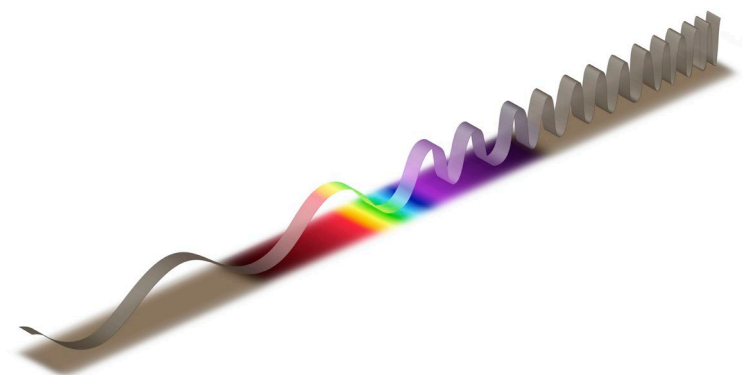


Scheme of Work

Cambridge O Level

Physics 5054

For examination from 2023



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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.

Guided learning hours

Guided learning hours give an indication of the amount of contact time you need to have with your learners to deliver a course. Our syllabuses are designed around 130 hours for Cambridge IGCSE courses. The number of hours may vary depending on local practice and your learners' previous experience of the subject. The table below gives some guidance about how many hours we recommend you spend on each topic area.

Topic	Suggested teaching time (% of the course)
1 Motion, forces and energy	It is recommended that this should take about 26% of the course.
2 Thermal physics	It is recommended that this should take about 10% of the course.
3 Waves	It is recommended that this should take about 18% of the course.
4 Electricity and magnetism	It is recommended that this should take about 27% of the course.
5 Nuclear physics	It is recommended that this should take about 8% of the course.
6 Space physics	It is recommended that this should take about 11% of the course.

Resources

You can find the up-to-date resource list, including endorsed resources to support Cambridge IGCSE Physics on the Published resources tab of the syllabus page on our public website [here](#).

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, you should refer to the updated specimen assessment materials.

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.bbc.co.uk/bitesize

www.falstad.com/mathphysics.html

www.mathsisfun.com/physics/index.html

<https://phet.colorado.edu>

www.physicsclassroom.com

<https://spark.iop.org>

www.stem.org.uk

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 IGCSE Physics 0625/0972 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 clear the knowledge they are trying to build. Pass these on to your learners by expressing them as 'We are learning to / about...'

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

Syllabus ref.	Learning objectives	Suggested teaching activities
Pressure	at a surface produces a force in a direction at right angles to the surface and describe an experiment to show this.	<p>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 conical flask implodes when cooled suddenly, Magdeburg hemispheres support significant force, etc. understand the presence and strength of air pressure around us.</p>
		<p>Resource Plus</p> <p>Carry out the <i>Pressure and the imploding can</i> experiment referring to Teaching Pack resources.</p>
		<p>Introduce the equation for hydrostatic pressure and explain its variables.</p> <p>Set learners questions for practice. (F)</p> <p>Introduce the barometer and how it is used to determine atmospheric pressure.</p> <p>Learners can make their own simple barometers and track weather patterns. (I)</p> <p>Learners can investigate pressure further by working with the Under Pressure simulations: (I) https://phet.colorado.edu/en/simulation/under-pressure https://phet.colorado.edu/en/simulation/legacy/fluid-pressure-and-flow</p>
1.8.6	Recall and use the equation for the	<p>Extension: Stretch and prepare for A level</p> <p>Derive the equation for hydrostatic pressure from $\text{pressure} = \text{force} / \text{area}$ 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 column.</p> <p>Learners can feel how a mass on a string will feel lighter when placed into water. They are feeling the upthrust of the water which supports some of its weight. This allows them to feel the difference in weight. Link this to the idea of an object feeling a pressure difference.</p>

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.

Resource Plus provides Teaching Packs and experiment videos to develop your learners' practical science skills. available for you to view and download at: www.cambridgeinternational.org/support.

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

Extension activities provide your more able learners with further challenge beyond the basic content of the course and help prepare them for A Level study and beyond.

Past papers, specimen papers and **mark schemes** are available for you to download at: www.cambridgeinternational.org/support

Past and specimen papers

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

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

1. Motion, forces and energy

Syllabus ref.	Learning objectives	Suggested teaching activities
1.1.1 Physical quantities and measurement techniques	Describe the use of rulers and measuring cylinders to find a length or a volume	Discuss the importance of measurements. Why do we take measurements? How do we ensure measurements are accurate and precise?
1.1.2	Describe how to measure a variety of time intervals using clocks and digital timers	Set up stations around the laboratory with different measuring instruments, as well as items for measurement, for learners to move around in small groups or pairs. Learners can take measurements of the following: width of a book, area of laboratory floor, thickness of a piece of paper (they should consider measuring multiples), volume of a small rock, time to get your attention, time to walk across the laboratory, time of one pendulum swing (measuring multiples), etc. Make sure learners understand the importance of taking multiple readings and calculating a mean. For a value of a small distance or a short interval of time, learners should measure multiples and calculate a mean (including the period of a pendulum).
1.1.3	Determine an average value for a small distance and for a short interval of time by measuring multiples (including the period of oscillation of a pendulum)	Interactive websites showing the scale of the real world: www.nikon.com/about/sp/universscale/scale.htm https://scaleofuniverse.com Extension: Stretch and prepare for A level Introduce precision, accuracy and error in measurements. The bull's-eye analogy may help you explain the difference between them. Discuss systematic errors and random errors. Bull's-eye analogy of precision and accuracy: https://www.mathsisfun.com/accuracy-precision.html
1.1.4 Physical quantities and measurement techniques	Understand that a scalar quantity has magnitude (size) only and that a vector quantity has magnitude and direction	Introduce the definitions of scalars and vectors. Using quantities learners have come across before for them to identify which are scalars and which are vectors. Add more examples of scalars to include: distance, speed, time, mass, energy, temperature and pressure. Add more examples of vectors to include: displacement, force, weight, velocity, acceleration, electric field strength and gravitational field strength.
1.1.5	Know that the following quantities are scalars: distance,	Use a ball to explain the difference between distance and displacement, relating back to the difference between scalars and vectors. Throw the ball to a learner and ask the class to estimate the distance the ball has travelled. What is the displacement? Learners should note that in this case the distance is the same as the displacement. The learner with the ball can then throw the ball back to you and the learners can estimate the distance and the displacement. Learners should now note that the distance and displacement have different values.

Syllabus ref.	Learning objectives	Suggested teaching activities
1.1.6	<p>speed, time, mass, energy and temperature</p> <p>Know that the following quantities are vectors: force, weight, velocity, acceleration, momentum, electric field strength and gravitational field strength</p>	<p>Emphasise that any quantity that links with a direction word is a vector. Both a force of 3.0 N <i>upwards</i> and a displacement of 0.45 m <i>west</i> make sense; but a temperature of 47 °C <i>sideways</i> does not.</p> <p>Explain that scalars always add to create a larger value. Discuss the example of going for a rambling walk. The walker might walk 1km north, 2km east and 5km north. In total the walker has travelled a distance of 8km and this is a scalar value.</p> <p>Explain that vectors have direction and this changes how they add. Introduce simple examples of multiple forces acting on a block in the left and right direction. Include up and down. Highlight how they can cancel out in some cases. What can we do when they do not cancel out and are perpendicular to each other?</p>
1.1.7	<p>Determine, by calculation or graphically, the resultant of two vectors at right angles, limited to forces or velocities only</p>	<p>Introduce how to add vectors graphically. Learners should pick an appropriate scale and use a protractor to measure and draw angles. Demonstrate both the 'head-to-tail' method and the 'parallelogram' method for the addition of two vectors. Learners practise adding and subtracting pairs of vectors graphically. You could use online simulations or diagrams to visually demonstrate vector addition. (F)</p> <p>Introduce how to add vectors at right angles to each other mathematically using Pythagoras' theorem. Learners now check the resultant vectors for any perpendicular vectors they have previously added graphically with this mathematical method. (F)</p> <p>Set learners more questions for practice. (F)</p> <p>A simple plenary task is sorting quantities into scalars and vectors. Do this either as a group activity on the board or in small groups with the quantities printed onto cards to sort.</p> <p>Vectors: www.mathsisfun.com/algebra/vectors.html</p> <p>Vector addition simulation: phet.colorado.edu/en/simulation/vector-addition</p> <p>Extension: Stretch and prepare for A level Introduce how to resolve a vector into vertical and horizontal components using trigonometry. Use online simulations and/or diagrams.</p> <p>Resolving vectors in components: www.s-cool.co.uk/a-level/physics/vectors-and-scalars-and-linear-motion/revise-it/resolving-vectors-into-components</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.2.1 Motion	Define speed as distance travelled per unit time; recall and use the equation $v = \frac{s}{t}$	Ask learners for a definition of speed. They may be able to explain that it depends on how far is travelled in a certain amount of time. Introduce the equation for speed and demonstrate a calculation. This is useful for calculating the speed at a specific point in time or over a small time interval e.g. how fast a car is travelling when caught by a speed camera. Explain that speed and velocity may have the same value, but velocity can have a negative symbol to show direction.
1.2.2	Define velocity as speed in a given direction	Consider average speed for journeys where the speed changes: a train making stops at stations, a car slowing down due to traffic, an athlete accelerating to reach their maximum speed in a sprint, etc. Explain that average speed can be calculated from knowing the total distance travelled and the time taken.
1.2.3	Recall and use the equation average speed = $\frac{\text{total distance travelled}}{\text{total time taken}}$	Introduce the equation for average speed and demonstrate a calculation. Learners take measurements of distance and time and use these to calculate speed. They can set up a course of a set distance (measured out with a trundle wheel or metre rules) and measure the time it takes for them to walk/run/travel the distance. Alternatively they can use a long corridor and measure the time it takes for other learners/teachers/visitors to travel the measured distance.
1.2.9	Define acceleration as change in velocity per unit time; recall and use the equation $a = \frac{\Delta v}{\Delta t}$	Set learners questions to practise calculation of speed, distance and time. (F) Speed and velocity: www.physicsclassroom.com/class/1DKin/Lesson-1/Speed-and-Velocity
1.2.12	Know that a deceleration is a negative acceleration and use this in calculations	Extended assessment: 1.2.9 and 1.2.12 Recap the difference between distance and displacement, and link to speed and velocity. Remind learners of the ball demonstration where learners estimate the distance and displacement of the ball as it is passed around the class. Remind learners that distance and displacement may have different values. Ask learners to give an example of acceleration. They may suggest a racing car accelerating very quickly off a start line. Clarify that all objects have to accelerate or decelerate to change velocity. Ask learners to define deceleration. Clarify that deceleration is negative acceleration and causes the velocity to decrease. Learners use ticker tape timers to investigate constant velocity, acceleration and deceleration. They measure the distance between dots, or the distance between a set number of dots and, using the frequency of the ticker tape timer, calculate values of velocity and acceleration.

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Learners use light gates and datalogger set-ups to measure the initial and final velocities of an interrupt card attached to a moving trolley or toy car and the time between those measurements. Learners then calculate the acceleration. Constant acceleration can be achieved by using a ramp or a mass on a pulley.</p> <p>Set learners questions to practise calculation of acceleration, change in velocity and time. (F)</p> <p>Extension: Stretch and prepare for A level Use the definition of acceleration to explain the units for acceleration. Show learners how they can be written as ms^{-2} rather than m/s^2 and explain this mathematically.</p>
<p>1.2.4 Motion</p> <p>1.2.5</p> <p>1.2.6</p> <p>1.2.7</p>	<p>Sketch, plot and interpret distance–time and speed–time graphs</p> <p>Determine, qualitatively, from given data or the shape of a distance–time graph or speed–time graph when an object is:</p> <p>(a) at rest (b) moving with constant speed (c) accelerating (d) decelerating</p> <p>Calculate speed from the gradient of a straight-line section of a distance–time graph</p> <p>Calculate the area under a speed–time graph to determine the distance travelled for</p>	<p>Learners, in pairs, each sketch a distance–time graph, act the motion shown to their partner, interpret the motion of their partner and draw the distance–time graph for the observed motion of their partner.</p> <p>Ask learners what the gradient of a distance–time graph represents. Learners may be able to link their understanding of how to calculate the gradient to the definition of speed. Show learners how to find the gradient, and thus the speed or velocity, of a distance–time graph.</p> <p>Give learners distance–time graphs to match up with the appropriate description. Examples can include an object moving at constant velocity, an object that is accelerating, a stationary object, etc.</p> <p>Give learners descriptions to draw as distance–time graphs. This works particularly well on miniature whiteboards as a group interactive task so that learners can compare and discuss what they’ve drawn. Examples can include someone walking to the bus stop, someone walking backwards, someone sprinting from standstill, etc.</p> <p>Learners use motion sensor and datalogger set-ups to investigate the relationship between motion and distance–time graphs. Set learners the challenge of recreating distance–time graphs you give to them – they have to interpret a distance–time graph and act out the motion. Learners investigate how constant speed, acceleration and deceleration appear on the distance–time graph created by a datalogger connected to a motion sensor.</p> <p>Learners use ticker tape timers to investigate motion. They measure the distance between dots and, using the time between each dot, plot distance–time graphs.</p> <p>Learners plot simple distance– or speed–time graphs for their journey to school. They can add more detail by labelling the events that take place on the journey e.g. the school bus stops at traffic lights.</p> <p>Set learners questions that involve interpreting and plotting distance–time graphs. (F)</p> <p>Learners can investigate motion and motion graphs further using The Moving Man simulation that plots motion: (I) https://phet.colorado.edu/en/simulation/legacy/moving-man</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
	motion with constant speed of constant acceleration	
1.2.10 Motion	Determine from given data or the shape of a speed-time graph when an object is moving with: (a) constant acceleration (b) changing acceleration	<p>To recap their understanding, give learners distance–time graphs for various types of motion such as constant speed, constant acceleration and changing acceleration. Learners match the descriptions to the graphs. Learners draw speed–time graphs from descriptions you give.</p> <p>Ask learners what the gradient of a speed–time graph represents. Learners may be able to link their understanding of how to calculate the gradient to the definition of acceleration.</p> <p>Set learners questions that involve interpreting and plotting speed–time graphs, as well as calculating acceleration from the gradient. (F)</p>
1.2.11	Calculate acceleration from the gradient of a speed-time graph	<p>Give learners distance–time graphs and speed–time graphs for various types of motions such as constant speed, acceleration and deceleration. Learners match up the graphs to reinforce their understanding of these two types of graph. (F)</p> <p>Resource Plus</p> <p>Carry out the <i>Speed–time graphs</i> experiment referring to Teaching Pack for lesson plans and resources.</p> <p>Extension: Stretch and prepare for A level</p> <p>Introduce the equation of motion $s = ut + \frac{1}{2}at^2$. Use 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. Demonstrate how to apply this equation of motion to simple examples.</p> <p>Introduce how the tangent of a curved graph can be used to find the acceleration at that point in time.</p>
1.2.8 Motion	State that the acceleration of free fall g for an object near to the surface of the Earth is approximately constant and is approximately 9.8 m/s^2	<p>Start the lesson by showing learners an apple and asking learners how much it weighs. Learners estimate the mass of the apple. Allow learners to make guesses without saying whether they are right or wrong. A learner may correctly give the unit of Newtons, rather than grams or kilograms. Introduce the idea that mass and weight are different quantities that are often confused.</p> <p>Learners investigate the relationship between mass and weight. They use an electronic balance to measure the mass of various objects or they can use slotted masses of 100g each. Learners use a force meter to measure the weight. They</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.3.1 Mass and weight	State that mass is a measure of the quantity of matter in an object at rest relative to the observer	<p>plot a graph of weight against mass and calculate the gradient. Introduce the value of the gradient as the gravitational field strength.</p> <p>Relate weight, mass and gravitational field strength together with the equation.</p> <p>Set learners simple questions for practice. (F)</p>
1.3.2	State that weight is a gravitational force on an object that has mass	<p>Define gravitational field strength and link to the acceleration of free-fall for an object near to the surface of the Earth. Highlight that this value is constant. Explain to learners that all objects experience the same acceleration due to free-fall, but often it does not appear this way due to the presence of air resistance. This will be covered further with terminal velocity.</p>
1.3.3	Define gravitational field strength as force per unit mass; recall and use the equation $g = \frac{w}{m}$ and know that this is equivalent to the acceleration of free fall	<p>Stick pictures of the planets and the Sun in our solar system on the walls of the classroom, with values of their gravitational field strength. Learners hunt to find the different planets and their values of g and use these to calculate their weight on these planets. Learners may need to first measure their mass using bathroom scales. Some learners may be sensitive about their mass so you may offer to share your mass with the class for use in calculations.</p> <p>Learners discuss how Olympic records might change if competitions were held on the surface of Mars one day. Assuming athletes had sufficient air and pressure, learners estimate how records for weightlifting, javelin, high jump, sprints, etc., would change with a different value of gravitational field strength.</p>
1.3.4	Know that weights, (and masses) may be compared using a balance	<p>Set learners more questions for practice. (F)</p> <p>Extended assessment: 1.3.5</p>
1.3.5	Describe, and use the concept of, weight as the effect of a gravitational field on a mass	<p>Clarify that a gravitational field is a region in which a mass experiences a force due to gravitational attraction and this value changes depending on the size of the mass creating the field and the distance away from this mass.</p> <p>Extension: Stretch and prepare for A level</p> <p>Introduce Newton's law of gravitation as an equation. 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. Discuss with learners why these forces go unnoticed.</p> <p>Learners can investigate attractive force between masses further using the Gravity Force Lab simulation: (I) https://phet.colorado.edu/en/simulation/gravity-force-lab-basics</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.4.1 Density	Define density as mass per unit volume; recall and use the equation $\rho = \frac{m}{V}$	Ask learners to define density. They may describe it in terms of how closely packed a substance's particles are or use the equation. Learners consider how heating a substance affects its density. Highlight water as an exception to the general rule that solids are denser than liquids.
1.4.2	Describe how to determine the density of a liquid, of a regularly shaped solid and of an irregularly shaped solid which sinks in a liquid (volume by displacement), including appropriate calculations.	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 . Use multiple metre rules to make a physical metre cubed, to help them to visualise and understand how squaring and cubing 1m also squares and cubes 100cm, producing a much larger number than they might expect. Set learners more questions for practice. (F) Learners investigate how density relates to floating, how to compare density data and how to find the volume of an object using Archimedes' principle with the Buoyancy simulation: (I) https://phet.colorado.edu/en/simulation/legacy/buoyancy
1.4.3	Determine whether an object floats based on density data	<div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> <p>Resource Plus</p> <p>Carry out the <i>Determining the density of solids and liquids</i> experiments referring to Teaching Pack for lesson plans and resources.</p> </div> <p>Extended assessment: 1.4.4</p>
1.4.4	Determine whether one liquid will float on another liquid based on density data given that the liquids do not mix	Learners can investigate liquids that do not mix and consider how their densities determine the order of the liquids. Learners can observe/investigate oil on water, coloured fresh water on saltwater, etc. They should compare the density data and make predictions. https://www.sciencefun.org/kidszone/experiments/layers-of-liquids/
1.5.1.3 Effects of forces	Determine the resultant of two or more forces acting along the same straight line	Ask learners to name as many different types of force as possible. Reinforce that all forces are measured in Newtons. Ask learners to sort the list of forces they have compiled into contact and non-contact forces. They may get confused with air resistance because air is invisible, but it does make contact at all times. Learners wave their hands around quickly to feel the 'wind' they produce as they move through the air and experience air resistance.
1.5.1.4	Know that an object either remains at rest	Introduce free-body diagrams as a simple and clear way of showing the size and direction of forces acting on a body.

