AQA
GCSE
9–1

Physics

Teacher Support Guide

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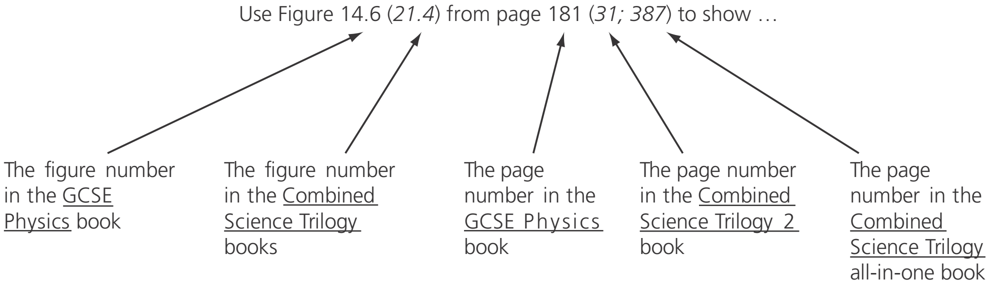
References to the textbooks in this teacher resource guide

References to the student textbooks are given in the following style:

- The first figure or page number always refers to the GCSE Physics book.
- The numbers in brackets refer to the Combined Science Trilogy books.
- Where there are two numbers in brackets, the first is for Combined Science Trilogy 1 or 2; the second number refers to the all-in-one Combined Science Trilogy book.



Use Figure 14.6 (*21.4*) from page 181 (*31; 387*) to show …

The figure number in the GCSE Physics book

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1 Energy

Overview

Specification points

4.1.1 Energy changes in a system, and the ways energy is stored before and after such changes, 4.1.2 Conservation and dissipation of energy and 4.1.3 National and global energy resources

Textbook chapter references

AQA GCSE (9-1) Physics: Chapter 1 pages 1–35

AQA GCSE (9-1) Combined Science Trilogy 1: Chapter 15 pages 258–90

AQA GCSE (9-1) Combined Science Trilogy: Chapter 15 pages 258–90

Recommended number of lessons: 18

Chapter overview	
AQA required practical(s)	Physics – RP1 CS Trilogy – RP14 Physics – RP2
Contains higher-tier material	Yes
Contains physics-only material	Yes

Useful Teaching and Learning resources

- Learning outcomes
- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–3
- Key terms
- Animation: Energy, power and efficiency
- Personal tutor: Energy and efficiency
- Personal tutor: Generating electricity
- Personal tutor: The usefulness of electrical appliances
- Personal tutor: Work done
- Practical: Determining the specific heat capacity of a material
- Teacher and technician notes: Determining the specific heat capacity of a material
- Practical: Investigating factors that affect thermal insulation – material
- Teacher and technician notes: Investigating factors that affect thermal insulation – material
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- Teacher and technician notes: Investigating factors that affect thermal insulation – thickness
- Practical video: Collecting the correct data
- Practical video: Determining specific heat capacity using the data
- Practical video: Investigating factors that affect thermal insulation
- Practical video: Investigating factors that may affect the thermal insulation by varying the thickness of a material
- Homework tasks (a) and (b)
- Quick quizzes 1–4
- Half-term test 4.1: Energy and power
- Half-term test 4.1.2: Conservation and dissipation of energy
- Answers for homework tasks
- Answers to all questions

Useful prior learning

- Energy *allows* things to happen but does not *cause* them to happen.
- Energy is a quantitative idea, and we can count or calculate the energy associated with particular systems or stores.
- The principle of conservation of energy states that energy can be neither created nor destroyed; effectively this means that the numbers always add up.
- Heat can be considered as an energy store, whereas temperature gives information about the average energy of particles in a sample. A small amount of heat may cause a large increase in temperature or vice versa.
- Our primary source of energy is the Sun. Energy reaches us from the Sun via electromagnetic (EM) radiation.
- Plants use this EM radiation in a process called photosynthesis to make glucose, a compound which provides animals (including us) energy to live.
- We generate electricity using fossil fuels and other resources.
- Energy can be transferred from a hot object to colder objects by several processes. Metals are good thermal conductors, which allow energy to be transferred quickly. Fluids (liquids and gases) transfer energy by convection.
- Energy is measured in joules, J.

Common misconceptions

- It is not a misconception as such, but many students will be more familiar with the ‘types and transformations’ model than the ‘stores and pathways’ model described here and in recent textbooks. The mathematics has not changed, only the description we use in place of numbers.
- Heat and temperature are often confused by students.
- Energy and power are frequently mixed up or used incorrectly; students will need to be

reminded to use precise physics language rather than 'everyday' English.
- The principle of conservation of energy seems to suggest that energy cannot be wasted (and students think of 'energy conservation' as saving energy by turning off lights). Describing energy as 'lost' makes this worse, and it is better to suggest that we have 'lost track of' the energy, which has been shared widely or dissipated.
- Students will frequently assume that nuclear power stations are highly dangerous, while ignoring the more serious (but gradual) concerns associated with fossil fuels, in both health and environmental contexts.

Preparation

The **T&L Topic overview** gives a brief introduction of the equations introduced during the topic, and is a useful reference for abbreviations and SI units. In most cases the mathematical approach will follow thorough consideration of the ideas with students, rather than serve as a starting point. It is probably best saved for student use as a review.

The **T&L Prior knowledge catch-up teacher sheet** has a good discussion of heat transfers, which students are likely to be familiar with from KS3 work. Depending on setting, the students will have had different experiences of energy language, and may not be familiar with the stores and pathways approach in the current KS3 specification.

Energy stores and systems: Lesson 1

Learning outcomes

1 Discuss energy store/fuel analogy.
2 List eight stores.

Suggested lesson plan

Starter

Show students several examples of chemical fuels, both foods and those that are more recognisably 'fuels'. Challenge them to identify what they have in common. Combustion and (biological) respiration may feature in their answers, which is an excellent starting point.

Main

Aim to move on quickly from the idea of 'potential' energy. Some fuels provide more energy than others, but all are stores of energy; they need the right circumstances for this to result in action. Showing students a steam engine, or a turbine spinning above a Bunsen flame, will soon suggest that there are measurable changes in the system as the fuel is consumed. Having students list changing variables is a good link to the different possible stores, but postpone discussing the mechanism if possible.

Once chemical stores are associated with fuels, students should be introduced to thermal, kinetic and gravitational stores. These are associated with changes in temperature, motion and height, respectively. Students are likely to be more confident if the equations are left until later.

Examples of other stores should be presented, perhaps as diagrams or photographs. Take care when choosing examples from previous versions of the 'energy circus' (often taught during KS3 and usually including kettles, hairdryers, etc.). Elastic stores involve a stretched or compressed object; magnetic and electrostatic stores are relevant when poles or charged objects move towards or away from each other; all atoms can be considered as nuclear stores, with an equation that most students will suggest with little prompting.

Plenary

Students can complete a table that links stores with the changing variables and, where relevant, an equation. Be clear about which of these will need to be recalled in the exam, as some are not covered quantitatively until after GCSE. Alternatively, the Test yourself questions 1–3 on page 4 of the textbook are a useful recap.

Support

Students who lack confidence in maths may find the kinetic store equation intimidating. All students may hesitate if they have not encountered the stores and pathways model before. Reinforce which measurements can be made to show a change in a particular variable, such as height or extension. The examples can be treated as a 'trailer' for lessons to come over the whole course.

Extension

Able students may be familiar with some equations already, and should be encouraged to consider the details of necessary measurements. If they suggest that the 'stores' are temporary, challenge them to suggest where the energy has gone; for example, as a moving bowling ball slows, the energy in its kinetic store is 'lost' to the thermal store of the ground (which warms up via friction) and the kinetic store of the air (the molecules of the gas are moved because of collisions).

Homework
Students could list examples of some stores from home or daily life. Nuclear, magnetic and electrostatic stores should probably be avoided at this point.

Counting energy, energy conservation: Lesson 2

Learning outcomes

1 Define the joule.
2 Practise/recall prefixes (kilo, etc.).
3 Recall the principle of conservation of energy.

Suggested lesson plan

Starter
How big a chemical store is an apple/chocolate bar/can of fizzy drink, etc? Display nutrition labels for a range of products and establish the different unit systems, calories (kcal) and joules (J). Why do we use more than one unit system? (As a hint, ask why we don't often measure human height in millimetres.)

Main
Define the joule (J) as the amount of energy needed to lift a weight of 1 newton (N) by 1 metre (m). Give some example values for common foods. This will quickly show why prefixes such as 'kilo' and 'mega' are necessary (1 kJ = 1000 J, 1 MJ = 1000 kJ = 1 000 000 J). Students may recognise higher prefixes ('giga' and 'tera') from computer memory. Provide practice questions and check answers.

Lift the apple in the air and repeat that its gravitational store has now gained a joule of energy (assuming a 100 g apple lifted 1 m). Ask students under what conditions other energy stores would be relevant; for example, a moving apple has more energy in its kinetic store. In each case, the value of energy, measured in joules, can be calculated and/or measured – which equations can they remember?

The energy must come from *somewhere*. Students should recall the principle of conservation of energy and be able to explain simple situations in terms of total energy in stores being the same before and after an event. Any apparent losses are usually due to neglecting a store, often the thermal store of the environment.

Plenary
Link these ideas by comparing the chemical store of the food eaten by a human in a day with the thermal store of the person and their surroundings. Where else does the energy 'go'? Is the energy truly lost, or just hard to measure?

Support
Calculator errors are likely to be the reason for mistakes, rather than a failure to understand the principle. Explain that this is why prefixes are used and establish a routine for calculations; for example, 'convert all numbers in a question to SI units and/or standard form before reaching for calculator'.

Some students will revert to energy *transformations* when explaining; encourage them to think of *transfers* between stores instead. Reminding them of the link to a measurable quantity may help: for example, an object that is carried upstairs (observable) has more energy in the associated gravitational store (abstract).

Extension
Able students can be encouraged to compare the quantity in joules for common situations; many will be surprised by just how much energy a chemical store involves compared with the energy stores of objects that are being lifted up or are moving fast. All equations give values in joules, and this demonstrates the principle of conservation of energy.

Homework
T&L Quick quiz: Energy 1 would be a good review of the first two lessons. Alternatively, the Test yourself questions from page 4 of the textbook could be used if not already attempted in class.

Transferring energy (circuits): Lesson 3

Learning outcomes

1 Recap eight stores, snapshot idea.
2 Consider examples of transfers.
3 Discuss common pathways/processes.

Suggested lesson plan

Starter
Provide a blank table as used in Lesson 1 and challenge students to fill in as many energy stores as possible. Remind them of the 'before and after' approach used in the previous lesson.

Main
Up to this point, energy stores have been discussed, but not how energy has been transferred between them. Return to the simple examples from the 'energy circus' and ask students to suggest possible mechanisms.

Model an explanation, emphasising the descriptions of particles and forces. It helps if verbs are used to make clear that the processes are ongoing, and can happen quickly or slowly. Students should be able to recognise common themes, becoming more fluent as they encounter more examples. Figures 1.2 to 1.5 (*15.2 to 15.4*) in the textbook may be useful prompts.

If a current flows then energy is being transferred by electrical working. Examples of heating by particles (conduction and convection) should be contrasted with heating by electromagnetic (EM) radiation. Often they will happen at the same time! If objects or particles collide and a force is exerted, this is described as mechanical working; this includes mechanical waves such as earthquakes and sound. It may also be useful to describe chemical reactions as a 'reacting process', which can be exothermic or endothermic.

Plenary
Students could be challenged to give two examples of each common pathway, one in the classroom and one from outside.

Support
Some of the ideas are abstract and students should be encouraged to return to familiar descriptions of particles and forces, rather than forcing processes into specific categories. A careful choice of examples will help them to see straightforward comparisons.

Extension
Students can be challenged to describe situations in which more than one process acts, for example a filament bulb will heat the environment by the action of particles *and* by radiation, only some of which is visible.

Homework
Sketch something that illustrates each store or describe common processes that transfer energy between them. Alternatively, attempt Chapter Review questions 1 and 2 from page 29 (*284*) of the textbook.

Calculating energy: Lesson 4

Learning outcomes

1 Introduce equations.
2 Use/explain worked examples.
3 Recall/choose correct equation to solve exam-style problems.

Suggested lesson plan

Starter
Have student 'volunteers' lift up empty and full boxes; ask which gravitational store will have more energy. Then have the same box lifted up by different heights and ask the same question. Finally, ask students to imagine identical boxes lifted by the same height – but one on Earth and the other on the Moon.

Main
Even students who think they struggle with maths can give good intuitive answers to the starter questions. Explain to the students that *they* have just told *you* the equation. In scientific language, the three factors are mass, height and strength of gravity (or gravitational field strength). Each energy store has an associated equation, but they only need to know a few of them. Record these, with definitions of variables and units.

Give a worked example for each equation to supplement those on page 6 (*263*) of the textbook. Students should attempt Test yourself questions 5–9 on page 7 (*263*) of the textbook, and could write their own questions for familiar situations. Reinforce good layout and working, possibly by adding commentary to example answers that show explanations of reasoning and marks gained.

Plenary
Read out old exam questions and have students write down which equation they would use; bonus points if they can rearrange them correctly!

Support
Encourage students to be clear about the difference between the symbols for the quantities and the abbreviations for the units; for example, *h* is the symbol for height, measured in metres, which is shortened to m. Rearranging equations (described as 'changing the subject' in maths lessons) can be an extra layer of confusion. A checklist approach may help: 'First I underline the numbers in the question, then I convert the values to SI units, then I write the symbol next to them, then I choose the equation…'.

Extension
Converting units to SI, for example kilometres into metres, is a natural next step. Able students may be tempted to skip steps; have them add their own commentary instead to enforce clarity of thought.

Homework
More questions are the obvious work to set; try Chapter review question 4 on page 29 (*284*) of the textbook. Alternatively, provide worked examples

for one or two questions *with mistakes* and have students correct them, adding explanations of what went wrong.

Changes in energy: Lesson 5

Learning outcomes

1 Test recall of equations.
2 Link equations in worked examples.
3 Solve problems independently.

Suggested lesson plan

Starter
Use Lesson starter 1 to check the students understanding of stores and pathways. This should not replace a test of their recall of the equations. Ideally, a short low-stakes recall test should continue at regular intervals throughout the course, with each new equation added to the possible questions.

Main
If not already done, a short recall test of equations would be a good idea. Hints could be provided, such as the units or abbreviations, or the measuring device used for each variable. Although not strictly needed, including equations for the elastic and thermal stores will make the test more worthwhile.

Return to the examples from previous lessons and have students choose the relevant equations for starting and ending stores. Remind students that the principle of conservation of energy means that with careful measurements the energy changes before and after will be equal, allowing calculation of unknowns. Pages 7–8 (*264*) of the textbook has some worked examples, but take time to discuss in words before the numbers are introduced.

- Falling object: gravitational store to kinetic store
- Object thrown upwards: kinetic store to gravitational store
- Object fired by spring: elastic store to kinetic store
- Object heated by burning fuel: chemical store to thermal store(s)

Students should attempt Test yourself questions 10–12 on pages 8–9 (*265*). If more are needed, direct them to Chapter review questions 5 and 6 on page 29 (*284*) of the textbook.

Plenary
Lead discussion of why real measurements may not show an *exact* match of energy before and after a process. Does this contradict the principle of conservation of energy? Dissipation is covered in a later lesson, but this reinforces the idea that we can rarely keep track of all relevant stores.

Support
Using not one but two equations to find an answer is likely to be one of the most mathematically challenging ideas in the course. Using a ‘word equation’ will help students to grasp the relationship before the calculations overwhelm them. Figures 1.2 and 1.3 (*15.2*) help to show the transfer between stores in a simple way before the equations are needed.

Extension
Challenge students to add a third column to Figure 1.5 (*15.4*) for the elastic store. Can they explain in words what is happening at each stage? Precise language (*accelerating*, *compressing*, etc.) should be expected for a clear explanation.

Homework
Students should focus on identified areas; some will need to consolidate their recall and use of one equation at a time, while others will be ready for more practice questions that link two equations to find a single value.

Work: Lesson 6

Learning outcomes

1 Recap force acting in newtons.
2 Use work done equation.
3 Link this to previous energy stores.

Suggested lesson plan

Starter
Use Lesson starter 2, which gives answers and asks students to suggest possible questions.

The second example is mgh. Write as $E = (mg)h$ alongside or under work done = force × distance and challenge students to explain the link. The best answers will recognise that weight is the force towards the centre of the Earth caused by gravity acting on a mass ($W = mg$), and that lifting an object up by a height h means exerting a force over a distance.

Main
Students should remember that forces are measured in newtons (N), and that forces have a direction. Remind them that dragging or pushing an object does not mean that you are exerting the same force as the object’s weight!

Give students a selection of objects and distances to raise/drag them through. Ask them to predict which will, in everyday language, be 'harder work'. Then have them calculate the work done in each case using the equation. Unsurprisingly, their intuition that larger forces acting over greater distances will require more effort is correct. Point out that simple machines such as ramps might allow the necessary force to be reduced, but the distance is greater.

Whenever a force is involved in moving energy between stores, we can say that work is done on an object.

Plenary
Challenge students with situations in which a force is applied that they must link to the store which gains energy, such as:

- lifting an object (gravitational)
- pushing a trolley to cause motion (kinetic)
- causing (slip) friction between surfaces (thermal)
- pushing magnets together or pulling them apart (magnetic)
- stretching a spring (elastic).

Support
The terms 'force' and 'energy' are often confused in everyday language, and it is important that students recognise when they must be more precise. It can be helpful to describe situations using a table with three columns. The first has what is observed ('I push the trolley'), the second includes an explanation of forces ('a push is a force') and the third covers energy ('it's moving so there is energy in the kinetic store').

Extension
Comparing two forces is surprisingly difficult, particularly if the students are supplying them; one person's gentle push is another's violent shove. Ask students to explain how a newtonmeter works with reference to forces and elastic stores.

Homework
Link the ideas covered so far in a mind map. Ask them to choose one colour for key words, another for maths and a third for everyday examples. This forces them to think about the ideas and how they link together, rather than using a hundred pretty colours.

Power: Lesson 7

Learning outcomes

1 Discuss 'energy' versus 'power'.
2 Define rate of energy transfer.
3 Calculate 'personal power'.

Suggested lesson plan

Starter
Batman and Wonder Woman compete to carry a heavy load to the top of Gotham Tower. Wonder Woman carries it in one trip while Batman takes longer because he splits it into 10 smaller loads. Who has done more work on the load?

Some students will recognise this is a trick question, as the *work done* is the same. The instinctive answer, that Wonder Woman has 'done' more, is about the *power* she has exerted.

Main
Introducing power as how fast work is done will allow students to grasp it quickly. Avoiding light bulbs will reduce confusion about 'wasted' energy, but speakers are likely to be familiar. Playing a louder sound requires more power so exhausts the chemical store of the battery faster. Graphs showing how electric cars deplete their battery over time are a good way to show the link to gradients. Depending on your setting, reaction rate and/or population graph curves may also be useful.

Define the watt (W) as the unit of power, equal to 1 joule transferred per second. In many cases, kilowatts (kW) and megawatts (MW) are needed. The worked example on page 11 (*267*) of the textbook is a good starting point, but try to give examples of changes to other energy stores too. You can give abstract values for the energy or have students calculate them using the equations.

The Test yourself questions on page 11 (*268*) of the textbook should not take students long.

A classic practical here (explained on page 11 (*267*) of the textbook, and including Figure 1.12 (*15.11*) is to have students calculate their personal 'power'. They need to first find the work done when they walk/run upstairs, which means measuring or calculating their weight (obviously sensitive in some cases, so having some sample data is helpful) and measuring the height of the stairs. They can then, with all due care for health and safety, race to the top. This provides work done and time taken for a power calculation.

Plenary
T&L Quick quiz: Energy 2 can be used here and also offers a good recap of previous lessons.

Support
Most students will grasp this idea without difficulty, but be prepared to prompt the use of correct 'scientific English' to distinguish between *energy* and *power* now and in the future. If in doubt, ask them which units they would use.

Extension
Encourage students to link the idea of quantitative power with the processes that transfer energy between stores; each of those can be considered as a rate, even if we do not measure it. Can they give examples of what would happen if the process was faster or slower?

Homework
T&L Half term test 4.1: Energy and power can be set as an open book exercise, or students can be given an overview and told to revise for it. Asking for evidence of revision encourages good habits, as it discourages the possibility of flicking through revision materials, and asks students to really engage with the material.

Energy changes in systems: Lesson 8

Learning outcomes

1 Discuss: temperature or heat?
2 Introduce quantity of specific heat capacity and the equation.

Suggested lesson plan

Starter
Ask students to compare the risk of a sparkler and a cup of soup at a fireworks display. What does this tell them about the difference between temperature and heat?

Main
Recap KS3 particle theory and define *temperature* as a way to measure the total energy in all of the individual kinetic stores. (This is effectively the same as the thermal store of the sample, treated as one object – the maths of this is why the gas laws work.) *Heating* is best defined as a process which transfers energy between stores and involves a temperature change.

Students should intuitively recognise that mass and amount of temperature change will affect the value of the energy change. Some materials are easier to heat up than others, which is described by their specific heat capacity. This leads to the equation (change in thermal energy = mass × specific heat capacity × temperature change), which students should be familiar with, although recall is not required. From the beginning, discourage the use of measured temperature in favour of a change, as this ensures clarity about heating or cooling.

It is likely that a worked example or two will be enough at this stage, but if practice questions are required the Test yourself questions on page 15 (*271*) of the textbook provide several. Most students will need support with these and it may be best to wait until they have seen other examples during the required practical and demonstrations.

Plenary
Using Figure 1.15 (*15.14*) on page 14 (*270*) of the textbook ask students what measurements (with devices and units) would be needed for calculating the temperature of the metal lump if both specific heat capacity values are known.

Support
Some students will panic as the equation does not naturally fit into the ‘triangle method’ for recall or rearrangement. Return to their intuitive understanding that more mass or a bigger change in temperature must mean more energy is transferred.

Extension
Have students revisit the starter. Can they explain why hot soup at a lower temperature of around 60ºC causes a worse burn than sparks at 600ºC? (Answers may reference the higher specific heat capacity of soup/water compared with iron filings, or the smaller mass of the sparks. In fact, both are relevant.)

Homework
If not attempted in the lesson, you may choose to set the Test Yourself questions on page 15 (*271*). Alternatively, students could explain why cooling a hot saucepan in cold water changes the temperature of one more than the other.

Required practical 1(*14*): Calculating specific heat capacity: Lesson 9

Learning outcomes

1 Collect data for temperature change.
2 Repeat for materials/insulation.

Suggested lesson plan

Starter
Recap the equation (change in thermal energy = mass × specific heat capacity × temperature change, $E = mc\,\Delta\theta$), pointing out that even if it is supplied in the exam the terms may not be defined. Show how it can be rearranged (‘changing the subject’ in maths language) for different situations.

Alternatively, the **T&L Practical video: Collecting the correct data** could be used as an introduction.

Main
The instructions on the **T&L Practical: Determining the specific heat capacity of a material (RP1) worksheet** should be discussed. (The details on the Teacher and technician notes may be worth keeping accessible.) The greatest complication for many students is the introduction of the equation for electrical power and you may choose to simply give an estimated or calculated power rating of the heater, instead of having the students measure current and voltage.

The experiment itself is very straightforward. Have students predict the effect of using a different material block (or a sample of water, if your heaters are suitable) and collect more data to check this. Insulating the block can also be tried, as this will reduce losses from the sample and so improve the accuracy of the calculated values.

Splitting the data collection and data analysis between two lessons allows both students and colleagues to concentrate on one aspect at a time. There are, of course, arguments to be made for other approaches and your knowledge of your class and lab arrangements will determine your choice.

Plenary
Before any calculations are performed, students should be encouraged to recognise the different results for the samples investigated, as well as the effect of insulation.

Support
As mentioned above, the calculation can appear complex if students are expected to use the equation power = current × potential difference ($P = IV$). (Please note, potential difference is often referred to as voltage, but the term that will appear in the AQA exam is potential difference).

Having a set of sample results with rounded numbers can be a useful way to reduce their anxiety.

Extension
Able students should be able to suggest reasons for their predictions and link this to real world contexts. Being clear about the direction of change (increase or decrease of measured temperature change) is a good step towards the calculations that are to follow.

Homework
Students could review the key terms for scientific measurements, many of which will be familiar from KS3, and apply a selection to the practical method used. The **T&L Key concept: Accuracy and precision** would be a good starting point here.

Calculating specific heat capacity (debrief): Lesson 10

Learning outcomes

1 Compare calculated/book values.
2 Discuss error/uncertainty.
3 Recap experimental language.

Suggested lesson plan

Starter
The **T&L Practical video: Determining specific heat capacity using the data (RP1)** would be a good recap, although you may wish to only use part of it depending on whether you provided power values in the previous lesson.

Main
At each stage of the calculation, it is worth having students explain what they are doing in words as well as running numbers through a calculator. The comparison between their calculated values and the ‘accepted data’ will naturally lead on to discussions about the quality of the data and how this was affected by the method.

The questions on the **T&L Practical: Determining the specific heat capacity of a material (RP1) worksheet** guide them through the mathematical process, although some support will be needed. (The answers are on the Teacher and technician notes.) It may be helpful to have them annotate the method with reasons and explanations, some of which are explicit in the textbook.

If the version using layers of material was attempted, this provides a good preview of the coming lessons in thermal insulation. It can be established now that the layers only slow down the loss of energy from the block’s thermal store to the surroundings. Sooner or later, everything cools down.

Plenary
Provide an example calculation with mistakes and ask students to identify and correct them, perhaps in pairs. To reinforce the importance of full working, try showing them an incorrect final answer and help them realise that they can’t identify where the mistake was.

Support
Make clear to students who struggle that the maths here is complex and will take patience to understand; this is particularly true if you have had them start from current and potential difference (voltage) readings. The key words used

when discussing the quality of data have meanings in science which are subtly different from everyday English and this should be highlighted for them.

Extension
Some students should be able to suggest improvements to the method that will lead to better data. Challenge them to consider the ideal case and why we can only approach that rather than reach it.

Homework
If not already done, the Test yourself questions in the textbook (page 15 (*271*)) and/or those on the worksheet should be completed; Chapter review questions 7 and 10 from pages 29 and 30 (*284 and 285*) are also relevant. You might also choose to use **T&L Quick quiz: Energy 3** as it covers specific heat capacity; alternatively, you could leave it for a later point as an application of spaced repetition.

Reducing energy dissipation: Lesson 11

Learning outcomes

1 Discuss why coffee cools down.
2 Define dissipated versus lost energy.
3 List cases of useful/wasted energy.

Suggested lesson plan

Starter
Place a fresh tea or coffee on the front desk and ask students to sketch the graph of temperature against time. What happens to the temperature of the room over this time? (It will increase but not by the same amount). You may choose to drink the coffee if it is safe to do so!

Main
Return to the concept of energy stores and label two boxes as thermal stores. The first is the tea/coffee while the second represents everything else in the room. The mechanism for the transfer is the focus for the following lesson, but you may choose to recap the mixture of processes involved. The focus is that the energy always moves from the higher to lower temperature object, and that because the room is larger the temperature change is much smaller.

We say that energy is wasted if it is transferred to stores we cannot easily control or use. This is often called *dissipation* and we can think of the energy as being so spread out it is inaccessible, often immeasurable. A useful comparison for students is that although the energy is still in existence, and so not technically ‘lost’, we *have* ‘lost track’ of it.

Discussion of a few examples will soon show that energy is always dissipated in some way. Although the processes vary, the end result is always the heating of the environment. The temperature rise is too small to measure in most cases because the environment is so large. Students should record some examples (such as those from the textbook) and be able to explain that we want to reduce the dissipation if possible.

Plenary
Describe or show a battery-powered electric motor lifting a mass up from the ground. Challenge them to use the idea of dissipation to explain why not all of the energy transferred from the battery’s chemical store ends up in the gravitational store of the load.

Support
This is a straightforward idea and most students will find it makes intuitive sense. Returning to the starter, it may help them to think of the hot drink as a concentrated thermal store while the room is a dilute thermal store.

Extension
Some students can be challenged to consider the implications of this. What happens when all of the other stores transfer their energy to thermal stores? What are the ultimate ‘surroundings’? (Answer: the universe… which means the energy will be *very* dissipated!)

Homework
Reviewing KS3 work on heat transfer would be a good link to the next few lessons; having students bullet-point features of conduction, convection and (thermal) radiation will prepare them for applications to house insulation.

Keeping warm at home: Lesson 12

Learning outcomes

1 Compare house insulation methods.
2 Describe in terms of reduced CCR.
3 Recap use of insulator for practical.

Suggested lesson plan

Starter
Some houses in Norway require no heating despite outside temperatures of −20°C. Can students explain how this is managed? (The people provide enough heat to keep the rooms warm as there is so much insulation that heat loss to the outside is very slow.)

Main
Provide students with a template (blank table, PowerPoint slides or similar) and have them research different house insulation methods. For each one, they should be able to explain which forms of heat transfer (conduction through solids, convection when hot gases rise, thermal radiation) is being reduced.

Figures 1.16 to 1.20 (*15.15 to 15.19*) in the textbook could be used to stimulate discussion or provide support. Ensure that their explanations are correct and encourage the use of precise language.

Plenary
An old Thermos™ flask can be carefully dismantled to show the metal or glass chamber, although the double-walled nature may need explaining. Students should be able to explain how insulating materials such as plastic reduce conduction, trapped gases or vacuum and a good seal reduce convection, and shiny surfaces reduce thermal radiation.

Support
Prompt students to associate key words with each kind of heat transfer, and explain that in most cases each method reduces one kind only. Choosing the 'best' kind depends on the situation. All together they account for dissipation from the thermal store of the house.

Extension
Can students explain the difference between *preventing* the transfer of heat and *reducing* how fast it happens? Their answers should use the idea of rates and how a higher rate will empty the thermal store of the hotter object more quickly.

Homework
Ask students to record a method, using numbered points and details about all measurements needed, to test a thermal cup that the school canteen is considering to buy for the winter.

Required practical 2: Investigating thermal insulation: Lesson 13 (Physics only)

Learning outcomes

1 List control variables, choose values.
2 Collect data for temperature change.

Suggested lesson plan

Starter
Define the results of the experiment as temperature change over a specified time and remind students that this is the *dependent variable*. Have them suggest possible *independent variables* and, once complete, clarify that anything not deliberately changed must be a *control variable* with a chosen *value*.

Main
You may wish to use one or both of the **T&L Practical videos: Investigating factors that affect thermal insulation** and **Investigating factors that affect thermal insulation by varying the thickness of a material**. If not used as an introduction, they would be a good review at the start of the following lesson.

The supporting resources focus on two possible variables, material and thickness (as number of layers). You may wish to vary the results tables depending on your practical equipment, but otherwise the two T&L Practical worksheets will cover most issues. The Teacher and technician notes will be a useful supplement.

As there is a lot of waiting around for measurements, students should be able to complete the questions in between readings. The point should be made that data loggers make it much easier to collect readings over different timescales, and in situations where humans would struggle; students are likely to suggest examples such as under the sea or in active volcanoes. It is possible to buy Bluetooth oven thermometers quite cheaply which are a good model for industrial applications.

Plenary
Given some sample data, can students predict the intermediate values? Discuss how the collected values will tell a story; students should be able to suggest (perhaps in silence using mini-whiteboards) that a graph is the best way to figure out what happens in between.

Support
Students sometimes struggle with the recording of data. Be clear that the best single value to consider is the temperature *change* over one particular timescale (the maximum on the sheet is 20 minutes). The other readings are useful because they allow the plotting of a curve.

Extension
Can students suggest what materials would be better or worse? What would happen with more layers than available in school?

Homework
Students could recap KS3 investigative work on repeating practicals, and the contrasting definitions of *repeatable* and *reproducible*. They

could also review maths work on calculating means (averages).

Investigating thermal insulation (debrief): Lesson 14 (Physics only)

Learning outcomes

1 Display data in graph/chart form.
2 Discuss consistency of class results.
3 Apply results to house insulation methods.

Suggested lesson plan

Starter

T&L Practical videos: Investigating factors that affect thermal insulation and **Investigating factors that affect thermal insulation by varying the thickness of a material** would be good here if not already used. If the students have seen them, turn off the sound and challenge them to offer their own subtitles for various points, using key vocabulary in their answers.

Main

It should be clear from the results of each group that no matter what insulation method is used, the water still cools down. Discussing the shape of the curve will allow students to focus on the temperature differential (water to room) as being important in determining cooling rate. There is likely to be some discussion about presenting the results. Number of layers is an *ordered categoric variable* – but if the thickness is measured instead, it can be treated as a *continuous variable*.

It is likely that variations in the method will make it hard to compare the numbers obtained by different groups, but the *order* obtained is likely to be more consistent. (i.e. three layers are better insulators than two layers, which are better than a single layer.) This is where clarity about *reproducible* versus *repeatable* is very important.

Plenary

Have students link the methods used to reduce the rate of heat transfer in these investigations with the house insulation methods from the earlier lesson.

Support

Having students explicitly 'translate' mathematical terms into those used in science is worthwhile for everyone. Bar charts and histograms are not quite the same, and in maths a line is *always* straight. The free download from the ASE project The Language of Maths in Science is a very valuable resource for teachers and other colleagues. If at all possible, a maths department colleague would be a really big help in your lesson.

Extension

Assign nominal costs to each method and ask students to choose the best combination for a particular budget. Contrast this with the costs of house insulation and the money saved over time.

Homework

Test yourself questions 22–25 from page 18 (*273*) of the textbook are a useful summary of the ideas from this lesson.

Efficiency: Lesson 15

Learning outcomes

1 Recap dissipated energy concept.
2 Use values in worked example.
3 Complete problems independently.

Suggested lesson plan

Starter

This could be an opportunity for another cooling cup of coffee, but a more interesting example might be a mobile phone. Treating the battery as a chemical store, can students describe:

1 Which stores the energy is transferred to over a day?
2 Which processes do most of the transferring?

(Effectively, all the energy is transferred to the thermal stores of the surroundings, but the processes are more interesting. Mechanical working by sound waves, heating by radiation including visible light from screen, EM for various data signals, heating by particles because it's warm to the touch…)

Main

Students will identify the heating by particles as a 'waste'. (Insert teacher-joke about the music they play being a waste too.) The reality is that, in most cases, because the energy always ends up in the thermal store of the surroundings, the interesting question is which *processes* are useful and which are not.

The worked examples on page 19 (*274*) of the textbook should provide a good starting point, but more practice is very helpful for most students. Efficiency is most often expressed as a percentage, but students should be reminded that, just as in maths, there is always an equivalent fraction or decimal. Efficiency can never be more than 100%.

You may choose to use Personal tutor: energy and efficiency to model the calculations. Students will also need to use the equations for various energy stores and this provides a chance for them to show if they have memorised them yet.

Plenary
Place devices on a number line from 0 to 100% efficiency based on supplied useful and wasted energy values.

Support
If students struggle with the different values, have them produce a table with columns for (a) input (b)useful output (c)wasted output (d)total output, which is the same as input. Any missing values can be figured out before using the efficiency equation (efficiency = useful power output/total power, or efficiency = useful output energy transfer/total input energy transfer output).

Extension
Provide figures for various lighting products and have students compare efficiency for incandescent bulbs, compact fluorescent lamp (energy saving) and LEDs. The same apparent brightness (so equal 'useful' power output) will have different supply power depending on method.

Homework
Extra practice is a very good idea here. Test yourself questions 26–29 from page 20 (*275*) of the textbook may be challenging for some students without support.

Increasing efficiency: Lesson 16

Learning outcomes

1. Recap work done equation.
2. Explain energy dissipated in work against friction and air resistance.
3. Give cases where these are reduced.

Suggested lesson plan

Starter
Test students on the various equations relating to energy, then concentrate on the equation for work done. When work is done against a force, it is likely that only some of the energy is transferred to a store such as gravitational or kinetic. Does this mean energy disappears?

(Answer: of course not, because that never happens. We need to look more carefully.)

Main
Remind students of lifting objects against gravity; we assume the force we work against is the weight of the object. But if, instead, we push a trolley along a surface, we are working against both 'slip' friction and the air resistance. *Some* of the work done means energy is transferred (from the chemical stores in our muscles in this case) to the kinetic store of the trolley. The rest is transferred to thermal stores, or to kinetic stores of particles in the air – which effectively means the same as the thermal store of the air anyway. This is, once more, *dissipation*.

It is worth pointing out explicitly that although slip friction reaches a maximum once an object is moving, air resistance increases with speed (although not in a linear way). This means that faster moving objects dissipate more energy to their surroundings, which means they are less efficient.

Students should be able to suggest simple ways in which friction and air resistance can be reduced, based on both KS3 science and daily experience. You may find it helpful to make links to technology lessons, as much of engineering is about reducing dissipation to increase efficiency. Try to use examples beyond the standard moving car and footballer; literally *any* object we want to move can be made more efficient.

Plenary
Swimmers at the Olympics can no longer wear the special full-body suits which had such low drag (like air resistance but for liquids) that they distorted recorded times. Why were they considered unfair?

Support
If students feel overwhelmed, encourage them to choose an example for each method of reducing dissipation that they can relate to their own daily experience, favourite sport or hobby. This reduces their stress so they can access the idea before extending it to a wider range of examples.

Extension
Students should be encouraged to explain how a moving object colliding with particles in a gas causes an increase in temperature, as this is more abstract than sliding friction between solids.

Homework
Finishing off the Test yourself questions on page 20 (*275*) of the textbook or similar practice questions will consolidate these ideas. Alternatively, they could recap energy resources work from KS3 in preparation for the next lesson.

Fossil fuels, (thermal) power stations: Lesson 17

Learning outcomes

1 Define three uses of energy resources.
2 Use data to discuss chosen resources.
3 Link process in fossil fuel power station to advantages/disadvantages.

Suggested lesson plan

Starter
If students were asked to do the preparation homework, Lesson Starter 3 would test how seriously they attempted it. If not, ask them to suggest which energy store supplies the electrical sockets in the classroom/lab. (Correct answer: it depends how far back you look.)

Main
Define an energy resource as something which allows for transport, heating or electricity generation. Power stations relate mainly to the last of these (although highlight electrical cars as a recent development).

Providing data allows for realistic comparisons, but students should be clear that recall of specific numbers is rarely needed. Instead they are expected to discuss patterns and, if needed, analyse data supplied in a question.

You will need to choose if you are teaching nuclear fission and biomass alongside fossil fuels because they are modified thermal power stations. Spending time on Figure 1.28 (*15.25*) on page 22 (*277*) of the textbook, and explaining the similarity to other fossil fuels, shows exactly why these are non-renewable but provide a much more reliable high output. Students have a tendency to think of pollution as the only possible environmental problem, and other implications should be raised.

Nuclear accidents are regarded as much more hazardous than coal-fired power stations, even though the extremely rare incidents have caused far fewer casualties than the continual use of fossil fuels.

Plenary
Challenge students to suggest alternatives to thermal power stations, and why they haven’t taken over completely. This will provide a good starting point for the next lesson.

Support
Offer reassurance that explanations, not exact recall of power output values, will be needed. The large number of linked facts for this part of the topic will be challenging for some students and you may find providing structures such as mind maps will help.

Extension
Insight into the longer-term implications should be encouraged for more able students. Encourage them to use strategies form other subjects, such as English and History, to see both sides of the arguments and recognise that there is rarely an obvious perfect solution.

Homework
Complete a summary table for thermal power stations showing the mechanism, advantages and disadvantages. If a second page covers the other power stations it will form the basis of the next lesson.

More power stations: Lesson 18

Learning outcomes

1 Define renewable/non-renewable.
2 Use different criteria to rank resources including environmental impact, carbon dioxide and cost.
3 Appreciate that no solution is perfect.

Suggested lesson plan

Starter
Have students place different resources on an opinion line from ‘non-renewable and running out now’ to ‘totally renewable’. The numbers are much less important than the approximate order.

Main
Discussing the difference between capital and running costs is likely to be a good use of time. By definition, non-renewable methods as covered previously have a high and increasing running cost because of the fuel needed.

Students can add facts to the summary table started for homework. These will soon show that, in different situations and locations, different methods seem more suitable. Many students will be surprised that even in the notoriously damp UK, solar cells provide more reliable power than (on-shore) wind turbines. The social and political implications of resource choices, both nationally and internationally, are likely to stimulate some heated discussion.

If there is time, the Test yourself questions on pages 25–26 (*280–281*) in the textbook will produce a good summary of the material.

Plenary
Students will now have covered all the content to attempt **T&L Quick quiz: Energy 4**.

Support
As in the previous lesson, the sheer amount of detail is likely to be intimidating to some students. This is likely to lead to discussion of effective revision methods, and you can point out that much of this material is familiar from KS3, although slightly elaborated.

Extension
Numerical examples of the power output from various methods in particular conditions could be used to show the complicated choices to be made. It rapidly becomes clear that without fairly dramatic changes in electricity generation our effect on the environment is likely to be negative for some time to come.

Homework
There are many choices at this point, but it is likely that you will be guided by your choice of topic test such as the **T&L Half term test 4.1.2: Conservation and dissipation of energy**.

T&L Homework tasks (a) and **(b)** could be used as in-class revision or as assigned preparation; if not used throughout the Chapter review questions from pages 29–30 (*284–285*) of the textbook could be used, perhaps in combination with the Practice questions from pages 31–33 (*286–288*).

Answers

AQA GCSE (9-1) Physics

Test yourself on prior knowledge

1 There are many possibilities, e.g.:
- going for a walk
- boiling water in an electric kettle
- going to school in a bus.

2 Coal, oil, gas.

3 Metals have free electrons which are able to move quickly and transfer thermal energy as they move from a hot part of a metal to a colder part.

Test yourself

1 **a)** Kinetic energy.
b) Elastic potential energy.
c) Chemical.
d) Gravitational potential energy.

2 The battery stores chemical energy. The battery does electrical work to light the bulb when a current flows from the battery.

3 **a)** An elastic potential energy store transfers energy to a kinetic energy store.
b) A kinetic energy store transfers energy to a thermal energy store.
c) A chemical energy store transfers energy to thermal energy stores (in the pan and in the surroundings).
d) A gravitational potential energy store transfers energy into a kinetic energy store. Then when the putty hits the ground it warms up. Then energy is transferred to a thermal energy store.

4 B 60 J
C 60 J
D 90 J

5
$$\begin{aligned} E_k &= \frac{1}{2}mv^2 \\ &= \frac{1}{2} \times 0.015 \times (240)^2 \\ &= 432\,\text{J (430 J to 2 sf)} \end{aligned}$$

6
$$\begin{aligned} E_p &= mgh \\ &= 50 \times 9.8 \times 440 \\ &= 215\,600\,\text{J} \end{aligned}$$
or 220 kJ to 2 sf

7
$$\begin{aligned} \text{Increase in } E_k &= \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 \\ &= \frac{1}{2} \times 1500 \times 20^2 - \frac{1}{2} \times 1500 \times 15^2 \\ &= 131\,250\,\text{J} \end{aligned}$$
or 130 kJ to 2 sf

8
$$\begin{aligned} E_e &= \frac{1}{2}ke^2 \\ &= \frac{1}{2} \times 2000 \times (0.08)^2 \\ &= 6.4\,\text{J} \end{aligned}$$

9
$$\begin{aligned} E_k &= \frac{1}{2}mv^2 \\ &= \frac{1}{2} \times 0.05 \times (30000)^2 \\ &= 22\,500\,000\,\text{J} \end{aligned}$$
or 22.5 MJ

10 **a)**
$$\begin{aligned} E_e &= \frac{1}{2}ke^2 \\ &= \frac{1}{2} \times 200 \times (0.01)^2 \\ &= 0.01\,\text{J} \end{aligned}$$

b) i) The elastic energy store in the ball is transferred to the gravitational energy store of the ball. So the ball has 0.01 J of E_p.

ii)
$$\begin{aligned} E_\text{p} &= mgh \\ 0.01 &= 0.0005 \times 9.8 \times h \\ h &= \frac{0.01}{0.0049} \\ &= 2.0\,\text{m to 2 sf} \end{aligned}$$

11 a) $E_e = \frac{1}{2}ke^2$

$= \frac{1}{2} \times 80 \times (0.15)^2$

$= 0.9\,\text{J}$

b) i) The elastic potential energy stored in the spring is transferred to the kinetic energy store of the trolley. So the trolley has 0.9 J of E_K.

ii) $E_k = \frac{1}{2}mv^2$

$0.9 = \frac{1}{2} \times 0.8 \times v^2$

$0.9 = 0.4v^2$

$v^2 = \frac{0.9}{0.4}$

$= 2.25$

$v = 1.5\,\text{m/s}$

12 a) $E_\text{p} = mgh$

$= 0.2 \times 9.8 \times 0.9$

$= 1.76\,\text{J}$

b) i) Gravitational potential energy stored in the mass is transferred to kinetic energy stored in the trolley and the mass. So they have a combined E_k of 1.76 J.

ii) $E_k = \frac{1}{2}(M + m)v^2$

$1.76 = \frac{1}{2} \times 1 \times v^2$

$1.76 = 0.5v^2$

$v^2 = \frac{1.76}{0.5}$

$= 3.52$

$v = 1.9\,\text{m/s}$

13 watt

14 $\text{power} = \frac{\text{energy transferred}}{\text{time}}$

15 $P = \frac{\text{work done}}{\text{time}}$

$= \frac{1200 \times 30}{90}$

$= 4000\,\text{W}$ or $4\,\text{kW}$

16 Peter: $\text{power} = \frac{\text{work done}}{\text{time}}$

$= \frac{760 \times 4.5}{3.80}$

$= 900\,\text{W}$

Hannah: $\text{power} = \frac{608 \times 4.5}{3.04}$

$= 900\,\text{W}$

17 a) work done = force × distance moved (in 1 second)

$= 150\,000\,80$

$= 12\,000\,000\,\text{J}$

or 12 MJ

b) power = work done in 1 second

= 12 MW

18 J/kg °C

19 $\Delta E = mc\Delta\theta$

$= 80 \times 1000 \times 12$

$= 960\,000\,\text{J}$

or 960 kJ

20 a) $\Delta E = mc\Delta\theta$

$= 60 \times 800 \times 30$

$= 1\,440\,000\,\text{J}$

or 1.4 = MJ to 2 sf

b) $P = \frac{E}{t}$

$200 = \frac{1440\,000}{t}$

$t = \frac{1440\,000}{200}$

$= 7200\,\text{s}$ or $2\,\text{h}$

21 a) $P = \frac{E}{t}$

$E = P \times t$

$= 700 \times 60$

$= 42\,000\,\text{J}$

b) $\Delta E = mc\Delta\theta$

$42\,000 = 0.3 \times 3800\,\Delta\theta$

$\Delta\theta = \frac{42\,000}{1140}$

$= 36.8\,°\text{C}$

final temperature = 42.8 °C (43 °C)

22 Dissipate means to spread energy out and to use wastefully.

23 Engineers streamline cars to reduce drag; engines are designed to be efficient in the use of fuel; moving parts are oiled to reduce friction.

24 Here are two more examples:

- We put a hat on when it is cold.
- We can use petrol efficiently by driving at a steady speed without rapid acceleration.

25 Here are some examples:

Loft insulation
Cavity wall insulation
Double-glazing
Carpets
Draft excluders

26 $\text{efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}}$

27 A

28 a) $E_p = mgh$
$= 72 \times 9.8 \times 0.5$
$= 353\,\text{J}$

b) $\text{efficiency} = \dfrac{353}{1500}$
$= 0.24$ or 24%

29 $\text{efficiency} = \dfrac{\text{output energy (work)}}{\text{input energy}}$

$0.36 = \dfrac{\text{output work}}{45\ \text{MJ}}$

output work $= 0.36 \times 45\,\text{MJ}$
$= 16.2\,\text{MJ}$, or 16 MJ to 2 sf

30 work done = force × distance moved in the direction of the force
If the frictional force is reduced by streamlining, less work is done against drag forces

31 a) Without the machine, the men would have to carry the bricks up the ladder in small loads. Then they have to lift their own body weight up the ladder too.

b) A lot of machines dissipate energy, e.g., a petrol driven lawn mower dissipates energy as it cuts the lawn. If we tried to cut the lawn as neatly by hand, we would dissipate more energy as we would get hot and sweaty in the process.

32 a) One that is used up and cannot be replaced, e.g. coal, oil, gas.

b) One that is replaced after it has been used, e.g. wind or wave power, wood, biofuels.

33 Uranium or plutonium; non-renewable

34 a) Coal is relatively cheap, we can use it when we want to and we can control the output of a power station.

b) Coal produces greenhouse gases which contribute to global warming, e.g. CO_2. Coal burning also produces sulfur dioxide (SO_2) which can make acid rain.

35 a) Forests and farmland can be lost. The habitats of wildlife can be destroyed. People might have to move home, as a large lake will cause extensive flooding.

b) Hydroelectric power is renewable and it is non-polluting.

36 Tides occur at regular times, twice a day; we cannot predict when the wind will blow.

37 If wind turbines are spread across the whole of Britain, we can generate some electricity when the wind is blowing in Scotland, but not in Cornwall.

38 The average power from a wind turbine is 0.4 MW.

number of turbines (N) $\times 0.4\,\text{MW} = 2000\,\text{MW}$

$N = \dfrac{2000}{0.4}$
$= 5000$

39 a) Pumped storage is useful because extra electricity can be produced at short notice when there is a need.

b) i) No, because no waste products are produced as the water falls down the mountain.

ii) This power station does not produce pollution or greenhouse gases as water is pumped up the hill; but if the electricity to do this work is generated by a coal fired power station, then that power station produces pollution and greenhouse gases.

c) $E_p = mgh$
$= 50\,000 \times 9.8 \times 200$
$= 98\,000\,000\,\text{J}$
or 98 MJ

d) power output $= 0.8 \times 98\,\text{MJ/s}$
$= 78\,\text{MW}$

e) i) In the evening.

ii) In the morning.
The station generates electricity at times of peak demand (evening) and uses electricity from other stations to pump water upwards at times of low demand (early morning).

Show you can

Page 5

The eight stores of energy are listed on Page 3, and examples of transfers are given on Pages 2 and 3.

Page 9

The principle of conservation of energy states that the total amount of energy always remains the same. Energy can be transferred from one store to another, but energy cannot be created or destroyed.

There are many demonstrations, for example:

- An object falls – energy is transferred from the gravitational potential energy store to the kinetic energy store.
- A torch cell can be used to drive a current through an electrical resistor; energy in the chemical store in the cell is transferred into the thermal energy store in the resistor and the surroundings.
- Also Questions 10, 11 and 12 give numerical examples of energy conservation.

Page 11

You need to design an experiment similar to the practical shown in Figure 1.12.

For examples: choose a weight you can lift reasonably easily (2–5 kg). Time how long it takes you to lift it, and measure the distance lifted, h.

Then $P = \frac{mgh}{t}$

This gives you the useful power of your arm but remember that you have also lifted the arm itself.

Page 15

Apparatus required:

- insulated beaker
- measuring beaker or cylinder
- heater of known power, P, when connected to a 12 V supply
- stop watch or clock
- thermometer
- power pack

Method

1 Measure 100 ml of water and pour into the insulated beaker. It is important that the beaker is insulated so that when the water is heated, the beaker does not absorb any energy. The mass of 100 ml of water is 0.1 kg.
2 Connect the heater to the power supply and place in the water. Wait for a minute and measure the temperature of the water, θ_1.
3 Turn on the power supply for 5 minutes, 300 s. Energy supplied to the water is $E = P \times t$.
4 Stir the water and measure the temperature, θ_2.
5 Now calculate the specific heat capacity using the equation:
energy supplied = mass × specific heat capacity × temperature rise
$E = m \times c \times (\theta_2 - \theta_1)$

Page 18

Calculations on the principle of energy conservation. Three examples of calculations are given in Questions 10, 11 and 12 (Pages 8 and 9).

Page 20

Connect a power supply (6 V d.c.) through a joulemeter to a 6 V d.c. motor. Turn the supply on to lift a load of mass, m. Turn off the supply when the mass has been lifted through your measured height, h.

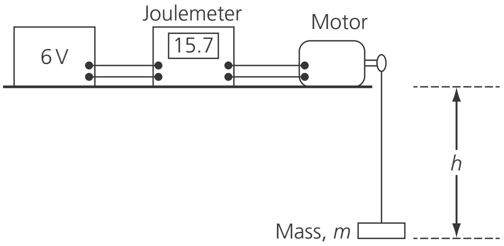
Then energy supplied is measured by the joulemeter, E_{in}.

Energy to lift the load is:

$E_p = mgh$

$$\text{efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}}$$

$$= \frac{mgh}{E_{in}}$$



Page 26

This is an open-ended question with a variety of answers, and can provide stimulus for research. By 2050 the UK government plans to reduce our CO_2 emissions by 80%. So any answer needs to include this goal. A good answer will need to consider these points, and students will be able to include many more too.

- The elimination of coal fired power stations.
- The use of gas only to boost electricity production at peak times.
- Should we use more nuclear power? What safety concerns are there here?
- How can we boost renewable energy supplies? More wind turbines? Will people protest about wind turbines on the landscape. Should we build tidal barrages? Can we boost hydroelectric power? Should we have solar panels on all houses or across the countryside?
- How much land should we use for growing crops to burn for bioelectricity production.
- Will there be new technologies for electricity production?
- Will we be able to capture carbon dioxide from power stations?

Teachers can direct students towards the government's 2050 pathways website, which allows models for an electricity generation strategy – but this provides more than is intended for this discussion question.

Required practical 1
Page 12

1 At the moment the heater is switched off, not all of the energy transferred to the heater has then been transferred to the block.

2 Not all of the energy transferred to the heater will result in an increase in the temperature of the block:
- some of the energy is used to warm up the heater itself
- some of the heater is in contact with the air so will transfer energy to the air and not to the block
- as the block warms up it will also transfer some energy to the air.

All of these factors mean that the temperature rise is not a high as it would have been had all of the energy transferred to the heater been transferred to the block. Dividing by $\Delta\theta$ means that the calculated value for c will be greater than the true value.

Required practical 2
Page 17

1 Do not put any material under the water container; keep the thermometer upright; if necessary, hold the thermometer in a clamp stand.

2 Yes – because the difference in the fall in temperature for each one of the materials was greater than 1 °C.
Or,
No – some of the materials produced the same fall in temperature so it is not possible to tell which the better insulator is. Measuring to a greater resolution may have given slightly different temperature falls.

