank, a wave in a rope, a wave through a line of people, etc. Use the Waves Intro simulation to show water and light. Highlight the peaks and troughs.</p> <p>Demonstrate longitudinal waves using a large spring or slinky. Use the Waves Intro simulation to introduce sound waves. Highlight the compressions and rarefactions.</p> <p>You can use the ripple tank to demonstrate various wave phenomena that may aid learners' general understanding of waves. A motorised dipper produces water waves with clear wave fronts that appear perpendicular to the direction of the wave's motion. Reflection can be demonstrated with obstacles and refraction by changing the depth of the water. Diffraction can be introduced by making a gap between two obstacles and observing how the wave spreads out through the gap. Learners can consider whether the following variables change in each of these phenomena: wavelength, wave speed, period, frequency, shape of wave front and direction.</p> <p>Set learners questions that focus on analysing and interpreting graphical representations of transverse and longitudinal waves. (F)</p> <p>Waves Intro simulation: https://phet.colorado.edu/en/simulation/waves-intro</p>
7.3 Doppler effect for sound waves KC3 KC4	7.3.1 Understand that when a source of sound waves moves relative to a stationary observer, the observed frequency is different from the source frequency. 7.3.2 use the expression $f_o = f_s v / (v \pm v_s)$ for	<p>Attach a buzzer to a piece of string and spin it in a circle with the learners standing a safe distance away in a circle around the buzzer. They should notice the sound appears to change in pitch as it moves away and towards them, but can they explain this themselves? Alternatively make a Doppler ball (see spark.iop link) and throw it past the learners. Can they hear the pitch change as it passes them?</p> <p>Video or sound clips of vehicles passing a stationary observer clearly demonstrate the Doppler effect for sound waves.</p> <p>Video clips or diagrams help to visualise the emitted sound waves and how a moving source changes the wavelength and frequency.</p> <p>Use a long spring (a slinky or a bed spring works well) to demonstrate how the sound waves are being emitted uniformly by the source, but if the observer moves away or towards the source, the frequency of the sound waves</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>the observed frequency when a source of sound waves moves relative to a stationary observer.</p>	<p>passing them appears to change e.g. if they move away, they increase the time it takes before another wave passes them, because they are moving away from the source emitting the waves. Although learners do not have to understand the Doppler effect for a stationary source and a moving observer, this demonstration helps learners to understand the idea of relative motion and the change of frequency.</p> <p>Set learners questions to practice using the expression $f_o = f_s v / (v \pm v_s)$. (F)</p> <p>Play the Doppler shift song to learners (see astrocappella.com link), who may choose to join in with the singing. The song refers to various examples and uses of the Doppler effect and extends beyond the content the learners need to know.</p> <p>Discuss how the Doppler effect can be used to find the speed of a variety of objects such as a tennis ball, motorists, snow and rain, stars, etc.</p> <p>Extension activity: As an extension task, learners can watch videos of aircraft creating sonic booms and discuss the physics involved.</p> <p>Experiment notes from the IoP on hearing the Doppler effect: https://spark.iop.org/hearing-doppler-effect</p> <p>Doppler shift song: www.astrocappella.com/doppler.shtml</p>
<p>7.4 Electromagnetic spectrum</p> <p>KC4</p>	<p>7.4.1 State that all electromagnetic waves are transverse waves that travel with the same speed c in free space.</p> <p>7.4.2 Recall the approximate range of wavelengths in free space of the principal regions of the electromagnetic spectrum from radio waves to γ-rays.</p>	<p>Ask learners to order the spectrum (a card sort or large signs on the board) as a starter task.</p> <p>Ask learners to share the uses of the electromagnetic spectrum that they already know. If the lesson started with ordering the spectrum on the board, the uses can be added to it to build a mind map.</p> <p>Identify the properties that all electromagnetic waves share.</p> <p>Draw or show a simple diagram of an electromagnetic wave as two waves interlocked at right angles to each other (see spark.iop.org/312 link). These waves are oscillations in the electric and magnetic fields and allow energy to pass through a vacuum.</p> <p>Use a microwave and either chocolate or cheese to find the speed of light (see spark.iop.org/324 link). By removing the turntable the antinodes of the stationary wave created by the microwave oven should be visible as melted patches in the chocolate or cheese. Alternatively, carry out this experiment later, after stationary waves have been covered.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>7.4.3 Recall that wavelengths in the range 400–700 nm in free space are visible to the human eye.</p>	<p>Electromagnetic charades can be used as a simple plenary task. Learners pick a type of electromagnetic wave and act out either how it is produced (hands in a ball, then spreading out), how it is detected (place hand above eyes as if looking around) or how it is used (run one finger down the open palm of the other hand as if running through a checklist). For example, they might first act out the checklist to let learners know they will act a use and then they could pretend to sunbathe as a clue for ultraviolet rays.</p> <p>Teacher notes and learner worksheets from the IoP on electromagnetic waves, the electromagnetic spectrum and measuring c: https://spark.iop.org/episode-312-preparation-electromagnetic-waves-topic https://spark.iop.org/electromagnetic-spectrum-0 https://spark.iop.org/episode-324-stationary-or-standing-waves</p> <p>Radio Waves & Electromagnetic Fields simulation and Microwaves simulation: https://phet.colorado.edu/en/simulation/legacy/radio-waves https://phet.colorado.edu/en/simulation/legacy/microwaves</p>
<p>7.5 Polarisation</p> <p>KC2</p> <p>KC3</p> <p>KC4</p>	<p>7.5.1 Understand that polarisation is a phenomenon associated with transverse waves.</p> <p>7.5.2 Recall and use Malus's law ($I = I_0 \cos^2\theta$) to calculate the intensity of a plane polarised electromagnetic wave after transmission through a polarising filter or a series of polarising filters.</p>	<p>Recap that an electromagnetic wave is made of two waves interlocked at right angles to each other.</p> <p>Introduce polarisers as optical filters that only allow oscillations in one plane, thus blocking some of the light. Demonstrate pairs of polarising filters such that they block out light entirely or, rotated at angles to each other, allow some light through. With a third polariser you can let light through a pair of crossed polarisers. You could also place polarisers in front of a calculator screen to change the colour of the screen.</p> <p>Use diagrams to help illustrate how polarisers only allow part of a light wave to travel through.</p> <p>A useful analogy involves a rope passing through a fence. When the rope has vertical oscillations sent along it, in line with the fence panels, the oscillation passes through without a problem. When the rope has horizontal oscillations sent along it, perpendicular to the fence panels, the oscillation is blocked and does not pass through the gap. When at an angle, only a component of the original wave can get through. You can demonstrate this by using a rope and a pair of metre rulers. Encourage learners to investigate what happens with a pair of 'polarisers' e.g. two pairs of metre rulers at an angle to each other.</p> <p>Introduce Malus's law to calculate the intensity of the transmitted light. Relate it to the relationship between intensity and amplitude.</p> <p>Set learners questions for practice. (F)</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Learners can investigate the polarisation of electromagnetic waves by using a microwave transmitter, a microwave detector and a grill. The transmitter will emit polarised microwaves. Rotating the grill through 90 degrees will reduce the detected signal from maximum to zero, demonstrating Malus's law.</p> <p>Discuss polarisation due to scattering. When light reflects off a shiny surface, such as glass, water or even snow, the reflected light is partly polarised. This is why polarised sunglasses and goggles are sold to reduce light reflected from the ocean or ski slopes.</p> <p>Learners can research other common uses of polarisers such as photographic filters, liquid crystal displays and optical fibre communications. (I)</p> <p>Polarisation and Malus's law: https://studynova.com/lecture/physics/waves/polarization-and-malus-law/</p> <p>Teacher notes and experiments from the IoP on polarisation: https://spark.iop.org/episode-313-polarisation</p>
<p>8.1 Stationary waves</p> <p>KC2</p> <p>KC4</p>	<p>8.1.1 Explain and use the principle of superposition.</p> <p>8.1.2 Show an understanding of experiments that demonstrate stationary waves using microwaves, stretched strings and air columns.</p> <p>8.1.3 Explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes.</p>	<p>Ask learners to think about what happens when two waves meet each other. They do not behave the same way that two balls would when they collide. Demonstrate the combination of waves with a large spring (a slinky or a bed spring works well). Ask learners to describe what they see. You could use slow motion video to spot the moment when two wave pulses combine to create a large amplitude.</p> <p>Introduce the principle of superposition.</p> <p>Use diagrams and simulations to demonstrate the combination of different types of waves. Identify the nodes and antinodes.</p> <p>Use a microwave transmitter and a metal sheet to reflect the microwaves back towards the transmitter to create a stationary wave. Move the microwave detector along the line between the transmitter and the sheet to find two consecutive antinodes. Ask learners how this distance relates to the wavelength. Using the frequency of the microwaves and measuring the wavelength, can they prove the wave speed is the speed of light?</p> <p>Demonstrate stationary waves in a string using an oscillating motor. You could use a strobe light to 'freeze' the string. Encourage learners to hold the stationary nodes or attempt to put their fingers 'through' the antinodes; of course, this will interrupt the oscillations and highlight that the stationary wave only appears stationary; it is constantly oscillating with stored energy. Use the Wave on a String simulation as an aid.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	8.1.4 Understand how wavelength may be determined from the positions of nodes or antinodes of a stationary wave.	<p>Introduce stationary waves in closed and open tubes. Relate the harmonics to the number of wavelengths that 'fit' inside the tube.</p> <p>Demonstrate the Ruben's tube as an example of a stationary wave in a closed tube. There are videos of this online. It might interest learners to watch the Veritasium video (see youtube.com link).</p> <p>Learners can investigate stationary waves in string instruments such as guitars, or wind instruments such as recorders. The school's music department may even help with demonstrations. (I)</p> <p>Set learners questions for practice. (F)</p> <p>Resource Plus</p> <p>Carry out the <i>Investigating stationary waves</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>Learners can investigate stationary waves in a tube of air held upright in a bucket of water as an example of a stationary wave in an open tube. Lifting the tube out of the water changes the length of the tube and tuning forks or a loudspeaker can be used to find points of resonance for different frequencies. Learners can make calculations based on the frequency of the emitted wave, the length of the column of air and the distance between subsequent points of resonance. It will be assumed that end corrections are negligible; knowledge of the concept of end corrections is not required.</p> <p>Standing waves: https://studynova.com/lecture/physics/waves/standing-waves/</p> <p>Wave on a String simulation: https://phet.colorado.edu/en/simulation/wave-on-a-string</p> <p>Lesson plan and experiments from the IoP on stationary waves: https://spark.iop.org/episode-324-stationary-or-standing-waves</p> <p>Veritasium YouTube channel: Musical Fire Table: www.youtube.com/watch?v=2awbKQ2DLRE&list=PL16649CCE7EFA8B2F&index=10&t=0s</p>
8.2 Diffraction KC2 KC4	8.2.1 Explain the meaning of the term diffraction.	Demonstrate the diffraction of white light using a distant light bulb and a tuning fork. Learners can investigate this individually. Encourage them to turn the tuning fork so that the gap between the forks effectively changes.

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>8.2.2 Show an understanding of experiments that demonstrate diffraction including the qualitative effect of the gap width relative to the wavelength of the wave.</p>	<p>Demonstrate the diffraction of water waves using a ripple tank. You could use simulations to aid this, or as an alternative.</p> <p>Demonstrate the diffraction of monochromatic light using a laser and a single slit.</p> <p>Ask learners to summarise their findings from the demonstrations. They may note that the pattern of intensity is symmetrical, but there are areas of higher and lower intensity. Introduce the terms maxima and minima.</p> <p>Learners can investigate diffraction of light further using the Wave Interference simulation. (I)</p> <p>Diffraction: https://studynova.com/lecture/physics/waves/diffraction/</p> <p>Teacher notes and learner worksheets from the IoP on diffraction: https://spark.iop.org/episode-323-diffraction</p> <p>Wave Interference simulation: https://phet.colorado.edu/en/simulation/wave-interference</p>
<p>8.3 Interference</p> <p>KC2</p> <p>KC4</p>	<p>8.3.1 Understand the terms interference and coherence.</p> <p>8.3.2 Show an understanding of experiments that demonstrate two-source interference using water waves in a ripple tank, sound, light and microwaves.</p> <p>8.3.3 Understand the conditions required if two-source interference fringes are to be observed.</p>	<p>Introduce interference and link back to the principle of superposition.</p> <p>It may help to quickly recap the definitions of phase difference and path difference.</p> <p>Learners can experiment with the interference of sound waves. Two loudspeakers can be set up attached to the same signal generator to produce coherent sound waves. Place them a couple of metres apart such that a noticeable interference pattern is heard when a listener walks in a line perpendicular to their emission.</p> <p>Highlight the differences between constructive and destructive interference. Both can be explained by the principle of superposition and require coherent wave sources but having different phase differences.</p> <p>Use a microwave transmitter and double slits set up to create two coherent sources and find areas of constructive and destructive interference. Move the microwave detector perpendicular to the microwaves' emission and find two consecutive points of constructive interference. Ask learners how this distance relates to the wavelength. Using the frequency of the microwaves and, by taking measurements, the wavelength, they can prove the wave speed is the speed of light.</p> <p>Show simulations of interference of different types of waves (see phet.colorado link).</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>8.3.4 Recall and use $\lambda = ax / D$ for double-slit interference using light.</p>	<p>Test learners' understanding of interference by offering different scenarios and asking what type of interference occurs e.g. if a coherent wave has a path difference of half of the wavelength, what is the phase difference and what is the outcome? For two identical waves, constructive interference results in a wave with double the amplitude of the original. Destructive interference only occurs when two identical waves are in antiphase. (F)</p> <p>Demonstrate Young's slits with monochromatic light from a laser and double slits. Learners should observe the fringe pattern on the screen and try to explain what they see.</p> <p>Derive the equation based on the experimental set up. Use diagrams that show the wave fronts to aid understanding.</p> <p>Learners can find the wavelength of the monochromatic light of the laser by using the equation and taking measurements of the experimental set up of Young's slits.</p> <p>Point out that the coloured patterns you see in soap bubbles or in oil spills are the result of the interference of white light. Demonstrate the interference of white light. Ask learners why this cannot be used to find the wavelength of white light.</p> <p>Interference: https://studynova.com/lecture/physics/waves/interference/</p> <p>Teacher notes and learner worksheets from the IoP on interference patterns: https://spark.iop.org/episode-321-interference-patterns</p> <p>Sound simulation and Wave Interference simulation: https://phet.colorado.edu/en/simulation/legacy/sound https://phet.colorado.edu/en/simulation/wave-interference</p> <p>Veritasium YouTube channel: The Original Double Slit Experiment: www.youtube.com/watch?v=luv6hY6zsd0</p>
<p>8.4 The diffraction grating</p> <p>KC2</p> <p>KC3</p> <p>KC4</p>	<p>8.4.1 Recall and use $d \sin \theta = n\lambda$.</p> <p>8.4.2 Describe the use of a diffraction grating to determine the wavelength of light.</p>	<p>Recap Young's slits and ask learners what will happen with more slits. Learners may think more slits means more light. It may surprise them to note that more slits results in more darkness and clearer separated points of light. If a range of diffraction gratings are available, demonstrate by increasing the number of slits each time so that fewer and fewer points of light are visible as more destructive interference occurs. Learners can count the number of bright spots, n, and observe as this value decreases with more slits. Can learners explain why less light is seen for a higher number of slits?</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Explain how the multiple slits produce more cases of destructive interference. Use diagrams as an aid.</p> <p>Derive the equation that relates wavelength and the diffraction spacing.</p> <p>Learners can find the wavelength of the monochromatic light of the laser by using the equation and taking measurements of the experimental set up.</p> <p>Learners can write notes on the use of diffraction gratings to determine the wavelength of light. They should note that this experiment is superior to Young's slits because it is easier to measure between the bright dots of light than the indistinct fringes. They do not need to be familiar with the structure and use of the spectrometer.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can investigate interference further using the Wave Interference simulation. (I)</p> <p>Slit diffraction: https://studynova.com/lecture/physics/waves/slit-diffraction/</p> <p>Teacher notes and learner worksheets from the IoP on diffraction gratings: https://spark.iop.org/episode-322-diffraction-gratings</p> <p>Wave Interference simulation: https://phet.colorado.edu/en/simulation/wave-interference</p>