Syllabus ref.	Learning objectives	Suggested teaching activities
1.5.1.5	<p>or continues in a straight line at constant speed unless acted on by a resultant force</p> <p>State that a resultant force may change the velocity of an object by changing its direction of motion or its speed</p>	<p>Learners investigate the effect of multiple forces by making a simple ball from scrap paper and using straws to apply similar forces from various angles. Working in small groups they observe what happens when a single force is applied by blowing through the straw at the paper ball, two forces from different angles and multiple forces in varied combinations. Learners make predictions before testing each scenario. They may note that in reality it is very difficult to each provide the same force and apply them at the correct angles. Learners may conclude that forces can 'cancel each other out' or add together depending on their values and direction, relating to the fact that forces are vectors.</p> <p>Introduce Newton's first law and the term 'resultant force' to explain how forces produce changes to motion or speed.</p> <p>Ask learners to consider what would happen if a tennis ball was thrown in space. They may be able to explain that, as long as the ball does not hit anything, it will travel forever as there are no forces to change its motion.</p>
1.5.1.11	<p>Recall and use the equation $F = ma$ and know that the force and the acceleration are in the same direction</p>	<p>Show learners simple free-body diagrams for them to quickly work out the resultant force. Learners can answer by using miniature whiteboards. (F)</p> <p>Learners carry out a 'tug of war' to demonstrate addition of forces as vectors. Different numbers of learners on either side should result in a clear win for the side with the most force.</p> <p>Set learners practice questions on finding the resultant force. (F)</p> <p>Learners investigate forces and motion further using the following simulations that investigate forces and motion: (I) https://phet.colorado.edu/en/simulation/forces-and-motion-basics https://phet.colorado.edu/en/simulation/legacy/forces-and-motion</p> <p>Extended assessment: 1.5.1.11</p> <p>Recap the idea that forces can cause changes in motion or speed, as well as shape. Link Newton's first law to the second by highlighting that changes in motion or speed means there must be acceleration.</p> <p>Introduce the equation $F = ma$</p> <p>Set learners simple questions for practice. (F)</p>
1.5.1.6 Effects of forces	<p>Describe solid friction as the force between two surfaces that may impede motion and produce heating</p>	<p>Show learners a video of a spacecraft re-entering Earth's atmosphere and landing safely in the ocean. Ask learners to explain why the spacecraft does not accelerate forever and why it gets so hot. Learners should link the force of friction to the idea of the spacecraft not traveling too fast and its increase in heat.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.5.1.7	Know that friction (drag) acts on an object moving through a liquid	<p>Remind learners that friction is present for all objects in motion on Earth due to our atmosphere. Ask learners to suggest other sources of friction and a scenario where friction is important e.g. brakes to control the motion of a car. Learners can feel how friction produces heating by quickly rubbing their hands together.</p> <p>Ask learners to explain the motion of objects acted on by constant forces.</p>
1.5.1.8	Know that friction (drag) acts on an object moving through a gas (e.g. air resistance)	<p>Remind learners that all objects experience the same acceleration due to free-fall, but often it does not appear this way due to the presence of air resistance. Demonstrate the guinea and feather drop: https://spark.iop.org/guinea-and-feather</p> <p>Show the Apollo 15 hammer-feather drop: https://moon.nasa.gov/resources/331/the-apollo-15-hammer-feather-drop/</p>
1.2.13 Motion	Describe the motion of objects falling in a uniform gravitational field with and without air/liquid resistance (including reference to terminal velocity)	<p>Extended assessment: 1.2.13</p> <p>Ask learners to identify the forces on a parachutist. Learners should identify weight and air resistance. Ask learners how, or if, these forces change during the fall.</p> <p>Show learners a video of a parachute jump, perhaps the extreme record-breaking free fall parachute jump in 2012. Ask learners to consider how the velocity changes throughout. Learners sketch a velocity–time graph of the motion as they watch the video: https://www.space.com/17961-supersonic-skydive-worlds-highest-space-jump.html</p> <p>Introduce the idea of terminal velocity and the conditions under which it occurs.</p> <p>Set learners qualitative questions to test understanding. (F)</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. (F)</p> <p>Learners investigate terminal velocity further by timing the fall of objects through a viscous liquid, such as concentrated cleaning detergent. Learners set up equal intervals of distance and measure the time it takes for the object to fall. If the time intervals are equal, the object is falling at terminal velocity.</p> <p>Learners investigate terminal velocity further using the simulation. Complete toolkit on terminal velocity including interactive simulation and animations: (I) www.physicsclassroom.com/Teacher-Toolkits/Terminal-Velocity/Terminal-Velocity-Complete-ToolKit</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Extension: Stretch and prepare for A level</p> <p>Set learners the task of drawing a series of free-body diagrams of a parachutist falling from a plane and opening a parachute over several snapshots of time. Learners should consider weight and air resistance, direction and size of both forces, motion before and after the parachute is opened and where terminal velocity occurs. Animations of parachutists may aid this. (F)</p> <p>Learners can research factors that affect the value of drag and qualitatively design an aerodynamic vehicle. (I)</p> <p>Learners can investigate space travel using constant acceleration, building on the idea of a constant driving force with no drag, and explain why a spacecraft cannot accelerate forever. (I)</p> <p>How does a package fall from a plane if it is 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 the idea of projectile motion to learners and see if they can identify other scenarios where it takes place, e.g. firing a cannon ball at an angle to the horizontal. Demonstrate projectile motion using a simulation: https://phet.colorado.edu/en/simulation/projectile-motion</p>
1.5.1.1 Effects of forces	Know that forces may produce changes in the size and shape of an object	Recap the idea that forces can cause changes in motion or speed, as well as shape.
1.5.1.2	Sketch, plot and interpret load–extension graphs for an elastic solid and describe the associated experimental procedures	Learners investigate Hooke’s law using a helical spring and masses. Clarify the difference between length and extension. Learners plot a load–extension graph of their results.
1.5.1.9	Define the spring constant as force per unit extension; recall and use the equation $k = \frac{F}{x}$	Learners write out the experimental procedure for collecting the results needed to produce a load–extension graph. Learners then swap procedures with each other and attempt to carry them out explicitly to highlight any errors or missing instructions.
		<p>Extended assessment: 1.5.1.9 and 1.5.1.10</p> <p>Introduce the equation $F = kx$ and link to the graph plotted. Define the spring constant and show the rearranged equation.</p> <p>Learners find the spring constant by finding the gradient of their graph. They use the spring constant to make predictions for the extension produced by values of force that they did not test.</p> <p>Set learners quantitative and qualitative questions for practice. (F)</p> <p>Use the load–extension graph to identify the limit of proportionality and link to Hooke’s law (an understanding of the elastic limit is not required).</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.5.1.10	Define and use the term 'limit of proportionality' for a load–extension graph and identify this point on the graph (an understanding of the elastic limit is not required)	<p>Learners investigate Hooke's law further with the Hooke's law simulation. They can use the simulation to collect, plot and analyse results: (I) https://phet.colorado.edu/en/simulation/hookes-law</p> <p>Learners find the value of weight for the various mystery masses using the Masses and Springs: Basics simulation (I): https://phet.colorado.edu/en/simulation/masses-and-springs-basics</p> <p>Extension: Stretch and prepare for A level Learners consider the energy stored by a spring and investigate this, amongst other activities, using the Masses and Springs simulation: (I) https://phet.colorado.edu/en/simulation/masses-and-springs</p>
1.5.3.1 Centre of gravity	State what is meant by centre of gravity	<p>Ask learners to find the centre of gravity for a ruler or pen from their pencil case. Learners will begin by balancing them on their fingers. Ask learners to define the centre of gravity.</p>
1.5.3.2	Describe an experiment to determine the position of the centre of gravity of an irregularly shaped plane lamina	<p>Learners investigate their own centre of gravity. Without bending at the knees or waist, they tip forwards while standing up until they feel they are about to fall. When does this occur? Learners may identify that when their centre of gravity is no longer supported by their base (their feet), they become unstable and fall. How can the learners be more stable? They may take up a sumo wrestler position with a wide stance and a lowered centre of gravity with bent knees.</p> <p>Learners try various tasks that are made much more difficult when they are not allowed to shift their centre of gravity: picking up a pen from the floor in front of them with their back and feet flat against a wall, lifting one leg while they stand sideways to the wall, etc. Learners should notice how they constantly shift their centre of gravity as they move.</p>
1.5.3.3	Describe, qualitatively, the effect of the position of the centre of gravity on the stability of simple objects	<p>Demonstrate 'tricks' that seem to defy gravity, but are simply utilising a non-central centre of gravity:</p> <ul style="list-style-type: none"> • Make a metre ruler balance on the edge of a desk using some string and a hammer www.education.com/science-fair/article/hammer-ruler-trick/ • Make a matchbox overhang a desk by more than half of its length by placing some coins to one side and holding them in place in the box with adhesive putty • Stack some books in a seemingly impossible arc as long as the centre of gravity remains over the table. <p>Learners find the centre of gravity of an irregular 2-D cardboard shape by suspending it from an optical pin and hanging a plumb line from the same point. The centre of gravity of the shape will lie beneath the suspension point and the plumb line will permit learners to mark a line where this must be. Changing the suspension point should allow them to find another line and where these lines cross is the centre of gravity.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Learners 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 modelling clay to a ruler.</p> <p>Set learners qualitative questions to test understanding. (F)</p> <p>Learners list objects that are unstable and pick one to redesign e.g. a wine glass or a filing cabinet can be designed to be wider and lower. (I)</p>
1.5.2.1 Turning effect of forces	Describe the moment of a force as a measure of its turning effect and give everyday examples	<p>Set up a balance beam with two items of different mass either side. Use objects that learners will recognise and engage with. Ask learners how the beam balances with the objects at different locations, but tips when one is moved.</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 should 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>
1.5.2.2	Define the moment of a force as moment = force \times perpendicular distance from the pivot; recall and use this equation	<p>Define the moment and introduce the equation.</p> <p>Learners identify the pivot, the location where the force is applied and the perpendicular distance on pictures of objects that use moments: water taps, a door, a spanner, a wheelbarrow, etc.</p>
1.5.2.3	Apply the principle of moments to situations with one force each side of the pivot, including balancing of a beam	<p>Learners investigate the amount of force required to tip a clamp stand over by using a force meter and measuring the force required at different heights (measured with a metre rule) from the base. Learners should find that the moment is roughly the same each time, but more force is required the shorter the distance is from the base (which acts as the pivot).</p> <p>Direct learners to set up their own balance beam to investigate. Set learners specific values of force (the weight of the masses) and distance and direct them to find the missing value that allows the beam to balance. Ask them what relationship links their results. Identify the point when the beam balances as equilibrium.</p>
1.5.2.4	State that, when there is no resultant moment, an object is in equilibrium	<p>Set learners qualitative and quantitative questions for practice. (F)</p> <p>Extended assessment: 1.5.2.5 and 1.5.2.6</p>
1.5.2.5	Apply the principle of moments to other situations, including those with more than	<p>Learners can investigate a balance beam with more than one force on each side.</p> <p>Learners can investigate other scenarios involving moments.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.5.2.6	<p>one force each side of the pivot</p> <p>Describe an experiment to demonstrate that there is no resultant moment on an object in equilibrium</p>	<p>Learners write their own method for demonstrating that there is no resultant moment on an object in equilibrium.</p> <p>Resource Plus</p> <p>Carry out the <i>Determining the principle of moments</i> experiment referring to Teaching Pack for lesson plans and resources.</p> <p>Learners can investigate moments further with the simulations: (I) https://phet.colorado.edu/en/simulation/balancing-act https://phet.colorado.edu/en/simulation/legacy/torque</p>
1.5.1.12 Circular motion	<p>Describe, qualitatively, motion in a circular path due to a force perpendicular to the motion as:</p> <p>(a) speed increases if force increases, with mass and radius constant</p> <p>(b) radius decreases if force increases, with mass and speed constant</p> <p>(c) an increased mass requires an increased force to keep speed and radius constant $(F = \frac{mv^2}{r}$ is not required</p>	<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 whether the bucket is accelerating and what happens if the rope breaks. Relate this last question to the Olympic field sports of the hammer throw or discus throw.</p> <p>Consider other examples of circular motion: cars travelling around bends, cars travelling over a hill, planets orbiting stars, electrons in orbit of a nucleus, a bung on a string, a Ferris wheel, a cyclist on a banked track, etc.</p> <p>Qualitatively describe circular motion in terms of force, speed, mass and radius.</p> <p>Set learners qualitative questions to test understanding. (F)</p> <p>Learners can investigate circular motion further using the Rotation simulation: (I) https://phet.colorado.edu/en/simulation/legacy/rotation</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: www.stem.org.uk/resources/elibrary/resource/228680/circular-motion-ball-tether-released-vertical-plane</p> <p>Extension: Stretch and prepare for A level $F = mv^2 / r$ is not required at Cambridge IGCSE Physics, but it might stretch and interest some learners to introduce this equation. Learners can carry out some simple calculations using the new equation.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.6.1 Momentum	Define momentum as mass \times velocity; recall and use the equation $p = mv$	Ask learners which has more momentum, a lorry or a football. The learners may not be able to define momentum, but they may identify that a lorry is likely to have more of it. Ask learners what variables they think affect momentum. They may identify mass and velocity (or speed). Define momentum and introduce the equation.
1.6.2	Define impulse as force \times time for which force acts; recall and use the equation impulse = $F\Delta t = \Delta(mv)$	Set learners simple questions for practice. (F) Define impulse and relate to momentum and force.
1.6.3	Apply the principle of the conservation of momentum to solve simple problems in one dimension	To stimulate learners' interest, look at real-life applications of impulse, force and momentum calculations, such as its consideration in car safety. Seat belts, air bags and crumple zones all function to increase the time over which the momentum changes, thus decreasing the force on the passengers in the vehicle if a sudden stop occurs. Animation of how airbags work: https://animagraffs.com/airbag/
1.6.4	Define resultant force as the change in momentum per unit time; recall and use the equation $F = \frac{\Delta p}{\Delta t}$	Animation of traffic collision reconstruction: https://animagraffs.com/traffic-collision-reconstruction/ A large cloth sheet can be held stretched out with a dip at the bottom and an egg thrown hard at it. The egg will not break on impact with the sheet, no matter how hard the egg is thrown, but instead faces the most danger from falling onto the ground afterwards. The sheet allows the egg to reduce its large momentum to zero gradually, just like the car features mentioned. If the egg hits the ground, its momentum reduces too quickly for it to remain intact. Introduce the conservation of momentum using examples of collisions such as a train and a truck, billiard balls, cars, etc. Demonstrate how to mathematically solve various simple problems to reiterate the importance of starting from the same concepts each time and logically reaching a solution. Set learners questions that use the conservation of momentum to solve simple problems in one dimension. (F) Demonstrate the transfer and conservation of momentum by dropping a football with a tennis ball below it such that the football's momentum is transferred to the tennis ball, causing it to shoot upwards quickly. Learners can investigate the conservation of momentum further using the Collision Lab simulation: (I) https://phet.colorado.edu/en/simulation/legacy/collision-lab

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Look at force–time graphs for impacts and relate to the change of momentum. Consider how a force-time graph for the object A and object B, and their forces, relate to Newton’s third law of motion</p> <p>Extension: Stretch and prepare for A level Relate the definition of impulse to Newton’s second law of motion.</p>
<p>1.7.1.1 Energy, work and power</p> <p>1.7.1.2</p> <p>1.7.1.3</p>	<p>State that energy may be stored as kinetic, gravitational potential, chemical, elastic (strain), nuclear, electrostatic and internal (thermal)</p> <p>Describe how energy is transferred between stores during events and processes, including examples of transfer by forces (mechanical working), electrical currents (electrical work done), heating, and by electromagnetic, sound and other waves</p> <p>Know the principle of the conservation of energy and apply this principle to simple examples including the interpretation of simple flow diagrams</p>	<p>Ask learners to suggest energy stores. Show pictures as prompts to help learners identify them all e.g. fire for thermal, magnets for magnetic, a runner for kinetic, etc.</p> <p>Ask learners if energy is ever lost. They may identify that energy can be wasted, or transferred to forms that are not useful, but it is never lost or destroyed.</p> <p>Introduce the principle of the conservation of energy. Provide some examples to show how energy can be transferred between stores during events and processes.</p> <p>Set up various demonstrations around the classroom with which learners can interact. Learners identify the energy stores and the events or processes that allow the energy to be transferred. These demonstrations can include: a dynamo, a spring-loaded toy, a pendulum, a cell-powered lamp, a microphone and oscilloscope, a mass on a spring, a tennis ball to be dropped, etc.</p> <p>Set learners qualitative questions for practice. (F)</p> <p>Learners can investigate the conservation of energy further using the Energy Skate Park simulations: (I) https://phet.colorado.edu/en/simulation/energy-skate-park-basics https://phet.colorado.edu/en/simulation/legacy/energy-skate-park</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.7.2.1 Work	Understand that mechanical or electrical work done is equal to the energy transferred	<p>Ask learners if 'work' is done when a bag is carried upstairs. What if the bag is carried along a corridor? What if the bag is dragged along the floor?</p> <p>Introduce work done and clarify the relationship between force and distance. Work is only done when some component of force is applied in the same direction as the distance moved. Work done is the same as energy transferred.</p>
1.7.2.2	Recall and use the equation for mechanical working $W = Fd = \Delta E$	<p>Consider examples of doing work, e.g. when a bag is carried upstairs, chemical energy (of the person carrying the bag) is converted into gravitational potential energy through the process of mechanical working.</p> <p>Introduce the equation and demonstrate simple calculations.</p> <p>Learners investigate the work done by using a force meter to move objects a measured distance: opening a door, lifting an object onto a table, pulling an object along the floor, etc. They then calculate the work done using their measurements of force and distance.</p> <p>Set learners questions for practice. (F)</p>
1.7.1.4 Energy	Recall and use the equation for kinetic energy $E_k = \frac{1}{2}mv^2$	<p>Recap the definition of gravitational potential energy. Ask learners what they think the equation depends on. They may identify mass, height and gravitational field strength as important variables.</p> <p>Derive gravitational potential energy using the definition of work done and weight.</p>
1.7.1.5	Recall and use the equation for the change in gravitational potential energy $\Delta E_p = mg\Delta h$	<p>Set learners simple questions for practice. (F)</p> <p>Learners investigate the gravitational potential energy of various objects by taking measurements of mass and height. (I)</p> <p>Recap the definition of kinetic energy. Ask learners what they think the equation depends on. They may identify mass and velocity as important variables.</p> <p>Introduce the equation and demonstrate a calculation to highlight the mistakes that learners often make with the $\frac{1}{2}$ and the square of the velocity.</p> <p>Highlight how doubling the velocity quadruples the kinetic energy. Relate to learners' understanding of car safety and speed limits.</p> <p>Show learners how the conservation of energy can be used to find the final velocity for a falling object by equating gravitational potential energy and kinetic energy.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Set learners more questions for practice. (F)</p> <p>Learners can use a falling ball to investigate energy transfer and efficiency by measuring initial and rebound heights.</p> <p>Using a curved track, ask learners to consider a marble (or ball bearing) rolling down a track that is shallow and then steep versus a track that is steep and then shallow. Is the kinetic energy at the end the same for both balls? Necessarily, because the initial gravitational potential energy will be the same if they are released from the same height. Is the final velocity the same? Necessarily, because the kinetic energy is the same. Does the ball take the same amount of time to travel down the track in both cases? No, because although the ball reaches the same final velocity in both cases, the one with the steeper track at the beginning will experience a larger acceleration earlier on, therefore having a higher average velocity and a shorter time.</p> <p>Extension: Stretch and prepare for A level</p> <p>Derive kinetic energy using the definition of work done and the equation of motion $v^2 = u^2 + 2as$. Explain the equation of motion first, if learners have not seen it before.</p>
1.7.3.1 Energy resources	<p>Describe how useful energy may be obtained, or electrical power generated, from:</p> <p>(a) chemical energy stored in fossil fuels</p> <p>(b) chemical energy stored in biofuels</p> <p>(c) water, including the energy stored in waves, in tides, and in water behind hydroelectric dams</p> <p>(d) geothermal resources</p> <p>(e) nuclear fuel</p>	<p>Ask learners the difference between renewable and non-renewable energy sources. They may be able to explain this simply. Clarify any misconceptions and see if learners can give any examples for either category.</p> <p>Assign the different energy sources, as listed in the syllabus, to learners such that they work in small groups to carry out research. They can then prepare and present their findings to the rest of the class. Learners should explain how these sources can be used to obtain useful energy and their advantages/disadvantages. Learners mark each other's presentations and handouts. It will be worth recapping the key points when learners finish their presentations.</p> <p>Identify the key energy stores and processes or events in each of the sources to aid understanding.</p> <p>Explain the key elements of an electrical power station, including a boiler, turbine and generator, as they are used with many of the sources.</p> <p>Set learners qualitative questions to consolidate their learning. (F)</p> <p>Learners can investigate simplified energy sources further using the Energy forms and changes simulation: (I) https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_en.html</p> <p>Solar cell animation: https://animagraffs.com/solar-cell-module/</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
1.7.3.2	<p>(f) light from the Sun to generate electrical power (solar cells)</p> <p>(g) infrared and other electromagnetic waves from the Sun to heat water (solar panels) and be the source of wind energy</p> <p>including references to a boiler, turbine and generator where they are used</p> <p>Describe advantages and disadvantages of each method in terms of renewability, availability, reliability, scale and environmental impact</p>	<p>Ask learners what it means for something to be considered 'efficient'. Define efficiency qualitatively and provide examples of efficient and inefficient devices e.g. an incandescent light bulb is very inefficient, with an efficiency as low as 2%, whilst a transformer is very efficient, with an efficiency of more than 95%.</p> <p>Extended assessment: 1.7.3.4, 1.7.3.5 and 1.7.3.6</p> <p>Ask learners to trace the energy obtained from various resources back to their source e.g. water stored behind hydroelectric dams was put there by the precipitation cycle through evaporation thanks to heat from the Sun, chemical energy in biofuels is captured through photosynthesis, etc. Most of these can be linked to the Sun as the main source of energy (exceptions: geothermal, nuclear and tidal).</p> <p>Discuss qualitatively how the Sun releases energy. The process of fusion will be covered in more detail in Topic 5 Nuclear physics.</p> <p>Discuss the current viability of nuclear fusion as the future of electrical energy on a large scale. Learners can research current advances, techniques, advantages and drawbacks. Learners can share their research and debate the value of funding nuclear fusion research versus other renewable energy resource investment.</p>
1.7.3.3	Understand, qualitatively, the concept of efficiency of energy transfer	
1.7.3.4	<p>Know that radiation from the Sun is the main source of energy for all our energy resources except geothermal, nuclear and tidal</p>	

Syllabus ref.	Learning objectives	Suggested teaching activities
1.7.3.5	Know that energy is released by nuclear fusion in the Sun	
1.7.3.6	Know that research is being carried out to investigate how energy released by nuclear fusion can be used to produce electrical energy on a large scale	
1.7.4.1 Power	<p>Define power as work done per unit time and also as energy transferred per unit time; recall and use the equations</p> <p>(a) $P = \frac{W}{t}$</p> <p>(b) $P = \frac{\Delta E}{t}$</p>	<p>Ask learners what it means when a light bulb is labelled as 60W. What is the difference between a 40W light bulb and a 60W light bulb? Learners may explain that this is a power rating, that the W stands for Watts or that it denotes the energy used by the bulb per second.</p> <p>Define power and introduce the equation. Clarify that 1 Watt is equal to 1 Joule per second.</p> <p>Set learners simple questions calculating power, work done and time for practice. (F)</p>
1.7.3.7 Energy resources	<p>Define efficiency as:</p> <p>(a) (%) efficiency = $\frac{\text{(useful energy output)}}{\text{(total energy input)}} \times 100\%$</p> <p>(b) (%) efficiency = $\frac{\text{(useful power output)}}{\text{(total power input)}} \times 100\%$</p> <p>recall and use these equations</p>	<p>Learners investigate their own power through a number of experiments with learners working in pairs or small groups. One option is one learner can do work by lifting masses from the ground to the table and another learner can time how long this takes. They should take measurements of the height travelled by the masses. Another option is one learner can do work by climbing stairs and another learner can time how long this takes. They should take measurements of the height of the stairs climbed by the learner. For both experiments, learners calculate force (weight), work done (force x height travelled) and power.</p> <p>Learners consider what it means for something to be more 'powerful'. They research different cars, planes, etc, and compare their powers. (I)</p> <p>Extended assessment: 1.7.3.7</p> <p>Learners consider what it means for something to be considered 'efficient'. Define efficiency and introduce the equations. Clarify that efficiency calculations can be made using energy, work done or power and that efficiency is written as a percentage.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Learners investigate the efficiency of a kettle. They measure the mass of water added to the kettle, the time that they have it switched on for and the temperature change of the water. There is no need to boil the water. Learners calculate the input energy by using the power rating on the kettle and the time measured. Learners then use the specific heat capacity of water to calculate the energy the water gains from its temperature rise ($E=mc\Delta\theta$), which is the useful energy output. They then calculate the efficiency of the kettle and consider any sources of error in the experiment.</p> <p>Set learners more questions on work done, power and efficiency for practice. (F)</p> <p>Learners investigate the efficiency of other common household items by considering the energy transfers. (I)</p> <p>Extension: Stretch and prepare for A level Derive $P = Fv$ and link to understanding of $P=W/t$, $F=ma$ and $v=s/t$.</p>
1.8.1 Pressure	Define pressure as force per unit area; recall and use the equation $p = \frac{F}{A}$	Introduce the concept of pressure through a simple experiment all learners can carry out. They will each need a drawing pin and a 100g mass. They place the drawing pin in the centre of their palm, point up. Placing the mass on top of the point, they should feel the force of the mass pressing into their palm. Now they flip the pin over and repeat the process. Cupping their palm will allow learners to balance the mass and gradually increase the amount of force on the pin point. Note: They should stop if it begins to hurt. This simple demonstration involves the same amount of force, but different values of surface area. Can the learners explain this properly?
1.8.2	Describe how pressure varies with force and area in the context of everyday examples	Define pressure and introduce the equation. Learners find their own pressure by using their weight as the force and drawing around their feet on graph paper and counting the centimetre squares to find the surface area.
1.8.3	Describe how pressure beneath the surface of a liquid changes with depth and density of the liquid	Set learners simple questions for practice. (F) Introduce varied examples of pressure: a camel's feet, a tractor's tyres, a stiletto heel, a bed of nails, etc. Ask learners to explain how varying the force or the surface area affects the resultant pressure.
1.8.4	Recall and use the equation for the change in pressure beneath the surface of a liquid $\Delta p = \rho g \Delta h$	Demonstrating a 'bed of nails' works well using a piece of wood with multiple nails hammered in place such that a balloon can be pressed onto them by another piece of wood. It takes a large amount of force to burst the balloon as the multiple nails have a cumulatively large surface area, reducing the pressure on the balloon. Learners can investigate the comparative pressure of a stiletto heel to a flat shoe by measuring the surface area as previously described or by using a tray of sand to produce an imprint for depth comparison.