Chapter review questions

1 The stores are:
- **a)** chemical
- **b)** kinetic
- **c)** elastic potential
- **d)** gravitational potential.

2 **a)** A chemical store in the battery transfers thermal energy to the surroundings.
b) A thermal store in the soup transfers thermal energy to the surroundings.
c) A chemical store in the battery transfers thermal energy to the surroundings and to a gravitational potential energy store in the load.
d) A chemical store in the firework transfers energy to a thermal store in the surroundings and into potential energy and kinetic energy stores in the firework.

3 The carpet is a poor conductor of heat, so not much heat is transferred from your feet. A kitchen tile conducts heat much better than the carpet, so your feet transfer thermal energy to the floor, and your feet feel cold.

4 **a)** $E_k = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 1400 \times 25^2$

$= 437\,500\,\text{J}$

$= 440\,\text{kJ}$ to 2 sf

b) $E_e = \frac{1}{2}ke^2$

$= \frac{1}{2} \times 40\,000 \times 0.05^2$

$= 50\,\text{J}$

c) $E_p = mgh$

$= 18 \times 9.8 \times 2.5$

$= 441\,\text{J}$

5 **a)** The potential energy store is transferred to a kinetic energy store.

$mgh = \frac{1}{2}mv^2$

$= 45 \times 9.5 \times 4 = \frac{1}{2} \times 45 \times v^2$

$v^2 = 78.4$

$v = 8.9\,\text{m/s}$ to 2 sf

b) A frictional force will slow the girl down.

6 The potential energy store is transferred to an elastic potential energy store.

$mgh = \frac{1}{2}ke^2$

$= 55 \times 9.8 \times 5 = \frac{1}{2} \times 35\,000 \times e^2$

$$e^2 = \frac{55 \times 9.8 \times 5}{\frac{1}{2} \times 35000}$$

$e^2 = 0.154$

$e = 0.39\,\text{m}$ or $39\,\text{cm}$

7 **a)** Energy is transferred from the gravitational potential energy store to the thermal energy store of the shot.

b) $E_p = 50 \times m \times g \times h$

$= 50 \times 0.05 \times 9.8 \times 1$

$= 24.5\,\text{J}$

c) $\Delta E = mc\Delta\theta$

$24.5 = 0.05 \times 160 \times \Delta\theta$

$$\Delta\theta = \frac{24.5}{0.05 \times 160}$$

$= 3.1\,°\text{C}$

d) Some thermal energy will be transferred from the lead shot to the surroundings.

8 The work done on the ball is equal to the gain in its kinetic energy store.

$F \times d = \frac{1}{2}mv^2$

$300 \times 2.0 = \frac{1}{2} \times 0.45 \times v^2$

$$v^2 = \frac{300 \times 0.2}{\frac{1}{2} \times 0.45}$$

$v^2 = 267$

$v = 16.3\,\text{m/s}$

9 $$\text{useful power out} = \frac{\text{work}}{\text{time}} = \frac{mgh}{\text{time}}$$

$$= \frac{80 \times 9.8 \times 3}{12}$$

$$= 196\,\text{W}$$

$$\text{efficiency} = \frac{\text{useful power out}}{\text{power input}}$$

$$= 196/800$$

$$= 0.245 \text{ or } 24.5\%$$

10 a) $$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$900 = \frac{\text{mass}}{200 \times 10^{-6}}$$

$$\text{mass} = 900 \times 200 \times 10^{-6}$$

$$= 0.18\,\text{kg}$$

b) $E = P \times t$

$= 24 \times 10 \times 60$

$= 14\,400\,\text{J}$

c) $\Delta E = mc\Delta\theta$

$14\,400 = 0.18 \times c \times 72$

$$c = \frac{14\,400}{0.18 \times 72}$$

$$= 1110\,\text{J/kg}\,°\text{C}$$

11 a) $$E_k = \frac{1}{2}mv^2$$

$$= \frac{1}{2} \times 0.0015 \times 3^2$$

$$= 0.00675\,\text{J}$$

b) $$= \frac{0.00675}{0.025}$$

$$= 0.27\,\text{W}$$

Practice questions

1 watts *[1 mark]*

2 J/kg °C *[1 mark]*

3 $$\text{efficiency} = \frac{\text{useful power out}}{\text{power input}}$$

$$= \frac{600}{2000}$$ *[1 mark]*

$$= 0.3 \text{ or } 30\%$$ *[1 mark]*

4 Advantages:

- wind power is renewable and never runs out
- wind power is clean and non-polluting. *[1 mark]*

Disadvantages:

- wind power is unreliable and only works when it is windy
- sometimes the wind is so strong that the turbines have to be switched off. *[1 mark]*

1 mark each for an advantage and one for a disadvantage.

5 a) Carbon dioxide is thought to contribute to global warming. *[1 mark]*

b) i) Coal. *[1 mark]*

ii) These are categoric variables. There are three specific types of fuel, there is no reason to look for a trend in a line graph. *[1 mark]*

c) i) Tides, hydroelectric, wind, geothermal. *[1 mark]*

ii) Plants grow again and they absorb CO_2 to enable them to grow. *[1 mark]*

6 a) i) Categoric. *[1 mark]*

ii) The amount of water in the same beaker. *[1 mark]*

The distance of the firelighter below the beaker. *[1 mark]*

iii) Burning your fingers. Inhaling fumes from the firelighter. *[1 mark]*

iv) Use a longer thermometer with a more sensitive scale

Or: use an electronic thermometer. *[1 mark]*

b) i) It looks as if H&S Firelighter is better than brand X. *[1 mark]*

However, we need to check it again to be certain that it is better than brand Y – the temperature difference is only 2°C. *[1 mark]*

ii) Energy is used to warm up the glass beaker and thermometer. *[1 mark]*

Energy is dissipated to the surroundings including the support for the firelighter and the tripod. *[1 mark]*

Energy is also radiated away from the flame as electromagnetic radiation and light. *[1 mark]*

2 of the 3 points earn both marks.

7 a) $E_p = mgh$

$= 60 \times 9.8 \times 495$ *[1 mark]*

$= 291\,060\,\text{J}$ or $291\,\text{kJ}$

[1 mark] [1 mark] unit

b) $$P = \frac{E}{t}$$

$$\frac{291060}{35 \times 60}$$ *[1 mark] [1 mark]* time in s

$= 138\,\text{W}$ *[1 mark]*

c) $$\text{efficiency} = \frac{\text{useful power out}}{\text{power input}}$$

$$0.2 = \frac{291060}{\text{input energy}}$$ *[1 mark]*

input energy $= \dfrac{291060}{0.2}$

$= 1\,455\,300\,\text{J}$ *[1 mark]*

$= 1455\,\text{kJ}$

So number of slices of bread $= \dfrac{1455}{400}$

$= 3.6$

The tourist needs to eat four slices to make sure he gets there. *[1 mark]*

d) Most of the energy is transferred to the thermal stores of the surroundings. *[1 mark]*

8 a) $E_p = mgh$ *[1 mark]*

$= 40 \times 9.8 \times 5.8$ *[1 mark]*

$= 2274\,\text{J}$ *[1 mark]*

b) Useful energy delivered per second:

$\dfrac{5 \times 2274}{60}$ *[1 mark]*

$= 189\,\text{J/s}$ or $189\,\text{W}$ *[1 mark]*

c) efficiency $= \dfrac{\text{useful power out}}{\text{power input}}$

$0.35 = \dfrac{189}{\text{input power}}$ *[1 mark]*

input power $= \dfrac{189}{0.35}$ *[1 mark]*

$= 541\,\text{W}$ or $540\,\text{W}$ to 2 sf *[1 mark]*

9 Increase in $E_k = \dfrac{1}{2}mv_1^2 - \dfrac{1}{2}mv_2^2$ *[1 mark]*

$\left(\dfrac{1}{2} \times 1500 \times 25^2\right) - \left(\dfrac{1}{2} \times 1500 \times 15^2\right)$ *[1 mark]*

$= 468\,750 - 168\,750$

$= 300\,000\,\text{J}$ *[1 mark]*

= or 300 kJ to 2 sf

10 a) $E_k = \dfrac{1}{2}mv^2$

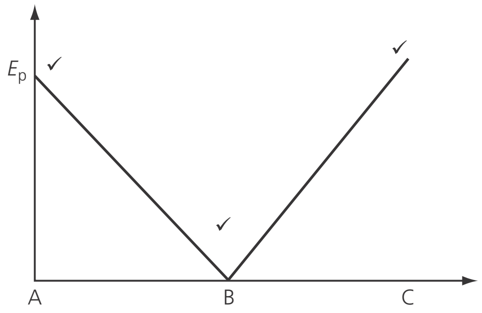
$10\,830 = \dfrac{1}{2} \times 60 \times v^2$ *[1 mark]*

$v^2 = \dfrac{10\,830}{30}$

$v^2 = 361$ *[1 mark]*

$v = 19\,\text{m/s}$ *[1 mark]*

b)



[3 marks]

c) Since energy is transferred from the child's potential energy story to the kinetic energy store as she falls, the original potential energy store is also 10 830 J.

So: $10\,830 = mgh$ *[1 mark]*

$10\,830 = 60 \times 9.8 \times h$ *[1 mark]*

$h = \dfrac{10\,830}{588}$

$= 18.4\,\text{m}$ or $18\,\text{m}$ to 2 sf *[1 mark]*

11 a) work = force × distance *[1 mark]*

$= 2000 \times 15$ *[1 mark]*

$= 30\,000\,\text{J}$ or $30\,\text{kJ}$ *[1 mark]*

b) distance = speed × time

$50 = 5 \times t$ *[1 mark]*

$t = 10\,\text{s}$ *[1 mark]*

c) power $= \dfrac{\text{energy}}{\text{time}}$

$6000 = \dfrac{E}{10}$ *[1 mark]*

$E = 60\,000\,\text{J}$ or $60\,\text{kJ}$ *[1 mark]*

d) efficiency $= \dfrac{\text{useful power out}}{\text{power input}}$

$= \dfrac{30\,\text{kJ}}{60\,\text{kJ}}$ *[1 mark]*

$= 0.5$ or 50% *[1 mark]*

12 a) $E_p = mgh$ *[1 mark]*

$= 1 \times 9.8 \times 7$ *[1 mark]*

$= 68.6\,\text{J}$ *[1 mark]*

b) volume = area × height *[1 mark]*

$= 200 \times 10^6 \times 5$

$= 10^9\,\text{m}^3$ *[1 mark]*

c) mass $= 1.4 \times 10^9 \times 1000$ *[1 mark]*

$= 1.4 \times 10^{12}$ *[1 mark]*

d) E_p = energy per kg × mass *[1 mark]*

$= 68.6 \times 1.4 \times 10^{12}$ *[1 mark]*

$= 6.86 \times 10^{13}\,\text{J}$ *[1 mark]*

e) power $= \dfrac{E}{t}$ *[1 mark]*

$= \dfrac{9.8 \times 10^{13}}{6 \times 3600}$ *[1 mark]*

$= 3.2 \times 10^9\,\text{W}$ or $3200\,\text{MW}$ *[1 mark]*

but this power is only generated for half the day, because no energy is generated when the tide is rising.

f) Advantages:

- This is a lot of power.
- There is no pollution.
- Tides are predictable.

Disadvantages:

- It would be expensive to build the barrier.
- It would damage the environment for birds.
- Power can only be generated for half the day.

1 mark for each of 2 advantages and disadvantages.

Working scientifically

1 (14.8 + 15.3 + 14.9) ÷ 3 = 15.0

2 **a)** From 2 N to 7 N (or 5 N)
  b) Weight lifted
  c) Height the weight was lifted

3 When reset it showed a reading of zero.

4 15.1

5 Graph drawn, line of best fit a curve peaking at 5 N (or slightly greater).

6 The efficiency of the motor increases with the weight until it reached 5 N.
Increasing the weight beyond 5 N decreases the efficiency.

AQA GCSE (9-1) Combined Science

Test yourself on prior knowledge

1 There are many possibilities, e.g.:
going for a walk
boiling water in an electric kettle
going to school in a bus.

2 Coal, oil, gas.

3 Metals have free electrons which are able to move quickly and transfer thermal energy as they move from a hot part of a metal to a colder part.

Test yourself

1 **a)** Kinetic energy.
  b) Elastic potential energy.
  c) Chemical.
  d) Gravitational potential energy.

2 The battery stores chemical energy. The battery does electrical work to light the bulb when a current flows from the battery.

3 **a)** An elastic potential energy store transfers energy to a kinetic energy store.
  b) A kinetic energy store transfers energy to a thermal energy store.
  c) A chemical energy store transfers energy to thermal energy stores (in the pan and in the surroundings).
  d) A gravitational potential energy store transfers energy into a kinetic energy store. Then when the putty hits the ground it warms up. Then energy is transferred to a thermal energy store.

4 B 60 J
C 60 J
D 90 J

5 $E_k = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 0.015 \times (240)^2$

$= 432\,\text{J}$ (430 J to 2 sf)

6 $E_p = mgh$

$= 50 \times 9.8 \times 440$

$= 215\,600\,\text{J}$

or 220 kJ (to 2 sf)

7 Increase in $E_k = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$

$= \frac{1}{2} \times 1500 \times 20^2 - \frac{1}{2} \times 1500 \times 15^2$

$= 131\,250\,\text{J}$

or 130 kJ (to 2 sf)

8 $E_e = \frac{1}{2}ke^2$

$= \frac{1}{2} \times 2000 \times (0.08)^2$

$= 6.4\,\text{J}$

9 $E_k = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 0.05 \times (30000)^2$

$= 22\,500\,000\,\text{J}$

or 22.5 MJ

10 a) $E_e = \frac{1}{2}ke^2$

$= \frac{1}{2} \times 200 \times (0.01)^2$

$= 0.01\,\text{J}$

b) **i)** The elastic energy store in the ball is transferred to the gravitational energy store of the ball. So the ball has 0.01 J of E_p.

ii) $E_p = mgh$

$0.01 = 0.0005 \times 9.8 \times h$

$h = \frac{0.01}{0.0049}$

$= 2.0\,\text{m}$ (to 2 sf)

11 a) $E_e = \frac{1}{2}ke^2$

$= \frac{1}{2} \times 80 \times (0.15)^2$

$= 0.9\,\text{J}$

b) **i)** The elastic potential energy stored in the spring is transferred to the kinetic energy store of the trolley. So the trolley has 0.9 IJ of E_K.

ii) $E_k = \frac{1}{2}mv^2$

$0.9 = \frac{1}{2} \times 0.8 \times v^2$

$0.9 = 0.4 \times v^2$

$v^2 = \frac{0.9}{0.4}$

$= 2.25$

$v = 1.5\,\text{m/s}$

12 a) $E_p = mgh$
$= 0.2 \times 9.8 \times 0.9$
$= 1.76\,\text{J}$

b) i) Gravitational potential energy stored in the mass is transferred to kinetic energy stored in the trolley and the mass. So they have a combined E_k of 1.76 J.

ii) $E_k = \frac{1}{2}(M + m)v^2$

$1.76 = \frac{1}{2} \times 1 \times v^2$

$1.76 = 0.5v^2$

$v^2 = \frac{1.76}{0.5}$

$= 3.52$

$v = 1.9\,\text{m/s}$

13 watt

14 $\text{power} = \frac{\text{energy transferred}}{\text{time}}$

15 $P = \frac{\text{work done}}{\text{time}}$

$= \frac{12000 \times 30}{90}$

$= 4000\,\text{w}$ or $4\,\text{kW}$

16 Peter: $\text{power} = \frac{\text{work done}}{\text{time}}$

$= \frac{760 \times 4.5}{3.80}$

$= 900\,\text{W}$

Hannah: $\text{power} = \frac{608 \times 4.5}{3.04}$

$= 900\,\text{W}$

17 a) work done = force × distance moved (in 1 second)
$= 150\,000 \times 80$
$= 12\,000\,000\,\text{J}$
or 12 MJ

b) power = work done in 1 second
= 12 MW

18 J/kg °C

19 $\Delta E = mc\Delta\theta$
$= 80 \times 1000 \times 12$
$= 960\,000\,\text{J}$
or 960 kJ

20 a) $\Delta E = mc\Delta\theta$
$= 60 \times 800 \times 30$
$= 1\,440\,000\,\text{J}$
or = 1.4 MJ (to 2 sf)

b) $P = \frac{E}{t}$

$200 = \frac{1\,440\,000}{t}$

$t = \frac{1\,440\,000}{t}$

$= 7200\,\text{s}$ or 2 h

21 a) $P = \frac{E}{t}$

$E = P \times t$
$= 700 \times 60$
$= 42\,000\,\text{J}$

b) $E = mc\Delta\theta$
$42\,000 = 0.3 \times 3800\,\Delta\theta$

$\Delta\theta = \frac{42\,000}{1140}$

$= 36.8\,°\text{C}$

final temperature = 42.8 °C (43 °C)

22 Dissipate means to spread energy out and to use wastefully.

23 Engineers streamline cars to reduce drag; engines are designed to be efficient in the use of fuel; moving parts are oiled to reduce friction.

24 Here are two more examples:
We put a hat on when it is cold.
We can use petrol efficiently by driving at a steady speed without rapid acceleration.

25 Here are some examples:
Loft insulation
Cavity wall insulation
Double-glazing
Carpets
Draft excluders

26 $\text{efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}}$

27 A

28 a) $E_p = mgh$
$= 72 \times 9.8 \times 0.5$
$= 353\,\text{J}$

b) $\text{Efficiency} = \frac{353}{1500}$

$= 0.24$ or 24%

29 $\text{efficiency} = \frac{\text{output energy (work)}}{\text{input energy}}$

$0.36 = \frac{\text{output work}}{45\text{MJ}}$

output work = 0.36 × 45 MJ

30 work done = force × distance moved in the direction of the force
If the frictional force is reduced by streamlining, less work is done against drag forces

31 a) Without the machine, the men would have to carry the bricks up the ladder in small loads. Then they have to lift their own body weight up the ladder too.

b) A lot of machines dissipate energy, e.g., a petrol driven lawn mower dissipates energy as it cuts the lawn. If we tried to cut the lawn as neatly by hand, we would dissipate more energy as we would get hot and sweaty in the process.

32 a) One that is used up and cannot be replaced, e.g. coal, oil, gas.

b) One that is replaced after it has been used, e.g. wind or wave power, wood, biofuels.

33 Uranium or plutonium; non-renewable

34 a) Coal is relatively cheap, we can use it when we want to and can control the output of a power station.

b) Coal produces greenhouse gases which contribute to global warming, e.g. CO_2. Coal burning also produces sulfur dioxide (SO_2) which can make acid rain.

35 a) Forests and farmland can be lost. The habitats of wildlife can be destroyed. People might have to move home, as a large lake will cause extensive flooding.

b) Hydroelectric power is renewable and it is non-polluting.

36 Tides occur at regular times, twice a day; we cannot predict when the wind will blow.

37 If wind turbines are spread across the whole of Britain, we can generate some electricity when the wind is blowing in Scotland, but not in Cornwall.

38 The average power from a wind turbine is 0.4 MW

number of turbines (N) × 0.4 MW = 2000 MW

$$N = \frac{2000}{0.4}$$
$$= 5000$$

39 a) Pumped storage is useful because extra electricity can be produced at short notice when there is a need.

b) i) No, because no waste products are produced as the water falls down the mountain.

ii) This power station does not produce pollution or greenhouse gases as water is pumped up the hill; but if the electricity to do this work is generated by a coal fired power station, then that power station produces pollution and greenhouse gases.

c) $E_p = mgh$

$= 50\,000 \times 9.8 \times 200$

$= 98\,000\,000\,\text{J}$

or 98 MJ

d) power output = 0.8×98 MJ/s

$= 78$ MW

e) i) In the evening.

ii) In the morning.

The station generates electricity at times of peak demand (evening) and uses electricity from other stations to pump water upwards at times of low demand (early morning).

Show you can

Page 261

Stores of energy: kinetic; chemical; internal (or thermal); gravitational potential; magnetic; elastic potential; nuclear.

Examples of transfer of energy include: chemical energy stored in a battery transferred to a light, and the light striking an object and increasing its internal energy; dropping a bunch of keys onto a table, which makes a sound wave which transfers energy to the air and surrounding objects causing an increase in their store of internal energy.

Page 265

The principle of conservation of energy states that the total amount of energy always remains the same. Energy can be transferred from one store to another, but energy cannot be created or destroyed.

There are many demonstrations, for example:

- An object falls – energy is transferred from the gravitational potential energy store to the kinetic energy store.
- A torch cell can be used to drive a current through an electrical resistor; energy in the chemical store in the cell is transferred into the thermal energy store in the resistor and the surroundings.
- Also the Test yourself questions 10, 11 and 12 on page 265 give numerical examples of energy conservation.

Page 268

You need to design an experiment similar to the practical shown in Figure 15.11 page 267.

For examples: choose a weight you can lift reasonably easily (2–5 kg). Time how long it takes you

To lift it, and measure the distance lifted, h.

Then $P = \frac{mgh}{t}$

This gives you the useful power of your arm but remember that you have also lifted the arm itself.

Page 271

Apparatus required:

insulated beaker

measuring beaker or cylinder

heater of known power, P, when connected to a 12 V supply

stop watch or clock

thermometer

power pack

Method

1 Measure 100 ml of water and pour into the insulated beaker. It is important that the beaker is insulated so that when the water is heated, the beaker does not absorb any energy. The mass of 100 ml of water is 0.1 kg.
2 Connect the heater to the power supply and place in the water. Wait for a minute and measure the temperature of the water, θ_1.
3 Turn on the power supply for 5 minutes, 300 s. Energy supplied to the water is $E = P \times t$.
4 Stir the water and measure the temperature, θ_2.
5 Now calculate the specific heat capacity using the equation:
energy supplied = mass × specific heat capacity × temperature rise

$$E = m \times c \times (\theta_2 - \theta_1)$$

Page 273

Calculations on the principle of energy conservation. Three examples of calculations are given in Test yourself questions 10, 11 and 12 Page 265.

Page 276

Connect a power supply (6 V d.c.) through a joulemeter to a 6 V d.c. motor. Turn the supply on to lift a load of mass, m. Turn off the supply when the mass has been lifted through your measured height, h.

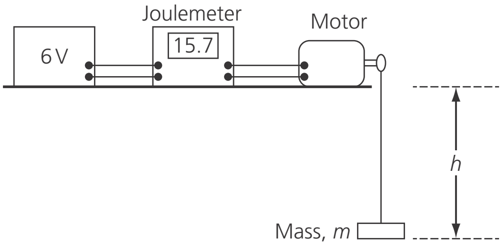
Then energy supplied is measured by the joulemeter, E_{in}.

Energy to lift the load is:

$E_p = mgh$

$$\text{efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}}$$

$$\text{efficiency} = \frac{mgh}{E_{in}}$$



Page 281

This is an open-ended question with a variety of answers, and can provide stimulus for research. By 2050 the UK government plans to reduce our CO_2 emissions by 80%. So any answer needs to include this goal. A good answer will need to consider these points, and students will be able to include many more too.

The elimination of coal fired power stations.

The use of gas only to boost electricity production at peak times.

Should we use more nuclear power? What safety concerns are there here?

How can we boost renewable energy supplies? More wind turbines? Will people protest about wind turbines on the landscape. Should we build tidal barrages? Can we boost hydroelectric power? Should we have solar panels on all houses or across the countryside?

How much land should we use for growing crops to burn for bioelectricity production.

Will there be new technologies for electricity production?

Will we be able to capture carbon dioxide from power stations?

Teachers can direct students towards the government's 2050 pathways website, which allows models for an electricity generation strategy – but this provides more than is intended for this discussion question.

Required practical 14
Page 269–70

1 At the moment the heater is switched off, not all of the energy transferred to the heater has then been transferred to the block.

2 Not all of the energy transferred to the heater will result in an increase in the temperature of the block:

- some of the energy is used to warm up the heater itself
- some of the heater is in contact with the air so will transfer energy to the air and not to the block
- as the block warms up it will also transfer some energy to the air.
- All of these factors mean that the temperature rise is not a high as it would have been had all of the energy transferred to the heater been transferred to the block. Dividing by $\Delta\theta$ means that the calculated value for c will be greater than the true value.

Chapter review questions

1 The stores are:

a) chemical

b) kinetic

c) elastic potential

d) gravitational potential.

2 a) A chemical store in the battery transfers thermal energy to the surroundings.

b) A thermal store in the soup transfers thermal energy to the surroundings.

c) A chemical store in the battery transfers thermal energy to the surroundings and to a gravitational potential energy store in the load.

d) A chemical store in the firework transfers energy to a thermal store in the surroundings and into potential energy and kinetic energy stores in the firework.

3 The carpet is a poor conductor of heat, so not much heat is transferred from your feet. A kitchen tile conducts heat much better than the carpet, so your feet transfer thermal energy to the floor, and your feet feel cold.

4 a)

$$E_k = \frac{1}{2}mv^2$$
$$= \frac{1}{2} \times 1400 \times 25^2$$
$$= 437\,500\,\text{J}$$
$$= 440\,\text{kJ (to 2 sf)}$$

b)

$$E_e = \frac{1}{2}ke^2$$
$$= \frac{1}{2} \times 40\,000 \times 0.05^2$$
$$= 50\,\text{J}$$

c)

$$E_p = mgh$$
$$= 18 \times 9.8 \times 2.5$$
$$= 441\,\text{J}$$

5 a) The potential energy store is transferred to a kinetic energy store.

$$mgh = \frac{1}{2}mv^2$$
$$= 45 \times 9.5 \times 4 = \frac{1}{2} \times 45 \times v^2$$
$$v^2 = 78.4$$
$$v = 8.9\,\text{m/s (to 2 sf)}$$

b) A frictional force will slow the girl down.

6 The potential energy store is transferred to an elastic potential energy store.

$$mgh = \frac{1}{2}ke^2$$
$$= 55 \times 9.8 \times 5 = \frac{1}{2} \times 35\,000 \times e^2$$
$$e^2 = \frac{55 \times 9.8 \times 5}{\frac{1}{2} \times 35000}$$
$$e^2 = 0.154$$
$$e = 0.39\,\text{m or } 39\,\text{cm}$$

7 a) Energy is transferred from the gravitational potential energy store to the thermal energy store of the shot.

b)

$$E_p = 50 \times m \times g \times h$$
$$= 50 \times 0.05 \times 9.8 \times 1$$
$$= 24.5\,\text{J}$$

c)

$$\Delta E = mc\Delta\theta$$
$$24.5 = 0.05 \times 160 \times \Delta\theta$$
$$\Delta\theta = \frac{24.5}{0.05 \times 160}$$
$$= 3.1\,°\text{C}$$

d) Some thermal energy will be transferred from the lead shot to the surroundings.

8 The work done on the ball is equal to the gain in its kinetic energy store.

$$F \times d = \frac{1}{2}mv^2$$
$$300 \times 2.0 = \frac{1}{2} \times 0.45 \times v^2$$
$$v^2 = \frac{300 \times 0.2}{\frac{1}{2} \times 0.45}$$
$$v^2 = 267$$
$$v = 16.3\,\text{m/s}$$

9

$$\text{useful power out} = \frac{\text{work}}{\text{time}} = \frac{mgh}{\text{time}}$$
$$= \frac{80 \times 9.8 \times 3}{12}$$
$$= 196\,\text{W}$$

$$\text{efficiency} = \frac{\text{useful power out}}{\text{power input}}$$

$$= 196/800$$

$$= 0.245 \text{ or } 24.5\%$$

10 a) $\text{density} = \dfrac{\text{mass}}{\text{volume}}$

$$900 = \frac{\text{mass}}{200 \times 10^{-6}}$$

$$\text{mass} = 900 \times 200 \times 10^{-6}$$

$$= 0.18\,\text{kg}$$

b) $E = P \times t$

$$= 24 \times 10 \times 60$$

$$= 14\,400\,\text{J}$$

c) $\Delta E = mc\Delta\theta$

$$14\,400 = 0.18 \times c \times 72$$

$$c = \frac{14\,400}{0.18 \times 72}$$

$$= 1111\,\text{J/kg}\,°\text{C}$$

11 a) $E_k = \dfrac{1}{2}mv^2$

$$= \frac{1}{2} \times 0.0015 \times 3^2$$

$$= 0.00675\,\text{J}$$

b) $= \dfrac{0.00675}{0.025}$

$$= 0.27\,\text{W}$$

Practice questions

1 watts *[1 mark]*

2 J/kg °C *[1 mark]*

3 $\text{efficiency} = \dfrac{\text{useful power out}}{\text{power input}}$

$= \dfrac{600}{2000}$ *[1 mark]*

$= 0.3$ or 30% *[1 mark]*

4 Advantages:

- wind power is renewable and never runs out
- wind power is clean and non-polluting.

Disadvantages:

- wind power is unreliable and only works when it is windy
- sometimes the wind is so strong that the turbines have to be switched off.

[2 marks, 1 for an advantage and 1 for a disadvantage]

5 a) Carbon dioxide is thought to contribute to global warming. *[1 mark]*

b) i) Coal. *[1 mark]*

ii) These are categoric variables. There are three specific types of fuel, there is no reason to look for a trend in a line graph. *[1 mark]*

c) i) Tides, hydroelectric, wind, geothermal. *[1 mark]*

ii) Plants grow again and they absorb CO_2 to enable them to grow. *[1 mark]*

6 a) i) Categoric. *[1 mark]*

ii) The amount of water in the same beaker. *[1 mark]*

The distance of the firelighter below the beaker. *[1 mark]*

iii) Burning your fingers. Inhaling fumes from the firelighter. *[1 mark]*

iv) Use a longer thermometer with a more sensitive scale

Or: use an electronic thermometer. *[1 mark]*

b) i) It looks as if H&S Firelighter is better than brand X. *[1 mark]*

However, we need to check it again to be certain that it is better than brand Y – the temperature difference is only 2 °C. *[1 mark]*

ii) Two of:

Energy is used to warm up the glass beaker and thermometer.

Energy is dissipated to the surroundings including the support for the firelighter and the tripod.

Energy is also radiated away from the flame as electromagnetic radiation and light. *[2 marks]*

7 a) $E_p = mgh$

$= 60 \times 9.8 \times 495$ *[1 mark]*

$= 291060\,\text{J}$ or $291\,\text{kJ}$

[1 mark for answer, 1 for unit]

b) $P = \dfrac{E}{t}$

$= \dfrac{291060}{35 \times 60}$ *[1 mark for correct working, 1 for time in s]*

$= 138\,\text{W}$ *[1 mark]*

c) $\text{efficiency} = \dfrac{\text{useful power out}}{\text{power input}}$

$0.2 = \dfrac{291060}{\text{input energy}}$ *[1 mark]*

$$\text{input energy} = \frac{291060}{0.2}$$

$= 1\,455\,300\,\text{J}$ *[1 mark]*

$$= 1455\,\text{kJ}$$

So number of slices of bread = 1455/400

= 3.6

The tourist needs to eat four slices to make sure he gets there. *[1 mark]*

d) Most of the energy is transferred to the thermal stores of the surroundings. *[1 mark]*

8 a) $E_p = mgh$ *[1 mark]*

$= 40 \times 9.8 \times 5.8$ *[1 mark]*

$= 2274\,\text{J}$ *[1 mark]*

b) Useful energy delivered per second:

$\frac{5 \times 2274}{60}$ *[1 mark]*

$= 189\,\text{J/s}$ or $189\,\text{W}$ *[1 mark]*

c) $\text{efficiency} = \frac{\text{useful power out}}{\text{power input}}$

$0.35 = \frac{189}{\textit{input power}}$ *[1 mark]*

$\text{input power} = \frac{189}{0.35}$ *[1 mark]*

$= 541\,\text{W}$ or $540\,\text{W}$ (to 2 sf) *[1 mark]*

9 Increase in $E_k = \frac{1}{2}mv_1^2 - \frac{1}{2}mv_2^2$ *[1 mark]*

$\left(\frac{1}{2} \times 1500 \times 25^2\right) - \left(\frac{1}{2} \times 1500 \times 15^2\right)$ *[1 mark]*

$= 468\,750 - 168\,750$

$= 300\,000\,\text{J}$ *[1 mark]*

= or 300 kJ (to 2 sf)

10 a) $E_k = \frac{1}{2}mv^2$

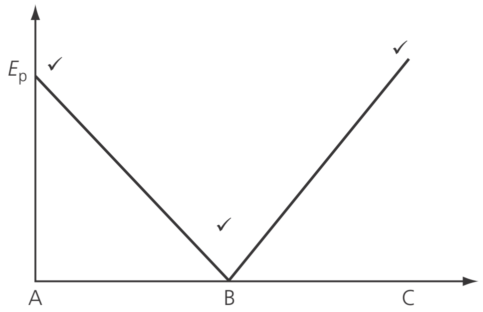
$10\,830 = \frac{1}{2} \times 60 \times v^2$ *[1 mark]*

$v^2 = \frac{10\,830}{30}$

$v^2 = 361$ *[1 mark]*

$v = 19\,\text{m/s}$ *[1 mark]*

b)



[3 marks]

c) Since energy is transferred from the child's potential energy story to the kinetic energy store as she falls, the original potential energy store is also 10 830 J.

So: $10\,830 = mgh$ *[1 mark]*

$10\,830 = 60 \times 9.8 \times h$ *[1 mark]*

$h = \frac{10\,830}{588}$

$= 18.4\,\text{m}$ or $18\,\text{m}$ (to 2 sf) *[1 mark]*

11 a) work = force × distance *[1 mark]*

$= 2000 \times 15$ *[1 mark]*

$= 30\,000\,\text{J}$ or $30\,\text{kJ}$ *[1 mark]*

b) distance = speed × time

$50 = 5 \times t$ *[1 mark]*

$t = 10\,\text{s}$ *[1 mark]*

c) $\text{power} = \frac{\text{energy}}{\text{time}}$

$6000 = \frac{E}{10}$ *[1 mark]*

$E = 60\,000\,\text{J}$ or $60\,\text{kJ}$ *[1 mark]*

d) $\text{efficiency} = \frac{\text{useful power out}}{\text{power input}}$

$= \frac{30\,\text{kJ}}{60\,\text{kJ}}$ *[1 mark]*

$= 0.5$ or 50% *[1 mark]*

12 a) $E_p = mgh$ *[1 mark]*

$= 1 \times 9.8 \times 7$ *[1 mark]*

$= 68.6\,\text{J}$ *[1 mark]*

b) volume = area × height *[1 mark]*

$= 200 \times 10^6 \times 5$

$= 10^9\,\text{m}^3$ *[1 mark]*

c) $\text{mass} = 1.4 \times 10^9 \times 1000$ *[1 mark]*

$= 1.4 \times 10^{12}\,\text{kg}$ *[1 mark]*

d) E_p = energy per kg × mass *[1 mark]*

$= 68.6 \times 1.4 \times 10^{12}$ *[1 mark]*

$= 6.86 \times 10^{13}\,\text{J}$ *[1 mark]*

e) $\text{Power} = \frac{E}{t}$ *[1 mark]*

$= \frac{9.8 \times 10^{13}}{6 \times 3600}$ *[1 mark]*

$= 3.2 \times 10^9\,\text{W}$ or $3200\,\text{MW}$ *[1 mark]*

but this power is only generated for half the day, because no energy is generated when the tide is rising.

f) Advantages:

- This is a lot of power.
- There is no pollution.
- Tides are predictable.

Disadvantages:

- It would be expensive to build the barrier.
- It would damage the environment for birds.
- Power can only be generated for half the day.

[1 mark for each of 2 advantages and disadvantages]

Working scientifically: Uncertainty, errors and precision

Pages 289–90

1 (14.8 + 15.3 + 14.9) ÷ 3 = 15.0
2 a) From 2 N to 7 N (or 5 N)
  b) Weight lifted
  c) Height the weight was lifted
3 When reset it showed a reading of zero.
4 15.1
5 Graph drawn, line of best fit a curve peaking at 5 N (or slightly greater).
6 The efficiency of the motor increases with the weight until it reached 5 N.
Increasing the weight beyond 5 N decreases the efficiency

2 Electricity

Overview

Specification points

4.2.1 Current, potential difference and resistance, 4.2.2 Series and parallel circuits, 4.2.3 Domestic uses and safety and 4.2.4 Energy transfers

Textbook chapter references

AQA GCSE (9-1) Physics: Chapter 2 pages 36–65

AQA GCSE (9-1) Combined Science Trilogy 1: Chapter 16 pages 291–317

AQA GCSE (9-1) Combined Science Trilogy: Chapter 16 pages 291–317

Recommended number of lessons: 21

Chapter overview	
AQA required practical(s)	Physics – RP3 CS Trilogy – RP15 Physics – RP4 CS Trilogy – RP16
Contains higher-tier material	Yes
Contains physics-only material	Yes

Useful Teaching and Learning resources

- Learning outcomes
- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–4
- Key terms
- Key concept: Plotting a graph
- Key concept: Unit prefixes
- Key concept: Solving numerical problems
- Key concept: Errors and uncertainties
- Key concept: Using a results table
- Personal tutor: The usefulness of electrical appliances
- Personal tutor: Static electricity
- Practical: Investigating how the length of a wire affects its resistance
- Teacher and technicians notes: Investigating how the length of a wire affects its resistance
- Practical: Investigating how series and parallel arrangements can affect the resistance of a circuit
- Teacher and technicians notes: Investigating how series and parallel arrangements can affect the resistance of a circuit
- Practical: Investigating the *I*–*V* characteristics of electrical components
- Teacher and technicians notes: Investigating the *I*–*V* characteristics of electrical components
- Practical video: Investigate factors that affect resistance of an electrical component – thickness of wire
- Practical video: Investigate factors that affect resistance of an electrical component – length of wire
- Practical video: Investigate factors that affect resistance of an electrical component – series and parallel circuits
- Practical video: Collecting data for the *I*–*V* characteristics of electrical components
- Practical video: Analysing the *I*–*V* characteristics of non-ohmic conductors
- Homework tasks (a) and (b)
- Quick quizzes 1–4
- Answers for homework tasks
- Answers to all questions
- Half-term test: Electricity
- Half-term test: Domestic uses and safety

Useful prior learning

- When two objects rub against each other, electrons can transfer from one object to another. When electrons transfer to an object it becomes negatively charged. When electrons leave an object it becomes positively charged.
- Two like charges repel each other. Two unlike charges attract each other.
- An electrical current is a flow of charge. In metals, current is a flow of electrons.
- Some materials are good conductors of electricity. Some materials do not conduct electricity. These are called insulators.
- A cell or battery has a chemical store of energy. The energy stored decreases when a charge flows.
- When the same current passes through a number of components they are said to be in series. In a parallel circuit, the current divides into different branches.

It is likely that students will feel they have covered these ideas thoroughly in KS3, but the planning here assumes that most ideas will need to be revisited. Misconceptions have often been internalised and, in particular, their practical experience is likely to be highly variable.

Common misconceptions

The main misconception is a fundamental one and it comes down to mental models. Many students think of electrons as separate objects carrying round a ‘lump’ of energy which they drop off with various components as they whizz around a circuit. This is a tempting model and can be reinforced by discussion of the maths, where we discuss each ‘coulomb’ carrying a joule of energy. It leads to the idea of current as being the speed of these particles. Many students will not be able to distinguish clearly between the ideas of current, potential difference (voltage) and power.

It is worth establishing a better model from the beginning, with a chain of electrons moving in step around the conductors. The *movement* is surprisingly slow (and this can be demonstrated with coloured ions on damp filter paper) but the *effect* is immediate because as one electron is pushed/pulled by the cell every other electron moves too. It is the movement of these particles through the components which transfers energy to them.

A useful parallel is a bicycle chain; the pedals never touch the back wheel, but the chain moves in a loop and energy is transferred. (A rusty chain is analogous to a conductor with a higher resistance, both causing heating.) For easy use in the classroom returning to a 'rope loop' model will be a useful approach through the whole topic.

Some students will struggle with the idea of quantitative resistance, failing to understand that it is a better description than the (over) simplification of conductors and insulators.

Preparation

Although the **T&L Prior knowledge catch-up student sheet** is useful in places, the high variation in settings means that local knowledge is the best guide to student starting point. Using their answers on this sheet to guide your planning will be more helpful than relying on the **T&L Prior knowledge catch-up teacher sheet** – or indeed this document – to tell you what they already know.

The **T&L Topic overview** is useful for planning and could be used as a checklist as you make progress through notes. As far as students are concerned, the content (particularly the mathematical detail) is likely to be intimidating at this stage; it may be better to produce a version with headings and key words, so they have structure without detail.

Circuit symbols: Lesson 1

Learning outcomes

1 Build a circuit from a photo.
2 Introduce basic circuit symbols.
3 List symbol, component, function.

Suggested lesson plan

Starter

Compare a standard diagram of Bunsen, tripod, beaker with a photo of the equipment. Remind them that in the same way, circuit diagrams may not look like the actual kit but they tell us what we need to know; mainly positions and connections.

Main

Have students try to build a circuit from a deliberately bad photo. When they identify the difficulty, provide a diagram with labelled components. Although we might expect them to have some recall from KS3 it is likely that understanding will be highly variable.

Introduce/recap the basic circuit symbols; you may also choose to show 'old' versions (such as the 'horseshoe' bulb) with an explanation that things change. Students should draw the symbols and include names and basic functions; you may choose to add to this list over the topic rather than covering everything now. To encourage fluency the symbols could be included with equations in a weekly recall test. (And, for reference, the symbols covered in the AQA specification can be found on page 38 (*293*) of the textbook).

Assuming all symbols are covered (at least briefly), Test yourself questions 1–4 from page 38 (*293*) of the textbook are a good check.

Plenary

Provide several diagrams and have students identify those with particular characteristics e.g. two bulbs or one cell. You could use this to assess recall of KS3 work by including features like 'parallel loops' or 'voltmeter connected wrongly'.

Support

If students struggle to make the link between drawn and actual circuits, a useful bridge is to lay out a circuit and sellotape the wires in straight lines. This allows the wire connections to be clearly matched to the diagram.

Extension

More sophisticated circuit diagrams with parallel loops and more components are a simple way to extend the complexity.

Homework

Revision of circuit symbols, components and functions.

Current and charge: Lesson 2

Learning outcomes

1 Define variables: V, I, Q.
2 Discuss the rope model of current.
3 Use relationship $Q = It$.

Suggested lesson plan

Starter

Students should be able to pick good conductors out of a list of materials. This will lead to a discussion of what allows a material to conduct, and a description of electrons that are free to move in a wire.

Main

Begin a table of quantities and remind students why symbols, units and abbreviations have different columns. You may wish to include a column for brief explanations and/or mathematical definitions.

Using *potential difference* rather than *voltage* has two benefits; it reminds students that it involves a comparison between two values and also links to the idea of this difference causing change, just like a temperature differential will lead to the transfer of heat in a predictable direction. (It is worth noting that in engineering *current* is often 'ampage', and this may be how 'voltage' came into common use.) Explaining that the symbol for current came from 'Intensity' may help some students.

Model an electrical circuit with a rope loop held loosely by students. As one person pushes/pulls (potential difference), the loop (electrons in wire) moves (current). If someone holds a little tighter (resistance), the movement is reduced and their hand feels warm (dissipation). Like all models, this is imperfect but the discussion of similarities and differences to an actual circuit can be illuminating. Adding marks to the rope with marker or electrical tape allows consideration of individual 'charges'. Counting the marks passing any point over a given time is a good introduction to current. Students will recognise that there is a link to speed, but may not be able to articulate it clearly. Buses on a route are another useful parallel; if they travel faster, then more buses will drive past your stop in a set amount of time, but frequency and speed are not the same number.

The notes on page 39 (*294*) of the textbook may seem intimidating at first glance; the common rearrangement of the equation $Q = It$ shows how the charge moved in a circuit = current flowing × time. Ensure that the definition provided highlights that time is measured in seconds and give practice calculations that force conversion of minutes into seconds. The equation can be rearranged to show that it defines one ampere or amp as one coulomb of charge (actually many electrons) passing through a point in one second.

Plenary

Linking symbols and concepts is probably the best priority here; mathematical confidence will come in time but establishing a good mental model should be the priority, particularly overcoming the assumption that current is about speed.

Support

Making explicit statements about what students can measure or model, and what is really happening, is the most important thing here. Analysing and comparing models is not always easy and telling students this can sometimes help if confidence is lacking.

Extension

Some students will be more able to describe the limitations of the model and this shows a better understanding of the physics underlying the observed situation. They should be able to explain how the measurements taken of an actual circuit link to both the model and the moving electrons.

Homework

Test yourself questions 5–7 on page 40 (*295*) of the textbook are worth using, but students may need reminders about unit conversions.

Controlling the current 1 – cells: Lesson 3

Learning outcomes

1. Discuss a troubleshooting approach.
2. Record results when changing cells.
3. Link reading on ammeter to bulb brightness.

Suggested lesson plan

Starter

Recap the main features of the rope model, in particular the link between the force exerted by the simulated cell and the resulting motion of the rope. Alternatively, use **T&L Lesson starter 1** to test their recall of component symbols *if* you introduced the whole set. By coincidence, if students choose BULB not LAMP for the third symbol, the word spells REBEL, which is a synonym for the electrical term RESIST.

Main

Talk students through a systematic approach with a demonstration of a broken circuit. Encourage them to 'think out loud' when trouble-shooting. What you model will depend on whether you use test circuits or multimeters, but emphasise that this demonstrates an understanding of the circuit itself.

Using a fixed number of bulbs, have students record changing brightness with an increasing number of cells. Adding an ammeter to the circuit allows a quantitative as well as qualitative description. The results will be much more convincing if all bulbs are identical. It should not be difficult for students to recognise that both bulb brightness and the measured current increase with more cells.

More than anything, this is an opportunity for students to increase their confidence with building and analysing electrical circuits. If preferred, this lesson could be combined with the one following. Make clear that you expect them to take turns with these tasks, rather than some being 'hands-on' while others record results. If their trouble-shooting technique is systematic you should have the opportunity to circulate and get a quick assessment of their skills, rather than spending the whole lesson fixing problems yourself.

Plenary
Return to the rope model; show that the results are consistent with the idea that with a fixed arrangement of components, the effect of increasing potential difference is to increase the current.

Support
It is likely that some students will make mistakes with the circuits; this is usually easily corrected with a systematic approach. Encourage them to check the built circuit against the diagram. You may find supplying a laminated copy of the diagram means that they can physically tick off the connections as they go.

Extension
With uniform cells (i.e. consistent potential difference for each) some students will recognise a roughly proportional relationship.

Homework
Returning to the previous lesson's key concept, have students work out how much charge flows to 'fill' the battery of their mobile phone; they will need to check the current rating and measure how long it takes. External batteries are now sold with their capacity in mAh; they should be able to convert this to coulombs (C).

$$I \times t = Q$$

$$\text{current} \times \text{time} = \text{charge}$$

$$1\,\text{A} \times 1\,\text{s} = 1\ \text{coulomb}$$

$$0.001\,\text{A} \times 3600\,\text{s} = 3.6\,\text{C}$$

Controlling the current 2 – components: Lesson 4

Learning outcomes

1 Recap effect of increasing cells.
2 Predict/test effect of more bulbs.
3 Use ammeters to test quantitative predictions.

Suggested lesson plan

Starter
Use a d.c. powerpack and ask students to predict the result of increasing potential difference (NB: use several bulbs because a single one will probably blow once you get above 6 V); this could be in terms of brightness or measured current. Once this is reviewed, the natural next step is to make a different change in the circuit.

Main
Have groups draw a sample circuit – perhaps on mini-whiteboards – and allow them to start once you have checked it. The number of cells should be fixed and the number of bulbs changing. Have them make a qualitative prediction then test quickly, before rebuilding the circuit with an ammeter.

Students should be quicker to build circuits this time and, in most cases, the results will match their expectations; more bulbs means a lower current. If there is time, the students could try moving the ammeter around in the circuit to confirm that current is the same throughout the loop.

Plenary
Provide contrasting circuit diagrams and have students predict which of each pair will have a higher current reading.

Support
As with the previous lesson, this lesson should cause no difficulties; it is effectively a review of KS3 concepts.

Extension
Challenge students to explain why the bulbs are not always the same brightness; if they suggest it is the order, have them rearrange the connections. The simple fact is that even apparently 'uniform' bulbs, e.g. from different suppliers, will have slightly different brightnesses for the same current.

Homework
Students can write a summary of the last two lessons' 'discoveries', drawing circuit diagrams to explain their points.

Ammeters, voltmeters and resistance: Lesson 5

Learning outcomes

1. Set up and use both meters.
2. Collect data for 'mystery' resistor.
3. Calculate resistance and compare with specified value.

Suggested lesson plan

Starter
Demonstrate a test circuit (cell, bulb) with a voltmeter in series, where an ammeter would logically go. Ask students why it isn't working and ask them to write down in silence their suggestions.

Main
You may have chosen to combine the previous lessons, but it is worth making sure that students can use the various meters correctly. This is particularly important if you use multimeters in your school. Good photos of the 'correct' settings with annotations may help as a ready-reference.

Have students draw a correct circuit with the voltmeter in parallel with the component being tested. They should build and use this circuit to find the potential difference across and the current through the 'mystery' resistor – ideally more than one variety so they can't easily cheat! If possible, have them repeat the readings with a different potential difference supplied (extra cells or using a d.c. powerpack).

Have them divide the potential difference by the current, then impress them by giving them the specified value of each resistor. There will be a close but not exact match in most cases. If they tried different potential differences, they should find that the calculated figure didn't change.

Explain that they have measured a basic property of a component, called *resistance* and measured in ohms (Ω). Some components have the same resistance all the time, and we say they are *ohmic*. Suggest that Ohm's law is more like a guideline because some components have varying resistance, depending on the conditions they are in; you could show them a variable resistor here. It is important they know that they can always calculate the resistance of a component, or a combination of components, using these two measurements and the relationship

$$\text{resistance} = \text{potential difference/current or } R = \frac{V}{I}.$$

Plenary
Students have now covered all the concepts for **T&L Quick quiz: Electricity 1**.

Support
There are two possible difficulties here. Some students will still be struggling with connections and proper use of the meters. Drawing the circuit on the desk (or sugar paper if needed) then taping components over the symbols may help with this. The second possibility, of course, is the maths; having results added to a table with headings that remind them of necessary steps may be a good intermediate step.

Extension
Asking students to rearrange the relationship to make current the subject will let them see potential difference as the cause, and current as the effect.

$$\frac{V}{R} = I$$

This makes it clear that doubling the potential difference would be expected to double the current. (Note that this only works for ohmic components.)

Homework
Students could attempt Test yourself questions 8 and 9 from page 42 (*297*) of the textbook, but may need to review the previous page first.

Required practical 3(*15*): Resistance – wires: Lesson 6

Learning outcomes

1. Draw table and circuit diagrams.
2. Change potential difference and record changing current.
3. Calculate resistance for various wires.

Suggested lesson plan

Starter
Have students copy the circuit diagram and recap the measurements they will need to take to calculate resistance for a component.

Main
Although there seems to be a lot to do, most of the readings will take moments. Providing printed results tables and clear instructions will make this much easier for students. After the more complex method is demonstrated, the readings of a multimeter can give the resistance directly. Discussion of the possible approaches

in the **T&L Teacher and technician notes** will inform your choice.

The same circuit can be used for each set of measurements; students will collect a series of matched readings of potential difference and current of a wire. The length or thickness will be increased. The aim here is to show how calculated resistance varies with the changing dimensions of the wire. Length is easy, but most students will not have used the micrometer needed to measure the diameter.

If multimeters/ohmeters are *not* used, you may choose to provide a spreadsheet to speed up the calculations of resistance. Naturally this should only be used once you are confident that they can carry them out manually if required.

The worksheets Practical: Investigating how the length of a wire affects its resistance (RP3 Part 1) and Practical: Investigating how the thickness of a wire affects its resistance (RP3 Part 2) guide students through the work and include questions. Whether you use the associated T&L Practical videos directly with students, or use them to plan your own explanations, will depend on the equipment you have available.

If there is time, students can draw the appropriate graphs in the lesson.

Plenary
A short discussion of the results should show that, unsurprisingly, longer wires have higher resistance. Students pointing out that the difference is tiny should be prompted to consider the implications for overhead cables and pylons. That wider wires have a lower resistance may be more surprising to students.

Support
Help with the unfamiliar equipment is likely to be appreciated; providing a multimeter/ohmmeter means that students can sidestep the maths.

Extension
Discussion of calibration (the equipment is likely to read a non-zero resistance even for a very short length of wire, known as a *zero error*) is a good way to remind students of the difference between *accurate* and *precise* readings. (A measurement or calculated value is considered *accurate* if it is close to the true value. A *precise* set of measurements of the same quantity will closely agree with each other.)

Homework
It is likely that students will need to finish the questions from the question sheets and possibly draw the graphs. Alternatively, the questions from page 42 (*297*) of the textbook may be a useful way to reflect on the work, but you may wish to wait until after the following lesson as all the practicals are summarised.

Required practical 3(*15*): Resistance – combinations: Lesson 7

Learning outcomes

1 Collect readings for various combinations of resistors.
2 Compare results within class.
3 Discuss the patterns and explain in words and equations.

Suggested lesson plan

Starter
Show students two equal resistors and ask them to record their predictions for the overall resistance in series and parallel. Can they explain their predictions by referring to last lesson's work?

Main
Be cautious with the **T&L worksheet Practical: Investigating how series and parallel arrangements can affect the resistance of a circuit**, as the introduction hints at the result. You may also choose to extend the practical by asking them to consider three bulbs in series and parallel, or having them check the results with labelled resistors.

The combinations of components may seem more complex than the previous lesson's wires. The simplest approach is for students to be given a set of laminated diagrams, each showing bulbs in combinations (two in series, two in series, two in parallel, three in parallel) which can be set up in between two terminals. Students must then measure the potential difference across and current through the combination (or use an ohmmeter if time is short).

A good summary point will be that components in series have more resistance and those in parallel have a smaller overall resistance; this should be linked to the previous work on the length and thickness of a wire (because two parallel wires are like one thicker wire). A mathematical relationship is easy for series components, but students are unlikely to recognise the relationship for parallel components without support; a later lesson extends this concept to a quantitative model.

Plenary
Ensure that students have recorded the main idea that resistances in series add up, while resistances in parallel give a lower overall resistance.

Support
Making explicit links to the previous lesson on length of wire (resistances in series) and thickness of wire (resistances in parallel) may be helpful. As before, students may struggle with the physical arrangement of components although hopefully progress will be visible to them and you.