Past and specimen papers

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

8 Electricity and d.c. circuits

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
9.1 Electric current KC1 KC4	<p>9.1.1 Understand that an electric current is a flow of charge carriers.</p> <p>9.1.2 Understand that the charge on charge carriers is quantised.</p> <p>9.1.3 Recall and use $Q = It$.</p> <p>9.1.4 Use, for a current-carrying conductor, the expression $I = Anvq$, where n is the number density of charge carriers.</p>	<p>Introduce elementary charge. Ask learners to calculate how many electrons are in 1 coulomb of charge.</p> <p>Demonstrate the ‘spooning of charge’ with a high voltage power supply, a coulomb meter and an insulated spoon. Investigate different-sized spoons and which way up the spoon should face (see spark.iop link).</p> <p>Demonstrate the shuttling ping-pong ball with a Van de Graaff generator. Use a milliammeter to measure the current. Direct learners to calculate how many electrons are carried by the ball each time it moves.</p> <p>Discuss the charge of an electron and how the movement of this charge produces current. Relate to the previous demonstrations. Define current and introduce the equation.</p> <p>Ask learners for alternative situations that allow current to flow other than metal conductors. Learners may suggest lightning through ionised air, fluorescent lights through plasma, protons through a vacuum in a particle accelerator, ions in an electrolyte, etc. Discuss the dangers of electricity and our role as a conductor.</p> <p>Why can charges in a vacuum travel so much faster than in a circuit? Clarify that delocalised electrons in metals are also known as conduction electrons and they are what makes metals such good conductors.</p> <p>Demonstrate conduction by ‘coloured’ ions (see tap.iop link). The ions move remarkably slowly. Can the speed be measured? How could the resistance of the paper be measured?</p> <p>Clarify that charges in circuits move very slowly and this happens as they are actually drifting through the metal’s lattice and continually colliding with the atoms in the lattice.</p> <p>Derive the equation that allows calculation of the mean drift velocity v as related to current. Relate it to the length and diameter of a conductor and conclude that as these variables change in a circuit, the speed of the electrons does too to ensure a constant current around the circuit. Remind learners that the drift velocity is a mean and not representative of every individual electron moving in the circuit.</p> <p>Insulators have low numbers of conduction electrons, if any, whereas semiconductors have around a millionth of the numbers metals have. Adding impurities increases n, allowing the electrons to travel much faster in a semiconductor than a conductor.</p> <p>Set learners questions for practice. (F)</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		Teacher notes and learner worksheets from the IoP on current as a flow of charge and drift velocity: https://spark.iop.org/episode-102-current-flow-charge https://spark.iop.org/episode-104-drift-velocity
9.2 Potential difference and power KC3 KC4	9.2.1 Define the potential difference across a component as the energy transferred per unit charge. 9.2.2 Recall and use $V = W / Q$. 9.2.3 Recall and use $P = VI$, $P = I^2 R$ and $P = V^2 / R$.	Define potential difference across as a component as the energy transferred per unit charge. Ask learners to recall how potential difference behaves in series and parallel circuits. Learners can investigate this with simple circuits and a voltmeter. Ask learners what it means when an appliance is labelled as '650W'? They should recall that W is the unit Watt, for power. They may explain that 650W means that 650J of energy is transferred every second. Ask them to explain what the difference is when an appliance has a higher power rating. Encourage learners to make links between everyday items and the electrical energy they use. Learners may have 'smart meters' (electricity meters that provide real-time information on energy usage) or power meter sockets in their homes that monitor energy usage. What happens when they turn on an electric kettle? Define power and derive equations for power in terms of voltage, current and resistance using the definition of power from Unit 5 <i>Work, energy, and power</i> and Ohm's law from Cambridge IGCSE (or equivalent). Set learners questions for practice. (F)
9.3 Resistance and resistivity KC2 KC3 KC4	9.3.1 Define resistance. 9.3.2 Recall and use $V = IR$. 9.3.3 Sketch the I - V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp. 9.3.4 Explain that the resistance of a filament lamp increases as current	Discuss the qualitative effect that resistance has on a circuit. Adding components to a circuit increases the overall resistance and decreases the current. Alternatively, it can be considered that resistance increases the 'volts per amp' needed to maintain the current, thus higher-resistance circuits require more voltage. Learners can carry out the Ohm's law experiment to collect results of current and voltage and prove the direct proportionality. They can plot an I - V graph and find values of resistance from points on the graph. They can repeat this for a filament lamp and a diode. Alternatively learners can investigate different components and then share their findings with each other. They should be able to sketch the appropriate I - V graphs. Learners may be interested in discussing LEDs in terms of their uses and their advantages in comparison to light bulbs. Define Ohm's law and state the equation. Link learners' understanding of resistance to the mean drift velocity. When a filament lamp gets hot, the electrons have more kinetic energy and have more collisions with the positive metal ions. This reduces the current, showing that the resistance has increased. Learners can investigate Ohm's law further using the Ohm's Law simulation. (I)

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>increases because its temperature increases.</p> <p>9.3.5 State Ohm's law.</p> <p>9.3.6 Recall and use $R = \rho L / A$.</p> <p>9.3.7 Understand that the resistance of a light-dependent resistor (LDR) decreases as the light intensity increases.</p> <p>9.3.8 Understand that the resistance of a thermistor decreases as the temperature increases.</p>	<p>Introduce resistivity as a measure of a specific material's resistance to the flow of current.</p> <p>Discuss how the variation with length and area affects the resistance of a wire. Use the analogy of a water pipe and how its length and area affects the flow of water.</p> <p>Learners can investigate resistance using conducting paper or putty. You could make conducting putty, or play dough, in advance of the lesson (see instructables.com link).</p> <p>Introduce the equation for resistivity and its variables. Ask learners to derive the unit of resistivity.</p> <p>Learners can investigate the resistivity of a material by measuring distance, voltage and current. Changing the length of the wire connected to the power supply changes the voltage and current. They should measure diameter of the wire to allow calculation of the area and this should be done in at least three different places, and in different directions, along the wire. Note: Warn learners that to avoid overheating the wire they should keep the voltage low and turn off the circuit when not collecting results.</p> <p>Ask learners to predict how a light-dependent resistor functions as light intensity changes. A simple analogy of how humans like the sunshine, making them happier and less 'resistive' or grumpy, might help learners to remember how an LDR works. You could demonstrate an LDR and discuss uses.</p> <p>Ask learners to predict how a thermistor functions as temperature changes. Learners need only be familiar with negative temperature coefficient thermistors. They should notice that the I-V graph is like an inverted I-V graph of a filament lamp. Relate this to their understanding of semiconductors and how increasing the temperature increases the number density of charge carriers. You could demonstrate a thermistor and discuss uses.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can investigate resistivity further using the Resistance in a wire simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on electrical resistance, Ohm's law and resistivity: https://spark.iop.org/electrical-resistance https://spark.iop.org/collections/ohms-law-and-resistance https://spark.iop.org/episode-112-resistivity</p> <p>Ohm's Law simulation: https://phet.colorado.edu/en/simulation/ohms-law</p> <p>How to make conductive play dough: www.instructables.com/id/How-to-make-conductive-play-dough/</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		Resistance in a wire simulation: https://phet.colorado.edu/en/simulation/resistance-in-a-wire
10.1 Practical circuits KC2 KC4	10.1.1 Recall and use the circuit symbols shown in the syllabus. 10.1.2 Draw and interpret circuit diagrams. 10.1.3 Define and use the electromotive force (e.m.f.) of a source as energy transferred per unit charge in driving charge around a complete circuit. 10.1.4 Distinguish between e.m.f. and potential difference (p.d.) in terms of energy considerations. 10.1.5 Understand the effects of the internal resistance of a source of e.m.f. on the terminal potential difference.	<p>Show a diagram of the circuit symbols shown in the syllabus without the names and ask learners to identify as many as possible. You can test learners later to ensure they have learnt the symbols. (F)</p> <p>Show circuit diagrams and ask learners to build the circuits. These can be simple series circuits, more complicated parallel circuits or a combination of the two types. Common misconceptions include the correct placement of the meters, how to add additional items, like a switch, into a parallel branch and understanding that current may be flowing through a filament lamp even if it is not visibly bright. Ensure all learners are comfortable interpreting circuit diagrams.</p> <p>Learners can test each other on their interpretation of circuit diagrams by working in pairs. One learner draws a circuit diagram and the other must build it. They can then swap over and increase the difficulty of the circuits.</p> <p>Learners can investigate simple circuits further using the Circuit Construction Kit DC simulation. (I)</p> <p>Define the electromotive force and clarify that it is not a force, it is the energy per unit charge supplied by the power supply. Learners may be able to link the volt to the joule through this definition. Clarify the difference between e.m.f. and p.d. The potential difference is the electrical energy per unit charge transferred into other forms e.g. into light and heat when the electrons pass through a lamp.</p> <p>Demonstrate the e.m.f. of a human. This can be done as a demonstration with one volunteer, or you can give every learner equipment. The human between the zinc and copper plates is the electrolyte and the multimeter reads their e.m.f. Link this to the first battery ever made by Alessandro Volta. The simplicity of this may surprise learners; it was basically layers of 'salty sponges' sandwiched between zinc and copper plates.</p> <p>Many items can be used as cells, as well as humans, such as lemons and potatoes (see spark.iop link). However, they have high internal resistance. What does this mean? Ask learners to explain what effect internal resistance has on the usefulness of a battery.</p> <p>Compare the energy transfer in a circuit to the energy transfer in a water wheel. Charge carriers are pushed around a circuit by the e.m.f. of the cell and do work in the lamp. They are not moved vertically but they do lose potential energy. The charge 'falls' from high electrical potential energy to lower potential electrical potential energy, like water in a water wheel. Energy, current and charge must all be conserved.</p> <p>Learners can investigate internal resistance further using the Internal Resistance simulation. (I)</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Hand battery demonstration: www.stem.org.uk/resources/elibrary/resource/28161/hand-battery Teacher notes and learner worksheets from the IoP on e.m.f. and internal resistance: https://spark.iop.org/collections/emf-and-internal-resistance https://spark.iop.org/internal-resistance-fruit-and-vegetable-cells</p> <p>Circuit Construction Kit DC – Virtual Lab simulation: https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab</p> <p>Internal Resistance simulation: www.physicslab.co.uk/emfandpd.htm</p>
<p>10.2 Kirchhoff's laws</p> <p>KC1</p> <p>KC2</p> <p>KC3</p> <p>KC4</p>	<p>10.2.1 Recall Kirchhoff's first law and understand that it is a consequence of conservation of charge.</p> <p>10.2.2 Recall Kirchhoff's second law and understand that it is a consequence of conservation of energy.</p> <p>10.2.3 Derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series.</p> <p>10.2.4 Use the formula for the combined resistance</p>	<p>Introduce Kirchhoff's first law by showing simple junction diagrams with the current labelled in all wires except one. Learners can calculate the missing value, as well as the direction, of the current. Remind learners that charge is conserved in a circuit. Kirchhoff's first law is an expression of this basic principle.</p> <p>Use example questions to demonstrate to learners how Kirchhoff's first law can be used to find the missing values of current.</p> <p>Ask learners what they would expect to find if they added all the e.m.f. in a circuit and all of the p.d. in a circuit. They may suggest that these values would be the same, which is Kirchhoff's second law and a consequence of the conservation of energy. In reality, some electrical energy from the battery may be used to heat the battery itself, due to internal resistance.</p> <p>Use example questions to demonstrate to learners how Kirchhoff's second law can be used to find the missing values of e.m.f. and p.d. Encourage learners to consider each 'loop' within the circuit.</p> <p>Using Kirchhoff's laws, derive formulae for the combined resistance of two or more resistors in series and in parallel.</p> <p>Learners can test the equations for combined resistance by connecting the resistors and measuring their resistance with a multimeter. Alternatively learners can use measurements of voltage and current along with Ohm's law to find the combined resistance of resistors in a circuit.</p> <p>Set learners simple circuit problems for practice. (F)</p> <p>Learners can more build circuits in reality or simulate their construction with the Circuit Construction Kit DC simulation to aid understanding. (I)</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>of two or more resistors in series.</p> <p>10.2.5 Derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in parallel.</p> <p>10.2.6 Use the formula for the combined resistance of two or more resistors in parallel.</p> <p>10.2.7 Use Kirchhoff's laws to solve simple circuit problems.</p>	<p>Kirchhoff's laws: https://studynova.com/lecture/physics/electricity-and-magnetism/kirchhoffs-laws/</p> <p>Teacher notes and learner worksheets from the IoP on Kirchhoff's laws: https://spark.iop.org/episode-117-kirchhoffs-laws</p> <p>Circuit Construction Kit DC – Virtual Lab simulation: https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab</p>
<p>10.3 Potential dividers</p> <p>KC2</p> <p>KC4</p>	<p>10.3.1 Understand the principle of a potential divider circuit.</p> <p>10.3.2 Recall and use the principle of the potentiometer as a means of comparing potential differences.</p> <p>10.3.3 Understand the use of a galvanometer in null methods.</p>	<p>Introduce a simple example of a potential divider e.g. a circuit with a cell and two resistors. Ask learners what values of p.d. would be measured by a voltmeter around each resistor if they are identical. How does this value change if the resistance of one is double the other? What would the values of p.d. be as a fraction of the e.m.f. of the cell? Learners may be able to explain that the ratio of the potential differences is the same as the ratio of the resistances.</p> <p>Introduce the term 'potential divider' and explain that it can be used for any circuit with multiple components that effectively 'divide' the e.m.f. of the power supply according to the resistances of the components. Thus, each component can have a different value of p.d. The potential divider can be used to supply a p.d. of between zero and maximum, where the maximum value depends on the e.m.f. of the power supply. This creates a varying power supply or a lower p.d. than the power supply.</p> <p>Set learners questions to find the voltage for different components in simple circuits for practice. (F)</p> <p>Introduce a variable resistor, thermistor or LDR into the circuit instead of one of the fixed resistors. Ask learners to discuss how each component would affect the circuit and the values of voltage. Learners may forget that not only</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>10.3.4 Explain the use of thermistors and light-dependent resistors in potential dividers to provide a potential difference that is dependent on temperature and light intensity.</p>	<p>will these components cause the values of p.d. to change, but that changing their resistance will change the overall resistance of the circuit and thus the current that flows too.</p> <p>Remind learners about how thermistors and LDRs can be used to automatically trigger switches. Look at examples of circuits that ‘turn on’ when outside variables change and affect the resistance of the components in a circuit.</p> <p>Ask learners to explain why an ammeter should have zero resistance. They should consider how its presence could affect the current and the voltage given to the other components if it had a higher resistance.</p> <p>Ask learners to explain why a voltmeter should have infinite resistance. They should consider what a voltmeter measures and how its presence could affect current if it had a lower resistance.</p> <p>Ask learners if it is likely for an ammeter to have zero resistance and a voltmeter to have infinite resistance. These imperfections add uncertainties into measurements. Explain how a galvanometer can be used in null methods.</p> <p>Learners can investigate dividing the voltage further using the Voltage divider simulation. (I)</p> <p>Potential divider: https://alevelphysics.co.uk/notes/potential-divider/</p> <p>Voltage divider simulation: www.falstad.com/circuit/e-voltdivide.html</p>