Syllabus ref.	Learning objectives	Suggested teaching activities
		<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>Extended assessment: 1.8.4</p> <p>Introduce the equation for hydrostatic pressure and explain its variables.</p> <p>Set learners questions for practice. (F)</p> <p>Learners can investigate pressure further by working with the Under Pressure simulations: (I) https://phet.colorado.edu/en/simulation/under-pressure https://phet.colorado.edu/en/simulation/legacy/fluid-pressure-and-flow</p> <p>Extension: Stretch and prepare for A level</p> <p>Derive the equation for hydrostatic pressure 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>Learners can feel how a mass on a string will feel lighter when placed into water. 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. Link this to the idea of an object feeling a pressure difference on its top and bottom surfaces.</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 conical flask with a fire starter, a heated can implodes when cooled suddenly, Magdeburg hemispheres support significant force, etc. These all help learners to understand the presence and strength of air pressure around us.</p> <p>Introduce the barometer and how it is used to determine atmospheric pressure. Learners can make their own simple barometers and track weather patterns. (I)</p> <p>Resource Plus</p> <p>Carry out the <i>Pressure and the imploding can</i> experiment referring to Teaching Pack for lesson plans and resources.</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

2. Thermal physics

Syllabus ref.	Learning objectives	Suggested teaching activities
2.1.1.1 States of matter	Know the distinguishing properties of solids, liquids and gases	Ask learners to describe the main properties of solids, liquids and gases. Alternatively, split the class into three groups and assign each group a state of matter. Direct the learners to work together in their group to model the behaviour of the states of matter, where each learner acts as a molecule or atom within the material. Each group then performs their demonstration and the other groups guess which state they were trying to represent, before offering improvements or changes to better represent the state.
2.1.1.2	Know the terms for the changes in state between solids, liquids and gases (gas to solid and solid to gas transfers are not required)	Learners match up statements about the different states of matter to the correct state of matter. This can be done on the whiteboard, on the projector screen, using a simple card sort or on a worksheet. Learners investigate the heating curve by starting with ice water and heating it over a Bunsen burner until boiling, taking regular measurements of temperature. Learners plot a temperature-time graph. They may be able to identify the point at which the change of state takes place.
2.1.2.1 Particle model	Describe the particle structure of solids, liquids and gases in terms of the arrangement, separation and motion of the particles, and represent these states using simple particle diagrams	Learners investigate the cooling curve 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 the test tube from the bath and observe the drop of temperature over time as the substance solidifies. Learners plot a temperature–time graph. They may be able to identify the point at which the change of state takes place. Learners need to know the terms for the changes in state between solids, liquids and gases. They can add these to a heating or cooling curve graph or draw them out as arrows between the names of the states. Set learners qualitative questions to test understanding. (F)
2.1.2.2	Describe the relationship between the motion of particles and temperature, including the idea that there is a lowest possible temperature ($-273\text{ }^{\circ}\text{C}$), known as absolute zero, where	Introduce absolute zero and the Kelvin scale. Link to learners' understanding of scalars; temperature is a scalar, so how are there negative values of temperature? Link the idea of absolute zero to the motion of the molecules or atoms within the substance and highlight that at this point the kinetic energy is at its lowest value. Link the degrees Celsius scale to the freezing and boiling points of water. Convert these values into Kelvin. Set learners simple questions to practise conversions. (F)

Syllabus ref.	Learning objectives	Suggested teaching activities
2.1.3.2	<p>the particles have least kinetic energy</p> <p>Convert temperatures between kelvin and degrees Celsius; recall and use the equation $T \text{ (in K)} = \theta \text{ (in } ^\circ\text{C)} + 273$</p>	<p>Learners can investigate changes of state further by using the simulation: (I) https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html</p> <p>Learners can research the hottest and coldest places on our planet and in the universe. (I)</p>
2.1.2.3 Particle model	Describe the pressure and the changes in pressure of a gas in terms of the motion of its particles and their collisions with a surface	<p>Ask learners to recap the main properties of solids, liquids and gases. Ask learners explain how pressure can be described in terms of the motion of the particles in gas and the collisions with a surface.</p> <p>Learners investigate the random motion of microscopic particles in a suspension. This can be done by trapping smoke from burning paper in a smoke cell and placing it under a microscope. This provides evidence for the kinetic particle model of matter and is sometimes known as Brownian motion. It can also be shown using polystyrene spheres in deionised water: https://www.stem.org.uk/resources/elibrary/resource/28836/brownian-motion.</p>
2.1.2.4	Know that the random motion of microscopic particles in a suspension is evidence for the kinetic particle model of matter	<p>Make use of simulations to show the arrangement and motion of the molecules or atoms in the different states of matter: https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html.</p> <p>Extended assessment: 2.1.2.6, 2.1.2.7 and 2.1.2.8</p> <p>Return to the properties of solids, liquids and gases and ask learners to explain how the forces and distances between the particles are important.</p>
2.1.2.5	Describe and explain this motion (sometimes known as Brownian motion) in terms of random collisions between the microscopic particles in a suspension and the particles of a gas or liquid	<p>Remind learners of the definition of pressure as force per unit area and ask them to describe the changes in pressure of a gas in terms of the forces exerted by particles colliding with surfaces.</p> <p>Reiterate that what is observed in Brownian motion are microscopic particles, not atoms or molecules. These microscopic particles may be moved by collisions with light fast-moving molecules (or atoms). As much larger objects, we are also continually bombarded by light fast-moving molecules (or atoms) but over such a large area these forces are negligible.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
2.1.2.6	Know that the forces and distances between particles (atoms, molecules, ions and electrons) and the motion of the particles affects the properties of solids, liquids and gases	
2.1.2.7	Describe the pressure and the changes in pressure of a gas in terms of the forces exerted by particles colliding with surfaces, creating force per unit area	
2.1.2.8	Know that microscopic particles may be moved by collisions with light fast-moving molecules and correctly use the terms atoms or molecules as distinct from microscopic particles	
2.2.1.1 Thermal expansion of solids, liquids and gases	Describe, qualitatively, the thermal expansion of solids, liquids and gases at constant pressure	Ask learners what they think will happen to the molecules or atoms inside a substance when the substance is heated. They may suggest it changes state or that the molecules or atoms move around more. Direct the learners to consider how the increasing kinetic energy of the molecules or atoms results in them spreading out and taking up more room. Alternatively, introduce this idea by asking learners to arrange themselves as if they were the molecules or atoms inside a solid. Direct them to move as if the solid was being heated. They may need some discussion time as a group to plan this. Without much instruction, it is likely that learners will move around more and begin to take up more space than previously.
2.2.1.2	Describe some of the everyday applications	

Syllabus ref.	Learning objectives	Suggested teaching activities
2.2.1.3	<p>and consequences of thermal expansion</p> <p>Explain, in terms of the motion and arrangement of particles, the relative order of magnitudes of the expansion of solids, liquids and gases as their temperatures rise</p>	<p>Learners investigate the expansion of a gas using a small conical flask and a beaker of water. Learners should upend the beaker so that the mouth is just submerged in the water in the beaker. One learner can wrap their hands around the conical flask so that the heat from their hands begins to warm the air inside the flask. With some patience, they can observe that the meniscus will begin to move down and bulge outwards into the water. A bubble of air may even escape. This is due to the expansion of the air inside of the flask.</p> <p>Learners investigate the expansion of a liquid using a flask filled with coloured water with a long thin glass tube coming out of a bung seal. If the flask is full of coloured water at room temperature and is placed inside a container such that it can be surrounded by boiling water, the thermal energy from the boiling water will cause the liquid in the flask to expand up and out of the long thin glass tube. Coloured water is used so that it is more visible. Learners may make the link to thermometers, as they work using the same principle.</p> <p>Learners investigate the expansion of a solid using a ball-and-ring setup. The ball should fit through the ring initially, but when heated it expands and no longer fits. Ask learners how to get the ball inside the ring again. They may suggest cooling it or they may suggest heating the ring. This is a good demonstration of how solids expand but it is not noticeable to our eyes. www.physics.purdue.edu/demos/display_page.php?item=3A-02</p> <p>Learners investigate the differing rates of expansion of materials through the heating and observation of a bimetallic strip. Learners research its use in thermostats.</p> <p>Learners consider what happens when a material is cooled. They should conclude that the process works in reverse and the material may shrink or contract.</p> <p>Set learners qualitative questions to test understanding. (F)</p> <p>Learners investigate various applications where the expansion of materials has been considered in the design process: leaving gaps between paving slabs to avoid cracking in heat, providing loops in hot water pipes to allow expansion, allowing slack in telephone wires in case of cooling and contraction in winter, etc. (I)</p> <p>Extended assessment: 2.2.1.3</p> <p>Learners consider the demonstrations of expansion they have seen and explain the relative order of magnitude of the expansion of solids, liquids and gases as their temperatures rise. Ask learners to link their understanding of the motion and arrangement of particles to this order of magnitude. Learners consider that gases can experience the most expansion due to having the weakest bonds between their particles.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
2.1.3.1 Gases and the absolute scale of temperature	Describe qualitatively, in terms of particles, the effect on the pressure of a fixed mass of gas of: (a) a change of temperature at constant volume (b) a change of volume at constant temperature	Ask learners to consider how increasing the temperature of a gas might affect its pressure, assuming the mass and volume are kept constant. Learners may explain that increasing the temperature will increase the kinetic energy of the molecules or atoms in the gas, thereby leading to an increased number of collisions between them and the container walls. This increased force leads to an increased pressure. Recap the definition of pressure as force per unit area. This is important for understanding how temperature (and volume) affects pressure. Learners qualitatively investigate the relationship between temperature and pressure using a sealed conical flask with a thermometer and pressure gauge attached to its bung. By placing the flask in different-temperature water baths, there should be a noticeable change in pressure. Volume and mass are kept constant. Learners consider how different materials will produce different pressure–temperature graphs, but they will all pass through the same point on the x-axis. Relate this to learners' understanding of absolute zero.
2.1.1.3	Recall and use the equation $pV = \text{constant}$ for a fixed mass of gas at constant temperature, including a graphical representation of the relationship	Ask learners to consider how decreasing the volume of a gas might affect its pressure, assuming the mass and temperature are kept constant. Learners may explain that decreasing the volume will increase the pressure, as there will be an increased number of collisions between the molecules or atoms and the container walls. This increased force leads to an increased pressure. Learners investigate the relationship between volume and pressure qualitatively with a plastic syringe. If the end is sealed or blocked with a finger, it becomes increasingly difficult to press the plunger as the volume decreases. Learners investigate the relationship between temperature and pressure using simulations. (I) Set learners qualitative questions to test understanding. (F) Extended assessment: 2.1.3.3 Learners investigate the relationship between volume and pressure using Boyle's Law apparatus. A column of air is compressed, its pressure can be measured on a gauge and the volume read from the scale on the tube. Learners plot a graph of pressure and 1/volume (or volume and 1/pressure) to show the inverse proportionality. Introduce the equation that links pressure and volume. Demonstrate how to use the equation. Learners investigate the relationship between volume and pressure further using simulations. Learners can collect results and plot a graph to prove the relationship. (I) Set learners more qualitative, as well as quantitative, questions to test understanding. (F)

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Simulations: https://phet.colorado.edu/en/simulation/gases-intro https://phet.colorado.edu/en/simulation/gas-properties https://phet.colorado.edu/en/simulation/states-of-matter</p> <p>Extension: Stretch and prepare for A level Ask learners to consider how increasing the temperature of a gas might affect its volume, assuming the mass and pressure are kept constant. Learners may explain that increasing the temperature will increase the volume, as there will be an increase in the kinetic energy of the particles. If the pressure is kept constant, the container must expand to keep the number of collisions with its walls constant.</p> <p>Introduce the ideal gas law, expressed in terms of the number of molecules and introduce the Boltzmann constant.</p> <p>Set learners simple questions for practice. (F)</p>
2.2.2.1 Specific heat capacity	Know that a rise in the temperature of an object increases its internal energy	<p>Ask what happens to the particles inside of an object when the temperature of the object is increased. They may recall that expansion occurs and link this to the idea of kinetic energy increasing, which is internal energy.</p> <p>Extended assessment: 2.2.2.2, 2.2.2.3 and 2.2.2.4</p>
2.2.2.2	Describe an increase in temperature of an object in terms of an increase in the average kinetic energies of all of the particles in the object	<p>Expand on the concept of the increasing kinetic energy of an object. An increase in temperature links to an increase in the average kinetic energies of all of the particles in the object.</p> <p>Ask learners why water is used in a hot water bottle. There are lots of good and sensible answers to this question but steer the discussion towards the idea that water is very good at holding its temperature.</p> <p>Ask learners why the sand at the beach feels hotter than the water of the sea. They will suggest all sorts of reasons, but steer the discussion towards the idea that although the land and the sea receive the same energy from the Sun, the land heats up quicker.</p>
2.2.2.3	Define specific heat capacity as the energy required per unit mass per unit temperature increase; recall and use the equation $c = \frac{\Delta E}{m\Delta\theta}$	<p>Define specific heat capacity and introduce the equation. Link to previous examples and highlight that water has a very high specific heat capacity.</p> <p>Learners investigate different metals and compare their properties by plotting multiple sets of results on the same graph axes. Learners can plan the experiment themselves considering the equation for specific heat capacity. Ask learners what they need to measure and how this can be measured. Demonstrate the circuit they need to build. Learners can</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
2.2.2.4	Describe experiments to measure the specific heat capacity of a solid and of a liquid	<p>either collect results throughout, allowing them to plot a graph, or they can measure the initial and final values and carry out a calculation.</p> <p>Measuring specific heat capacity: www.bbc.co.uk/bitesize/guides/z2gjt4/revision/6</p> <p>Learners investigate the specific heat capacity of water in a similar way to the metal blocks. Learners should remember to stir the water before taking a measurement of temperature. Alternatively, provide learners with the specific heat capacity of water and they find the energy the water gains by measuring the temperature change.</p> <p>Learners write a method for the experiment to measure the specific heat capacity of a solid and of a liquid, clarifying the differences in investigating the two states of matter.</p> <p>Learners investigate the varied uses of water and its high specific heat capacity: it is commonly used as a coolant in power plants, it is essential in regulating the temperature of our planet, etc.</p> <p>Learners investigate how the specific heat capacity affects the efficiency of processes e.g. a copper cooking pot will waste less energy in cooking due to its low specific heat capacity.</p> <p>Set learners quantitative and qualitative questions to test understanding. (F)</p> <p>Extension: Stretch and prepare for A level Return to the concept of internal energy and define it. Learners can consider the factors that affect the internal energy.</p>
2.2.3.1 Melting, boiling and evaporation	Describe melting and boiling in terms of energy input without a change in temperature	Return to the cooling curve (or heating curve) covered previously. Ask learners to identify when the changes of state happen. Ask learners to identify the different states shown on the graph. Explain that throughout the experiment, energy is being provided or is being lost. What is happening to the molecules or atoms when the temperature is rising? Learners may explain that a rise in temperature increases the kinetic energy of the molecules or atoms in the object. Clarify that melting, solidification, boiling and condensation can be achieved without a change in temperature. This is difficult to reproduce in the laboratory. Show clear graphs to highlight these changes of state.
2.2.3.2	Know the melting and boiling temperatures for water at standard atmospheric pressure	Show the heating curve for water. At what temperature does ice melt and water boil? How do these values change at different altitudes? Learners may be able to explain that when climbing a mountain there is lower atmospheric pressure and this means that water boils at a lower temperature. Learners could watch the BBC Earth Lab (boiling water on Everest) video clip showing this effect: https://www.youtube.com/watch?v=8lyqFkFsH28
2.2.3.3	Describe condensation and solidification in terms of particles	

Syllabus ref.	Learning objectives	Suggested teaching activities
2.2.3.4	Describe evaporation in terms of the escape of more energetic molecules from the surface of a liquid	Ask learners what happens to a glass water when left out over several days. They may identify that the water evaporates. How can the water evaporate when there is no heat source to increase the temperature? Learners can explain that the molecules that escape from the surface are more energetic.
2.2.3.5	Know that evaporation causes cooling of a liquid	Ask learners how evaporation affects the temperature of an object. They may recall feeling cold when wet from the rain or after getting out of a swimming pool. They may explain that the evaporation of water from their skin cools them down. This same process causes liquids to cool as evaporation of the most energetic molecules at the surface occurs. Set learners qualitative questions to test understanding. (F)
2.2.3.6	Describe the differences between boiling and evaporation	Learners investigate states of matter further using simulations: (I) https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html https://phet.colorado.edu/en/simulation/states-of-matter
2.2.3.7	Describe how temperature, surface area and air movement over a surface affect evaporation	Extended assessment: 2.2.3.6, 2.2.3.7 and 2.2.3.8 Return to the idea of evaporation causing cooling. Learners can explain how this happens. Ask learners to identify the differences between evaporation and boiling. Learners investigate evaporation. This can be done in the laboratory or as a homework task. In the laboratory learners work in pairs, each pair starting with a known mass and temperature of water. Challenge them to evaporate as much of it as possible in a set time or give them different variables to investigate. Learners should note that the liquid cools as the more-energetic molecules escape from the surface of the liquid. At home, learners can set up various containers of the same mass and temperature of water and place them in varied positions. Learners should vary the size of the container and the location in terms of air movement and temperature. In both versions of the experiment, learners investigate how temperature, surface area and air movement affect evaporation. They should be able to come to their own conclusions and be able to explain that evaporation occurs when the more-energetic molecules or atoms escape from the surface of the liquid. (I)
2.2.3.8	Explain the cooling of an object in contact with an evaporating liquid	Extension: Stretch and prepare for A level Return to the cooling curve (or heating curve) and ask learners what happens to the energy when it does not produce a temperature rise. Learners may explain that this is required to change the state of the substance. Explain how this hidden, or 'latent', heat is required to make or break the molecular bonds between the molecules or atoms. Define latent heat as the energy required to change the state of a substance and explain it in terms of particle behaviour and the forces between particles. Introduce the equation for specific latent heat. Set learners simple questions for practice. (F)