Extension
Encourage a careful quantitative approach and ask how close they would expect the numbers to be before the pattern seemed reliable.

Homework
Provide a reminder of key investigative terms and ask students to write sentences applying some of these to their results; for some you may wish to be specific about the words to use.

Components that resist: Lesson 8

Learning outcomes

1. Compare negligible resistance of wire in small circuit with resistor.
2. Practise calculating resistance.
3. Specify other component symbols.

Suggested lesson plan

Starter
Set up a simple circuit with a resistor and an ammeter. Ask students what the effect on the current will be of adding extra cables in series (i.e. making a longer loop). Most will correctly suggest it will be minimal, as the resistor has a much bigger contribution.

Main
Provide unlabelled resistors (possibly soldered inside terminal boxes) and have students take measurements to find the value of their resistance. The aim is for them to become fluent with both the measurements and the calculations.

Provide a results table and have them take a series of readings, this time changing the potential difference supplied and including negative values. Lines of best fit can be plotted on a current/potential difference or I–V graph. If time, they should plot the line for a second resistor on the same axes, and label them accordingly.

Many will (correctly) suggest that the gradient is linked to the resistance; they may need assistance to recognise that the gradient is, in fact, the inverse of the resistance. Ideally, a sketch could be added to notes reminding them that a steep line is a low resistance component (good conductor), while a shallow line is a high resistance component (bad conductor). Make the point that *all* lines go through the origin because if there is no potential difference, the current *must* be zero.

Plenary
On similar axes, where would the line be for a perfect electrical insulator? (Perfectly horizontal, on x-axis.) What about a superconductor with zero resistance? (Perfectly vertical, on y-axis.) Of course, we can only approach these, e.g. with a big enough potential difference a spark will jump across an otherwise insulating material like air.

Support
Remind students that a ‘best-fit line’ in science can be a curve or straight; in this case, the points should make a clear straight line. It is likely that support with graph drawing will be more necessary than with the measurements.

Extension
Physicists sometimes use the concept of ‘conductance’ rather than resistance. After all, resistance is a measure of how *bad* a conductor a material or component is. Challenge students to explain why we don’t switch over to this for general use.

Homework
Setting some mathematical problems is unlikely to be necessary at this point; bullet-point summaries of key ideas may be more constructive. Alternatively, set a recall test of component symbols and the equations covered so far.

Required practical 4(*16*): Resistors that vary: Lesson 9

Learning outcomes

1. Collect data for changing resistance in thermistor, LDR or both.
2. Plot graphs of results.
3. Discuss common applications.

Suggested lesson plan

Starter
T&L Lesson starter 2 introduces/recaps the circuit symbols; students could be asked about why those particular symbols were designed.

Alternatively, remind students of the variable resistor and reinforce that although the resistance at any point can be measured (or calculated from measurements, to be picky) this resistance may change if the conditions change. Other components do this too.

Main
Students can collect data for the changing resistance of one or both components; the thermistor will need to be subjected to a range of temperatures while a light-dependent resistor (LDR) reacts to changing brightness. Some practical details are given on page 45 (*300*) of the textbook but it is likely that school equipment has a well-established method.

It is much easier to collect quantitative data for the thermistor, as numerical description of brightness is surprisingly challenging. Students should include at least a sketch of the graphs for each component, which have the same general shape; resistance is high in the 'low' condition (cold/dark) and decreases with an inverse dependent relationship, so resistance is low in the 'high' condition (hot/bright). Figure 2.18 (*16.17*) on page 44 (*299*) of the textbook (also available in the **T&L Diagram bank**) is a good example for a thermistor. At any given value for the independent variable (temperature or brightness), the component will have a consistent value for resistance, which means that it can be calibrated and used in sensors.

Plenary
Students should be able to suggest applications for both thermistors and LDRs in environmental or industrial sensors; they should be guided in recording good examples.

Support
Some students will struggle with the idea that the resistance is variable with conditions, but constant for any particular value of that variable. Figure 2.19 (*16.18*) on page 44 (*299*) of the textbook (also available in the DL Diagram bank) shows the straight lines on an *I*–*V* graph, like the resistors from the previous lesson, that can be produced if an LDR is tested in bright and dim conditions.

Extension
Ask students to describe the method they would use to calibrate a thermistor for a boiler system that needs to act differently depending on water temperature. Answers should focus on finding the resistance of the thermistor at specific temperatures.

Homework
If a specific homework is required, Test yourself questions 10–14 from page 46 (*301*) of the textbook could be used. These refer to the *I*–*V* graph of a filament bulb, which may not have been covered, but students do not need to do anything more than interpret a provided graph.

Required practical 4(*16*): *I*–*V* graphs: Lesson 10

Learning outcomes

1 Change *V* (+ and –) and record *I* for each mystery component.
2 Plot each set of values to obtain characteristic *I*–*V* graph and hence identify component.

Suggested lesson plan

Starter
Remind students of the method they used to produce *I*–*V* graphs for resistors. A straight line on these axes means that the component is *ohmic* and the component has a fixed resistance.

Main
You may wish to adapt the **T&L worksheet Practical: Investigating the *I*–*V* characteristics of electrical components** depending on the confidence of your class. One way to increase engagement is to provide 'mystery components', so that students must identify them from the behaviour. Even though they have completed this procedure in a previous lesson for fixed resistors (if these plans have been followed) it is probably worth repeating, so they have a comparison. Questions on this sheet may be used in combination with those on page 45 (*300*) of the textbook.

Refer to the **T&L Teacher and technician notes** for sketches showing expected results, and the answers to the prompt questions on the student resource. The explanations for the behaviour on page 43 (*298*) of the textbook will be helpful, particularly for the changing resistance of the filament lamp.

Plenary
Students should be able to identify components from sketches of their *I*–*V* graphs.

Support
The biggest challenge for many students in this practical is the switch from providing a positive and a negative potential difference across the component. In some ways, the easiest solution is to read the value, with sign, from the voltmeter across it and put the data in the appropriate line of the table.

Extension
Suggest to students that collecting more data for the filament lamp (i.e. a smaller interval) would provide more certainty about the shape of the graph; can they check this?

Homework
Add summary explanations of component behaviour to notes and the circuit symbol table.

I–*V* graphs (debrief): Lesson 11

Learning outcomes

1. Discuss characteristic graphs.
2. Explain heating effect in filament lamp and effect on resistance.
3. Predict values (and test) for smaller intervals of potential difference.

Suggested lesson plan

Starter
Sketch graph identification: which component is in which box? Professionals working with electrical systems will take these kinds of measurements to identify components and diagnose faults.

Main
Ensure that students understand that although the shapes of the graphs are characteristic and predictable, the values will depend on the component itself. All filament lamps will have the curved *I*–*V* graph, but a bulb from the school circuits tray will have very different values compared with a demonstration bulb used on a film set.

The changes in the filament lamp need to be clearly understood. When a higher potential difference is across the lamp, the current is higher. This high current causes heating. Hot wires have a higher resistance. Each regular increase in potential difference, therefore, causes a smaller increase in current because the resistance is increasing too.

As well as discussing the electrical concepts, this is an ideal opportunity to review some more key terms for investigative work, such as *interval* and *range*. Hopefully by now most of these are familiar to students as they have been used in all practicals, 'required' and otherwise. Have students provide a commentary, using this vocabulary, as you repeat the readings for a component but with a smaller potential difference interval.

Plenary
Ask students to explain the differences between filament lamps and light-emitting diodes (LEDs); they should be able to explain that LEDs will only work when the current flows in one direction. It is worth pointing out that because filament lamps work by getting hot they are always much less efficient.

Support
The key terms are likely to cause some confusion, particularly those with meanings that are different in science compared with everyday English. In particular, compare *repeatable* (the same practical gives similar results) and *reproducible* (doing the same kind of investigation gives the same pattern of results) Experience with clear examples and lots of practice are the only real solutions, but this is likely to be unpopular with some students.

Extension
Ask students to explain the circuit symbols chosen for diodes and LEDs. (They have an arrow to show the direction of current needed for conduction.)

Homework
Students should review work on components in series and parallel from RP3(Part 3).

Series and parallel circuit rules: Lesson 12

Learning outcomes

1. Discuss provided rules for circuits.
2. Test the principles and explain any discrepancies.

Suggested lesson plan

Starter
Give students a blank summary table and have them fill in symbols, units and abbreviations for electrical quantities (Q, I, t, V, R).

Main
Students should be able to use the notes on pages 46–47 (*301–302*) of the textbook to write a method and results table. After measuring the resistance of individual components, they should make numerical predictions for various combinations.

During the course of the practical, students should be able to confirm both listed rules for series circuits: $V_{\text{supply}} = V_1 + V_2$ and $R_{\text{total}} = R_1 + R_2$.

Test yourself questions 15–19 on page 48 (*303*) of the textbook are a good review, but students will need to read the questions carefully to be sure which diagram is being referred to.

Plenary
Students could find and correct mistakes in a paragraph summing up the results, as if they were a teacher marking work from a class. Alternatively, all the material from Quick Quiz: Electricity 2 has now been covered (note that in Q2 students must think back to the Energy topic for the unit of power).

Support
Asking students to predict a range of possible results, rather than a specific value, allows you to gauge their confidence and reduces the intimidation factor.

Extension
Review the effects of increasing length and thickness of wire on resistance and guide students in single-sentence explanations for what is happening at an electron level. Alternatively, ask students investigating resistors in parallel to include columns in their table for $1/R_1$ and $1/R_2$; they may be able to recognise the relationship, but should understand that this goes beyond GCSE content.

Homework
If the Test yourself questions from page 48 (*303*) have not been attempted, they could be set for practice at home. Summary notes of the rules could also be useful.

Solving circuit problems: Lesson 13

Learning outcomes

1. Go through a simple circuit in theory and practice.
2. Discuss ways to calculate values.
3. Increase fluency with independent practice.

Suggested lesson plan

Starter
Choose a question from the previous lesson and have students annotate it with their thinking and method. How would they explain their approach to a student who missed the lesson?

Main
Students often find circuit problems overwhelming and don't know where to start. Taking time to model a systematic approach and linking to mnemonics used in English and History will show that this is a learnable skill, not a scientific mystery.

Providing prompt questions as possible starting points can be very helpful, even more so if the students recognise them as things they have tried before. 'Do I know two out of the three numbers *VI* and *R*?' 'What facts about component X do I remember?' are often good places to start. Underlining numbers in the question or diagram and labelling them with the symbol are also good exam practice (because they help, not because they're an artificial or arbitrary feature).

Spending time modelling answers, thinking 'out loud', is a vital addition to examples like those in the textbook; Test yourself questions on page 50 (*305*) can then be used for practice.

Plenary
Have students highlight the key facts/starting points on a fresh question – there will be more than one!

Support
Laminated prompt cards can be useful here as ticking off the questions as they're tried means students aren't left with a blank page if they're 'stuck'. The hope, of course, is that over time they will use a mental checklist fluently, rather than needing an external reminder.

Extension
There is a fine line between recognising a starting point without a prompt, and beginning a question in the most constructive way. Even when students can attempt more challenging problems, remind them to describe their steps for maximum credit.

Homework
Supply further practice questions with the requirement that students include explanations of their method, not just a numerical answer. Alternatively, **T&L Half-term test 4.2: Electricity** can be attempted *if Q11 is missed out*.

Oscilloscopes – direct and alternating p.d.: Lesson 14

Learning outcomes

1. Demonstrate key features of oscilloscope trace.
2. Record key values for UK mains.
3. Read values from diagrams.

Suggested lesson plan

Starter
Return to rope model and discuss how the push/pull corresponds to potential difference, the movement of the rope is a model for moving electrons, and the amount of grip is a useful analogy for resistance. Holding on to any two points on the rope allows you to compare the difference in 'pull'; this is like measuring potential difference in the circuit.

Main
Setting up the oscilloscope is often a time-consuming task. You may be able to use software versions which show the readings on a virtual

screen on the IWB. PicoScope is well-respected and affordable. Alternatively, using a visualiser will make it clearer for the class. A good starting point is to show the oscilloscope trace for a cell; a horizontal line at the level of the cell potential difference. Adding a second cell doubles the value but the line is still flat. Explain that what the oscilloscope does is to record the potential difference many times per second and show that on the screen; it's basically an early version of a data logger, giving a measurement in volts (V).

Explain that although you can't plug the oscilloscope into the mains, you can show them a safer version. This time use an a.c. supply with a similar value to the cells. Students will instantly recognise the difference on the trace, but the implications may need some prompting. In particular, the potential difference reversing direction means that the current flows in one direction, then the other. This is why it is called *alternating current* or a.c. The *frequency* is how often the cycle repeats itself in a second, and the unit is hertz (Hz).

There should be the opportunity to practise reading potential difference from a trace, and students could calculate the frequency from the time interval for one cycle. (frequency = 1/time interval). This could be set as homework after an example; the explanation from page 183 in the Waves topic (*CS2 page 257; 613*) can be modified for this if needed.

Students must record the key numbers for UK mains: 230 V effective potential difference and a frequency of 50 Hz. The explanations from page 50 (*305*) of the textbook lead naturally to the Test yourself questions 23 and 24 on page 51 (*questions 22 and 23 on page 306*).

Plenary
Once more, consider the rope model. Changing direction of the push and pull (potential difference reversing direction) means that the rope moves back and forth, rather than in a continuous direction. In a.c., energy is transferred because of the movement of electrons back and forth rather than being carried from one store to another by delivery electrons.

Support
The only likely difficulty here is the mathematical link between time period and frequency, which is not strictly needed for this topic. Students can be reassured that they need to recognise that a higher frequency means less time for each cycle, which is intuitive.

Extension
Ask students to imagine a high-speed camera focused on two lights, both connected to the mains. One is an LED, the other a filament lamp. One flickers 50 times per second, the other at 100 times per second. Which is which and why? (LED is directional, so only lights up once each cycle. The filament gives out light any time current is high enough, so both directions work. 2 × 50 = 100 times per second, although it will dim rather than go out because it doesn't have time to cool down.)

Homework
Good preparation for a future lesson would be to review the power equation from the previous topic (power = energy/time). The electrical power equation may have been briefly introduced, depending on how RP1 (Specific heat capacity) was done.

Electrical safety at home: Lesson 15

Learning outcomes

1 Complete three-pin plug diagram.
2 Annotate fuse, earth wire.
3 Identify faults in plugs/diagrams.

Suggested lesson plan

Starter
List electrical devices that plug into mains sockets; it should be easy to get around the class without duplication. Clearly, mains supply is very important to daily life.

Main
Open up an electrical plug and point out the important features; students may be able to recall some from KS3 or from their own experience. A diagram should be completed which highlights the three connections and the safety features. Explain that although this has been covered before, you're expecting better explanations now that they are working at GCSE. The specification does not technically include recall of the plug details, but it is an excellent context to demonstrate understanding of the principles.

The earth wire connects the outer metal casing to ground. In normal operation this does absolutely nothing, but if the live wire touches the case it means that the circuit is completed to the ground, not through a person touching it. The notes from page 51 (*306*) of the textbook discuss the normal potential differences of each wire. The fuse melts at high currents, breaking the circuit; no more detail is needed here as it has a full lesson later in the topic.

Test yourself question 25 on page 52 of the textbook (Physics only) won't take very long; it may be worth using longer questions from exam past papers. Showing students photographs or actual mis-wired plugs is a good way for them to check their understanding of how they should be wired. If time allows they could wire their own plugs (made safe according to CLEAPSS guidance) which is often a popular activity.

Plenary
Reinforce the importance of not doing home electrical work unless a competent adult checks what they have done. Reminding them of the effects of a high current on the brain and heart may help with this, and can be accompanied by first aid advice!

Support
Students may struggle with three wires when most familiar circuits need only two to work. Repeat that the live and neutral wires are usually the only ones carrying current, just like a test circuit in the school lab.

Extension
Students should be encouraged to describe values of potential (compared to earth) for the live and neutral wires. It is important to note that 230 V a.c. means a constantly changing potential difference which will peak a little above 230 V.

Homework
Students could explain how earthing keeps them safe, perhaps by annotating Figure 2.41 (Physics only). They could check to see which devices at home have an actual earth connection and which have none – this is sometimes visible as a plastic central pin on the plug. Why is it not always needed? (Answer: the appliance may have been designed so that the live wire cannot touch any casing, or because the appliance has plastic casing.)

Electrical power equations: Lesson 16

Learning outcomes

1. Recap definitions of power, energy.
2. Discuss worked examples of power equations.
3. Compare energy transferred by common appliances.

Suggested lesson plan

Starter
Ask students to recall the equations from the Energy topic; you could award half-marks for listing the correct variables.

- Work done = force × distance
- $E_k = \frac{1}{2}mv^2$
- $E_p = mgh$
- $P = \frac{E}{t}$
- $\Delta E = mc\Delta\theta$ (not technically one they need to remember for the exam)

Main
Focus on the link between energy and power and discuss the difference between the stores involved and the energy transferred between them. Animations may be useful, and the explanation starting on page 52 (*307*) of the textbook approaches the idea using a resistor. Emphasise that talking about 'more electricity' is meaningless; we must be specific about the quantities being measured.

It may help to consider the meaning of current and potential difference. Current describes the rate of charge flow; students can reasonably imagine an ammeter counting how much charge (in coulombs) goes through each unit of time (in seconds). Potential difference describes how much energy (in joules) is transferred by each quantity of that charge (again in coulombs). So if we know how much energy has been transferred in each second, we have the power of this transfer: current × potential difference.

There are several derivations which could be used, but students only need to recall the resulting equations:

- Energy transferred = potential difference × charge ($E = VQ$)
- Power = potential difference × current ($P = VI$)
- Power = current squared × resistance ($P = I^2R$)

Test yourself questions 26 and 27 from page 54 (*questions 24 and 25 on page 308*) of the textbook allow practice of several of the equations. More will probably be a good idea, in particular, allowing students to identify the needed equation based on the data provided. Note that working out energy supplied to household devices (using kilowatt-hours) is no longer on the specification.

Plenary
If not already covered, you could show that multiplying the units of potential difference ($1\,V = 1\,J/C$) and current ($1\,A = 1\,C/s$) gives the unit of power: 1 J/s or 1 W.

Support
Students who lack confidence with the maths will need reassurance here; in particular, they may worry about being able to show the derivation of one equation from the others. Ensure that they focus on identifying data in a question and choosing the appropriate equation.

Extension
Although not needed for the exam, some students will want to understand the link between equations more clearly; ensure that they are able to describe the observed situation in terms of measurements as well as an abstract mathematical model.

Homework
Students could try writing their own questions, perhaps having been provided with some sample data for current and resistance. They should include a worked answer with explanations.

Choosing fuses (calculating current): Lesson 17

Learning outcomes

1. Observe/record fuse wire melting.
2. Calculate current from values.
3. Calculate required fuses for household devices.

Suggested lesson plan

Starter
Demonstrate the use of iron wool as a (brief) conductor in a circuit with a bulb. The wool will combust in a very pretty way, and the bulb goes out. This tends to blow fuses of power packs so you may prefer to use a 9 V battery (this is a standard survival skill but effectively teaches students how to start fires. You know your students best).

Main
The simple idea here for students to record is that current causes heating, and that sometimes heating is enough to melt a wire. (In most fuses the wire melts rather than catching fire.) We use this idea to make a wire with just the right amount of resistance that it melts at a specific current.

Students can, with appropriate safety precautions, test samples of fuse wire to find their threshold current. In most cases, this will be slightly above the rated value. In theory, a fuse could be made to 'blow' at any value, but in most cases the 1, 3, 5 and 13 A versions work well enough. The aim is to reduce the damage caused to devices and people by high currents.

Students should be able to use a rearrangement of the electrical power equation (current = power/potential difference) to find the current flowing in any device. Remind them that they are expected to remember that the UK mains potential difference is 230 V, and know how to convert kilowatts into watts. The worked examples on page 54 (*308*) and Test yourself question 28 (Physics only) should be useful here.

Plenary
Repeat the iron wool demo, but have students explain what is happening. If available, a cosmic ball or 'energy stick' is an interesting contrast as you can discuss the much lower power, which means that both current and heating effect are tiny.

Support
Conversions from kilowatts to watts (simply multiplying by 1000) should be modelled by students who find this challenging. Point out the qualitative model: that a higher power rating (with the same potential difference) means a higher current.

Extension
Can students explain why most heating devices need high value fuses?

Answer: heating objects up needs a large amount of energy, so power must be high, which means current is (relatively) high. Microwaves are an exception because heating by EM radiation is much more efficient than by particles.

Homework
Students could calculate the current in some of their own household devices by finding the power ratings, usually on the back or underneath the device, and doing these calculations. Can they identify which fuse should be used?

The National Grid: Lesson 18

Learning outcomes

1. Recap use of energy resources for electricity.
2. Complete diagram labelling step-up and step-down transformers.
3. Explain use of high p.d. with reference to power equation.

Suggested lesson plan

Starter
Ask students why we don't all have a power station in our garden. Producing a list of possible power stations shouldn't be difficult and most are clearly impractical for a single house.

Main
Important: you may choose to pre-empt the detailed discussion of transformers, and the associated equation, which is listed as part of the Magnetism and Electromagnetism topic. If so it's probably worth taking a lesson on the maths involved.

Provide a diagram to label/complete with the different parts of the National Grid. Remind them about current causing heating, and that if the energy has been transferred to thermal stores then it is not available for devices plugged in to the mains. This is the reason for transformers, which, in turn, means that a.c. must be used; transformers don't work with direct current.

Test yourself questions 29–30 on page 55 (*questions 26 and 27 on page 310*) of the textbook provide some mathematical practice, showing why transformers are necessary (but not how they work). Although not explicit in the notes, it is worth reinforcing that high potential differences (such as in overhead wires) are dangerous because any sparks can travel further. That's why overhead cables are, well, high overhead.

Plenary
Despite the title, **T&L Lesson starter 4** could also be used to *finish* this lesson: students must spot (and explain) the deliberate mistakes on the diagram.

Support
Ensure that students are happy that the description of the transformer (*step-up* or *step-down*) refers to the potential difference. They may struggle with the idea that a higher potential difference means a lower current, when several lessons were spent showing that, in a circuit, a higher potential difference causes a higher current. (The best explanation involves the cause; in the lab the potential difference causes the current, while in these cases the potential difference is caused by electromagnetic induction.)

Extension
Students could be encouraged to consider the heating effect and why transmission cables tend to be thicker than strictly necessary. Why do we use aluminium which has a higher resistance than copper?

Answer: aluminium cables can be thicker but still lighter, and the resistance is much less of an issue than the effect of reducing the current by using transformers.

Homework
Students can complete **T&L Quick quiz: Electricity 3** now (but you may wish to see their working for mathematical questions alongside their automatically collected scores). For combined science students, **T&L Homework tasks (a)** and **(b)** could be used as in-class revision or as assigned preparation for end of topic tests; the Chapter review questions on pages 311–312 of the textbook could be used, perhaps in combination with the Practice questions on pages 313–315.

Making static: Lesson 19 (Physics only)

Learning outcomes

1. Discuss sparks and lightning.
2. Van de Graaff demonstration.
3. Record main features of static charge and brief current.

Suggested lesson plan

Starter
Give some context for potential difference; a spark from a door handle is a few thousand volts. Sparks from synthetic fabrics, e.g. sports tops, will be less than this, but may still be visible in a dark room. In contrast, a lightning 'bolt' is a spark across a potential difference of up to 100 million volts.

Main
Doing Van de Graaff generator demonstrations can be intimidating, but when they work well it is very memorable for students; the trick is to link the drama to scientific principles! Have a back-up plan, because the kit tends to be temperamental, but have fun. Your students will.

During the demonstrations, the focus needs to be on two parallel ideas. One is the build-up of static charge, basically because of friction causing an imbalance of electrons. The second is that when the potential difference is 'big enough' – a value affected by many factors including the weather – a spark will happen, which is a brief electrical current through the air.

Alongside these, many of the demonstrations will show the idea of repulsion of similar charges; these will be covered in the next lesson. You may wish to get some good photos or video to use as prompts. Discuss what the evidence suggests about the 'static' charges, which we now understand to be electrons separated from nuclei and unable to move freely because they are not in contact with conductors.

Plenary
Remind students that large potential differences cause shocks, while large currents cause damage.

Support
Some students will not want to be involved with the demonstrations; this should obviously be respected. The main ideas are straightforward.

Extension
If required, students could calculate the energy transfers involved given sample data for the sparks

in the lesson demonstrations. It is more likely that better quality explanations will be given spontaneously by some students.

Homework
Students could research ways in which buildings are protected from lightning strikes and link this to the dangers of sparks in the air (which only happen with higher potential difference and so have higher current, and also start fires).

Forces on charged objects: Lesson 20 (Physics only)

Learning outcomes

1 Observe attraction/repulsion effects with charged rods.
2 Discuss effects in terms of electron movement.

Suggested lesson plan

Starter
Use **T&L Lesson starter 3** to recap the effect of a static charge being *discharged* as lightning. This is what electric current is; a difference in potential (positive and negative) causing electrons to flow to balance out the difference.

Main
Remind students that static charge happens when electrons are separated from nuclei. The overall charge is still neutral, but objects can now be treated as having positive and negative parts. Until a charged object is *earthed* or *grounded* – effectively sharing the imbalance with the Earth – the effect of this imbalance is a force, which is usually only noticeable when charged objects are close together.

Using different combinations of rods and cloths, students can investigate the forces involved. They should be guided in their summaries to record the pattern, which is very similar to that covered in KS3 magnetism work: similar charges *repel*, while opposite charges *attract*. Depending on timing, you could discuss the parallel with positive and negative ions on a particle scale in chemistry.

Return to the examples in the Van de Graaff demonstration, perhaps with photos to annotate. Objects charged to the same potential repel each other, which is why hairs separate and apparent levitation can be induced. If the fluorescent tube demonstration was used, this will be discussed in the next lesson on fields.

Plenary
Reinforce that electrons have a negative charge and are the mobile particles, moved by friction and then trapped to cause an imbalance.

Support
Students may need to be reminded that although the rules are the same as for magnetism, the cause is different; we talk about positive and negative charges rather than north and south poles.

Extension
Encourage students to include electrons in their explanations, rather than simply rely on the observed principles.

Homework
Most of the Test yourself questions 31–34 on page 58 of the textbook can now be attempted. You may prefer to set some wider revision work as the end of the topic is approaching; students can now complete **T&L Half-term test 4.2: Domestic uses and safety**.

Electric fields: Lesson 21 (Physics only)

Learning outcomes

1 Define ‘field’ as region in which certain objects experience a force.
2 Draw results of semolina/oil demo.
3 Record factors affecting force.

Suggested lesson plan

Starter
Ask students that if a football field is where football happens, what is an electric field? This demonstrates the partial link between Science English and everyday English.

Main
Show students the semolina and oil demonstration of electrical fields and ask them what the patterns remind them of. Details of the semolina demonstration can be found here: http://practicalphysics.org/electric-fields.html. Most will immediately suggest iron filings around a magnet, and this is a good starting point. Students should draw the patterns and annotate them with explanations.

Objects with electric charge cause an electrical field, and when in such a field experience a force. Whether they move will depend on other factors of course! Return to the ideas of attraction and repulsion, which show that the direction of the force experienced depends on the relative charge of the objects in question. Students do not need to know the equation for the force acting around a charged object, but will probably be able to suggest important factors (size of charge, distance from the object) with little prompting.

If students saw a fluorescent tube light up near the Van de Graaff, you can explain this by the field causing movement of electrons in the gas, i.e. a current.

It will probably be useful to have students describe the effects in their own words, perhaps using copies of Figure 2.51 as starting points.

Plenary
T&L Quick quiz: Electricity 4 covers these ideas (with a little maths too).

Support
The ideas can seem abstract here so return at every point to the effects seen with charged rods in the previous lesson. Basic rules can be observed, described and memorised.

Extension
Ask students to imagine that they are provided with a charged object, electrically isolated. How would they find out whether the charge on it was positive or negative?

Homework
T&L Homework tasks (a) and **(b)** could be used as in-class revision or as assigned preparation for end of topic tests; the Chapter review questions from page 59 of the textbook could be used, perhaps in combination with the Practice questions from page 61. Be aware that previous specifications contained considerably different content if using past paper questions.

Answers

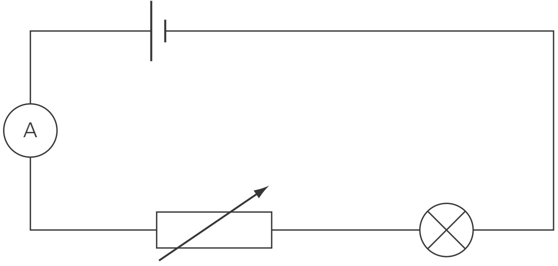
AQA GCSE (9-1) Physics

Test yourself on prior knowledge

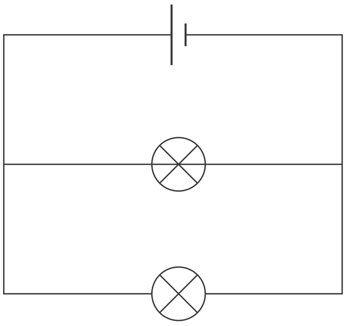
1 They are in parallel – they can be turned on and off independently.
2 a) All metals, e.g. copper, silver, brass; carbon (graphite).
  b) Plastic, china, glass, rubber, air.
3 a) Electrons have been transferred from the cloth to the plastic.
  b) Positive.

Test yourself

1 b)
2 A diode; B lamp; C cell; D switch
3

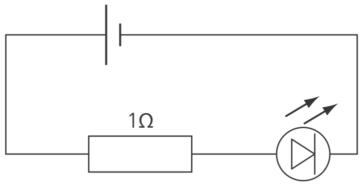


4

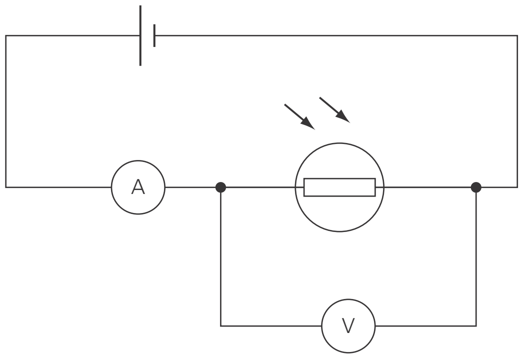


5 a) volt
  b) amp
  c) coulomb
6 Both 0.08 A
7 a) $Q = It$
  $3 = I \times 2$
  $I = 1.5\,\text{A}$
  b) $Q = It$
  $= 0.3 \times 20 \times 60$
  $= 360\,\text{C}$
  c) $Q = It$
  $5 = I \times 2 \times 10^{-4}$
  $I = 25\,000\,\text{A}$
  d) $Q = It$
  $= 10^{-4} \times 30 \times 60$
  $= 0.18\,\text{C}$
8 You need to make the resistance smaller, to make the lamp brighter.
9 Resistor – 0.075 A
  Lamp – 4600 Ω
  Heater – 10 A
  LED – 3 V
  Motor – 1.5 Ω
10 a) 2200 Ω
  b) 900 Ω
  c) 300 Ω
11 In an ohmic resistor the current flowing through it is proportional to the p.d. across the resistor, provided the temperature remains constant.
12 a) $R = \frac{V}{I}$
  $= \frac{1}{0.2}$
  $= 5\,\Omega$
  b) $R = \frac{V}{I}$
  $= \frac{3}{0.29}$
  $= 10.3\,\Omega$
13 a) $R = \frac{V}{I}$
  $= \frac{2}{0.03}$
  $= 67\,\Omega$
  b) $= 800\,\Omega$

14 a)



b)



15 2 A

16 a) i) 35 Ω

ii) 2150 Ω

b) Less than 10 Ω

17 a) 9 V

b) 12 V

18 $A_1 = 3\text{ A}$; $A_2 = 2\text{ A}$; $A_3 = 1\text{ A}$; $A_4 = 5\text{ A}$

19 a) 18 V

b) 6 V

c) 27 V

20 a) $V = IR$

$4 = I \times 6$

$I = 0.67\text{ A}$

b) $V = 4\text{ V} + 8\text{ V}$

$= 12\text{ V}$

21 a) $V = IR$

$8 = I \times 24$

$I = 0.33\text{ A}$

b) p.d. across R = 12 V – 8 V = 4 V

$$R = \frac{V}{I}$$

$$= \frac{4}{0.33}$$

$$= 12\,\Omega$$

22 p.d. across 10 Ω resistor $= IR = \frac{1}{4} \times 10 = 2.5\text{ V}$

p.d. across $R = 10 - 2.5 = 7.5\text{ V}$

$$R = \frac{V}{I}$$

$$= \frac{7.5}{0.25}$$

$$= 30\,\Omega$$

23 a) a.c. is an alternating current

d.c. is a direct current

b) A direct p.d. remains at a constant value in the same direction.

When an alternating p.d. is applied across a resistor, the p.d. switches direction many times per second.

24 In the UK, the supply is rated at 230 V and 50 Hz. Therefore the p.d. in the USA has half the value of the UK supply. At 60 Hz, the USA changes direction 60 times per second rather than 50, as in the UK.

25 a) The metal case of an appliance is connected to the earth through an earth wire.

b) The live wire has a large alternating p.d., which can give a shock.

26 a) $P = V \times I$

$= 12 \times 90$

$= 1080\text{ W}$

b) $P = 230 \times 2.5$

$= 575\text{ W}$

c) $P = 3 \times 0.0003$

$= 0.0009\text{ W}$

or 0.9 mW

27 a) $W = VQ$

$= 12 \times 200$

$= 2400\text{ J}$

b) $W = VIt$

$= 230 \times 0.2 \times 30 \times 60$

$= 82\,800\text{ J}$

or 83 kJ to 2 sf

c) $W = VIt$

$= 6 \times 0.002 \times 2 \times 60 \times 60$

$= 86.4\text{ J}$

or 86 J to 2 sf

28 Lamp – 0.048 A

TV – 0.65 A

Hair dryer – 2.1 A

Kettle – 9.6 A

29 a) i) $P = I^2R$

$= 100^2 \times 200$

$= 2\,000\,000\text{ W}$

or 2 MW

ii) $P = I^2R$

$= 1000^2 \times 200$

$= 200\,000\,000\text{ W}$

or 200 MW

b) The power dissipated by a current, I, flowing through a resistor, R, is $P = I^2R$. So when a low current flows, less power is dissipated, which saves energy and money.

30 a) $I = 3\text{ A}$

So $P = I^2R$

$= 3^2 \times 4$

$= 36\text{ W}$

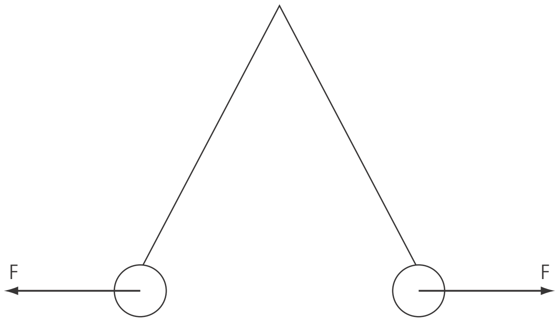
b) The two wires dissipate 36 W, so only $\frac{1}{3}$ of the power lights the lamp.

31 a) Electrons have been removed and placed on the cloth.

b) Negative.

32 a) Charges have the same size.

b)



33 a) Negative.

b) Each hair is negative; like charges repel, so the hairs repel each other, and they are repelled from the head which is also negatively charged.

c) This insulates him – without the insulating mat, charge could flow from his body to Earth.

34 a) $Q = It$

$5 = I \times 0.002$

$$I = \frac{5}{0.002}$$

$= 2500\,\text{A}$

b) $W = VQ$

$= 100\,000\,000 \times 5$

$= 500\,000\,000\,\text{J}$

or 500 MJ

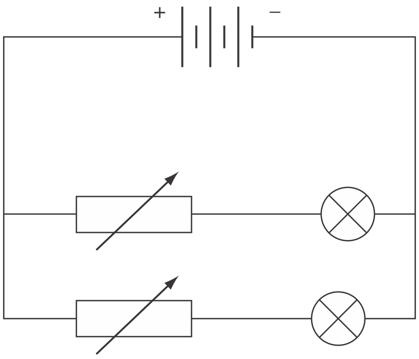
c) $P = VI$

$= 1 \times 10^8 \times 2.5 \times 10^3$

$= 2.5 \times 10^{11}\,\text{W}$

Show you can

Page 38



Page 40

Current = the rate at which charge flows or how much charge flows per second.

$$I = \frac{Q}{t}$$

Page 46

a) An LDR is a light dependent resistor. Its resistance depends on the light intensity; its resistance is high at low light intensity and low in bright light.

b) An LED is a light emitting diode. This is a diode that only allows current to flow one way. When there is a potential difference of about 0.8 V across the diode it emits light. [The colour of light and this p.d. depend on the diode.]

c) A thermistor is a thermally sensitive resistor. Its resistance depends on its temperature. Here you have met a thermistor whose resistance is high at low temperatures and low at high temperature.

Page 55

a) A step-up transformer at a power station steps up the potential difference to a very high level – 400 000 V. Although the p.d. is stepped up, the current carried by the lines is reduced.

The power dissipated by heating the transmission lines depends on the current ($P = I^2R$). So a low current reduces waste.

b) A p.d. of 230 V is low enough to minimise the chance of electrocution, but high enough to power our kettles and heaters.

Page 58

When the balloon is rubbed on the head, it becomes charged. The hair becomes charged also, but with the opposite charge to the balloon. Because the hair and balloon have opposite electric charges, they attract each other.

Required practical 3

Page 42

1. Resistance of the wire.
2. Using a low voltage power supply.
   Switching the circuit on only when readings were being taken.
3. Systematic error.

Required practical 4

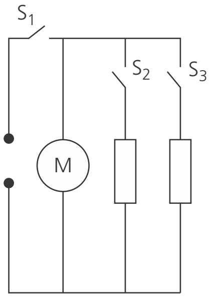
Page 45

1 The resistance does not depend on the direction of the current.
2 For a diode connected in the reverse direction (negative), there is zero current. For a filament lamp, a current flows in both directions.
3 The plotted points will be closer together so it is easier to see the trend in the pattern.
4 0.5 V

Chapter review questions

1 Largest A; smallest B

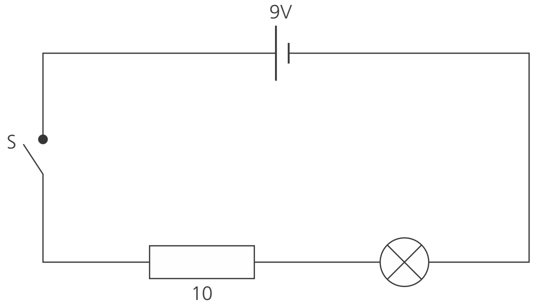
2



Ⓜ is the symbol for a motor – fan in this case.

3 **a)** Sidelights.
b) S_1, but S_2 also has to be closed for the headlights to work.
c) Yes, when S_2 is closed current flows through the sidelights to the car body
d) Yes, because current flows in parallel to the headlights.
e) A wire would have to carry the current back to the battery rather than the metal body of the car.

4 **a)**



b) i) $P = VI$
$= 9 \times 0.3$
$= 2.7\,\text{W}$

ii) p.d. across resistor $= IR$
$= 0.3 \times 10$
$= 3\,\text{V}$
so $P = VI$
$= 3 \times 0.3$
$= 0.9\,\text{W}$
or $P = I^2R$
$= 0.3^2 \times 10$
$= 0.9\,\text{W}$

iii) power in lamp $= 2.7\,\text{W} - 0.9\,\text{W}$
$= 1.8\,\text{W}$
or p.d. across lamp $= 9\,\text{V} - 3\,\text{V}$
$= 6\,\text{V}$
$P = VI$
$= 6 \times 0.3$
$= 1.8\,\text{W}$

5 **a)** 6 V
b) 6 V
c) 0.6 A
d) i) $R = V/I$

$$= \frac{6}{0.2}$$

$= 30\,\Omega$

ii) $R = V/I$

$$= \frac{6}{0.4}$$

$= 15\,\Omega$

6 p.d. across the $24\,\Omega$ resistor is:
$V = IR$
$= 0.2 \times 24$
$= 4.8\,\text{V}$
p.d. across X is 7.2 V
resistance of X is:

$$R = \frac{7.2}{0.2}$$

$= 36\,\Omega$

7 **a)** p.d. across each lamp is:

$$\frac{230}{115} = 2\text{V}$$

b) $R = V/I$

$$= \frac{2}{0.05}$$

$= 40\,\Omega$

c) $R = 115 \times 40$
$= 4600\,\Omega$

d) $P = VI$
$= 230 \times 0.05$
$= 11.5\,\text{W}$
Or $P = I^2R$
$= (0.05)^2 \times 4600$
$= 11.5\,\text{W}$

8 The resistance increases in a filament as the current rises because the filament gets hotter. As the atoms get hotter, their increased vibrations hinder the passage of electrons.

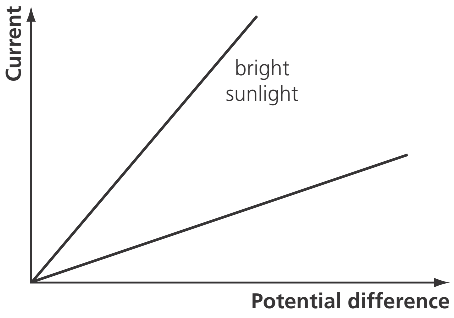
9 The component next to the lamp is a thermistor. At low temperatures the thermistor has a high resistance; at high temperatures the thermistor has a lower resistance. When the switch is closed, current flows; the thermistor begins to warm up. The resistance of the thermistor drops and the current rises, so the lamp gets brighter.

Practice questions

1 a) 1.5 V *[1 mark]*
b) 6 V *[1 mark]*
c) 0.25 A *[1 mark]*
d) Greater than. *[1 mark]*
The lamp and resistor have the same potential difference across them, so the lamp has a greater resistance as less current flows through it. $R = \frac{V}{I}$. *[1 mark]*

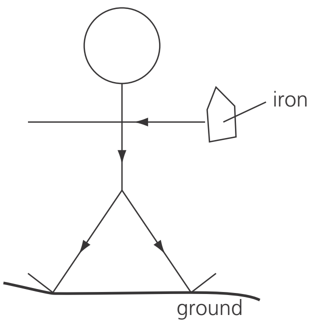
2 a) Positively, jumper. *[1 mark] [1 mark]*
b) Change ‘repel’ to ‘attract’. *[1 mark]*
c) i) Copper, because it is a good conductor of electricity. *[1 mark] [1 mark]*
ii) Greater than. *[1 mark]*
iii) Current. *[1 mark]*

3 a) The resistance of an LDR gets less as the light intensity increases. *[1 mark]*
b) i) 8 mA (you must have the unit). *[1 mark]*
ii) $R = \frac{V}{I}$
$= \frac{3}{0.008}$ *[1 mark]*
$= 375\,\Omega$ *[1 mark]*
iii) It could be used as a lightmeter.
c)



[1 mark]

4 a)



[1 mark]

b) $V = IR$
$230 = I \times 46\,000$ *[1 mark]*
$I = \frac{230}{46000}$ *[1 mark]*
$= 0.005$ A or 5 mA *[1 mark]*

5 a) A1 = 1.2 A *[1 mark]*
A2 = 0.7 A *[1 mark]*
b) Both resistors have the same potential difference across them. So R_1 is bigger because there is a smaller current through it than through R_2. *[2 marks]*
c) $R = \frac{V}{I}$ *[1 mark]*
$= \frac{12}{0.3}$ *[1 mark]*
$= 40\,\Omega$ *[1 mark]*

6 a) The current rises quickly after the lamp is switched on, reaching a peak after about 0.1 s. After 0.8 s the current reaches a steady value. *[2 marks]*
b) i) 4.7 A *[1 mark]*
ii) 2.0 A *[1 mark]*
c) When the current is switched on the lamp is cold and the resistance is low.
Since $I = \frac{V}{R}$, the current is high. *[1 mark]*
As the lamp warms, resistance (R) increases so the current drops. *[1 mark]*
After 1 s the lamp has reached a steady temperature, so the current remains the same. *[1 mark]*
d) $P = VI$
$= 12 \times 2$ *[1 mark]*
$= 24$ W *[1 mark] [1 mark]* unit

7 a) 0.8 V *[1 mark]*
b) $V = IR$
$= 20 \times 10^{-3} \times 260$ *[1 mark] [1 mark]*
$= 5.2$ V *[1 mark]*
c) $V = 5.2 + 0.8$
$= 6.0$ V *[1 mark]*

8 a) A thermistor. *[1 mark]*
b) 37 °C *[1 mark]*
c) $V = IR$
$12 = I \times 1000$ *[1 mark]*
$I = 0.012$ A or 12 mA *[1 mark] [1 mark]* for the unit
d) As the temperature rises the resistance of X decreases and the current rises. *[1 mark]*
When the current rises the p.d. across the 750 Ω resistor rises, so the p.d. across X decreases and the voltmeter reading falls. *[1 mark] [1 mark]*
1 mark for each good point – up to 3.

9 a) i) The lamp has the greatest resistance, because the current through it is smallest. *[1 mark]*
$I = \frac{V}{R}$
All the appliances have the same p.d. across them. *[1 mark]*

ii) The cable needs to be thicker to carry a large current. If the cable is thin, a large current can heat it. *[1 mark]*
The kettle needs an earth wire. *[1 mark]*

b) $P = VI$
$= 230 \times 11.5$ *[1 mark]*
$= 2645\,\text{W}$ *[1 mark] [1 mark]* for the unit

c) i) $R = \frac{V}{I}$
$= \frac{230}{11.5}$
$= 20\,\Omega$ *[1 mark]*
$I = \frac{V}{R}$
$= \frac{115}{20}$ *[1 mark]*
$= 5.75\,\text{A}$ *[1 mark]*
or you can say that since the p.d. is halved, the current is halved:
$\frac{11.5V}{2} = 5.75\text{A}$ *[3 marks]*

ii) $P = VI$
In USA, V is halved, I is halved so the power is reduced by a factor of 4. *[2 marks]*
Now the kettle boils in four times the time = 360 s. *[1 mark]*
$P = \frac{E}{t}$
$t = \frac{E}{P}$

Working scientifically

1

Quantity	Unit	Symbol
charge	coulomb	C
current	ampere	A
energy	joule	J
frequency	hertz	Hz
potential difference	volt	V
power	watt	W
resistance	ohm	Ω
time	second	s

2 They share a common understanding
or
they can compare directly values measured in different places.

3 Draw a horizontal line from the voltmeter reading to the graph line; draw a vertical line down from this point on the graph line.

4 Because the calibration graph is not linear; joining only two data points would give a straight line and not a curve.

5 Between 8.4 and 8.6.

6 The resolution gets worse; a larger change in temperature is needed to produce the smallest measurable change in the voltmeter reading.

AQA GCSE (9-1) Combined Science

Test yourself on prior knowledge

1 They are in parallel – they can be turned on and off independently.

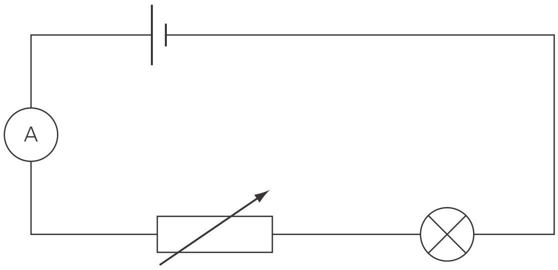
2 **a)** All metals, e.g. copper, silver, brass; carbon (graphite).
b) Plastic, china, glass, rubber, air.

Test yourself

1 b)

2 A diode; B lamp; C cell; D switch

3



4 **a)** volt
b) amp
c) coulomb

5 Both 0.08 A

6 **a)** $Q = It$
$3 = I \times 2$
$I = 1.5\,\text{A}$
b) $Q = It$
$= 0.3 \times 20 \times 60$
$= 360\,\text{C}$
c) $Q = It$
$5 = I \times 2 \times 10^{-4}$
$I = 25\,000\,\text{A}$
d) $Q = It$
$= 10^{-4} \times 30 \times 60$
$= 0.18\,\text{C}$

7 You need to make the resistance smaller, to make the lamp brighter.

8 Resistor – 0.075 A
Lamp – 4600 Ω
Heater – 10 A
LED – 3 V
Motor – 1.5 Ω

9 **a)** 2200 Ω
b) 900 Ω
c) 300 Ω

10 In an ohmic resistor the current flowing through it is proportional to the p.d. across the resistor, provided the temperature remains constant.

11 a) i) $R = \frac{V}{I}$

$= \frac{1}{0.2}$

$= 5\,\Omega$

ii) $R = \frac{V}{I}$

$= \frac{3}{0.29}$

$= 10.3\,\Omega$

b) Resistance provided by the bulb.

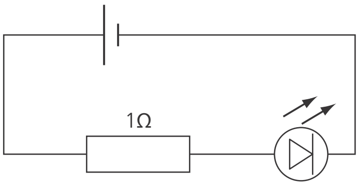
12 a) $R = \frac{V}{I}$

$= \frac{2}{0.03}$

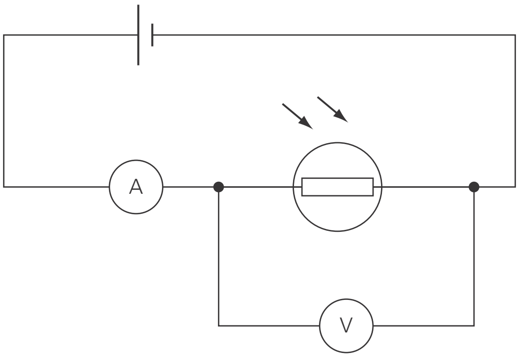
$= 67\,\Omega$

b) $= 800\,\Omega$

13 a)



b)



14 2 A

15 a) i) 35 Ω

ii) 2150 Ω

b) Less than 10 Ω

16 a) 9 V

b) 12 V

17 $A_1 = 3\,A$; $A_2 = 2\,A$; $A_3 = 1\,A$; $A_4 = 5\,A$

18 a) 18 V

b) 6 V

c) 27 V

19 a) $V = IR$

$4 = I \times 6$

$I = 0.67\,A$

b) $V = 4\,V + 8\,V$

$= 12\,V$

20 a) $V = IR$

$8 = I \times 24$

$I = 0.33\,A$

b) p.d. across $R = 12\,V - 8\,V = 4\,V$

$R = \frac{V}{I}$

$= \frac{4}{0.33}$

$= 12\,\Omega$

21 p.d. across 10 Ω resistor $= IR = \frac{1}{4} \times 10 = 2.5\,V$

p.d. across $R = 10 - 2.5 = 7.5\,V$

$R = \frac{V}{I}$

$= \frac{7.5}{0.25}$

$= 30\,\Omega$

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d.c. is a direct current

b) A direct p.d. remains at a constant value in the same direction.

When an alternating p.d. is applied across a resistor, the p.d. switches direction many times per second.

23 In the UK, the supply is rated at 230 V and 50 Hz. Therefore the p.d. in the USA has half the value of the UK supply. At 60 Hz, the USA changes direction 60 times per second rather than 50, as in the UK.

24 a) $P = V \times I$

$= 12 \times 90$

$= 1080\,W$

b) $P = 230 \times 2.5$

$= 575\,W$

c) $P = 3 \times 0.0003$

$= 0.0009\,W$

or 0.9 mW

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$= 82\,800\,J$

or 83 kJ (to 2 sf)

c) $W = VIt$

$= 6 \times 0.002 \times 2 \times 60 \times 60$

$= 86.4\,J$

or 86 J (to 2 sf)

26 a) i) $P = I^2R$

$= 100^2 \times 200$

$= 2\,000\,000\,W$

or 2 MW

ii) $P = I^2R$

$= 1000^2 \times 200$

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b) The power dissipated by a current, I, flowing through a resistor, R, is $P = I^2R$. So when a low current flows, less power is dissipated, which saves energy and money.

27 a) $I = 3\,\text{A}$

So $P = I^2R$

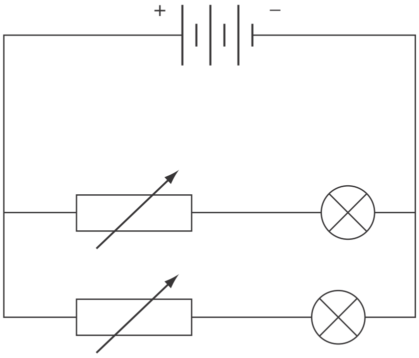
$= 3^2 \times 4$

$= 36\,\text{W}$

b) The two wires dissipate 36 W, so only $\frac{1}{3}$ of the power lights the lamp.

Show you can

Page 293



Page 295

Current = the rate at which charge flows or how much charge flows per second.

$$I = \frac{Q}{t}$$

Page 301

a) An LDR is a light dependent resistor. Its resistance depends on the light intensity; its resistance is high at low light intensity and low in bright light.

b) An LED is a light emitting diode. This is a diode that only allows current to flow one way. When there is a potential difference of about 0.8 V across the diode it emits light. [The colour of the light and this p.d. depend on the diode.]

c) A thermistor is a thermally sensitive resistor. Its resistance depends on its temperature. Here you have met a thermistor whose resistance is high at low temperatures and low at high temperature.

Page 310

a) A step-up transformer at a power station steps up the potential difference to a very high level: 400 000 V. Although the p.d. is stepped up, the current carried by the lines is reduced.

The power dissipated by heating the transmission lines depends on the current ($P = I^2R$). So a low current reduces waste.

b) A p.d. of 230 V is low enough to minimise the chance of electrocution, but high enough to power our kettles and heaters.

Required practical 15

Page 297

1 Resistance of the wire.

2 Using a low voltage power supply.
Switching the circuit on only when readings were being taken.

3 Systematic error.

Required practical 16

Page 300

1 The resistance does not depend on the direction of the current.

2 For a diode connected in the reverse direction (negative), there is zero current.
For a filament lamp, a current flows in both directions.

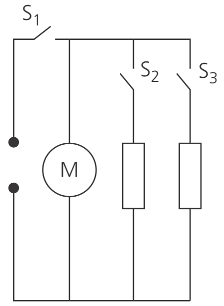
3 The plotted points will be closer together so it is easier to see the trend in the pattern.

4 0.5 V

Chapter review questions

1 Largest A; smallest B

2



Ⓜ is the symbol for a motor – fan in this case.