Past and specimen papers

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

9 Motion in a circle

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
12.1 Kinematics of uniform circular motion KC1 KC3 KC5	12.1.1 Define the radian and express angular displacement in radians. 12.1.2 Understand and use the concept of angular speed. 12.1.3 Recall and use $\omega = 2\pi/T$ and $v = r\omega$.	<p>Introduce motion in a circle by demonstrating a spinning bucket with water inside. Learners can volunteer to try this. The bucket can be spun horizontally or vertically and as long as it moves fast enough, no water is spilt. Ask learners to identify the forces acting on the water, which force is essential to keep the water in place, whether the bucket is accelerating and what happens if you let go. Relate this last question to the Olympic field sports of the hammer throw or discus throw.</p> <p>Introduce the radian as the measure of angular displacement. Relate it to degrees and revolutions, making the link to learners' understanding of wavelength from Unit 7 <i>Waves and superposition</i>. Make use of diagrams and the Ladybug revolution simulation.</p> <p>Direct learners to derive an equation for linear speed in a circle by using the definition of speed and substituting in the circumference and time period.</p> <p>Introduce angular velocity and relate to linear velocity. Relate to the sensation of being on a playground roundabout when you lean out and then pull your body in. Other examples that could be discussed are a record player and a carousel. Does every part of the object travel at the same speed?</p> <p>Set learners simple questions for practice. (F)</p> <p>Ladybug revolution simulation: https://phet.colorado.edu/en/simulation/legacy/rotation</p> <p>Teacher notes and learner worksheets from the IoP on circular motion: https://spark.iop.org/episode-224-describing-circular-motion https://spark.iop.org/episode-225-quantitative-circular-motion</p>
12.2 Centripetal acceleration KC2 KC3	12.2.1 Understand that a force of constant magnitude that is always perpendicular to the direction of motion causes centripetal acceleration.	<p>Return to the example of the bucket of water spinning in a circle. What was the force that held the water in place? In which direction does the force act? Where does the acceleration act? Learners may identify that the force and the acceleration acts towards the centre of the circular path. This is the centripetal force and centripetal acceleration that produces circular motion. Ask learners to comment on the angular velocity. For a constant centripetal acceleration, the angular speed is constant, but the linear velocity is constantly changing.</p> <p>Derive the centripetal acceleration equation using radians.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
KC5	<p>12.2.2 Understand that centripetal acceleration causes circular motion with a constant angular speed.</p> <p>12.2.3 Recall and use $a = r\omega^2$ and $a = v^2 / r$.</p> <p>12.2.4 Recall and use $F = mr\omega^2$ and $F = mv^2 / r$.</p>	<p>Consider other examples of circular motion and identify the centripetal force in each case: cars travelling around bends, cars travelling over a hill, planets orbiting stars, electrons in orbit of a nucleus, a bung on a string, the London Eye, a cyclist on a banked track, etc.</p> <p>Learners can investigate the centripetal force by whirling a bung above their head. Varying the angular frequency and the length of the string affects how much mass can be lifted (see spark.iop 225 link).</p> <p>Set learners more challenging questions for practice. (F)</p> <p>Learners may find it interesting to watch videos of vehicles attempting a loop-the-loop, athletes performing Olympic throws and ice skaters changing their speed as they bring their arms in during spins.</p> <p>Learners may find it interesting to watch videos of circular motion in a weightless environment, such as those made by Tim Peake on the International Space Station (see stem.org link). They can then carry out analysis of data. (I)</p> <p>Teacher notes and learner worksheets from the IoP on circular motion: https://spark.iop.org/episode-225-quantitative-circular-motion</p> <p>Circular motion and mission Principia: www.stem.org.uk/resources/elibrary/resource/228680/circular-motion-ball-tether-released-vertical-plane</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

10 Gravitational fields

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
13.1 Gravitational fields KC1 KC4	13.1.1 Understand that a gravitational field is an example of a field of force and define gravitational field as force per unit mass. 13.1.2 Represent a gravitational field by means of field lines. 13.2.1 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.	<p>Ask learners to define a field. Explain that a field is a region where a force is felt. Ask them to name types of fields. Learners may name gravitational, electric and magnetic. Ask learners what makes gravitational fields different to the other two. Highlight that all masses attract. Define gravitational field strength as the force per unit mass. Highlight that gravitational field strength is a vector and has direction.</p> <p>Ask learners how fields can be represented. They may suggest field lines, which they may recall from Cambridge IGCSE (or equivalent). Ask a volunteer to draw the gravitational field around the Earth. They may draw the magnetic field instead. Give hints: field lines tell us the strength and direction of the field, think about where all the Earth's field lines would meet, think about where an object with mass would move when placed in any position above the Earth's surface, etc.</p> <p>Ask learners to draw the gravitational field lines to scale for the room they are in. They may try to draw radiating lines again, but may realise that on our scale the field appears uniform so the lines are parallel.</p> <p>Introduce the inverse square law for the gravitational field strength around a point object or a sphere like an astronomical body. You can clarify this with a diagram showing the field lines spreading out in 3D space. Highlight that for a point outside a uniform sphere, the mass of the sphere may be considered to be a point mass at its centre.</p> <p>Set learners simple questions for practice. (F)</p> <p>Teacher notes and learner worksheets from the IoP on fields, field lines and field strength: https://spark.iop.org/episode-402-fields-field-lines-and-field-strength</p>
13.2 Gravitational force between point masses 13.3 Gravitational field of a point mass KC1 KC3	13.2.2 Recall and use Newton's law of gravitation $F = Gm_1m_2 / r^2$ for the force between two point masses. 13.2.3 Analyse circular orbits in gravitational fields by	<p>Ask learners to estimate their gravitational attraction to any other person in the room. This may be a complete guess or they may consider what their gravitational attraction is to the Earth, their weight, and estimate it as much smaller than that. Do not provide any affirmation this stage; return to the answer later.</p> <p>Ask learners to suggest the variables that will affect the gravitational force felt between two objects with mass. They may be able to correctly identify mass and distance.</p> <p>Introduce Newton's law of gravitation in words and as an equation.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
<p>KC4</p>	<p>relating the gravitational force to the centripetal acceleration it causes.</p> <p>13.2.4 Understand that a satellite in a geostationary orbit remains at the same point above the Earth's surface, with an orbital period of 24 hours, orbiting from west to east, directly above the Equator.</p> <p>13.3.1 Derive, from Newton's law of gravitation and the definition of gravitational field, the equation $g = GM / r^2$ for the gravitational field strength due to a point mass.</p> <p>13.3.2 Recall and use $g = GM / r^2$.</p> <p>13.3.3 Understand why g is approximately constant for small changes in height near the Earth's surface.</p>	<p>Introduce the gravitational constant and highlight its small scale. This helps to explain why only very large masses produce significant forces.</p> <p>Ask learners to calculate their gravitational attraction to any other person in the room. They can compare their result to their initial guess. Was anyone close?</p> <p>Give learners the distance between the Sun and the Earth and ask them to calculate the mass of the Sun. They may be able to link their understanding of Unit 9 <i>Motion in a circle</i> to Newton's law of gravitation. By equating the gravitational force to the centripetal force, the mass of the Sun can be found by assuming that the Earth has a circular orbit, the time period is 365.25 days and the Sun is stationary. It may interest learners to know that the Sun has a slight wobble and astronomers look for this when trying to spot stars that have planetary systems.</p> <p>Highlight that when there are more than two objects with mass, the resultant gravitational force can be calculated through vector addition.</p> <p>Set learners simple questions for practice. (F)</p> <p>Learners can investigate Newton's law of gravitation further using the Gravity force lab simulation. (I)</p> <p>Show learners a picture of <i>Sputnik 1</i>. Can any of the learners identify what it is and provide its name? Introduce a satellite as an object orbiting a planet and explain the properties of a geostationary satellite.</p> <p>Ask learners to explain why a geostationary satellite must orbit at a specific height above the Earth. Learners can calculate this height knowing the Earth's mass and radius.</p> <p>Learners may find it interesting to watch live data of satellites orbiting our planet (see n2yo.com link).</p> <p>Direct learners to derive an equation for the gravitational field strength using the definition and Newton's law of gravitation. This is the gravitational field strength due to a point mass.</p> <p>Direct learners to calculate the gravitational field strength of the Earth using its mass and radius, considering Earth as a point mass.</p> <p>Direct learners to calculate the gravitational field strength of the Earth at the top of Mount Everest. Highlight that even at the top of the highest mountain on our planet, there is no significant change to the gravitational field strength. We can consider the gravitational field strength to be approximately constant for small changes in height near the Earth's surface.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Learners may find it interesting if you show them a diagram of the Earth with the varying values of gravitational field strength marked. In reality there are small variations in the gravitational field strength around the planet. Ask learners to suggest why this might be the case. They could also look at diagrams of other planets.</p> <p>Set learners more challenging questions for practice. (F)</p> <p>Gravity force lab simulation: https://phet.colorado.edu/en/simulation/gravity-force-lab</p> <p>Why only one geostationary orbit? https://spark.iop.org/why-only-one-geostationary-orbit</p> <p>Live satellite tracking: www.n2yo.com</p>
<p>13.4 Gravitational potential</p> <p>KC3</p> <p>KC4</p>	<p>13.4.1 Define gravitational potential at a point as the work done per unit mass in bringing a small test mass from infinity to the point.</p> <p>13.4.2 Use $\phi = -GM / r$ for the gravitational potential in the field due to a point mass.</p> <p>13.4.3 Understand how the concept of gravitational potential leads to the gravitational potential energy of two point masses and use $E_P = -GMm / r$.</p>	<p>Define gravitational potential. Ask learners to suggest what the units are and whether it is a vector or a scalar. Show learners a diagram and a worked example to clarify the new definition. A graph of gravitational potential against distance may also be helpful.</p> <p>Show learners a graph of gravitational potential against distance for the Earth and the Moon. Ask them to explain how and why it changes. When <i>Apollo 8</i> astronauts first travelled around the Moon, NASA scientists amused themselves by calculating the precise moment the astronauts would reach equipotential. This is the point where the gravitational potential between the Earth and the Moon is closest to zero and the gravitational force felt from each is equal and opposite.</p> <p>Show a video of a rocket launch. Relate this to the concept of doing work to escape the Earth's gravitational field. Highlight that we take the potential as zero at infinity and increasingly negative as we move towards a mass. This 'negative energy' is the amount of energy required to escape a gravitational field. The more mass an object has, the more energy it requires, but all objects experience the same gravitational potential as this is defined as the work done per unit mass.</p> <p>Learners may be able to derive the gravitational potential energy using the definition of gravitational potential, the definition of work done from Unit 5 <i>Work, energy and power</i> and Newton's law of gravitation.</p> <p>Return to the graph of gravitational potential against distance and highlight that the area under the line is the work done in moving the mass.</p> <p>Set learners questions for practice. (F)</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		Teacher notes and learner worksheets from the IoP on field strength and energy: https://spark.iop.org/episode-408-field-strength-and-energy
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