Syllabus ref.	Learning objectives	Suggested teaching activities
2.3.1.1 Conduction	Describe experiments to demonstrate the properties of good thermal conductors and bad thermal conductors (insulators)	Learners investigate conduction using rods made of different materials: glass, aluminium, copper, iron, brass, etc. Learners place one end in the roaring flame of a Bunsen burner while they hold the other end. Learners should place their rod carefully on a heat mat once they feel the warmth reach their hand. This will give (a rather subjective) introduction to the concept of materials being better or worse at conducting.
2.3.1.2	Describe thermal conduction in all solids in terms of atomic or molecular lattice vibrations and also in terms of the movement of free (delocalised) electrons in metallic conductors	<div data-bbox="672 391 2016 486" style="border: 1px solid black; padding: 5px;"> <p>Resource Plus Carry out the <i>Heat conduction in metal rods</i> experiment referring to Teaching Pack for lesson plans and resources.</p> </div> <p>Extended assessment: 2.3.1.2, 2.3.1.3 and 2.3.1.4</p> <p>A wooden rod attached to a metal rod tightly wrapped in paper and held over a Bunsen burner flame will scorch on the wooden half but not the metal half. Ask learners to explain why this occurs. They may be able to explain that the metal half conducts the heat energy away, 'protecting' the paper, but the wood and the paper are both insulators.</p> <p>An ice cube left on a metal plate will quickly melt, but an ice cube left on a plastic plate will stay solid for much longer. Ask learners to explain why this occurs. They may be able to explain that the metal conducts heat from the surroundings to the ice cube, but the plastic is an insulator.</p>
2.3.1.3	Describe, in terms of particles, why thermal conduction is bad in gases and most liquids	Place a small ice cube inside a test tube and hold in place with a small piece of metal gauze. The test tube should be filled with water and held at an angle above a Bunsen burner's roaring flame such that the top is directly heated, but the bottom is not. It is possible to have the top part of the water boiling while the ice in the bottom remains frozen, demonstrating that water is a poor conductor.
2.3.1.4	Know that there are many solids that conduct thermal energy better than thermal insulators but do so less well than good thermal conductors	<p>An analogy can be used to explain why metals are generally much better conductors than other materials. Direct the learners to stand shoulder-to-shoulder facing the same direction, such that they represent a row of molecules or atoms in a solid. When one end of the row is 'heated', the learner on the end will vibrate on the spot and bump into their neighbour, who then bumps into <u>their</u> neighbour, passing the 'energy' down the row. Use one learner and a ball to demonstrate that the delocalised electrons in a metal speed up this process of passing on energy. Throw the ball to the learner at the end of the row, while the row transfers the 'energy' through bumping their neighbours. The ball should easily win the race, confirming that delocalised electrons speed up conduction.</p> <p>Learners consider examples of materials being the same temperature as their surroundings but feeling colder e.g. a steel bench versus a wooden bench. Explain that metals conduct our heat energy away from us, giving us the sensation of coldness.</p> <p>Learners investigate uses of conductors and insulators e.g. saucepans are made from metal but their handles are made from plastic or wood.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Learners order the states of matter from best conductor to worst conductor. Reiterate that gases do not conduct well due to the large spacing of their molecules or atoms.</p> <p>Set learners qualitative questions to test understanding. (F)</p>
<p>2.3.2.1 Convection</p> <p>2.3.2.2</p>	<p>Know that convection is an important method of thermal energy transfer in liquids and gases</p> <p>Explain convection in liquids and gases in terms of density changes and describe experiments to illustrate convection</p>	<p>Ask learners how a convection heater is able to heat the whole room. Link suggestions to their understanding of expansion and density.</p> <p>Learners observe a convection current in a convection tube. A Bunsen burner heats the water in one of the bottom corners and the potassium permanganate that colours the water can be seen to move around in a loop.</p> <p>Resource Plus Carry out the <i>Convection currents</i> experiment referring to Teaching Pack for lesson plans and resources.</p> <p>Learners observe convection using a glass-fronted box with two chimneys. Placing a lit candle below one of the chimneys produces an upward draft of warm air heated by the candle. Placing a source of smoke, such as a burning straw, above the second chimney will allow learners to see how the second chimney draws in air before it is heated by the candle and rises out of the chimney above.</p> <p>Convection (including convection tube and double chimney glass-fronted box) : www.schoolphysics.co.uk/age11-14/Heat%20energy/Transfer%20of%20heat%20energy/text/Convection_/index.html</p> <p>Learners can observe convection when two containers of coloured water are brought together and are allowed to mix. One container should be full of hot water and one should be full of cool or room temperature water. If the hot water is placed on top, it remains on top and takes a long time to mix with the cool water. If the hot water is placed underneath, it very quickly moves upwards and mixes with the cool water. www.stevespanglerscience.com/lab/experiments/colorful-convection-currents/</p> <p>Learners investigate convection by cutting a cardboard circle into a spiral and hanging it from a clamp stand above a candle. When the candle is lit, it heats the air above it, which rises and causes the spiral to spin. www.monstersciences.com/energy/energy-science-experiment-heat-spirals/</p> <p>Learners investigate some real-life applications of convection currents: sea and land breezes, a house's hot water system, fires used in tin mines to ventilate the shafts, hot air balloons, etc. (I)</p> <p>Set learners qualitative questions to test understanding. Ensure learners understand why convection cannot take place in solids. (F)</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
2.3.3.1 Radiation	Know that thermal radiation is infrared radiation and that all objects emit this radiation	Introduce radiation as the third and final type of thermal energy transfer and clarify that this type of radiation is unrelated to radioactivity. Highlight that it does not require a medium to travel; the Sun heats the Earth through the vacuum of space.
2.3.3.2	Know that thermal energy transfer by thermal radiation does not require a medium	Learners observe radiation from different surfaces using Leslie's cube. They judge the relative temperatures of the surfaces by placing their hand 1cm away from the surface. They should not touch the surface. They use a thermometer to measure the temperature of the water inside, and an infrared thermometer to measure the surface temperatures. Learners draw conclusions as to which surfaces radiate thermal energy best.
2.3.3.3	Describe the effect of surface colour (black or white) and texture (dull or shiny) on the emission, absorption and reflection of infrared radiation	Use an infrared camera to observe various objects in the room as well as the learners themselves, and/or find images online. Learners may link these images to the idea of night vision equipment used by the military and often depicted in action movies. Extended assessment: 2.3.3.4, 2.3.3.5, 2.3.3.6, 2.3.3.7, 2.3.3.8 and 2.3.3.9
2.3.3.4	Know that for an object to be at a constant temperature it needs to transfer energy away from the object at the same rate that it receives energy	Learners investigate radiation using identical test tubes or metal containers painted black and white. The black surface should absorb radiation better than the white, producing a noticeable temperature increase over time. Learners investigate how the surface temperature and the surface area affect the quantity of radiation emitted.
2.3.3.5	Know what happens to an object if the rate at which it receives energy is less or more than the rate at which it transfers energy away from the object	Learners write their own methods on how to investigate radiation. Learners consider how the surface temperature and surface area of an object affects the rate of emission of radiation. Learners consider how radiation leads to cooling. If the rate at which it transfers energy away is more than the rate at which it receives energy, it will cool. Learners consider the opposite effect e.g. how food is cooked under an oven grill or in a toaster. Learners research and explain how the temperature of the Earth is affected by factors controlling the balance between incoming radiation and radiation emitted from the Earth's surface. (I) Learners research how a star's surface temperature and surface area affects the quantity of radiation received by orbiting planets. (I) Set learners qualitative questions to test understanding. (F)
2.3.3.6	Know how the temperature of the Earth is affected by	Radiation: www.bbc.co.uk/bitesize/guides/ztttd2p/revision/3

Syllabus ref.	Learning objectives	Suggested teaching activities
2.3.3.7	factors controlling the balance between incoming radiation and radiation emitted from the Earth's surface Describe experiments to distinguish between good and bad emitters of infrared radiation	
2.3.3.8	Describe experiments to distinguish between good and bad absorbers of infrared radiation	
2.3.3.9	Describe how the rate of emission of radiation depends on the surface temperature and surface area of an object	
2.3.4.1 Consequences of thermal energy transfer	Explain some of the basic everyday applications and consequences of conduction, convection and radiation, including: (a) heating objects such as kitchen pans (b) heating a room by convection	Recap concepts introduced in previous lessons to improve understanding of heating objects such as kitchen pans (conduction) and heating a room (convection). Learners feel the warming effect of having their own body heat reflected back to them by using a space blanket (also known as emergency or survival blankets). Learners investigate their properties and how the blankets were designed and used by NASA. Learners investigate methods of insulation. They insulate identical test tubes in a variety of ways, as well as having a control, and place freshly boiled water inside the tubes. They should measure the initial temperature of the water and the final temperature after a set time. Learners draw conclusions as to which materials and methods produce the best insulation. Learners research and investigate the elements of a vacuum flask that make it such an efficient insulator of heat. (I)

Syllabus ref.	Learning objectives	Suggested teaching activities
2.3.4.2	<p>Explain some of the complex applications and consequences of conduction, convection and radiation where more than one type of thermal energy transfer is significant, including:</p> <p>(a) a fire burning wood or coal</p> <p>(b) a radiator in a car</p>	<p>Learners research the methods used to insulate homes: cavity wall insulation, double glazed windows, loft insulation, etc. (I)</p> <p>Learners research other examples of using our understanding of heat transfer methods for insulation: reflective fireman suits, ironing boards covered in silver material, layered clothing for warmth, etc. (I)</p> <p>Set learners qualitative questions to test understanding. (F)</p> <p>Extended assessment: 2.3.4.2</p> <p>Learners research and explain examples where more than one type of thermal energy transfer is significant, such as a fire burning wood or coal and a radiator in a car. Learners identify the types of thermal energy transfer present and how they contribute to cooling/heating.</p>

Past and specimen papers

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

3. Waves

Syllabus ref.	Learning objectives	Suggested teaching activities
3.1.1 General properties of wave	Know that waves transfer energy without transferring matter	Ask learners to name as many waves as they can. They may suggest light, sound, ocean waves, some types of electromagnetic waves, etc. Add them as a list or mind map to the board.
3.1.2	Describe what is meant by wave motion as illustrated by vibrations in ropes and springs, and by experiments using water waves	<p>Introduce the concept that waves transfer energy without transferring matter. A good example of this is a ripple on a pond or a wave on the open ocean. These water waves can cause boats or ducks to bob up and down, but they do not transport them to shore. Clarify that ocean waves come in and out of shore due to tides and rear up due to the reducing depth.</p> <p>Learners investigate water waves, individually or in pairs, with the use of trays of water and rulers. They dip a ruler in the water at one end to produce straight wavefronts that travel down the length of the tray.</p> <p>Introduce the categories of transverse and longitudinal waves. Sort the waves learners previously named into the two categories. Clarify the relationship between the direction of vibration and the direction of the energy transfer for both.</p>
3.1.3	Describe the features of a wave in terms of wavefront, wavelength, frequency, crest (peak), trough, amplitude and wave speed	<p>Direct learners to model a wave by working together to make a 'Mexican wave'. They stand shoulder-to-shoulder facing the same direction and create a delayed and repeated motion down the line to produce a motion similar to a transverse wave. Learners try increasing the wavespeed, amplitude and wave speed of a wave pulse.</p> <p>Define wavelength, frequency, amplitude and wavespeed. Use the waves introduction simulation to aid these explanations: https://phet.colorado.edu/en/simulation/waves-intro</p>
3.1.4	Recall and use the equation $v = f \lambda$	Label the wavefront, crest and trough on appropriate diagrams of waves. Label wavelength and amplitude on appropriate diagrams of a waveform.
3.1.5	Know that for a transverse wave, the direction of vibration is at right-angles to the direction of the propagation and understand that electromagnetic radiation, water waves	<p>Introduce the wave equation and demonstrate how it is used.</p> <p>Set learners simple questions for practice. (F)</p> <p>Learners investigate waves further using the waves simulation: (I) https://phet.colorado.edu/en/simulation/wave-on-a-string</p> <p>Resource Plus</p> <p>Carry out the <i>Demonstrating wave phenomena</i> experiment referring to Teaching Pack for lesson plans and resources.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
3.1.6	<p>and seismic S-waves (secondary) can be modelled as transverse</p> <p>Know that for a longitudinal wave, the direction of vibration is parallel to the direction of the propagation and understand that sound waves and seismic P-waves (primary) can be modelled as longitudinal</p>	<p>Learners carry out the waves in springs part of the teaching pack (Worksheet E).</p> <p>Demonstrate the difference between seismic P-waves and S-waves by using multiple springs (or slinkies). Seismic waves in slinkies: www.earthlearningidea.com/PDF/304_Slinky_seismic_waves.pdf www.burkemuseum.org/static/earthquakes/cur-act-slinkies.pdf</p> <p>Learners can research how earthquakes and seismic waves are produced. They may enjoy looking at the <i>Earthquake Track</i> website: (I) https://earthquaketrack.com</p> <p>Extension: Stretch and prepare for A level Learners investigate what happens when two waves meet in a spring (or slinky). Two waves travelling towards each other do not reflect off each other, like two balls would bounce off each other. Introduce the idea of superposition of waves and how they can lead to constructive and destructive interference.</p>
3.1.7 General properties of wave 3.1.8	<p>Describe how waves can undergo:</p> <p>(a) reflection at a plane surface (b) refraction due to a change of speed (c) diffraction through a narrow gap</p> <p>Describe the use of a ripple tank to show:</p> <p>(a) reflection at a plane surface (b) refraction due to a change in speed caused by a change in depth (c) diffraction due to a gap (d) diffraction due to an edge</p>	<p>Introduce the phenomena of reflection, refraction and diffraction using a ripple tank. Reflection can be shown at different angles using a barrier. Refraction can be tricky to demonstrate clearly; it requires a shallower/deeper region of water. You could use a simulation to help clarify.</p> <p>Set learners qualitative questions for practice. (F)</p> <p>Show learners different diagrams depicting reflection, refraction or diffraction and ask learners to identify which case is shown. They could use miniature whiteboards for their answers. (F)</p> <p>Learners investigate these phenomena further using the ripple tank simulation: (I) http://falstad.com/ripple/</p> <p>Resource Plus</p> <p>Carry out the <i>Demonstrating wave phenomena</i> experiment referring to Teaching Pack for lesson plans and resources.</p> <p>Learners carry out the waves in ripple tank part of the teaching pack (Worksheet G).</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
3.1.9	Describe how wavelength and gap size affects diffraction through a gap	Extended assessment: 3.1.9 and 3.1.10 Learners identify that diffraction through different-sized gaps will show different amounts of spreading and can cause the wavefront to become more or less curved. The size of wavelength also affects the diffraction through a gap, as well as at an edge.
3.1.10	Describe how wavelength affects diffraction at an edge	Set learners more qualitative questions which involve sketching diffraction patterns for practice. (F) Extension: Stretch and prepare for A level Demonstrate the diffraction of white light. Ask learners to explain why this produces rainbows. Have they got any idea as to why it produces patches of darkness?
3.2.1.1 Reflection of light	Define and use the terms normal, angle of incidence and angle of reflection	Learners set up the experiment to investigate the law of reflection. Resource Plus Carry out the <i>Demonstrating wave phenomena</i> experiment referring to Teaching Pack for lesson plans and resources.
3.2.1.2	Describe the formation of an optical image by a plane mirror, and give its characteristics, i.e. same size, same distance from mirror, virtual	Learners carry out the reflection part of the teaching pack (Worksheet F). Introduce the law of reflection. Link to the results learners found with measuring the angles of incidence and reflection for a light ray reflecting from a plane mirror. Ask learners what they notice when they look at their reflection in a plane mirror. They can act as a mirror to a volunteer as they raise their arms up and down or move from side to side in front of them. They may highlight that the left- and right-hand sides are flipped. Identify the characteristics of an optical image formed by a plane mirror (same size, same distance from mirror as object and virtual). Learners may need an explanation of real images and virtual images. It may help to explain briefly how both are formed. This will be explained in more depth in the section on lenses.
3.2.1.3	State that for reflection, the angle of incidence is equal to the angle of reflection; recall and use this relationship	Image characteristics: www.physicsclassroom.com/class/refln/Lesson-2/Image-Characteristics
3.2.1.4	Use simple constructions, measurements and calculations for	Images formed by plane mirrors: https://opentextbc.ca/universityphysicsv3openstax/chapter/images-formed-by-plane-mirrors/ Show learners a simple image reflected in a mirror but with small errors: the image might be upside down when it should be upright, the image might not be laterally inverted, etc. Learners identify the error in each example, using miniature whiteboards. (F)

Syllabus ref.	Learning objectives	Suggested teaching activities
	reflection by plane mirrors	<p>Set learners qualitative questions for practice. (F)</p> <p>Learners investigate uses of reflection: the periscope, 'Pepper's ghost', etc. They could make their own simple periscope using mirrors and cardboard, or 'Pepper's ghost' using clear plastic, a filament lamp, a cardboard box and spare cardboard. (I)</p> <p>Extended assessment: 3.2.1.4</p> <p>Learners use the law of reflection to determine the final destination of a light ray on a sheet of paper as it reflects off a variety of plane mirrors. They practise their accuracy with using a protractor and drawing ray diagrams. (F)</p> <p>Give learners a simple image and ask them to draw how it would appear as an image in a plane mirror. (F)</p> <p>Learners carry out an experiment to find position and characteristics of an optical image formed by a plane mirror using optical pins. Investigating the position of an image in a plane mirror: www.bbc.co.uk/bitesize/guides/znksd6f/revision/3</p>
3.2.2.1 Refraction of light	Define and use the terms normal, angle of incidence and angle of refraction	<p>Introduce refraction with a few simple experiments. Learners observe a pencil placed in a beaker of water. How does the pencil appear from different positions of observation? They use a rectangular Perspex (or glass) block to look at a piece of text. How does the image change when viewed from different angles and through the different edges? Learners place a coin in an opaque cup and move so it is just out of view. Adding water to the cup slowly should make the coin visible. Can learners explain how this happens? All of these are examples of refraction.</p>
3.2.2.2	Describe an experiment to show refraction of light through transparent blocks of different shapes	<p>Coin in cup demonstration: www.lovemyscience.com/risingcoin.html</p> <p>Direct learners to investigate refraction using a Perspex (or glass) block and a ray box set-up:</p>
3.2.2.3	Describe the passage of light through a transparent material (limited to the boundaries between two media only)	<p>Resource Plus</p> <p>Carry out the <i>Demonstrating wave phenomena</i> experiment referring to Teaching Pack for lesson plans and resources.</p> <p>Learners carry out the refraction part of the teaching pack (Worksheet F).</p> <p>Learners identify the normal, angle of incidence and angle of refraction on a diagram of refraction and define each term. Learners label their own diagram of refraction and write their own method for the experiment.</p>
3.2.2.4	State the meaning of critical angle	

Syllabus ref.	Learning objectives	Suggested teaching activities
3.2.2.5	Describe internal reflection and total internal reflection using both experimental and everyday examples Define refractive index, n , as the ratio of speeds of a wave in two different regions	<p>Explain that refraction occurs due to the light ray changing speed as it travels through a different material. You could use the analogy of a shopping trolley or a vehicle traveling from smooth ground to muddy ground at an angle to the verge, and how this affects the wheels, to help learners understand why the change of speed causes a change in direction.</p> <p>It may help learners to remember that when a light ray slows down, it bends towards the normal; 'slow' and 'towards' both contain the letter combination 'ow'.</p> <p>Give learners simple combinations of materials for them to decide how the light ray will behave e.g. if the light ray travels from air to diamond, the light ray slows down / speeds up and bends towards/away from the normal. Learners answer the questions by raising their left or right hands for the two options or by using miniature whiteboards. (F)</p>
3.2.2.6	Define refractive index, n , as the ratio of the speeds of a wave in two different regions	<p>Give learners a light ray 'obstacle course' where they estimate the path a light ray takes as it travels through different materials e.g. if it travels from air to helium, it will bend away from the normal, but if it then travels into glass it will bend towards the normal. (F)</p> <p>Learners consider other everyday examples of refraction e.g. a fish will appear in a different location to its actual location due to the refraction of light through water, so a spear fisher should bear this in mind when aiming for the fish.</p>
3.2.2.7	Recall and use the equation $n = \frac{\sin i}{\sin r}$	Learners observe how transparent hydrobeads are visible in air and invisible in water. They share the same refractive index as water which results in their invisibility.
3.2.2.8	Recall and use the equation $n = \frac{1}{\sin c}$	<p>Learners observe the refraction of a laser through a large transparent container of coloured water.</p> <p>Learners can investigate refraction through different-shaped transparent blocks.</p>
3.2.2.9	Describe the use of optical fibres, particularly in telecommunications	<p>Learners investigate refraction through a semi-circular transparent block:</p> <div data-bbox="667 1038 2011 1134" style="border: 1px solid black; padding: 5px;"> <p>Resource Plus Carry out the <i>Measuring refraction and total internal reflection</i> experiment referring to Teaching Pack for lesson plans and resources.</p> </div> <p>Learners carry out the total internal reflection part of the teaching pack (Worksheet E).</p> <p>Recap the critical angle and the cases of refraction and total internal reflection in a semi-circular block using simulations: www.reading.ac.uk/virtualexperiments/ves/tir.html https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html</p> <p>Show learners different diagrams depicting the critical angle, refraction or total internal reflection and ask them to quickly identify which case is shown. They can answer the questions using miniature whiteboards. (F)</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Extended assessment: 3.2.2.6, 3.2.2.7, 3.2.2.8 and 3.2.2.9</p> <p>Learners share their results for the angle of incidence and the angle of refraction. Compile the results on the board.</p> <p>Introduce the refractive index and its equation. Highlight that the refractive index has no unit. Learners substitute their results into the equation to find the refractive index of Perspex (or glass). Learners should find similar values. Highlight that the refractive index is a property of a material and can be used to identify an unknown material. It can also be calculated as the ratio of speeds of a wave in two different regions.</p> <p>Introduce the equation that links the refractive index to the critical angle.</p> <p>Set learners quantitative and qualitative questions for practice. (F)</p> <p>Demonstrate total internal reflection through optical fibres.</p> <p>Learners research uses of total internal reflection, particularly optical fibres used in telecommunications. (I)</p>
3.2.3.1 Thin lenses	Describe the action of thin converging and thin diverging lenses on a parallel beam of light	<p>Introduce lenses through qualitative investigation. Learners view their thumb through a convex lens with a short focal length, using the lens like a magnifying glass. They use the same lens to produce a real image on a piece of paper with their back to a window. They should be able to see a flipped image of the window and its contents if it is a bright day. They may have to move the lens around to find the correct focus.</p> <p>Learners use the same lens to produce a real image on a piece of greaseproof paper facing the window. They should place the greaseproof paper between their eyes and the window, and the lens between the window and the paper. They may have to move the lens around to find the correct focus. Alternatively, instead of a window, learners can use a brightly illuminated object. The laboratory can be darkened and a learner, lit by a spotlight, can sit still as the object.</p> <p>Explain the difference between converging and diverging lens. Demonstrate and/or allow learners to observe both.</p> <p>Introduce ray diagrams for lenses and define the focal length, principle axis and principle focus (or focal point).</p> <p>Demonstrate how to draw ray diagrams for the formation of a real image by a converging lens. Break down the steps so they are clear and simple to follow.</p> <p>Learners draw ray diagrams for objects placed at different distances from the converging lens and focal point. They investigate the location, size, orientation and nature of different distances. (F)</p>
3.2.3.2	Define and use the terms focal length, principal axis and principal focus (focal point)	
3.2.3.3	Draw and use ray diagrams for the formation of a real image by a converging lens	
3.2.3.4	Describe the characteristics of an image using the terms	

Syllabus ref.	Learning objectives	Suggested teaching activities
3.2.3.5	enlarged/same size/diminished, upright/inverted and real/virtual Know that a virtual image is formed when diverging rays are extrapolated backwards and does not form a visible projection on a screen	Explain to learners that a virtual image is formed when diverging rays are extrapolated backwards and it does not form a visible projection on a screen. Extended assessment: 3.2.3.6, 3.2.37. and 3.2.3.8 Demonstrate how to draw ray diagrams for the formation of a virtual image by a converging lens. The steps are the same as for a diverging lens but produce a virtual image. Learners draw ray diagrams for objects placed at different distances from the diverging lens and focal point. They investigate the location, size, orientation and nature of different distances. (F) Learners can research uses and examples of lenses: projector, photocopier, camera, spotlight, etc. Direct learners to draw the ray diagram to show how an image is formed in a magnifying glass, camera and projector.
3.2.3.6	Draw ray diagrams for the formation of a virtual image by a converging lens	Relate the idea of a glass lens to the tissue lens inside the human eye. Lenses and the human eye: https://www.cyberphysics.co.uk/topics/medical/Eye/eye_ad.html
3.2.3.7	Describe the use of a single lens as a magnifying glass	Animation of a how a human eye works: https://animagraffs.com/human-eye/
3.2.3.8	Describe the use of converging and diverging lenses to correct long-sightedness and short-sightedness	Direct learners to draw ray diagrams showing a short-sighted eye and a long-sighted eye. Introduce the concept of using lenses to correct long-sightedness and short-sightedness. Direct learners to draw ray diagrams showing the correction of a short-sighted eye and a long-sighted eye using lenses. Set learners quantitative and qualitative questions for practice. (F) Lenses: www.bbc.co.uk/bitesize/guides/zt42srd/revision/2
3.2.4.1 Dispersion of light	Describe the dispersion of light as illustrated by the refraction of white light by a glass prism	Ask learners what colours can be found in white light. Learners may identify the seven colours of the rainbow. Set learners the challenge of 'finding a rainbow' using a ray box set-up and a prism. Direct learners to now use their prism to identify the different colours visible by the refraction of white light.