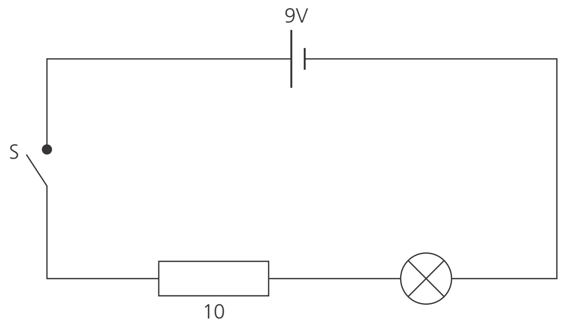
3 **a)** S_1, but S_2 also has to be closed for the headlights to work.

b) Yes, when S_2 is closed current flows through the sidelights to the car body.

c) Yes, because current flows in parallel to the headlights.

d) Wiring would need to be added as plastic is an insulator.

4 a)



b) i) $P = VI$
$= 9 \times 0.3$
$= 2.7\,\text{W}$

ii) p.d. across resistor $= IR$
$= 0.3 \times 10$
$= 3\,\text{V}$

so $P = VI$
$= 3 \times 0.3$
$= 0.9\,\text{W}$
or $P = I^2R$
$= 0.3^2 \times 10$
$= 0.9\,\text{W}$

iii) power in lamp $= 2.7\,\text{W} - 0.9\,\text{W}$
$= 1.8\,\text{W}$
or p.d. across lamp $= 9\,\text{V} - 3\,\text{V}$
$= 6\,\text{V}$

$P = VI$
$= 6 \times 0.3$
$= 1.8\,\text{W}$

5 a) 6 V
b) 6 V
c) 0.6 A

d) i) $R = \dfrac{V}{I}$
$= \dfrac{6}{0.2}$
$= 30\,\Omega$

ii) $R = \dfrac{V}{I}$
$= \dfrac{6}{0.4}$
$= 15\,\Omega$

6 p.d. across the 24 Ω resistor is:
$V = IR$
$= 0.2 \times 24$
$= 4.8\,\text{V}$
p.d. across X is 7.2 V
resistance of X is:
$R = \dfrac{7.2}{0.2}$
$= 36\,\Omega$

7 a) p.d. across each lamp is:
$\dfrac{230}{115} = 2V$

b) $R = \dfrac{V}{I}$
$= \dfrac{2}{0.05}$
$= 40\,\Omega$

c) $R = 115 \times 40$
$= 4600\,\Omega$

d) $P = VI$
$= 230 \times 0.05$
$= 11.5\,\text{W}$
Or $P = I^2R$
$= (0.05)^2 \times 4600$
$= 11.5\,\text{W}$

8 The resistance increases in a filament as the current rises because the filament gets hotter. As the atoms get hotter, their increased vibrations hinder the passage of electrons.

9 The component next to the lamp is a thermistor. At low temperatures the thermistor has a high resistance; at high temperatures the thermistor has a lower resistance. When the switch is closed, current flows; the thermistor begins to warm up. The resistance of the thermistor drops and the current rises, so the lamp gets brighter.

Practice questions

1 a) 1.5 V *[1 mark]*
b) 6 V *[1 mark]*
c) 0.25 A *[1 mark]*
d) greater than *[1 mark]*
The lamp and resistor have the same potential difference across them, so the lamp has a greater resistance as less current flows through it. $R = \dfrac{V}{I}$. *[1 mark]*

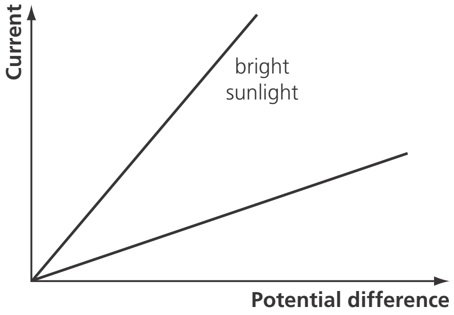
2 a) The resistance of an LDR gets less as the light intensity increases. *[1 mark]*

b) i) 8 mA (you must have the unit for the mark). *[1 mark]*

ii) $R = \dfrac{V}{I}$
$= \dfrac{3}{0.008}$ *[1 mark]*
$= 375\,\Omega$ *[1 mark]*

iii) It could be used as a lightmeter.

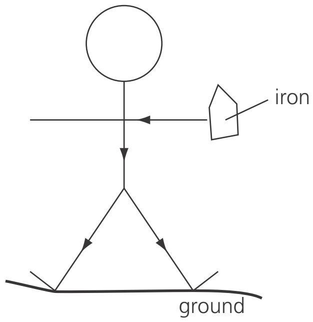
c)



[1 mark]

3 In a direct current the current flows in the same direction all the time *[1 mark]*. An alternating current switches direction (50 times a second for mains electricity). *[1 mark]*.

4 a)



[1 mark]

b) $V = IR$

$230 = I \times 46\,000$ *[1 mark]*

$I = \dfrac{230}{46000}$ *[1 mark]*

$= 0.005\,\text{A}$ or $5\,\text{mA}$ *[1 mark]*

5 a) A1 = 1.2 A *[1 mark]*

A2 = 0.7 A *[1 mark]*

b) Both resistors have the same potential difference across them. So R_1 is bigger because there is a smaller current through it than through R_2. *[2 marks]*

c) $R = \dfrac{V}{I}$ *[1 mark]*

$= \dfrac{12}{0.3}$ *[1 mark]*

$= 40\,\Omega$ *[1 mark]*

6 a) The current rises quickly after the lamp is switched on, reaching a peak after about 0.1 s. After 0.8 s the current reaches a steady value. *[2 marks]*

b) i) 4.7 A *[1 mark]*

ii) 2.0 A *[1 mark]*

c) When the current is switched on the lamp is cold and the resistance is low. Since $I = \dfrac{V}{R}$, the current is high. *[1 mark]*

As the lamp warms, resistance (*R*) increases so the current drops. *[1 mark]*

After 1 s the lamp has reached a steady temperature, so the current remains the same. *[1 mark]*

d) $P = VI$

$= 12 \times 2$ *[1 mark]*

$= 24\,\text{W}$ *[2 marks, 1 for answer, 1 for unit]*

7 a) 0.8 V *[1 mark]*

b) $V = IR$

$= 20 \times 10^{-3} \times 260$ *[2 marks]*

$= 5.2\,\text{V}$ *[1 mark]*

c) $V = 5.2 + 0.8$

$= 6.0\,\text{V}$ *[1 mark]*

8 a) A thermistor. *[1 mark]*

b) 37 °C *[1 mark]*

c) $V = IR$

$12 = I \times 1000$ *[1 mark]*

$I = 0.012\,\text{A}$ or $12\,\text{mA}$

[2 marks, 1 for answer, 1 for unit]

d) As the temperature rises the resistance of X decreases and the current rises.

When the current rises the p.d. across the 750 Ω resistor rises, so the p.d. across X decreases and the voltmeter reading falls.

[3 marks, 1 for each good point]

9 a) i) The lamp has the greatest resistance, because the current through it is smaller. *[1 mark]*

$I = \dfrac{V}{R}$

All the appliances have the same p.d. across them. *[1 mark]*

ii) The cable needs to be thicker to carry a large current. If the cable is thin, a large current can heat it. *[1 mark]*

The kettle needs an earth wire. *[1 mark]*

b) $P = VI$

$= 230 \times 11.5$ *[1 mark]*

$= 2645\,\text{W}$ *[1 mark for answer, 1 mark for unit]*

c) i) $R = \dfrac{V}{I}$

$= \dfrac{230}{11.5}$

$= 20\,\Omega$ *[1 mark]*

$I = \dfrac{V}{R}$

$= \dfrac{115}{20}$ *[1 mark]*

$= 5.75\,\text{A}$ *[1 mark]*

or you can say that since the p.d. is halved, the current is halved:

$\dfrac{11.5V}{2} = 5.75\,\text{A}$

[3 marks]

ii) $P = VI$

In USA, V is halved, I is halved so the power is reduced by a factor of 4. *[2 marks]*

Now the kettle boils in four times the time = 360 s. *[1 mark]*

$$t = \frac{E}{P}$$

10 a) B (as this has the largest resistance) *[1 mark]*

b) D (as this has the least resistance) *[1 mark]*

Working scientifically: Units and calibration

Pages 316–17

1

Quantity	Unit	Symbol
charge	coulomb	C
current	ampere	A
energy	joule	J
frequency	hertz	Hz
potential difference	volt	V
power	watt	W
resistance	ohm	Ω
time	second	s

2 They share a common understanding

or

they can compare directly values measured in different places.

3 Draw a horizontal line from the voltmeter reading to the graph line; draw a vertical line down from this point on the graph line.

4 Because the calibration graph is not linear; joining only two data points would give a straight line and not a curve.

5 Between 8.4 and 8.6.

6 The resolution gets worse; a larger change in temperature is needed to produce the smallest measurable change in the voltmeter reading.

3 Particles

Overview

Specification points

4.3.1 Changes of state and the particle model,
4.3.2 Internal energy and energy transfers, and
4.3.3 Particle model and pressure

Textbook chapter references

AQA GCSE (9-1) Physics: Chapter 3 pages 66–86

AQA GCSE (9-1) Combined Science Trilogy 1: Chapter 17 pages 318–36

AQA GCSE (9-1) Combined Science Trilogy: Chapter 17 pages 318–36

Recommended number of lessons: 10

Chapter overview	
AQA required practical(s)	Physics – RP5 CS Trilogy – RP17
Contains higher-tier material	Yes
Contains physics-only material	Yes

Useful Teaching and Learning resources

- Learning outcomes
- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–3
- Key terms
- Personal tutor: Energy transfers
- Practical: Determining the density of regularly shaped solids
- Teacher and technician notes: Determining the density of regularly shaped solids
- Practical: Determining the density of irregularly shaped solids
- Teacher and technician notes: Determining the density of irregularly shaped solids
- Practical: Determining the density of liquids
- Teacher and technician notes: Determining the density of liquids
- Practical video: Determining the density of regularly shaped solids
- Practical video: Determining the density of irregularly shaped solids
- Practical video: Determining the density of liquids
- Homework tasks (a) and (b)
- Quick quizzes 1–4
- Answers for homework tasks
- Answers to all questions
- Half-term test: Particle model of matter

Useful prior learning

As well as the points below – mainly based on KS3 expectations – it is worth remembering that KS4 chemistry lessons will have provided prior learning as well. Depending on the sequence followed, students may have encountered parts of this topic under the heading of Chemistry Unit 2.

- Matter is made up of atoms and molecules.
- There are three states of matter: solid, liquid, gas.
- In a solid, atoms are packed together in regular patterns.
- In a liquid, atoms are in contact and are able to flow past each other.
- In a gas, atoms or molecules are spread out and are free to move around.
- The density of a substance measures the mass of that substance in a given volume. Solids and liquids are usually denser than gases.

Common misconceptions

It is to be hoped that by this stage students will understand that particles – whether atoms or molecules – are not actually solid spheres like snooker balls. They may need reminding that there are not large gaps between particles in a liquid, and that particles in a solid are not moving *around*, but are moving *in place* (vibrating), but the main ideas should be fairly well established. Although not a misconception, reminders about clear language may be useful for distinguishing between heating and melting/evaporating, cooling and condensing/solidifying.

Preparation

The **T&L Prior knowledge catch-up student sheet** is a very good starting point, and the accompanying answers will allow you to check their understanding. Students may need reassuring that forgetting odd words is not the same as misunderstanding; this topic has a much lower maths demands than the previous two, but the vocabulary will still need attention.

Students will probably have enough prior knowledge that the **T&L Topic overview** is not unduly intimidating. They could use a printed copy of the slides to tick the areas they feel they understand and add question marks to those that are less familiar. It is worth emphasising that there is too much information on these to be used as revision cards, but they *can* guide review work; this may be a good opportunity to provide the overviews for previous topics.

Many computer simulations are available that will support your students during this topic;

they range from simple animations to complex virtual experiments allowing you to consider individual particles in a gas sample. PhET is often a good place to start, but be aware the language used for energy is still based on the types and transformations model.

Required practical 5(*17*): Calculating density: Lesson 1

Learning outcomes

1 Define zero error and calibration.
2 Draw a table.
3 Complete density practicals as circus.

Suggested lesson plan

Starter
Demonstrate the balances used and show how to reset the scale. Ask how to find the mass of 100 ml of water and then try out their suggestions.

Main
Our intuitive understanding is often to describe things as 'heavy' when what we mean is *dense*. Introduce the equation (density = mass/volume) and provide a structure by giving a table with columns for each part of the calculation.

The three **T&L Practical worksheets** are fairly straightforward, and it should not be difficult for students to try the different approaches in a single lesson. You may choose to spread them over two lessons rather than as a circus, adding several extras for context. For example, can students collect data on a selection of toy bricks to show which is the odd one out? Mega-Bloks^{TM} versus Lego^{TM} works well, or try Lego versus Duplo^{TM}. (Other bricks are available.) Or provide several lumps of plasticene, one with a ball bearing inside, and see if they identify it as an anomaly on the graph.

If you use **T&L Practical video: Determining the density of regularly shaped solids**, then be aware that the micrometer shown is a digital one. Providing instructions for the models you have in school is probably a good idea. The point is made clearly to use kilograms and cubic metres, but it bears repeating.

Plenary
Challenge students to describe the density of a piece of bubble wrap – or if available, aerogel. What about a sponge?

Support
Although the maths involved in the density calculation itself is simple, some students will struggle with the unit conversions. You may find it helpful to compare notes with maths department colleagues to see if they have models of cubes showing the relationship between side lengths and volume.

Extension
Some students should be able to explain the importance of anomalous results and how this can show an actual difference rather than being a mistake.

Homework
Students could answer the questions on the sheets if not done alongside the practicals. There are also some questions accompanying the notes from pages 68–70 (*320–322*) in the textbook.

Calculating density (debrief): Lesson 2

Learning outcomes

1 Define anomaly.
2 Draw and compare lines of best fit.
3 Use data to practise using equation.

Suggested lesson plan

Starter
T&L Lesson starter 2 invites students to consider the difference between an object being light and having low density. You could also use it to introduce the idea that water is an anomaly, with the solid being less dense than the liquid.

Main
If it's not already been done, the data from the more involved density practicals can be analysed using graphs. Alternatively, data from a simulated industrial test could be provided with students invited to play the part of quality controllers. Which metal is less pure than claimed?

Use Test yourself questions 1–4 from page 70 (*322*) of the textbook and other practice questions to help students become fluent with density calculations, including conversions of units.

Plenary
Provide an explanation of density with added mistakes and ask students to correct them.

Support
Again, the major issue for students is likely to be with the unit conversions. Reinforcing a clear method is likely to be useful for exam technique in the future anyway.

Extension
Ask able students to explain the principles for choosing whether to include the origin when plotting a graph.

Homework
Students should review KS3 work (and their Chemistry notes) to check their understanding of the particle model of matter.

States of matter: Lesson 3

Learning outcomes

1. Recap particle arrangement models.
2. Link energy stores to particle motion.
3. Discuss change of state in terms of particles and compare with non-reversible chemical changes.

Suggested lesson plan

Starter
T&L Lesson starter 1 could be used here; you may wish to show a video of the equipment shown if it is not available in the department. Figure 3.32 (*17.28*) from page 85 (*335*) of the textbook (also available in the **T&L Diagram bank**) is a diagram of the equipment in isolation.

Main
Between KS3 work and Chemistry topic 2, this should all be review for students. Ensure that they are confident with the vocabulary for state changes and can describe particle arrangement, separation and motion for each state of matter, linking these characteristics to observable behaviour. It makes sense to most students that providing energy to a substance makes the particles move more quickly, and this can now be linked to the idea of particles as kinetic stores.

Students can attempt Test yourself questions 5–6 from page 71 (*323*) of the textbook.

It may be worth discussing the periodic table and that atoms, although more or less the same size, have different masses. Students may be surprised how little the atomic radius changes, but should be able to see why this makes most metals denser than non-metals.

Plenary
Everything has now been covered for **T&L Quick quiz: Particle Model 1**.

Support
Although most students will confidently describe the particle model, linking it to measurable quantities in the lab may be more difficult.

Extension
For some students this is an ideal opportunity to discuss the use of models in science; they should be able to describe the limitations of the particle model and why it is still a helpful one in most cases.

Homework
Students could prepare for a brief vocabulary test on state changes.

Heat and temperature: Lesson 4

Learning outcomes

1. Discuss thermal stores.
2. Define internal energy in terms of particle motion and potential.

Suggested lesson plan

Starter
Demonstrate a swinging pendulum and ask what kind of energy store is involved. Arguments about whether it is a gravitational store, a kinetic store or both will follow.

Main
Remind students that when we use the energy stores model, we are representing something very abstract. The starting point is always to consider something measurable in the real world, such as the amount of fuel remaining or the height to which an object is lifted above the ground. Suggest to them that the temperature of a sample gives us important information about the energy stored, and that we use the concept of a thermal store for this. In contrast, heating is a process which changes the temperature of a sample.

The notes in the textbook on page 72 (*324*) describe internal energy in terms of kinetic and potential stores. This is *not* accidentally vague; we can’t measure the particle interactions (gravitational, electric, kinetic) so we admit they all exist but group them together. What we *measure* is the temperature of the sample. Return to the pendulum; it’s hard to say how much energy is in the gravitational store or the kinetic store at any moment, but we can say that the total is the same.

Use Test yourself questions 7–9 from page 73 (*325*) of the textbook.

Plenary
Provide statements for students to match of changes in particle motion/position and (measurable) temperature differences; have them focus on increase and decrease rather than specifics.

Support
Students may struggle to see that 'internal energy' is just a way of describing the thermal store in terms of particles. Always return to the measurable quantities of the sample as a whole. Another useful comparison is that the wind exerts a force which is actually the total of many tiny impact forces from each individual particle. It's about perspective; many of the truths we cling to depend greatly on our own point of view.

Extension
This is another opportunity to discuss the limitations of a model and how we must deduce what is happening on a particle level from what is observable to us.

Homework
Students should produce a summary of the work done on specific heat capacity in the first topic.

Specific heat capacity: Lesson 5

Learning outcomes

1 Recap use of equation ($\Delta E = mc\Delta\theta$).
2 Complete example questions.
3 Discuss applications, e.g. cooling of high value for water.

Suggested lesson plan

Starter
Provide a simple statement that heating 10 kilograms of water by 10 degrees Celsius involves an energy change of 420 000 J or 0.42 MJ. Ask what alteration they could make so the energy change was 0.21 MJ or 0.84 MJ. (Some will give answers involving doubling/halving the amount or mass of water; others will double or halve the temperature change.)

Main
Whether they gave the equation $\Delta E = mc\Delta\theta$ (explored on page 74 (*326*) of the textbook) or not, explain that they have covered the main points; they should understand that both mass of the substance and the temperature change are factors in the relationship. The third factor, the specific heat capacity, is the 'unheatability' of the substance. The higher the number, the harder it is to heat.

Give some worked examples to remind students of working; by now they may be more confident rearranging. It may still be necessary to point out that this equation does not fit well into a triangle mnemonic. Remind them also that when explaining the factors, marks may be lost if they are vague about the 'amount' rather than using the term *mass*.

Although they will not need to recall numbers, it may be helpful to plot sample specific heat capacity values on a number line. Students should list applications of water's significantly higher value (starting with cooling things down). Figures 3.9 (*17.9*) a) and b) offer a vivid contrast.

Test yourself questions 10–12 from page 75 (*327*) of the textbook could be done in the lesson or as homework.

Plenary
Students can now attempt **T&L Quick quiz: Particle Model 2**.

Support
Be ready to remind students about unit conversions and using standard form. This lesson offers useful consolidation of the ideas covered in the Energy topic.

Extension
Ask students why we always specify temperature *change* rather than actual temperature. The following discussion may lead towards the idea of an absolute temperature scale and a zero point.

Homework
If not used in the lesson, Test yourself questions 10–12 from page 75 (*327*) of the textbook could be used. Alternatively, students could use the data on page 74 (*326*) to write their own questions, with annotated mark schemes for each.

Measuring latent heat: Lesson 6

Learning outcomes

1 Work through equations.
2 Set up experiment and collect data.
3 Compare with book value.

Suggested lesson plan

Starter
Ask students to compare *in words* the internal energy of a kilogram of water at 100°C with a kilogram of steam at the same temperature. Ask them why it increases, referring back to the particle behaviour. Alternatively, if the state changes vocab was set as revision in an earlier lesson, this would be an appropriate point to test student recall.

Main
It may be useful to add the energy changes described to a change of state diagram, similar to Figure 2.19 from the chemistry resources.

It is not hard to demonstrate that both an increase in temperature and a change of state require energy to be supplied. Explain that so far the only equation they have used applies to the first of these. Ask what measurements they would need to take to find the energy needed to change water into steam – a change that happens at 100 °C. This would be a good time to specify that the latent heat (in J/kg) is different for the two state changes, *fusion* and *vaporisation*.

Describe how the energy input can be measured or calculated using a similar method to the specific heat capacity practical. Finding the mass involved is slightly more complex as it may mean measuring a change in mass, assuming what is 'lost' has become a gas. The method given on page 76 (*328*) of the textbook is clear and the calculation is laid out clearly.

Students should practise the calculations, which are more straightforward than those for specific heat capacity. This is an equation that will be provided in the exam if needed.

Plenary
Students could describe heating a sample from ice at –10°C to steam at 110°C, explaining for each stage which equation is relevant.

Support
Some students may struggle to differentiate between specific heat capacity and specific latent heat. You can point out that the latent heat unit doesn't involve °C because there is no temperature change.

Extension
Ask students to explain why the latent heat of vaporisation is always much higher than that of fusion. (The particle separation is much greater.)

Homework
Test yourself questions 13–15 from pages 77–78 (*329–330*) of the textbook. This will provide a mixture of material covered and what is to come in the next lesson. As well as answering questions using the notes in the book, students should list any questions on cooling curves to focus their attention in class.

Cooling graphs: Lesson 7

Learning outcomes

1 Diagram of equipment, data logger.
2 Discuss particle bonds.
3 Sketch cooling curve from IWB.

Suggested lesson plan

Starter
Ask students to sketch the temperature graphs for coffee cooling and ice melting in a room, thinking of the work done last lesson on latent heat. (Only the line for ice melting should have a level stage because the coffee does not change state.)

Main
There are several alternatives to demonstrate this effect, including stearic acid and ethanamide. It is likely that this practical will be done as a demonstration; students can be shown the equipment (with data logger) and draw their diagrams/results tables as the numbers are collected.

During this time, the cooling curve for coffee can be discussed and the point made that the gradient changes, depending on the temperature difference between the sample and the surroundings. This is why the rate of heat 'loss' (asking students why 'loss' is a poor word to use will remind them of discussions about *dissipation* and conservation of energy) is high at first and then decreases. Coffee is briefly very hot, quite hot for a while and warm for ages.

Displaying results from the data logger will show that the line is more interesting if a state change is involved. During the change from a liquid to a solid, the temperature will remain constant even while energy is transferred to the thermal store of the surroundings. This is because the internal energy of the sample is decreasing as bonds form between the particles. It is important that students appreciate that these are *physical* rather than *chemical* bonds.

Plenary
Students can now attempt **T&L Quick quiz: Particle Model 3**.

Support
Have students describe what is happening at each stage of the cooling curve (e.g. Figure 3.15 (*17.15*) on page 77 (*329*) of the textbook, also available in the DL Diagram bank), clearly distinguishing between temperature changes (cooling) and state changes (solidifying).

Extension
Adding milk to coffee lowers the temperature by 5 °C. If a teacher wants their coffee to be as hot as possible at the end of break, should they add the milk at the start or end of the time? (At the start, so the rate of heat loss is lower over the time involved.)

Homework
If not already done, Test yourself questions 13–15 from pages 77–78 (*329–330*) of the textbook cover latent heat calculations and state changes. Alternatively, students should be able to explain

Figures 3.16 and 3.17 (*17.6 and 17.17*) (page 77 (*329*) of the textbook, or create a printed version from the versions available in the **T&L diagram bank**) in terms of latent heat.

Brownian motion: Lesson 8

Learning outcomes

1. Recap historical scientific method.
2. Observe movements of smoke particles though a microscope.
3. Describe the meaning of observations.

Suggested lesson plan

Starter

Ask students how they can prove that the gas around them is made of particles.

Main

Although not described in the textbook, if there is time students will gain much from doing (or at least seeing) this practical. Although it may seem overly dramatic, it is even worth running it first as a microscope practical rather than using a visualiser so they literally see the same effect first described nearly 200 years ago. http://practicalphysics.org/brownian-motion-smoke-cell.html

Although pollen grains in water were described first, Brownian motion is used to refer to particles of soot or smoke in air. The soot particles move randomly, as collisions with (invisible) air particles drive them first one way then another. Einstein was one of several scientists who used this as evidence for atoms a little over a century ago. Although this may seem like ancient history, it is worth putting this in context with other ideas studied, in science and outside (we have had cars longer than we have had proof of atoms).

This is an excellent way to recap the models we use for matter and how they have been obtained; this is particularly apt as the next group of lessons examine these models in terms of the gas laws. Once the motion of the particles in a gas has been demonstrated, students can sum up the ways in which it may change.

Plenary

Students should record how temperature can be considered as a measure of the average kinetic store of the particles within it (the notes on page 78 (*330*) of the textbook may help).

Support

Assuming that the practical goes well, students often find this helps them grasp the rather abstract nature of the particle model. The scale involved may be a challenge so simply emphasise that many small particles are required for any measurable force on a surface.

Extension

Encourage students to consider both the link between model and observed reality, and the numbers involved for even a small quantity of gas, reminding them of Avogadro's constant from chemistry.

Homework

As the topic is nearing completion, setting some revision may be appropriate. They could attempt **T&L Homework task (a)** or **(b)**, in both cases omitting question 9.

Pressure and volume: Lesson 9 (Physics only)

Learning outcomes

1. Imploding/exploding can demos.
2. Explain $PV =$ constant relationship.
3. Draw diagrams linking cumulative impacts with overall pressure.

Suggested lesson plan

Starter

Display the equation for pressure ($P = \frac{F}{A}$) and ask students to define quantities and units.

- P = pressure in pascals (Pa) or newtons per square metre (N/m^2)
- F = force in newtons (N)
- A = area in square metres (m^2)

Main

Students may remember the imploding and exploding can demonstrations from KS3, but that doesn't mean they're not relevant. In each case, students should be encouraged to describe (and link) particle behaviour and their observations. The notes on page 79 (*331*) of the textbook are probably best saved for after the demonstration.

Squeezing an inflated balloon will help get over the idea that pressure and volume are inversely proportional; as one is increased the other decreases, as long as temperature remains constant. Students should record the relationship ($PV = constant$) but you may need to emphasise that the constant is for that particular system. Statements about relative changes (doubling and halving) are worth discussing. Be sure to point out that although Figure 3.23 gives the *length* of the column as the *x*-axis, this is still proportional to the volume.

Be careful using the word *expand* for increasing volume, as students tend to associate it with temperature increases.

Variations on Figure 3.20 may be useful for students; they could draw how the number of impacts and the speed (and therefore force) changes with varying volume and pressure. Returning to the KS3 simulation with students running around the room may be going too far, but they could certainly imagine it!

Plenary
Discuss what happens to an inflated balloon as it is lowered beneath the surface of the sea; pressure on the balloon increases, so what happens to the volume?

Support
Providing a partially filled-in table with columns for particle behaviour and observations might help some students.

Extension
Although well above this level, some students may find it helpful to see the ideal gas equation ($PV = nRT$) to help them to appreciate how the constant depends on the situation provided. Emphasise that this is A-level work!

Homework
Test yourself questions 16–19 from page 80 of the textbook (Physics only). Alternatively (or as well), students can now attempt **T&L Quick quiz: Particle model 4**. (There is a very brief mention of work done on a gas, but they can eliminate the other answers using what they have covered.)

Work and energy: Lesson 10 (Higher tier and Physics only)

Learning outcomes

1 Recap work done equation.
2 Use simulations to investigate increasing pressure.
3 Describe everyday applications.

Suggested lesson plan

Starter
T&L Lesson starter 3 (which can and should be accompanied by the bicycle pump demo pictured) works well here.

Main
Remind students of the work done equation as used in the first topic (work done = force applied × distance moved). It makes intuitive sense that applying a larger force or having to exert it while moving along a greater distance will require more energy.

In the case of the bicycle pump, it is clear that the work is done on the particles of gas. The pump warms up because it is in contact, but we are often more interested in the particles, which will be moving faster; the effect is the same (the gas temperature increases) and we can consider individual particles. Computer simulations, as in many of the lessons in this topic, are often helpful and PhET are usually a good place to start. These allow students to see how temperature is affected. You may find it helpful to discuss how a higher temperature will, in turn, increase the pressure on the container walls.

The use of controlled explosions to increase pressure and temperature in a predictable way, which then does work, may seem an odd concept to students until you explain that this is exactly how internal combustion works.

Plenary
Test yourself question 20 from page 81 of the textbook (Physics only).

Support
Although this is higher tier work, the difference is likely to be that some students struggle to put their explanations in a clear sequence. You may choose to provide example sentences that they can use in their answers.

Extension
Ask students to explain why a gas cylinder on a camping stove in use feels so cold; condensation on the outside shows that the fuel is at a much lower temperature than the surroundings.

Homework
From the textbook, the Chapter review questions (page 82 (*332*)) and Practice questions (pages 83–84 (*333–334*)) will be helpful if not used to extend learning throughout the topic. The timing of assessments in your setting will determine how the topic test is used; due to the shortness of the topic only one is available, **T&L Half-term test 4.3: Particle model of matter**.

Answers

AQA GCSE (9-1) Physics

Test yourself on prior knowledge

1 Solid, liquid, gas.
2 There are fewer atoms (or molecules) in 1 m^3 of gas than 1 m^3 of solid. There is a lot of space between gas atoms; in a solid, atoms are packed closely together.

3 The molecules in steam are much more widely separated than the molecules in water.

Test yourself

1 A cork floats on water because it has a lower density than water. A stone sinks because it has a higher density than water.

2 $$\text{density} = \frac{\text{mass}}{\text{volume}}$$
$$= \frac{0.1732}{0.101 \times 0.048 \times 0.013}$$
$$= 2750\,\text{kg/m}^3$$
Note: it is easier to turn the mass into kg first, and the lengths into m.

3 a) i) volume = 120 ml − 100 ml = 20 ml

ii) volume = $20 \times 10^{-6}\,\text{m}^3$

b) $$\text{density} = \frac{m}{v}$$
$$= 4500\,\text{kg/m}^3$$

4 water – $1000\,\text{kg/m}^3$
alcohol – $4\,\text{m}^3$
titanium – 2250 kg
cork – $0.001\,\text{m}^3$
gold – $19\,500\,\text{kg/m}^3$

5 Refer to Figure 3.6 page 71.

6 The molecules in gases are further apart than the molecules in liquids and solids, so gases have less mass in a given volume; therefore the density is lower.

7 a) A change of state occurs when a liquid changes to a solid or a gas, for example.
b) i) Water freezing
ii) Alcohol evaporating

8 Melting snow; breaking a matchstick; mixing salt and sugar.

9 a) The internal energy rises.
b) There is a change of stage: melting or evaporating/boiling.

10 a) $$\Delta E = mc\Delta\theta$$
$$= 60 \times 800 \times 25$$
$$= 1\,200\,000\,\text{J}$$
or 1.2 MJ

b) $$\Delta E = mc\Delta\theta$$
$$4180 = 0.5 \times 380 \times \Delta\theta$$
$$\Delta\theta = \frac{4180}{190}$$
$$= 22\,°\text{C}$$

c) $$\Delta E = mc\Delta\theta$$
$$21\,120 = m \times 880 \times 16$$
$$m = \frac{21120}{880 \times 16}$$
$$= 1.5\,\text{kg}$$

11 a) $$\Delta E = mc\Delta\theta$$
$$13\,500 = 1.2 \times c \times 45$$
[Note: the joulemeter is set to kJ.]
$$c = \frac{13\,500}{1.2 \times 45}$$
$$= 250\,\text{J/kg}\,°\text{C}$$

b) i) There will be heat losses to the surroundings.
ii) Energy is used to warm up the heater itself and the thermometer.

12 a) $$\Delta E = mc\Delta\theta$$
$$= 0.75 \times 4200 \times 80$$
$$= 252\,000\,\text{J}$$

b) $$P = \frac{\Delta E}{t}$$
$$2000 = \frac{252000}{t}$$
$$t = \frac{252000}{2000}$$
$$= 126\,\text{s}$$

13 a) Energy is transferred from the body's thermal store to evaporate the sweat.
b) If you get out of the sea on a windy day, water from the skin evaporates quickly. This removes energy quickly from the body's thermal store and you cool down.

14 a) i) The substance melts over the period BC and
ii) boils over the period DE.
b) 155 °C
c) Vaporisation – it takes longer for the substance to evaporate than to melt, so more energy is supplied to evaporate the substance than to melt it.

15 a) The specific latent heat of fusion is the energy required to turn 1 kg of ice at 0 °C to 1 kg of water at the same temperature. If you use ice at −18 °C, you also measure the energy required to warm it up.

b) $$E = P \times t$$
$$= 50 \times 60$$
$$= 3000\,\text{J}$$ (Remember to turn 1 minute into 60 s.)

c) $$E = mL$$
$$3000 = 0.008\,L$$
$$L = \frac{3000}{0.008}$$
$$= 375\,000\,\text{J/kg}$$

d) i) Energy might be lost to the surroundings directly from the heater because the ice is not in contact with the heater.
ii) Some energy from the surroundings could melt the ice.
iii) The ice might be colder than 0 °C.

16 a) The particles move rapidly in random directions.

b) The molecules move faster as the temperature rises.

17 a) At 1200 °C the molecules move much faster than at room temperature. Therefore the molecules hit the walls of the cylinder harder and more often; the temperature rises.

b) The pressure could cause the cylinder to explode.

18 a) The molecules strike the walls of the container. Each molecule exerts a force, which produces the pressure $\left(\text{pressure} = \dfrac{\text{force}}{\text{area}}\right)$.

b) The molecules move faster. Each collision exerts a larger force; the collisions are more frequent. Both factors cause the pressure to rise.

19

$$P_1V_1 = P_2V_2$$
$$100 \times 240\,000 = 800 \times V_2$$
$$V_2 = 30\,000\,\text{m}^3$$

20 a) The piston hits the moving molecules and makes them rebound at a greater speed. A greater average speed of the molecules corresponds to a higher temperature. You could also explain this by saying that the moving piston does work on the gas, which causes an increase in its internal or thermal energy.

b) Now the molecules rebound from the moving piston more slowly, as the piston is moving away from the molecules. A slower average speed of molecules corresponds to a lower temperature. Or you could say that the gas does work as it expands, and the source of this work is the internal energy of the gas.

Show you can

Page 70

- Measure the mass of a measuring beaker by placing it on an electronic balance. Record its mass in grams, m_1.
- Fill the beaker with the liquid – to the 100 ml mark.
- Measure the mass again, m_2.
- Calculate the mass of the liquid, $m_2 - m_1$.
- The density of the liquid is calculated using:
- density = $(m_2 - m_1)$/volume
- To calculate the density in kg/m^3, convert grams to kilograms ($1\,\text{g} = 10^{-3}\,\text{kg}$) and remember that $1\,\text{ml} = 10^{-6}\,\text{m}^3$.

Page 78

Neither method of burning is to be recommended. Steam is much more dangerous because it releases latent heat when it condenses to water at 100 °C and the specific latent heat of steam is very high.

Page 80

The pressure exerted by the gas depends on how hard the molecules hit the walls of the container and how often. If the temperature of the gas stays the same, the molecules will travel at the same speed – so the collisions are no harder. But because the volume is reduced there are more collisions per second, so the pressure rises.

Required practical

Page 68

1 The percentage error in the measurement will be smaller
or
the error in the measurement will be less significant.

2 The smallest change in mass that can be measured is 0.1 g.

Page 69

1 The sides of the cuboid could be slightly worn away or rounded.

2 Stack 500 sheets of paper on top of each other. Measure the thickness of the stack and then divide by 500.

Page 70

1 A mass of zero must have a volume of zero.

2 An anomalous data point will not be close to the line of best fit.

Chapter review questions

1 a) volume = 0.04 × 0.03 × 0.05

$$= 6 \times 10^{-5}\,\text{m}^3$$

b)

$$\rho = \frac{m}{v} = \frac{0.03}{6 \times 10^{-5}} = 500\,\text{kg/m}^3$$

Hint: Work in m and kg from the start. Do not try to convert g/cm^3 to kg/m^3, which is the harder way to do the problem.

2 a) Mass – measure on an electronic balance.
Volume – measure the volume by displacing a volume of water.

b)

$$\rho = \frac{m}{v} = \frac{0.32}{26 \times 10^{-6}} = 12\,300\,\text{kg/m}^3$$

c) A lead ornament with a gold cover.

3 When a liquid evaporates, energy must be supplied from the surroundings to cause the evaporation. When ether is on the skin, energy is supplied from the body for it to evaporate. The loss of energy makes the skin feel cold.

4 **a)** The molecules in ice are in fixed positions; the molecules in water are free to move past each other. [See Figure 3.6 Page 71 for an example of a diagram.]

b) Energy must be supplied to melt ice at 0 °C. Energy comes from the drink to melt the ice, so cooling the drink.

c) Ice is less dense than water.

5 **a)** $\Delta E = mc\Delta\theta$

$200 \times 10^3 = 40 \times 1000 \times \Delta\theta$

$$\Delta\theta = \frac{200\,000}{40\,000} = 5\,°\text{C}$$

so the air temperature rises from 15 °C to 20 °C

b) $\Delta E = mc\Delta\theta$

$$= 60 \times 800 \times (48 - 13)$$
$$= 60 \times 800 \times 35$$
$$= 1\,680\,000\,\text{J or } 1.68\,\text{MJ}$$

6 **a)** Molecules are in a state of constant motion. The molecules hit the walls of the container and thereby exert a force on the walls. Pressure is a measure of that force per unit area.

b) At a higher temperature, the molecules move faster. Therefore, the molecules hit the walls harder and more often.

7 **a)** $P = \frac{E}{t}$

$$500 = \frac{E}{5 \times 60}$$

$E = 500 \times 300$

$= 150\,000\,\text{J}$

b) $L = \frac{E}{m}$

$$2500\,000 = \frac{150\,000}{m}$$

$$m = \frac{150\,000}{2500\,000}$$

$= 0.06\,\text{kg}$

8 $P_1V_1 = P_2V_2$

$600 \times 0.8 = 100 \times V_2$

$$V_2 = \frac{600 \times 0.8}{100}$$

$= 4.8\,\text{m}^3$

Practice questions

1 kg/m^3 *[1 mark]*

2 **d)** X and Z *[1 mark]*

3 **a)** liquid

b) solid

c) liquid

d) gas

e) gas

f) solid *[1 mark]* each

4 **a)** It remains the same. *[1 mark]*

b) It gets smaller. *[1 mark]*

c) It increases. *[1 mark]*

d) It increases. *[1 mark]*

5 The substance could melt or boil (or evaporate). *[1 mark] [1 mark]*

6 Atoms in a solid remain in fixed positions, but can vibrate about those fixed positions. *[2 marks]*

The atoms in a gas are separated and free to move around at random at large speeds. *[2 marks]*

7
- Measure the mass, M, of the marbles using the balance. *[1 mark]*
- Put some water in the cylinder and measure the volume V_1. *[1 mark]*
- Put the marbles in and measure the new volume V_2. Volume of the marbles, V, is $V_2 - V_1$. *[1 mark]*
- Calculate the density, ρ, using

$$\rho = \frac{m}{v}$$ *[1 mark]*

8 **a)** $\Delta\theta = 70 - 30$

$= 40\,°\text{C}$ *[1 mark]*

b) $\Delta E = mc\Delta\theta$

$48\,000 = 2 \times c \times 40$ *[1 mark]*

$$c = \frac{48000}{80}$$ *[1 mark]*

$= 600\,\text{J/kg}\,°\text{C}$ *[1 mark] [1 mark unit]*

c) $P = \frac{E}{t}$ *[1 mark]*

$$= \frac{48\,000}{10 \times 60}$$ *[1 mark]*

$= 80\,\text{W}$ *[1 mark]*

9 **a)** 53 °C *[1 mark]*

b) The energy that is supplied by the heater is used to break the bonds which keep the wax as a solid. When the bonds break, the internal energy of the solid increases. *[2 marks]*

c) $L = \frac{E}{m}$ *[1 mark]*

$$= \frac{4000}{0.05}$$ *[1 mark]*

$= 80\,000\,\text{J/kg}$ *[1 mark] [1 mark]* unit

$P = h\rho g$

10 **a)** **i)** $= 25 \times 1000 \times 9.8$ *[2 marks]*

$= 245\,000\,\text{Pa}$ *[1 mark]*

or 245 kPa

ii) $P = 245\,\text{kPa} + 100\,\text{kPa}$

$= 345\,\text{kPa}$ *[1 mark]*

b) **i)** $P_1V_1 = P_2V_2$

$345 \times 5 = 100 \times V_2$ *[1 mark]*

$V_2 = \frac{345 \times 5}{100}$ *[1 mark]*

$= 17.25\,\text{l}$ *[1 mark]*

ii) The pressure inside the lungs is 345 kPa; at the surface the pressure is 100 kPa. This pressure difference would rupture the lungs. So the diver must get rid of air as he rises. *[1 mark]*

11 a) The helium atoms are moving quickly in random directions. They hit the walls of the cylinder and bounce back. As they hit the walls they exert a force. *[2 marks]*

b) $P_1V_1 = P_2V_2$

$1.0 \times 10^7 \times 0.1 = 1.2 \times 10^5 \times V_2$ *[1 mark]*

$V_2 = \frac{10^6}{1.2 \times 10^5}$ *[1 mark]*

$= 8.33\,\text{m}^3$ *[1 mark]*

c) The total volume is 8.33 m^3 but 0.1 m^3 is left in the cylinder leaving 8.23 m^3 for the balloons, *[1 mark]* so he can fill 823 balloons. *[1 mark]*

$[8.23 = n \times 0.01]$

Working scientifically

1 A ball and spring model for the internal energy of a solid.

2 The acceleration would increase (in direct proportion to the increase in force); this could be tested experimentally by applying different forces to an object (e.g. laboratory trolley) and measuring the acceleration.

3 A model of the Solar System.

4 New evidence (observations or data) that support a prediction made by a model and cannot be explained by the other models.

AQA GCSE (9-1) Combined Science

Test yourself on prior knowledge

1 Solid, liquid, gas.

2 There are fewer atoms (or molecules) in 1 m^3 of gas than 1 m^3 of solid. There is a lot of space between gas atoms; in a solid, atoms are packed closely together.

3 The molecules in steam are much more widely separated than the molecules in water.

Test yourself

1 A cork floats on water because it has a lower density than water. A stone sinks because it has a higher density than water.

2 $\text{density} = \frac{\text{mass}}{\text{volume}}$

$= \frac{0.1732}{0.101 \times 0.048 \times 0.013}$

$= 2750\,\text{kg/m}^3$

Note: it is easier to turn the mass into kg first, and the lengths into m.

3 a) i) volume = 120 ml − 100 ml

= 20 ml

ii) volume = $20 \times 10^{-6}\,\text{m}^3$

b) $\text{density} = \frac{m}{v}$

$= \frac{0.09}{20 \times 10^{-6}}$

$= 4500\,\text{kg/m}^3$

4 water – 1000 kg/m^3
alcohol – 4 m^3
titanium – 2250 kg
cork – 0.001 m^3
gold – 19 500 kg/m^3

5 Refer to Figure 17.6 page 323.

6 The molecules in gases are further apart than the molecules in liquids and solids, so gases have less mass in a given volume; thus the density is lower.

7 a) A change of state occurs when a liquid changes to a solid or a gas, for example.

b) Any two suitable examples such as: water freezing; alcohol evaporating.

8 Melting snow; breaking a matchstick; mixing salt and sugar.

9 a) The internal energy rises.

b) There is a change of stage: melting or evaporating/boiling.

10 a) $\Delta E = mc\Delta\theta$

$= 60 \times 800 \times 25$

$= 1\,200\,000\,\text{J}$

or 1.2 MJ

b) $\Delta E = mc\Delta\theta$

$4180 = 0.5 \times 380 \times \Delta\theta$

$\Delta\theta = \frac{4180}{190}$

$= 22\,°\text{C}$

c) $\Delta E = mc\Delta\theta$

$21\,120 = m \times 880 \times 16$

$m = \frac{21120}{880 \times 16}$

$= 1.5\,\text{kg}$

11 a) $\Delta E = mc\Delta\theta$

$13\,500 = 1.2 \times c \times 45$

[Note: the joulemeter is set to kJ]

$c = \frac{13\,500}{1.2 \times 45}$

$= 250\,\text{J/kg}\,°\text{C}$

b) There will be heat losses to the surroundings. Energy is used to warm up the heater itself and the thermometer.

12 a) $\Delta E = mc\Delta\theta$

$= 0.75 \times 4200 \times 80$

$= 252\,000\,\text{J}$

b) $P = \frac{\Delta E}{t}$

$2000 = \frac{252000}{t}$

$= 126\,\text{s}$

13 a) Energy is transferred from the body's thermal store to evaporate the sweat.

b) If you get out of the sea on a windy day, water from the skin evaporates quickly. This removes energy quickly from the body's thermal store and you cool down.

14 a) i) The substance melts over the period BC and **ii)** boils over the period DE.

b) 155 °C

c) Vaporisation – it takes longer for the substance to evaporate than to melt, so more energy is supplied to evaporate the substance than to melt it.

15 a) The specific latent heat of fusion is the energy required to turn 1 kg of ice at 0 °C to 1 kg of water at the same temperature. If you use ice at −18 °C, you also measure the energy required to warm it up.

b) $E = P \times t$

$= 50 \times 60$

$= 3000\,\text{J}$ (Remember to turn 1 minute into 60 s.)

c) $E = mL$

$3000 = 0.008L$

$$L = \frac{3000}{0.008}$$

$= 375\,000\,\text{J/kg}$

d) Energy might be lost to the surroundings directly from the heater because the ice is not in contact with the heater. Some energy from the surroundings could melt the ice. The ice might be colder than 0 °C.

Show you can

Page 322

Measure the mass of a measuring beaker by placing it on an electronic balance. Record its mass in grams, m_1.

Fill the beaker with the liquid – to the 100 ml mark.

Measure the mass again, m_2.

Calculate the mass of the liquid, $m_2 - m_1$.

The density of the liquid is calculated using:

density = $(m_2 - m_1)$/volume

To calculate the density in kg/m^3, convert grams to kilograms ($1\,\text{g} = 10^{-3}\,\text{kg}$) and remember that $1\,\text{ml} = 10^{-6}\,\text{m}^3$.

Page 330

Neither method of burning is to be recommended. Steam is much more dangerous because it releases latent heat when it condenses to water at 100 °C and the specific latent heat of steam is very high.

Required practical 17

Page 320

1 The percentage error in the measurement will be smaller
or
the error in the measurement will be less significant.

2 The smallest change in mass that can be measured is 0.1 g.

Page 321

1 The sides of the cuboid could be slightly worn away or rounded.

2 Stack 500 sheets of paper on top of each other. Measure the thickness of the stack and then divide by 500.

Page 322

1 A mass of zero must have a volume of zero.

2 An anomalous data point will not be close to the line of best fit.

Chapter review questions

1 a) volume $= 0.04 \times 0.03 \times 0.05$

$= 6 \times 10^{-5}\,\text{m}^3$

b) $\rho = \dfrac{m}{V}$

$$= \frac{0.03}{6 \times 10^{-5}}$$

$= 500\,\text{kg/m}^3$

Hint: Work in m and kg from the start. Do not try to convert g/cm^3 to kg/m^3, which is the harder way to do the problem.

2 a) Mass – measure on an electronic balance. Volume – measure the volume by displacing a volume of water.

b) $\rho = \dfrac{m}{V}$

$$= \frac{0.32}{26 \times 10^{-6}}$$

$= 12\,300\,\text{kg/m}^3$

c) A lead ornament with a gold cover.

3 When a liquid evaporates, energy must be supplied from the surroundings to cause the evaporation. When ether is on the skin, energy is supplied from the body for it to evaporate. The loss of energy makes the skin feel cold.

4 a) The molecules in ice are in fixed positions; the molecules in water are free to move past each other. (See Figure 17.6 parts a) and b) page 323 for an example of a diagram.)

b) Energy must be supplied to melt ice at 0 °C. Energy comes from the drink to melt the ice, so cooling the drink.

c) Ice is less dense than water.

5 a) $\Delta E = mc\Delta\theta$

$200 \times 10^3 = 40 \times 1000 \times \Delta\theta$

$$\Delta\theta = \frac{200\,000}{40\,000}$$

$= 5\,°\text{C}$

so the air temperature rises from 15 °C to 20 °C.

b) $\Delta E = mc\Delta\theta$

$= 60 \times 800 \times (48 - 13)$

$= 60 \times 800 \times 35$

$= 1\,680\,000\,\text{J}$ or $1.68\,\text{MJ}$

6 a) Molecules are in a state of constant motion. The molecules hit the walls of the container and thereby exert a force on the walls. Pressure is a measure of that force per unit area.

b) At a higher temperature, the molecules move faster. Therefore, the molecules hit the walls harder and more often.

7 a) $P = \dfrac{E}{t}$

$$500 = \frac{E}{5 \times 60}$$

$E = 500 \times 300$

$= 150\,000\,\text{J}$

b) $L = \dfrac{E}{m}$

$$2500\,000 = \frac{150\,000}{m}$$

$$m = \frac{150\,000}{2500\,000}$$

$= 0.06\,\text{kg}$

Practice questions

1 kg/m^3 *[1 mark]*

2 d) X and Z *[1 mark]*

3 a) liquid *[1 mark]*

b) solid *[1 mark]*

c) liquid *[1 mark]*

d) gas *[1 mark]*

e) gas *[1 mark]*

f) solid *[1 mark]*

4 The substance could melt or boil (or evaporate). *[1 mark]*
The energy added provides the energy required to bring about the change of state *[1 mark]*

5 Atoms in a solid remain in fixed positions, but can vibrate about those fixed positions. *[2 marks]*
The atoms in a gas are separated and free to move around at random at large speeds. *[2 marks]*

6 Measure the mass, M, of the marbles using the balance. *[1 mark]*
Put some water in the cylinder and measure the volume V_1. *[1 mark]*
Put the marbles in and measure the new volume V_2. Volume of the marbles, V, is $V_2 - V_1$. *[1 mark]*

Calculate the density, ρ, using $\rho = \dfrac{m}{V}$ *[1 mark]*

7 a) $\Delta\theta = 70 - 30$

$= 40\,°\text{C}$ *[1 mark]*

b) $\Delta E = mc\Delta\theta$

$48\,000 = 2 \times c \times 40$ *[1 mark]*

$$c = \frac{48000}{80}$$ *[1 mark]*

$= 600\,\text{J/kg}\,°\text{C}$

[1 mark for answer, 1 mark for unit]

c) $P = \dfrac{E}{t}$ *[1 mark]*

$$= \frac{48\,000}{10 \times 60}$$ *[1 mark]*

$= 80\,\text{W}$ *[1 mark]*

8 a) 53 °C *[1 mark]*

b) The energy that is supplied by the heater is used to break the bonds which keep the wax as a solid. When the bonds break, the internal energy of the solid increases. *[2 marks]*

c) $L = \dfrac{E}{m}$ *[1 mark]*

$$= \frac{4000}{0.05}$$ *[1 mark]*

$= 80\,000\,\text{J/kg}$

[1 mark for answer, 1 mark for unit]

Working scientifically: Physical models

Pages 335–36

1 A ball and spring model for the internal energy of a solid.

2 The acceleration would increase (in direct proportion to the increase in force); this could be tested experimentally by applying different forces to an object (e.g. laboratory trolley) and measuring the acceleration.

3 New evidence (observations or data) that support a prediction made by a model and cannot be explained by the other models.

4 Atomic structure

Overview

Specification points

4.4.1 Atoms and isotopes, 4.4.2 Atoms and nuclear radiation, 4.4.3 Hazards and uses of radioactive emissions and of background radiation and 4.4.4 Nuclear fission and fusion

Textbook chapter references

AQA GCSE (9-1) Physics: Chapter 4 pages 87–115

AQA GCSE (9-1) Combined Science Trilogy 1: Chapter 18 pages 337–56

AQA GCSE (9-1) Combined Science Trilogy: Chapter 18 pages 337–56

Recommended number of lessons: 18

Chapter overview	
Contains AQA required practical	No
Contains higher-tier material	Yes
Contains physics-only material	Yes

Useful Teaching and Learning resources

- Learning outcomes
- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–4
- Key terms
- Animation: Nuclear fission and fusion
- Personal tutor: Nuclear fission and fusion
- Homework tasks (a) and (b)
- Quick quizzes 1–4
- Answers for homework tasks
- Answers to all questions
- Half-term test 4.4: Atomic structure

Useful prior learning

- All materials are made up of tiny particles called atoms.
- Elements are made up of only one type of atom.
- An atom has a very small positively charged nucleus.
- The nucleus contains protons and neutrons.
- Negatively charged electrons orbit the nucleus.
- The proton carries a positive charge and the electron carries a negative charge of the same size as the proton.
- An atom is neutral in charge, because the positive charge on the nucleus is balanced by the negative charge of the electrons.

Common misconceptions

Most of the misconceptions students have about this topic are cultural, rather than related to their youth. It is likely that a fair part of the topic will involve myth-busting, although hopefully students will not believe that nuclear radiation will give them superpowers! By now, they should be happy with the idea that atoms are not the smallest possible particle so you don't have to start the lessons with the classic (and unpopular) line 'Everything you know about elements is wrong.'

An issue to address early is the distinction between nuclear radiation and other uses of the word, particularly thermal and electromagnetic (EM) radiation. If a nucleus isn't changing, nuclear radiation isn't involved – so mobile phones and TVs don't give out *nuclear* radiation.

Students – like much of the public – may struggle with the idea that a certain level of nuclear radiation is perfectly safe. One alpha particle won't 'give you cancer', for example. A useful comparison is to drugs, legal and otherwise, asking what would happen if someone took a year's supply of painkillers in one go. In the UK, cancer that can be linked directly to nuclear radiation is effectively unheard of (with the exception of bystanders to old bomb tests). In contrast, lung cancer (smoking and industrial pollutants), cervical cancer (a virus, HPV) and skin cancer (ultraviolet light) have well-evidenced causes and high death tolls.