11 Temperature, ideal gases and thermodynamics

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
14.1 Thermal equilibrium 14.2 Temperature scales KC4	14.1.1 Understand that (thermal) energy is transferred from a region of higher temperature to a region of lower temperature. 14.1.2 Understand that regions of equal temperature are in thermal equilibrium. 14.2.1 Understand that a physical property that varies with temperature may be used for the measurement of temperature and state examples of such properties. 14.2.2 Understand that the scale of thermodynamic temperature does not depend on the property of any particular substance. 14.2.3 Convert temperatures	<p>Demonstrate the transfer of thermal energy via convection. Set up two pairs of bottles of heated and coloured water (see stevespanglerscience.com link). Placing the two mouths together, observe how when the heated water is in the bottom bottle it rises and mixes with the cool water, but when it is in the top bottle, it barely mixes at all. Relate this to Unit 6 <i>Density, pressure and deformation of solids</i> and learners' understanding of convection.</p> <p>Ask learners to explain how thermal energy is transferred. They may explain that energy is transferred from a region of higher temperature to a region of lower temperature and this can be done through a number of processes.</p> <p>Introduce thermal equilibrium. Highlight that zero resultant energy is transferred between two regions of equal temperature. Discuss simple examples e.g. the objects left in the room overnight will be in thermal equilibrium with each other.</p> <p>Discuss physical properties that vary with temperature that may be used for the measurement of temperature. Examples include the density of a liquid, volume of a gas at constant pressure, resistance of a metal and e.m.f. of a thermocouple. The first two will link to later parts of this topic and the last two can be related to Unit 8 <i>Electricity and d.c. circuits</i>.</p> <p>Introduce the scale of thermodynamic temperature in kelvin. This scale is independent of any property of any particular substance. Highlight that zero kelvin is absolute zero and there is no temperature lower than this. Learners may find it interesting to discuss what the degrees Celsius and Fahrenheit scales are based on as they are commonly used in everyday life.</p> <p>Link some key numerical values in degrees Celsius to kelvin e.g. absolute zero, ice point, room temperature, etc.</p> <p>Set learners simple questions to practise conversions between kelvin and degrees Celsius. Remind learners that it is impossible to get negative values of temperature in kelvin. (F)</p> <p>Learners can investigate how temperature is transferred in a substance using the States of Matter simulation. They can increase or decrease the temperature and observe how this affects the behaviour of the atoms or molecules. (I)</p> <p>Colourful convection currents: www.stevespanglerscience.com/lab/experiments/colorful-convection-currents/ </p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>between kelvin and degrees Celsius and recall that $T / K = \theta / ^\circ\text{C} + 273.15$.</p> <p>14.2.4 Understand that the lowest possible temperature is zero kelvin on the thermodynamic temperature scale and that this is known as absolute zero.</p>	<p>States of Matter simulation: https://phet.colorado.edu/en/simulation/states-of-matter</p>
<p>14.3 Specific heat capacity and specific latent heat</p> <p>KC2</p> <p>KC3</p> <p>KC4</p>	<p>14.3.1 Define and use specific heat capacity.</p> <p>14.3.2 Define and use specific latent heat and distinguish between specific latent heat of fusion and specific latent heat of vaporisation.</p>	<p>Introduce specific heat capacity by defining its meaning and clarifying that ‘specific’ refers to any value per unit mass. In this case, although slightly unclear, ‘heat’ refers to energy. Link to the equation.</p> <p>Relate the specific heat capacity values of everyday materials to their properties. Water is a particularly interesting example and plays an important role in regulating the temperature of our planet.</p> <p>Ask learners which substance stores more energy when in thermal equilibrium, a substance with a high specific heat capacity or a substance with a lower specific heat capacity. Relate this to cooking e.g. a cake and its tin are in thermal equilibrium in a hot oven, but touching the tin will burn but touching the cake probably will not. It might interest learners to watch the Veritasium video (see youtube.com link) exploring misconceptions about heat.</p> <p>Learners can find the specific heat capacity of a solid block of metal or a liquid, such as water, using a simple circuit and an immersion heater (see spark.iop 607 link). They can take measurements of time, p.d. and current to calculate the electrical energy and combine with measurements of temperature change and mass to find the specific heat capacity.</p> <p>Introduce specific latent heat. Define latent as ‘hidden’ and clarify it refers to the energy required to change the state, which does not produce a change in temperature. Introduce the terms fusion and vaporisation to refer to melting and evaporating.</p> <p>Resource Plus</p> <p>Carry out the <i>Finding specific latent heat using electrical methods</i> experiment referring to the Teaching Pack for lesson plans and resources.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Set learners questions for practice. (F)</p> <p>Learners can investigate changes of state further using the States of Matter simulation. (I)</p> <p>Veritasium youtube channel: Misconceptions About Heat www.youtube.com/watch?v=hNGJ0WHXMyE</p> <p>Teacher notes and learner worksheets from the IoP on specific heat capacity and specific latent heat: https://spark.iop.org/episode-607-specific-heat-capacity https://spark.iop.org/episode-608-latent-heat</p> <p>States of Matter simulation: https://phet.colorado.edu/en/simulation/states-of-matter</p>
<p>15.1 The mole</p> <p>15.2 Equation of state</p> <p>KC1</p> <p>KC2</p> <p>KC3</p> <p>KC4</p>	<p>15.1.1 Understand that amount of substance is an SI base quantity with the base unit mol.</p> <p>15.1.2 Use molar quantities where one mole of any substance is the amount containing a number of particles of that substance equal to the Avogadro constant N_A.</p> <p>15.2.1 Understand that a gas obeying $pV \propto T$, where T is the thermodynamic temperature, is known as an ideal gas.</p>	<p>Introduce the mole as the amount of substance that simplifies certain calculations and is commonly used by chemists. Relate it to the number of molecules and the Avogadro constant.</p> <p>Introduce Boyle's law as the relationship between pressure and volume for a fixed temperature and mass of gas. Ask learners to explain how this relationship might work. Learners can carry out a simple experiment to verify this law and plot results in a graph (see spark.iop 601 link).</p> <p>Introduce Charles' law as the relationship between temperature and volume for a fixed pressure and mass of gas. Ask learners to explain how this relationship might work. Show various simple demonstrations of temperature changing the volume of an object e.g. the ball and hoop demonstration (see preproom.org link).</p> <p>Introduce the pressure law as the relationship between pressure and temperature for a fixed volume and mass of gas. Ask learners to explain how this relationship might work. Learners can verify this with a conical flask with a thermometer and pressure gauge inserted through the bung that seals the opening. The flask can be submerged in various heat baths to produce changes in temperature and pressure. Relate the law back to the imploding can demonstration from Unit 6 <i>Density, pressure and deformation of solids</i> where the decreased temperature caused a decrease of pressure, producing a large pressure difference and resulting in the implosion. A temperature-pressure graph can be extrapolated to find the y-intercept, giving absolute zero.</p> <p>Show a set of pV against T axes and ask learners to sketch the line of the graph. Ask learners how the line changes for more mass or less mass. What does the gradient represent?</p> <p>Define an ideal gas and explain that the gas laws describe ideal gases.</p> <p>Combine all three laws to make the ideal gas law, expressed in terms of the number of moles and the number of</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>15.2.2 Recall and use the equation of state for an ideal gas expressed as $pV = nRT$, where n = amount of substance (number of moles) and as $pV = NkT$, where N = number of molecules.</p> <p>15.2.3 Recall that the Boltzmann constant k is given by $k = R / N_A$.</p>	<p>molecules, and introduce the molar gas constant and the Boltzmann constant. Link these two constants via the Avogadro constant.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can investigate the gas laws further using the Ideal Gas Behaviour simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on ideal gases and imploding can demonstration: https://spark.iop.org/episode-601-brownian-motion-and-ideal-gases https://spark.iop.org/episode-602-ideal-gases-and-absolute-zero https://spark.iop.org/gas-pressure-rises-temperature</p> <p>Ball and hoop demonstration: www.preproom.org/equipment/eq.aspx?eqID=5001</p> <p>Ideal Gas Behaviour simulation: www.physicslab.co.uk/gas.htm</p>
<p>15.3 Kinetic theory of gases</p> <p>KC1</p> <p>KC3</p> <p>KC4</p>	<p>15.3.1 State the basic assumptions of the kinetic theory of gases.</p> <p>15.3.2 Explain how molecular movement causes the pressure exerted by a gas and derive and use the relationship $pV = 1/3Nm\langle c^2 \rangle$, where $\langle c^2 \rangle$ is the mean-square speed.</p> <p>15.3.3 Understand that the root-mean-square speed $c_{r.m.s.}$ is given by $\langle c^2 \rangle$.</p>	<p>Introduce the constant motion of molecules in a gas using the Gas Properties simulation.</p> <p>Recap the key properties of solids, liquids and gases. Discuss the potential and kinetic energies each has.</p> <p>A gas can be described in terms of mass, volume, pressure, etc on the macroscopic scale, or it can be described in terms of the motion of its large number of molecules on the microscopic scale. Introduce the basic assumptions of the kinetic theory of gases and explain each so they are clear for learners. Link to the conservation of energy from Unit 5 <i>Work, energy and power</i> and momentum from Unit 3 <i>Dynamics</i>.</p> <p>Derive a statement for pressure starting from the change of momentum and relating it to the force of an individual molecule on the container wall.</p> <p>Introduce the idea that molecules in a gas move at a range of speeds in different directions. Finding the mean velocity would give an answer of zero. Introduce the root-mean-square speed as an alternative value that reflects the range of velocities and links to other useful equations. Show how the root-mean-square speed can be calculated.</p> <p>Derive the equation that explains how molecular movement causes the pressure exerted by a gas using the mean-square speed. A simple model considering one-dimensional collisions and then extending to three dimensions using $1/3\langle c^2 \rangle = \langle c_x^2 \rangle$ is sufficient (see spark.iop link).</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>15.3.4 Compare $pV = 1/3Nm\langle c^2 \rangle$ with $pV = NkT$ to deduce that the average translational kinetic energy of a molecule is $3/2 kT$.</p>	<p>Introduce the Maxwell-Boltzmann distribution of the speeds of particles where higher temperatures have a wider spread of values. The root-mean-square speed is higher than the mean speed and the most probable speed.</p> <p>Derive the equation for the average translational kinetic energy using the previous equation and the ideal gas law for molecules. This shows that energy and temperature are directly proportional for an ideal gas.</p> <p>Link this idea to how certain gases escape our atmosphere e.g. helium atoms travel faster than carbon dioxide molecules due to the difference in mass, despite being in thermal equilibrium with the atmosphere.</p> <p>Set learners questions for practice. (F)</p> <p>Gas Properties simulation: https://phet.colorado.edu/en/simulation/gas-properties</p> <p>Teacher notes and learner worksheets from the IoP on the kinetic model: https://spark.iop.org/episode-603-kinetic-model-ideal-gas</p>
<p>16.1 Internal energy</p> <p>KC1</p> <p>KC4</p>	<p>16.1.1 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.</p> <p>16.1.2 Relate a rise in temperature of an object to an increase in its internal energy.</p>	<p>Define internal energy and check learners' understanding by asking simple questions e.g. if a container of gas is taken for a drive on the motorway, does this increase the gas's internal energy? External changes cannot affect the internal energy of the molecules of a system.</p> <p>Relate internal energy to the changes of state and ideal gas laws already covered. Cooling a substance decreases the internal energy and reduces the pressure. Heating a substance increases kinetic energy and may increase the potential energy if the substance changes state.</p> <p>Ask learners to sketch a temperature against time or energy graph. Identify where changes of kinetic energy take place, linking to the average translational kinetic energy equation, and where changes of potential energy take place, linking to the changes of state.</p> <p>Learners can investigate changes of state for water by starting with ice in a beaker and taking measurements of time and temperature as it heats to boiling over a Bunsen burner. Learners can plot a temperature– time graph and qualitatively describe the changes observed.</p> <p>Alternatively, learners can investigate changes of state using a substance that is solid at room temperature e.g. cetyl alcohol. Heat the substance in a test tube by placing in a warm water bath, remove from the bath and observe the drop of temperature over time as it solidifies. Learners can plot a temperature–time graph.</p> <p>Demonstrate changes of state using the States of Matter simulation.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Clarify the factors that can affect the internal energy and link to the ideal gas law. Clarify that internal energy cannot be affected by external changes.</p> <p>Set learners qualitative and quantitative questions for practice. (F)</p> <p>States of Matter simulation: https://phet.colorado.edu/en/simulation/states-of-matter</p>
<p>16.2 The first law of thermodynamics</p> <p>KC1</p> <p>KC3</p> <p>KC4</p>	<p>16.2.1 Recall and use $W = p\Delta V$ for the work done when the volume of a gas changes at constant pressure and understand the difference between the work done by the gas and the work done on the gas.</p> <p>16.2.2 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 to the system by heating) and the work done on the system.</p>	<p>Introduce the first law of thermodynamics and link to the conservation of energy as covered in Unit 5 <i>Work, energy and power</i>.</p> <p>Introduce the example of a fixed mass of gas trapped in a container with a tightly fitting piston that moves up and down, compressing the gas or allowing the gas to expand. Ask learners to suggest how the temperature, or the internal energy, of the gas can be increased. They may suggest compressing the gas, which requires work to be done on the system, or heating the container, which requires energy to be added to the system.</p> <p>Direct learners to consider how the internal energy changes as heat enters/exits the system and as positive/negative work is done on the gas.</p> <p>Direct learners to derive $W = p\Delta V$ for the work done when the volume of a gas changes at constant pressure from the definition of work done from Unit 5 and pressure from Unit 6 <i>Density, pressure and deformation of solids</i>.</p> <p>Set learners quantitative and qualitative questions for practice. (F)</p> <p>Teacher notes and learner worksheets on the first law of thermodynamics: https://spark.iop.org/episode-605-first-law-thermodynamics</p> <p>The first law of thermodynamics: www.khanacademy.org/science/physics/thermodynamics/laws-of-thermodynamics/a/what-is-the-first-law-of-thermodynamics</p>

Past and specimen papers

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

12 Oscillations

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
17.1 Simple harmonic oscillations KC1 KC3 KC4	17.1.1 Understand and use the terms displacement, amplitude, period, frequency, angular frequency and phase difference in the context of oscillations, and express the period in terms of both frequency and angular frequency. 17.1.2 Understand that simple harmonic motion occurs when acceleration is proportional to displacement from a fixed point and in the opposite direction. 17.1.3 Use $a = -\omega^2 x$ and recall and use, as a solution to this equation, $x = x_0 \sin \omega t$. 17.1.4 Use the equations $v = v_0 \cos \omega t$ and	<p>Introduce the topic by demonstrating simple harmonic oscillations with examples e.g. a pendulum, a mass on a spring, a dynamics trolley tethered by springs between two retort stands, etc.</p> <p>Ask learners to describe what they notice about these examples of motion. They may use terms from Unit 7 <i>Waves and superposition</i> and Unit 9 <i>Motion in a circle</i> to explain their observations.</p> <p>Define displacement, amplitude, period, frequency, angular frequency and phase difference in the context of oscillations. Relate these to learners' understanding of terms from Unit 7 and Unit 9.</p> <p>Explain that simple harmonic motion occurs when acceleration is proportional to displacement from a fixed point and in the opposite direction. Ask learners to draw this relationship on an acceleration–displacement graph.</p> <p>Learners can demonstrate simple harmonic motion by setting up a funnel hanging from string such that it oscillates up and down. They place water or sand in the funnel and with a long piece of paper running underneath, the oscillating funnel creates a sinusoidal pattern (see spark.iop 305 link).</p> <p>Learners can investigate simple harmonic motion further by using the dynamics trolley tethered by springs between two retort stands and a motion sensor connected to a datalogger to track the oscillation.</p> <p>An oscillation circus can be set up for learners to observe more examples (see spark.iop 301 link).</p> <p>Introduce equations that allow description of simple harmonic motion and calculation of variables. Relate to the mathematical treatment of Unit 9 <i>Motion in a circle</i>.</p> <p>Analyse displacement–, velocity– and acceleration–time graphs and relate them to the equations.</p> <p>Set learners qualitative questions on graphical representation of simple harmonic motion and quantitative questions using the equations that describe the variables of motion. (F)</p> <p>Learners can investigate oscillations further using the Simple Harmonic Motion simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on simple harmonic motion and its mathematical treatment: https://spark.iop.org/episode-305-energy-simple-harmonic-motion https://spark.iop.org/episode-301-recognising-simple-harmonic-motion</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	$v = \pm \omega (x_0^2 - x^2)$. 17.1.5 Analyse and interpret graphical representations of the variations of displacement, velocity and acceleration for simple harmonic motion.	https://spark.iop.org/episode-302-getting-mathematical Simple Harmonic Motion simulation: www.physicslab.co.uk/shm.htm
17.2 Energy in simple harmonic motion KC3 KC4	17.2.1 Describe the interchange between kinetic and potential energy during simple harmonic motion. 17.2.2 Recall and use $E = \frac{1}{2}m\omega^2x_0^2$ for the total energy of a system undergoing simple harmonic motion.	Ask learners to describe qualitatively what happens in terms of energy during simple harmonic motion. A simple demonstration may aid explanation as learners observe and explain what is happening e.g. a mass on a spring demonstrates the change of potential energy to kinetic energy as it bounces. Use the Energy Skate Park simulation to set up a simple harmonic oscillation of a skater on a frictionless track. The simulation can show the change in potential, kinetic and total energy as the skater moves. Learners can predict what the graph will look like before releasing the skater or you can ask them to explain the graph once it has been plotted. Introduce the equation for energy and relate to learners' understanding of kinetic energy from Unit 5 <i>Work, energy and power</i> . Set learners questions for practice. (F) Teacher notes and learner worksheets from the IoP on energy in simple harmonic motion: https://spark.iop.org/episode-305-energy-simple-harmonic-motion Energy Skate Park simulation: https://phet.colorado.edu/en/simulation/legacy/energy-skate-park
17.3 Damped and forced oscillations, resonance KC1 KC4	17.2.1 Understand that a resistive force acting on an oscillating system causes damping. 17.2.2 Understand	Demonstrate examples of oscillations dying away due to friction e.g. water in a U-tube, a marble on a curved track, a skateboarder on a half pipe, etc. Introduce this loss of energy in an oscillatory system as damping. Ask learners to sketch the displacement–time graph for damping. Learners may identify the exponential nature of damping, but need not calculate this. Learners can investigate damped oscillations using a mass on a spring and a motion sensor connected to a

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>and use the terms light, critical and heavy damping and sketch displacement–time graphs illustrating these types of damping.</p> <p>17.2.3 Understand that resonance involves a maximum amplitude of oscillations and that this occurs when an oscillating system is forced to oscillate at its natural frequency.</p>	<p>datalogger (see spark.iop datalogging link).</p> <p>Introduce light, critical and heavy damping and provide examples of each. Direct learners to sketch appropriate displacement–time graphs for each example.</p> <p>Learners may be interested to learn more about the uses of damping e.g. shock absorbers, dampers on fire doors, etc. They can relate these examples to the appropriate type of damping.</p> <p>Demonstrate Barton’s pendulums to introduce resonance.</p> <p>Explain resonance and relate to an oscillating system’s natural frequency.</p> <p>Discuss examples of forced oscillations e.g. a cyclist turning the pedal, pushing a child on a swing, etc.</p> <p>Show video clips of extreme cases of resonance such as a wine glass breaking, the Tacoma bridge collapse and the ‘wobbly’ Millennium Bridge in London.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can investigate oscillations further using the Free and Forced Oscillations simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on datalogging simple harmonic motion, damped simple harmonic motion and resonance: https://spark.iop.org/datalogging-shm-mass-spring https://spark.iop.org/episode-306-damped-simple-harmonic-motion https://spark.iop.org/episode-307-resonance</p> <p>Free and Forced Oscillations simulation: www.physicslab.co.uk/Pull-it.htm</p>