Syllabus ref.	Learning objectives	Suggested teaching activities
3.2.4.2	Know the traditional seven colours of the visible spectrum in order of frequency and in order of wavelength	<p>Explain that the order of the colours is related to the order of the frequency (or the wavelength).</p> <p>Set learners qualitative questions for practice. (F)</p> <p>Learners investigate dispersion of light further using the prism bending light simulation: (I) https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html</p>
3.2.4.3	Recall that visible light of a single frequency is described as monochromatic	<p>Learners can make their own Newton's disc (or colour wheel) to demonstrate the mixing of colours to make white light or the mixing of primary colours to make secondary colours: www.royalacademy.org.uk/article/family-how-to-make-a-colour-wheel-1</p> <p>Learners research how rain droplets refract and reflect light to produce the spectrum of colour in a rainbow. (I)</p> <p>You could use the <i>Roy G Biv</i> song by <i>They Might Be Giants</i> as a fun way to help learners remember some (simple) physics content.</p> <p>Extended assessment: 3.1.4.3</p> <p>Introduce the term "monochromatic" to describe visible light of a single frequency. Demonstrate a laser as an example of monochromatic light.</p>
3.3.1 Electro-magnetic spectrum	Know the main regions of the electromagnetic spectrum in order of frequency and in order of wavelength	<p>Ask learners which travels fastest, light or sound. Can they provide examples where this is evident? Learners may suggest lightning and thunder, fireworks and their bang, a starting pistol, etc. Highlight that light travels approximately a million times faster than sound.</p> <p>Introduce the electromagnetic spectrum as the range of waves that have certain properties in common, whilst other properties are different. Explain that all electromagnetic waves have the same speed and can travel in a vacuum.</p>
3.3.2	Know that all electromagnetic waves travel at the same high speed in a vacuum	<p>Split learners into small groups and assign each group a part of the electromagnetic spectrum. Learners may use their textbooks and online resources to research their part of the spectrum. They note down the role in applications, and damage caused by, their part of the spectrum on a piece of paper. They then present the key information to the rest of the class and add their piece of paper to the whiteboard, in order of wavelength and frequency. Recap the key points as given in the syllabus.</p>
3.3.3	Describe the typical uses of the different regions of the electromagnetic spectrum including: (a) radio waves; radio	<p>Highlight the use of electromagnetic waves in communication, particularly the use of microwaves by artificial satellites.</p> <p>Set learners qualitative questions for practice. (F)</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
	<p>and television transmissions, astronomy, radio frequency identification (RFID)</p> <p>(b) microwaves; satellite television, mobile phones (cell phones), microwave ovens</p> <p>(c) infrared; electric grills, short range communications such as remote controllers for television, intruder alarms, thermal imaging, optical fibres</p> <p>(d) visible light; vision, photography, illumination</p> <p>(e) ultraviolet; security marking, detecting fake bank notes, sterilising water</p> <p>(f) X-rays; medical scanning, security scanners</p> <p>(g) gamma rays; sterilising food and medical equipment, detection of cancer and its treatment</p>	<p>You could use the <i>Electromagnetic Spectrum</i> song by <i>Emerson and Wong Yann</i> as a fun way to help learners remember some physics content, as well as the order of the spectrum.</p> <p>The Scale of the Universe website includes the size of the electromagnetic spectrum wavelengths and allows comparison to everyday objects: (I) https://scaleofuniverse.com</p> <p>Extended assessment: 3.3.6, 3.3.7, 3.3.8, 3.3.9 and 3.3.10</p> <p>Return to the earlier comparison of the speed of light and the speed of sound. Explain that all electromagnetic waves, including light, travel at 3.0×10^8 m/s in a vacuum and this speed is approximately the same in air</p> <p>Expand on the uses of electromagnetic waves in communication, including: mobile phones, wireless internet, Bluetooth, cable television and high-speed broadband. Learners should understand which part of electromagnetic spectrum is used in each case.</p> <p>Ask learners the difference between digital and analogue. Learners may use the example of digital and analogue watches. Explain the difference between the two types of signals in the context of electromagnetic waves and that sound can be transmitted as either. Learners research the benefits of digital signalling over more traditional analogue signals.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
3.3.4	<p>Describe the harmful effects on people of excessive exposure to electromagnetic radiation, including:</p> <ul style="list-style-type: none"> (a) microwaves; internal heating of body cells (b) infrared; skin burns (c) ultraviolet; damage to surface cells and eyes, leading to skin cancer and eye conditions (d) X-rays and gamma rays; mutation or damage to cells in the body 	
3.3.5	<p>Know that communication with artificial satellites is mainly by microwaves:</p> <ul style="list-style-type: none"> (a) some satellite phones use low orbit artificial satellites (b) some satellite phones and direct broadcast satellite television use geostationary satellites 	
3.3.6	<p>Know that the speed of electromagnetic waves in a vacuum is 3.0×10^8 m/s and is</p>	

Syllabus ref.	Learning objectives	Suggested teaching activities
3.3.7	<p>approximately the same in air</p> <p>Know that many important systems of communications rely on electromagnetic radiation including:</p> <p>(a) mobile phones (cell phones) and wireless internet use microwaves because microwaves can penetrate some walls and only require short aerial for transmission and reception</p> <p>(b) Bluetooth uses radio waves radio waves pass through walls and the signal is weakened on doing so</p> <p>(c) optical fibres (visible light or infrared) are used for cable television and high-speed broadband because glass is transparent to visible light and some infrared; visible light and short wavelength</p>	

Syllabus ref.	Learning objectives	Suggested teaching activities
3.3.8	infrared can carry high rates of data Know the difference between a digital or analogue signal	
3.3.9	Know that a sound can be transmitted as a digital or analogue signal	
3.3.10	Explain the benefits of digital signalling including increased rate of transmission of data and increased range due to accurate signal regeneration	
3.4.1 Sound	Describe the production of sound by vibrating sources	<p>Introduce sound with some simple experiments. Learners investigate a 'tin can telephone', vibrating a ruler against a desk edge and tuning forks. They hit a tuning fork against a rubber bung before submerging it in water, or placing next to a ping pong ball hanging from a thread. Can learners explain the splash or the sudden movement of the ball? They hit a metal fork or spoon, attached to the end of two pieces of string, against a desk with the ends of the string in the learner's ears. They should hear the sound travel through the string and the air. Which sound travels faster? Learners add different amounts of water to glass bottles and blow across the mouth of the bottles. Which bottle produces the higher-pitched sound? Does it depend on the amount of water present or the amount of air?</p> <p>Remind learners that sound is a longitudinal wave.</p> <p>Introduce Boyle's vacuum pump experiment to show that sound cannot be transmitted in a vacuum and remind learners that sound requires a medium to travel:</p> <p>http://science.cleapss.org.uk/Resource/Ringing-bell-jar-experiment.vid</p> <p>Introduce how a microphone detects sound waves and a cathode ray oscilloscope allows interpretation of them. Ask learners what they notice when loud/quiet/high/low sounds are detected. Identify the amplitude and frequency on the oscilloscope trace. Relate these variables to the volume and pitch of the sound that is heard.</p>
3.4.2	Describe the longitudinal nature of sound waves	
3.4.3	State the approximate range of frequencies audible to humans as 20 Hz to 20 000 Hz	
3.4.4	Know that a medium is needed to transmit sound waves	

Syllabus ref.	Learning objectives	Suggested teaching activities
3.4.7	Describe how changes in amplitude and frequency affect the loudness and pitch of sound waves	<p>Resource Plus</p> <p>Carry out the <i>Use of a cathode ray oscilloscope (CRO) to visualise sound waves</i> experiment referring to Teaching Pack for lesson plans and resources.</p>
3.4.10	Describe compression and rarefaction	<p>Show learners simple wave traces and ask them to identify the properties of the sound: which sound is highest, which sound is louder, which sound has a lower frequency, etc. Learners can answer the questions using miniature whiteboards. (F)</p>
3.4.11	Know that, in general, sound travels faster in solids than in liquids and faster in liquids than in gases	<p>Learners investigate wave traces further using the simulation of a keyboard and an oscilloscope: (I) www.physics-chemistry-interactive-flash-animation.com/electricity_electromagnetism_interactive/oscilloscope_description_tutorial_sounds_frequency.htm</p> <p>Introduce the idea that humans, as well as other animals, have a specific hearing range. This can be tested simply using a signal generator and a loudspeaker. Learners should be quiet throughout. They raise their hands when they believe they first hear the sound (around 20Hz) and lower it when they can no longer hear the sound (20 000 Hz). As the range decreases as humans age, it is likely that your learners will have a larger range than you.</p> <p>Set learners qualitative questions for practice. (F)</p> <p>Extended assessment: 3.4.10 and 3.4.11</p> <p>Learners look at diagrams of a longitudinal wave and identify compressions and rarefactions.</p> <p>Remind learners of the metal fork/spoon on a string experiment. The sound travelled faster up the string than through the air. Can learners explain how the state of the medium (solid, liquid or gas) affects the speed of propagation of the sound wave? Learners can research how whales communicate over long distances. (I)</p> <p>Extension: Stretch and prepare for A level</p> <p>Show learners more complicated wave traces showing different sound sources e.g. a range of instruments. These wave traces are unlikely to be sinusoidal, unlike the waves they have seen previously. Highlight that although the sound sources can emit the same frequency, the waves can have different qualities (timbres).</p> <p>Introduce learners to the concept of the Doppler shift and how it changes the frequency and wavelength of a sound wave so it sounds different. Use simple diagrams that show a source moving into its own sound waves to help learners visualise this. Redshift will be explored as part of Topic 6 Space physics.</p> <p>Interference simulation: https://phet.colorado.edu/en/simulation/wave-interference</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
3.4.9 Sound	Define ultrasound as sound with a frequency higher than 20 kHz	Remind learners of the demonstration of the human hearing range from the previous lesson. Explain that ultrasound is any sound above 20 000 Hz and ask learners if they know of any use of this high frequency sound. They may suggest prenatal scans.
3.4.12	Describe the uses of ultrasound in non-destructive testing of materials, medical scanning of soft tissue and sonar including calculation of depth or distance from time and wave speed	<p>Extended assessment: 3.4.12</p> <p>Learners research the uses of ultrasound in cleaning, prenatal and other medical scanning, and in sonar (including calculation of depth or distance from time and wave speed). Learners will have the opportunity to measure the speed of sound later. (I)</p>
3.4.5	Know that the speed of sound in air is approximately 330-350 m/s	Ask learners to come up with a method to measure the speed of sound. Learners should realise that this is a difficult experiment to carry out because sound travels relatively fast.
3.4.6	Describe a method involving a measurement of distance and time for determining the speed of sound in air	<p>Ask learners to define an “echo”. They will explain that an echo is the reflection of sound waves. Learners can research how bats “see” with echolocation. (I)</p> <p>Introduce the idea of measuring the sound over a large distance. This can be done using a starter pistol or by making use of echoes.</p> <p>Measuring the speed of sound using echoes: https://spark.iop.org/measuring-speed-sound-using-echoes</p>
3.4.8	Describe an echo as the reflection of sound waves	<p>Measuring the speed of sound using a starter pistol: www.schoolphysics.co.uk/age11-14/Sound/text/Speed_of_sound/index.html</p> <p>If you choose the echo method, relate this to learners’ understanding of sonar. Use wooden blocks to produce a clear and distinct sound. This needs to reflect off a large flat surface like the side of a building. Learners need to match the next ‘clap’ to the echo of the previous; it may take some practice to establish the correct rhythm. Learners then work together to measure the time for multiple claps (20 or so) and the distance travelled.</p> <p>If you use the starter pistol method, an average result of time should be taken and the experiment should be done over a large distance (at least 100m).</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Learners draw a diagram of the experiment they carried out, write a method, collect their results in a table and calculate the speed of sound. They assess the accuracy of their answer and identify any sources of error.</p> <p>Set learners qualitative questions for practice. (F)</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

4. Electricity and magnetism

Syllabus ref.	Learning objectives	Suggested teaching activities
4.1.1 Simple phenomena of magnetism	Describe the forces between magnetic poles and between magnets and magnetic materials, including the use of the terms north pole (N pole), south pole (S pole), attraction and repulsion, magnetised and unmagnetised	<p>Ask learners what they know about magnetism. They may suggest various basic concepts and examples.</p> <p>Introduce magnetism with some simple experiments. Learners investigate opposite and like poles, suspending a bar magnet from a clamp stand so it is free to move. What happens when a second bar magnet is brought close to the hanging bar magnet?</p> <p>Learners investigate which materials are magnetic by using a bar magnet. Can they identify the three magnetic elements on the Periodic Table?</p> <p>Learners magnetise a bar of steel by stroking the steel in the same direction multiple times with the same end of the bar magnet. They test how well it works by trying to pick up steel paperclips.</p>
4.1.2	Describe induced magnetism	<p>Learners investigate a magnet's effect on iron filings and plotting compasses. They will learn about fields later.</p> <p>Learners observe a simple 'magic trick' using a bar magnet and a large steel paperclip. Attach a piece of string to the paperclip and secure the end of the string to the base of a clamp stand. Clamp the bar magnet above so that the paperclip reaches up to touch it but adjust its position so there is a slight gap. The paperclip appears to 'float' up, straining against its string tether, due to the magnetic attraction to the bar magnet.</p>
4.1.4	State the difference between magnetic and non-magnetic materials	<p>Learners play with magnetic 'toys': magnetic balls that can be made into geometric shapes, rattle magnets that vibrate together to produce noise, etc.</p> <p>Learners write observations and explanations of the experiments.</p> <p>Clarify the key terms in this topic, in particular the difference between a magnetic material and a magnetised material.</p> <p>Learners should be able to explain how to induce magnetism in a magnetic material by stroking it multiple times with a magnet or by placing it next to a magnet.</p> <p>Set learners qualitative questions for practice. (F)</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
4.1.5 Simple phenomena of magnetism	Describe a magnetic field as a region in which a magnetic pole experiences a force	Ask learners how they would define a magnetic field. Describe a magnetic field as a region in which a magnetic pole experiences a force. Direct learners to plot magnetic field lines with iron filings to show the shape of the magnetic field.
4.1.6	Draw the pattern and direction of the magnetic field lines around a bar magnet	Direct learners to plot magnetic field lines with a compass and how to use the compass to determine the direction of the magnetic field. Their plots should also show the shape of the magnetic field. Learners should be able to sketch the pattern and direction of the magnetic field lines around a bar magnet.
4.1.7	State that the direction of a magnetic field at a point is the direction of the force on the N pole of a magnet at that point	Set learners qualitative questions for practice. Give them diagrams of combinations of bar magnets and ask them to identify which are the North and which are the South poles. (F) Learners investigate making their own compass to detect the Earth's magnetic field. Can they explain why the North pole of a magnet points to the North pole of the Earth?
4.1.8	Describe the plotting of magnetic field lines with a compass or iron filings and the use of a compass to determine the direction of the magnetic field	Learners research information about the magnetic field of the Earth, how it produces the Northern (and Southern) lights and if other planets have magnetic fields. (I) Learners investigate magnetic fields further using the simulation: (I) https://phet.colorado.edu/en/simulation/legacy/magnet-and-compass Extended assessment: 4.1.10 and 4.1.11
4.1.10	Explain that magnetic forces are due to interactions between magnetic fields	Remind learners of the magnetic field lines they plotted earlier using iron filings and/or plotting compasses. The strength of the magnetic field is represented by the spacing of the magnetic field lines.
4.1.11	Know that the relative strength of a magnetic field is represented by the spacing of the magnetic field lines	Remind learners of the definition of a "force" and introduce a magnetic force as due to the interactions between magnetic fields. Learners have felt this force when investigating the interaction between magnetic poles previously, as like poles will push apart (repulsive magnetic force) and opposite poles will pull together (attractive magnetic force).

Syllabus ref.	Learning objectives	Suggested teaching activities
4.1.3 Simple phenomena of magnetism	State the differences between the properties of temporary magnets (made of soft iron) and the properties of permanent magnets (made of steel)	<p>Ask learners if they know any everyday items that use electromagnets. Learners may be surprised by how common they are.</p> <p>Ask learners to sketch the magnetic field around a single current-carrying wire. They can draw this in 3-D or in 2-D from above or below. You could introduce the cross-and-dot notation to show the direction of the current in a wire in a 2-D diagram. Learners will probably sketch various shapes for the field; remind them that field lines only end on poles and their spacing represents their strength.</p>
4.1.9	Describe uses of permanent magnets and electromagnets	<p>Introduce the right-hand grip rule to aid memory of the direction of the current in relation to the direction of the magnetic field.</p> <p>Demonstrate the magnetic field around a current-carrying wire by using plotting compasses (or iron filings) on a sheet of cardboard held at a right angle to the wire carrying direct current.</p>
4.5.3.1 Magnetic effect of current	Describe the pattern and direction of the magnetic field due to currents in straight wires and in solenoids	<p>Extend the concept of the magnetic field around a straight wire to a loop of wire and a solenoid. Learners should be able to logically link the diagrams together by using the right-hand grip rule to predict how each part of wire would produce a field that interacts with its neighbours' fields.</p>
4.5.3.2	Describe an experiment to identify the pattern of a magnetic field (including direction) due to currents in straight wires and solenoids	<p>Highlight that a loop of wire carrying direct current is equivalent to two straight wires carrying direct current in opposite directions. Consider how parallel conductors produce magnetic field patterns due to their currents. Relate these to the forces on the conductors. If the currents are in the same direction, the force is attractive; with oppositely directed currents the force is repulsive.</p> <p>Introduce the basic structure of an electromagnet. Highlight the importance of the magnetic core and how iron is used as a temporary magnet.</p>
4.5.3.4	State the qualitative variation of the strength of the magnetic field around straight wires and solenoids	<p>Resource Plus</p> <p>Carry out the <i>How to make an electromagnet</i> experiment referring to Teaching Pack for lesson plans and resources.</p> <p>Ask learners what would happen if an electromagnet had a core made of steel. Explain that this would magnetise the steel and produce a permanent magnet, assuming d.c. is used. Recap the stroking method of magnetisation. Learners write methods on how to magnetise magnetic materials.</p>
4.5.3.5	Describe the effect on the magnetic field around straight wires and solenoids of	<p>Ask learners how to demagnetise a magnetic material. They may suggest using current again, this time alternating. Learners investigate the methods of hammering and heating on pieces of magnetised iron.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
	<p>changing the magnitude and direction of current</p>	<p>Learners consider the benefits of electromagnets in comparison to permanent magnets. They may identify that these can be controlled in terms of the strength of the field and be turned on and off as needed.</p> <p>Learners research the uses of electromagnets, such as maglev trains, loudspeakers, relays, electric bells, industrial lifting magnets, etc. (I)</p> <p>Set learners qualitative questions for practice. (F)</p> <p>If your school uses electromagnetic door locks, show them in action. Paperclips can be stuck to the lock when the electromagnet is on. They will fall when the electromagnet is turned off.</p> <p>Extended assessment: 4.5.3.4 and 4.5.3.5</p> <p>Ask learners what variables affect the strength of the magnetic field around straight wires and solenoids. Use the right-hand grip rule to demonstrate how changing the direction of the current changes the direction of the magnetic field. Make use of the magnets and electromagnets simulation to show how the magnitude of the current affects the magnetic field. This can also be demonstrated using an electromagnet, a d.c. power supply and steel paperclips. Higher magnitudes of current will hold more paperclips, implying a stronger magnetic field. Demonstrate how changing the direction of the current flowing through a straight wire or solenoid changes the direction of the plotting compasses showing the direction of the magnetic field.</p> <p>Magnets and electromagnets simulation: https://phet.colorado.edu/en/simulation/legacy/magnets-and-electromagnets</p>
<p>4.2.1.1 Electric charge</p> <p>4.2.1.2</p>	<p>State that there are positive and negative charges</p> <p>State that positive charges repel other positive charges, negative charges repel other negative charges, but positive charges attract negative charges</p>	<p>Introduce the concept of charge, positive and negative.</p> <p>Learners investigate the build-up of static charge using plastic rods and clothes. Rubbing the rods with the clothes should build up charge on the rods such that they can pick up small scraps of paper, bend a small stream of water or repel another like-charged rod.</p> <p>Learners may be able to identify other examples where static charge is built up: when taking off a woollen jumper, shuffling along the carpeted floor with socks on, jumping on a trampoline with socks on, etc.</p> <p>Learners may enjoy observing the Van de Graaff generator. There are lots of demonstrations that can be done with the generator to show the effects of static electricity.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
4.2.1.3	Describe simple experiments to show the production of electrostatic charges by friction and to show the detection of electrostatic charges	Clarify that charging of solids by friction involves only a transfer of negative charge (electrons). Positive charge (protons) are trapped inside of the nucleus and cannot be transferred by friction. Learners investigate static electricity further using the balloons simulation: (I) https://phet.colorado.edu/en/simulation/balloons-and-static-electricity Learners research uses and dangers of static electricity: xerography, discharging vehicles, electrostatic spray painting, inkjet printers, etc.
4.2.1.4	Explain that charging of solids by friction involves only a transfer of negative charge (electrons)	Set learners qualitative questions for practice. (F) Resource Plus Carry out the <i>Static electricity</i> experiment referring to Teaching Pack for lesson plans and resources.
4.2.1.7	State that charge is measured in coulombs	Extended assessment: 4.2.1.7 Introduce the unit for charge, the coulomb.
4.2.1.8 Electric charge	Describe an electric field as a region in which an electric charge experiences a force	Extended assessment: 4.2.1.8, 4.2.1.9 and 4.2.1.10 Define an electric field, building on learners' understanding of gravitational and magnetic fields. Describe an electric field as a region in which an electric charge experiences a force.
4.2.1.9	State that the direction of an electric field at a point is the direction of the force on a positive charge at that point	Explain that electric field lines: <ul style="list-style-type: none"> • 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 • are more closely packed when the field is stronger.
4.2.1.10	Describe simple electric field patterns, including the direction of the field: (a) around a point charge (b) around a charged conducting sphere	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 (end effects will not be examined). Demonstrate an electric field's effect on semolina in castor oil using a high voltage power supply. Set learners qualitative questions for practice. (F)