Preparation

The **T&L Prior knowledge catch-up student sheet** covers much of the first lesson, so you could move on to lesson 2 if their answers were confident and correct. Alternatively, it would be a good first homework. The accompanying **T&L Prior knowledge catch-up teacher sheet** makes the excellent point that much of the initial content is also effectively chemistry. It is worth noting that at this level of physics, electron configuration is mostly irrelevant. Sub-atomic particles are either inside the nucleus, or orbiting; only when EM radiation emission/absorption is considered will the idea of higher or lower levels be mentioned.

The **T&L Topic overview** is probably too densely packed to give students much reassurance at the start. You could issue a few slides at a time as summaries (they would give a good basis for creating 'spot the mistakes' exercises, for example). From a teacher's point of view, they provide a good checklist for reference during lessons to ensure coverage of important points.

One of the key points of this topic is that, apart from some simulations, students will not complete any practical work. Instead the principles must be demonstrated by the teacher or a technician, and it is worth checking over the equipment and your school procedures well in advance. You should have a nominated *Radiation Protection Supervisor*, a teacher who can work through the demonstrations with you. If in any doubt, contact CLEAPSS. The guidance at http://practicalphysics.org/atoms-and-nuclei.html is very helpful.

Subatomic particles: Lesson 1

Learning outcomes

1 Define and describe particles.
2 Recap ions from Chemistry.
3 Complete table of similarities and differences.

Suggested lesson plan

Starter

Ask students, 'How many ingredients in the universe?' Their answers will show that this is a question which depends on your point of view; a chemist might list elements, while a physicist can explain that most of it is made of three particles.

Main

It should not take long for students to complete a summary table of the particle properties. 'Building' atoms with sweets, Lego blocks or balls of paper on a series of concentric circles will allow them to get a feel for the idea that the atoms made are simply a combination of sub-atomic particles. This leads naturally to the idea of atoms losing or gaining electrons, which they should be able to explain clearly from chemistry lessons.

A key point to emphasise is that electrons being gained or lost does not change the make-up of the nucleus. A lead nucleus is a lead nucleus, and can't be *chemically* changed into gold no matter what the alchemists believed. (Much to the disappointment of physicists, making this happen by changing nuclei in particle accelerators is time-consuming and expensive.) Remind students of the meaning of the various numbers near a symbol: O_2 is a compound, O^{2-} is an ion. This will be useful when isotopes are discussed next lesson.

Later lessons return to the idea, but spending a little time on scale is worthwhile. Students should start to appreciate not only just how small an atom is, possibly via Avogadro's number, but also how much of an atom is, well, nothing. The example comparing atomic and nuclear size on page 89 (*339*) of the textbook may help.

Plenary

Show slides of particle arrangements and challenge students to distinguish between atoms and ions.

Support

The maths needed to consider the atomic and nuclear scale may cause some students difficulty; as with other examples of standard form, it may help to provide the same examples they are familiar with from maths lessons.

Extension

Some students may be ready to consider details of the nucleus after a quick review. It is likely that the first two lessons of this topic could be combined.

Homework

Students could prepare for a recall test of particle properties. The best way to do this would be to combine the material with that in the next lesson on mass and atomic numbers.

From the periodic table: Lesson 2

Learning outcomes

1 Annotate worked example using data from periodic table.
2 Practise extracting particle numbers.
3 Compare isotopes of an atom.

Suggested lesson plan

Starter

Ask students to consider the world's best microscope which zooms in on an ice cube. As the scale changes they can see first physical bonds between molecules (Topic 3), then the chemical bonds holding hydrogen and oxygen atoms together, and finally the bonds inside the nucleus.

Main

Provide a periodic table, ideally the same format as will be provided in the exam, as there isn't one in the Physics textbook. Remind students that a lithium atom is electrically neutral and then model the steps needed to turn the values in each square into mass and atomic numbers.

Ensure that students know that the atomic number is also called the *proton number*, which in some ways is more descriptive. Although the term neutron number is not used as often, students may find it helps to consider it explicitly. A blank table for the first ten or twenty elements will give them practice with the process.

Choose an element as a model for isotopes; chlorine can work well as a starter, because most periodic tables will give the (weighted average) atomic mass as a non-integer. This is because, unlike most elements, there's more than one stable common isotope.

Remind the class of the notation used for compounds and ions, and compare this with the format used for atomic and mass number. Explain that ^{24}Na gives all the necessary information as *every* sodium atom has an atomic number of 11. (It is worth pointing out that the alternative notation of sodium-24 or Na-24 is sometimes used for the isotope too.)

Plenary
Students are now ready for **T&L Quick quiz: Atomic structure 1**. Alternatively, you could use it as a starter next lesson to review the topic so far.

Support
The maths can be made easy; spend time with confused students on a word equation (mass number = proton number + neutron number) instead. Using counters on models can really help as they literally count the protons and neutrons in and out.

Extension
Occasionally, students will recognise the paradox that positive charges repel each other but the nucleus does not fall apart. (If they don't ask, don't raise it!) You can explain this by introducing the strong nuclear force, which holds protons and neutrons together at very close range; it is discussed more at A-level.

Homework
Use Test yourself questions 1–7 on page 90 (*340*) from the textbook.

Science in action – electrons: Lesson 3

Learning outcomes

1 Recap scientific method.
2 Notes on Thompson's work.
3 Diagram of plum pudding model.

Suggested lesson plan

Starter
Give students a hypothesis that revolving doors are powered by mice in rotating wheels, and offer the evidence that they squeak. Ask them how they would disprove this hypothesis.

Main
The notes on scientific models on pages 85–86 (*335–336*) of the textbook may be a useful review. Every teacher will have preferred examples of a model which, although imperfect, is useful for both explanations and predictions. The focus should be that predictions can be tested and the results will support (*not* confirm) or contradict the model. Emphasising that scientists *accept* models based on evidence, rather than *believing* them, may help when students are faced with ideas that challenge their personal beliefs.

Thompson's work identified discrete negatively-charged particles, electrons, which were understood to make up some part of atoms. Students should record this stage of the developing model with some kind of diagram similar to Figure 4.3 (*18.3*) on page 91 (*341*) of the textbook (and also available in the **T&L Diagram bank**). Explain that these days we might describe it as a 'chocolate-chip muffin' model instead of a 'plum pudding model' to help with visualisation.

If you choose to move on, students will need to consider how Thompson's model led to predictions about the behaviour of alpha particles directed at gold foil – predictions that were not fulfilled. A simpler version of Figure 4.4 (*18.4*) on page 91 (*341*) of the textbook or from the **T&L Diagram bank** may help. Finishing the lesson with the results will set the scene for the nuclear model proposed by Rutherford.

Plenary
This would be a good time for a review test of the vocabulary of the first two lessons. Even if it was not set as revision, students should be able to demonstrate basic recall.

Support
Some students will struggle to reconcile the models being explained with the work of the first two lessons. Explain that you are giving the historical perspective, like flashbacks explaining how a situation came about. The focus is on how the old model was shown to be wrong and how the nuclear model works better to explain the results of experiments.

Extension
Ensure that students with a better understanding are able to give a clear explanation of how the changes in the atomic model reflect the more general process of the scientific method, with more evidence allowing us to improve the models we use.

Homework
Students could read ahead in the text book or use online resources to consider the main headings of the next lesson; explaining alpha scattering and the Bohr atom which brings chemistry and physics together.

Changing models of the atom: Lesson 4

Learning outcomes

1. Create a timeline of changing models of the atom.
2. Identify key evidence that led to changes in the model to present day.
3. Record limitations of the Bohr model.

Suggested lesson plan

Starter
Although the calculation is challenging, **T&L Lesson starter 1** is good to make the point about relative scales of the nucleus and atom.

Main
If it's not been covered in the previous lesson, students could *now* consider how Thompson's model led to predictions for the behaviour of alpha particles directed at gold foil (to reiterate – predictions that were not fulfilled. Again, a simpler version of Figure 4.4 (*18.4*) may help, and the results set the scene for the nuclear model proposed by Rutherford.

The notes on page 92 (*342*) of the textbook can be used to build a timeline, which will include the significant steps in identifying protons as individual positive charges, and Chadwick's later work to isolate the neutron. If preferred, students could be given prompt questions to link the evidence from experiments with the discovery in each case.

The Bohr model should be introduced with the simplified diagrams showing energy levels for atoms; students will recognise that this matches the idea of orbits or shells from chemistry. Ensure that students recognise that the emission or absorption of electromagnetic (EM) radiation does not mean the electron is destroyed, or leaves the atom entirely. They may need to be reminded that, as three-dimensional objects, the shells are hard to show on a page – computer simulations may be helpful to show the various suggestions.

Plenary
Despite the title of the resource, **T&L Lesson starter 2** is good to show changing models over time. The focus should be on the features of the evolving model at each stage rather than dates and names.

Support
This can seem more like a history lesson than science; emphasise the collection of evidence and how models were suggested and changed over time.

Extension
Students should appreciate that even these details are only the highlights of what was, at times, an acrimonious and bitter dispute with many competing suggestions. The models are now more reliable because of scientists spending time looking for evidence that competitors and colleagues were wrong.

Homework
Use Test yourself questions 8–13 on page 93 (*343*) of the textbook if they've not already been used in lessons. A good way to do this would be to have students answer in 'test conditions', then reread the notes on the previous two pages before correcting any mistakes and/or filling in any gaps.

Nuclear decay and equations: Lesson 5

Learning outcomes

1. Compare emission properties.
2. Appreciate, explain nuclear change.
3. Complete exam-style examples.

Suggested lesson plan

Starter
Give students a list of phenomena and ask which are considered to be radiation. Be sure to include heating through a vacuum and light travelling in air, as well as some others which are better described as waves (e.g. earthquakes). Students answers should allow you to emphasise the need to be clear about *nuclear radiation* being emitted from a nucleus.

Main
Students should record the properties of each nuclear emission (alpha, beta, gamma, neutron); be aware that neutron radiation is a new addition to KS4 content. In each case, their notes should include the nuclear equation, showing how the mass and atomic numbers have changed. The summary table at the bottom of page 94 (*344*) in the textbook may be a useful addition to their notes.

It is important to model the process, describing how to find the 'new' mass and atomic numbers so that students can see where they come from. Annotated examples will show how the numbers are conserved if the equation is correct. Students need to be able to use a periodic table to find the daughter nucleus produced, and may need reminders to look for the matching atomic number.

Once several examples have been completed, they can use Test yourself question 17 on page 96 (*346*) of the textbook for more practice.

Plenary
You could give students a list of changes (e.g. 'emits a massive particle with +2 charge' or 'mass doesn't change but atomic number goes up by one', and ask them to link each one to a specific kind of nuclear change.

Support
Although the maths is not particularly complex, some students will struggle with this concept. Returning to hands-on models, such as the counters described in lesson 2 may help, as they reinforce the conservation aspect.

Extension
Emphasise that gamma emission always follows alpha or beta decay, but are both nuclear and electromagnetic radiation. How might this cause confusion?

Homework
Setting more practice questions is worthwhile, or students could produce summaries of each emission using diagrams but an arbitrary maximum number of words. The danger, of course, is that students will hear this as 'draw a poster' which is not quite the aim!

Ionisation and detectors: Lesson 6

Learning outcomes

1 Annotate diagrams of spark counter, electroscope demos.
2 Discuss ionisation process and different result for each emission.

Suggested lesson plan
Starter
Ask students to identify the four types of nuclear emission (alpha, beta, gamma, neutron) as described last lesson.

Main
Depending on available time, you may choose to combine this lesson with the next one; apart from other reasons, it means the sources only need to come out once.

If possible, demonstrating ionisation in real life will help to show the effects of some nuclear emissions. (You may choose to combine this demonstration with the standard alpha/beta/gamma penetration practical.) It is worth showing both a gold-leaf electroscope and a spark counter if available; apart from the dramatic nature of the latter, it lays the foundation for the workings of a Geiger-Muller tube.

Draw attention to the notes on page 95 (*345*) of the textbook; although the particles *cause* ionisation, it is not the charge of the emitted particle itself which is detected. This is why gamma and neutron radiation are still ionising, even though they have no charge; they create ions during absorption/collision.

This might be a good opportunity to discuss why nuclear radiation can be damaging – and frightening. We can't detect it, so have no way of knowing when the damage is occurring. You could also point out that DNA can be damaged in other ways (carcinogens like tar and benzene, for example, or viruses like HPV). It is likely that students will be able to tell you that the possible end result of all this incremental damage is cancer. (You may wish to point out that the stereotypical sign of pollution around nuclear power stations, fish and frogs with abnormalities, is due to the thermal pollution rather than radioactive waste.)

Plenary
An internal diagram of a GM-tube is easily found online and although students do not need to record the details, they should be able to see how ionisation in the chamber is detected as an electrical signal.

Support
Emphasise that all kinds of nuclear emission can damage atoms in such a way that they become ions. That's all ionisation means. The ions made are detected in various ways and can tell us when nuclear radiation is present.

Extension
Ask students to explain why alpha and beta particles are both detected by a gold-leaf electroscope with a positive charge.

Homework
Use Test yourself questions 14–19 starting on page 95 (*345*) of the textbook; this reviews the previous lessons (if question 17 was used for nuclear equation practice it is unlikely you will want students to repeat it) and prepares them for the next lesson looking more closely at observed nuclear radiation properties.

Alpha, beta and gamma: Lesson 7

Learning outcomes

1 Notes on properties as observed.
2 Explain different safety precautions.
3 Link ionisation with health risk.

Suggested lesson plan

Starter
Have students fill in a blank table for alpha, beta and gamma characteristics, in particular, mass and charge. You might wish to include columns for the demonstration so that all the information is together.

Main
This is one of those lessons where fluency with the practical really pays off. A good starting point is to let the students gather and notice for themselves the occasional 'clicks' from the equipment. Explain that each of those is the detector picking up one emission of radiation. You will want to mention background radiation as a concept here, promise to return to it, then lift out the first sample.

Students should record the range in air and penetrating power for each source. In between these demonstrations, explain the school safety precautions. Students should be able to use what they know about ionisation to say why they are needed. You can probably show that the count rate is increased even when the samples are in the boxes, which may cause some alarm.

It is worth making clear that the exposure for the students during this demonstration is so small that it is immeasurable. If they ate a banana for lunch, it would expose them to more radiation.

Plenary
Display a safety badge for a radiation worker and ask students what exposure in the different sections would suggest. (This has been an exam question several times and is a good way to bring together comparative penetration.)

Support
The ideas here are relatively straightforward; students who need support are likely to be those who are anxious, rather than those who don't understand.

Extension
Ask students to explain why different alpha sources will show different ranges in air, but each source will have its own characteristic range. (Range links to the energy of the alpha particle which is determined by how it is formed during the nuclear decay.) Alternatively, blow their minds by pointing out that all helium atoms on the Earth's surface are alpha particles which gained electrons after many collisions.

Homework
Students could complete either **T&L Quick quiz: Atomic structure 2** or Test yourself questions 20–24 from page 98 (*questions 20–22 on page 347*) of the textbook (or both).

Sources of background radiation: Lesson 8 (Physics only)

Learning outcomes

1 Suggest natural/artificial sources.
2 Display results in different formats.
3 Understand exposure in context.

Suggested lesson plan

Starter
Remind students of the count rate detected before the samples came out of the boxes. Where did that radiation come from? (In most cases it will be cosmic radiation.)

Main
Students can research the different contributors to background radiation online; you may want to give them prompt questions for guidance.

It is important to emphasise that the lists of sources of background radiation are not fixed. By definition, it is highly variable and local in nature; it will be higher in areas with lots of granite geology, or at altitude due to higher exposure to cosmic rays. Sites of nuclear pollution are obviously a special case, but weapons test sites are much more of an issue here than accidents.

This is a good opportunity for some data analysis, as this context adds interest to otherwise dry questions. Check for past paper questions so that students practise converting tables to graphs and charts to trends. They are not expected to recall any particular values or percentages, but simply that, in most locations, the background radiation will be from natural rather than human sources. The table on page 103 (*350*) of the textbook may be useful – or the classic xkcd infographic on radiation dosage (https://xkcd.com/radiation) – to discuss our definition of 'background' radiation.

Students can answer Test yourself questions 25-26 from page 98 of the textbook (Physics only).

Plenary
Identify local contributors to background radiation, natural and artificial. This will provide a useful preview for the later lesson on uses of radiation in industry and healthcare.

Support
Issues here are likely to result from students who struggle with manipulating data. Ensure that they are using a systematic approach to numerical questions and can explain the sources of background radiation qualitatively if needed.

Extension
Ask students to explain why we have such low limits for exposure, even for workers in the nuclear industry, compared with the lowest annual dose where there is evidence of increased risk.

Homework
If the questions were not attempted in the lesson, they could be used as homework. Otherwise, this would be an opportunity for a mid-topic review, perhaps with a recall test to follow.

Half-life in theory: Lesson 9

Learning outcomes

1 Discuss meaning of 'random' for coin tosses.
2 Appreciate nuclei change but do not vanish.
3 Define half-life.

Suggested lesson plan

Starter
Draw axes with 'time' on the horizontal, 'height of water remaining' on the vertical. Show students a two litre bottle filled with water, no top, and explain that you're going to make a hole in the bottom then mark the height of water every ten seconds. Ask them to sketch the line graph.

Regarding the demonstration:

- It's easier if you make the hole first then cover with duct tape.
- Don't start the timer until you're at the uniform part of the bottle.
- It might be best to do this outside, for obvious reasons.
- You may have a specific piece of kit for this, with water pressure practicals.
- If the hole is particularly large you might need to record every five seconds!

The points make a nice exponential curve, not the diagonal line students predict.

Main
Ask students to explain why tossing a coin is both predictable and random. The best answers will show an understanding of the contrast between one random result and the predictability of a large number of results.

Review one of the nuclear equations from the previous lessons. Remind students that the number of nuclei hasn't changed, because they change or decay rather than disappear. In a sample, how many atoms will decay in a given amount of time?

Make clear that some isotopes are less stable than others. Rather than using 'a bit unstable' and 'really unstable' physicists take measurements and can show that, for every isotope, there is a characteristic amount of time for half of the atoms to decay. This is called the half-life ($t_{1/2}$). In the same amount of time, the activity of the sample will be halved too, and this is what is usually measured. Define the becquerel (Bq) as one count per second measured by the detector.

If available, students can record data collected from a *staff demonstration* of half-life. Some schools will have a protactinium generator, while a more recent version uses a gas mantle in a sealed system. In either case, data can be collected in a few minutes with a reading every ten seconds. Students can then plot a graph to show the characteristic exponential decay curve.

Using this curve (or one that is provided), model finding the time taken for the activity or count rate to be halved. Show that this time interval is consistent, no matter where you start on the graph. Students should have the opportunity to try this with another second set of data.

Plenary
Review previous lessons, including nuclear decay equations, with **T&L Quick quiz: Atomic structure 3**.

Support
Half-life is a challenging idea and students should be reassured if they do not understand immediately. Make clear that there are more lessons and more practice to follow. Ensure that students can reliably read values from an activity/time graph as this will be a good foundation.

Extension
Some students will appreciate that the half-life is measured based on averages. Ask them what they would expect to happen to the calculations as a sample gets smaller (and the number of undecayed nuclei reduces).

Homework
Have students plot the graph for the simulated data on page 99 of the textbook (Physics only) (or another dataset provided by you). Ask them to draw their working on the graph for the half-life, taking at least three measurements and then finding the mean.

Simulating half-life: Lesson 10

Learning outcomes

1 Complete dice/cubes simulation.
2 Compare group and class results to see increased smoothness of curve.
3 Calculate 'half-life' value.

Suggested lesson plan

Starter
Review the work from the previous lesson, concentrating on the definition of half-life. Alternatively, you may wish to use **T&L Quick quiz: Atomic structure 3** if this was not completed because of a lack of time.

Main
Explain that you will use a simulation to model radioactive decay. Each group starts with 100 dice and they roll them together (in a tray works best). Each die that rolls a six is removed and they are counted; these have 'decayed' and the number remaining is recorded.

Ask students to write down their prediction of how many rounds will be needed for them all to be removed. As well as recording their results individually, it can be useful to have the students enter the numbers on a collective spreadsheet.

When the results are all collected – which usually needs between 16 and 20 rounds – have the students plot graphs and work out the half-life for this simulation. If you have a set of cumulative class results, you can show that a) all graphs have the same exponential curve and b) the cumulative graph is smoother than that of any one set. A discussion of the random nature of nuclear decay is likely to follow.

If not saved for homework, you can now use Test yourself questions 27–33 on page 101 (*questions 23–28 on page 349*) of the textbook. You may wish to attempt some in class for feedback with the rest to be attempted at home for consolidation.

Plenary
Remind students of the caesium-137 (^{137}Cs) sample used in the radioactivity demonstration. This has a half-life of 30 years. How long will it be before the sample is no longer radioactive?

Some students will recognise that it doesn't stop being radioactive until the last unstable atom has decayed. (30 years: half remaining. 60 years: quarter remaining. 90 years: eighth remaining etc. – never gets to zero.) The real question is when it is indistinguishable from the background count rate.

Support
Most difficulties here come from failing to follow the instructions. It can be worth asking each group to pause after three or four rounds until you have checked that they are removing the dice correctly. The first few rows of their table should look something like:

Round	How many at start	Rolled 6, removed	Running total
0			100
1	100	18	100 – 18 = 82
2	82	14	82 – 14 = 68
3	68	13	68 – 13 = 55

Extension
Ask students to predict what would happen to the curve if the dice were removed with a) 5 or 6, or b) any even number. What kinds of isotope are these changes simulating? (Less stable/shorter half-life.)

Homework
Students could complete whichever of Test yourself questions 27–33 from page 101 (*questions 23–28 on page 349*) of the textbook were not used in the lesson.

Half-life in reality, C-14 dating: Lesson 11

Learning outcomes

1 Record range of half-lives.
2 Show carbon dating method with notes on correction for background.
3 Calculate age of artefacts from data; appreciate uncertainty.

Suggested lesson plan

Starter
Ask the class to decide what value of half-life they would use as a cut-off between stable and unstable isotopes.

Main
While emphasising that they do not need to memorise any values, provide some sample values for half-life. Point out that the shorter the half-life, the faster the isotope is decaying – so the higher the level of emitted radiation (in becquerels).

Remind students of the idea of background radiation and show how readings should be corrected for the background rate. Obviously, this will only make a big difference when the readings are relatively low.

Show students the nuclear equation for carbon-14 decay; they should be able to identify this as a beta emission. Explain that because anything that contains carbon from the environment (i.e. all living things) will contain the same proportion of ^{14}C, we can estimate the age of an object by seeing what fraction of the undecayed isotope it still contains. If it contains half, it is around one half-life since the living material died. If it contains a quarter, it is two half-lives, and so on.

If we know the half-life, we can estimate the age. For carbon-14 this is 5700 years. Similar techniques can be used with other isotopes, but carbon-dating is most useful for history (+/– decades) and recent prehistory (+/– centuries).

Give some example questions and model the working needed. Be aware that some students may be highly resistant to the evidence about some religious artefacts, or indeed to the idea of human specimens being dated as more than a few thousand years old.

Plenary
A sample that should be pure iodine-131 (half-life 8 days) has an activity one eighth of what is expected. Estimate the age of the sample. Why is this an estimate?

Support
The best way to ensure clarity for some students is to work from the number of half-lives, matching this to a fraction each time. They can then multiply the number of half-lives by the time for each one.

Extension
Ask students to show, using a decay curve, how ages in between integer values of half-lives can be estimated. For example, how old is a sample with ¾ of the expected ^{14}C in it?

Homework
Use Test yourself questions 34–35 on page 101 of the textbook (Physics only). Extend this by asking why archaeologists use carbon dating but geologists prefer to use potassium. (Answer: potassium is one of the most abundant rock types in the Earth's crust, and has a far longer half-life than carbon. Potassium-40, for example, has a half-life of 1.26 billion years; this means there is still enough to measure accurately.)

Hazards: Lesson 12 (Physics only)

Learning outcomes

1 List stereotypes of radiation danger.
2 Compare direct/indirect damage.
3 Assess risk of everyday activities.

Suggested lesson plan

Starter
Display a cartoon of a nuclear power station and ask students to list the dangers of nuclear radiation.

Main
(Depending on your class, you may wish to include the material from lesson 14, irradiation versus contamination, in this one.)

Test students on their recall of ionisation, and the varying amounts caused by different kinds of emission. Students should record the possibility of direct damage but understand that, in most cases, the real issue is ionisation, which causes indirect damage to DNA leading to possible cancers.

Explain why 'most dangerous' is not an easy definition; the danger from an alpha source outside the body is negligible but huge if ingested. Define the unit of as radiation dose as the sievert (Sv). Converting from a count rate in becquerels to a dose in sieverts is not straightforward and certainly is not relevant at GCSE.

Students can consider the table on page 103 (*350*) of the textbook, which contains some possibly surprising information. Contrast the average annual exposure due to background radiation in the UK (2.4 mSv) with the lowest annual dose with evidence for increased cancer risk (100 mSv).

Students should be able to give reasons for limiting exposure and ways in which this can be done. Examples might include why radiographers wear lead shields during X-rays but patients don't need to worry, or explaining why air crews are considered at high risk of radiation exposure.

Plenary
At the same level of exposure, why are children at a higher risk than adults? (If needed, provide a hint that DNA is vulnerable to mutation when it is dividing, i.e. at times of rapid growth.)

Support
Return to the familiar idea that the dose is important as well as absolute danger. 75 mg of aspirin can be given daily with no ill-effect, even for

years (it's used for patients at risk of heart attack). But a larger amount taken in one dose can kill.

Extension
Ask students to explain why medical procedures such as mammograms (3 mSv) and CT scans (10 mSv) are carried out when they increase the long-term risk of cancer, even if only a little. Good answers will show an understanding of the benefit being greater than the risk for the average patient.

Homework
Use Test yourself question 36–39 on page 104 (*questions 29 and 30 on page 351*) of the textbook.

Diagnosis and therapy: Lesson 13 (Physics only)

Learning outcomes

1. Recap detection, ionisation.
2. Describe use of tracers.
3. Compare risk of procedures versus benefit to health.

Suggested lesson plan

Starter
Provide a paragraph on detection and ionisation and have students either fill in missing words or correct mistakes you have added. The information could include the idea that gamma radiation will not be absorbed well by soft materials such as human tissue, to prepare students for the use of tracers.

Main
It may be worth starting with the statistic that, over our lifetimes, 1 in 3 British people will be diagnosed with some kind of cancer. This is a good opportunity to remind students of rules about bringing personal experience into the classroom, but there may still be intense reactions to various parts of the content.

Make the distinction between *diagnosis* (identifying and explaining a medical problem) and *therapy* (treating or curing the problem).

Animations are often useful to explain the use of tracers in medicine. Students should record the basic procedure; a gamma emitter is introduced into the body (ingested, injected, or inhaled) and detectors are used to find out where it gets to and how quickly. Emphasise that the low energy gamma radiation causes a low amount of damage, and that the advantages outweigh the potential problems. They are particularly useful to show blockages or restrictions in the body.

Although damage to cells has been discussed as leading to mutation, it will not surprise students to find out that cells can be destroyed as well. *Radiotherapy* uses very carefully aimed gamma rays to destroy cancer cells while minimising damage to healthy cells.

Use Test yourself questions 40–45 on pages 105–106 (*question 31 on page 351*) of the textbook.

Plenary
Explain to the class that some companies offer annual full-body CT scans to customers. How would they explain that this is not always a good idea?

Support
The contradiction between helpful and harmful radiation may be difficult for some students. Emphasise that the benefit of identifying or treating a serious illness must be greater than the risk of further harm for these methods to be used. Only by collecting lots of results from real patients can we make better decisions about when the risks are justified.

Extension
Why might a patient who has been injected with Technetium-99 stay in hospital overnight, even if they feel fine, rather than going home to their family?

Homework
Students could start preparing for the end of the topic, perhaps by producing summary materials of the vocabulary used or methods for half-life calculations. Setting a short recall test will ensure that revision is spread out rather than waiting for the very end of the topic.

Irradiation versus contamination: Lesson 14

Learning outcomes

1. Who killed Litvinenko?
2. Recap school safety rules.
3. Explain dangers of contamination.

Suggested lesson plan

Starter
Depending on your preferences, you may wish to adapt **T&L Lesson starter 4** and return to the question on irradiation as part of your plenary.

Main
Ask students why it is perfectly safe to eat strawberries that have been sterilised by gamma irradiation to last longer. Define irradiation as

exposure to a source of nuclear radiation. Remind students about the potential risks, as described in the previous lesson.

Describe the symptoms of Alexander Litvinenko, a Russian journalist living in London. First diagnosed with food poisoning, it wasn't long before he was found to be suffering with radiation sickness. It was hard to understand how, as he hadn't been out of London and there no detectable radiation outside his body.

But he *was* an ex-spy who had been for a drink with his old colleagues.

This was a dramatic case, but it is not a recent one. Ask students why the radioactive source was not detected outside the body. They should also be able to explain why it would not have been harmful until it got into his body. The polonium-210 is an alpha-emitter, and the evidence scientists gathered contributed to the 2016 judgment that he had been deliberately poisoned with a radioactive isotope.

Once contamination has been defined as the isotopes themselves being in places we cannot control, students should be able to explain school and lab safety rules for the handling of isotopes.

Plenary
Strontium-90 is a beta-emitter found after nuclear weapons tests and nuclear accidents. Ask students to compare the effects of irradiation and contamination with ^{90}Sr.

Ask if they would be more or less worried to know that strontium is chemically similar to calcium. (If ingested, the body incorporates some of it into bone tissue and it causes a lot of damage to the bone marrow.)

Support
The ideas here are not complicated; ensure that students know that pointing a school sample at a chair might irradiate it, but dropping the sample would be an example of contamination (and a large bill for the science department).

Extension
Ask students to explain why CLEAPSS recommend keeping a damp cloth handy during radioactivity demonstrations; how would this help if a sample is dropped?

(The aim is to prevent fragments being carried around the room by drafts.)

Homework
Students could be asked either to explain various uses of radioactive isotopes (thickness testing of paper/aluminium, leak testing in pipes) in terms of their properties, or review the electricity generation part of the Energy topic.

For combined science students, **T&L Homework task (b)** could be used. From the textbook, the Chapter review questions (pages 352–353) and Practice questions (pages 354–355) will be helpful if not used to extend learning through the topic. **T&L Half-term test 4.4: Atomic structure** could be used as an open-book assessment at home if not in test conditions in school.

Energy from nuclear fission: Lesson 15 (Physics only)

Learning outcomes

1 Recap energy resources +/–.
2 Compare energy released from fission process to other resources.
3 Annotate example fission equation.

Suggested lesson plan

Starter
Ask students to list advantages and disadvantages of various energy resources. You could have everyone consider the same two (e.g. wind turbines versus coal) or look at a wider range by giving each pair of students a different resource.

Main
If students can complete some notes as homework, this lesson could be combined with the next.

Give example figures of 8 kWh available from one kilogram of coal, and 12 kWh from 1 kg of oil. (Emphasise that they will not need to recall these; you are simply asking them to compare.) How much do they think is available from 1 kg of nuclear fuel? The answer is around 24 *million* kWh.

Students could draw out the process of fission as well as considering the nuclear equation, as in Figure 4.23. The term 'daughter nuclei' is often used to describe the two smaller nuclei produced from the fission or splitting of the original one, which is either uranium or plutonium. It is worth being clear that the fission products are often unstable themselves. The spent fuel contains a mixture of unstable elements, and this means they can be dangerous for a long time.

Emphasise that the nuclear equation (given at the top of page 108 of the textbook) is one possible sequence, and others may happen more or less often depending on conditions in the reactor. (In fact, the decay products are often so characteristic that a sample can be used to identify the reactor, decades later.)

Plenary
Using the example nuclear equation, explain that there is a measurable mass change. This change of mass represents the nuclear store change. Have students follow the working (again, emphasising that this is not content to revise), using a mass change of 5 g per second.

$E = mc^2 = 0.005 \times 3 \times 10^8 \times 3 \times 10^8 = 4.5 \times 10^{14}$ J

Support
Encourage students to return to the familiar procedure of comparing total mass and total atomic number on each side of the nuclear equation. The same rules apply; it's just that the numbers are bigger.

Extension
Guide students through the understanding that alpha decay can be seen as spontaneous nuclear fission with daughter nuclei of very different sizes.

Homework
Provide students with several other fission equations, with missing elements. They should be able to use the numbers included to fill the gaps.

Chain reactions, reactor design: Lesson 16 (Physics only)

Learning outcomes

1 Draw diagram/flow chart of process.
2 Define critical level for a chain reaction to be sustained.
3 List features/functions in reactor.

Suggested lesson plan

Starter
Display an annotated diagram or nuclear equation for fission. Highlight the neutrons at the start and end of the process; students could consider why they are significant.

Main
Describe how the neutrons emitted by one fission process trigger the next one – or several. Students should record notes and draw a diagram, similar to that in Figure 4.24 on page 107 of the textbook and available in the **T&L Diagram bank**. They will probably recognise for themselves that if all neutrons emitted start another reaction, it will soon become uncontrolled, which is how nuclear weapons work.

The notes on page 107 of the textbook for a reactor core are brief, and it may be helpful to make a few points clear. In particular, the heating effect of the fuel rods on the gas is one step in the process which results in electricity being generated. They may also read in other sources about moderator rods, which reduce the speed of the neutrons so they are absorbed more easily by ^{235}U. Students should annotate a diagram of the reactor with explanations linking back to characteristics of nuclear radiation.

You can use Test yourself questions 46, 48–50, and 52–53 on page 108 of the textbook (omitted questions reference nuclear fusion).

Plenary
If you use **T&L Quick quiz: Atomic structure 4,** be aware that the last question refers briefly to nuclear *fusion*.

Support
It may help to remind students of how many uranium atoms will be present in a kilogram of fuel; this will help them to understand why so much energy can be released.

Extension
Ask students to explain how the loss of power to the cooling facilities at Fukushima led to an accident. (Once the core could not be cooled, the built-up heat and pressure caused an explosion which scattered nuclear isotopes over a wide area.)

Homework
Students could now attempt all of **T&L Homework task (a)**; alternatively, they could now give a better explanation for the advantages and disadvantages of a nuclear power station compared with fossil fuels.

Nuclear fusion in stars: Lesson 17 (Physics only)

Learning outcomes

1 Describe problems of fission, i.e. cost, U or Pu needed, waste.
2 Compare nuclear equation to fission.
3 Reference $E = mc^2$ for interest.

Suggested lesson plan

Starter
Review the idea of chain reactions from last lesson with **T&L Lesson starter 3**.

Main
The content needed here is brief, so you may choose to combine it with a previous lesson, or

cover it before moving on the review material listed at the end.

Students should be able to list the problems of nuclear fission. Although uranium is technically a non-renewable resource, the high cost is not because of scarcity. And the amount of highly dangerous waste produced, world-wide, is surprisingly small (one estimate is less than 1000 tonnes total which could be piled up on the pitch at Wembley). But these are still problems.

Give the nuclear equation for the simplest form of fusion; proton + proton = deuterium atom. Explain that deuterium is a stable isotope of hydrogen, ^{2}H. This reaction also releases energy.

Fusion offers the possibility of high energy output, a cheap and easily available reactant and a product which is non-polluting. If we can only get it to work; currently it works in lab conditions but only at such high temperatures that it is not cost-effective.

Plenary
Contrast fission and fusion and ensure that students spell them correctly; if the word used is ambiguous (fision or fussion) then mark schemes usually deny the point.

Support
If students are confused by both fission and fusion releasing energy, emphasise that they are not reversible; in both cases, the processes are moving towards the most stable nuclei, in the middle of the periodic table (iron, to be precise).

Extension
Students could be asked to consider our closest sustained fusion reactor, which continues the cycle to make helium nuclei from deuterium. (Hint: do not look directly at it.)

Homework
T&L Homework task (b) could be used as preparation. From the textbook, the Chapter review questions (pages 109–110) and Practice questions (pages 111–113) will be helpful if not used to extend learning through the topic. **T&L Half-term test 4.4: Atomic structure** could be used as an open-book assessment at home if not in test conditions in school.

Answers

AQA GCSE (9-1) Physics

Test yourself on prior knowledge

1 Proton, neutron.
2 Proton.
3 An atom is neutral; protons and electrons carry charges of the same size but opposite sign.

Test yourself

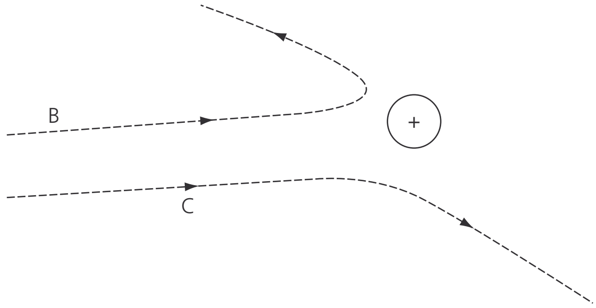
1 a) 10^{-10} m
  b) 10 000
2 B and C. They each have four of the same type of particle – which must be a proton.
3 a) i) 7
    ii) 14
  b) It has seven protons and seven electrons. Since a proton has a positive charge and an electron a negative charge, of the same size, the atom is neutral.
4 a) 8 protons, 9 neutrons
  b) 80 protons, 120 neutrons
  c) 92 protons, 146 neutrons
  d) 1 protons, 2 neutrons
5 a) 64 is the atomic number which tells us the number of protons in the nucleus.
  156 and 158 are the mass numbers, which tell us the combined number of protons and neutrons in the nucleus.
  b) i) number of protons – 64
    ii) number of neutrons – 92 and 94
6 Elements can have more than one isotope. Each isotope has the same number of protons in the nucleus, but different numbers of neutrons.
7

$$\frac{\text{radius of atom}}{\text{radius of nucleus}} = \frac{1.5 \times 10^{-10}}{3.0 \times 10^{-15}}$$
$$= 50\,000 \text{ or } 5 \times 10^{4}$$

8 a) Uniformly throughout the atom.
  b) In the nucleus.
9 The alpha particle is repelled by the charge on the nucleus. Like charges repel, so the alpha particles and nucleus carry the same sign of charge.
10 The radius of the nucleus is very small in comparison with the radius of the atom. Therefore most alpha particles pass through without getting close enough to the nucleus to be deflected by the nuclear charge.
11 The plum pudding model describes the atom as a positive charge distributed through the atom. Then inside this solid substance there are small electrons, with a negative charge, which can move around.
12 a) The Bohr model of the atom has a small nucleus with a positive charge e.g. + 8. Then outside the nucleus are eight electrons (with charge –1 each). These electrons orbit in fixed orbits/energy levels, like planets going round the Sun.
  You could add a diagram like Figure 4.7 (page 92) to help your answer.
  b) i) The electron gains energy and, in an atom, the electron can jump up an energy level.

ii) The electron loses energy and, in an atom, the electron can fall from a high energy level to a lower one.

13



B is deflected more than A.
C is deflected less than A.

14 a) A helium nucleus.
b) An electron.
c) Electromagnetic radiation.

15 B

16 a) An atom or molecule is ionised when an electron is removed from it or added to it.
b) When an electron is removed from an atom or molecule, it leaves a positive ion behind. That free electron can be thought of as a negative ion, or the electron might attach itself to another atom or molecule, so making a negative ion.

17 a) ${}^{3}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{0}_{-1}\mathrm{e}$
b) ${}^{229}_{90}\mathrm{Th} \rightarrow {}^{225}_{88}\mathrm{Ra} + {}^{4}_{2}\mathrm{He}$
c) ${}^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$
d) ${}^{209}_{82}\mathrm{Pb} \rightarrow {}^{209}_{83}\mathrm{Bi} + {}^{0}_{-1}\mathrm{e}$
e) ${}^{225}_{89}\mathrm{Ac} \rightarrow {}^{221}_{87}\mathrm{Fr} + {}^{4}_{2}\mathrm{He}$

18 Uranium
${}^{238}_{92}\mathrm{U} \rightarrow {}^{4}_{2}\mathrm{He} \rightarrow {}^{0}_{-1}\mathrm{e} \rightarrow {}^{0}_{-1}\mathrm{e} \rightarrow {}^{234}_{92}\mathrm{U}$

19 The alpha particles create both positive and negative ions near the electroscope. The negative ions are repelled by the electroscope and the positive ions are attracted by it. The positive ions neutralise the negative charge on the electroscope.

20 B

21 Radon gas. (See Figure 4.14, Page 97)

22 a) Alpha.
b) Alpha and beta.

23 Radiation is dangerous to us, so the teacher keeps the source as far away as possible from his/her body.

24 It emits both alpha and beta particles.
alpha count is 120 − 75 = 45 Bq
beta count is 75 Bq

25 a) Background radiation is the radiation we are exposed to due to the environment we live in. Sources of background radiation include rocks, food, cosmic rays, some places of work (e.g. hospitals, nuclear power stations).
b) An airline pilot as he/she is more exposed to cosmic rays. The atmosphere protects us from many cosmic rays, but aircraft fly at heights around 12 000 m.

26 a) Radon is a gas, so we inhale it into our lungs. Then alpha particles are emitted inside our lungs. These particles are strongly ionising and can damage our body tissues.
b) Gamma rays travel a long way though air and can penetrate our bodies.

27 Count rate.

28 a) C
b) A
c) B

29 ‘Random’ describes an occurrence which is unpredictable.

30 Radioactive decay is random, so we cannot predict exactly the same count rates over a short period of time.

31 Over a period of 15 minutes, half of the radioactive material will decay.
60 minutes is four half-lives. So
$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{16}$ of the material is left.

32 a) An average count rate for the background radiation is measured e.g. 5 Bq. This is then subtracted from any measurement of the count rate from a radioactive source.
[In this experiment, the background count becomes significant by the time the source activity reaches 70 Bq after 5 minutes.]
b) Your graph should reveal a half-life of about 77 s. So an answer in the range 74 s to 80 s is near enough.

33 a) 12 noon on 2 March to 4.00 am on 3 March is a period of 16 h.
This is two half-lives, so the count rate reduces to $\frac{1}{4} \times 2400\ \mathrm{Bq} = 600\ \mathrm{Bq}$.
b) 600 Bq 4.00 am on 3 March
300 Bq 12 noon on 3 March
150 Bq 8.00 pm on 3 March
75 Bq 4.00 am on 4 March

34 a) $\frac{1}{16}$ corresponds to four half-lifes.
So the bones are 4 × 5700 = 22 800 years old.
b) After a long time the count rate gets so small that it is difficult to record with any accuracy.

35 Suppose at $t = 0$ the amount of K = 8 and A = 0. Then:

t	K	A	Ratio
0	8	0	
$t_{½}$	4	4	1:1
$2\,t_{½}$	2	6	1:3
$3\,t_{½}$	1	7	1:7

Rock X – 1.3×10^9 years

Rock Y – 3.9×10^9 years

36 Alpha, beta, gamma, neutron.

37 At an annual dose of 100 mSv, there is a small risk of cancer being caused by the radiation. 50 mSv is set at the safe limit for radiation workers (see table on page 103).

38 $\frac{10}{2.4} = 4.2$ years

39 a) It is difficult to say as we do not know the size of the doses. But $\frac{50}{800} = 1$ in 16 people died after exposure to alpha particles; $\frac{20}{7000} = 1$ in 350 people died after exposure to gamma rays. So on this limited evidence alpha particles seem much more dangerous.

b) If we assume that the two atomic bombs were of the same strength, then neutrons appear more dangerous than gamma rays.

Hiroshima: $\frac{100}{15000} = \frac{1}{150}$

Nagasaki: $\frac{20}{7000} = \frac{1}{350}$

c) Correct, we have no data about the size of the doses received.

40 Greater than

41 A medical tracer is a radioactive material that is absorbed into the body for a short period of time. The radiation emitted allows doctors to study the internal workings of the body.

42 You should discuss tracers and cancer treatment.

43 a) Iodine-131 has a half-life of 8 days. It is highly radioactive and is absorbed by the thyroid gland.

b) Caesium-137 has a half-life of 30 years, so it can cause long term contamination. When something is contaminated, it contains a radioactive source that we could swallow when, e.g. drinking water.

44 a) Lead absorbs gamma rays (or most of them) so it makes the source safe.

b) There is no direct line for the gamma rays to escape through the aperture.

c) $^{60}_{27}$Co: 27 protons, 27 electrons, 33 neutrons

d) 500 000 Bq

e) Possible safety precautions:

- do it quickly; reduce the time of exposure to radiation
- handle it remotely with tongs
- wear a protective lead apron
- wear a radiation badge to monitor the dose.

45 a) Xenon-133. It is a gas, which can be inhaled into the lungs. It has a short half-life so it has a high activity. The gas can be exhaled after half a minute.

b) Bismuth-213 is the better choice. It has a short half-life. So it is more active than a long half-life isotope, and after a few hours the activity of the source in the body is very low.

46 Neutron.

47 Nuclear fusion.

48 Missing words: fission, energy, the Sun.

49 a) In nuclear fission, a large nucleus divides into two smaller nuclei, giving out a lot of energy in the process.

b) i) Both processes emit energy.

ii) But radioactive decay cannot be controlled and fission can be controlled, as the process is triggered by a neutron being absorbed by a nucleus.

50 A neutron is absorbed by a nucleus; the nucleus splits into two smaller nuclei and emits 2 or 3 neutrons; these neutrons are then absorbed by other nuclei. The reaction keeps going; this is a chain reaction.
The chain reaction is under control in a power station. Only one neutron from each fission is absorbed by another nucleus. In a bomb, the reaction is uncontrolled.

51 In a nuclear fusion reaction, two nuclei fuse together to form a large nucleus. Energy is released in the process.

52 a) This is a biological shield to absorb neutrons and gamma radiation.

b) Uranium-235.

c) No, a boron nucleus can absorb a neutron; the nucleus can only absorb one neutron, so this cannot go on for ever.

d) Lower the control rods into the reactor.

53 $^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3\,^{1}_{0}\text{n}$

Show you can

Page 90

Atoms are very small with a radius of about 10^{-10} m. The atom has an even smaller nucleus with radius less than a $\frac{1}{10\,000}$ of the atom. The nucleus contains nearly all of the mass of the atom. Inside the nucleus are protons and neutrons. The proton has a positive charge; the neutron is neutral. Electrons with a negative charge orbit the nucleus. The mass number of the atom is the sum of the number of neutrons and protons. The atomic number is the number of protons. In a neutral atom, the numbers of protons and electrons are the same.

Page 93

Alpha particles, which are small energetic positively charged particles were aimed at a thin piece of gold foil. Most of the particles travelled through the foil without deflection. A small number underwent very large deflections. This led to the idea of a very small, massive, positively charged nucleus.

Page 96

The answers for this question are to be found on Page 94.

Page 98

Note, you are not allowed to do this experiment yourself.

You need a pure alpha source, e.g. Americium-241.

Place the source close to the GM tube. Move the source away until the count rate on the GM tube reduces to zero.

Place the source close to the GM tube. Insert a thin piece of tissue paper between the source and the GM tube. Observe the fall in count rate.

Continue inserting extra pieces of tissue paper until the count rate falls to zero. It is possible that one sheet will be sufficient to stop all the alpha particles.

Page 102

- Half-life means the time taken for the number of radioactive nuclei in a sample of material to halve. However, there is no 'whole-life'; in a second half-life the number of nuclei halves again leaving a quarter of the original number.
- Random means without a definite pattern, but there is a little more to its meaning. If you throw a dice, there is a 1 in 6 chance of throwing a six, but we all know that you will not get one six every 6 throws – it is random. However, if there are lots of dice, then we begin to see a pattern. The decay of radioactive nuclei is random – we cannot make predictions about one nucleus, but we can about billions of nuclei.
- Radiation in this context refers to alpha and beta particles, neutrons and gamma rays.

Page 104

Radiation causes damage by two mechanisms:

- direct – an alpha or beta particle directly collides with a cell, tearing it apart
- indirect – ionisation produces acids which attack cells.

The amount of damage to our bodies depends on the exposure to radiation – the dose. By monitoring the dose, we can rest a radiation worker if they are exposed to too high a dose.

Page 106

Answers to this can be found on Pages 104–105. Or students can research some of their own.

Page 108

Fission is explained on Page 106, Figure 4.23. A chain reaction is explained on Page 107 and Figure 4.24.

Chapter review questions

1 **a)** 3
  b) 7
  c) 3

2 **a)** **i)** Stable means that the isotope does not emit a radioactive particle and become another element.

  ii) An isotope is one type of nucleus of a particular element. Different isotopes of the same element have the same number of protons but different numbers of neutrons.

  b) Carbon-12, 6 protons, 6 neutrons; Carbon-13, 6 protons, 7 neutrons

3 They have different numbers of protons in the nucleus, and different numbers of electrons.

4 **a)** **i)** ${}^{241}_{94}\text{Pu} \rightarrow {}^{237}_{92}\text{U} + {}^{4}_{2}\text{He}$

  ii) ${}^{229}_{90}\text{Th} \rightarrow {}^{225}_{88}\text{Ra} + {}^{4}_{2}\text{He}$

  iii) ${}^{213}_{84}\text{Po} \rightarrow {}^{209}_{82}\text{Pb} + {}^{4}_{2}\text{He}$

b) i) ${}^{237}_{92}\mathrm{U} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{0}_{-1}\mathrm{e}$

ii) ${}^{59}_{26}\mathrm{Fe} \rightarrow {}^{59}_{27}\mathrm{Co} + {}^{0}_{-1}\mathrm{e}$

iii) ${}^{32}_{14}\mathrm{Si} \rightarrow {}^{32}_{15}\mathrm{P} + {}^{0}_{-1}\mathrm{e}$

5 a) ${}^{1}_{0}\mathrm{n} + {}^{239}_{94}\mathrm{Pu} \rightarrow {}^{100}_{42}\mathrm{Mo} + {}^{134}_{52}\mathrm{Te} + 6{}^{1}_{0}\mathrm{n}$

b) ${}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{140}_{54}\mathrm{Xe} + {}^{94}_{38}\mathrm{Sr} + 2{}^{1}_{0}\mathrm{n}$

6 The plum pudding model assumed that the atom has a uniform density, with positive charge spread through the atom. Such an atom was not expected to deflect an alpha particle. Geiger and Marsden's work showed that alpha particles could be deflected by large angles by metal foils. This can only be explained by a model which places nearly all the mass and all the positive charge of an atom in a small nucleus.

7 a) More will bounce back when the foil is thicker, as the alpha particle has more chance of meeting a nucleus.

b) Fewer will bounce back, because the charge on the aluminium nucleus is much less than it is on a gold nucleus; there is a smaller force between the alpha particle and nucleus for a given separation.

8 a) A helium nucleus.

b) Alpha particles are strongly ionising. Inside the body, alpha particles can cause intense localised damage to tissues.

9 Gamma rays can escape from the body and be detected to allow an image of the inside of the body to be made.
Gamma rays are safer for the patient than alpha and beta particles.
The short half-life means that the radiation dose for the patient is less.

10 a) i) Time.

ii) Count rate.

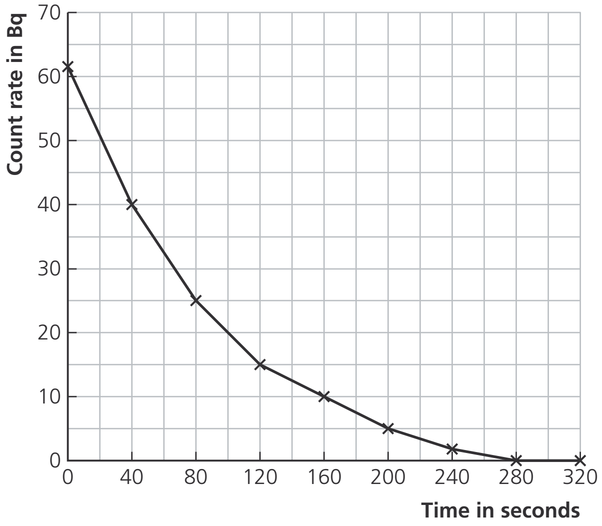
b) Geiger-Muller tube.

c) About 4 counts/second.

d)

Time in seconds	Count rate/Bq
0	62
40	40
80	26
120	16
160	9
200	5
240	2
280	0
320	0

e)



f) i) 60 to 30
4 s to 68 s
A time of 64 s

ii) 40 to 20
40 s to 100 s
A time of 60 s

iii) 30 to 15
68 s to 120 s
A time of 52 s

g) Average value measured for the half-life is:

$$\frac{1}{3}(64 + 60 + 52) = 59\mathrm{s}$$

11 a) A half-life is the time taken for a radioactive material to decay to half its original amount.

b) i) Ionising radiation is radiation that ionises material which it meets by knocking out electrons from atoms or molecules.

ii) Alpha

c) i) Cobalt-60: it can be used for a few years without being replaced; gamma rays will penetrate the syringe and plastic bag.

ii) Technetium-99: gamma rays can escape from the body; a short half-life limits the dose to the patient.

iii) Bismuth-213 can be used provided it can be carefully targeted to the leukaemia. Alpha radiation can destroy cancerous cells and the half-life is short, which means the treatment lasts a short time.

Practice questions

1 a) i) Number of electrons, 4 *[1 mark]*
Number of protons, 4 *[1 mark]*
Number of neutrons, 5 *[1 mark]*

ii) Atomic number 4 – the number of protons determines the atomic number. *[2 marks]*

b) i) Missing word: neutron. *[1 mark]*
ii) C *[1 mark]*
c) i) 4.2 million years. *[1 mark]*
ii) 1.4 million years. *[1 mark]*

2 a) i) $\frac{1}{1000}$ *[1 mark]*
ii) 50% *[1 mark]*
iii) B *[1 mark]*
iv)
- Nuclear power stations.
- Medical treatment with X-rays. [1 mark]

b) Half of 5 mSv is 2.5 mSv – more than our usual background dose. *[1 mark]*
In two weeks, the extra dose is
$\frac{2}{52} \times 2.5\text{mSv} = 0.1\text{mSv}$ *[1 mark]*
so the extra dose is very small compared with the usual safe dose we receive in Britain. *[1 mark]*
Up to 2 marks for explaining that the extra dose received over 2 weeks is very small.