Past and specimen papers

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13 Electric fields

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
18.1 Electric fields and field lines KC1 KC5	18.1.1 Understand that an electric field is an example of a field of force and define electric field as force per unit positive charge. 18.1.2 Recall and use $F = qE$ for the force on a charge in an electric field. 18.1.3 Represent an electric field by means of field lines.	<p>Introduce electric fields. It may help to recap the key elements of static electricity e.g. how insulators can be charged by friction, how like charges repel and opposites attract, etc. Demonstrate the shuttling ping-pong ball with a Van de Graaff generator and ask learners to explain why the ball moves back and forth.</p> <p>Ask learners to define electric field strength based on their understanding of Unit 10 <i>Gravitational fields</i>. Instead of the force being felt by any object with mass, the force is felt by any object with charge. However, masses always attract each other but charged objects can attract or repel depending on their charge. Define a test charge as a small positive charge that feels the force of the electric field without distorting it. Highlight that electric field strength is a vector quantity and the positive or negative symbol links to the direction the charge moves.</p> <p>Explain that electric field lines: show the path a small positive test charge would take, point from positive charges to negative charges, are at right angles to the surface of a conductor and are more closely packed when the field is stronger. A uniform field is shown by equally spaced parallel field lines. Ask learners to draw the field lines for different combinations of point charges, charged spheres and charged plates.</p> <p>Demonstrate an electric field's effect on semolina in castor oil using a high voltage power supply (see spark.iop link).</p> <p>Set learners simple questions for practice. (F)</p> <p>Learners may enjoy watching NASA astronaut Don Pettit build a Van de Graaff generator with LEGO on the International Space Station (see youtube.com link). Most fascinating of all, towards the end of the video clip, astronaut Don Pettit gets a small piece of polystyrene to orbit the charged Van de Graaff generator, only achievable in a weightless environment.</p> <p>Learners can investigate electric fields further using the Charges and Fields simulation. (I)</p> <p>Experiment notes from the IoP on electric field patterns: https://spark.iop.org/electric-field-patterns</p> <p>Observe the force between charged objects in space with NASA astronaut Don Pettit: www.youtube.com/watch?v=m0Ei6h3LVb0&feature=emb_logo</p> <p>Charges and Fields simulations:</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		https://phet.colorado.edu/en/simulation/charges-and-fields
18.2 Uniform electric fields KC3 KC5	18.2.1 Recall and use $E = \Delta V / \Delta d$ to calculate the field strength of the uniform field between charged parallel plates. 18.2.2 Describe the effect of a uniform electric field on the motion of charged particles.	<p>Return to the idea that parallel plates with opposite charges create a uniform field.</p> <p>The rearrangement of the equation for the force on a charge in an electric field gives one way to calculate the electric field strength. Consider the definition for work done and direct learners to derive the electric field strength between two parallel plates, distance d apart and with a p.d. V across them.</p> <p>Highlight that this equation gives an alternative set of units for electric field strength: Vm^{-1}.</p> <p>Ask learners to suggest what happens to a charged particle when placed into the uniform field between a pair of oppositely charged parallel plates. They may suggest that the charged particle will move. Ask them to explain the motion of the charged particle mathematically. They may make the link between electric field strength, force and acceleration. A uniform field creates a constant force and acceleration.</p> <p>Demonstrate or show a video of an electron gun that uses a cathode and an anode to accelerate a beam of electrons.</p> <p>Relate a charged particle's acceleration due to an electric field to linear particle accelerators, or linacs, like the Stanford Linear Accelerator Laboratory in the USA.</p> <p>Set learners qualitative and quantitative questions for practice. (F)</p>
18.3 Electric force between point charges KC2 KC3 KC5	18.3.1 Understand that, for a point outside a spherical conductor, the charge on the sphere may be considered to be a point charge at its centre. 18.3.2 Recall and use Coulomb's law $F = Q_1 Q_2 / (4\pi\epsilon_0 r^2)$ for the force between two point charges in free space.	<p>Introduce Coulomb's law and highlight similarities to Newton's law of gravitation. The much larger constant of proportionality suggests that electric forces are stronger and indeed on the scale of individual particles electric forces are much more significant than gravitational forces. However, on the scale of astronomical bodies such as stars and planets, electric forces are negligible.</p> <p>Set learners qualitative and quantitative questions for practice. (F)</p> <p>Learners can investigate the force between charged objects using conductive spheres charged by a Van de Graaff generator (see stem.org link). Alternatively, an insulated charged sphere can be placed on a top pan balance while another is brought close to it. The force of repulsion should produce a small change in mass on the top pan balance, which will allow calculation of the force. The distance can be measured by using a light source and a shadow board. Charge will dissipate quickly by ionising the air, but learners may be able to collect enough results of force and distance to plot a graph and prove Coulomb's law.</p> <p>Learners can investigate the force between charges further using the Coulomb's Law simulation. (I)</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Teacher notes and learner worksheets from the IoP on Coulomb's law: https://spark.iop.org/episode-407-coulombs-law</p> <p>Teacher notes and experimental procedure on Coulomb's law: www.stem.org.uk/resources/elibrary/resource/27904/unit-3-field-and-potential</p> <p>Coulomb's Law simulation: https://phet.colorado.edu/en/simulation/coulombs-law</p>
<p>18.4 Electric field of a point charge</p> <p>KC3</p> <p>KC5</p>	<p>18.4.1 Recall and use $E = Q / (4\pi\epsilon_0 r^2)$ for the electric field strength due to a point charge in free space.</p>	<p>Direct learners to substitute Coulomb's law into the definition of electric field strength to derive the equation for the electric field strength due to a point charge in free space.</p> <p>Highlight that point charges are a convenient expression for a charged object in a situation where the distance, r, away from the charge is considered much larger than the size of the charged object.</p> <p>Recap the field patterns for point charges.</p> <p>Compare the electric field of a point charge to the gravitational field of a mass.</p> <p>Set learners qualitative and quantitative questions for practice. (F)</p>
<p>18.5 Electric potential</p> <p>KC3</p> <p>KC5</p>	<p>18.5.1 Define electric potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to the point.</p> <p>18.5.2 Recall and use the fact that the electric field at a point is equal to the negative of potential gradient at that point.</p> <p>18.5.3 Use $V = Q / (4\pi\epsilon_0 r)$ for the electric potential</p>	<p>Ask learners what would happen if you were able to push two identically charged objects together. They may compare this to compressing a spring; the charges will store potential energy and need more and more work as they get closer together. What happens if you let go? The charges would spring apart and the energy would be recovered.</p> <p>Show learners a force–separation graph. Due to the inverse square law, this does not give a straight line. The area underneath the graph gives the work done in moving a charge between two points. The total area is the work done to move a charge from infinity. The work done is equal to the electric potential energy.</p> <p>Direct learners to derive an equation for work done using the definition and work done and Coulomb's law. Highlight that if one of the charges is negative, the work done will be negative. This is not a negative energy but represents the amount of external energy required to completely separate the charged particles. This is what happens when atomic or molecular bonds are broken.</p> <p>Define electric potential as the work done per unit positive charge in bringing a small test charge from infinity to that point. Direct learners to derive an equation for electric potential in terms of distance, r, using this new definition and the previous equation for work done.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>in the field due to a point charge.</p> <p>18.5.4 Understand how the concept of electric potential leads to the electric potential energy of two point charges and use $E_P = Qq / (4\pi\epsilon_0 r)$.</p>	<p>Ask learners to identify the units of electric potential. Have they in fact worked with electric potential before? Link this new concept to learners' understanding of potential difference from Unit 8 <i>Electricity and d.c. circuits</i>.</p> <p>Explain that the electric potential difference between two points is the difference between the two values of electric potential at those points. Placing a voltmeter between two points a distance away from a charged sphere should show the work done per unit charge, but voltmeters do not function in empty space. A diagram may aid explanation.</p> <p>Link the definition of electric field strength to the concept of potential gradient. Analogous comparisons to contour lines on a map may aid understanding.</p> <p>Set learners questions for practice. (F)</p> <p>Notes and explanation of electric potential: www.khanacademy.org/science/electrical-engineering/ee-electrostatics/ee-fields-potential-voltage/a/ee-electric-potential-voltage www.physicsclassroom.com/class/circuits/Lesson-1/Electric-Potential</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

14 Capacitance

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
19.1 Capacitors and capacitance KC1 KC3 KC5	19.1.1 Define capacitance, as applied to both isolated spherical conductors and to parallel plate capacitors. 19.1.2 Recall and use $C = Q / V$. 19.1.3 Derive, using $C = Q / V$, formulae for the combined capacitance of capacitors in series and in parallel. 19.1.4 Use the capacitance formulae for capacitors in series and in parallel.	<p>Introduce a simple capacitor as insulator sandwiched between two conducting plates. This can be made more compact by adding another layer of insulator and rolling it all up into a cylinder. A capacitor can be charged easily and its stored electrical energy can be easily retrieved. Relate the design of a capacitor to learners' understanding of Unit 13 <i>Electric fields</i>.</p> <p>Define capacitance and how it can be calculated. Introduce the Farad as its unit. Highlight how 1 Farad is a very large capacitance and most capacitors tend to be in the microfarad region. Explain how a perfect capacitor builds up charge almost instantaneously.</p> <p>Electrolytic capacitors need their positive terminal connected to the positive terminal of a power supply or it will be destroyed, so highlight the need to check the terminal symbols carefully.</p> <p>With a high p.d. the insulator may break down so capacitors are also marked with their maximum p.d.</p> <p>Demonstrate the breakdown of a capacitor using a heat mat and a safety screen. A small 47 microfarad capacitor at 25V will produce an impressive bang. Alternatively a video clip could be shown.</p> <p>Learners can find the capacitance of a capacitor by measuring p.d. and charge (see spark.iop 126 link). Plotting charge against p.d. and finding the gradient will allow the capacitance to be found.</p> <p>Demonstrate the breakdown of a capacitor by building a simple capacitor with tin foil ,a bin bag or plastic wrap. Use a high voltage power supply and ensure learners are a safe distance away as it sparks.</p> <p>Derive formulae for the combined capacitance of capacitors in series and in parallel.</p> <p>Set learners calculation questions for practice. (F)</p> <p>Learners can test the equations for combined capacitance by connecting the capacitors and measuring their p.d. and charge. Plotting charge against potential difference and finding the gradient will allow the combined capacitance to be found.</p> <p>Learners can research common uses of capacitors such as a camera flash, cardiac defibrillators, audio equipment and accelerometers. (I)</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Teacher notes and learner worksheets from the IoP on a bin-bag capacitor demonstration, capacitance and capacitors in series and in parallel: https://spark.iop.org/bin-bag-capacitor https://spark.iop.org/episode-126-capacitance-and-equation-qcv https://spark.iop.org/episode-127-capacitors-series-and-parallel</p>
<p>19.2 Energy stored in a capacitor</p> <p>KC3</p> <p>KC5</p>	<p>19.2.1 Determine the electric potential energy stored in a capacitor from the area under the potential–charge graph.</p> <p>19.2.2 Recall and use $W = \frac{1}{2}QV = \frac{1}{2}CV^2$.</p>	<p>Explain that capacitance does not depend on p.d. and that as the charge stored on a capacitor increases, more work has to be done to add more charges.</p> <p>Show learners a charge against p.d. set of axes. Ask them to sketch the graph line on the axes. They may be able to explain that as capacitance is constant, and the gradient is equal to the capacitance, there is a direct proportionality between charge and p.d. producing a straight diagonal line on the graph. Ask learners what the area under the graph represents. They may link this to the work done, or the energy stored by the capacitor, through their understanding of Unit 8 <i>Electricity and d.c. circuits</i>. Links can also be made with the energy stored by a spring from Unit 6 <i>Density, pressure and deformation of solids</i>.</p> <p>Direct learners to derive alternative formulae for work done using the definition of capacitance and the definition of voltage from Unit 8.</p> <p>Set learners calculation questions for practice. (F)</p>
<p>19.3 Discharging a capacitor</p> <p>KC2</p> <p>KC3</p> <p>KC5</p>	<p>19.3.1 Analyse graphs of the variation with time of potential difference, charge and current for a capacitor discharging through a resistor.</p> <p>19.3.2 Recall and use $\tau = RC$ for the time constant for a capacitor discharging through a resistor.</p> <p>19.3.3 Use equations of the form $x = x_0 e^{-(t/RC)}$ where</p>	<p>Ask learners to suggest what happens as a capacitor discharges. You could show a circuit with a capacitor, resistor, ammeter and voltmeter to prompt discussion. Learners may recognise that the resistor will cause the capacitor to discharge more slowly and the ammeter and voltmeter will read decreasing values over time. Some learners may even recognise that the values will decrease at a decreasing rate.</p> <p>Ask learners to sketch graphs of the current against time in a circuit for a capacitor discharging through a resistor. Ask them to sketch graphs of charge and potential difference also. They may identify that these graphs will look the same and all show an exponential decrease.</p> <p>Explain that for exponential decay, the time taken to reach half the original value is always the same. Introduce the time constant and show example graphs to aid understanding.</p> <p>Ask learners to find the units for CR (capacitance multiplied by resistance). They may be able to prove that a farad ohm is the same as a second and make the link to the time constant.</p> <p>Introduce the exponential equations that explain the exponential decay of current, charge and potential difference.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>x could represent current, charge or potential difference for a capacitor discharging through a resistor.</p>	<p>Learners can collect measurements of current and voltage over time by slowly charging and/or discharging a capacitor through a resistor. Results can be plotted such that the exponential pattern is verified (see spark.iop link 129). With sufficient results, the time constant can also be verified.</p> <p>Set learners calculation questions for practice. (F)</p> <p>Learners can investigate charging and discharging a capacitor through a resistor further using the Capacitor simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on the discharge of a capacitor: https://spark.iop.org/episode-129-discharge-capacitor</p> <p>Capacitor simulation: www.falstad.com/circuit/e-cap.html</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