Syllabus ref.	Learning objectives	Suggested teaching activities
	(c) between two oppositely charged parallel conducting plates (end effects will not be examined)	<p>Learners investigate electric fields further using the field simulation: (I) https://phet.colorado.edu/en/simulation/charges-and-fields</p> <p>Experiment notes from the IoP on electric field patterns: https://spark.iop.org/electric-field-patterns</p> <p>Extension: Stretch and prepare for A level Define electric field strength, building on learners' understanding of gravitational field strength. Set learners simple questions to practise calculations using the equation.</p> <p>Ask learners what variables they think the force between two charged particles will depend on. Introduce Coulomb's law. Set learners simple questions to practise using the equation.</p> <p>Learners can investigate the force between charges further using the Coulomb's Law simulation: (I) https://phet.colorado.edu/en/simulation/coulombs-law</p>
4.2.1.5 Electric charge	Describe an experiment to distinguish between electrical conductors and insulators	<p>Can learners describe the difference between an electrical conductor and an insulator? Can they provide examples of each?</p> <p>Ask learners how they would test whether a material is a conductor or an insulator. What items would they use?</p> <p>Introduce basic circuit symbols for a connecting cable, cell and lamp. Learners use these items to test whether objects are conductors or insulators. They complete a simple table of conductors and insulators by testing objects in the laboratory.</p> <p>Explain the properties of a conductor and why metals are such good conductors. Describe electrical conduction in metals in terms of the movement of free electrons. Remind learners of the demonstration of thermal conduction from Topic 1 Motion, forces and energy where electrons helped transfer the energy quicker.</p> <p>Conductivity simulation: https://phet.colorado.edu/en/simulation/legacy/conductivity</p>
4.2.1.6	Recall and use a simple electron model to explain the difference between electrical conductors and insulators and give typical examples	<p>Set learners qualitative questions for practice. (F)</p> <p>Learners investigate the conductivity of various items using the circuit simulation: (I) https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc</p>
4.2.2.3 Electric current	Describe electrical conduction in metals in terms of the movement of free electrons	

Syllabus ref.	Learning objectives	Suggested teaching activities
		Learners could research semiconductors and how they function to exhibit the properties of both insulators and conductors, depending on the circumstance. (I)
4.2.2.1 Electric current	Know that electric current is related to the flow of charge	Ask learners what measuring instrument is used to measure current, what the unit is for current and what the symbol is. Learners may struggle to remember the unit and symbol as they do not appear to link to the name of 'current'. Explain that current is related to the flow of charge.
4.2.2.2	Describe the use of ammeters (analogue and digital) with different ranges	Introduce the ammeter. Demonstrate analogue and digital ammeters: how to connect them in a circuit, how they can be read and how different ranges can be used depending on the current being measured. Learners should recall the difference between analogue and digital from Topic 3 Waves.
4.2.2.4	Know the difference between direct current (d.c) and alternating current (a.c.)	Set learners the task of investigating the current in various circuits. They measure the current at various points around simple series and parallel circuits and draw a conclusion on how current behaves qualitatively. They may struggle to see the pattern in the parallel circuit if the values are not very accurate. Explain that the learners have been working with direct current. Introduce and explain the properties of alternating current.
4.2.2.5	Define electric current as the charge passing a point per unit time; recall and use the equation: $I = \frac{Q}{t}$	Alternating current and direct current: www.furryelephant.com/player.php?subject=physics&jumpTo=ee/10Ms3 Extended assessment: 4.2.2.5, 4.2.2.6, 4.3.2.8 (a) and 4.3.2.9
4.2.2.6	State that conventional current is from positive to negative and that the flow of electrons is from negative to positive	Define electric current as the charge passing a point per unit time, define the ampere and introduce the equation. Learners may need a reminder of charge and its unit. Highlight the common use of conventional current, which is from positive to negative. In reality, it is the electrons that move and this flow of electrons is from negative to positive due to their negative charge. Remind learners of their findings from investigating the current in various circuits and explain in more detail. Show learners simple circuit diagrams with the current labelled at some of the points around the circuit. Learners calculate the missing values of the current using their understanding of how current behaves in series and parallel circuits. They should recall that the current at every point in a series circuit is the same. (F)
4.3.2.1 Series and parallel circuits	Know that the current at every point in a series circuit is the same	Show learners simple junction diagrams with the current labelled in all wires except one. Learners calculate the missing value, as well as the direction, of the current. They should recall that the sum of the currents into a junction in a parallel circuit is equal to the sum of the currents that leave the junction.

Syllabus ref.	Learning objectives	Suggested teaching activities
4.3.2.5	State that, for a parallel circuit, the current from the source is larger than the current in each branch	Set learners questions to practise using the equation and applying their understanding of current in series and parallel circuits. (F) Learners investigate the flow of charge further using the circuit simulation. The simulation can show electron movement or conventional current. Learners use the ammeter to take readings of current at points around various circuits. (I)
4.3.2.8 (a)	Recall and use in calculations, the fact that: (a) the sum of the currents entering a junction in a parallel circuit is equal to the sum of the currents that leave the junction	Circuit simulation: https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc Extension: Stretch and prepare for A level Introduce Kirchhoff's first law by reminding learners that the sum of the currents into a junction in a parallel circuit is equal to the sum of the currents that leave the junction. This is an example of the conservation of charge. Kirchhoff's first law is an expression of this basic principle.
4.3.2.9	Explain that the sum of the currents into a junction is the same as the sum of the currents out of the junction	
4.2.3.1 Electromotive force and potential difference	Define electromotive force (e.m.f) as the electrical work done by a source in moving a unit charge around a complete circuit	Ask learners what measuring instrument is used to measure voltage, what the unit is for voltage and what the symbol is for voltage. Introduce the terms electromotive force (e.m.f), the energy supplied from a power source to a circuit, and potential difference (p.d), the energy transferred by a current to the components in a circuit. Both are measured in volts.
4.2.3.2	Know that e.m.f is measured in volts (V)	Introduce the voltmeter. Demonstrate analogue and digital voltmeters: how to connect around a component in a circuit, how they can be read and how different ranges can be used depending on the e.m.f or p.d being measured.
4.2.3.3	Define potential difference (p.d) as the work done by a unit charge passing through a component	Set learners the task of investigating the total e.m.f of several sources when arranged in series and in parallel. Extended assessment: 4.2.3.6, 4.2.3.7 and 4.3.2.8 (b) and (c)

Syllabus ref.	Learning objectives	Suggested teaching activities
4.2.3.4	Know that p.d between two points is measured in volts (V)	Set learners the task of investigating the e.m.f and p.d of components in various circuits. They measure the e.m.f around the power supply and the p.d of components in simple series and parallel circuits. They draw a conclusion on the behaviour of e.m.f and p.d They may struggle to see the pattern in the series circuit if the values are not very accurate.
4.2.3.5	Describe the use of voltmeters (analogue and digital) with different ranges	Learners may struggle to understand how the p.d across each branch of a parallel circuit can be the same. Explain this using an analogy. Two learners act as lamps in the circuit, you act as the power supply and the remaining learners are the electrons in the circuit. Direct the 'electrons' to move around the circuit, picking up energy (marbles or small sweets) from the 'power supply' (you) and distributing them to the 'lamps'. When the 'lamps' are in series, they should share the energy from the 'power supply', but when they are in parallel they can receive all of the energy that the 'electrons' carry from the 'power supply' as each 'electron' only passes one 'lamp'. This highlights that the energy per unit charge, the p.d, is the same as each branch in a parallel circuit and the same as the e.m.f of the source.
4.2.3.6	Recall and use the equation for e.m.f $E = \frac{W}{Q}$	Show learners simple circuit diagrams with the values of e.m.f and p.d labelled for some of the components in the circuit. Learners calculate the missing values using their understanding of e.m.f and p.d in series and parallel circuits. They should recall that the total p.d across the components in a series circuit is equal to the sum of the individual p.d.s across each component and that the p.d across an arrangement of parallel resistors is the same as the p.d across one branch in the arrangement of the parallel resistors. (F)
4.2.3.7	Recall and use the equation for p.d $V = \frac{W}{Q}$	Remind learners of the definitions of e.m.f and p.d and introduce the equations. Demonstrate calculations using the equations.
4.3.2.3 Series and parallel circuits	Calculate the combined e.m.f of several sources in series	Set learners quantitative and qualitative questions for practice. (F)
4.3.2.8 (b) and (c)	Recall and use in calculations, the fact that: (b) the total p.d across the components in a series circuit is equal to the sum of the individual p.d.s across each component (c) the p.d across an arrangement of parallel resistances is the same as the p.d across one branch in the arrangement of the parallel resistances	Learners investigate the voltage further using the circuit simulation. Learners can use the voltmeter to take readings of voltage around components in various circuits. (I) Circuit simulation: https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc Voltage simulation: https://phet.colorado.edu/en/simulation/legacy/battery-voltage Extension: Stretch and prepare for A level Introduce Kirchhoff's second law, linking to learners' understanding of e.m.f and p.d in circuits. Explain how it relates to the conservation of energy. In reality, some electrical energy from the battery may be used to heat the battery itself, due to internal resistance.

Syllabus ref.	Learning objectives	Suggested teaching activities
4.2.4.1 Resistance	Recall and use the equation for resistance $R = \frac{V}{I}$	Introduce resistance and ask learners how it will affect current in a circuit. Use analogies to introduce the concept of resistance e.g. comparing resistance to the difficulty in moving down a corridor with a lot of other learners moving around you.
4.2.4.2	Describe an experiment to determine resistance using a voltmeter and an ammeter and do the appropriate calculations	Direct learners to investigate the relationship between the current flowing through a resistor and the voltage across it. Learners build the circuit from a diagram or may need a demonstration of the set-up. They should collect various results of current and voltage. They should avoid letting the resistor overheat; you may need to tell them a maximum value of current or voltage that they should not exceed to ensure this. Introduce the equation for resistance and how it can be used to calculate the resistance from the results of the experiment.
4.2.4.3	State, qualitatively, the relationship of the resistance of a metallic wire to its length and cross-sectional area	Learners should write a method for the experiment they carried out and explain how to find the resistance of the resistor. Ask learners what variables the resistance of a component depends on. You can use analogies, but make sure they help rather than confuse learners e.g. a wider corridor (representing the cross-sectional area of the wire) decreases the resistance, but not because there is more room (there will be more charge carriers).
4.2.4.4	Sketch and explain the current–voltage graphs for a resistor of constant resistance, a filament lamp and a diode	Ask learners what they think the combined resistance will be when multiple resistors are connected in series. Introduce how to calculate the combined resistance. Learners measure the combined resistance of resistors using a multimeter. They test different combinations and come to the conclusion that resistance in series is additive, whilst adding more resistance in parallel decreases the combined resistance such that the resistance is less than that of either resistor by itself.
4.2.4.5	Recall and use the following relationship for a metallic electrical conductor: (a) resistance is directly proportional to length (b) resistance is inversely proportional to cross-sectional area	Show learners simple combinations of resistors and ask them to quickly calculate or estimate the combined resistance. Learners could answer the questions on miniature whiteboards. (F) Set learners simple calculation and qualitative questions for practice. (F) Extended assessment: 4.2.4.4, 4.2.4.5 and 4.3.2.10 Learners repeat the experiment to find the resistance of a filament lamp and a diode. Alternatively, learners can investigate these components through simulation or discuss qualitatively. Learners should be able to sketch and explain the current–voltage graphs of a resistor of constant resistance, a filament lamp and a diode. Return to the instruction from the experiment not to overheat the resistor. Ask learners how overheating would affect the experiment's results. Learners should identify that this is the reason that the lamp does not have a fixed resistance.

Syllabus ref.	Learning objectives	Suggested teaching activities
4.3.2.4	Calculate the combined resistance of two or more resistors in series	Set learners qualitative questions for practice on different components and their current–voltage graphs. Show graphs that learners match to the components. (F)
4.3.2.6	State that the combined resistance of two resistors in parallel is less than that of either resistor by itself	<p>Resource Plus</p> <p>Carry out the <i>Factors affecting the resistance of a wire</i> experiment referring to Teaching Pack for lesson plans and resources.</p> <p>Remind learners that the combined resistance of two resistors in parallel is less than that of either resistor by itself. Introduce how to calculate the combined resistance and demonstrate a calculation.</p>
4.3.2.10	Calculate the combined resistance of two resistors in parallel	<p>Set learners questions to test their understanding of the direct proportionality between resistance and the length, and the inverse proportionality between resistance and the cross-sectional area of a wire, as well as the combined resistance of two resistors in parallel. (F)</p> <p>Learners can investigate the resistance further using circuit simulation. Learners can change the wire resistivity and take measurements of voltage and current to find the resistance of combinations of resistors. (I)</p> <p>Battery-resistor circuit simulation: https://phet.colorado.edu/en/simulation/legacy/battery-resistor-circuit</p> <p>Circuit simulation: https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc</p> <p>Ohm's law simulation: https://phet.colorado.edu/en/simulation/ohms-law</p> <p>Extension: Stretch and prepare for A level</p> <p>Introduce the equation for the resistance of a wire. Link to the variables already discussed. Set learners simple questions for practice. (F)</p> <p>Teach learners how to calculate the combined resistance of multiple resistors in parallel.</p> <p>Resistance in a wire simulation: https://phet.colorado.edu/en/simulation/resistance-in-a-wire</p>
4.3.1.1 Circuit diagrams	Draw and interpret circuit diagrams containing cells, batteries, power	<p>Show learners circuit symbols and ask them to identify what they represent.</p> <p>Set learners the task of constructing simple circuits by interpreting a circuit diagram of symbols.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
and circuit components	supplies, generators, potential dividers, switches, resistors (fixed and variable), heaters, thermistors (NTC only), light-dependent resistors (LDRs), lamps, motors, ammeters, voltmeters, magnetising coils, transformers, fuses, relays, and know how these components behave in the circuit	<p>Learners can build a simple circuit containing cells and lamps and investigate what happens if one bulb “blows”/is removed/is short circuited. Learners can also compare the brightness of bulbs in various circuits whilst keeping the number of cells constant. Ask learners how they think the lights in their house are wired. They build simple circuits using cells, lamps and switches to model the lighting in a house. What are the advantages of connecting lamps in parallel in a lighting circuit?</p> <p>Learners play ‘pairs’ or any simple match up game with the circuit symbols and their names to aid recall.</p> <p>Set learners a simple recall test on the circuit symbols to aid and test recall. (F)</p> <p>Introduce the NTC thermistor and light-dependent resistor (LDR) and explain their use as input sensors.</p> <p>Set learners qualitative questions on thermistors and LDRs.</p> <p>Remind learners of their investigation into resistance of a light bulb as current and p.d changes. Ask learners why the resistance changes. Learners consider how to keep the current in a circuit constant whilst the resistance of a component changes. Learners recall and apply $V=IR$ to show that the p.d across an electrical conductor increases as its resistance increases for a constant current.</p>
4.3.1.2	Draw and interpret circuit diagrams containing diodes and light-emitting diodes (LEDs), and know how these components behave in a circuit	<p>Set learners quantitative and qualitative questions to practise calculating current, voltage and resistance on parts of a circuit or on the whole circuit.</p> <p>Extended assessment: 4.3.1.2, 4.3.3.2 and 4.3.3.3</p>
4.3.2.2	Know how to construct and use series and parallel circuits	<p>Introduce the diode and the light-emitting diode (LED) and explain how they behave in a circuit. Remind learners of conventional current and highlight how the arrowhead of the diode circuit symbol must point in the same direction as conventional current flow for the diode to allow current to flow.</p> <p>Learners could research common uses of diodes. (I)</p>
4.3.2.7	State the advantages of connecting lamps in parallel in a lighting circuit	<p>Introduce a variable potential divider. Demonstrate how it can be used in a circuit and take measurements of p.d to show how it works to divide the potential difference.</p>
4.3.3.1	Know that the p.d across an electrical conductor increases as its resistance	<p>Introduce the equation for two resistors used as a potential divider. Demonstrate how to use this equation.</p> <p>Set learners calculation questions on potential dividers for practice.</p> <p>Extension: Stretch and prepare for A level</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
4.3.3.2	increases for a constant current Describe the action of a variable potential divider	Using Kirchhoff's laws, derive formulae for the combined resistance of two or more resistors in series and in parallel. Return to the concept of a potential divider and introduce using a variable resistor, thermistor or LDR. Learners discuss how each component would affect the circuit and the values of voltage. Learners may forget that not only 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.
4.3.3.3	Recall and use the equation for two resistors used as a potential divider $\frac{R_1}{R_2} = \frac{V_1}{V_2}$	Set learners questions to find the voltage for different components in simple circuits for practice. (F)
4.2.5.1 Electrical energy and electrical power	Understand that electric circuits transfer energy from a source of electrical energy, such as an electrical cell or mains supply, to the circuit components and then into the surroundings	Introduce electrical energy and power, building on learners' understanding from Topic 1 Motion, forces and energy. Introduce the equations for electrical energy and power. Demonstrate how to use the equations. Set learners simple questions for practice. (F)
4.2.5.2	Recall and use the equation for electrical power $P=IV$	Introduce the idea that energy is paid for, linking to learners' understanding of energy sources (and later electricity generation). Introduce the kilowatt-hour as an alternative unit for energy, one much more appropriate for the scale of energy used in homes. Set learners the task of estimating the electrical energy used for a period of time (an hour, a day, a week or a year) in their bedroom or home. They calculate the energy in kilowatt-hours and then calculate the cost using current energy prices.
4.2.5.3	Recall and use the equation for electrical energy $E=IVt$	Learners look at a real electricity bill to interpret the cost of electricity and how many kilowatt-hours are used in an average home. Set learners more quantitative and qualitative questions on electricity usage. (F)
4.2.5.4	Define the kilowatt-hour (kW h) and calculate the cost of using electrical appliances where the energy unit is the kW h	Learners practise their recall of the variables, symbols and units of current, voltage, resistance, charge, energy and power using simple match-up games. Alternatively, they play 'electricity bingo' where they fill in a bingo sheet with their choice of symbols and you read out definitions for them to identify.