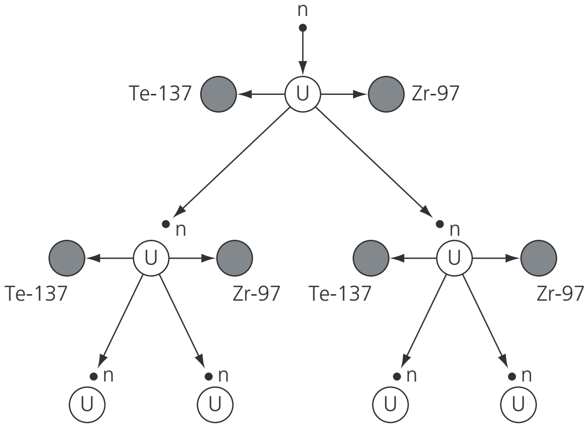
3 a) i) C
ii) B *[2 marks]*
b) i) X *[1 mark]*
ii) Irradiation keeps them fresher, so they are better to eat. *[1 mark]*

4 a) i) Protons 15
Neutrons 16
Electrons 15 *[2 marks]*
1 mark for 2 correct
ii) Phosphorus-32 has 17 neutrons so it is heavier than phosphorus-31. *[1 mark]*
iii) $^{32}_{15}\text{P} \rightarrow {}^{32}_{16}\text{S} + {}^{0}_{-1}\text{e}$ *[1 mark]*
b) i) A Geiger-Muller tube (or GM tube). *[1 mark]*
ii) Cancer. *[1 mark]*

5 a) β and γ *[1 mark]*
b) γ *[1 mark]*

6 a) B *[1 mark]*
b) C *[1 mark]*
c) A *[1 mark]*

7 a) i) Nuclear fission. *[1 mark]*
ii)



[3 marks]

iii) It increases by 1. *[1 mark]*

8 a) Caesium-137 has three more neutrons than caesium-134. *[1 mark]*
b) A beta particle is an electron. *[1 mark]*
Gamma radiation is electromagnetic radiation *[1 mark]*
(or an electromagnetic wave).
c) To reduce to ¼ of the count rate will take 2 half-lives – 16 days. *[2 marks]*
d) Caesium-137 – after 50 years there will be only a very small amount of caesium-134 and iodine-131. *[1 mark]*

9 a) An electron. *[1 mark]*
b) Half-life is the time taken for half of a radioactive source to decay. *[1 mark]*
c) E *[1 mark]*
It emits gamma radiation which can pass through the patient's body. *[1 mark]*
Gamma radiation is safer than beta or alpha radiation *[1 mark]*
A half-life of 6 hours means the patient has a smaller dose. *[1 mark]*
1 mark each for 2 of the reasons.
d) Putting the waste into drums sounds safe, but these are some of the concerns:
- after many years, the drums could leak and radioactive waste could get into water
- the drums have to be transported to the caverns – there could be a road accident on the way that spills waste
- unlikely – but an earthquake or collapse of the cavern could fracture the drums and spill the waste.

2 marks for the first well-explained answer, plus a third mark for a second relevant idea.

10 a) $^{11}_{5}\text{B} \rightarrow {}^{7}_{3}\text{Li} + {}^{4}_{2}\text{He}$ *[1 mark]* for each
b) Both are positively charged and like charges repel. *[1 mark]*
c) The fast-moving nuclei damage and kill the cancerous tissue. *[1 mark]*
d) Because radiation can actually cause cancer – this is a risky procedure but the benefits outweigh the risks. *[1 mark]*

11
- Include a diagram like Figure 4.5 Page 91. [2 marks]
- A very small number of nuclei are deflected back by 180°. This shows that the nucleus is very small in comparison with the atom. *[2 marks]*
- The nucleus must be massive to repel the alpha particle and be positively charged, because the alpha particle is positively charged. *[2 marks]*

Working scientifically

1
- Handle the source with tongs.
- Wear disposable plastic gloves.
- Do not point the source at anyone.
- When not in use keep the source in a lead lined box.

2 a, b, d

3 **a)** The benefit of having the scan outweighs the risk.

b) It is estimated that you need to travel about 13 000 km (8000 miles). This is a little less than the average distance a person drives in 1 year.

AQA GCSE (9-1) Combined Science

Test yourself on prior knowledge

1 Proton, neutron.

2 Proton.

3 An atom is neutral; protons and electrons carry charges of the same size but opposite sign.

Test yourself

1 **a)** 10^{-10} m

b) 10 000

2 B and C. They each have four of the same type of particle – which must be a proton.

3 **a) i)** 7; the atomic number is the number of protons

ii) 14; the mass number is the number of protons and neutrons

b) It has seven protons and seven electrons. Since a proton has a positive charge and an electron a negative charge, of the same size, the atom is neutral.

4 **a)** 8 protons, 9 neutrons

b) 80 protons, 120 neutrons

c) 92 protons, 146 neutrons

d) 1 proton, 2 neutrons

5 **a)** 64 is the atomic number which tells us the number of protons in the nucleus.
156 and 158 are the mass numbers, which tell us the combined number of protons and neutrons in the nucleus.

b) i) number of protons – 64

ii) number of neutrons – 92 and 94

6 Elements can have more than one isotope. Each isotope has the same number of protons in the nucleus, but different numbers of neutrons.

7
$$\frac{\text{radius of atom}}{\text{radius of nucleus}} = \frac{1.5 \times 10^{-10}}{3.0 \times 10^{-15}}$$
$$= 50\,000 \text{ or } 5 \times 10^{4}$$

8 **a)** Uniformly throughout the atom.

b) In the nucleus.

9 The alpha particle is repelled by the charge on the nucleus. Like charges repel, so the alpha particles and nucleus carry the same sign of charge.

10 Because the radius of the nucleus is very small in comparison with the radius of the atom.
So most alpha particles pass through without getting close enough to the nucleus to be deflected by the nuclear charge.

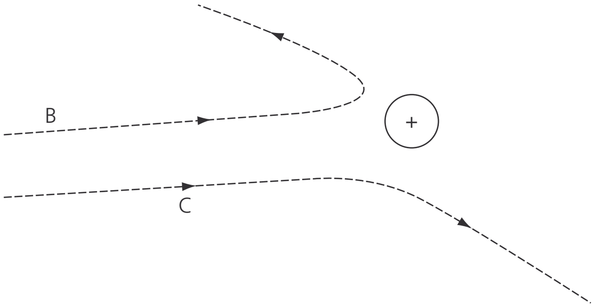
11 The plum pudding model describes the atom as a positive charge distributed through the atom. Then inside this solid substance there are small electrons, with a negative charge, which can move around.

12 **a)** The Bohr model of the atom has a small nucleus with a positive charge e.g. + 8. Then outside the nucleus are eight electrons (with charge −1 each). These electrons orbit in fixed orbits/energy levels, like planets going round the Sun.
You could add a diagram like Figure 18.7 page 342 to help your answer.

b) i) The electron gains energy and, in an atom, the electron can jump up an energy level.

ii) The electron loses energy and, in an atom, the electron can fall from a high energy level to a lower one.

13



B is deflected more than A.
C is deflected less than A.

14 **a)** A helium nucleus.

b) An electron.

c) Electromagnetic radiation.

15 B

16 **a)** An atom or molecule is ionised when an electron is removed from it or added to it.

b) When an electron is removed from an atom or molecule, it leaves a positive ion behind. That free electron can be thought of as a negative ion, or the electron might attach itself to another atom or molecule, so making a negative ion.

17 a) ${}^{3}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{0}_{-1}\mathrm{e}$

b) ${}^{229}_{90}\mathrm{Th} \rightarrow {}^{225}_{88}\mathrm{Ra} + {}^{4}_{2}\mathrm{He}$

c) ${}^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$

d) ${}^{209}_{82}\mathrm{Pb} \rightarrow {}^{209}_{83}\mathrm{Bi} + {}^{0}_{-1}\mathrm{e}$

e) ${}^{225}_{89}\mathrm{Ac} \rightarrow {}^{221}_{87}\mathrm{Fr} + {}^{4}_{2}\mathrm{He}$

18 Thorium

19 The alpha particles create ions in the air – negative ions are repelled from the electroscope but positive ones are attracted so the charge is neutralised.

20 B It will travel through several metres of air.

21 a) alpha

b) beta

22 Radiation is dangerous to us, so the teacher keeps the source as far away as possible from his/her body.

23 Count rate.

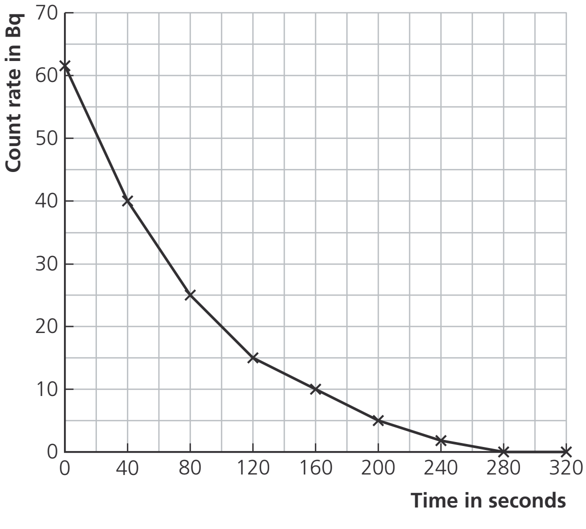
24 a) C

b) A

25 'Random' describes an occurrence which is unpredictable.

26 Over a period of 15 minutes, half of the radioactive material will decay.
60 minutes is four half-lives. So
$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{16}$ of the material is left.

27



Half-life = 1.3 minutes

28 a) 12 noon on 2 March to 4.00 am on 3 March is a period of 16 h.
This is two half-lives, so the count rate reduces to $\frac{1}{4} \times 2400\,\mathrm{Bq} = 600\,\mathrm{Bq}$

b)

600 Bq	4.00 am on 3 March
300 Bq	12 noon on 3 March
150 Bq	8.00 pm on 3 March
75 Bq	4.00 am on 4 March

29 Alpha, beta, gamma, neutron.

30 a) It is difficult to say as we do not know the size of the doses. But $\frac{50}{800} = 1$ in 16 people died after exposure to alpha particles; $\frac{20}{7000} = 1$ in 350 people died after exposure to gamma rays. So on this limited evidence alpha particles seem much more dangerous.

b) If we assume that the two atomic bombs were of the same strength, then neutrons appear more dangerous than gamma rays.
Hiroshima: $\frac{100}{15000} = \frac{1}{150}$
Nagasaki: $\frac{20}{7000} = \frac{1}{350}$

c) Correct, we have no data about the size of the doses received.

31 Greater than

Show you can

Page 340

Atoms are very small with a radius of about 10^{-10} m. The atom has an even smaller nucleus with radius less than a $\frac{1}{10\,000}$ of the atom. The nucleus contains nearly all of the mass of the atom. Inside the nucleus are protons and neutrons. The proton has a positive charge; the neutron is neutral. Electrons with a negative charge orbit the nucleus. The mass number of the atom is the sum of the number of neutrons and protons. The atomic number is the number of protons. In a neutral atom, the numbers of protons and electrons are the same.

Page 343

Alpha particles, which are small energetic positively charged particles were aimed at a thin piece of gold foil. Most of the particles travelled through the foil without deflection. A small number underwent very large deflections. This led to the idea of a very small, massive, positively charged nucleus.

Page 346

The answers for this question are to be found on Page 344.

Page 347

Note: you are not allowed to do this experiment yourself.

You need a pure alpha source, e.g. Americium-241.

Place the source close to the GM tube. Move the source away until the count rate on the GM tube reduces to zero.

Place the source close to the GM tube. Insert a thin piece of tissue paper between the source and the GM tube. Observe the fall in count rate.

Continue inserting extra pieces of tissue paper until the count rate falls to zero. It is possible that one sheet will be sufficient to stop all the alpha particles.

Page 351

Radiation causes damage by two mechanisms:

- direct – an alpha or beta particle directly collides with a cell, tearing it apart
- indirect – ionisation produces acids which attack cells.

The amount of damage to our bodies depends on the exposure to radiation – the dose. By monitoring the dose, we can rest a radiation worker if they are exposed to too high a dose.

Chapter review questions

1 **a)** 3
  b) 7
  c) 3

2 **a) i)** Stable means that the isotope does not emit a radioactive particle and become another element.
  ii) An isotope is one type of nucleus of a particular element. Different isotopes of the same element have the same number of protons but different numbers of neutrons.
  b) Carbon-12, 6 protons, 6 neutrons; Carbon-13, 6 protons, 7 neutrons

3 They have different numbers of protons in the nucleus, and different numbers of electrons.

4 **a) i)** ${}^{241}_{94}\mathrm{Pu} \rightarrow {}^{237}_{92}\mathrm{U} + {}^{4}_{2}\mathrm{He}$
  ii) ${}^{229}_{90}\mathrm{Th} \rightarrow {}^{225}_{88}\mathrm{Ra} + {}^{4}_{2}\mathrm{He}$
  iii) ${}^{213}_{84}\mathrm{Po} \rightarrow {}^{209}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$
  b) i) ${}^{237}_{92}\mathrm{U} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{0}_{-1}\mathrm{e}$
  ii) ${}^{59}_{26}\mathrm{Fe} \rightarrow {}^{59}_{27}\mathrm{Co} + {}^{0}_{-1}\mathrm{e}$
  iii) ${}^{32}_{14}\mathrm{Si} \rightarrow {}^{32}_{15}\mathrm{P} + {}^{0}_{-1}\mathrm{e}$

5 The plum pudding model assumed that the atom has a uniform density, with positive charge spread through the atom. Such an atom was not expected to deflect an alpha particle. Geiger and Marsden's work showed that alpha particles could be deflected by large angles by metal foils. This can only be explained by a model which places nearly all the mass and all the positive charge of an atom in a small nucleus.

6 **a)** More will bounce back when the foil is thicker, as the alpha particle has more chance of meeting a nucleus.
  b) Fewer will bounce back, because the charge on the aluminium nucleus is much less than it is on a gold nucleus; there is a smaller force between the alpha particle and nucleus for a given separation.

7 **a)** A helium nucleus.
  b) Alpha particles are strongly ionising. Inside the body, alpha particles can cause intense localised damage to tissues.

8 **a) i)** Time.
  ii) Count rate.
  b) Geiger-Muller tube.

9 **a)** A half-life is the time taken for a radioactive material to decay to half its original amount.
  b) i) Ionising radiation is radiation that ionises material which it meets by knocking out electrons from atoms or molecules.
  ii) Alpha

Practice questions

1 **a) i)** Number of electrons, 4 *[1 mark]*
  Number of protons, 4 *[1 mark]*
  Number of neutrons, 5 *[1 mark]*
  ii) Atomic number 4 – the number of protons determines the atomic number. *[2 marks]*
  b) i) Missing word: neutron. *[1 mark]*
  ii) C *[1 mark]*
  c) i) 4.2 million years. *[1 mark]*
  ii) 1.4 million years. *[1 mark]*

2 **a) i)** C
  ii) B *[2 marks]*
  b) i) X *[1 mark]*
  ii) Irradiation keeps them fresher, so they are better to eat. *[1 mark]*

3 **a) i)** Protons 15
  Neutrons 16
  Electrons 15
  [2 marks for all 3, 1 mark for 2 correct]
  ii) Phosphorus-32 has 17 neutrons so it is heavier than phosphorus-31. *[1 mark]*
  iii) ${}^{32}_{15}\mathrm{P} \rightarrow {}^{32}_{16}\mathrm{S} + {}^{0}_{-1}\mathrm{e}$ *[1 mark]*
  b) i) A Geiger-Muller tube (or GM tube). *[1 mark]*
  ii) Cancer. *[1 mark]*

4 **a)** β and γ *[1 mark]*
  b) γ *[1 mark]*

5 **a)** Caesium-137 has three more neutrons than caesium-134. *[1 mark]*
  b) A beta particle is an electron. *[1 mark]*
  Gamma radiation is electromagnetic radiation (or an electromagnetic wave). *[1 mark]*

c) To reduce to ¼ of the count rate will take 2 half-lives – 16 days. *[2 marks]*

d) Caesium-137 – after 50 years there will be only a very small amount of caesium-134 and iodine-131. *[1 mark]*

6 a) An electron. *[1 mark]*

b) Half-life is the time taken for half of a radioactive source to decay. *[1 mark]*

c) Putting the waste into drums sounds safe, but these are some of the concerns:

- after many years, the drums could leak and radioactive waste could get into water
- the drums have to be transported to the caverns – there could be a road accident on the way that spills waste
- unlikely – but an earthquake or collapse of the cavern could fracture the drums and spill the waste.

[2 marks for the first well-explained answer, plus a third mark for a second relevant idea.]

7 a) $^{11}_{5}B \rightarrow ^{7}_{3}Li + ^{4}_{2}He$ *[1 mark for each]*

b) Both are positively charged and like charges repel. *[1 mark]*

c) Because radiation can actually cause cancer – this is a risky procedure but the benefits outweigh the risks. *[1 mark]*

8 Include a diagram like Figure 18.4 page 341. *[2 marks]*
A very small number of nuclei are deflected back by 180°. This shows that the nucleus is very small in comparison with the atom. *[2 marks]*
The nucleus must be massive to repel the alpha particle and be positively charged, because the alpha particle is positively charged. *[2 marks]*

Working scientifically: Risk and perception of risk

Page 356

1 Handle the source with tongs.
Wear disposable plastic gloves.
Do not point the source at anyone.
When not in use keep the source in a lead-lined box.

2 a), b), d)

5A Forces

Overview

Specification points

4.5.1.1 Scalars and vector quantities, 4.5.1.2 Contact and non-contact forces, 4.5.1.3 Gravity, 4.5.1.4 Resultant forces, 4.5.2 Work done and energy transfer, 4.5.3 Forces and elasticity, 4.5.4 Moments, levers and gears and 4.5.5 Pressure and pressure differences in fluids

Textbook chapter references

AQA GCSE (9-1) Physics: Chapter 5A pages 116–45

AQA GCSE (9-1) Combined Science Trilogy 2: Chapter 33A pages 206–23

AQA GCSE (9-1) Combined Science Trilogy: Chapter 33A pages 562–79

Recommended number of lessons: 19

Chapter overview	
AQA required practical(s)	Physics – RP6 CS Trilogy – RP18
Contains higher-only material	Yes
Contains physics-only material	Yes

Useful Teaching and Learning resources

- Learning outcomes
- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–3
- Key terms
- Animation: Moments
- Personal tutor: Forces and their effects
- Personal tutor: Centre of mass
- Practical: Investigating the relationship between force and extension for a spring
- Teacher and technician notes: Investigating the relationship between force and extension for a spring
- Practical video: Collecting the data to investigate the relationship
- Practical video: Analysing the data to investigate the relationship
- Homework tasks (a) and (b)
- Quick quizzes 1–4
- Answers for homework tasks
- Answers to all questions
- Half-term test 4.5: Forces and motion 2
- Half-term test 4.5: Moments, levers and gears

Useful prior learning

- A force is a push or a pull.
- A force can squash or stretch an object.
- A force can twist or turn an object.
- The resultant force acting on an object is the sum of the forces acting on the object.
- Turning moment = force × perpendicular distance from the pivot
- Pressure = force/area

Common misconceptions

Many of the misconceptions in this topic will hopefully have been addressed in previous years. Some are likely to linger, as they are based on students' daily experience in a world with air resistance, friction and gravity, such as:

- opposing forces 'cancel out'
- a stationary object has no forces acting on it
- the reaction force to weight will often be described as 'upthrust'
- weight and mass are the same thing.

It is easy to use a small variety of contexts when teaching forces; moving cars, heavy machines and a small number of sports. There is compelling evidence that using a greater range – and every object and movement in the world has associated forces, so this is not difficult – engages more students with the topic.

Preparation

The **T&L Prior knowledge catch-up student sheet** will make clear just how much of this topic is a clear extension of KS3 work. The problem, of course, is to ensure that students recognise the gains they are making rather than seeing it as the same material. The test questions will allow you to assess how much they remember. If you are concerned students will be complacent as the content seems familiar, you could have them attempt **T&L Half-term tests 4.5 Forces and motion 2** and **4.5 Moments, levers and gears** at the beginning. (Avoid **Half-term test 4.5 Forces and motion 1**, as it includes the motion questions from Chapter 5B (*33B*)).

You could use the **T&L Topic overview** for the same purpose; provide a version with headings only and have students complete it, with what they remember from KS3. You can then show them the full version so they can see the gaps. Alternatively, leave this for now and supply a few slides at a time as students complete the lessons.

Scalars and vectors: Lesson 1

Learning outcomes

1 Define scalar and vector.
2 Identify common examples.
3 Display vector quantities with arrows.

Suggested lesson plan

Starter

Ask students: why do we sometimes use the word speed and sometimes velocity?

Main

Define a *scalar* quantity as one with size or magnitude. Give some examples (mass, temperature). Compare this with a force, which needs both magnitude and a direction to describe fully. This makes it a *vector* quantity.

Return to the question posed in the starter and explain that although speed and velocity are used interchangeably in everyday life, in science the terms are different. Only *velocity* has a specific direction, which makes it a vector as opposed to the scalar equivalent *speed*. Give some examples and ask students to check if some sample sentences use the terms correctly.

Although velocity and displacement are represented as arrows in Figure 5.1 (*33.1*) on page 118 (*208; 564*) of the textbook, and also available in the **T&L Diagram bank** it will reduce confusion if you tell students that in most cases arrows are used for forces only. From the beginning, be clear that the length of the arrow tells us about the magnitude of the force. It may help to discuss the fact that although force arrows may be drawn differently by different staff members or in different resources, this is effectively a change in handwriting; they always mean the same thing.

Plenary

Have students pick out vectors or scalars from a mixed-up list.

Support

Students will understand the ideas, but may be unsure of language. Reinforce, for example, magnitude = size.

Extension

Ask students to explain how an athlete running around an 800 m track can have a constant speed but changing velocity.

Homework

Use Test yourself questions 1–3 on page 118 (*208; 564*) of the textbook.

Contact and non-contact forces, units: Lesson 2

Learning outcomes

1 Suggest everyday examples.
2 Divide into contact and non-contact.
3 Define the newton and give example values for context.

Suggested lesson plan

Starter

Check recall by having students repeat the ‘spot the vector’ activity from the end of last lesson.

Main

A good starting point is to ask students to provide examples of forces, and add them to categories as the suggestions are made. Students will quickly be able to spot similarities and define the different effects that forces can have (as listed on page 118 (*208; 564*) of the textbook).

When discussing contact forces, it is worth spending some time working through the different ways we use the term *friction*. Sometimes we mean ‘grip’, when there is a force between surfaces in contact that prevents movement (and so no work is done). At other times, ‘slip’ friction is meant, when surfaces slide against each other and the work done causes heating. It can be argued that drag forces, such as air resistance, are an example of friction caused by particles rather than a surface.

Discussing all non-contact forces together is very helpful; ensure students realise that although gravity always causes attractive forces, both electrostatic and magnetic fields are associated with both attractive and repulsive forces.

Define the unit of force as the newton (N). If it is not measured in newtons, it cannot be a force. It may be worth pointing out that ‘force’ is frequently misused in everyday life (not to mention science fiction films) and that mass, speed and acceleration are *not* forces.

You may wish to demonstrate the magnitude of everyday forces using newtonmeters. Try not to limit the examples to weight; pushing and pulling objects should also be familiar to students.

Plenary

Ask students to describe the forces involved with various situations, perhaps from photos.

Support

There should be no major issues here for most students; much of the language used will be familiar from KS3. Use this lesson to consolidate language use and increase confidence in breaking down examples to basic parts.

Extension

Some examples are more complex than others. You could challenge some students to link the ideas about forces with those regarding motion and energy.

Homework

Ask students to review work on weight from KS3 topics on Forces and Space.

Weight: Lesson 3

Learning outcomes

1. Explain why weight, not gravity, is the force acting ‘down’.
2. Explain worked cases of equation.
3. Solve problems independently.

Suggested lesson plan

Starter

T&L Lesson starter 2 would be a good way to check student recall of the ideas from the previous lesson.

Main

Remind students that all forces are measured in newtons. This leads naturally into the apparent paradox that the everyday use of ‘weight’ must be wrong, because it is measured in kilograms (or stones and pounds). Explain this is because until very recently, we could treat them as the same idea because they always went together.

Ask students to point in the direction weight acts; they will immediately point down. Ask what would happen if a class of Australian students were asked the same question. A quick sketch will show that ‘down’ is not a single direction; instead it is towards the Earth’s centre. Define gravitational attraction as a force that acts between any two objects with *mass*. What we notice is *weight*, which is the force the smaller object experiences towards the larger one. In theory, every object with mass is attracted to every other object, but in practice this is immeasurably tiny unless one of the objects is huge.

Define the local gravitational field strength, g, as 9.8 N/kg. On different planets, the value is different but the rule is the same. Each kilogram of mass will experience the same force towards the centre of the planet; on Earth this is 9.8 N. This gives us the equation: weight = mass × gravitational field strength or $W = mg$.

Give several worked examples for Earth and provide data for a range of practice questions. Extending this to other planets gives an opportunity to reinforce that mass is constant but weight depends on location.

Plenary

Have students improve a paragraph with mistakes discussing the difference between mass and weight.

Support

Remind students of the difference between mass (scalar quantity) and weight (vector). The maths is straightforward, but students may struggle if asked to consider other planets. It will help if they can recall that g is a local value.

Extension

Provide the weight of an object on the Moon ($g = 1.7$ N/kg) and ask them to find the weight on Earth. This will involve two steps and the rearrangement of the equation.

Homework

Set further questions for fluency.

Combining forces along a line: Lesson 4

Learning outcomes

1. Explain net force during tug of war.
2. Solve problems independently.
3. Show with arrows drawn to scale.

Suggested lesson plan

Starter

You could use **T&L Lesson starter** 1, although it may show that students can effectively skip the lesson.

Main

Beginning with a tug of war is useful because students can tell *you* how it works; it is also clear to them that although the forces may be balanced, they do not cancel out. Discuss how pulling on one end of the rope means there is tension in it. With this, as with each stage below, it is helpful to include a simple diagram with each example. You may choose to have students draw every diagram with a labelled square to save time; otherwise it’s amazing how much effort they put into the artwork of cars, people and so on.

Ask what will happen if one side pulls with just one newton more than the other. Asking about the size of ‘the effect’ is helpful, as it sidesteps the argument about whether forces cause motion, or the more correct description of them causing *a change in* motion. Providing some examples of two forces acting in the same direction will lead students to the intuitive result that forces can be added or subtracted; remind them that this overall force is called the *resultant*.

Provide a range of practice questions, ideally using different ways of defining direction along a straight line (up/down, forward/backward, left/right, north/south, east/west).

Plenary

Provide multiple choice questions with several plausible answers (added and subtracted) so they can’t just find the only number which combines the values.

Support
Laminated arrows of different lengths are a good way for students to see what happens when forces add up or work against each other. Drawing diagrams to scale can of course be used too, but students can get caught up in the 'scale' part and lose track of the physics.

Extension
Ask what happens when forces are not in the same/opposite direction, e.g. 15 N towards the east and 15 N towards north. This is the subject of a future lesson but is a good way to challenge those who grasp the simple ideas immediately. Have them extrapolate from the scale drawings approach.

Homework
Use Test yourself questions 4–8 from page 121 (*211; 567*) of the textbook.

Free-body diagrams: Lesson 5 (Higher tier)

Learning outcomes

1 List principles of a simple diagram.
2 Draw and label forces in everyday situations.
3 Use diagrams to solve numerical problems.

Suggested lesson plan

Starter
Return to one of the diagrams from the previous lesson and ask students how the arrows help to understand what is happening. Explain that this lesson will be spent using the same approach to better describe and understand other situations.

Main
Any description of a force should make clear what is exerting the force, what kind it is and what the force acts on. Have students apply this to a box on a table: the *box* exerts the force that we call *weight* on the *table*. At the same time the table exerts a reaction force (upwards) on the box. Because these two forces are balanced, there is no resultant force and the motion does not change; it remains stationary. This is a good time to introduce the term *equilibrium* if not already done.

Show these forces with arrows, making clear where they start (weight acts from the centre of mass, reaction force from the surface in contact). We often simplify a diagram to show everything acting from the centre of mass, as if the object is a point; Figure 5.9 (*33.9*) shows this (page 122 (*212; 568*) of the textbook, or also available in the **T&L Diagram bank**). Give example situations to label; you may choose to provide a list of possible forces. For moving objects, be clear about whether the velocity is constant or changing. It will be easier if moving objects have a constant force acting in the direction of motion (*thrust* or driving force) as students will struggle to believe that a thrown object has no forward force acting.

Choose a few answers from the class and supply some numbers. Ask students to solve them based on the ideas from the previous lesson. The best way to do this is to make sure that, until the last example, there is only a resultant force in one direction.

Plenary
Ask students to match names of forces with guidelines to remember, e.g. *weight* can be matched with 'always points down'.

Support
By choosing careful examples you can avoid the likely difficulties, which usually come from students linking the idea of force with motion. A common misconception is that force is somehow conserved when an object moves; what students are thinking of here is something more like momentum. These examples are best left for the motion part of the topic.

Extension
Ask students to explain what will happen if specified forces increase, e.g. 'How will the resultant force in this situation change if there is more friction?'

Homework
Students could write their own questions based on situations from home or school, perhaps drawing the arrows for someone else to complete. (Obviously they should list the answers and their explanations too!)

Resultant forces at right angles, diagrams: Lesson 6 (Physics only)

Learning outcomes

1 Suggest 'common-sense' solution when forces act at an angle.
2 Annotate worked case of diagram.
3 Practise resolving forces into components using scale drawings.

Suggested lesson plan

Starter
Describe an object on wheels that is free to move in any direction; even better if you have a

Gratnell's trolley or similar to show them. Ask the class to predict the resultant force for different combinations, starting with N + N (addition), N + S (difference), then N and E. They will probably see the 'diagonal' force as intuitive.

Main
Explain that it is sometimes useful to know the 'ingredients' of a resultant force. This is particularly true when the two (or more) forces are not in the same line. Students should recognise that there are all kinds of possible combinations that would give the same resultant, but that we can identify pairs of forces at right angles to be most useful. This is called *resolving* the resultant force.

The example in Figure 5.10 (*33.10*) on page 123 (*213; 569*) of the textbook, also available in the **T&L Diagram bank**, can be understood best as resolving the resultant force into one that lifts the box vertically against weight and one which pulls it horizontally against friction. Remind them that this is about finding minimum effort, e.g. when dragging a box across carpet, lifting it a little reduces the friction so it is easier.

The maths involved with these processes (combining and resolving) is mostly saved for A-level. Instead, students can draw force arrows to scale. It is often worth having students start by drawing two components to find the angle (direction) and length (magnitude) of a diagonal resultant. They can then see how the process works in reverse. Several examples should be drawn before students attempt some independently.

Plenary
Provide two force arrows and ask students how they could combine for maximum and minimum resultant force.

Support
Using the scale drawings (or laminated arrows as a model) reduces the difficulty of the process. Encourage students to use simple scales; you may wish to produce example rulers with 'forces' marked with masking tape at 1 cm intervals.

Extension
Ask students how the angles and magnitudes of the forces could be calculated, rather than measured. Prompt them by pointing out the triangle implicit in the diagram. Emphasise that they are not expected to combine or resolve forces using trigonometry until A-level.

Homework
Use Test yourself questions 9–13 from page 123 (*213; 569*) of the textbook.

Work done: Lesson 7

Learning outcomes

1 Recap equation for work done.
2 Practise solving problems.
3 Explain link to energy store changes.

Suggested lesson plan

Starter
Test recall of several equations, including definitions of terms and units. Follow up by focusing on work done = force applied × distance moved.

Main
It may be helpful to treat this is a recap and consolidation lesson, depending on how deeply it was understood in the energy topic. (The equation was also reviewed when looking at hydraulics.)

Remind students that the force acting downwards because of gravity is weight. (And that 'gravity' is not the force because it is not measured in newtons.) Lift a 100 g mass (i.e. 1 N) by 1 m. Units are defined so that this amount of work done, 1 newton-metre (Nm), is equal to 1 joule (J).

Ensure that examples given make clear the forces involved, in words and numbers. Lifting an object means that the force is equal to weight; horizontal movement may involve both friction and air resistance (often combined into 'resistive forces'). It is often helpful to write out 'work done' so that W can be used for weight. You may wish students to repeat previous practicals with newtonmeters and rulers.

While students are attempting practice questions, it may be helpful for them to consider which stores are being filled when work is done on an object. Common stores will be gravitational (when lifting), kinetic (when object continues to move after force stops) and thermal (when working against friction); the source of this energy will usually be a chemical store (associated with muscles/fuel/battery). Ensure that students recognise that only when there is movement as a result of the force can we calculate work done.

Plenary
Give an example calculation with mistakes and have students annotate them with corrections.

Support
As effectively review work, this is a good opportunity for students to practise their calculation methods and show clear working. Understanding should not be an issue, as it makes intuitive sense that increasing the effort needed (force) or distance moved will increase the work done.

Extension
If doing some hands-on work, students could briefly investigate the effect of changing the angle at which a force is applied when dragging an object along a bench. This will demonstrate the interaction of vertical and horizontal forces.

Homework
Use Test yourself questions 14-17 from page 125 (*215; 571*) of the textbook.

Elastic and inelastic deformation: Lesson 8

Learning outcomes

1. Recap effects of forces.
2. Give examples showing the difference between temporary and permanent change.
3. Distinguish between length and extension for a stretched spring.

Suggested lesson plan

Starter
T&L Lesson starter 2 can now be used as students should recall the units of work done from last lesson.

Main
It may be helpful to make clear from the beginning that in physics, *elastic* is a technical term which does not just mean 'stretchy'; this is discussed more in a later lesson plan. This lesson and the following three could be combined into two if time is particularly short and your students are capable of completing more work at home.

Ask students to give situations when a force has changed the shape of something. Divide the examples given into temporary and permanent changes. Define *deformation* as a change in shape and explain that to make measurements easier, we often look at examples where only the length changes, which is called *extension* or *compression*.

You may wish to show students some old newtonmeters and explain that they have become permanently damaged because the spring no longer returns to the original length. This is *inelastic deformation* and happens because of a larger force; you could even discuss the changes on a molecular level. Until this point we use the term *elastic deformation*.

Recap the linked ideas of *zero error* and *calibration* (pages 34 and 70 (*CS1 pages 289 and 322*) of the textbook may be useful). Measure the length of a stretched or compressed spring and ask students why this value is *not* the extension. Ask how they would work out the true value for extension.

Plenary
Have students distinguish between examples of inelastic and elastic deformation.

Support
Simple toys are a good way to reinforce the idea of temporary and permanent shape change; you can also show this with table tennis balls which return to their original shape when a small force is applied, but can be damaged if the force is larger.

Extension
Some students will be able to link these ideas to the elastic store with little prompting; ask them why there is not an equivalent 'inelastic store'. (The permanent change means the energy has been dissipated, often by heating.)

Homework
Students could write a summary of the rules for drawing graphs, as a checklist that can be followed, and the reasons why they matter.
You may wish to give them some words to use including *axis*, *origin*, *scale*, *points*, *best-fit*, *label*.

Required practical 6(*18*): Force and extension: Lesson 9

Learning outcomes

1. Create a table with columns for both length and extension.
2. Collect data for at least one spring.
3. Plot a graph of the collected data.

Suggested lesson plan

Starter
You could recap the difference between length and extension for the spring, or use **T&L Practical video: Investigating the relationship between force and extension for a spring**. As suggested previously, showing such a clip without sound, and asking students to suggest subtitles, is a good way to increase attention.

Main
The standard method is one the students will probably have used before, at KS3. You may wish to add in some variation by repeating the experiment for a rubber band (with smaller masses) or using a copper wire, with weights hanging over the edge of a table using a pulley, and measuring extension by taping a straw to the wire as a pointer.

The **T&L worksheet, Practical: Investigating the relationship between force and extension for a spring** takes them through all the necessary steps. You may need to highlight the reversal of axes suggested, as they may otherwise miss the detail. The questions are, as usual, answered on the **T&L Teacher and technician notes resource**.

Depending on timing, you may wish to set the graph plotting and/or finishing the sheet questions as homework.

Plenary
If students have got to the stage of plotting graphs, you should be able to discuss the meaning of the gradient and how this gives the unit of N/m for the stiffness constant, *k*.

Support
Plotting the graph may need some support, but the practical itself is a familiar one. If the method is followed there should be little chance of students overstretching the springs provided.

Extension
Ask students to consider how this applies to other materials, for example those used in construction and sports.

Homework
Discussion of the experimental results will be useful, possibly structured by the questions on the sheet or those in the textbook, page 127 (*217; 573*).

Force and extension (debrief): Lesson 10

Learning outcomes

1 Compare results with those for a rubber band.
2 Calculate the spring constant.
3 Discuss the meaning of the calculated value.

Suggested lesson plan

Starter
Compare the maths term *positive correlation* with the science term *directly proportional*; students often treat them as meaning the same thing, but in science directly proportional means not only a straight line, but one that goes through the origin.

Main
Depending on which practicals were included last lesson, you may wish to demonstrate the data obtained from rubber bands, copper wire (or strawberry laces). Ask them to look for similarities and differences.

Discuss the use of the straight section on the graph – which may not be the whole range of data – to calculate the stiffness constant *k*. This can be thought of as the force needed to cause each metre of extension. Explain that the term *elastic* applies to any material while it is behaving in this proportional way, so to a physicist (or materials scientist, engineer etc.) an ‘elastic’ band is not always elastic!

Provide sample data – perhaps some example graphs – and have students identify the elastic range and stiffness constant, if relevant. Point out that some materials behave very differently if heated or cooled; you are unlikely to have liquid nitrogen to hand for a demonstration but attempting to stretch Plasticine at room temperature and directly from the freezer is a good equivalent.

Plenary
Show students a sample answer to an exam-style question and ask them to suggest improvements.

Support
Some students may find the reversal of axes confusing; normally the independent variable would go on the horizontal axis. This is done simply so the gradient calculation gives the stiffness constant without an extra step.

Extension
Students should be able to describe the behaviour of materials directly from force–extension graphs.

Homework
Use Test yourself questions 18–22 from pages 128–129 (*219; 575*) of the textbook.

Proportionality limit, energy stored: Lesson 11

Learning outcomes

1 Annotate sketches showing the proportional (straight) region and the limit of proportionality.
2 Use the equation to calculate the energy stored in various examples of stretched or compressed objects.

Suggested lesson plan

Starter
Demonstrate a bouncy ball dropping from a height and bouncing back up. Ask students to explain what happens using terms from the energy topic, e.g. *gravitational store*, *kinetic store*, *elastic store*, *thermal store*, *dissipation*.

Main
Remind students of the graphs obtained, for example Figure 5.20 (*33.20*) on page 128 (*218; 574*) of the textbook, also available in the **T&L Diagram bank**. The *limit of proportionality* should be identified and the consequences discussed. Students may find it useful

to discuss the terms used in technology for different materials which are strong but do not stretch.

You may wish to review all energy change equations from the energy topic (pages 5 and 6 (*262*) of the textbook). After a worked example, students should be able to work out the energy in the spring's elastic store at each stage of the practicals they completed. Provide more questions for them to attempt independently, including both stretched and compressed materials.

Emphasise that as soon as inelastic deformation occurs, the energy is instead transferred to the thermal store of the material. If an IR thermometer is available, you could show the spring temperature increasing after being overstretched.

Plenary
Return to the bouncing ball and check that students can link the equations needed for each store.

Support
Ensure that students realise that this is an equation to use in exams, but not one they will need to recall. Some may need help with the power function, and this is a good chance to check their calculator use.

Extension
Students should be encouraged to consider and explain how changes to stiffness and extension affect the amount of energy stored in a spring.

Homework
Students should review the work in the topic to date before moving on to moments. You may wish to schedule a recall test, or set a selection from the Chapter review questions from page 140 (*220; 576*) of the textbook (question 1 then 5–9 (*1–5 in CS*)).

For combined science students, as it is the end of (this part) of the topic, you may wish to use **T&L Homework tasks (a)** and **(b)**, and the **T&L Half-term test 4.5: Forces and motion 2**. Parts of **Half-term test 4.5: Forces and motion** 1 could also be used, or it could be saved for when students have covered the motion part of the topic.

Investigating moments: Lesson 12 (Physics only)

Learning outcomes

1 Predict effect of moving a load with common examples, e.g. seesaw.
2 Use simple equipment to identify relationship between load and effort.

Suggested lesson plan

Starter
Ask for a 'strong' volunteer – think carefully about phrasing so as not to reinforce gender stereotypes. Have the student lean with one hand on a marked spot near the hinge of the classroom door. Demonstrate that you (or another, ideally smaller) student) can overcome their force with a single finger, by pushing at the far edge of the door. Ask the class to explain the result.

Main
Depending on how thoroughly this was covered at KS3, you may feel it appropriate to combine this lesson with the following one.

Students should draw a diagram of the starter, as a way to identify the *pivot*, *load* and *effort*. If available, simple see-saws give an opportunity for a quick investigation. Asking students to identify the 'rules' works best if you give them some situations to test. Show a picture of a small child at one end of a seesaw. Ask where the parent should sit so that it balances. Most students will intuitively (and correctly) suggest close to the centre.

Define the *moment* as the turning effect of a force about a pivot (you may wish to preempt confusion by emphasising it is nothing to do with momentum). Have students identify the load and effort from diagrams (e.g. Figures 5.27a–c, page 131 of the textbook and also available in the **T&L Diagram bank**), and suggest ways in which we use a large moment to overcome a large load with a smaller effort. Ensure that the examples include different positioning of load and effort compared with the pivot.

Plenary
Use **T&L Quick quiz 1** to review a range of ideas from the topic so far.

Support
Emphasise to students that this lesson is about adding scientific language to situations they already understand; effectively, this is a good introduction to the idea of machines which allow humans to 'cheat'.

Extension
Some students will fluently use calculations without prompting; have them return to verbal explanations and real-life examples.

Homework
Use Test yourself questions 23–24 from page 133 of the textbook.

Calculating moments – levers, loads: Lesson 13 (Physics only)

Learning outcomes

1 Distinguish between force/moment.
2 Consider worked examples.
3 Solve problems independently, perhaps with the use of diagrams.

Suggested lesson plan

Starter
Provide a diagram with several labelled forces at difference distances from the pivot. Ask students to explain which has the largest effect and why.

Main
Discuss explanations and ensure that students are able to compare moments rather than forces. It may be useful to introduce the idea of moments being ‘clockwise’ or ‘anticlockwise’ instead of ‘left’ or ‘right’. Define moment = force × perpendicular distance ($M = F \times d$). Remind students that this is the size or magnitude – the direction must be specified as a moments is a vector quantity.

Return to the examples used in the previous lesson, but now add data so students can see you working through the process of calculation. It is worth pointing out that if the material is flexible, not all of the force acts at the pivot so the effect is reduced.

Give students data so that they can practise the calculations independently. Including a sketch with their answers will enforce a systematic approach, and be useful when moving on to the more complex examples of equilibrium next lesson.

Have students list contexts where the principles are used to increase the turning effect of a modest force.

Plenary
Many video clips are available showing what happens when cranes are not operated with moments in mind – just be aware that footage may need to be played with audio turned off due to the comments.

Support
The use of diagrams is a useful support for many students; even those who may feel confident without them now may find them a useful foundation for more complex problems. Ensure that students appreciate that the units of a turning effect are newton-metres (Nm) not newtons per metre (N/m). This will also remind them to convert units of length to metres from centimetres.

Extension
Combining two clockwise or two anticlockwise moments can be a useful parallel to the idea of a resultant force; it will also set the scene for equilibrium in the next lesson.

Homework
Use Test yourself questions 25–27 from page 133 of the textbook.

Moments and gears in action: Lesson 14 (Physics only)

Learning outcomes

1 Define the principle of moments.
2 Explain solutions to complex problems.
3 Define gear effects, explicitly parallel to moments.

Suggested lesson plan

Starter
Student responses to **T&L Lesson starter 3** will be a good way to test their explanations of moments.

Main
Remind students of the need to describe moments as clockwise or anticlockwise. Define the principle of moments as listed on page 132 of the textbook. Have students show their working for an example of equilibrium, such as people on a see-saw or similar.

Discuss the difficulty of finding an exact balance or equilibrium point in the real world, when every passing particle in the air exerts a force and so a turning effect. This is a good way to remind them of the limitations of any mathematical description of situations which are rarely truly static.

For each worked example (and later practice question), students could make a prediction of the effect based on what they ‘feel’ is the right answer. They are relying on their real world experience and the calculations will provide the systematic evidence for their intuition. It is important that they realise that making such predictions may help them to structure or start a calculation, but that the maths is still necessary!

For gears, it is not immediately obvious to students that the increased number of interlocking ‘teeth’ implies an increased radius – and so an increased turning moment. Remind them that the circumference (and so the number of teeth that can be fitted in) is directly proportional to the radius (which is the perpendicular distance to the pivot). Adding lines to Figure 5.30 (the gears diagram on page 133 of the textbook, and also available in the **T&L Diagram bank**) may help.

(Be aware that clipart cogs and gears are often non-functional, so should be used in lessons with caution. Colleagues from the technology department may be able to offer more useful examples.)

Plenary
Students have now covered all they need to answer **T&L Quick quiz 2**.

Support
Complex examples can be broken down into individual calculations; this is where diagrams can be very helpful. When introducing gears, make an explicit link between levers and gears which both allow a small input force (effort) exerted over a large distance to cause a large output force (load) to act over a small distance. Consider (or measure) how far the handle of a spanner moves when a nut turns just a few millimetres.

Extension
Students may be able to explain why, in many examples, the *mass* of loads can be used in place of *weight* (mass and weight are proportional so the principle still holds true).

Homework
Use Test yourself questions 28–29 from page 134 of the textbook.

Pressure in a fluid: Lesson 15 (Physics only)

Learning outcomes

1 Use example of marbles to explain how a fluid works.
2 Use the equation to calculate values when supplied with data.

Suggested lesson plan

Starter
Students could annotate standard diagrams for particles in different states of matter, e.g. Figure 3.6 (page 71 of the textbook or also available in the Particles section of the **T&L Diagram bank**).

Main
It can be useful to demonstrate the motion of marbles in a tray; push a ruler along the tray and ensure that students see that not all marbles move in the same direction, but that they collide with each other. The 2p coin drop machines at arcades may be a useful example. Computer simulations are often worth introducing too, explaining that they are based on the maths which has been tested in real-world situations. Students should be able to explain that the effect of many small impact forces is added together, and acts on all surfaces no matter the direction of the original force.

Define *pressure* as the force applied by a fluid per unit area on a surface, with the associated equation ($P = F/A$). Be very clear that the units for pressure are pascals (Pa), but are often given as N/m^2. Students will need to distinguish them from those for moments (Nm) and stiffness in springs (N/m).

Choose careful examples for explanation and then practice; often students struggle not with the pressure calculation but with working out the surface area. The same equation is often used for solids but the result is better described as *stress*, which is beyond this specification.

Plenary
Test recall of previous parts of the topic, perhaps based on the work set as review homework a few lessons previously. Alternatively, review the different equations and the units of quantities.

Support
Conceptually, students will find this easier with the support of physical models to imagine the effects of particle collisions; the maths can then be seen as a way to describe the understanding. The surface area part of the calculation may cause difficulties; in particular, the need to convert to square metres.

Extension
Remind students of the ideas covered in the Particles topic and ask how pressure will be affected by temperature in systems involving liquids and gases. (There is little effect in liquids, but increasing temperature increases gas pressure so a greater force on the surfaces.)

Homework
Set more pressure calculation questions, perhaps involving rearrangements. If preferred, the moments contexts in the Chapter review questions 2, 3, 10, 11 (pages 140 and 141) could be used as preparation for the end of the subtopic.

Hydraulic machines: Lesson 16 (Physics only)

Learning outcomes

1 Use sealed syringes to measure effects of changing CSA.
2 Annotate mathematical explanations of the effect.
3 Give examples of hydraulics in everyday use.

Suggested lesson plan

Starter

Syringes filled with coloured liquid and joined with a sealed tube will allow you to demonstrate the basic principle of hydraulics; force acting at one end is transmitted through the fluid, no matter the angle or change of direction.

Main

Give students an opportunity to try out different combinations of syringes, ideally over trays as the sealed tubes have a tendency to become unsealed. They can record both qualitative and quantitative observations, and should be encouraged to recognise the pattern of observations.

If needed, prompt students by reminding them of the relationship between pressure, force and area; making clear that pressure in the fluid is the same against all surfaces will help them to recognise the idea that a smaller area (narrower syringe) will increase the force that acts.

Use examples from real-world situations that demonstrate how a force can be 'magnified' at the cost of increasing the distance through which the input force must act. Figure 5.37 (page 136 of the textbook, also available in the DL Diagram bank) shows how brake pedals work, but does not make clear that for every millimetre the brakes move the pedal must move much further.

Students should record in their notes that hydraulics allow forces to be magnified and effectively shared between several outputs; alongside these advantages, the importance of maintaining pressure should be remembered.

Plenary

This would be a good point to emphasise that the current gender imbalance in careers such as engineering has no justification in the average difference in physical strength; the whole point of using machines is that the individual's physical ability is irrelevant.

Support

Providing a structured worksheet with a table that specifies 'input' and 'output' values for force and area may be helpful. Encourage them to see the link between this and moments.

Extension

Have students annotate the brake pedal diagram with the forces involved; encourage them to recognise that the four hydraulic outputs effectively quadruple the output surface area.

Homework

Students should review these ideas and attempt further practice questions; alternatively, they could read ahead so that the next lessons can be combined.

Pressure at depth: Lesson 17 (Higher tier and Physics only)

Learning outcomes

1 Observe different force of jet at varying depths.
2 Use equation to calculate pressure at depth.

Suggested lesson plan

Starter

Comparing the length of water jet when a 2-litre bottle has three equally sized holes at different heights is a good introduction; be sure to have students commit to predictions before showing the result. A good one to do outside…

Main

This lesson and the one following can probably be combined if students have been able to read ahead and/or review the work effectively.

Students will probably be well aware of the increasing pressure with depth of water; they should now be able to write explanations of why this should be the case, using the idea of the weight above an object. A simple diagram showing a column of water leads to the equation, which is one to use rather than memorise: pressure = column height × liquid density × gravitational field strength.

Worked examples should make it clear that the pressure experienced is made up of atmospheric pressure as well as the water pressure; looking for the word 'extra' in questions is important. Students can be given some questions to attempt as practice; they may be shocked by the values calculated under truly deep water (e.g. Atlantic average depth is 3500 m, maximum nearly 8500 m – deeper than Everest is tall.)

Plenary

Challenge students to explain why waterproofing is rated for *static* water, e.g. 1 m. (The reason is that moving under water increases the pressure on one side, the same as moving into the wind increases the force on one side.)

Support

Some students will struggle to understand why the size of the object is not part of the equation; remind them of the previous lesson's work showing that all surfaces experience the same pressure (but different forces).

Extension

Link the ideas to the adaptations seen in deep-sea fishes, and why humans would have problems in a vacuum.

Homework
Use Test yourself questions 30-32 from page 138 of the textbook.

Floating and sinking: Lesson 18 (Higher tier and Physics only)

Learning outcomes

1. Recap free body diagrams.
2. Annotate diagram showing larger arrows at bottom of object.
3. Extend this idea to objects with varying densities.

Suggested lesson plan

Starter
Ask students to add labelled arrows to a diagram of an object on a desk. They should be able to label an arrow pointing 'down' as weight, and one up as the reaction or contact force from the desk. Some may add the effect of air pressure on every exposed surface; if so ensure, that they realise that these are balanced so can often be ignored.

Main
Remind students of the idea from last lesson of increasing pressure with depth. This means that if the object is placed in a bowl of water, the arrows drawn for the forces acting will be larger (i.e. longer) at the bottom than at the top.

Return to the idea of resultant forces and show that the *weight* and this force upwards, *upthrust*, are opposed. If they are equal, then the forces balance (*not* cancel). Upthrust is itself a resultant as it acts because of all the particles in the liquid acting together.

An object that floats still has weight, and the arrow should still be labelled. The difference is that the upthrust is large enough that there is no resultant vertical force. Students may find it helps if you point out that the shape of an object will change the amount of upthrust from the liquid, as this is dependent on surface area. Making 'boats' out of plasticene which float, compared to a sinking lump with the same mass, may be useful here.

Students should record that the upthrust is equal to the weight of liquid displaced. This is why objects float higher in liquids with higher densities; this can be shown with wax cubes in water and salt water (and depending on local rules, mercury).

Plenary
T&L Quick quiz 3 can now be used to check recall.

Support
A good general rule is that uniform objects with density higher than the liquid will sink, whereas a lower density means they will float. The difficulty is that shaped objects such as boats have an effectively low density due to the air within them.

Extension
Ask students to explain why boats which travel up rivers from the sea will float at different levels depending on how loaded they are and where in the journey we measure. (They will float higher in salt water than fresh water, but the amount of cargo will change the weight also.)

Homework
Use Test yourself question 33 from page 138 of the textbook.

Atmospheric pressure: Lesson 19 (Higher tier and Physics only)

Learning outcomes

1. Recap gas pressure.
2. Discuss atmosphere to put numbers in context.
3. Use pressure equation to solve problems.

Suggested lesson plan

Starter
You may choose to use diagrams or animations from the Particles topic to remind students about gas pressure. Alternatively, provide inflated balloons and ask students to explain the forces involved.

Main
There are many bar tricks and similar which use the effects of air pressure to amaze and surprise. A simple one is to upend a drink in a sports bottle with the cap open; after a few moments it will stop dripping out. The flow will resume if you make a hole in the bottle (level with the air pocket to avoid confusion).

Remind students of the increasing pressure observed with depth of water. Explain that, in the same way, on the Earth's surface we are at the bottom of a pile of gas many kilometres high. This fluid behaves in the same way as the ocean's water, exerting pressure on us which we do not notice as long as it acts on all sides and surfaces equally.

Using a value for atmospheric pressure at 'sea-level' of 100 kPa, demonstrate how to calculate the force acting on a given surface. This is a review of the previously used pressure equation so students should be able to attempt practice questions with relatively little difficulty; just remind them of the importance of units.

T&L Quick quiz 4 may be a useful recap.

Plenary

Show students balloons filled with different gases and ask why they behave differently, their answers should recognise the different density, compared with atmospheric density, similar to the floating and sinking discussions from the previous lesson.

Support

The values used in most everyday situations may be confusing for some students; pressure must be converted into pascals (atmospheric pressure is often given as 100 kPa, which is 100 000 Pa) and area must be used in square metres rather than square centimetres. Some will need to be reminded not to equate 1 m^2 to 100 cm^2.

Extension

Give students comparison values of air pressure from weather charts, showing how pressure can increase or decrease with this factor as well as height. How does the force on a surface change and why don't we normally notice? (It's the same on all sides, so is balanced.)