15 Magnetic fields and alternating currents

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
20.1 Concept of a magnetic field 20.4 Magnetic fields due to currents KC1 KC2 KC5	20.1.1 Understand that a magnetic field is an example of a field of force produced either by moving charges or by permanent magnets. 20.1.2 Represent a magnetic field by field lines. 20.4.1 Sketch magnetic field patterns due to the currents in a long straight wire, a flat circular coil and a long solenoid. 20.4.2 Understand that the magnetic field due to the current in a solenoid is increased by a ferrous core. 20.4.3 Explain the origin of the forces between current-carrying conductors and determine the	<p>Introduce magnetic fields. It may help to recap the key elements of magnetism e.g. the difference between a magnetic material and a magnetised material, how to magnetise and demagnetise a magnetic material, what happens when different poles are brought together, etc.</p> <p>Ask learners to draw the magnetic field patterns around different combinations of poles. They can investigate the magnetic field patterns around bar magnets using iron filings and plotting compasses (see spark.iop links). Highlight that the direction of the field arrows go from North to South.</p> <p>Ask learners to define a magnetic field based on their understanding of Unit 10 <i>Gravitational fields</i> and Unit 13 <i>Electric fields</i>. Focus on what makes the field, rather than what is affected by it.</p> <p>Demonstrate the magnetic field pattern around a single current-carrying wire using plotting compasses or iron filings. Demonstrate the magnetic field pattern around a loop of wire. Demonstrate the magnetic field pattern around a solenoid. Show diagrams to clarify the patterns and link each pattern to the next to show how they build to create a field similar to that around a bar magnet.</p> <p>Ask learners to identify where a magnetic field pattern is uniform.</p> <p>Set learners simple qualitative questions for practice. (F)</p> <p>Learners may enjoy watching video clips of incredibly strong magnets destroying everyday items like pieces of fruit.</p> <p>Learners can investigate magnetic fields further using the Magnet and Compass simulation. (I)</p> <p>Learners can investigate magnets and electromagnets further using the Magnets and Electromagnets simulation. (I)</p> <p>It might interest learners to watch the Veritasium video (see youtube.com link) exploring whether humans can sense magnetic fields.</p> <p>Teacher notes from the IoP on representing magnetic fields: https://spark.iop.org/representing-magnetic-fields-practice https://spark.iop.org/drawing-magnetic-field-patterns-activity</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	direction of the forces.	<p>Magnet and Compass simulation: https://phet.colorado.edu/en/simulation/legacy/magnet-and-compass</p> <p>Magnets and Electromagnets simulation: https://phet.colorado.edu/en/simulation/legacy/magnets-and-electromagnets</p> <p>Veritasium youtube channel: Can Humans Sense Magnetic Fields? www.youtube.com/watch?v=dg3pza4y2ws</p>
<p>20.2 Force on a current-carrying conductor</p> <p>KC1</p> <p>KC2</p> <p>KC3</p> <p>KC5</p>	<p>20.2.1 Understand that a force might act on a current-carrying conductor placed in a magnetic field.</p> <p>20.2.2 Recall and use the equation $F = BIL \sin \theta$, with directions as interpreted by Fleming's left-hand rule.</p> <p>20.2.3 Define magnetic flux density as the force acting per unit current per unit length on a wire placed at right-angles to the magnetic field.</p>	<p>Demonstrate the catapult field. Ask learners to explain what they see. They may explain that the two magnetic fields are interacting and this results in motion.</p> <p>Introduce Fleming's left-hand rule and direct learners to use it to predict the resulting motion. Swap the magnetic poles and the direction of current flow to demonstrate how these changes affect the motion. Encourage learners to use their left hand to predict the outcome each time to practise and improve recall of how to use Fleming's left-hand rule.</p> <p>Show diagrams of the set up of equipment for the catapult field demonstration, the separate magnetic fields and the resultant magnetic field.</p> <p>Ask learners what variables cause more 'motion' or force. They may identify the strength of the magnetic field, the size of the current and how many coils there are, or rather, the length of the conductor in the field. Introduce the equation that links these variables and explain that if there is an angle between zero and 90 degrees between the direction of the current and the direction of the magnetic field, this must be included in the calculation. At zero degrees there is no force and at 90 degrees there is a maximum force. Use diagrams to help explain this.</p> <p>Introduce the term magnetic flux density as the correct term for magnetic field strength. This can be defined using the equation just introduced.</p> <p>Learners can investigate the force on a current-carrying wire in a magnetic field by using a metal rod, a top pan balance and a pair of magnadur magnets in a rectangular yoke (see cyberphysics.co.uk link). Learners take measurements of current, length of wire in the field and mass and calculate the magnetic flux density of the pair of magnadur magnets.</p> <p>Set learners calculation questions for practice. (F)</p> <p>Teacher notes and learner worksheets from the IoP on the catapult magnetic field and $F = BIL$: https://spark.iop.org/catapult-magnetic-field https://spark.iop.org/episode-412-force-conductor-magnetic-field</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>An experiment to illustrate the force on a wire in a magnetic field: www.cyberphysics.co.uk/topics/magnetsm/electro/expt.htm</p>
<p>20.3 Force on a moving charge</p> <p>KC2</p> <p>KC3</p> <p>KC5</p>	<p>20.3.1 Determine the direction of the force on a charge moving in a magnetic field.</p> <p>20.3.2 Recall and use $F = BQv \sin \theta$.</p> <p>20.3.3 Understand the origin of the Hall voltage and derive and use the expression $V_H = BI / (ntq)$, where t = thickness.</p> <p>20.3.4 Understand the use of a Hall probe to measure magnetic flux density.</p> <p>20.3.5 Describe the motion of a charged particle moving in a uniform magnetic field perpendicular to the direction of motion of the particle.</p> <p>20.3.6 Explain how electric and magnetic</p>	<p>Start the lesson with a simple diagram showing a single charged particle moving at right angles to a magnetic field. Ask learners what will happen. They may explain that due to the particle's charge, it will feel a force at right angles to its motion due to Fleming's left-hand rule. Highlight that a particle with the opposite charge would be pushed in the opposite direction.</p> <p>Ask learners to derive an equation for force that describes the force felt by a charged particle rather than a current-carrying wire of length, l.</p> <p>You could demonstrate the deflection of charged particles by a magnetic field using an electron gun and a strong bar magnet or a Teltron tube and a Helmholtz coil. Alternatively, show a video clip can. A Teltron tube can also be used to demonstrate the combined effect of an electric field and a magnetic field, which is the basis of velocity selection. This is the first stage in a Bainbridge mass spectrometer. The velocity of the particles that pass straight through a velocity selector is equal to the ratio of the electric field strength to the magnetic flux density.</p> <p>Ask learners what happens when a charged particle moves in a uniform magnetic field perpendicular to the direction of motion of the particle, without being pushed out of the field. Learners may link the motion to Unit 9 <i>Motion in a circle</i>. They may be able to derive an expression for the radius a particle describes within the magnetic field of flux density, B, in terms of its mass, m, velocity, v, and charge, Q.</p> <p>Relate a charged particle's circular motion due to magnetic field to circular particle accelerators like the Large Hadron Collider at CERN in Switzerland.</p> <p>Set learners calculation questions for practice. (F)</p> <p>Link the origin of the Hall voltage to learners' understanding of the force on a charge moving in a magnetic field.</p> <p>Return to the concept of velocity selection and link to the Hall voltage. Direct learners to derive an expression for the voltage starting from the electric force and the magnetic force.</p> <p>Learners may find it interesting to discuss some common uses of Hall probes such as wheel speed sensors, proximity sensors, automotive fuel level indicator, etc.</p> <p>Velocity selector notes: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/maspec.html#c3</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	fields can be used in velocity selection.	<p>How an accelerator works: https://home.cern/science/accelerators/how-accelerator-works</p> <p>Hall effect notes: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/Hall.html</p>
<p>20.5 Electromagnetic induction</p> <p>KC1</p> <p>KC2</p> <p>KC3</p> <p>KC5</p>	<p>20.5.1 Define magnetic flux as the product of the magnetic flux density and the cross-sectional area perpendicular to the direction of the magnetic flux density.</p> <p>20.5.2 Recall and use $\Phi = BA$.</p> <p>20.5.3 Understand and use the concept of magnetic flux linkage.</p> <p>20.5.4 Understand and explain experiments that demonstrate:</p> <ul style="list-style-type: none"> • that a changing magnetic flux can induce an e.m.f. in a circuit • that the induced e.m.f. is in such a direction as to oppose the change producing it 	<p>Learners can investigate electromagnetic induction with three simple experiments. Pass a length of wire connected to a multimeter measuring d.c. voltage between a pair of magnetized magnets in a rectangular yoke. Pass a bar magnet through the same length of wire now looped into coils with the ends connected to a multimeter measuring d.c. voltage. Turn the shaft of a 12V d.c. motor connected to a multimeter measuring d.c. voltage. Ask learners to share what they notice and to provide explanation. Can they link the changing direction of motion to the negative and positive symbol seen on the multimeter? Ask them to explain ways that they can increase the induced e.m.f. shown on the multimeter. Does it matter if it's the wire or the magnet that moves?</p> <p>Introduce electromagnetic induction and explain the simple experiments the learners have carried out. Link the motion of the charges that produces charge separation to learners' understanding of $F = BQv$. Diagrams and simulations may aid this. Ask learners to identify the variables that can increase the induced e.m.f.</p> <p>Introduce and define magnetic flux and flux linkage. Relate them to learners' understanding of magnetic flux density. Show diagrams to aid explanation.</p> <p>Introduce Faraday's law of electromagnetic induction. Explain the variables and highlight the negative symbol. This will be explained later with Lenz's law.</p> <p>Demonstrate Faraday's law using a strong magnet (a stack of neodymium magnets works well), a Helmholtz coil and a sensitive ammeter or voltmeter connected to a datalogger. Drop the magnets through the coil and record the results of induced current or e.m.f. using the datalogger. Ask learners to explain the non-symmetrical pattern that is created. Learners can investigate this further by moving the magnet near the Helmholtz coil and observing the datalogger's plotted data.</p> <p>It might interest learners to hear about the scientist Michael Faraday's expansive work in electromagnetism and electrochemistry, as well as his less privileged background.</p> <p>Introduce Lenz's law. Show diagrams and ask learners to identify which type of pole will be made by the coil as a magnetic pole is moved towards or away from it. Ask learners to explain what would happen if the opposite happened. They may identify that a 'magnet gun' would be created and the conservation of energy would be broken. Explain the importance of the conservation of energy and the idea of doing work. A force must be exerted</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<ul style="list-style-type: none"> the factors affecting the magnitude of the induced e.m.f. <p>20.5.5 Recall and use Faraday's and Lenz's laws of electromagnetic induction.</p>	<p>on the magnet to move it and energy is transferred to the electrical circuit through the medium of the magnetic field.</p> <p>Set learners qualitative and quantitative questions for practice. (F)</p> <p>Resource Plus</p> <p>Carry out the <i>Investigating electromagnetic induction</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>Learners can measure the magnetic field strength of the Earth using a sensitive voltmeter and a long wire (around 30 metres). A trundle wheel and compass can be used to mark out an area where the movement of one side of the wire will cut through the angled magnetic field of the Earth. The movement can be timed with a stopwatch and carried out both vertically and horizontally. Measurements of induced e.m.f. can be collected using a multimeter and the magnetic flux density can be calculated.</p> <p>Learners can investigate Faraday's law further using the Faraday's Law simulation and Faraday's Electromagnetic Lab simulation. (I)</p> <p>Notes on Faraday's law and induction from a magnet moving through a coil: www.khanacademy.org/science/physics/magnetic-forces-and-magnetic-fields/magnetic-flux-faradays-law/a/what-is-faradays-law</p> <p>Veritasium YouTube channel: Electromagnetic Induction: www.youtube.com/watch?v=txmKr69jGBk&list=PL16649CCE7EFA8B2F&index=17&t=0s</p> <p>Faraday's Law simulation: https://phet.colorado.edu/en/simulation/faradays-law</p> <p>Faraday's Electromagnetic Lab simulation: https://phet.colorado.edu/en/simulation/legacy/faraday</p>
<p>21.1 Characteristics of alternating current</p> <p>21.2 Rectification and smoothing</p> <p>KC3</p>	<p>21.1.1 Understand and use the terms period, frequency and peak value as applied to an alternating current or voltage.</p>	<p>Introduce the alternator as a generator of alternating current. As the coil moves up and down through a magnetic field, alternating current is induced due to Faraday's law and Lenz's law. The direction of current continuously changes.</p> <p>Ask learners to identify the variables that will increase the induced e.m.f. in a generator. Link this to the variables in Faraday's law.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
KC5	<p>21.1.2 Use equations of the form $x = x_0 \sin \omega t$ representing a sinusoidally alternating current or voltage.</p> <p>21.1.3 Recall and use the fact that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current.</p> <p>21.1.4 Distinguish between root-mean-square (r.m.s.) and peak values and recall and use $I_{r.m.s.} = I_0 / \sqrt{2}$ and $V_{r.m.s.} = V_0 / \sqrt{2}$ for a sinusoidal alternating current.</p> <p>21.2.1 Distinguish graphically between half-wave and full-wave rectification.</p> <p>21.2.2 Explain the use of a single diode for the half-wave rectification of an alternating current.</p>	<p>Learners can investigate generators further using the Generator simulation. (I)</p> <p>Direct learners to use the terms period, frequency and peak value to explain how an alternator works. Learners should recall definitions of period and frequency from Unit 12 <i>Oscillations</i>. Clarify any misconceptions and definitions.</p> <p>Ask learners to sketch voltage–time and current–time graphs. These are sinusoidal and give an average value of zero. Introduce the equation that represents alternating current or voltage. Introduce the root-mean-square value of current and voltage. Introduce how to calculate these and link to the graphs. Link to the root-mean-square speed from Unit 11 <i>Temperature, ideal gases and thermodynamics</i>.</p> <p>Ask learners to sketch a power–time graph for an alternator. Highlight the maximum power and the mean power. The mean power is what is actually used and is half of the maximum.</p> <p>Ask learners to explain what would happen if you placed a diode in an a.c. circuit. Learners may recall the properties of a diode from Unit 8 <i>Electricity and d.c. circuits</i>. They may sketch a voltage–time or current–time graph to show their answer. This is the basis of half-wave rectification.</p> <p>Ask learners for suggestions of how the half-wave rectified current and e.m.f. of an alternating current could be smoothed. This means it is made more like the constant value d.c. provides. If they cannot suggest any ideas, hint at Unit 14 <i>Capacitors</i>.</p> <p>Introduce the use of a capacitor in smoothing. The capacitor charges when the diode allows current to flow and discharges when the diode does not allow current to flow. Show the voltage–time graph to clarify. Link the time constant, dependent on the load resistance and the capacitance of the capacitor, to the time frequency of a.c. The time constant needs to be much larger than the time period. Ask learners to explain why this is the case.</p> <p>Introduce full-wave rectification as a method that allows both ‘halves’ of the a.c. sinusoidal pattern to be made positive. With the capacitor charging and discharging continuously, the pattern can be smoothed and begins to appear more like a d.c. constant value of voltage.</p> <p>Introduce four diodes, known as a bridge rectifier, for the full-wave rectification of an alternating current. This also produces a rectified and smoothed e.m.f. Use diagrams to aid the explanation of how it works. Be aware that some learners may be intimidated or confused by how complicated the circuit appears.</p> <p>Generator simulation: https://phet.colorado.edu/en/simulation/legacy/generator</p> <p>Alternating current:</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>21.2.3 Explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current.</p> <p>21.2.4 Analyse the effect of a single capacitor in smoothing, including the effect of the values of capacitance and the load resistance.</p>	<p>https://studynova.com/lecture/physics/electromagnetic-induction/alternating-current/</p> <p>Half-wave rectification and smoothing (from 5:49): https://studynova.com/lecture/physics/electromagnetic-induction/transformers-and-half-wave-rectification/</p> <p>Full wave rectification (and diode bridge): https://studynova.com/lecture/physics/electromagnetic-induction/full-wave-rectification-and-diode-bridge/</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

16 Quantum physics

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
22.1 Energy and momentum of a photon KC1 KC2 KC4	22.1.1 Understand that electromagnetic radiation has a particulate nature. 22.1.2 Understand that a photon is a quantum of electromagnetic energy. 22.1.3 Recall and use $E = hf$. 22.1.4 Use the electronvolt (eV) as a unit of energy. 22.1.5 Understand that a photon has momentum and that the momentum is given by $p = E / c$.	<p>Introduce the topic by discussing different types of models: concrete, abstract and mathematical. Give examples for each. Highlight that for light there are two models that explain its behaviour. Sometimes these models appear to contradict each other. Introduce the quantum model of light where light is considered as photons, massless particles of energy, as opposed to waves.</p> <p>Introduce the energy of a photon and $E = hf$. Introduce the Planck constant, h, and highlight its smallness. The size of Planck's constant is related to why the effects of quantum mechanics mainly appear on the atomic scale and were only discovered more recently with advances in technology. Relate the damaging effects of high-frequency electromagnetic waves to the idea that they carry more energy.</p> <p>Demonstrate the Geiger-Muller counter as an example of discrete measurement of radiation, some of which are gamma photons.</p> <p>Introduce the electronvolt as an alternative unit for energy. Ask learners why it's used. Relate its name to its definition. Demonstrate how to convert between joules and electrovolts. Highlight common prefixes used with the electronvolt such as keV, MeV and GeV.</p> <p>Set learners more questions for practice, including conversions between units. (F)</p> <p>Introduce the concept of an LED emitting photons of light due to the energy provided by an electron passing through it.</p> <p>Learners can find Planck's constant, h, using LEDs of different wavelengths and a milliammeter (see scienceinschool.org link). Improve accuracy of results by making the room as dark as possible and using a black cardboard viewing tube around the LED. Learners use a variable resistor to vary the voltage across the LED and measure the current and voltage for when the LED lights. Learners should use results to plot a graph and find a value for Planck's constant. Learners can complete an error analysis and evaluation of their results.</p> <p>Ask learners what the momentum of a photon would be. They may suggest it has no momentum as it has no mass. Introduce $p = E / c$ as an alternative method for calculating the momentum of a photon.</p> <p>Measuring the Planck constant: www.scienceinschool.org/2014/issue28/planck</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
22.2 Photoelectric effect KC1 KC2 KC5	22.2.1 Understand that photoelectrons may be emitted from a metal surface when it is illuminated by electromagnetic radiation. 22.2.2 Understand and use the terms threshold frequency and threshold wavelength. 22.2.3 Explain photoelectric emission in terms of photon energy and work function energy. 22.2.4 Recall and use $hf = \Phi + \frac{1}{2}mv_{\max}^2$. 22.2.5 Explain why the maximum kinetic energy of photoelectrons is independent of intensity, whereas the photoelectric current is proportional to intensity.	<p>Demonstrate the photoelectric effect by using a gold leaf electroscope, a zinc plate and a UV light source (see stem.org link). This simple demonstration can be repeated with visible light (nothing happens) and with a piece of glass between the UV source and the plate (nothing happens). Encourage learners to think about what is happening and to try and explain it.</p> <p>Explain the photoelectric effect step by step. Use animations and diagrams as an aid.</p> <p>Relate the photoelectric effect to the phenomenon of surface charging, a particular problem for the International Space Station. The build up of positive charge can damage electronic components inside of the spacecraft due to high-energy electromagnetic radiation from the Sun causing electrons to be emitted from the metal surfaces.</p> <p>Ask learners to explain the photoelectric effect using the wave model. They should reason that, according to the wave model, high-intensity red light should release photoelectrons but dim blue light would not, but this is not the case. In fact, the energy a photoelectron receives is independent of the light's intensity.</p> <p>Reiterate the concept of the photoelectric effect being a one-to-one interaction between a photon and an electron. However, if a photon does not have enough energy, the electron will not be released.</p> <p>Define the work function, the threshold frequency and the threshold wavelength.</p> <p>Use an analogy to explain the photoelectric effect. Place a football on a small cardboard tube so that it balances in a stable position. The football represents an electron at the surface of the metal plate. Learners can throw multiple ping-pong balls at the football, which represent lower energy photons, but they won't have enough energy to knock the football off and their energies cannot add together. Learners can throw a single tennis ball at the football, which represents a higher-energy photon, and just one of these will knock the football off.</p> <p>An analogy of a well can be used to explain how the electrons require a certain amount of energy, the work function, to be free, but it must be delivered in one photon. It's like having the right-sized ladder to escape the well. Multiple small 'ladders' cannot be added together to escape.</p> <p>Ask learners what happens to any 'extra' energy left over from the photon that releases the photoelectron. Introduce the idea of this giving the photoelectron kinetic energy and explain the equation.</p> <p>Analyse the graph of the photon's energy against the photon's frequency. The gradient is found to be the Planck constant, the x-intercept is the threshold frequency and the y-intercept is the work function. Ask learners to explain why different metals will shift the line, but it will always have the same gradient.</p> <p>Set learners more questions for practice. (F)</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Learners can investigate the photoelectric effect further using the simulation. This is particularly helpful as it very accurately simulates how photoelectric current is proportional to intensity. (I)</p> <p>Teacher notes and learner questions from the IoP on the photoelectric effect: https://spark.iop.org/wholesale-photoelectric-effect https://spark.iop.org/episode-502-photoelectric-effect</p> <p>Photoelectric effect demonstration: www.stem.org.uk/resources/elibrary/resource/28841/photoelectric-effect</p> <p>Photoelectric Effect simulation: https://phet.colorado.edu/en/simulation/legacy/photoelectric</p>
<p>22.3 Wave-particle duality</p> <p>KC1</p> <p>KC2</p> <p>KC4</p>	<p>22.3.1 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.</p> <p>22.3.2 Describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles.</p> <p>22.3.3 Understand the de Broglie wavelength as the wavelength</p>	<p>Introduce the idea that, if waves can behave as particles, perhaps particles can behave as waves.</p> <p>Demonstrate or show videos of an electron gun with a crystalline diffraction grating. The fluorescent screen should show a circular diffraction pattern. Ask learners to predict what they will see, giving them the full information in advance, or ask them to explain what they see as it is demonstrated. Learners may need to be reminded how an electron gun works. It may help to show a diagram of the crystalline structure that is diffracting the electrons. Relate the work done in accelerating the electrons to the kinetic energy gained by the electrons. Highlight the significance of the experiment as the electrons accelerate as particles by the high voltage, diffract as waves and hit the screen as discrete particles.</p> <p>Relate the pattern seen on the electron gun screen to Young's slits. Ask learners to explain the difference in the patterns observed.</p> <p>Introduce the de Broglie equation and the idea that all particles can be treated as waves. Discuss the largest atom that has been diffracted to date.</p> <p>Learners can calculate their own wavelength. Ask them to explain why they could not be diffracted. They should recall their understanding of diffraction and the importance of the size of the gap.</p> <p>Highlight the practical use of this phenomenon, such as in crystallography and electron microscopes.</p> <p>Set learners more questions for practice. (F)</p> <p>Teacher notes and learner questions from the IoP on particles as waves and the De Broglie wavelength: https://spark.iop.org/episode-506-particles-waves https://spark.iop.org/de-broglie-wavelength</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>associated with a moving particle.</p> <p>22.3.4 Recall and use $\lambda = h / p$.</p>	
<p>22.4 Energy levels in atoms and line spectra</p> <p>KC1</p> <p>KC4</p>	<p>22.4.1 Understand that there are discrete electron energy levels in isolated atoms.</p> <p>22.4.2 Understand the appearance and formation of emission and absorption line spectra.</p> <p>22.4.3 Recall and use $hf = E_1 - E_2$.</p>	<p>Scatter white light on the surface of a CD to create rainbows as a starter. Why does this happen?</p> <p>Remind learners of the classical model of an atom like a miniature solar system. If this was the case, orbiting electrons radiating energy would spiral towards the nucleus as they lost energy, resulting in a catastrophic collapse of the atom. The Bohr atomic structure has quantised orbits with discrete energy levels for the electrons.</p> <p>Introduce energy levels and spectra. Electrons can move between these levels by absorbing or emitting photons of specific energies.</p> <p>Clarify that the electrons do not have negative energy; rather the negative energies refer to the amount of energy an electron would need to be released from the atom.</p> <p>Learners can use spectroscopes to observe the spectra from different light sources: a sodium lamp, a mercury lamp, a candle, a Bunsen burner, the Sun, a fluorescent light, etc. They should notice differences between the patterns that they see. For example, the Sun has a lot of higher-energy violet light and a sodium lamp has a lot of lower-energy red light.</p> <p>Relate the energy levels to the photoelectric effect. Remind learners that electrons required specific amounts of energy to be freed from the surface of a metal plate and this energy had to be delivered in a single photon.</p> <p>Discuss the excitation and de-excitation of electrons e.g. an electron in a neon light is excited to a higher energy level by the p.d. across the tube and then it transitions to a lower energy level, releasing a photon with a specific frequency. Relate to $E = hf$. Use animations and diagrams as an aid.</p> <p>Introduce spectroscopy as the study of spectra produced when matter interacts with or emits electromagnetic radiation. Although we have not visited the stars, we are able to analyse their starlight to determine their elements. It might interest learners and enthuse the girls in particular to hear about scientist Cecilia Payne-Gaposchkin's discovery that stars are mainly made of hydrogen and helium.</p> <p>Learners can analyse the absorption line spectra of various stars and identify various elements present.</p> <p>Introduce the relationship between the energy emitted or absorbed and the change in energy levels.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
		<p>Set learners more questions for practice using the real energy levels of elements such as hydrogen. (F)</p> <p>Learners can investigate models of the atom further with the Models of the Hydrogen Atom simulation. (I)</p> <p>Models of the Hydrogen Atom simulation: https://phet.colorado.edu/en/simulation/legacy/hydrogen-atom</p> <p>Teacher notes and learner questions from the IoP on spectra and energy levels: https://spark.iop.org/episode-501-spectra-and-energy-levels</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