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Learners investigate lamps in series and parallel further using the circuit simulation. They use the voltmeter and ammeter to take readings in various circuits. They also calculate the power using the results of voltage and current. (I)</p> <p>Circuit simulation: https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc</p>
<p>4.4.1 Electrical safety</p>	<p>State the hazards of:</p> <ul style="list-style-type: none"> (a) damaged insulation (b) overheating cables (c) damp conditions (d) excess current from overloading of plugs, extension leads, single and multiple sockets when using a mains supply 	<p>Introduce the topic of electrical hazards through some 'common sense' scenarios. Ask learners to identify why the following are hazardous: frayed cables, long cables, damaged plugs, water around sockets, pushing metal objects into sockets, etc.</p> <p>Lead learners through the identification and explanation of why the following specific hazards are dangerous: damaged insulation, overheating cables, damp conditions and overloading of plugs, extension leads, single and multiple sockets when using a mains supply.</p> <p>Introduce a mains circuit and identify the live wire (line wire), the neutral wire and the earth wire.</p> <p>Introduce double insulation and explain how it protects the user of the electrical appliance. Ask learners to suggest common examples of electrical appliances that have double insulation: a hairdryer, a mains radio, an electric drill, a desk fan, etc.</p> <p>Introduce the role of earthing and the fuse and how they work together to protect the user of the electrical appliance.</p>
<p>4.4.2</p>	<p>Know that a mains circuit consists of a live wire (line wire), a neutral wire and an earth wire and explain why a switch must be connected to the live wire for the circuit to be switched off safely</p>	<p>Demonstrate how a fuse 'blows' when the current flowing through it is too high. Fuse wire (or any thin easily overheated wire) can be used for this. Increase the current gradually until the wire glows red hot and melts. Clarify that a fuse melts and breaks, but this is often referred to as 'blowing'.</p> <p>Demonstrate the hazard of an electrical device having no double insulation and no earth wire. Demonstrate the hazard of an electrical device having an earth wire but no fuse. Demonstrate how the earth wire and fuse work to protect the user of the electrical device.</p> <p>Introduce trip switches as 'resettable' fuses. Ask learners to imagine how awkward it would be to have to replace every fuse on every electrical device in their home. Instead, trip switches protect the home and its appliances. Learners may be able to identify where the trip switches are in their home: under the stairs, in the garage, in a coat cupboard.</p>
<p>4.4.3</p>	<p>Explain the use and operation of trip switches and fuses and choose appropriate fuse</p>	<p>Explain that fuse ratings and trip switch settings depend on the working current of the electrical appliance.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
4.4.4	<p>ratings and trip switch settings</p> <p>Explain why the outer casing of an electrical appliance must be either non-conducting (double insulated) or earthed</p>	<p>Set learners simple questions to identify the fuse needed for various electrical appliances. You could set learners more difficult questions where they calculate the working current using their knowledge of electrical equations from previous lessons. (F)</p> <p>Explain that fuses and circuit breakers are wired into the live conductor so that they can protect the user of the electrical appliance. They all cause a break in the circuit such that current can no longer flow.</p> <p>Learners investigate the fuse further using the circuit simulation. Learners add cells to increase the current and intentionally blow the fuse. (I)</p>
4.4.5	<p>State that a fuse without an earth wire protects the circuit and the cabling for a double-insulated appliance</p>	<p>Circuit simulation: https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc</p> <p>Learners may enjoy trying to wire a plug themselves using their knowledge of the mains circuit. Ensure that learners do not plug in their plug to the mains.</p>
4.5.3.3 Magnetic effect of a current	<p>Describe how the magnetic effect of a current is used in relays and loudspeakers and give examples of their application</p>	<p>Recap the relay and the loudspeaker from when learners learnt about electromagnets. These both use the magnetic effect of current. The relay uses it to magnetically link two circuits, without sharing current. The loudspeaker uses it to produce motion. How does this work?</p> <p>Introduce the motor effect through demonstration. The rolling bar demonstration requires a moveable conductor to be placed on parallel conducting rods and in a magnetic field such that when direct current flows the bar rolls out of the field. The kicking wire demonstration uses a flexible wire or thin strip of conducting metal. It should be connected to a direct current power supply such that it sits in a magnetic field. When the circuit is turned on, the wire or strip will move out of the field.</p>
4.5.4.1 Force on a current-carrying conductor	<p>Describe an experiment to show that a force acts on a current-carrying conductor in a magnetic field, including the effect of reversing:</p> <p>(a) the current (b) the direction of the field</p>	<p>The rolling bar: www.gcse.com/energy/rolling_bar.htm</p> <p>The kicking wire: https://physicsmax.com/kicking-wire-experiment-force-conductor-magnetic-field-7869</p> <p>Use the motor effect to explain how a loudspeaker works. The magnetic effect of current in the coil interacts with the permanent magnetic field, producing motion. In this case, due to the alternating current used, vibration is caused and sound is made.</p> <p>Animations of how loudspeakers work:</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
4.5.4.2	Recall and use the relative directions of force, magnetic field and current	<p>https://animatedscience.co.uk/how-a-loudspeaker-works https://animagraffs.com/loudspeaker/</p> <p>Extended assessment: 4.5.4.2 and 4.5.2.3</p>
4.5.4.3	Determine the direction of the force on beams of charged particles in a magnetic field	<p>Explain that the motor effect is when a current-carrying wire in the presence of a magnetic field experiences a force. The relative directions of force, magnetic field and current are all at right angles to each other and can be recalled using Fleming's left-hand rule. Use the rule to explain and predict the movement shown previously in the demonstrations.</p> <p>Extend learners' understanding of the motor effect to explain what would happen to a beam of charged particles in a magnetic field, including the effect of reversing the current or the direction of the magnetic field. Learners treat the beam of charged particles as the current, bearing in mind the charge of the particles. Learners should be able to predict which direction the particles will move in, if it all.</p> <p>Set learners qualitative questions for practice. (F)</p> <p>Extension: Stretch and prepare for A level 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.</p> <p>Introduce the equation $F = BIL$ to calculate the force felt by a wire carrying a current, I, of length, L, due to the interaction with the magnetic field of strength, B. Set learners simple questions to practise.</p>
4.5.5.1 The d.c. motor	<p>Know that a current-carrying coil in a magnetic field may experience a turning effect and that the turning effect is increased by increasing:</p> <p>(a) the number of turns on the coil (b) the current (c) the strength of the magnetic field</p>	<p>Introduce the electric motor as a use of the motor effect previously studied. Ask learners what variables will affect the turning speed of the motor. They may identify the current, the strength of the magnetic field and the number of turns on the coil.</p> <p>Set learners qualitative questions for practice. (F)</p> <p>Learners research the uses of electric motors in everyday household items: a washing machine, a vacuum cleaner, microwave, extractor fan, etc. (I)</p> <p>Extended assessment: 4.5.5.2</p> <p>Explain the operation of an electric motor by building up how it works from the force on a current-carrying conductor in a magnetic field previously covered. Introduce two parallel wires with oppositely directed direct currents. Join them into a coil. Place them in a permanent magnetic field. Learners should be able to suggest that this will cause the coil to move up and down in a repeating motion, but without completing a full turn. How can we make the coil move continuously in</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
4.5.5.2	Describe the operation of an electric motor, including the action of a split-ring commutator and brushes	<p>one direction? Introduce the split-ring commutator and the brushes as a means of reversing the direction of the current in time with the motion of the coil.</p> <p>Electric motor animation: www.animatedspace.co.uk/animations/</p> <p>Learners improve their understanding of an electric motor by building one in pairs: www.matrix.edu.au/hsc-physics-how-to-build-a-dc-motor-video-and-step-by-step-guide/ www.instructables.com/id/How-to-Build-Your-Own-DC-Motor/</p> <p>Learners label the parts of the electric motor and their role on a diagram.</p>
4.5.1.1 Electro-magnetic induction	Know that a conductor moving across a magnetic field or a changing magnetic field linking with a conductor can induce an e.m.f in the conductor	<p>Introduce electromagnetic induction through a series of experiments. Learners carry out these experiments individually or in small groups.</p> <ul style="list-style-type: none"> Each group requires two pole facing magnets on a yoke, a cable and a multimeter for the first experiment. Moving the wire quickly through the pair of magnets on the yoke, or moving the yoke around the wire, induces a small reading of voltage on the more sensitive voltmeter setting of the multimeter. Each group requires a bar magnet, a cable and a multimeter for the second experiment. Moving the magnet quickly into the coiled cable, or moving the coiled cable around the magnet, induces a small reading of voltage. Each group requires a small electric motor, two cables and a multimeter for the third experiment. Spinning the motor's shaft induces a small reading of voltage. <p>For all three experiments, learners investigate how they can increase the voltage reading and what happens if they reverse the motion.</p> <p>Explain that electromagnetic induction produces an e.m.f (or voltage and, if connected in a circuit, a current) across an electrical conductor in a changing magnetic field. This is known as the induced e.m.f (and induced current). Inducing an e.m.f requires movement, either directly of the field or of the conductor within the field. Moving quicker increases the e.m.f induced. Increasing the length of the conductor in the field, or increasing the number of turns in a coil, increases the e.m.f induced.</p>
4.5.1.2	Describe an experiment to demonstrate electromagnetic induction	
4.5.1.3	State the factors affecting the magnitude of an induced e.m.f	
4.5.1.4	Know that the direction of an induced e.m.f opposes the change causing it	
		<p>Learners write a method to explain how to demonstrate electromagnetic induction.</p> <p>Set learners qualitative questions for practice. (F)</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
4.5.1.5	State and use the relative directions of force, field and induced current	<p>Learners could create their own animation to show electromagnetic induction and how the variables affect the induced e.m.f using simple software like PowerPoint. (F)</p> <p>Learners could investigate electromagnetic induction further using the induced e.m.f (Faraday) simulations: (I) https://phet.colorado.edu/en/simulation/legacy/faraday https://phet.colorado.edu/en/simulation/faradays-law</p> <p>Extended assessment: 4.5.1.4 and 4.5.1.5</p> <p>Link the changing direction of current produced by the induced e.m.f to the changing direction of motion of the conductor or the magnetic field. Introduce Lenz's Law to explain this relationship.</p> <p>Explain the importance of the conservation of energy and the idea of doing work. A force must be exerted on the magnet to move it and energy is transferred to the electrical circuit through the medium of the magnetic field.</p> <p>Introduce the right hand rule (similar to Fleming's left hand rule) to aid learners in identifying and predicting the relative directions of force, field and induced current.</p> <p>Extension: Stretch and prepare for A level Introduce Faraday's law of electromagnetic induction. Explain the variables and highlight the negative symbol, explained by Lenz's law.</p> <p>Set learners simple questions to practise this new equation. (F)</p>
4.5.2.1 The a.c. generator	Describe a simple form of a.c. generator (rotating coil or rotating magnet) and the use of slip rings and brushes where needed	<p>Extended assessment: 4.5.2.1 and 4.5.2.2</p> <p>Recap how the electric motor can be used in 'reverse' to induce an e.m.f by moving the shaft. Ask learners what the problem is with this set-up. They may identify that it would create a direct current, when electricity generation requires alternating current. Ask learners how this can be solved. They may suggest removing the commutator. Introduce the slip rings as the alternative that will allow a.c. to be generated.</p>
4.5.2.2	Sketch and interpret graphs of e.m.f. against time for simple a.c. generators and relate the position of the generator coil to	<p>As the coil moves up and down through a magnetic field, alternating current is induced. The direction of current continuously changes. Demonstrate this with models and/or animations.</p> <p>Sketch a graph of e.m.f against time for a simple a.c. generator and relate the position of the generator coil to the peaks, troughs and zeros of the e.m.f.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
	the peaks, troughs and zeros of the e.m.f.	<p>Set learners qualitative questions for practice. (F)</p> <p>Learners can investigate generators further using the generator simulation: (I) https://phet.colorado.edu/en/simulation/legacy/generator</p> <p>Extension: Stretch and prepare for A level Explain the generator more using Faraday's law and Lenz's law.</p>
4.5.6.1 The transformer	Describe the construction of a simple transformer with a soft iron core, as used for voltage transformations	<p>Explain that electricity generation produces alternating current and this is essential for its transport.</p> <p>Introduce the transformer by describing its construction.</p> <p>Demonstrate how different values of coils changes the secondary voltage and current. Can learners spot a pattern? Refer to the primary and secondary sides of the transformer.</p>
4.5.6.2	Use the terms primary, secondary, step-up and step-down	<p>Introduce the equation that links the voltage and the number of turns on the coil.</p> <p>Explain that a step-up transformer increases the voltage and the number of turns on the coil but decreases the current. A step-down transformer does the reverse.</p>
4.5.6.3	Recall and use the equation $\frac{V_P}{V_S} = \frac{N_P}{N_S}$ where p and s refer to primary and secondary	<p>Set learners quantitative and qualitative questions for practice. (F)</p> <p>Demonstrate a model of how transformers are used in the transmission of electricity. If possible, use a multimeter to take measurements of voltage before and after the step-up or step-down transformers. Explain the advantages of high-voltage transmission.</p>
4.5.6.4	Describe the use of transformers in high-voltage transmission of electricity	<p>Transformers and electricity transmission: www.bbc.co.uk/bitesize/guides/zgb9hv4/revision/3</p> <p>Learners can investigate electricity transmission further using the power lines animation: (I) www.schoolphysics.co.uk/animations/Electricity%20-%20magnetism%20animations/Power_lines/index.html</p>
4.5.6.5	State the advantages of high-voltage transmission	<p>Extended assessment: 4.5.6.6, 4.5.6.7 and 4.5.6.8</p> <p>Explain the function of a transformer by breaking down how it works into simple steps.</p>
4.5.6.6	Explain the principle of operation of a simple iron-cored transformer	<p>Demonstrate the structure of a transformer and repeat the explanation of its principle of operation.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
4.5.6.7	Recall and use the equation for 100% efficiency in a transformer $I_p V_p = I_s V_s$ where <i>p</i> and <i>s</i> refer to primary and secondary	<p>Introduce the equation for power and the equation relating power, current and resistance. Demonstrate how to carry out calculations with these equations.</p> <p>Set learners calculation questions for practice. (F)</p> <p>Explain how transformers reduce power loss in the transmission of electricity. Relate to learners' understanding of resistance and energy conservation, linking to the equations.</p>
4.5.6.8	Recall and use the equation $P = I^2 R$ to explain why power losses in cables are smaller than the voltage is greater	
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

5. Nuclear physics

Syllabus ref.	Learning objectives	Suggested teaching activities
5.1.1.1 The atom	Describe the structure of an atom in terms of a positively charged nucleus and negatively charged electrons in orbit around the nucleus	<p>Ask learners to describe the structure of the atom in terms of a positively charged nucleus and negatively charged electrons in orbit around the nucleus. The nucleus is composed of protons and neutrons. Clarify any misconceptions and ensure sound understanding of the basics.</p> <p>Ask learners how ions are made. They may be able to explain that atoms form positive ions by losing electrons or negative ions by gaining electrons.</p> <p>Define the terms <i>proton number</i> (atomic number), Z and <i>nucleon number</i> (mass number), A.</p>
5.1.1.2	Know how atoms may form positive ions by losing electrons or form negative ions by gaining electrons	<p>Set learners simple questions to work out the nucleus number knowing the proton number and the nucleon number. (F)</p> <p>Introduce the term <i>nuclide</i> and use the nuclide notation A_ZX.</p> <p>Set learners simple questions to work out the number of protons and neutrons by interpreting nuclide notation. (F)</p>
5.1.1.3	<p>Describe how the scattering of alpha (α) particles by a sheet of thin metal supports the nuclear model of the atom, by providing evidence for:</p> <p>(a) a very small nucleus surrounded by mostly empty space</p> <p>(b) a nucleus containing most of the mass of the atom</p> <p>(c) a nucleus that is positively charged</p>	<p>Introduce the term <i>isotope</i> and how one element may have a number of isotopes. Show learners examples of this: uranium, carbon, radon, etc.</p> <p>Set learners simple questions to practise interpreting nuclide notation and identifying isotopes. (F)</p> <p>Learners can investigate the structure of the atom further using the simulation: (I) https://phet.colorado.edu/en/simulation/build-an-atom</p> <p>Extended assessment: 5.1.1.3, 5.1.2.7 and 5.1.2.8</p> <p>Introduce the alpha-particle scattering experiment. Explain scientists' understanding of the atom at the time (the plum pudding model) for context. What would the scientists have expected to observe? Describe the observations made by the scientists. What conclusions can be drawn? Explain that this experiment is important evidence for a very small charged nucleus surrounded by mostly empty space, containing most of the mass of the atom. Use diagrams and/or animations to help your explanation.</p> <p>Learners can investigate the alpha-particle scattering experiment further using the simulation: (I) https://phet.colorado.edu/en/simulation/rutherford-scattering</p> <p>Link learners understanding of relative charges and mass of the nucleons to the proton number and nucleon number.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
5.1.2.1 The nucleus	Describe the composition of the nucleus in terms of protons and neutrons	Set learners questions to practise interpreting the proton number and nucleon number. (F)
5.1.2.2	State the relative charges of protons, neutrons and electrons as +1, 0 and -1 respectively	
5.1.2.3	Define the terms proton number (atomic number), Z and nucleon number (mass number), A and be able to calculate the number of neutrons in a nucleus	
5.1.2.4	Use the nuclide notation A_ZX	
5.1.2.5	Explain what is meant by an isotope and state that an element may have more than one isotope	
5.1.2.7	Know the relationship between the proton number and the relative charge on a nucleus	
5.1.2.8	Know the relationship between the nucleon	

Syllabus ref.	Learning objectives	Suggested teaching activities
	number and the relative mass of a nucleus	
5.2.2.1 The three types of emission	Describe the emission of radiation from a nucleus as spontaneous and random in direction	<p>Introduce radiation as a random and spontaneous process. The emission of radiation from an unstable and decaying nucleus is random in direction and time.</p> <p>Introduce the three types of radiation: α, β and γ radiation. Rank the type of radiation in terms of their relative ionising effects and penetrating powers.</p>
5.2.2.2	Identify alpha (α), beta (β) and gamma (γ) emissions from the nucleus by recalling: <ol style="list-style-type: none"> their nature their relative ionising effects their relative penetrating abilities (β^+ are not included, β^- particles will be taken to refer to β^-) 	<p>Demonstrate the relative penetrating powers of the three types of radiation using radioactive sources and sheets of paper, aluminium and lead. Care should be taken with the radioactive sources and learners should observe at a safe distance.</p> <p>Describe the nature of each type of radiation: α-particles are two protons and two neutrons (helium nuclei), β-particles are high-speed electrons and γ radiation are high-frequency electromagnetic waves.</p> <p>Clarify that radioactive decay creates a more stable nucleus and during α-decay or β-decay, the nucleus changes to that of a different element.</p> <p>Set learners qualitative questions for practice. (F)</p> <p>Extended assessment: 5.2.2.3, 5.2.2.4, 5.2.3.3, 5.2.3.4 and 5.2.4.5</p> <p>Link the relative ionising effects of the different types of radiation to the kinetic energy and electric charge. When radiation causes a lot of ionisation, it does not penetrate very far as it loses energy and slows down.</p>
5.2.2.3	Describe the deflection of α -particles, β -particles and γ -radiation in electric fields and magnetic fields	<p>Learners consider the charge of each of the types of radiation, using their understanding of the charge of the components of the atom. Learners should identify that an α-particle has a relative charge of +2, β-particles has a relative charge of -1 and γ radiation has no charge.</p> <p>Learners consider how the types of radiation will deflect in electric fields and magnetic fields, recalling knowledge from Topic 4 Electricity and Magnetism. Deflection will depend upon the relative charge of the radiation.</p>
5.2.2.4	Explain their relative ionising effects with reference to: <ol style="list-style-type: none"> kinetic energy electric charge 	<p>Remind learners of nuclide notation and use it to explain the decay equations for α, β and γ radiation.</p> <p>Show learners different decay equations and ask them to quickly identify which type of radiation is shown. Learners can answer the questions using miniature whiteboards. (F)</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
5.2.3.1 Radioactive decay	Know that radioactive decay is a change in an unstable nucleus that can result in the emission of α -particles or β -particles and/or γ -radiation and know that these changes are spontaneous and random	<p>Set learners more complicated questions to test their understanding of α, β and γ radiation and to practise decay equations. (F)</p> <p>Learners can investigate alpha and beta decay further using the simulations. (I)</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> <p>Extension: Stretch and prepare for A level</p>
5.2.3.2	State that during α -decay or β -decay, the nucleus changes to that of a different element	<p>Learners may be interested in the decay (or 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, etc.</p> <p>Explain what occurs inside the nucleus for beta plus decay, as well as beta minus decay, and refer to the conservation of charge.</p>
5.2.3.3	Know that isotopes of an element may be radioactive due to an excess of neutrons in the nucleus and/or the nucleus being too heavy	
5.2.3.4	Describe the effect of α -decay, β -decay and γ -emissions on the nucleus, including an increase in stability and a reduction in the number of excess neutrons; the following change in the nucleus occurs during β -emission neutron \rightarrow proton + electron	

Syllabus ref.	Learning objectives	Suggested teaching activities
5.2.3.5	Use decay equations, using nuclide notation, to show the emission of α -particles, β -particles and γ -radiation	
5.2.1.1 Detection of radioactivity	Know what is meant by background radiation	Introduce the idea that radiation is all around us. Demonstrate the Geiger-Müller tube and counter and how it sporadically detects radiation without a radioactive source being present.
5.2.1.2	Know the sources that make a significant contribution to background radiation including: (a) radon gas (in the air) (b) rocks and buildings (c) food and drink (d) cosmic rays	Give learners a list of common (and less common) sources of background radiation: radon gas (in the air), rocks and buildings, food and drink, cosmic rays (from the Sun), nuclear weapons testing, nuclear power, medical, etc. Ask learners to rank them in order of most radioactive. Learners may be surprised by the order and realise that background radiation is common and largely harmless. Introduce how the count rate (as shown on a Geiger-Müller counter) is measured in counts/minute. Demonstrate how to calculate the counts/s. Introduce the cloud chamber for detection of alpha-particles. Cloud chambers can detect ionising particles, and alpha-particles leave a thick and recognisable track due to their relatively high ionisation power. Make and demonstrate a cloud chamber in the laboratory: https://home.cern/news/news/experiments/how-make-your-own-cloud-chamber
5.2.1.3	Know that ionising radiation can be measured using a detector connected to a counter	Alternatively, show learners videos of a cloud chamber in action. Introduce the spark counter as an alternative for the detection of alpha-particles. You could show videos of a spark chamber in action: www.ep.ph.bham.ac.uk/DiscoveringParticles/detection/spark-chamber/
5.2.1.4	Use count rate measured in counts/s or counts/minute	Set learners simple questions for practice. (F) Learners may enjoy watching the Veritasium video on the most radioactive places on Earth: (I) www.youtube.com/watch?v=TRL7o2kPqw0
5.2.1.5	Use measurements of background radiation to determine a corrected count rate	Extended assessment: 5.2.1.5