Homework

Use Test yourself questions 34–36 from page 139 of the textbook for this section; as it is the end of (this part) of the topic, you may wish to use **T&L Homework tasks (a)** and **(b)**, and the **T&L Half-term tests 4.5: Forces and motion 2** and **4.5: Moments, levers and gears**. Parts of **Half-term test 4.5: Forces and motion 1** could also be used, or it could be saved for when students have covered the motion part of the topic.

Answers

AQA GCSE (9-1) Physics

Test yourself on prior knowledge

1 There are many, e.g. gravity, friction, a push or a pull to move a chair.

2 **a)** Turning moment = force × perpendicular distance
= 30 × 0.2
= 6 N m

b) Because the distance is larger and then a larger turning moment can be produced with the same force.

3 $P = \frac{F}{A}$

$= \frac{900}{0.6}$

$= 15\,000 \text{ N/m}^2$

Test yourself

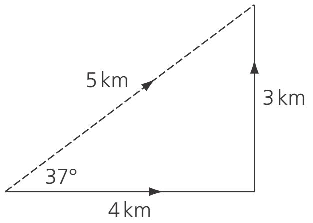
1 **a)** energy
b) force

2 Velocity also needs to specify a direction.

3 **a)** You need to draw an arrow pointing northwards and mark it 4 km.

b) Displacement is 0; distance travelled is 8 km.

c)



i) Displacement is 5 km, in a direction 37° north of east.
ii) 7 km

d) When you go for a walk you cover a distance over the ground: e.g. we walked 7 km today. Displacement states the distance and direction away from your starting point.

4 **a)** A contact force is exerted by one body on another when the two bodies are in contact (touching each other).
b) Friction.

5 **a)** A non-contact force is exerted over a distance, when two bodies are not in contact.
b) Electrostatic.

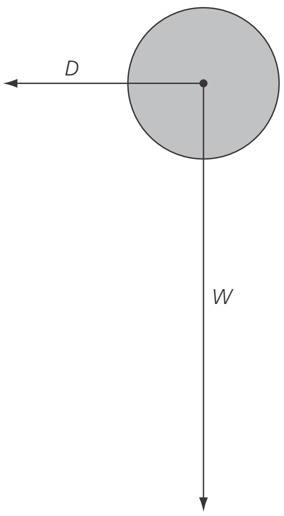
6 One magnet can support another one which is in contact with it. Since the lower one does not fall, the magnetic force must be bigger than the pull of gravity.

7 570 N

8 **a)** 3 N to the right
b) 4 N upwards
c) 1 N to the left
d) 10 N to the right
e) 0
f) 0

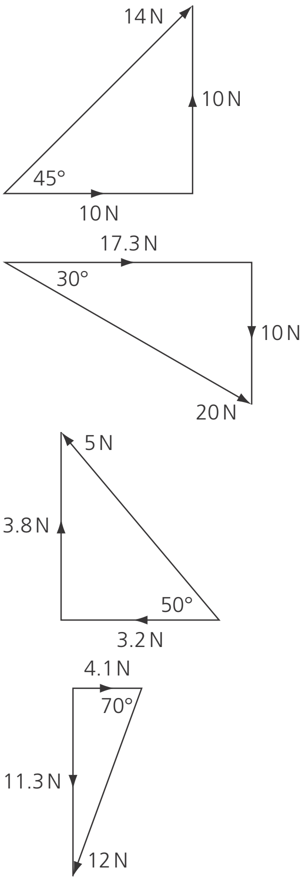
9 $W = mg$
$= 120 \times 3.7$
$= 444 \text{ N}$

10



The ball is moving horizontally to the right.

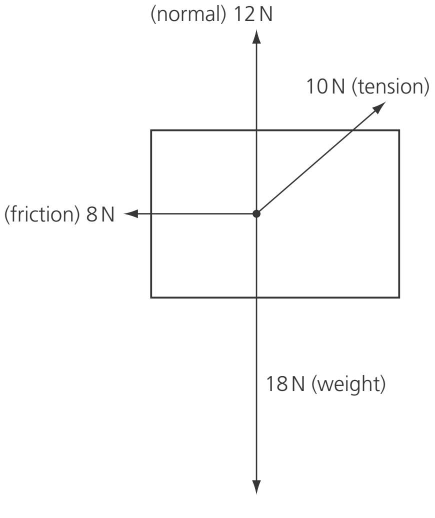
11



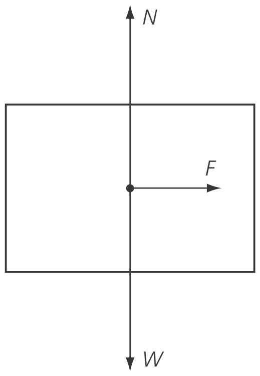
12 a) 8 N to the left

b) 18 N – 6 N = 12 N

c)



13 a)



b) There is an unbalanced force to the right that slows the box down.

14 b), c)

15 a) 50 J

b) 600 J

16 Opening door 7.2 J
Wheeling suitcase 20 N
Lifting box 1.5 m
Pushing toy 0.35 J
Driving 15 MJ

17 a) $W = mg$
$= 150 \times 1.6$
$= 240\,\text{N}$

b) Work $= \text{F} \times \text{d}$
$= 240 \times 8$
$= 1920\,\text{J}$

18 B, C
B and C will ‘spring’ back to their unstretched position as soon as the compressive forces are removed, so elastic potential energy is stored. A and D have no energy stored in them, as there is no force applied to stretch them elastically.

19 When something is stretched elastically, it can return to its original shape once the stretching force is removed.

20 a) 4.6 N

b) $F = kx$
$4.6 = k \times 0.136$
$$k = \frac{4.6}{0.136}$$
$= 33.8\,\text{N/m}$
or 34 N/m to 2 sf

21 $$K = \frac{F}{x}$$
$$= \frac{600}{0.03}$$
$= 2 \times 10^4\,\text{N/m}$

22 See the Required practical 1, Page 127.

23 a) 24 Nm

b) 1400 Nm

c) 32 Nm

24 Turning moment = force × perpendicular distance

a) A long handle allows a larger turning moment for a given applied force.

b) A smaller force can be applied when the door handle is far from the hinge.

25 a) The counter balance balances a large turning moment caused by a heavy load on the other side of the crane.

b) They move the counterbalance to the left, increasing the distance, *d*. The counter-balance now exerts a larger turning moment caused by the larger force on the right.

c) i) moment $= 2500 \times 3.0$
$= 7500\,\text{Nm}$

ii) moment $= 5000 \times 1.5$
$= 7500\,\text{Nm}$

iii) The clockwise turning moment about the centre balances the anticlockwise turning moment about the centre.

26 a) 1.6 N m

b) The weight of the lid exerts a moment to help close the lid.

27 a) The working radius is the perpendicular distance between the line of the weight and the bottom of the jib.

b) On the scale, the working radius is 6.2 cm and 10 m measures 2.4 cm

so $r = 10\,\text{m} \times \dfrac{6.2}{2.4}$
$= 26\,\text{m}$

28 a) turning moment = force × perpendicular distance

so longer handles allow a greater turning moment to be exerted.

b) At point A. The turning moments at A are balanced by the turning moments carried by the forces *F*. So if the distance from A to the pivot is small, the forces exerted by the cutter at A must be large.

c) $210 \times 0.05 = F \times 0.3$

$F = \dfrac{210 \times 0.05}{0.3}$
$= 35\,\text{N}$

29 a) input shaft moment $= 250 \times 0.1$
$= 25\,\text{N m}$

output shaft moment $= 250 \times 0.2$
$= 50\,\text{N m}$

b) The smaller input shaft cogwheel can turn a larger output shaft cogwheel, which then exerts a larger output turning moment.

c) The input shaft because each tooth has to do twice the work.

30 With greater depth there is a greater weight of water; since $P = \dfrac{F}{A}$, as *F* increases the pressure increases.

31 pressure $= \dfrac{\text{force}}{\text{area}}$

so force = pressure × area

The bag is inflated to a pressure, then, because the area of the bag is large, it exerts a large force to lift the bag.

32 a) i) $P = h\rho g$
$= 5 \times 1000 \times 9.8$
$= 49\,000\,\text{Pa}$

so the total pressure $= 100\,000\,\text{Pa} + 49\,000\,\text{Pa}$
$= 149\,000\,\text{Pa}$

ii) $P = h\rho g$
$= 28 \times 1000 \times 9.8$
$= 274\,400\,\text{Pa}$

and the total pressure is 374 400 Pa

b) $P = h\rho g$
$= 30 \times 1000 \times 9.8$
$= 294\,000\,\text{Pa}$

or including atmospheric pressure, $P = 394\,000\,\text{Pa}$

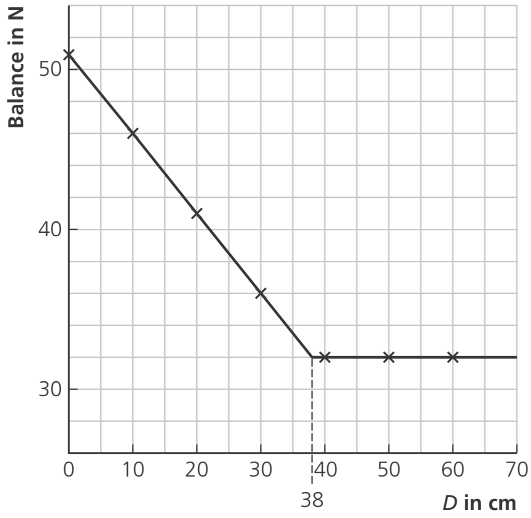
$P = \dfrac{F}{A}$

$394\,000 = \dfrac{F}{0.02}$

$F = 394\,000 \times 0.02$
$= 7900\,\text{N}$

c) The pressure is the same on either side of the mask, so the unbalanced force on the mask is zero.

33 a)

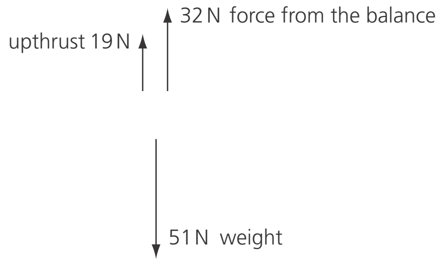


b) You must draw the two straight lines as shown in the graph in a) above. The cylinder is totally immersed after it has been lowered 38 cm – this is its length.

c) 51 N

d) 51 N – 32 N = 19 N

e)



Show you can
Page 118

A scalar quantity only has size (magnitude). A vector quantity has magnitude and direction. So speed is a scalar – something travels at 15 m/s; velocity is a vector – something travels at 15 m/s due east.

You can find other examples on pages 117 and 118.

Page 122

If you cannot answer this, look at Figure 5.8. Figure b) shows 2 N and 2 N adding up to 4 N; Figure c) shows 2 N and 3 N in opposite directions adding up to a resultant force of 1 N to the left.

Page 123

Your mass remains the same everywhere in the universe, because it is determined by the amount of matter in your body. Your weight is a force – it is the pull of gravity on you. A larger planet exerts a larger pull.

$W = mg$ (page 120)

Page 125

Work done = force × distance moved in the direction of the force.

Work is only done if an object moves in the direction of an applied force.

In Figure 5.15, Samantha does no work as she is not moving the weight. In Figure 5.14, Martin does no work because he is pushing in the wrong direction.

Page 129

This idea can be demonstrated well using an empty drinks can. If you give the can a gentle squeeze, it bends in slightly; when you take your fingers away, the can returns to its original shape. This is elastic deformation. If you squeeze the can hard, the can deforms inelastically; when you remove your fingers, the deformation of the can is permanent.

Page 134

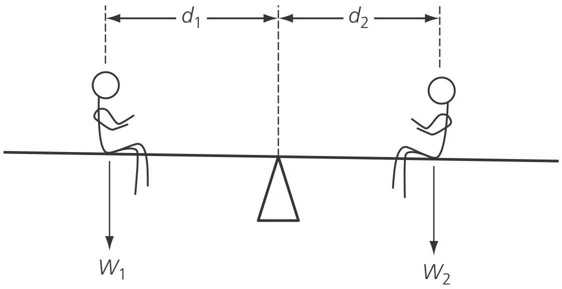
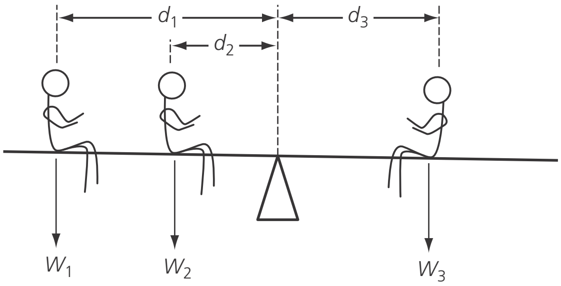


Figure a) shows the balance for two children. Here, the condition for balance is:

$W_1d_1 = W_2d_2$



In Figure b) there are three children, and the condition for balance is:

$W_1d_1 + W_2d_2 = W_3d_3$

Page 138

This is explained in Figure 5.39. The pressure in a fluid increases with depth. So the pressure P_2 is greater than P_1. This means that the fluid exerts a larger force on the bottom of the cylinder than it does on the top. The difference between these two forces provides the upthrust. If the upthrust is greater than the cylinder's weight, the cylinder floats; this happens when the density of the fluid is greater than the density of the cylinder.

Page 139

A larger, more massive planet exerts a stronger pull on objects near its surface. Therefore gases are pulled more strongly to its surface. This makes the gases denser so there is a greater pressure. On a small planet, the gravitational field strength is low and the pressure low; on some planets, the gravitational field is so low that gases escape altogether and there is no atmosphere and no pressure at all.

Required practical
Page 127

1 Clamp the retort stand to the bench and wear eye protection. The method is valid if the data recorded shows a clear relationship.
3 By removing the masses one at a time and measuring the extension as the force decreases.
4 Fix a light pointer (a pin) at the bottom of the spring so that the pointer is across the ruler and moves with the spring.
or
Use a set square to line up the bottom of the spring with the scale on the ruler.

Chapter review questions
1 Scalar: speed, mass, temperature.
Vector: force, weight.
2 The principle of moments states that a body is balanced (in equilibrium) when the sum of the clockwise turning moments equals the sum of the anticlockwise turning moments.

3 The force of the wind on the sail tends to tip the boat to the left; the weight of the sailors tends to tip the boat to the right.

4 The clockwise moments = the anticlockwise moments

$55 \times 0.8 = F \times 0.4$

$F = 110\,\text{N}$

5 **a)** **i)** The force of gravity acts over a distance.

ii) Magnetic force; electrostatic force.

b) $W = mg$

$= 85 \times 10$

$= 850\,\text{N}$

6 work done $= F \times d$

$= 600 \times 300$

$= 180\,000\,\text{J}$ or $180\,\text{kJ}$

7 No work is done, because the masses have not been moved. (Work = force × distance moved in the direction of the force.)

8 **a)** When something is deformed elastically, it returns to its original shape.

b) The stretched spring can be released and the stored energy can be used to accelerate a mass, so giving the mass kinetic energy.

9 $F = kx$

$10 = k \times 0.025$

$$k = \frac{10}{0.025}$$

$= 400\,\text{N/m}$

10 The anticlockwise moments = the clockwise moments

$160 \times 1.2 = W \times 0.8$

$$w = \frac{160 \times 1.2}{0.8}$$

$= 240\,\text{N}$

11 **a)** The anticlockwise moments = the clockwise moments

$390 \times 2 = W \times 3$

$$w = \frac{390 \times 2}{3}$$

$= 260\,\text{N}$

b) The pivot exerts a force to support the children and the seesaw.

$= 390\,\text{N} + 260\,\text{N} + 300\,\text{N}$

$= 950\,\text{N}$

12 pressure $= h\rho g$

This equation shows that pressure increases with depth, or you can say:

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

so at the bottom of the pool you experience a larger force due to the weight of water above you.

Practice questions

1 Velocity *[1 mark]*

2 **a)** $W = mg$

$= 18\ 9.8$ *[1 mark]*

$= 176\,\text{N}$ *[1 mark]*

b) Work $= F \times d$

$= 176 \times 2.1$ *[1 mark]*

$= 370\,\text{J}$ *[1 mark] [1 mark]* unit

3 **a)** turning moment = force × perpendicular distance

By pushing at the end, the man gets a larger turning moment, so it is easier to lift the load [or he can lift the load with a smaller force]. *[2 marks]*

b) turning moment $= F \times d$

$= 240 \times 1.5$

$= 360\,\text{Nm}$ *[1 mark] [1 mark]*

You must have the correct unit.

c) Clockwise turning moments = anticlockwise turning moments

$F \times 4.5 = 360$ *[1 mark]*

$$F = \frac{360}{4.5}$$

$= 80\,\text{N}$ *[1 mark] [1 mark]*

You must have correct unit.

4 **a)** The force on the sail tends to tip it to the right. *[1 mark]*

She must balance this turning moment by leaning to the left. *[1 mark]*

b) turning moment $= F \times d$

$= 750 \times 0.7$ *[1 mark]*

$= 525\,\text{N m}$ *[1 mark] [1 mark]*

You must have the correct unit.

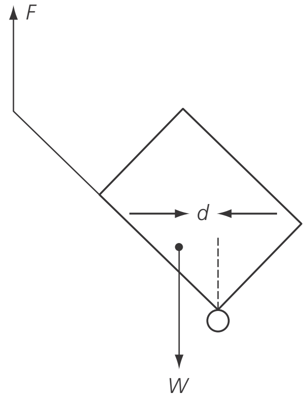
c) turning moment = force × perpendicular distance.

By leaning further, the distance between the line of the force and mast increases. *[1 mark]*

Her weight provides a larger turning moment, which can balance the larger turning moment exerted by the stronger wind. *[1 mark]*

5 turning moment = force × perpendicular distance. *[1 mark]*

The weight of the objects exerts a turning moment to pull the case downwards. This is equal to $W \times d$. *[1 mark]*



The closer the weight is to the wheels the smaller the turning moment. This means that the woman can exert a smaller force, *F*, to balance the turning moment of the weight. *[1 mark]*

Tip. You can draw on the diagram in an exam paper to show these forces. This makes your answer clear.

6 a) $\text{pressure} = \dfrac{\text{force}}{\text{area}}$ *[1 mark]*

b) i) Molecules in air are moving very quickly. They exert a force by hitting the sides of the can. When air is removed from the inside of the can, there is nothing to balance the large pressure on the outside. The can collapses. *[1 mark] [1 mark]*

ii) Gravity acts to pull the air in the atmosphere towards the Earth. At greater heights, there is less air, so the pressure is less. By measuring the pressure we can determine the height. *[1 mark]*

c) i) $P = \dfrac{F}{A}$

$= \dfrac{90}{0.0004}$ *[1 mark]*

$= 225\,000\text{ N}$ *[1 mark]*

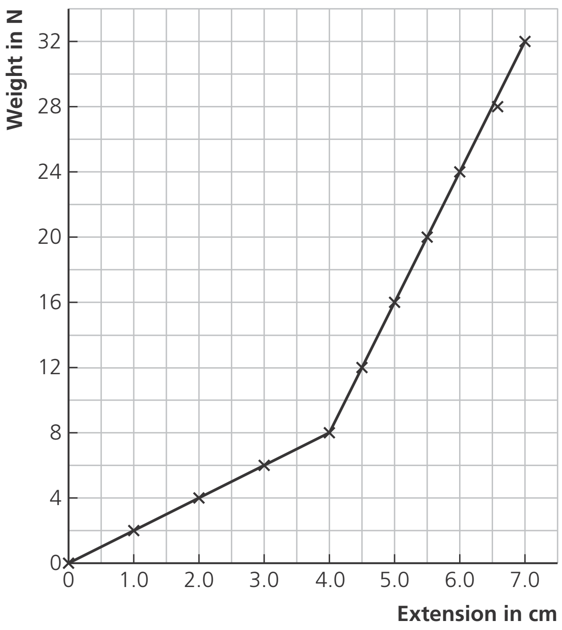
ii) $P = \dfrac{F}{A}$

$225000 = \dfrac{F}{0.0024}$ *[1 mark]*

$F = 225\,000 \times 0.0024$

$= 540\text{ N}$ *[1 mark]*

7 a)



[4 marks]

1 well-chosen scale
1 labelled axes
1 accurately plotted points
1 two correctly drawn straight lines

b) 28.0 N and 6.5 cm *[1 mark]*

c) i) 3.0 N *[1 mark]*

ii) 17.6 N *[1 mark]*

d) This statement is true up to a weight of 8 N. The graph is a straight line going through the origin. *[1 mark]*
Above 8 N, the graph changes slope; this is because the top spring stops stretching. *[1 mark]*

8 a) i) $W = mg$

$= 24 \times 9.8$ *[1 mark]*

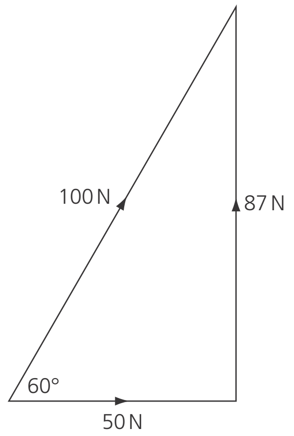
$= 235\text{ N}$ *[1 mark]*

ii) The balance reads the resultant force:
balance reading = 235 N − 100 N *[1 mark]*
= 135 N *[1 mark]*

b) i) Only a component of the force now acts upwards. *[1 mark]*

ii) The vertical component of the force is:
235 N − 148 N = 87 N *[2 marks]*

iii)



horizontal component = 50 N *[3 marks]*

iv) The mass remains stationary because there is no resultant force on it. *[1 mark]*
There must be a 50 N frictional force to the left. *[1 mark]*

Working scientifically

1 People were able to see that the two objects did not hit the ground at exactly the same time.
2 Other factors not taken into account (in this case, air resistance) would affect the results.
3 To check for any anomalies and to calculate a mean.
4 0.325 s.
5 Yes they were repeatable as all of the values for time were similar.
6 The time taken by each of the sheets to fall 50 cm is almost the same so, although the sheets have different masses, each one must have accelerated at the same rate. This supports Galileo's idea.

AQA GCSE (9-1) Combined Science

Test yourself on prior knowledge

1 There are many, e.g. gravity, friction, a push or a pull to move a chair.
2 A single force that has the same effect as the combined effect of all the other forces acting on an object.

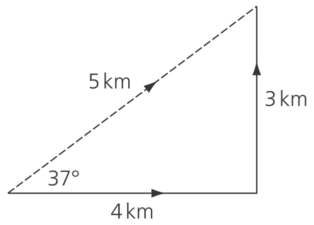
Test yourself

1 **a)** energy
  b) force

2 Velocity also needs to specify a direction.

3 **a)** You need to draw an arrow pointing northwards and mark it 4 km.

  b) Displacement is 0; distance travelled is 8 km.
  c)



   i) Displacement is 5 km, in a direction 37° north of east.
   ii) 7 km
  d) When you go for a walk you cover a distance over the ground: e.g. we walked 7 km today. Displacement states the distance and direction away from your starting point.

4 **a)** A contact force is exerted by one body on another, when the two bodies are in contact (touching each other).
  b) Friction.

5 **a)** A non-contact force is exerted over a distance, when two bodies are not in contact.
  b) Electrostatic.

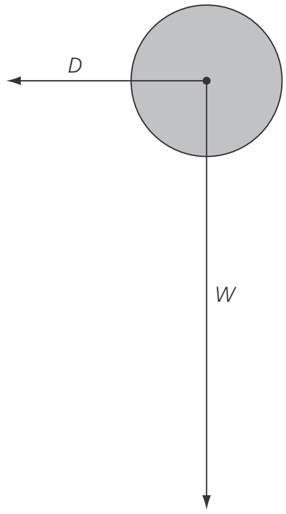
6 One magnet can support another one which is in contact with it. Since the lower one does not fall, the magnetic force must be bigger than the pull of gravity.

7 570 N

8 **a)** 3 N to the right
  b) 4 N upwards
  c) 1 N to the left
  d) 10 N to the right
  e) 0
  f) 0

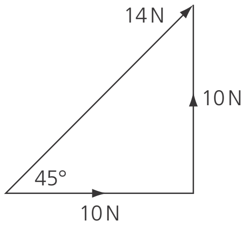
9 $W = mg$
  $= 120 \times 3.7$
  $= 444\ \text{N}$

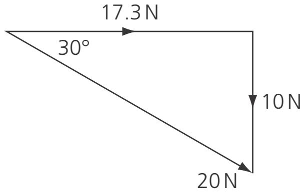
10

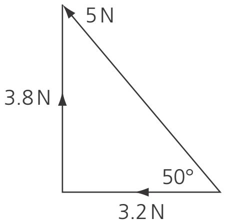


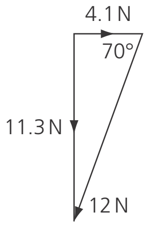
The ball is moving horizontally to the right.

11

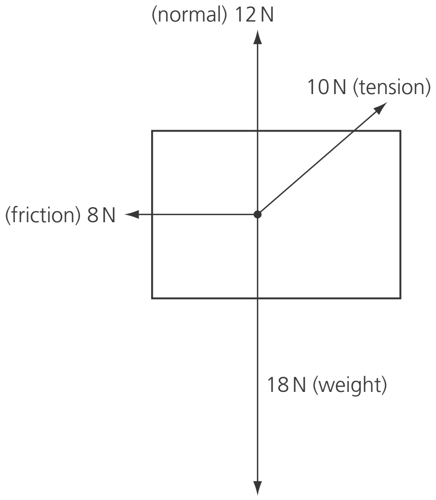




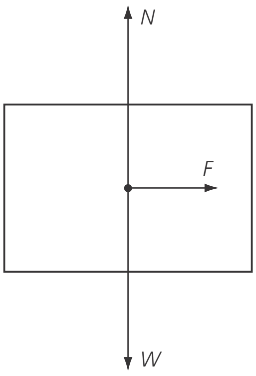




12 **a)** 8 N to the left
  b) 18 N – 6 N = 12 N
  c)



13 a)



b) There is an unbalanced force to the right that slows the box down.

14 In both b) and c) energy is being transferred, and something is being moved. In a) and d) there is no movement, so no work is being done.

15 a) 50 J

b) 600 J

16 Opening door 7.2 J
Wheeling suitcase 20 N
Lifting box 1.5 m
Pushing toy 0.35 J
Driving 15 MJ

17 a) $W = mg$
$= 150 \times 1.6$
$= 240\,\text{N}$

b) $\text{Work} = F \times d$
$= 240 \times 8$
$= 1920\,\text{J}$

18 B, C
B and C will 'spring' back to their unstretched position as soon as the compressive forces are removed, so elastic potential energy is stored.
A, D have no energy stored in them, as there is no force applied to stretch them elastically.

19 When something is stretched elastically, it can return to its original shape once the stretching force is removed.

20 a) 4.6 N

b) $F = kx$
$4.6 = k \times 0.136$
$$k = \frac{4.6}{0.136}$$
$= 33.8\,\text{N/m}$
or 34 N/m (to 2 sf)

21 $$k = \frac{F}{x}$$
$$= \frac{600}{0.03}$$
$= 2 \times 10^4\,\text{N/m}$

22 See the Required practical 18, page 217.

Show you can

Page 208

A scalar quantity only has size (magnitude). A vector quantity has magnitude and direction. So speed is a scalar – something travels at 15 m/s; velocity is a vector – something travels at 15 m/s due east.

You can find other examples on pages 207 and 208.

Page 212

If you cannot answer this, look at Figure 33.8 page 212. Figure b) shows 2 N and 2 N adding up to 4 N; Figure c) shows 2 N and 3 N in opposite directions adding up to a resultant force of 1 N to the left.

Page 213

Your mass remains the same everywhere in the universe, because it is determined by the amount of matter in your body. Your weight is a force – it is the pull of gravity on you. A larger planet exerts a larger pull.

$W = mg$ (page 210)

Page 215

Work done = force × distance moved in the direction of the force

Work is only done if an object moves in the direction of an applied force.

In Figure 5.15, Samantha does no work as she is not moving the weight. In the diagram of a car (Figure 33.14) on top of page 215, Martin does no work because he is pushing in the wrong direction.

Page 219

This idea can be demonstrated well using an empty drinks can. If you give the can a gentle squeeze, it bends in slightly; when you take your fingers away, the can returns to its original shape. This is elastic deformation. If you squeeze the can hard, the can deforms inelastically; when you remove your fingers, the deformation of the can is permanent.

Required practical 18

Page 217

1. Clamp the retort stand to the bench and wear eye protection.
2. Yes as the investigation produces a set of result that answers the question being asked. The method is valid if the data recorded shows a clear relationship.

3 By removing the masses one at a time and measuring the extension as the force decreases.

4 Fix a light pointer (a pin) at the bottom of the spring so that the pointer is across the ruler and moves with the spring.
or
Use a set square to line up the bottom of the spring with the scale on the ruler.

Chapter review questions

1 Scalar: speed, mass, temperature.
Vector: force, weight.

2 **a) i)** The force of gravity acts over a distance.
ii) Magnetic force; electrostatic force.
b) $W = mg$
$= 85 \times 10$
$= 850\,\text{N}$

3 work done $= F \times d$
$= 600 \times 300$
$= 180\,000\,\text{J}$ or $180\,\text{kJ}$

4 **a)** When something is deformed elastically, it returns to its original shape.
b) The stretched spring can be released and the stored energy can be used to accelerate a mass, so giving the mass kinetic energy.

5 $F = kx$
$10 = k \times 0.025$
$k = \frac{10}{0.025}$
$= 400\,\text{N/m}$

6 **a)** 50 N to the left
b) They have both a size and a direction.

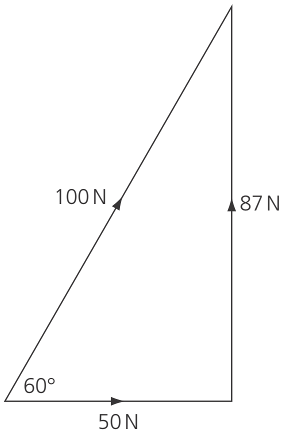
Practice questions

1 velocity *[1 mark]*

2 **a)** $W = mg$
$= 18 \times 9.8$ *[1 mark]*
$= 176\,\text{N}$ *[1 mark]*
b) Work $= F \times d$
$= 176 \times 2.1$ *[1 mark]*
$= 370\,\text{J}$ *[1 mark for answer, 1 for unit]*

3 **a)** Newton *[1 mark]*
b) Limit of proportionality *[1 mark]*
c) A and B *[1 mark]*
d) A force of 200 N must be applied *[1 mark]*
to stretch the spring 1 metre *[1 mark]*

4 **a) i)** $W = mg$
$= 24 \times 9.8$ *[1 mark]*
$= 235\,\text{N}$ *[1 mark]*
ii) The balance reads the resultant force:
balance reading = 235 N − 100 N *[1 mark]*
= 135 N *[1 mark]*
b) i) Only a component of the force now acts upwards. *[1 mark]*
ii) The vertical component of the force is:
235 N − 148 N = 87 N *[2 marks]*
iii)



Horizontal component = 50 N *[3 marks]*
iv) The mass remains stationary because there is no resultant force on it. *[1 mark]*
There must be a 50 N frictional force to the left. *[1 mark]*

Working scientifically: Hypotheses and predictions

Pages 222–23

1 People were able to see that the two objects did not hit the ground at exactly the same time.

2 Other factors not taken into account (in this case, air resistance) would affect the results.

3 To check for any anomalies and to calculate a mean.

4 0.325 s.

5 Yes they were repeatable as all of the values for time were similar.

6 The time taken by each of the sheets to fall 50 cm is almost the same so, although the sheets have different masses, each one must have accelerated at the same rate. This supports Galileo's idea.

5B Observing and recording motion

Overview

Specification points

4.5.6.1 Describing motion along a line, 4.5.6.2 Forces, accelerations and Newton's laws of motion, 4.5.6.3 Forces and braking and 4.5.7 Momentum

Textbook chapter references

AQA GCSE (9-1) Physics: Chapter 5B pages 146–79

AQA GCSE (9-1) Combined Science Trilogy 2: Chapter 33B pages 224–53

AQA GCSE (9-1) Combined Science Trilogy: Chapter 33B pages 580–609

Recommended number of lessons: 17

Chapter overview	
AQA required practical(s)	Physics – RP7 CS Trilogy – RP19
Contains higher-tier material	Yes
Contains physics-only material	Yes

Useful Teaching and Learning resources

- Learning outcomes
- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–3
- Key terms
- Key concept: Calculating the gradient and area of a graph
- Animation: Moments
- Personal tutor: Forces and their effects
- Personal tutor: Centre of mass
- Practical: Investigating the effect of varying the force on the acceleration of an object
- Teacher and technician notes: Investigating the effect of varying the force on the acceleration of an object
- Practical: Investigating the effect of varying the mass on the acceleration of an object
- Teacher and technician notes: Investigating the effect of varying the mass on the acceleration of an object
- Practical video: Investigating the effect of varying the force on the acceleration of an object
- Practical video: Investigating the effect of varying the mass on the acceleration of an object
- Homework tasks (a) and (b)
- Quick quizzes 1–4
- Answers for homework tasks
- Answers to all questions
- Half-term test 4.5: Forces and motion 1

Useful prior learning

- A force can cause an object to speed up, slow down or change the direction of a moving object.
- When the resultant force acting on an object is zero, the object remains stationary or it moves at a constant speed in a straight line.
- Speed = distance travelled/time

There are unsurprisingly many clear links between the previous topic and this one; the language used and methods of displaying forces are vital building blocks before attempting the ideas here. Unless the order has been changed around, it is unlikely that many students will have forgotten much of this detail.

Common misconceptions

- Some may struggle with the various units for speed, in particular, the contrast between mph and m/s. They may assume that the larger number always means a higher speed, no matter what unit follows.
- Many students will still think of *force* as some kind of conserved quantity, which is retained by moving objects. Unless dealing with non-contact forces, this is something that must be overcome. What they mean isn't 'force' so much as some vague model of *momentum*.
- Many will link force with 'movement', rather than the more specific model that a *resultant* force will cause a *change in motion*, i.e. acceleration.
- The everyday use of *acceleration* as 'getting faster' can cause difficulties; this is another case where students may need to be clear on there being two contrasting definitions.
- Not so much a misconception as a set of assumptions; students often struggle with the different aspects of *distance–time/displacement–time* and *velocity–time* graphs. They will treat any point on the horizontal axis as representing a stationary object and all flat lines as a constant speed, no matter what kind of graph.
- Students will often describe soft materials as 'absorbing the force of impact' in collisions; what they mean is that the increased time for the interaction reduces the average force acting over that time.

Preparation

The **T&L Prior knowledge catch-up student sheet** would be a good bridge between Chapter 5A (*33A*) and the coming content. A good approach can be to have students attempt the questions, then provide the review material and ask them to make changes or improvements in a different colour; this allows them to see for themselves the gap between recall and understanding.

The **T&L Topic overview** slides would probably work better as a mid-topic review, rather than as an introduction. The first three slides are an exception to this, as they mostly cover the materials included at KS3.

It is important that students recognise the close links between this topic and the one immediately prior. In fact, it is likely that some material from this topic will have been taught alongside previous planned content; ensure that students treat repeated material as a chance to review the ideas, or simply highlight the relevance to motion and move on.

Average versus instantaneous speeds: Lesson 1

Learning outcomes

1 List typical speeds.
2 Explain a walking journey in terms of speed at various points and as an average.
3 Practise use of equation.

Suggested lesson plan

Starter
Have students describe a typical walk to school to the person next to them, then swap. Ask them to explain how the typical walking speed can be described as 1.5 m/s even though they speed up and slow down.

Main
Students should record the 'typical speeds' from the specification and understand that these may be examined; walking at 1.5 m/s, running at 3.0 m/s, cycling at 6.0 m/s, as well as typical vehicles. The table on page 147 (*225; 581*) of the textbook is a useful reference, but students should be able to explain why these values represent a range.

Break down the meaning of the unit for speed (direction is not specified so speed, not velocity is correct) and how this reminds us of the equation: speed = distance/time (or $v = s/t$). Ensure that students note the symbols used carefully:

- s is used for both distance travelled and the vector equivalent, displacement (metres, m)
- v is used for speed and velocity (metres per second, m/s)
- t is used for time in seconds (seconds, s)

A summary table, like that suggested for the electricity topic, is probably worthwhile. Provide some worked examples and plenty of practice questions, including ones needing rearrangement of the equation.

A range of contexts, including sporting events as well as everyday situations, will be helpful. Make clear that many situations giving the total time for a journey conceal the variation of actual or instantaneous speed at different points, as the starter implied.

Plenary
Have students put typical moving objects on a scale, from walking at 1.5 m/s to a jet at 200 m/s. It may be useful to have two scales and include Olympic level athletes as non-typical examples for contrast.

Support
This can be confusing, not because of the ideas but the notation. Students seeing the letter *s* could think of it as representing speed (wrong symbol but understandable), time (because the unit is seconds) or distance (the correct symbol). If in doubt, annotate with words rather than letters.

Extension
Provide students with data in non-standard units for conversion. Challenge them to find rough conversion factors between UK (mph), European (kph) and scientific (m/s) units.

(mph values = 5/8 kph values, m/s values roughly half of mph values, m/s values roughly a quarter of kph values)

Homework
Provide more practice questions, either to solve from scratch or some with deliberate mistakes that need to be corrected.

Vectors and scalars: Lesson 2

Learning outcomes

1 Recap vectors and scalars.
2 Define pairs of quantities.
3 Give examples of changing velocity at constant speed (HT only).

Suggested lesson plan

Starter
T&L Lesson starter 1 could be used here and may show that the lesson can be abbreviated. Note the wording on the slides which states 'HT only'; you may choose to remove this until after all students have attempted the problem.

Main
If students show a good understanding of the distinction, you may feel able to combine this lesson with the following one.

Students should be able to define vector and scalar as well as give examples of each. Where possible, prompt them to give pairs of quantities, e.g. speed/velocity, distance/displacement.

Define *displacement* as distance from an origin in a particular direction. Discuss how a person walking forwards then back has increasing then decreasing displacement even though distance travelled is increasing the whole time. Ensure that students recognise that in most contexts we define a positive and negative direction, which could be left/right, forwards/back and so on.

The examples given on page 149 (*227; 583*) of the textbook should be discussed. In school the best approach is often to remind students of PE lessons, in particular the 400 m. A student who completes this in one minute and twenty seconds is travelling at a speed of 5m/s, but their velocity is changing as they go around in a circle; the direction is changing even if their speed is uniform.

Plenary
Provide values and have students identify whether the missing numbers are scalar or vector quantities, as well as the numerical value.

Support
Using expanded terms can help: ‘displacement from’ and ‘distance travelled’. As this is a review of work covered in Chapter 5A (*33A*), it may be worth returning to notes and examples given then.

Extension
Some students may recognise the apparent paradox that an object travelling in a circle at a constant speed is accelerating. All calculations of acceleration at this stage involve a change in the magnitude of the velocity, rather than direction, but we still use the word to describe what is happening (and infer that a force must be acting).

Homework
Ask students to review previous work from *I–V* graphs (Chapter 2 (*16*) Electricity), Hooke’s law (Chapter 5A (*33A*) Forces) and reaction rates (featured in the Student Book). They should identify the common skills being used (working out gradients) and summarise the process.

The story of a (distance–time) graph: Lesson 3

Learning outcomes

1 Describe motion in words.
2 Interpret a graph with numbers.
3 Plot a graph from provided data.

Suggested lesson plan

Starter
Show students a set of axes with several lines, each starting at the origin and finishing at 100 m. Ask them which runner is the winner, who starts off the fastest and so on.

Main
Warning: the exam board content followed the DfE specifications, and it is possible that the material was originally intended to cover displacement–time graphs. You may wish to teach both versions, as the A-level Physics course will otherwise involve a fair amount of catch-up. The term ‘*d–t* graph’ is used even though, technically, it should be *s* for distance or displacement.

Break an example distance-time graph into sections. Point out that because it is distance–time, not displacement–time, the lines can only ever go up as any/all direction change is ignored. Ensure that students record the possible features: a flat or horizontal line means stationary; the steeper the line the faster the motion. Check understanding of this and comparisons between lines, without any explicit maths.

Model calculating speed from the gradient of a graph, starting with a straight line and then extend this to curves where students will have to first draw a tangent to the line. Examples like those in Figure 5.57 (*33.30*) on page 149 (*227; 583*) of the textbook, and also available in the **T&L Diagram bank**, are helpful because they make clear that it is the change in distance and time that needs to be used, not the absolute values. Students might find it useful to write the equation in this form: $v = \Delta s/\Delta t$ with the delta (Δ) representing a change in the quantity.

As well as analysing and describing a provided graph, they need the opportunity to draw their own *d–t* graphs. Bullet pointing the rules is worthwhile, especially as they are not drawn quite the same as others; in particular you will need to emphasise that this is the one time in physics when ‘join-the-dots’ is not just acceptable, but required.

Plenary
Ask students to describe the speed for each section of a distance–time graph, and draw out what happens at the points in between; they will hopefully use the idea of acceleration and may even suggest a force is involved.

Support
Providing a simple table so students can link ‘graph feature’ with ‘real-world event’ will be a useful support while they are getting more familiar with the ideas.

Extension
Giving examples of the lines drawn on a displacement–time graph – with downwards lines representing movement back towards the origin – will lead them to more sophisticated thinking about what is happening.

Homework
Use Test yourself questions 1–8 on page 151 (*229; 585*) of the textbook.

Acceleration: Lesson 4

Learning outcomes

1. Compare everyday versus physical meaning of 'acceleration'.
2. Annotate worked examples.
3. Solve problems independently.

Suggested lesson plan

Starter
Give sample sentences using the term *acceleration* and have students compare the meaning. Most everyday uses are limited to 'getting faster'.

Main
Give contrasting examples of cars which increase their velocity from 0 to 30 m/s; one takes ten seconds, the other twenty. Students will accept that although both accelerate by the everyday meaning, there must be more to it from a physics viewpoint.

Define acceleration as the rate of change of velocity. It may help to link it to other rates students have encountered in science lessons, such as population change and product mass. You can then introduce the equation,
acceleration = velocity change/time taken ($a = \Delta v/t$).
Give the units of acceleration as metres per second squared, written m/s^2.

Use the two cars in the example to show the working needed:

$$a = \Delta v/t = (30 - 0)/10 = 30/10 = 3\,m/s^2$$

$$a = \Delta v/t = (30 - 0)/20 = 30/20 = 1.5\,m/s^2$$

To reinforce that the change in velocity is what matters, give a third example of a car which accelerates from 10 to 35 m/s in 20s.

Before calculating, ask the students how the acceleration will compare with the first two vehicles. Those who say this one is highest have used the final velocity, not the change; if they say it is the lowest they have used the initial velocity instead.

$$a = \Delta v/t = (35 - 10)/10 = 25/10 = 2.5\,m/s^2$$

You may wish to introduce the notation used for comparing changes in velocity here; *u* is used for initial velocity, *v* for the final velocity. Point out that if the final velocity is lower, the acceleration will be negative and this is often described as *deceleration*.

Provide a range of practice questions, ideally including positive and negative acceleration values.

Plenary
Ask students to identify features of a car which will mean it has a higher maximum acceleration; some will point out that the behaviour of the driver is also a factor!

Support
This is another case when the distinction between everyday language and the use of a word in science is important – and sometimes challenging. The mathematical difficulty can come from the fact that they are finding the rate of a change in rate; paradoxically asking them to explicitly compare the two velocities without including units allows them to concentrate on the numbers.

Extension
Ask students how they would find the acceleration of a tennis ball which took 0.1 second for a change of velocity from 20 m/s in one direction to 25 m/s in the opposite direction. In this case, $\Delta v = 20\,m/s - (-25)m/s = 45\,m/s$.

Homework
More practice questions are the best way to improve confidence with this. Include the term 'at rest' for a velocity of zero in some questions (defining it first if not covered in the lesson). Make sure some do *not* include a zero value to check that students are correctly finding the velocity change.

Velocity–time graphs: Lesson 5

Learning outcomes

1. Recap distance–time graphs.
2. Interpret *v*–*t* graph, including distance travelled = area under (HT only).
3. Use of $v^2 = u^2 + 2as$.

Suggested lesson plan

Starter
Show students a distance–time (or displacement–time if covered) graph and ask them to summarise the features to look for.

Main
Provide data and have students plot a velocity–time graph; ideally this should include several stages with acceleration and at least one with deceleration. Remind them that they should draw the simplified case, which means join-the-dots. Once complete, talk through the graph on the board (or using a visualiser if possible).

Be explicit about the features of a velocity–time graph, and have students annotate their own for reference. Flat (horizontal) lines mean a steady speed, i.e. constant velocity. Straight lines mean a constant acceleration, which can be positive (speeding up) or negative (slowing down). Students are likely to point out that the gradient gives the value of the acceleration. They may have found the area under a graph in maths lessons but are unlikely to realise that for a velocity–time graph this represents the distance travelled; they do not need the proof but do need to be able to estimate it. **T&L Key concept: Calculating the gradient and area of a graph** may be useful.

Model the use of letters to denote parts of a graph, and how this provides structure in a description of motion. Students should try describing a velocity–time graph (in words and mathematically) and sketch a graph from a detailed description. Individual whiteboards are a good way to do this in a low-stakes way.

Give the relationship $v^2 = u^2 + 2as$, reminding them of the variables, if necessary. Rearranging this may be intimidating for some; point out that if either the initial or final velocity is zero it becomes much easier. Provide practice questions after reviewing the first worked example on page 153 (*231; 587*) of the textbook.

Plenary
Despite the title, **T&L Lesson starter 3** could be used here to check understanding of the difference between displacement–time and velocity–time graphs.

Support
The area under the graph is only required for higher tier; the use of the equation is required for both but for students having difficulty it is important to balance spending a lot of time on it with consolidating other material. Ensure that students have a summary table contrasting what different features represent in distance–time and velocity–time graphs.

Extension
The use of the equation will provide scope for challenging questions; point out that (ignoring air resistance) falling objects experience a constant acceleration equal to *g* and ask them to calculate impact speed for objects falling from different heights.

Homework
Use Test yourself questions 9–15 on page 154 (*232; 588*) of the textbook.

Using data loggers/cameras/tickers: Lesson 6

Learning outcomes

1. Explain disadvantage of stopwatch for timing rapid motion.
2. Use electronic methods to show that acceleration down a ramp is constant.

Suggested lesson plan

Starter
Demonstrate a trolley rolling down a ramp. Hand out stopwatches and ask students to record the time for the trolley to move between two markers. Compare the readings and discuss the sources of error; will repeated readings be helpful?

Main
Which methods you demonstrate will depend, obviously, on the equipment available. Data loggers and software tend to have very specific instructions, so the important thing for students is the principle rather than the local details.

As well as the methods described on page 155 (*233; 589*) of the textbook, it should be possible to show camera footage with a modern device, perhaps even a mobile phone. Free software can compare individual frames; ensuring that a running stopwatch is in frame is an easy way to collect data matching position and time. You may wish to run a carousel with different methods, but it may help if your technician and/or TA can support the students with confidence.

An object rolling or sliding freely down a ramp because of gravity will have a constant acceleration; students may expect this to be equal to 9.8 m/s^2 until you point out that it's not falling. (Depending on your equipment it may be possible to collect data for an object falling vertically as a comparison.) Demonstrate that although the final velocity increases with a longer ramp, the acceleration is consistent.

If the object starts at rest, the equation $v^2 = u^2 + 2as$ can be rearranged to give $a = v^2/2s$.

Students should record (and be able to explain) the advantages of mechanical and electronic methods compared with humans with stopwatches. 'Human error' is not an acceptable answer in most cases; previous exam questions and mark schemes will be helpful here.

Plenary
Compare original readings with those obtained using the technology available.

Support
If possible, students should be encouraged to focus on the broad principles as details of the methods (software options for setting up data loggers, mechanical tinkering with the ticker-timer and so on) are likely to distract from what matters. Making explicit links between the problems identified in the starter with the solutions offered by technology should help.

Extension
Encourage students to explain how the values recorded by the technological methods are effectively parallel to those a person with a stopwatch can measure directly.

Homework
No matter what methods have been demonstrated in the lesson, questions 1–3 in the Light gates practical and questions 1–2 in the Ticker timer practical on page 155 (*233; 589*) of the textbook will be useful.

Parachutes: Lesson 7

Learning outcomes

1 Recap air resistance.
2 Collect fall time data for various falling parachutes.

Suggested lesson plan

Starter
The 'guinea and feather' demonstration, if available, is a very vivid example of the effect of air resistance on a falling object. More information on this can be found here: http://practicalphysics.org/guinea-and-feather.html. Explain to students that because we rarely experience motion without drag (or friction, for that matter) it is something we need to take time understanding.

Main
Assign different ideas for students to review; the particle model of gases, contact forces and atmospheric pressure (pages 78 (*330*), 119 (*209; 565*) and 139 (Physics only) respectively) are a good start. With time to discuss the ideas they should be able to summarise the common features (i.e. the link between observable forces and individual particle collisions).

Define *air resistance* as a force which opposes movement in a gas, due to these particle collisions. There can be no air resistance for an object stationary compared with the air. (If a wind is blowing you could argue that the air is not stationary, even if the object is.)

There are several methods students could use to investigate air resistance; the most straightforward use varying surface area for a falling object. The method on page 157 (*235; 591*) of the textbook will be popular, but, you may find that a variant using coffee filters is more reliable as the falling objects are more stable. If other factors are equal, the students will find larger parachutes fall more slowly. Ensure that repeated readings are compared and the *repeatability* is discussed. As an alternative, plasticene objects can be dropped in a glycerol tube. Data collected is equally unreliable as the objects rarely maintain their planned orientation as they fall. In either case, this will only need a few minutes but students will happily spend several lessons on it if allowed.

Draw and analyse the velocity-time graph for a skydiver (Figure 5.70 (*33.43*) on page 156 (*234; 590*) of the textbook or available from the **T&L Diagram bank**). At each stage, students should be able to draw and/or explain the upward (air resistance) and downward (weight) forces, and the effect of any resultant force.

Plenary
If the students are reliable, a fun extension is to take them outside with a bin-bag parachute. Ensure that they realise these are not for jumping out of windows, but for them to try walking/jogging/running; it shows that increasing speed leads to an increase in air resistance.

Support
Ensure that if mass is varied, students realise that it makes a big difference to stability as well as

any other effect on falling. Dropping two water balloons, one mostly filled with air and the other mostly with water, can be helpful; fall time is identical despite the different mass.

Extension
Some students will be able to give a much more sophisticated explanation of the skydiver's velocity-time graph. They could also be challenged to explain why, ignoring air resistance, all objects fall at the same rate. (Although the force of an object's weight varies, it is always proportional to the mass it acts on, so acceleration is always the same, *g*.)

Homework
Use Test yourself questions 16–19 on page 157 (*235; 591*) of the textbook.

No force, no acceleration: Lesson 8

Learning outcomes

1. Recap resultant forces.
2. Use examples of balanced forces and constant speed, e.g. skydiver.
3. Draw labelled free-body diagrams to explain everyday cases.

Suggested lesson plan

Starter
Return to the skydiver graph and have students match force arrow combinations to different stages of the velocity–time graph.

Main
Remind students that resultant forces cause, not motion, but a change in motion, i.e. acceleration. (They might now point out that we would describe this as *deceleration* if the resultant force is opposed to the direction of motion.) This means that a moving object will keep moving at the same velocity until a resultant force acts.

Discuss why 'balanced' is a better choice of words than 'cancel out' when there is no resultant force to cause acceleration. Ensure that students realise this means that the velocity will be constant, but it does not have to be zero.

Contrast an example of a moving vehicle with a thrown object; students should recognise that, although both experience resistive forces, the vehicle can travel at a constant velocity as long as there is a *driving force* or *thrust* to balance them. If that driving force is removed or reduced, the vehicle will decelerate until the forces are in balance once more. Draw free-body diagrams and explain that we usually neglect the forces which remain in balance, e.g. weight and reaction force for a rolling vehicle are consistent, so are often ignored.

Provide a list of moving objects and have students divide them into those which can travel at constant velocity (due to a something exerting a forward force) and those which must be decelerating. Students may claim that some objects are not decelerating simply because they are still moving quickly; ask them to 'zoom out' and consider what happens as the motion continues. For example, a foam dart fired from a Nerf™ gun will not slow down noticeably across a room, but we can infer the reduced velocity by comparing how the impact feels at different ranges. Choose your targets with care.

Plenary
Ask students to predict what will happen to the acceleration of an object when the resultant force increases. Most will suggest that the acceleration will be greater. If time, ask them to bullet point some ideas for investigating this quantitatively, with reference to the methods covered in the previous lessons.

Support
If students hesitate, ask them to return to the possible forces and how they compare. When forces are in balance, there is no reason for the motion to change. Unless an object is in a vacuum and separated from all surfaces, there will be some drag and/or friction, even if it does not intuitively seem enough to make a difference.

Extension
Some students will have a better appreciation of how small resultant forces will have a subtle effect which is not easily measured in the classroom. You may wish to give them examples where vertical forces are almost balanced because of lift: for example, that generated by spin on a cricket ball or a rotating Frisbee™.

Homework
Students could prepare for the investigation of force and acceleration if the method details can be shared; this will depend on equipment available in school. The *risk assessment* should be part of this.

Required practical 7(*19*): Testing the relationship between force and acceleration: Lesson 9

Learning outcomes

1. Identify key points, e.g. object must be falling when *a* is measured.
2. Collect data using electronic methods.
3. Plot a graph of *a* against *F*.

Suggested lesson plan

Starter

You could begin by reminding students of their predictions from the previous lesson, that a greater force will cause a greater acceleration. An alternative would be for them to annotate a diagram of the apparatus to be used.

Main

Collection of data is likely to be rapid; in most settings the time is spent putting the kit together. It is worth being very explicit about the method, highlighting key points and common mistakes. One way to check understanding with any demo like this is to do it twice; the first time you give the information, and then repeat it, picking on students to provide the commentary one sentence at a time.

The T**&L worksheet, Practical: Investigating the effect of varying the force on the acceleration of an object** could be used with caution. It includes both the ticker-timer and light gate methods, so it is is likely that only some of it will be relevant. It's also important to remember that when changing the force (by adding masses to the hanger below the pulley) the total mass must be kept constant. The easiest way for students to do this is to choose a constant number of masses, and move them from a secure container on the trolley to the hanger. The instructions on page 160 (*236; 592*) of the textbook make this clear.

(You may choose to have students collect all the data while the equipment is set up. If not, the following paragraph should be ignored until next lesson.)