17 Particle physics and nuclear physics

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
11.1 Atoms, nuclei and radiation KC1 KC2 KC5	11.1.1 Infer from the results of the α -particle scattering experiment the existence and small size of the nucleus. 11.1.2 Describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons. 11.1.3 Distinguish between nucleon number and proton number. 11.1.4 Understand that isotopes are forms of the same element with different numbers of neutrons in their nuclei. 11.1.5 Understand and use the notation A_ZX for the representation of nuclides. 11.1.6 Understand that nucleon number	<p>Introduce the atom, originating from the Greek word 'atomos', as the name of what was once considered an indivisible particle. Henri Becquerel's discovery of radioactivity in 1896 inspired many scientists to work in this area of physics and Rutherford's scattering experiment was conceived as a result. It may interest learners to discuss more of the history of the discovery of the atom and its components.</p> <p>Introduce the set up of Rutherford's scattering experiment and the expected results. Share the observations that were made and ask learners to link them to our current understanding of the atom.</p> <p>Learners can calculate the size of the nucleus using their understanding of Unit 13 <i>Electric fields</i> (see spark.iop 522 link).</p> <p>Define the nucleon number and proton number of a nuclide. Learners may remember this from Cambridge IGCSE (or equivalent). Give examples of isotopes and discuss the difference between an isotope and an atom.</p> <p>Introduce the unified atomic mass unit, u, as a unit of mass.</p> <p>Recap the electronvolt as an alternative unit for energy. The Large Hadron Collider at CERN in Switzerland functions in the TeV range.</p> <p>Explain that an antiparticle has the same mass but opposite charge to the corresponding particle. The first antiparticle predicted and discovered was the positron, the antiparticle of an electron.</p> <p>Set learners simple nuclear process questions to practise their use of nucleon numbers, proton numbers and the conservation of charge. (F)</p> <p>Learners may be interested to see the nuclear equations for historically important reactions such as Becquerel's first observation of radioactivity, the first artificial transmutation of nitrogen to oxygen, the nuclear fission of Uranium, the collision of protons inside the Large Hadron Collider at CERN, etc. You could edit the nuclear equations to allow learners to work out the missing values. (F)</p> <p>Introduce the three types of radioactivity: α, β and γ. They are easily distinguished by their behaviour in an electric field, which learners may be able to explain using their understanding of Unit 13. Describe the composition, mass and charge of each and show the nuclear equations for α- and β-decay. Highlight the production of neutrinos and antineutrinos in β-decay; the emission of antineutrinos in β-decay allows for a continuous range of energies but α-</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>and charge are conserved in nuclear processes.</p> <p>11.1.7 Describe the composition, mass and charge of α-, β- and γ-radiations.</p> <p>11.1.8 Understand that an antiparticle has the same mass but opposite charge to the corresponding particle, and that a positron is the antiparticle of an electron.</p> <p>11.1.9 State that (electron) antineutrinos are produced during β^- decay and (electron) neutrinos are produced during β^+ decay.</p> <p>11.1.10 Understand that α-particles have discrete energies but that β-particles have a continuous range of energies because (anti)neutrinos are emitted in β-decay.</p> <p>11.1.11 Represent α-</p>	<p>particles have discrete energies.</p> <p>Ask learners how magnetic fields affect the three types of radioactivity. They may be able to use their understanding of Unit 15 <i>Magnetic fields and alternating currents</i> to explain how the charges of α- and β-particles will cause deflection in a magnetic field.</p> <p>Learners can investigate the penetrating powers of α-, β- and γ-sources under supervision. Alternatively you can demonstrate this.</p> <p>Learners can investigate radioactive decay further using the Alpha Decay simulation and the Beta Decay simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on Rutherford's experiment, the size of the nucleus and particles: https://spark.iop.org/episode-521-rutherfords-experiment https://spark.iop.org/episode-522-size-nucleus https://spark.iop.org/episode-533-particle-zoo</p> <p>Alpha Decay simulation: https://phet.colorado.edu/en/simulation/legacy/alpha-decay</p> <p>Beta Decay simulation: https://phet.colorado.edu/en/simulation/legacy/beta-decay</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	and β -decay by a radioactive decay equation of the form ${}_{92}^{238}\text{U} \rightarrow {}_{90}^{234}\text{Th} + {}_2^4\alpha$. 11.1.12 Use the unified atomic mass unit (u) as a unit of mass.	
23.2 Radioactive decay KC1 KC2 KC3 KC5	23.2.1 Understand that fluctuations in count rate provide evidence for the random nature of radioactive decay. 23.2.2 Understand that radioactive decay is both spontaneous and random. 23.2.3 Define activity and decay constant, and recall and use $A = \lambda N$. 23.2.4 Define half-life. 23.2.5 Use $\lambda = 0.693 / t_{1/2}$. 23.2.6 Understand the exponential nature of radioactive decay, and sketch	Demonstrate a Geiger-Muller counter and highlight the random nature of the radiation it detects. It is measuring background radiation and does not distinguish between α -, β - or γ -radiation. Learners may find it interesting to discuss some of the common sources of background radiation. Learners can measure the average background radiation using the Geiger-Muller counter and a stopwatch. They can measure the radiation from a radioactive source, supervised, and calculate the corrected count rate by subtracting the average background radiation. Define the terms random and spontaneous and highlight their importance in describing the nature of radioactive decay. Learners may be able to explain that radioactive decay cannot be predicted. Define activity and the decay constant and relate them together with the equation. Use graphs and examples to aid explanation. Define the half-life as the average time taken for the radioactivity to fall to half of its original value. This allows different samples to be compared regardless of size or concentration. Relate the half-life to decay constant and introduce the exponential decay equation. Direct learners to consider the unit for the decay constant and how it relates to the half-life. Relate the exponential decay equation for radioactivity to learners' understanding of Unit 14 <i>Capacitance</i> and the discharging of capacitors. Learners can model radioactive decay using dice (see spark.iop link) to investigate its random and exponential nature. They can plot a graph of results and calculate the half-life. Set learners qualitative and quantitative questions on radioactive decay using graphs and calculations. (F)

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>and use the relationship $x = x_0e^{-\lambda t}$, where x could represent activity, number of undecayed nuclei or received count rate.</p>	<p>Learners may be interested to watch the Veritasium video (see youtube.com link) on the most radioactive places on Earth. (I)</p> <p>Learners can investigate radioactivity further by using the Radioactive Decay simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on radioactive decay formula: https://spark.iop.org/episode-515-radioactive-decay-formula</p> <p>Veritasium YouTube channel: The Most Radioactive Places On Earth: www.youtube.com/watch?v=TRL7o2kPqw0&t=604s</p> <p>Radioactive Decay simulation: www.physicslab.co.uk/decay.htm</p>
<p>11.2 Fundamental particles</p> <p>KC1</p> <p>KC5</p>	<p>11.2.1 Understand that a quark is a fundamental particle and that there are six flavours (types) of quark: up, down, strange, charm, top and bottom.</p> <p>11.2.2 Recall and use the charge of each flavour of quark and understand that its respective antiquark has the opposite charge.</p> <p>11.2.3 Recall that protons and neutrons are not fundamental particles and describe protons and neutrons in terms of their quark</p>	<p>Introduce the standard model. All particles are either leptons or hadrons. Hadrons are made up of quarks. All of these particles have antiparticles with opposite charges, including quarks. No knowledge of any other properties of quarks is required. One quark and one antiquark make a meson, and three quarks make a baryon. Learners may find it difficult to learn multiple new names of particles all at once; they could do some pre-reading ahead of the lesson. The definitions of each may need to be repeatedly recapped for them to feel confident with the new language.</p> <p>Explain the quark composition of a neutron and a proton. Direct learners to calculate the charge of each, based on the component quarks' charge.</p> <p>Reiterate that an electron is a fundamental particle known as a lepton.</p> <p>Refer to the Large Hadron Collider at CERN in Switzerland. It collides hadrons, specifically protons which are baryons. Previously the same tunnel housed the Large Electron-Positron Collider, which collided leptons.</p> <p>Introduce β-decay as an example of quarks changing flavour and thus changing the baryon. Go through the particle equation, the quark equation and the simplified quark equation for both β^- and β^+ decay. Show learners how to check that charge, baryon number, lepton number, strangeness and mass (or energy) are conserved.</p> <p>Learners can consolidate their understanding of β-decay by using the Beta Decay simulation. (I)</p> <p>Learners may find it interesting to learn more about particle detectors and the analysis of particle tracks (see spark.iop 519 link).</p> <p>The standard model:</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>composition.</p> <p>11.2.4 Understand that a hadron may be either a baryon (consisting of three quarks) or a meson (consisting of one quark and one antiquark).</p> <p>11.2.5 Describe the changes to quark composition that take place during β^- and β^+ decay.</p> <p>11.2.6 Recall that electrons and neutrinos are fundamental particles called leptons.</p>	<p>https://home.cern/science/physics/standard-model</p> <p>Beta Decay simulation: https://phet.colorado.edu/en/simulation/legacy/beta-decay</p> <p>Teacher notes and learner worksheets from the IoP on antiparticles, leptons and particle detectors: https://spark.iop.org/episode-534-antiparticles-and-lepton-family https://spark.iop.org/episode-519-particle-detectors</p>
<p>23.1 Mass defect and nuclear binding energy</p> <p>KC1</p> <p>KC3</p> <p>KC5</p>	<p>23.1.1 Understand the equivalence between energy and mass as represented by $E = mc^2$ and recall and use this equation.</p> <p>23.1.2 Represent simple nuclear reactions by nuclear equations of the form ${}^{14}_7N + {}^4_2He \rightarrow {}^{17}_8O + {}^1_1H$.</p>	<p>Introduce Einstein's principle of equivalence of mass and energy. Learners may be interested in how this relates to Einstein's theory of relativity.</p> <p>Recap the unified atomic mass unit, u, as a unit of mass.</p> <p>Recap the importance of the conservation of mass (or energy) and charge. This is used to balance nuclear equations.</p> <p>Introduce the famous equation and explain how it can be used. Learners can calculate the energy equivalent to 1kg of mass and 1u of mass to give an idea of scale.</p> <p>Direct learners to calculate the total mass of an atom from its individual components e.g. knowing that an atom of calcium has of mass of 39.9626u and that it is made up of 20 protons, 20 neutrons and 20 electrons, find the total mass in u. Learners will find a difference in the answers.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>23.1.3 Define and use the terms mass defect and binding energy.</p> <p>23.1.4 Sketch the variation of binding energy per nucleon with nucleon number.</p> <p>23.1.5 Explain what is meant by nuclear fusion and nuclear fission.</p> <p>23.1.6 Explain the relevance of binding energy per nucleon to nuclear reactions, including nuclear fusion and nuclear fission.</p> <p>23.1.7 Calculate the energy released in nuclear reactions using $E = c^2\Delta m$.</p>	<p>Introduce mass defect and binding energy and relate to the difference between the mass of the separate particles and the mass of the whole atom due to the work done in separating the particles.</p> <p>Introduce the binding energy values for other atoms via the binding energy per nucleon against nucleon number graph. Ask learners to suggest what iron's significance is and what happens to atoms that are heavier/lighter than iron. Learners may identify that atoms heavier than iron may undergo fission, whilst atoms lighter than iron may undergo fusion.</p> <p>Introduce nuclear fusion and nuclear fission. Explain their processes. Link the atoms that undergo these reactions to the binding energy per nucleon available. Highlight that these reactions are induced, not spontaneous like α-, β- and γ-radiations.</p> <p>Learners may find it interesting to learn more about fission reactors, current research into fusion on Earth as an energy resource and some of the historical accidents that have occurred, such as Chernobyl or Fukushima Daiichi.</p> <p>Set learners more complicated nuclear reaction questions to calculate the energy released using Einstein's equivalence of mass and energy. (F)</p> <p>Learners can investigate fission further using the Nuclear Fission simulation. (I)</p> <p>Teacher notes and learner worksheets from the IoP on binding energy, fission and fusion: https://spark.iop.org/episode-525-binding-energy https://spark.iop.org/episode-527-nuclear-transmutation https://spark.iop.org/episode-528-controlling-fission</p> <p>Nuclear Fission simulation: https://phet.colorado.edu/en/simulation/legacy/nuclear-fission</p>