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Demonstrate how to find the count rate of a radioactive source by measuring the background radiation without the radioactive source. This reading is subtracted from the measurement of the radioactive source to determine a corrected count rate.</p> <p>Set learners questions to practise finding the corrected count rate. (F)</p> <p>Extension: Stretch and prepare for A level The cloud chamber can also be used to observe fundamental particles (electrons and muons). Introduce learners to the common tracks seen in a cloud chamber, what is making them and why they behave the way they do.</p> <p>The standard model: https://home.cern/science/physics/standard-model</p>
5.2.4.1 Half-life	Define the half-life of a particular isotope as the time taken for half the nuclei of that isotope in any sample to decay; recall and use this definition in simple calculations, which might involve information in tables or decay curves (calculations will not include background radiation)	<p>Introduce the half-life as the time taken for half the nuclei of that isotope in any sample to decay.</p> <p>Show learners decay curves and demonstrate how these can be interpreted to find the half-life.</p> <p>Demonstrate how to find the half-life from information in tables.</p> <p>Set learners simple questions to practise calculating the half-life from different forms of information. (F)</p> <div data-bbox="667 863 2011 959" style="border: 1px solid black; padding: 5px;"> <p>Resource Plus Carry out the <i>Model to determine half-life</i> experiment referring to Teaching Pack for lesson plans and resources.</p> </div> <p>Learners can investigate the half-life further using the radioactive half-life simulation: (I) www.glencoe.com/sites/common_assets/science/virtual_labs/E18/E18.html</p> <p>Extended assessment: 5.2.4.2 and 5.2.4.3</p> <p>Learners research the use of radiation in a household fire (smoke) alarm. (I)</p> <p>Explain how the half-life of the isotope within a household fire (smoke) alarm should be long enough to avoid regular changing of the source. Clarify that the source is not dangerous to humans in the house due to its type, location and shielding.</p> <p>5.2.4.2 Calculate half-life from data or decay curves from which background radiation has been subtracted</p> <p>5.2.4.3 Explain how the type of radiation emitted and the half-life of the isotope determine</p> <p>Show learners the inside of a household fire (smoke) alarm and use a Geiger-Müller tube and counter to detect the radiation when the shield is removed.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
	<p>which isotope is used for applications including:</p> <p>(a) household fire (smoke) alarms</p> <p>(b) irradiating food to kill bacteria</p> <p>(c) sterilisation of equipment using gamma rays</p> <p>(d) measuring and controlling thicknesses of materials with the choice of radiations used linked to penetration and absorption</p> <p>(e) diagnosis and treatment of cancer using gamma rays</p>	<p>Learners research the use of radiation to irradiate food to kill bacteria. This process makes use of radiation's ability to damage and kill living cells. (I)</p> <p>Learners research the use of radiation in measuring and controlling thicknesses of materials with the choice of radiations used linked to penetration and absorption. (I)</p> <p>Learners research the use of radiation in medicine to diagnose and treat cancer, as well as the use of sterilisation of medical equipment. (I)</p> <p>Set learners qualitative questions on the uses of radiation and half-life for practice. (F)</p> <p>Extension: Stretch and prepare for A level Introduce carbon dating as a process that dates any object that was once alive. Carbon-14 exists naturally in our atmosphere and is absorbed by plant matter through photosynthesis. This carbon is then transferred to animals who eat the plant matter or who eat animals who eat the plant matter. When a plant or animal dies, the carbon-14 decreases through radioactive decay and the amount left can be used to date the remains.</p> <p>Learners can investigate the carbon dating further using the radioactive dating game: (I) https://phet.colorado.edu/en/simulation/radioactive-dating-game</p>
5.1.2.6 The nucleus	<p>Describe the processes of nuclear fission and nuclear fusion as the splitting or joining of nuclei, to include the nuclide equation and qualitative description of mass and energy changes without values</p>	<p>Extended assessment: 5.1.2.6</p> <p>Introduce fission and fusion as different to the radiation studied so far as they are not random. They are triggered processes that release nuclear energy. However, they still carry many of the same dangers as random radiation.</p> <p>Introduce fission as the process of a massive isotope absorbing a neutron and producing two daughter nuclei and a release of energy. U-235 nuclei are commonly used and they also release two or more neutrons. These neutrons can create a chain reaction. You could use animations or simulations to help your explanation.</p> <p>Introduce fusion as the process of combining two smaller nuclei to form a larger nucleus, with the release of energy.</p> <p>Set learners simple questions for practice. (F)</p> <p>Learners can investigate nuclear fission further using the simulation: (I) https://phet.colorado.edu/en/simulation/legacy/nuclear-fission</p> <p>Extension: Stretch and prepare for A level</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		<p>Introduce the main components of a nuclear reactor, including the moderators and control rods. These components help to control the nuclear reactions and have specific roles.</p> <p>Learners identify the main components of a nuclear reactor on a diagram and link the other parts to their understanding of electricity generation: turbine, heat exchanger, etc.</p> <p>Learners may be interested to hear about, or to research, the Chernobyl disaster of 1986. The Fukushima Daiichi nuclear disaster of 2011 may also be of interest. Learners consider the similarities and differences between a nuclear disaster and a nuclear bomb. (I)</p> <p>Explain the nuclear equation for fission of uranium in nuclear reactors.</p> <p>Explain that fusion is the source of energy for stars and explain the nuclear equation for fusion of hydrogen in stars.</p> <p>Learners research current information on fusion on Earth and the difficulties scientists face in making this process viable for large-scale electricity generation.</p>
5.2.5.1 Safety precautions	State the effects of ionising radiations on living things, including cell death, mutations and cancer	<p>Learners research the health hazards of ionizing radiation. (I)</p> <p>Explain that radiation can cause damage of cells, through mutation and cell death. It can also lead to cancer.</p> <p>Learners consider in which cases α, β and γ radiation is most dangerous to humans. They should take into account their relative penetrating and ionisation powers. They should conclude that α is most dangerous when ingested or inhaled, and that β and γ can travel through the skin to damage the body internally. (I)</p>
5.2.5.2	Describe how radioactive materials are moved, used and stored in a safe way	<p>Learners research the safety precautions for handling radioactive materials. (I)</p> <p>Set learners qualitative questions for practice. (F)</p>
5.2.5.3	Explain safety precautions for all ionising radiation in terms of reducing exposure time, increasing distance between source and living tissue and using shielding to absorb radiation	<p>You could tell learners about the story of Alexander Litvinenko, who died from radiation poisoning in 2006. Using their understanding of penetrating powers they may be able to identify which type of radiation was used.</p> <p>Extended assessment: 5.2.5.3</p> <p>Discuss safety precautions. Reducing exposure time, increasing distance between source and living tissue, and using shielding are all good practices.</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
		Extension: Stretch and prepare for A level 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.
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

6. Space physics

Syllabus ref.	Learning objectives	Suggested teaching activities
6.1.1.1 The Earth	Know that the Earth is a planet that rotates on its axis, which is tilted, once in approximately 24 hours, and use this to explain observations of the apparent daily motion of the Sun and the periodic cycle of day and night	<p>Ask learners why the North and South poles of our planet experience 24 hours of darkness in winter and 24 hours of light in summer.</p> <p>Introduce the fact that the Earth rotates on its axis around the Sun at an angle. Use diagrams and/or animations to aid this explanation. Use balls to demonstrate this in the laboratory: one learner can be the Sun and you, or a second learner, move around the 'Sun' with a ball representing the Earth, rotating the 'Earth' on its axis at an angle as it orbits.</p> <p>Ask learners how long it takes for the Earth to orbit the Sun. Clarify that the orbit is slightly elliptical, but the motion can be approximated as a circle when it comes to models and calculations.</p> <p>Ask learners how long it takes for the Earth to rotate on its axis and how long it takes for the Moon to orbit the Earth. Learners may get slightly confused, so simulations may help understanding.</p>
6.1.1.2	Know that the Earth orbits the Sun once in approximately 365 days and use this to explain the periodic nature of the seasons	<p>Ask learners how long it takes for light from the Sun to reach the Earth. Clarify that although light travels faster than anything else, it still takes time to reach us.</p> <p>Extended assessment: 6.1.1.4</p>
6.1.1.3	Know that it takes approximately one month for the Moon to orbit the Earth and use this to explain the periodic nature of the Moon's cycle of phases	<p>Ask learners to define speed. They should remember the equation from Topic 1 Motion, forces and energy. If planets orbit in a circle, how can the distance they travel in one orbit be calculated? Learners may suggest using the circumference of the circle. Introduce the time period as the time it takes for one full orbit. Explain the equation and demonstrate how to use it in calculations.</p> <p>Learners practise using the orbital speed equation by calculating the speed of the hour, minute and second hand on a clock. (F)</p> <p>Set learners more questions for practice. (F)</p>
6.1.1.4	<p>Define average orbital speed from the equation $v = \frac{2\pi r}{T}$, where r is the average radius of the orbit and T is the orbital period;</p>	<p>Learners may be interested to use Google Earth or other Earth viewing apps/websites to observe our planet. NASA's Earth-Now app shows orbiting satellites. With Google Earth learners can orbit the planet or zoom in on a location, amongst other things: (I)</p> <p>https://earth.google.com/web/</p> <p>Learners investigate orbital motion further using the simulation: (I)</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
	recall and use this equation	https://phet.colorado.edu/en/simulation/gravity-and-orbits
6.1.2.1 The Solar System	<p>Describe the Solar System as containing:</p> <ul style="list-style-type: none"> (a) one star, the Sun (b) the eight named planets and know their order from the Sun (c) minor planets that orbit the Sun, including dwarf planets such as Pluto and asteroids in the asteroid belt (d) moons, that orbit the planets (e) smaller Solar System bodies, including comets and natural satellites 	<p>Ask learners to name the planets. They may be able to name all of the planets and place them in the correct order. Mnemonics may aid recall e.g. My Very Easy Method Just Speeds Up Naming. Learners can make up their own mnemonic.</p> <p>Explain that the solar system contains our Sun, the planets, dwarf planets (e.g. Pluto), moons and other smaller bodies such as comets.</p> <p>Put learners into small groups to research, prepare and present a short presentation on an assigned planet or component of the solar system. Learners should include key information about their astronomical body such as orbital distance, orbital duration, density, surface temperature and uniform gravitational field strength at the planet's surface. Learners peer mark the presentations and give critical feedback on possible improvements.</p> <p>Introduce the accretion model for the formation of the Solar System and link to learners' understanding of gravity (Topic 1 Motion, force and energy), circular motion (if covered, Topic 1 Motion, force and energy) and the components in the Solar System.</p> <p>Remind learners about gravitational forces from Topic 1 Motion, forces and energy. They should recall that different planets have different values of gravitational field strength and that this affects the gravitational force of attraction.</p> <p>Introduce the idea that the strength of the gravitational field depends on the mass of the planet and the distance from the planet.</p> <p>Introduce the idea that the Sun contains most of the mass of the Solar System and thus has a much stronger gravitational field at its surface in comparison to the planets. It is this attractive gravitational force that keeps an object in orbit around the Sun.</p> <p>Learners could use Google Mars or other apps/websites to observe the components of our solar system: (I) www.google.com/mars/</p> <p>Learners could find out how many astronauts are orbiting the Earth right now aboard the International Space Station. They research information about the astronauts and their current missions. (I)</p> <p>How many people are in space right now?: https://www.howmanypeopleareinspace.com</p>
6.1.2.2	<p>Know that, in comparison to each other, the four planets nearest the Sun are rocky and small and the four planets furthest from the Sun are gaseous and large, and explain this difference by referring to an accretion model</p>	

Syllabus ref.	Learning objectives	Suggested teaching activities
6.1.2.3	<p>for Solar System formation, to include:</p> <ul style="list-style-type: none"> (a) the model's dependence on gravity (b) the presence of many elements in interstellar clouds of gas and dust (c) the rotation of material in the cloud and the formation of an accretion disk <p>Know that the strength of the gravitational field</p> <ul style="list-style-type: none"> (a) at the surface of a planet depends on the mass of the planet (b) around a planet decreases as the distance from the planet increases 	<p>Extended assessment: 6.1.2.7, 6.1.2.8, 6.1.2.9 and 6.1.2.10</p> <p>Use comets as an example of an object in an elliptical orbit and explain that it travels faster when closer to the Sun. Use diagrams/simulations to aid this explanation. Link the motion to the conservation of energy from Topic 1 Motion, forces and energy. Clarify that planets and minor planets actually orbit in ellipses, but they are often considered approximately circular, unlike comets. Clarify that the Sun is not at the centre of an elliptical orbit.</p> <p>Consider an object traveling in an elliptical orbit and how its speed changes. Link the distance from the Sun to the gravitational attraction felt and the speed at which it travels. Link to the conservation of energy (Topic 1 Motion, forces and energy).</p> <p>Learners can investigate elliptical orbits and the variation of speed and distance using marbles: https://www.esa.int/ESA_Multimedia/Videos/2014/07/Marble-ous_ellipses_-_classroom_demonstration_video_VP02</p> <p>Set learners questions to practise analysing and interpreting planetary data: finding the mass of a planet using its density and radius (using knowledge from Topic 1 Motion, forces and energy), calculating the orbital speed using the orbital distance and duration, ranking planets in terms of their surface temperature and assessing which might be suitable for human life, calculating the weight of various masses on a planet's surface, etc. (F)</p> <p>Ask learners what happens to the gravitational force as the distance from the Sun increases. They may be able to explain that the force will decrease. Ask learners how this affects the orbital speed of the planets. Learners may make the link between the gravitational force decreasing and the orbital speed decreasing. Explain this clearly and use animations/simulations as needed. https://phet.colorado.edu/en/simulation/gravity-and-orbits</p> <p>Set learners more complicated questions to test their understanding. (F)</p>
6.1.2.5	<p>Know that the Sun contains most of the mass of the Solar System and this explains why the planets orbit the Sun</p>	
6.1.2.6	<p>Know that the force that keeps an object in orbit around the Sun is</p>	

Syllabus ref.	Learning objectives	Suggested teaching activities
6.1.2.7	<p>the gravitational attraction of the Sun</p> <p>Know that planets, minor planets and comets have elliptical orbits, and recall that the Sun is not at the centre of the elliptical orbit, except when the orbit is approximately circular</p>	
6.1.2.8	<p>Analyse and interpret planetary data about orbital distance, orbital period, density, surface temperature and uniform gravitational field strength at the planet's surface</p>	
6.1.2.9	<p>Know that the strength of the Sun's gravitational field decreases and that the orbital speeds of the planets decrease as the distance from the Sun increases</p>	
6.1.2.10	<p>Know that an object in an elliptical orbit travels faster when closer to the Sun and explain this using the conservation of energy</p>	

Syllabus ref.	Learning objectives	Suggested teaching activities
6.1.2.4 The Solar System	Calculate the time it takes light to travel a significant distance such as between objects in the Solar System	<p>Link the fact that it takes approximately 500 s for light from the Sun to reach the Earth to learners' understanding of the speed of light (previously referred to as the speed of electromagnetic waves in Topic 3 Waves). Knowing the time and the speed of light, learners calculate the approximate distance from the Sun to the Earth. They also calculate the time it takes for light to reach the other planets or for messages to reach astronauts (via radio satellites).</p> <p>Astronomical distances can be measured in light-years, where one light-year is the distance travelled in a vacuum by light in one year. This unit of distance can be useful for establishing how far away different stars are.</p>
6.2.1.1 The Sun as a star	Know that the Sun is a star of medium size, consisting mostly of hydrogen and helium, and that it radiates most of its energy in the infrared, visible and ultraviolet regions of the electromagnetic spectrum	<p>Learners could investigate the relative sizes of moons, planets, stars and galaxies using online videos/animations. (I) Scale of the Universe: https://scaleofuniverse.com</p> <p>Introduce the Sun as a star, one of many in our galaxy. In fact, it is a rather average star of a medium size. Discuss its properties and its importance to life on Earth.</p> <p>Ask learners to name stars they know. They may name the Sun, as well as commonly known stars like the Pole star (Polaris), Sirius, Betelgeuse, etc.</p>
6.2.1.2	Know that stars are powered by nuclear reactions that release energy and that in stable stars the nuclear reactions involve the fusion of hydrogen into helium	<p>Explain that stars are powered by nuclear reactions that release energy. Link to learners' understanding of fusion from Topic 1 Motion, forces and energy and Topic 5 Nuclear physics.</p> <p>Introduce the idea that a galaxy is made up of billions of stars and that ours is called the Milky Way. Other stars in our galaxy are much further away than our Sun, hence why they appear so small (and dim) in comparison.</p> <p>Extended assessment: 6.2.1.2, 6.2.2.2 and 6.2.2.3</p> <p>Learners need to know the distance of a light-year in metres. More practice calculations may aid memory recall.</p>
6.2.2.1 Stars	<p>State that:</p> <p>(a) galaxies are each made up of many billions of stars</p> <p>(b) the Sun is a star in the galaxy known as the Milky Way</p> <p>(c) other stars that make up the Milky Way are much</p>	<p>Hand out cards with the names of the stages of a star's life cycle for learners to sort. They may not have any idea of the order at this point. Move around the classroom to give them some clues.</p> <p>Explain the life cycle of a star, differentiating between less massive and more massive stars. Explain each stage, the key properties of that stage and what causes the star to transition to the next stage. Show images of each stage (where possible) and name examples: Betelgeuse is a red supergiant, the Sun is a stable star with nuclear reactions that involve the fusion of hydrogen into helium, etc.</p> <p>Set learners qualitative questions to assess understanding. (F)</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
	<p>further away from the Earth than the Sun is from the Earth</p> <p>(d) astronomical distances can be measured in light-years, where one light-year is the distance travelled in (the vacuum of) space by light in one year</p>	<p>Learners could look at photos taken by the Hubble Space Telescope. These images are amongst the best images taken of the components of our Universe and show a wide range of stars, galaxies and other astronomical bodies: (I) https://spacetelescope.org/images/archive/top100/</p> <p>Learners could look at how humans have interpreted apparent groupings of stars to form constellations and how these have been used for navigation throughout history. (I)</p>
6.2.2.2	<p>Know that one light-year is equal to 9.5×10^{15} m</p>	
6.2.2.3	<p>Describe the life cycle of a star:</p> <p>(a) a star is formed from interstellar clouds of gas and dust that contain hydrogen</p> <p>(b) a protostar is an interstellar cloud collapsing and increasing in temperature as a result of its internal gravitational attraction</p> <p>(c) a protostar becomes a stable star when the inward force of</p>	

Syllabus ref.	Learning objectives	Suggested teaching activities
	<p>gravitational attraction is balanced by an outward force due to the high temperature in the centre of the star</p> <p>(d) all stars eventually run out of hydrogen as fuel for the nuclear reaction</p> <p>(e) most stars expand to form red giants when most of the hydrogen in the centre of the star has been converted to helium</p> <p>(f) a red giant from a less massive star forms a planetary nebula with a white dwarf at its centre</p> <p>(g) a red supergiant explodes as a supernova, forming a nebula containing hydrogen and new heavier elements, leaving behind a neutron star or a black hole at its centre</p> <p>(h) the nebula from a</p>	

Syllabus ref.	Learning objectives	Suggested teaching activities
	supernova may form new stars with orbiting planets	
6.2.3.1 The Universe	Know that the Milky Way is one of many billions of galaxies making up the Universe and that the diameter of the Milky Way is approximately 100 000 light-years.	<p>Introduce our place in the Universe: we live on Earth, orbiting the Sun, the star in our solar system, part of the Milky Way galaxy, one of billions of galaxies in the finite Universe.</p> <p>Remind learners of the definition of a light-year and explain that our nearest galaxy neighbour, Andromeda, is at least 25000 light-years away from the Earth.</p> <p>Remind learners about wavelength from Topic 3 Waves and how it relates to the colour of light.</p>
6.2.3.2	Describe redshift as an increase in the observed wavelength of electromagnetic radiation emitted from receding stars and galaxies	<p>Introduce redshift as an increase in the observed wavelength of electromagnetic radiation emitted from receding stars and galaxies. If there is time, you could start by explaining the Doppler shift with sound. Learners will have heard this effect, even though they may not have realised it.</p> <p>Explain that most galaxies, made up of billions of stars, show redshift. Galaxies further away have more redshift, so they must be moving faster. Explain Hubble's Law to tie these concepts together.</p>
6.2.3.3	Know that the light emitted from distant galaxies appears redshifted in comparison to light emitted on the Earth	<p>Explain that if all the galaxies are expanding away from each other, this suggests they may have once been very close together. Introduce the <i>Big Bang</i> theory and explain how redshift is evidence for this theory. You could give a bit of history on the <i>Big Bang</i> theory: why it was a controversial theory at the time when it was proposed, the Cosmic Microwave Background as another piece of evidence, etc.</p> <p>Demonstrate a simple analogy for the <i>Big Bang</i> theory using a balloon. Partially inflate the balloon and mark multiple 'galaxies' on the surface of the balloon using a marker pen. Inflate the balloon further and explain that the 'galaxies' all move away from each other.</p>
6.2.3.4	Know that redshift in the light from distant galaxies is evidence that the Universe is expanding and supports the Big Bang theory	<p>Set learners qualitative questions for practice. (F)</p> <p>Learners investigate the expanding Universe using elastic bands and metal washers. They attach the elastic bands and metal washers in an alternating line such that there are 10 washers separated by 9 elastic bands. The washers represent the galaxies, held together by their own gravity, and the elastic bands represent the space between the galaxies. Learners pick a 'home' galaxy and measure the distance from their home galaxy to all of the other galaxies. Then they 'expand' the Universe by stretching the whole chain of elastic bands and measure the new distances. They plot a graph of the increase in distance against the original distance and consider what the experiment shows.</p> <p>The expanding Universe experiment:</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
6.2.2.5	Know that microwave radiation of a specific frequency is observed at all points in space around us and is known as cosmic microwave background radiation (CMBR)	<p>https://spark.iop.org/elastic-band-universe</p> <p>You could show learners a full timeline of the Universe to get a sense of scale and the very small amount of time humans have existed.</p> <p>Learners may enjoy the <i>Doppler Shifting</i> song by <i>AstroCapella</i>. The song is quite advanced in content, but memorable and detailed: www.astrocappella.com/doppler.shtml</p>
6.2.2.6	Explain that the CMBR was produced shortly after the Universe was formed and that this radiation has been expanded into the microwave region of the electromagnetic spectrum as the Universe expanded	<p>Learners may enjoy classifying galaxies as part of the volunteer science project Galaxy Zoo: (I) www.zooniverse.org/projects/zookeeper/galaxy-zoo/about/research</p> <p>Extended assessment: 6.2.2.5, 6.2.2.6, 6.2.2.7, 6.2.2.8, 6.2.2.9, 6.2.2.10 and 6.2.2.11</p> <p>Introduce the CMBR and Hubble's law as key evidence for the Big Bang theory. Explain how the CMBR was produced, how the signal has changed over time and how it can be detected today. Link to learners' understanding of the electromagnetic spectrum from Topic 3 Waves. Learners may find it interesting to hear how the CMBR was discovered by Penzias and Wilson whilst carrying out a separate experiment.</p> <p>Return to redshift and introduce the idea that the speed at which a galaxy is moving away from the Earth can be found from the change in wavelength of the galaxy's starlight. Explain that how far away a galaxy is can be found using the brightness of a supernova in that galaxy.</p>
6.2.2.7	Know that the speed v at which a galaxy is moving away from the Earth can be found from the change in wavelength of the galaxy's starlight due to redshift	<p>Introduce Edwin Hubble as the scientist who showed that there were many more galaxies in the Universe than people of the time thought and who investigated the motion of distant galaxies. 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. Learners need to recall and use the equation and know the current estimate for Hubble's constant. They should know that combining the equation and the constant allows for an estimate for the age of the Universe.</p>
6.2.2.8	Know that the distance of a far galaxy d can be determined using the brightness of a supernova in that galaxy	<p>Set learners questions for practice. (F)</p> <p>Ask learners what else can be surmised 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>Extension: Stretch and prepare for A level</p>

Syllabus ref.	Learning objectives	Suggested teaching activities
6.2.2.9	Define the Hubble constant H_0 as the ratio of the speed at which the galaxy is moving away from the Earth to its distance from the Earth; recall and use the equation $H_0 = \frac{v}{d}$	<p>Explain the Doppler shift of sound, as well as light, and introduce the expression $f_o = f_s v / (v \pm v_s) f$.</p> <p>Attach a buzzer to a piece of string and spin it in a circle with 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?</p> <p>Video or sound clips of vehicles passing a stationary observer clearly demonstrate the Doppler effect for sound waves. You could use video clips or diagrams to help learners visualise the emitted sound waves and how a moving source changes the wavelength and frequency.</p>
6.2.2.10	Know that the current estimate for H_0 is 2.2×10^{-18} per second	<p>Use a long spring (a slinky or a bed spring works well) to demonstrate how the waves are being emitted uniformly by the source, but if the observer moves away or towards the source, the frequency of the waves 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.</p>
6.2.2.11	Know that the equation $\frac{d}{v} = \frac{1}{H_0}$ represents an estimate for the age of the Universe and that this is evidence for the idea that all matter in the Universe was present at a single point	<p>Set learners questions to practise using the expression $f_o = f_s v / (v \pm v_s) f$. (F)</p>

Past and specimen papers

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