Past and specimen papers

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

18 Medical physics

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
24.1 Production and use of ultrasound KC3 KC4	24.1.1 Understand that a piezo-electric crystal changes shape when a p.d. is applied across it and that the crystal generates an e.m.f. when its shape changes. 24.1.2 Understand how ultrasound waves are generated and detected by a piezoelectric transducer. 24.1.3 Understand how the reflection of pulses of ultrasound at boundaries between tissues can be used to obtain diagnostic information about internal structures. 24.1.4 Define the specific acoustic impedance of a medium as $Z = \rho c$, where c is the speed of sound in the	<p>What are the advantages of an ultrasound scan? Learners may know a little about this diagnostic procedure and be able to explain that it is non-invasive and does not involve ionising radiation.</p> <p>Explain that ultrasound imaging uses frequencies above the human hearing range and they are created by piezo-electric crystals. A piezoelectric transducer on the body's surface directs the pulses of ultrasound into the body. These reflect off internal boundaries e.g. between tissue and bone. The probe can detect the reflected pulses and the information is converted into an image. A piezo-electric crystal changes shape when a p.d. is applied across it and the crystal generates an e.m.f. when its shape changes. Thus, a p.d. is applied across the crystal, causing it to vibrate at high frequency and produce ultrasonic pulses. The same crystal changes shape when the reflected pulses return, generating an e.m.f. Use diagrams and animations to aid this explanation.</p> <p>Show learners a simple ultrasound and accompanying diagram, e.g. scan data for an eye and a diagram of an eye, and ask them to relate the echoes to the boundaries in media.</p> <p>Define specific acoustic impedance and introduce the equation that relates it to the medium. Ask learners to find the units of acoustic impedance. Ultrasound reflects at internal boundaries between media because the acoustic impedance of such media differ. Show diagrams to illustrate this.</p> <p>Ask learners why they think a gel is used with the transducer. Many will have seen this used in TV shows and films for pre-natal sonograms. They may be able to explain that it is used to ensure the ultrasound enters the body and does not reflect from the boundary between air and skin. This is known as impedance matching and is important to ensure good transmission values.</p> <p>Introduce the relationship between acoustic impedance and intensity. This can be used to calculate the reflected intensity of the ultrasound or the specific acoustic impedance, allowing identification of media.</p> <p>Introduce the exponential equation for attenuation (the reduction of the intensity of the ultrasound).</p> <p>Set learners questions for practice on acoustic impedance and attenuation. (F)</p> <p>Show learners ultrasound images. Learners may enjoy trying to identify what they are looking at in the images.</p> <p>Teacher notes and learner worksheets from the IoP on ultrasound: https://spark.iop.org/ultrasound-scans</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>medium.</p> <p>24.1.5 Use $I_R / I_0 = (Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$ for the intensity reflection coefficient of a boundary between two media.</p> <p>24.1.6 Recall and use $I = I_0 e^{-\mu x}$ for the attenuation of ultrasound in matter.</p>	<p>Video from the IoP on ultrasound with notes and worksheets: www.stem.org.uk/elibrary/resource/31828</p> <p>How equipment works: Ultrasound: www.howequipmentworks.com/ultrasound_basics/</p>
<p>24.2 Production and use of X-rays</p> <p>KC3</p> <p>KC4</p>	<p>24.2.1 Explain that X-rays are produced by electron bombardment of a metal target and calculate the minimum wavelength of X-rays produced from the accelerating p.d.</p> <p>24.2.2 Understand the use of X-rays in imaging internal body structures, including an understanding of the term contrast in X-ray imaging.</p> <p>24.2.3 Recall and use $I = I_0 e^{-\mu x}$ for the attenuation of X-rays in matter.</p>	<p>Show learners the first known X-ray image of the hand of Wilhelm Roentgen's wife from 1895. Can they identify what the lump is on the second finger? Mrs Roentgen exclaimed 'I have seen my death' upon seeing the image. It may interest learners to learn that the use of X-rays quickly spread around the world and became a media sensation.</p> <p>Recap the key properties of X-rays asking learners to share what they recall from Unit 7 <i>Waves and superposition</i>. Highlight their high energy and thus their danger to living cells.</p> <p>Explain how X-rays are produced and make use of a diagram to show the process. Direct learners to link the energy the electrons gain from the accelerating p.d. to the energy of the X-ray photons produced. Learners can calculate the wavelength of the photons knowing the accelerating p.d.</p> <p>Discuss the uses of X-rays and the use of contrasts. Learners will be familiar with X-rays being used to image bones and may have experienced this diagnostic procedure themselves. Explain how a contrast can be used to improve the imaging of soft tissues, which would normally be indistinguishable. Discuss barium meals and the use of iodine dye in the bloodstream.</p> <p>Introduce the exponential equation for attenuation (the reduction of the intensity of the X-rays). Link it to equation for the attenuation of ultrasound.</p> <p>Explain that the attenuation coefficient depends on the density of the media. Ask learners to explain why an X-ray appears to create a 'shadow' of bones.</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>24.2.4 Understand that computed tomography (CT) scanning produces a 3D image of an internal structure by first combining multiple X-ray images taken in the same section from different angles to obtain a 2D image of the section, then repeating this process along an axis and combining 2D images of multiple sections.</p>	<p>Link the attenuation coefficient to learners' understanding of half-life from Unit 17 <i>Particle physics and nuclear physics</i> by asking learners to calculate the half-value thickness of a material e.g. the thickness of bone that causes the intensity to drop to half of the original X-ray.</p> <p>Set learners questions on attenuation for practice. (F)</p> <p>Show learners X-ray images. Learners may enjoy trying to identify what they are looking at in the images. Highlight the limitations of X-rays. They are superimposed images of information from different depths within the body and they do not show clear differences in soft tissue. Explain how X-rays can be used to produce a 3D image, known as computed tomography (CT). The word 'tomos' comes from the Greek for 'slice'; a CT scan builds up the 3D image by scanning in layers. Videos and/or diagrams may help explain this process.</p> <p>Teacher notes and learner worksheets from the IoP on X-rays: https://spark.iop.org/x-ray-imaging</p> <p>Videos from the IoP on X-rays with notes and worksheets: www.stem.org.uk/resources/elibrary/resource/31829/x-ray-imaging</p> <p>Computed Tomography (CT): www.radiologyinfo.org/en/info.cfm?pg=bodyct</p>
<p>24.3 PET scanning</p> <p>KC3</p> <p>KC4</p>	<p>24.3.1 Understand that a tracer is a substance containing radioactive nuclei that can be introduced into the body and is then absorbed by the tissue being studied.</p> <p>24.3.2 Recall that a tracer that decays by β^+ decay is used in positron emission tomography.</p> <p>24.3.3 Understand</p>	<p>Introduce a tracer as a substance containing radioactive nuclei that can be introduced into the body and is then absorbed by the tissue being studied.</p> <p>Ask learners to explain β^+ decay as covered in Unit 17 <i>Particle physics and nuclear physics</i>. Explain that this is the type of radioactivity used in positron emission tomography.</p> <p>Ask learners what they think happens when a particle meets an antiparticle, e.g. a positron and an electron. They may suggest that this results in annihilation when both particles cease to exist and their mass is converted into energy in the form of photons.</p> <p>When the positron, emitted by β^+ decay of the tracer, meets an electron, it annihilates and produces a pair of gamma-ray photons travelling in opposite directions.</p> <p>Learners can calculate the energy of the gamma-ray photons emitted during the annihilation of an electron-positron pair using the equivalence between energy and mass covered in Unit 17.</p> <p>Ask learners to use their understanding of the nature of gamma-ray photons from Unit 17 to explain what happens after the annihilation. They may be able to explain that the gamma-ray photons will travel out of the body due to</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>that annihilation occurs when a particle interacts with its antiparticle and that mass-energy and momentum are conserved in the process.</p> <p>24.3.4 Explain that, in PET scanning, positrons emitted by the decay of the tracer annihilate when they interact with electrons in the tissue, producing a pair of gamma-ray photons travelling in opposite directions.</p> <p>24.3.5 Calculate the energy of the gamma-ray photons emitted during the annihilation of an electron-positron pair.</p> <p>24.3.6 Understand that the gamma-ray photons from an annihilation event travel outside the body and can be detected, and an image of the tracer concentration in the</p>	<p>their high penetrating power. Explain that the gamma-ray photons can be detected and their arrival times allow an image of the tracer concentration in the tissue to be created.</p> <p>Show learners PET images. Learners may enjoy trying to identify what they are looking at in the images. Set learners questions for practice. (F)</p> <p>Teacher notes and learner worksheets from the IoP on Positron Emission Tomography (PET): https://spark.iop.org/positron-emission-tomography-pet</p> <p>Video from the IoP on Positron Emission Tomography (PET) with notes and worksheets: www.stem.org.uk/elibrary/resource/31832</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	tissue can be created by processing the arrival times of the gamma-ray photons.	
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

19 Astronomy and cosmology

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
25.1 Standard candles KC1 KC2 KC5	<p>25.1.1 Understand the term luminosity as the total power of radiation emitted by a star.</p> <p>25.1.2 Recall and use the inverse square law for radiant flux intensity F in terms of the luminosity L of the source $F = L / (4\pi d^2)$.</p> <p>25.1.3 Understand that an object of known luminosity is called a standard candle.</p> <p>25.1.4 Understand the use of standard candles to determine distances to galaxies.</p>	<p>Introduce the term luminosity and relate to learners' knowledge of power from Unit 5 <i>Work, energy and power</i>. Highlight that luminosity is independent of how far away we are from the star. Stars may have a high luminosity but appear less bright because they are further away.</p> <p>Recap the inverse square law for intensity of electromagnetic waves as covered in Unit 7 <i>Waves and superposition</i>. The radiant flux intensity can be calculated in a similar way in terms of the luminosity of the source.</p> <p>Introduce standard candles. These are astronomical objects with known luminosities that can be used to determine how far away these objects, and the surrounding galaxy, are from Earth. Learners may be interested to learn about some of the commonly used types of stars that can act as standard candles. It might enthuse the girls in particular to hear about the scientist Henrietta Swan Leavitt's work in discovering the relationship between the luminosity and the period of Cepheid variables, the first standard candle used in astronomy.</p> <p>Set learners simple questions for practice. (F)</p> <p>Learners can investigate the inverse square law of light through an experiment using a point light source and shade boxes (see nasa.gov link).</p> <p>Learners can investigate the inverse square law of light using a light intensity metre and a point light source.</p> <p>Stellar luminosity calculator: https://astro.unl.edu/naap/hr/hr_background2.html</p> <p>Standard candles: www.astro.ex.ac.uk/people/hatchell/rinr/candles.pdf</p> <p>The inverse square law of light experiment: www.nasa.gov/pdf/583137main_Inverse_Square_Law_of_Light.pdf</p>
25.2 Stellar radii KC1	25.2.1 Recall and use Wien's displacement law $\lambda_{\max} \propto 1 / T$ to estimate the peak	Show a video of a metal being heated until it begins to melt and direct learners to observe the change in colour of the metal over time. Does the colour of the metal relate to its temperature? Learners may link colour to wavelength.

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
<p>KC3</p> <p>KC5</p>	<p>surface temperature of a star.</p> <p>25.2.2 Use the Stefan–Boltzmann law $L = 4\pi\sigma^2 T^4$.</p> <p>25.2.3 Use Wien’s displacement law and the Stefan–Boltzmann law to estimate the radius of a star.</p>	<p>Introduce Wien’s law as the relationship between temperature and wavelength. Specifically it links the temperature in kelvin to the inverse of the peak wavelength at which its intensity is maximum.</p> <p>Show learners an intensity–wavelength graph of blackbody radiation at various temperatures so they understand what is meant by ‘peak wavelength’.</p> <p>Learners can use Wien’s displacement law to estimate the wavelengths emitted by various everyday items. They can first estimate, measure or research temperature and then calculate a wavelength. Items can include: a Bunsen burner, a log fire, a human being, a filament lamp, the Sun, etc.</p> <p>Learners can investigate Wien’s displacement law further with the Blackbody spectrum simulation. (I)</p> <p>Introduce the Stefan–Boltzmann law and the variables on which luminosity depends.</p> <p>Ask learners to combine Wien’s displacement law and the Stefan–Boltzmann law to find the radius of a star. Give learners the Sun’s peak wavelength at which its intensity is maximum, and its luminosity. Learners may link this wavelength to the colour green, its abundance on our planet and a human’s eye’s sensitivity to the visible light spectrum.</p> <p>Set learners questions for practice. (F)</p> <p>Wien’s displacement law and the temperature of a star: www.schoolphysics.co.uk/age16-19/Astrophysics/text/Luminosity_and_brightness/index.html</p> <p>Blackbody spectrum simulation: https://phet.colorado.edu/en/simulation/blackbody-spectrum</p>
<p>25.3 Hubble’s law and the Big Bang theory</p> <p>KC1</p> <p>KC2</p> <p>KC5</p>	<p>25.3.1 Understand that the lines in the emission spectra from distant objects show an increase in wavelength from their known values.</p> <p>25.3.2 Use $\Delta\lambda / \lambda \approx \Delta f / f \approx v / c$ for the redshift of electromagnetic</p>	<p>Remind learners of the Doppler effect for sound waves as covered in Unit 7 <i>Waves and superposition</i>. Any wave can be Doppler shifted and the Doppler effect for light waves can be used to find the speed of astronomical objects.</p> <p>Remind learners of the equation for the Doppler effect from Unit 7 and relate it to wavelength.</p> <p>Introduce Edwin Hubble as the scientist who showed that there were many more galaxies in the Universe than people thought and who investigated the motion of distant galaxies.</p> <p>How did Hubble investigate the motion of distant galaxies? Remind learners about line spectra from Unit 16 <i>Quantum physics</i>. Hubble knew what line spectra the stars should have, but he found them to be redshifted and calculated their velocity. It may help to show images of line spectra. Remind learners of Henrietta Swan Leavitt’s</p>

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	<p>radiation from a source moving relative to an observer.</p> <p>25.3.3 Explain why redshift leads to the idea that the Universe is expanding.</p> <p>25.3.4 Recall and use Hubble's law $v \approx H_0 d$ and explain how this leads to the Big Bang theory.</p>	<p>work on standard candles, which were used by Edwin Hubble to find the distance to galaxies.</p> <p>Show learners a graph of Hubble's results. Ask learners to make their own conclusion. They may explain that galaxies that are further away move faster, suggesting that everything is moving away from everything else, which leads to the conclusion that the Universe is expanding.</p> <p>Introduce Hubble's law and the equation. Hubble's law can be expressed in alternative units, but candidates will only be required to use SI units.</p> <p>Set learners questions for practice. (F)</p> <p>Ask learners what else can be deduced by Hubble's evidence of redshift. What happens if we run time backwards? The Universe would be a lot smaller, denser and hotter than it is now, until eventually it is all in a single point. This is the basis of the Big Bang theory and Hubble's law is a key piece of evidence.</p> <p>Learners can investigate the Big Bang theory using a balloon and coloured stickers (see schoolsobservatory.org link). This models the balloon as space–time, which expands, and the stickers as galaxies. Learners measure the distances between each galaxy and a home galaxy using string and a ruler before and after a period of expansion and plot the results on a graph.</p> <p>Learners can investigate the Big Bang theory with metal rings and rubber bands (see spark.iop link). This models the metal rings as galaxies, held together by their own gravity, and the rubber bands as the space between them, which expand as the Universe expands. The rubber bands can be looped through the metal rings to create a straight chain of 'galaxies'. Learners measure the distances between each galaxy and a home galaxy with a ruler before and after a period of expansion and plot the results on a graph.</p> <p>Learners may enjoy looking at images captured by the Hubble Space Telescope, as named after Edwin Hubble. (I)</p> <p>Teacher notes and learner worksheets from the IoP on the expanding universe: https://spark.iop.org/episode-704-expanding-universe</p> <p>Big Bang demo: www.schoolsobservatory.org/discover/quick/uniball</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

Cambridge Assessment International Education
The Triangle Building, Shaftesbury Road, Cambridge, CB2 8EA, United Kingdom
t: +44 1223 553554
e: info@cambridgeinternational.org www.cambridgeinternational.org
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