Once students have gathered data on changing force, they can move on to the second variable: mass. Again, it is worth reading the **T&L worksheet Practical: Investigating the effect of varying the mass on the acceleration of an object (RP7, part 2)** carefully and perhaps editing it for clarity regarding the equipment you have available. In particular, most datalogging software will work out acceleration values for the students, rather than showing the graph of light intensity against time mentioned on the worksheet. Students should also be aware that the term 'indirectly proportional' on the sheet is often expressed as 'inversely proportional'.

The **T&L Teacher and technician notes** will be helpful if you choose to use the student sheets, in particular, the questions.

Plenary

Students should be able to confirm that (resultant) force is directly proportional to acceleration. Discrepancies can often be explained by accounting for resistive forces on the trolley. This might be a good opportunity to clarify that *directly proportional* is an exact relationship (if force doubles, so does acceleration) rather than the vaguer maths term *positive correlation*.

Support

Students may not see why the mass of the trolley must be changed. A useful response to this is to point out that the force is accelerating the whole system, including masses, hanger, string and trolley. If the *total* mass of this system changes, the control variable has not been kept constant.

Extension

Students may be able to estimate the mass (of the system, not the trolley alone) by using paired values of force and acceleration and the relationship $m = F/a$.

Homework

If incomplete, students could finish the graphs from these practicals and the relationships found. If students are confident with the use of the equation, they could also use Test yourself question 20–22 on page 161 (*239; 595*) of the textbook.

Using $a = F/m$ (debrief): Lesson 10

Learning outcomes

1. Compare calculated and measured value of mass – why are they different? (friction)
2. Extend practical to show how mass of object affects acceleration.
3. Define inertial mass. (HT only)

Suggested lesson plan

Starter

Show students a worked example using data from the practical, as described in 'Extension' for the previous lesson. Compare this with the mass as measured with a lab balance. Why are they different? (Their answers may feature *friction* or *drag*, or the inclusive term *resistive forces*.)

Main

(Students may have completed the second series of readings in the previous lesson, depending on your choices about lab requests. If so, ignore the following paragraph.)

Once students have gathered data on changing force, they can move on to the second variable: mass. Again, it is worth reading the **T&L worksheet Practical: Investigating the effect of varying the mass on the acceleration of an**

object carefully and perhaps editing it for clarity regarding the equipment you have available. In particular, most datalogging software will work out acceleration values for the students, rather than showing the graph of light intensity against time mentioned on the worksheet. Students should also be aware that the term 'indirectly proportional' on the sheet is often expressed as 'inversely proportional'.

If not checked, you may wish to go over the graphs drawn for the practicals. It is worth annotating to make clear that, ignoring resistive forces, the gradient in each case allows the value of the control variable to be calculated.

It is often more helpful to discuss the equation in the form: force/mass = acceleration ($F/m = a$). We do not often use the relationship to find the force acting. Instead, this rearrangement – and of course discussing with students that they need all three forms in different contexts – develops naturally from the intuitive understanding students have. It is clear that increasing the force will increase the acceleration. It is equally clear that increasing the mass, because this means dividing by a larger value, will decrease the acceleration.

After some worked examples, give students plenty of practice with both rearranging and solving problems.

The notes on page 161 (*239*; *595*) of the textbook explain *inertial mass* clearly. It is important that students recognise that inertia is not a result of weight; sliding or rolling objects still have inertia.

Plenary
Students have now covered all they need to attempt **T&L Quick quizzes 1** and **2**.

Support
By using the equation in the rearranged $F/m = a$ format, students will probably find it easier to explain their reasoning and then attempt numerical questions.

Extension
Students should be able to give good explanations about how a change in the experimental conditions e.g. a trolley with a greater mass or one that is more streamlined would affect the readings collected. They should point out that the relationships between the values will follow the same pattern.

Homework
Use Test yourself questions 23–27 on page 162 (*240*; *596*) of the textbook. (Questions 26 and 27 are HT only.)

Force pairs: Lesson 11

Learning outcomes

1 Discuss the weight of an object acting on a table.
2 Draw labelled diagrams showing force pairs.
3 List key points.

Suggested lesson plan

Starter
Ask students to label the forces acting on a stationary object such as a mug on a school table.

(Answer: weight and reaction force.)

Main
The important thing in this lesson is to build on the example from the starter. Often students will see the weight and reaction force as a pair, but this should be challenged explicitly.

Several of the examples from the textbook (Figures 5.81 and 5.82 (*33.54 and 33.55*) from pages 162–163 (*240–241*; *596–597*), and available from the **T&L Diagram bank**) can be replicated in the school lab, perhaps as a circus for students to explore. Use the starter example to make clear the opposite force to each of those originally labelled: the Earth is attracted to the mug with an equal and opposite gravitational force. The table exerts a reaction force on the mug, but the mug also exerts a force on the table.

Students should record the principles of Newton's third law pairs and apply them to the other examples; non-contact forces are easier for them to grasp in most cases. Compression and tension are also straightforward. Contact forces are probably the most challenging to consider. Taking time with different examples is better than trying to move ahead too quickly.

Encourage students to use contexts from their own experience; watersports are a particularly good one as it is intuitively clear that the swimmer exerts a force on the water (which moves back) and the water, in turn, exerts a force on the swimmer (who moves forward).

Plenary
Give the classic example of a kayaker pushing off from the side of a river. Ask students to draw the force arrows acting on both them and the side.

Support
Remind students who are struggling that just because the forces are of equal magnitude, that does not mean the effect is equal. A student exerts the same force on the Earth as vice versa, but the effect of that force (remind them of $a = F/m$) will be much greater for the student than the planet.

Extension
The more force pairs are involved, the harder this is to grasp – that is why we start by considering the forces on *one* object, which explicitly excludes force pairs. Ask them to return to earlier examples and annotate them with the paired opposite force and what it acts on.

Homework
Use Test yourself questions 28–29 on page 163 (*241; 597*) of the textbook.

Investigating friction: Lesson 12

Learning outcomes

1. Plan and carry out investigation of the effect of different surfaces on time taken to slide down a ramp.
2. Identify key ideas about friction.

Suggested lesson plan

Starter
Ask students to explain why the air track carts move so much more quickly when the air is blowing. (Demonstrating this will make the later lessons on momentum much easier.)

Main
If students are both confident and competent, then the ideas from this lesson could be combined with the next and the investigation missed out.

Students will often give a one-word answer when asked why moving objects slow down. It is worth asking them to 'zoom in' so that any misconceptions can be addressed. Microscope photographs of apparently smooth surfaces can help make the point about interlocking textures, and they can then start to distinguish between 'grip' friction (preventing objects from moving) and 'slip' friction (resistive force to movement which means work is done, causing heating).

Students can plan a lesson to investigate either form of friction; they could record time taken to slide down a ramp, or measure the force needed to drag an object up the ramp using a newtonmeter. Increasing the angle to find which surface provides most friction tends to be unreliable. Often more time is spent tying string onto the object than taking measurements.

Remind students of the concept of work done and establish that when work is done against friction, energy is transferred to the thermal stores of the surfaces. If a sliding object is stopped by friction, then the energy is transferred from the kinetic store.

Plenary
Ask students to predict the effect of adding different materials to a ramp before sliding. (You may wish to use a plastic-covered ramp to avoid upsetting the technicians.) Include examples which reduce (water, oil) and increase (treacle) the slip friction.

Support
The ideas here should be familiar from KS3; explaining that distinguishing between grip and slip friction is necessary because one word covers two concepts may help with long-held confusion.

Extension
Encourage students to compare the effect of a few drops of water (which can provide a seal on some surfaces, increasing friction) with a lot (which reduces friction so much it almost floats).

Homework
Students could review previous work, perhaps by attempting the first few Chapter review questions (starting on page 172 (*247; 603*) of the textbook, select from questions 1–7). Alternatively, because it should be familiar from KS3, they could prepare for the lessons on stopping distances by reading ahead.

The Highway Code: Lesson 13

Learning outcomes

1. Define stopping distance and plot increasing distance with speed.
2. List factors affecting the time taken to stop.
3. Divide these into factors affecting thinking and braking distance.

Suggested lesson plan

Starter
Describe a driver travelling at 30 mph outside school when they see a child step out in front. How far do they travel before they stop? What is the 'safe distance'?

Main
This is a lesson which is usually taught at KS3; depending on when it was covered, you may feel able to abbreviate the content.

Students should record the definitions for *stopping distance* and be able to explain how it is made up of *thinking distance* and *braking distance*. Making an explicit link between reaction time and thinking distance will help.

Students should record the 'typical reaction time' as 0.7 seconds; because we give speeds in mph it is not straightforward to use this value to show the distance travelled at various speeds, but a single worked example may be helpful to establish the principle. Emphasise that higher speeds mean greater stopping distances.

Given a list of factors, students could divide them into those that affect reaction times (and so thinking distance) and those that affect braking distance. They will recognise that those involving friction, as discussed in the previous lesson, affect the brakes themselves rather than the driver. Emphasise that specific answers are necessary; 'weather conditions' is often too vague as fog will affect visibility, and so affect thinking distance, while rain or snow will affect the brakes.

If possible, use a trundle-wheel or similar to show students the stopping distances for typical urban speeds; linking this to the speed limit of the roads near the school will show just how important this can be. This is a good point to revisit student predictions; you could have them stand at their chosen distance and see how many survive.

Plenary
T&L Quick quiz 3 could be used here or after the next lesson on reaction times, as preferred. Students could always attempt it twice and compare their answers.

Support
Reinforce that students are not expected to memorise all the values; being able to suggest a couple of factors affecting each component of the stopping distance may be easier by putting the ideas in the context of bicycles or skateboards.

Extension
Ask students to predict what the values would be for a modern car; the Highway Code values are best described as historical. You could also ask them to think about the effect of a vehicle being overloaded (braking distance will be greater).

Homework
Use Test yourself questions 30–36 starting from page 165 (*243; 599*) of the textbook.

Investigating reaction times: Lesson 14

Learning outcomes

1 Collect data using provided method.
2 Discuss various distractions.
3 Record typical reaction times.

Suggested lesson plan

Starter
Ask students to define thinking distance from the previous lesson and suggest factors which will increase it.

Main
You may have chosen to combine this lesson with the previous one; if so it is likely that the activities will have been fitted in between the definitions and the factors affecting braking distance. Note that distractions can take many forms and that part of learning to drive is about improving focus.

Students should try the 'reaction and distraction' practical on page 165 (*243; 599*) of the textbook, which is very straightforward (and versions of it were used for Biology ISAs in the previous specification). The explanation given in the textbook is brief, and students will quickly recognise that their time improves (i.e. is reduced) with practice. If there is time, you may wish to link the discussions to biology concepts such as sensory and motor neurones. (Figures 11.7 (a) and (b), available from the Biology section of the **T&L Diagram bank**, may help make the method clearer.)

The repeated results will vary widely and you may wish to use this as an opportunity to review means and the use of repeated readings. It is likely that past practicals using stopwatches will have led to a discussion of reaction time; revisiting those discussions will help them see why other methods are often preferable.

Students should record possible distractions and recognise that they are often very individual. They will often underestimate the distraction of mobile phones and it may be worth pointing out that even talking hands-free on the phone makes a driver four times more likely to have an accident.

Plenary
If it wasn't used in the previous lesson, **T&L Quick quiz 3** can be used here.

Support
Students may use the word 'better' to describe reaction times or say that someone 'reacts more quickly'; it is best to be more specific with 'shorter reaction time'.

Extension
Ask students if, when timing an event, reaction times could be said to be a systematic or random error. (Arguably, they are both; the time taken for the stopwatch to respond is a systematic delay but the person pressing the button may be fast or slow.)

Homework
Produce summaries of earlier parts of the topic, ideally, with some questions that can be used for peer work as a revision activity.

Defining momentum: Lesson 15 (Higher tier)

Learning outcomes

1. Discuss 'unstoppability'.
2. Record use of equation and the units used for momentum.

Suggested lesson plan

Starter
Ask students to define *inertial mass* (technically HT only, and mentioned briefly in Lesson 10) and remind students that objects with more mass are harder to start moving.

Main
Tell students that a scientist has discovered a property of moving objects which she has called 'unstoppability' or 'unstoppableness'. Some objects are harder to stop moving than others. Ask what measurements of the moving objects they would take and what effect on 'unstoppableness' they might have.

It will probably not need much prompting for students to recognise that faster, more massive objects are harder to stop moving. If they collide with other objects, they will have a bigger effect. This property is, of course, what we call *momentum* and is calculated by multiplying mass and velocity ($p = mv$). Students should record this equation and the unit, kilogram metres per second or kg m/s.

Two objects with the same mass and travelling at the same speed, but in opposite directions, clearly do not have the same momentum. Students should recognise that this shows momentum to be a *vector* quantity, like velocity.

Complete worked examples and show how a small but fast object may have the same momentum as a large but slow one. Be clear that stationary objects have zero momentum.

Have students complete practice questions to work out the momentum of moving objects. (You may wish to include some unit conversions, but, if so, sticking to using grams for mass is probably advisable.) Once they are confident with this, have them calculate the change of momentum when an object speeds up or slows down; for this, they just need to use the *change in velocity* (Δv) instead of an absolute value.

Plenary
Return to the idea of inertia; students may not be able to articulate it, but most will recognise the link between objects having inertial mass at all times and having momentum when in motion. Arguably, momentum is the basic property of motion in physics and is what students are intuitively referring to when they say that moving objects 'carry a force'.

Support
As this is HT material, most students working on it should not struggle with what is, after all, relatively basic maths. Remind them that the calculations simply describe the property they have understood their whole lives, just in a mathematical way. If they can link these ideas to everyday experience, the next few lessons will be much less intimidating.

Extension
Challenge students to explain why a change of momentum is often assumed to be due to a change in velocity. (They are unlikely to suggest many examples where an object changes in mass).

Homework
Students could revise the earlier work on force and acceleration; having the equations fresh in their minds will be helpful with the next steps looking at how forces change the momentum of an object.

Momentum and force: Lesson 16 (Higher tier and Physics only)

Learning outcomes

1. Define impulse to link force with momentum.
2. Give examples of safety features that increase interaction time.
3. Annotate model answer.

Suggested lesson plan

Starter
Describe an object in motion with increasing velocity and ask students to calculate the increase in momentum.

Main
Before attempting the derivation, it is often helpful to prefigure the link by asking students to consider what they know already. A change in velocity – even if the time taken for this change is not yet defined – can only happen when a resultant force acts. Logic then demands that both time and force are going to be relevant.

Students do not need the derivation but it is may help them to recognise that an increase in velocity implies acceleration. The sequence on page 167 of the textbook can be used, although there are obviously minor variations possible in the order. However students prefer to follow the reasoning, the end result is clearly the same. Force is equal to the rate of change of momentum, written as $F = \Delta mv/t$. (Although p is used for momentum, writing the change as Δmv means the links to other relationships are clearer.)

Give worked examples showing how to work out the force which acts because of a change in momentum (usually a change in velocity for obvious reasons). Make clear that for any object's change in motion, the force is inversely proportional to the time taken. This means that the only way to reduce the impact force is to increase the time taken. (The force will act for a longer period of time but as it is the peak force which breaks objects and bones this is not so serious.)

Students should be able to describe several methods used to increase the duration of the momentum change. Reinforce that they already understand the need for this; the maths simply explains why bending knees on landing/moving hands back when catching/rubber mats under slides work. Crumple zones and seat belts in cars are a good visual example. Like all such cases, ensure that students give explanations in terms of increasing time rather than 'absorbing force'. Adding commentary to a model answer – perhaps with reference to examiner's reports – is a very useful exercise.

Preparing numerical examples in advance is highly recommended; trying to generate values in front of a class is even more fraught here than the average question.

Plenary
Save one context that students should be able to explain in terms of the methods or materials used to increase interaction time and so reduce peak force.

Support
Giving a clear structure to answers is the best way to address difficulties; students will be familiar with examples from PE and other sports, and these are a good way to work through the ideas in words before using the values for mathematical answers.

Extension
Some students may be able to recognise the link to forces causing permanent deformation, and how this means that materials involved in a collision may need to be replaced afterwards, e.g. bike helmets.

Homework
Use Test yourself questions 37–40 on page 169 of the textbook.

Closed systems: Lesson 17 (Higher tier)

Learning outcomes

1 Recap other conservation principles.
2 Investigate colliding objects.
3 Predict momentum after a collision using these ideas.

Suggested lesson plan

Starter
Check understanding of car safety with **T&L Lesson Starter 2**. When it comes to the part of the second slide about 'absorbing energy', students should be asked to think about this, and see if they can 'spot a mistake' in it; ask students to improve it. (Absorbing energy is better than 'absorbing force'; but what it means is that energy from the kinetic store is used to do work on the crumple zones, etc. so is not transferred to the individual kinetic stores of the people in the car.)

Main
Because momentum cannot be measured directly, only calculated, it is only by interactions that useful patterns can be seen. Before students use the equipment, it is a good idea to reinforce that momentum before and after a collision (or explosion) is conserved *when no other forces act*. You may find linking this to other conservation principles is helpful, as students will, for example, have seen that conservation of mass in chemistry relies on all reactants and products being measured.

Which practicals you choose to conduct with students will depend on the equipment available; it may be worth operating a carousel with individual stations for calculations, trolley interactions and the classic air track. For all calculations, ensure that students use notation which makes clear which values are relevant before and after. Diagrams are often helpful, as is defining the situation as a collision or an explosion. It may be that students make qualitative observations (faster and slower) and you then demonstrate to the whole class using data loggers.

Provide several worked examples and give students plenty of time to practise; you may find the Test yourself questions listed as Homework below more useful in class.

Plenary
T&L Quick quiz 4 can now be used to test student understanding of momentum.

Support
The terms *elastic* and *inelastic* that were used in Chapter 5A (*33B*), Lesson 8 will crop up again here. Students can become confused when interactions are described as *elastic* or *inelastic*. It helps to explicitly link this to changes of shape. If a collision is elastic, momentum is conserved and any changes of shape are temporary (from an energy point of view, all energy transfers are between kinetic stores). If a collision is inelastic, momentum is not conserved, either because there are permanent changes of shape (something breaks) or because energy is transferred to a store other than kinetic (usually thermal).

Extension
Linking other equations, for example to find a new velocity as in the example on page 171 (Physics only), is at the extreme of what students could be expected to achieve here. Students who grasp these ideas should be encouraged to describe the observations based on a calculation, or suggest useful calculations based on observed examples. Linking qualitative and quantitative approaches in this way will consolidate both.

Homework
Use Test yourself questions 41–44 on page 171 of the textbook (Physics only) for the work on conserving momentum. Students can also complete **T&L Homework tasks (a) and (b),** the Chapter review questions from pages 172–174 (*247–249; 603–605*) (some may have been attempted already) and the Practice questions from pages 175–177 (*250–252*; *606–608*). It should be emphasised that exam questions will often need students to link material from Chapters 5A and 5B (*33A* and *33B*). The **T&L Half-term test 4.5: Forces and motion 1** concentrates on the motion content, but there is some overlap. It might be worth combining the three tests for all the Forces content.

Answers

AQA GCSE (9-1) Physics

Test yourself on prior knowledge

1 The forces balance; when an unbalanced force acts the parachute accelerates or decelerates.

2 **a)** Along the road in the direction of the acceleration.
b) Zero.
c) There is a resultant (or unbalanced) force acting backwards.

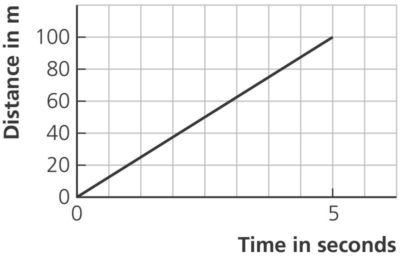
3 **a)** $$\text{speed} = \frac{10}{3.33} = 3\,\text{km/h}$$

b) $$\text{speed} = \frac{d}{t}$$
$$80 = \frac{560}{t}$$
$$t = \frac{560}{80} = 7\,\text{h}$$
so the total time taken is 8 hours, when two 30 minute breaks are included.

Test yourself

1 **a)** $$\text{speed} = \frac{d}{t} = \frac{300}{2} = 150\,\text{km/h}$$
b) The velocity is 15 km/h on a bearing of 150°

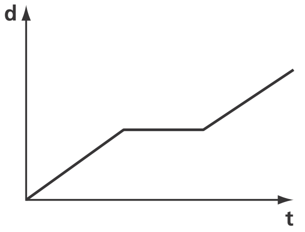
2



3 **a)** 40 s
b) The last part – the gradient is steeper after his stop at the traffic lights.

4 Row 1: Average speed = 10.4 m/s
Row2: Time = 19.4 s
Row 3: Time = 44.9 s
Row 4: Event distance = 1491 m (1500 m)
Row 5: Average speed = 5.7 m/s
Row 6: Distance = 42.196 km (Marathon)

5

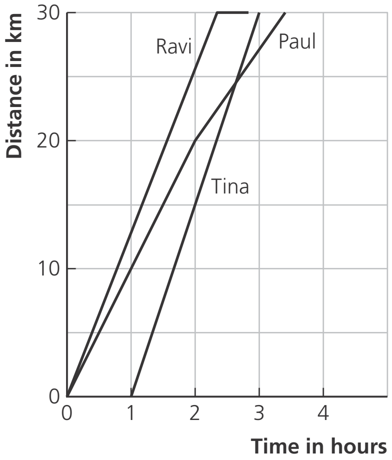


6 10 m/s

7 Your speed could be constant, but you are changing direction.

8 **a)** Ravi – the gradient is constant, and the gradient is equal to the speed.
b) $$\text{average speed} = \frac{30}{3.4} = 8.8\,\text{km/h}$$
c) He slowed down.

d)



e) Tina has run about 24 km.

9 m/s^2

10 a) $\text{acceleration} = \dfrac{\text{change of velocity}}{\text{time}}$

b) i) $a = \dfrac{v - u}{t}$

$= \dfrac{30}{2}$

$= 15\ m/s^2$

ii) $a = \dfrac{v - u}{t}$

$= \dfrac{1}{0.001}$

$= 1000\ m/s^2$

11 a) $a = \dfrac{v - u}{t}$

$= \dfrac{12}{4}$

$= 3\ m/s^2$

b) $\text{area} = \left(\dfrac{1}{2} \times 12 \times 8\right) + (12 \times 8) + \left(\dfrac{1}{2} \times 12 \times 4\right)$

$= 48 + 96 + 24$

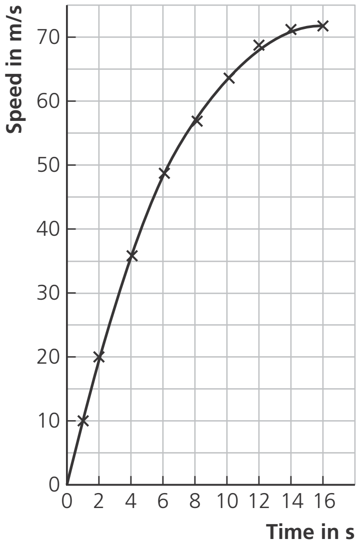
$= 168\ m$

c) $\text{average speed} = \dfrac{d}{t}$

$= \dfrac{168}{20}$

$= 8.4\ m/s$

12 a)



b) i) 0

ii) $10\ m/s^2$

c) About 800 m

13 Cheetah 30 m/s

Train $0.1\ m/s^2$

Aircraft 60 m/s

Car crash 0.2 s

14 a) $\text{speed} = \dfrac{400}{6}$

$= 67\ m/s$

b) $a = \dfrac{150}{6}$

$= 25\ m/s^2$

15 $v^2 - u^2 = 2as$

$60^2 - 0 = 2 \times 2.5 \times s$

$s = \dfrac{3600}{5}$

$= 720\ m$

16 Her weight is the same size as the air resistance.

17 An object falls at its terminal velocity when the drag acting on it upwards is the same size as the weight acting downwards.

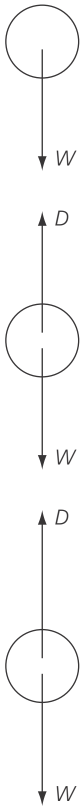
18 Air resistance on the sheet of paper is large so the paper falls slowly. When screwed into a ball, the air resistance is much less, so the paper ball accelerates.

19 a) 5 m/s

b) As she falls faster, the air resistance (or drag) on her increases. So the resultant force on her decreases and therefore so does the acceleration ($F = ma$).

c) 1000 m

d)



20 $F = ma$ and $a = \frac{F}{m}$, so the lower the mass the greater the acceleration for the force provided.

21 The shot is massive, so the force we can apply only accelerates it slowly. Since the mass of the tennis ball is low, we can accelerate it faster.

22 a)
$$\begin{aligned} F &= ma \\ &= 8 \times 2.5 \\ &= 20\,\text{N} \end{aligned}$$

b)
$$\begin{aligned} a &= \frac{F}{m} \\ &= \frac{15}{3} \\ &= 5\,\text{m/s}^2 \end{aligned}$$

c)
$$\begin{aligned} m &= \frac{F}{a} \\ &= \frac{10}{4} \\ &= 2.5\,\text{kg} \end{aligned}$$

23 $a = \frac{F}{m}$

Because the mass is so large, the deceleration is very slow.

24 a)
$$\begin{aligned} a &= \frac{v - u}{t} \\ &= \frac{84 - 32}{1.3} \\ &= 40\,\text{m/s}^2 \end{aligned}$$

b)
$$\begin{aligned} F &= ma \\ &= 730 \times 40 \\ &= 29\,200\,\text{N} \end{aligned}$$

25 a)
$$\begin{aligned} g &= \frac{W}{m} \\ &= \frac{48\,000}{30\,000} \\ &= 1.6\,\text{N/kg} \end{aligned}$$

b) i) 63 000 N – 48 000 N = 15 000 N

ii)
$$\begin{aligned} a &= \frac{F}{m} \\ &= \frac{15\,000}{30\,000} \\ &= 0.5\,\text{m/s}^2 \end{aligned}$$

26 The passenger needs a force for him to accelerate with the train. A force can be exerted if he is holding on to a seat or a rail. Without a force, he stays where he is (inertia); then he loses his balance.

27 The car has brakes whereas the parcel does not have brakes. So the parcel keeps moving forwards until it is slowed by contact with the floor in front of it.

28 a) You exert a force on the wall; it exerts an equal and opposite force back again.

b) You push the water backwards; the water pushes you forwards.

c) There is very little friction between you and the ice so the ice does not provide a forwards force to enable you to move forwards.

29 850 N

30 a) i) Thinking distance is the distance a car travels while the driver moves his foot from the accelerator to the brake, as the driver reacts to a hazard ahead.

ii) Braking distance is the distance a car travels while braking.

b) stopping distance = thinking distance + braking distance

31 An icy road.

32 a) Missing words: force, speed.

b) Mobile phone.

33 The surface can be made rougher.

34 a) When the tread is less, the braking distance is increased.

b) The data shows that the braking distance is always greater on the concrete surface.

35 a) The braking distance increases from 23 m to 36 m when you travel at 40 mph instead of 30 mph.

b) At 20 mph the stopping distance is only 12 m – half the stopping distance at 30 mph. This means a pedestrian is much safer in a crowded town centre.

c)
$$\begin{aligned} \text{Speed } 48\,\text{km/h} &= \frac{48\,000\,\text{m}}{3600\,\text{s}} \\ &= 13.3\,\text{m/s} \\ \text{distance} &= \text{speed} \times \text{time} \\ 9 &= 13.3 \times t \\ t &= \frac{9}{13.3} \\ &= 0.68\,\text{s} \end{aligned}$$

36 $v^2 - u^2 = 2as$

a)
$$\begin{aligned} 20\,\text{mph} &= 32\,\text{km/h} \\ &= \frac{32000\,\text{m}}{3600\,\text{s}} \\ &= 8.9\,\text{m/s} \\ v^2 &= 2as \\ 8.9^2 &= 2a \times 6 \\ &= \frac{8.9^2}{12} \\ &= 6.6\,\text{m/s}^2 \end{aligned}$$

b)
$$\begin{aligned} 60\,\text{mph} &= 96\,\text{km/h} \\ &= \frac{96000}{3600} \\ &= 26.7\text{m/s} \\ v^2 &= 2as \\ 26.7^2 &= 2a \times 55 \\ &= \frac{26.7^2}{110} \\ &= 6.5\,\text{m/s}^2 \end{aligned}$$

Note that, in each case, you must work in m/s and use the braking distance, because the deceleration takes place over the braking distance.

37 a) $p = mv$

$= 1200 \times 30$

$= 36\,000\text{ kg m/s}$

b) $p = 60 \times 8$

$= 480\text{ kg m/s}$

c) $p = 0.4 \times 7$

$= 2.8\text{ kg m/s}$

d) $p = 500 \times 16$

$= 8000\text{ kg m/s}$

38 $F = \dfrac{\text{change of momentum}}{\text{time}}$

a) Bending your knees increases the time in which you stop so the force on you exerted by the ground is less.

b) When a car crumples, the time taken to stop is increased so the force exerted by the seat belts on the passengers is decreased.

c) When you land on your heel, the gas is compressed. This increases the time in which your foot is slowed down by the force from the ground. So the force on your heel is reduced.

39 A car (or coach) has a rigid structure (cell) to protect passengers in a crash. Outside this cell, there are crumple zones that increase the passengers' stopping time in a crash. By being strapped in, the passengers can use all this stopping time, so reducing the force acting to slow them down: $F = \dfrac{mv}{t}$.

If they are not strapped in, the passengers keep moving until they are stopped in a very short time, which means they experience a dangerously large force.

40 You stop in a short time, so the force exerted on you is large: $F = \dfrac{mv}{t}$.

41 Momentum before the collision = momentum after the collision

a) $3 \times 3 + 2 \times 2 = 5v$

$13 = 5v$

$v = 2.6\text{ m/s}$

b) $2 \times 2 + 0 = 4v$

$v = 1.0\text{ m/s}$

c) $2 \times 4 - 1 \times 2 = 3v$

$6 = 3v$

$v = 2\text{ m/s}$

Note: We define + to the right and – to the left.

42 a) Estate car (left): $p = 70 \times 10$

$= 700\text{ kg m/s}$ (to the right)

Saloon car (right): $p = 70 \times 30$

$= 2100\text{ kg m/s}$ (to the left)

b) Estate car: $F = \dfrac{mv}{t}$

$= \dfrac{700}{0.25}$

$= 2800\text{ N}$

Saloon car: $= \dfrac{mv}{t}$

$= \dfrac{2100}{0.25}$

$= 8400\text{ N}$

c) The second one: the force is three times as large.

43 a) $p = 18\,000 \times 10$

$= 180\,000\text{ kg m/s}$

b) $180\,000\text{ kg m/s}$

c) Momentum is conserved

$180\,000 = 20\,000v$

$v = 9\text{ m/s}$

d) Lorry driver: momentum change $= 80(10 - 9)$

$= 80\text{ kg m/s}$

Car driver: momentum change $= 80(9 - 0)$

$= 720\text{ kg m/s}$

e) $F = \dfrac{mv}{t}$

Lorry driver: $= \dfrac{80}{0.2}$

$= 400\text{ N}$

$= 3600\text{ N}$

The car driver is more likely to be injured as he experiences nine times the force.

f) The crumple zone increases the time taken to stop, so the force is less.

g) i) The seat belt keeps the passengers strapped to the car, so that they use all the available time to stop. If you are not strapped in, you stop in a shorter time, so experience a larger force.

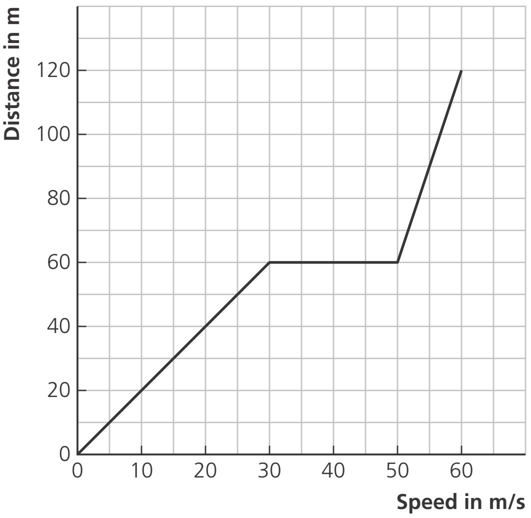
ii) The stretch in the seat belt allows an even longer time to stop, as you keep going a little further before stopping.

44 a) Before the bullet is fired, the combined momentum of the gun and bullet is zero. After the bullet is fired, the combined momentum is still zero – and the gun must have momentum (negative) in the opposite direction.

b) Before you start swimming, the combined momentum of you and the water is zero. The combined momentum is still zero after you start swimming, but you have positive momentum and the water has negative momentum.

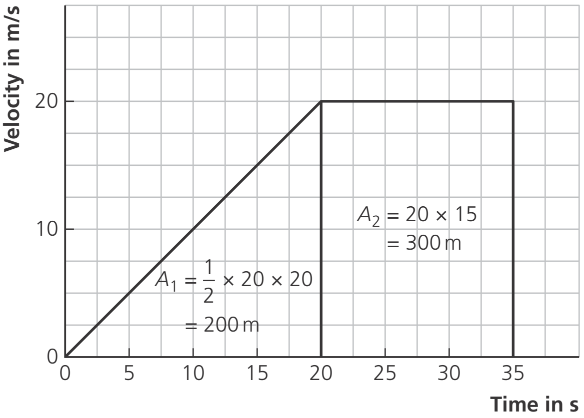
Show you can

Page 151



The gradient of the graph is the man's speed.

Page 154



The acceleration over the first 20 seconds is calculated as follows:

$$\begin{aligned} a &= \frac{v - u}{t} \\ &= \frac{20}{20} \\ &= 1\,\text{m/s}^2 \end{aligned}$$

The distance travelled is the 'area' under the graph, which is the area of the triangle, A_1, and the rectangle, A_2.

$$A_1 = \frac{1}{2} \times 20 \times 20 = 200\,\text{m}$$

$$A_2 = 20 \times 15 = 300\,\text{m}$$

So the total distance travelled = 500 m

Page 161

You can answer this question by summarising 'Required practical 7' on Page 160, or by explaining how you did this practical yourself.

Page 162

Newton's first law of motion states that an object remains at rest or continues to move in a straight line at a constant speed, unless acted on by an unbalanced force (page 158). There are many demonstrations to choose. For example:

- You can hang a 1 N weight (about 100 g mass) on a spring balance. Then explain that the weight stays at rest because the weight down (1 N) is balanced by the (1 N) pull of the spring upwards.
- Drop a cupcake holder, which falls at a constant speed. Weight is balanced by air resistance.
- Set up an air track. Show that a slider, when pushed, moves at a constant speed – there is no force pushing the slider and air resistance is very small.

Page 163

Newton's third law states that to every force there is an equal and opposite force.

- If you lean against a wall, you exert a force on it. You do not fall over because the wall pushes you back. Or you can lean against another person – you each feel the force.
- Set up two small polystyrene balls or two balloons. Then charge them with the same sign of charge. They exert a force on each other, as shown in Figure 5.82 (d).
- Connect two dynamic trolleys, of the same mass, with springs. Mark the centre between them. Pull the trolleys apart, then release them. They return to the central place, showing that each exerts the same force on the other. [Newton's law also works, of course, for trolleys with different masses, but they move different distances.]

Page 166

Information to answer this question is included under thinking distance on page 164 and braking distance on page 165.

Page 171

The total momentum of the two trolleys is conserved.

So momentum before the collision = momentum after the collision.

But, you need to remember that, because the trolleys move in different directions, one has a negative velocity.

Before the collision, momentum = $m_1v_1 - m_2v_2$

After the collision, momentum = $(m_1 + m_2)v$

v can be determined by solving the equation:

$$m_1v_1 - m_2v_2 = (m_1 + m_2)v$$

Practicals

Page 155 – Light gates

1 The light gates need to be adjusted to measure the time taken for the diameter of the ball to pass through. So the light gates need to be at the height of the centre of the ball.

2 a) 0.52 m/s

b) 0.69 m/s

3 $a = \frac{v_B - v_A}{t}$

$= \frac{0.69 - 0.52}{0.23}$

$= 0.74\text{ m/s}^2$

Page 155 – Ticker timer

1 50 cm/s or 0.5 m/s

2 0.1 m/s

Page 157 – Terminal velocity and surface area

1 Consider a safe place to drop the parachute – do not stand on a stool balanced high on a bench. Drop a small mass.

2 You need to measure the distance the parachute falls and the time taken to fall. Repeat the measurements.

3 You can gauge the speed as it falls. Better than that, you can repeat the experiment dropping from a different height and check that the speed is the same.

4 Area of the parachute.

5 Distance the parachute falls; weight of the figure.

Required Practical

Page 160

1 The time used to calculate the velocity is taken while the trolley is still accelerating.

2 The values for acceleration would have been slightly greater as the effect of friction would have been reduced.

3 Both mass and accelerating force are variables that affect the acceleration of an object. If both are changed at the same time it is not possible to tell what effect each has on the acceleration.

Chapter review questions

1 a) A to B – the gradient is steeper.

b) i) 100 s

ii) 1500 m

iii) 1000 m

c) speed $= \frac{d}{t}$

$= \frac{1500}{100}$

$= 15\text{ m/s}$

2 a) speed $= \frac{d}{t}$

$45 = \frac{d}{30}$

$d = 30 \times 45$

$= 1350\text{ m}$

b) speed $= \frac{d}{t}$

$45 = \frac{9000}{t}$

$t = \frac{9000}{45}$

$= 200\text{ s}$

3 a) i) 23 m/s – 5 m/s = 18 m/s

ii) $a = \frac{v - u}{t}$

$= \frac{18}{6}$

$= 3\text{ m/s}^2$

b) i) $a = \frac{v - u}{t}$

$= \frac{23 - 15}{20}$

$= 0.4\text{ m/s}^2$

ii) $F = ma$

$= 1500 \times 0.4$

$= 600\text{ N}$

4 When the arms are spread out and loose clothing worn, the skydiver provides a larger surface area. Then the drag is bigger for a particular speed. The skydiver reaches terminal velocity when drag balances the weight. This balance occurs at a lower speed when the area is larger.

5 a) $a = \frac{v - u}{t}$

$= \frac{80}{40}$ [choose any point on the graph]

$= 2\text{ m/s}^2$

b) Distance covered equals the area under the graph.

$d = \frac{1}{2} \times 90 \times 45$

$= 2025\text{ m}$

6 a) work $= F \times d$

$= 400 \times 80$

$= 32\,000\text{ J}$

b) work $= F \times d$

$= 470 \times 3.6$

$= 1692\text{ J}$

$= 1700\text{ J}$ to 2 sf

c) No work is done because the object has not been moved.

d) work $= F \times d$

$= 60\,000 \times 3000$

$= 1.8 \times 10^8\text{ J}$ or 180 MJ

7 a) 700 N – drag and weight balance.

b) There is now a resultant force of 800 N upwards, so she slows down until the drag again balances the weight.

8 a) The head decelerates because the bag exerts a force to slow it down.

b) By allowing air to escape, the bag allows the head to keep moving and then to slow down over a longer time.

Since $F = \dfrac{\text{change of momentum}}{\text{time}}$

the force acting on the head is reduced.

c) Injury is reduced in two ways:

- The force on the head is less due to the longer time to stop the head.
- The bag prevents collisions with sharp objects, which would exert a large pressure on part of the head.

9 momentum $= m \times v$

$195\,000 = m \times 6.5$

$m = 30\,000\text{ kg}$

10 a) $a = \dfrac{v - u}{t}$

$= \dfrac{20}{8}$

$= 2.5\text{ m/s}^2$

b) $F = ma$

$= 800 \times 2.5$

$= 2000\text{ N}$

c) i) acceleration $= \dfrac{\text{force}}{\text{mass}}$

Now the mass is greater, but the force remains the same. So acceleration is reduced.

ii) acceleration $= \dfrac{2000}{1250}$

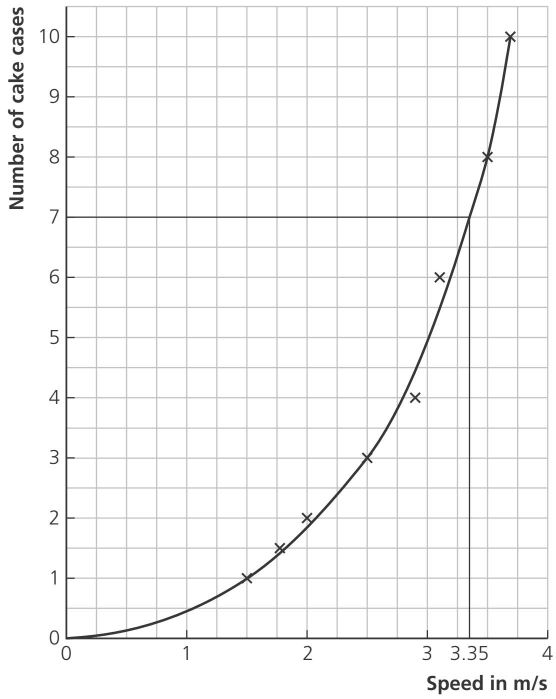
$= 1.6\text{ m/s}^2$

11 a) To reduce the effect of random timing errors.

b)

Number of cake cases	Time of fall in s	Average time in s	Average speed in m/s
1	2.7, 2.6, 2.6	2.63	1.5
1.5	2.2, 2.3, 2.2	2.23	1.8
2	2.0, 2.0, 1.9	1.97	2.0
3	1.5, 1.6, 1.7	1.60	2.5
4	1.4, 1.4, 1.4	1.40	2.9
6	1.3, 1.3, 1.2	1.27	3.1
8	1.1, 1.1, 1.2	1.13	3.5
10	1.1, 1.1, 1.0	1.07	3.7

c)



d) This is difficult to do as the exact line of the curve is hard to predict. But the answer lies in the range 3.3 s to 3.4 s.

e) The graph suggests that the terminal velocity of the cake cases increases with their weight.

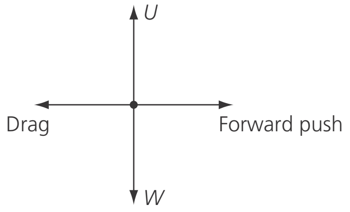
f) Since they fall at a constant speed, the drag is the same size as the weight. So we can conclude that drag increases with speed.

12 There are many factors; here are some you might have found.

- Cars have many safety features: seat belts, crumple zones, air bags, side impact bars.
- We have an MOT test to ensure: safe tyres, safe brakes and many other safety features.
- There are speed limits.
- We have hazard warning signs.
- There are crash barriers at corners.
- We have hazard lights and fog lights on our cars.
- There are barriers in towns to protect pedestrians.
- There are pedestrian crossings.
- We have traffic lights.
- There are well-designed junctions and roundabouts.
- There are laws about driving with drink and drugs in our bodies.
- There are laws about dangerous and careless driving, with penalties.
- We have driving tests – first introduced in 1935.
- We educate people to drive carefully and raise awareness of how dangerous driving can be.
- Lorry drivers and bus drivers have to take a more advanced test.
- Motor cyclists have to wear crash helmets.
- We have cycle and bus lanes.

Practice questions

1 a)



The four forces are:

- Forwards push from the water (shown)
- Drag backwards *[1 mark]*
- Weight (*W*) *[1 mark]*
- Upthrust (*U*) *[1 mark]*

b) i) $\text{speed} = \frac{\text{distance}}{\text{time}}$

$= \frac{1500}{1200}$

$= 1.25\,\text{m/s}$ *[1 mark]*

ii) $\text{speed} = \frac{\text{distance}}{\text{time}}$

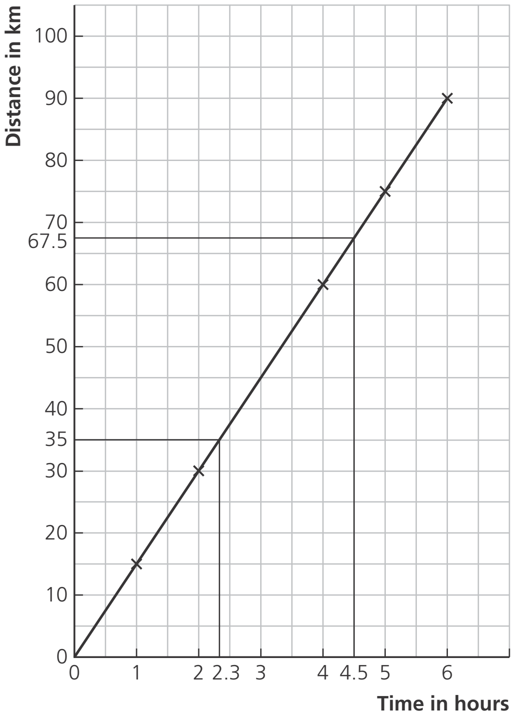
$= \frac{51\,500}{6800}$ *[1 mark]*

$= 7.6\,\text{m/s}$ *[1 mark]*

Add all the distances, then divide by the sum of the times.

c) The gradient of the graph is the speed. *[1 mark]*
For 700 s he went at a constant speed. *[1 mark]*
Then he slowed down, then went quickly again, *[1 mark]*
before slowing down towards the end. *[1 mark]*
One mark for each point (up to 3).

2 a)



Label axes *[1 mark]*
Accurate points *[1 mark]*
Straight line *[1 mark]*

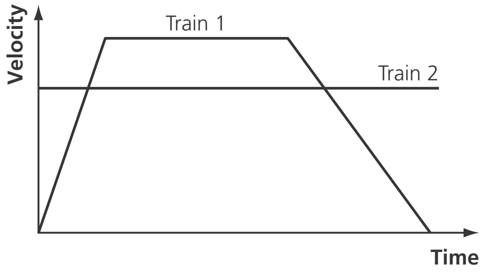
b) i) 67.5 km *[1 mark]*
ii) 2.3 hours *[1 mark]*

c) $\text{speed} = \frac{\text{distance}}{\text{time}}$ *[1 mark]*

3 a) The train is slowing down. *[1 mark]*
OR The gradient of the graph is negative. *[1 mark]*

b) The distance travelled is the area under the graph.
[Areas A + B + C] *[1 mark]*

c)



1 mark for a constant velocity.
1 mark for a velocity between 0.5 and 0.9 of the original velocity.

4 a) i) *F* is bigger because the lorry accelerates in the direction of the resultant force. (*F*–*B*). *[1 mark]*

ii) resultant force = mass × acceleration *[1 mark]*

iii) $F = ma$

$15\,000 = 12\,500 \times a$ *[1 mark]*

$a = \frac{15\,000}{12\,500}$

$= 1.2\,\text{m/s}^2$ *[1 mark] [1 mark]*

You must include the correct unit.

b) i) The driver is distracted. *[1 mark]*
Or The driver is under the influence of alcohol or drugs.
Or
Some drivers are just slower than others.

ii) An icy road. *[1 mark]*
Or Worn tyres.
Or The road surface – water or mud.
Or Worn brakes.
Or The speed of the car.
Or Having a heavy load in the car.

c) The driver's reaction time does not depend on the speed. *[1 mark]*
The councillor should have said the braking distance is less at 20 mph. *[1 mark]*

5 a) stopping distance = thinking distance + braking distance *[1 mark]*

b) The graph shows:
the thinking distance is proportional to the speed *[1 mark]*
the braking distance increases rapidly at high speeds. *[1 mark]*

c) About 30 m. *[1 mark]*

d) For the minimum stopping distance, you need to take the smallest distance found in the test. *[1 mark]*

e) i) There is no change to the thinking distance. *[1 mark]*
This just depends on the reaction time of the driver. *[1 mark]*

ii) The braking distance increases, because there is a smaller braking force on the car, so its deceleration is less. *[1 mark]* *[1 mark]*

6 a) $$\text{acceleration} = \frac{\text{change of speed}}{\text{time}}$$
$$= \frac{78}{60}$$ *[1 mark]*
$= 1.3\ \text{m/s}^2$ *[1 mark]* *[1 mark]*

You must have the correct unit.

So the resultant force on the plane decreases. *[1 mark]*

Acceleration decreases, because resultant force = mass × acceleration. *[1 mark]*

c) Distance = area under the graph *[1 mark]*
The area is about 30 squares. *[1 mark]*
1 square = 10 m/s × 10 s = 100 m
So distance = 30 × 100
= 3000 m *[1 mark]*

7 a) $$\text{acceleration} = \frac{\text{change of speed}}{\text{time}}$$
$$= \frac{4}{8}$$ *[1 mark]*
$= 0.5\ \text{m/s}^2$ *[1 mark]* *[1 mark]*

You must have the correct unit.

b) resultant force = mass × acceleration
$60 - R = 80 \times 0.5$ *[1 mark]*
$60 - R = 40$ *[1 mark]*
$R = 20\ \text{N}$ *[1 mark]*

8 a) momentum = mv
$= 68 \times 6$
$= 408\ \text{kg m/s}$ *[1 mark]* *[1 mark]*

You must have the correct unit.

b) $$\text{force} = \frac{\text{change of momentum}}{\text{time}}$$
$$= \frac{840}{0.14}$$ *[1 mark]*
$= 6000\ \text{N}$ *[1 mark]*

c) i) Worn tyres.
Worn brakes.
Carrying a heavy load.
Speed.
Road conditions (e.g. ice, water, mud).
One mark for each correct answer, up to 2.

ii) $$\text{force} = \frac{\text{change of momentum}}{\text{time}}$$

A crumple zone increases the time a car takes to stop. *[1 mark]*
Therefore the force acting on the car and its passenger is lower. *[1 mark]*

9 a) i) The length of the card. *[1 mark]*

ii) If the track is tilted, gravity will slow down or speed up the glider. Friction would slow the glider down. *[1 mark]*

b) i) A vector has direction as well as size (or magnitude). *[1 mark]*

ii) momentum = $m \times v$
$= 2.4 \times 0.6$ *[1 mark]*
$= 1.44\ \text{kg m/s}$ *[1 mark]*

You must have the correct unit.

iii) Zero.

c) i) Momentum is conserved, so combined momentum = 1.44 kg m/s *[1 mark]*

ii) momentum = mass × velocity
$1.44 = m \times 0.4$ *[1 mark]*
$$= \frac{1.44}{0.4}$$
$= 3.6\ \text{kg}$ *[1 mark]*
mass of Q = 3.6 − mass of P
= 3.6 − 2.4
$m = 1.2\ \text{kg}$ *[1 mark]*

iii) change of momentum = $mv_1 - mv_2$
$= 2.4 \times 0.6 - 2.4 \times 0.4$ *[1 mark]*
$= 1.44 - 0.96$
$= 0.48\ \text{kg m/s}$ *[1 mark]*

iv) $$\text{force} = \frac{\text{change of momentum}}{\text{time}}$$ *[1 mark]*
$$= \frac{0.48}{0.05}$$ *[1 mark]*
$= 9.6\ \text{N}$ *[1 mark]*

v) 9.6 N *[1 mark]*

Working scientifically

1 The 500 g mass has inertia; it is also an example of Newton's third law of motion.

2 **a)** Type of material used for the crumple zone.
b) How far the 500 g mass moved forwards before stopping.

3 The area and thickness of the materials used to model the crumple zone.

4 From 8.0 cm (no material) to 14.8 cm (rubber carpet underlay); the range could also be expressed as 6.8 (14.8 – 8.0).

5 Bar chart drawn, *x*-axis labelled type of material, *y*-axis labelled distance 500 g mass moves before stopping.

6 Type of material is a categoric variable.

7 Yes, they are consistent; for each force, the order of the materials for increasing stopping distance is the same.

8 To check repeatability, identify and remove any anomalies and to give values for which a mean (average) could be calculated.

9 Both sets of data do support Tracy's analysis. For both forces, the rubber carpet underlay gave the longest stopping distance which means that the trolley took the greatest time to stop. Since the trolley always hit the barrier at the same speed, it always had the same momentum. The longer the time taken to stop, the smaller the rate of change of momentum of the trolley and the smaller the force.

You could also consider this in terms of deceleration. The longer the time taken to stop, the smaller the deceleration. Since acceleration and force are directly proportional, the smaller the deceleration, the smaller the force

AQA GCSE (9-1) Combined Science

Test yourself on prior knowledge

1 The forces balance; when an unbalanced force acts the parachute accelerates or decelerates.

2 **a)** Along the road in the direction of the acceleration.

b) Zero.

c) There is a resultant (or unbalanced) force acting backwards.

3 **a)** $\text{speed} = \dfrac{10}{3.33} = 3\,\text{km/h}$

b) $\text{speed} = \dfrac{d}{t}$

$$80 = \frac{560}{t}$$

$$t = \frac{560}{80} = 7\,\text{h}$$

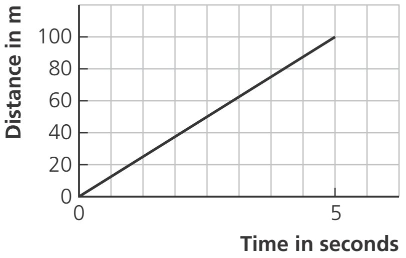
so the total time taken is 8 hours, when two 30 minute breaks are included.

Test yourself

1 **a)** $\text{speed} = \dfrac{d}{t} = \dfrac{300}{2} = 150\,\text{km/h}$

b) The velocity is 15 km/h on a bearing of 150°

2

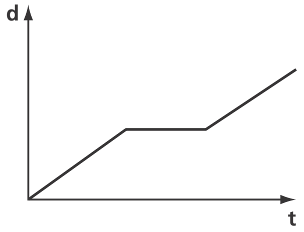


3 **a)** 40 s

b) The last part – the gradient is steeper after his stop at the traffic lights.

4 Row 1: Average speed = 10.4 m/s
Row 2: Time = 19.4 s
Row 3: Time = 44.9 s
Row 4: Distance = 1491 m (1500 m)
Row 5: Average speed = 5.7 m/s
Row 6: Distance = 42.196 km (Marathon)

5



6 10 m/s

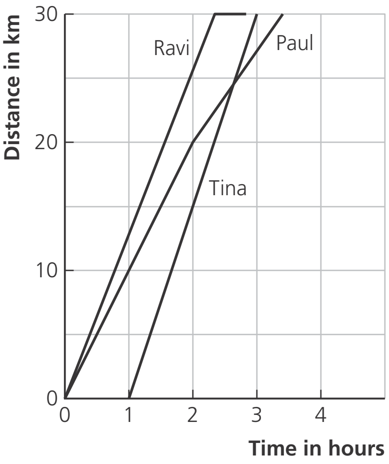
7 Your speed could be constant, but you are changing direction.

8 **a)** Ravi – the gradient is constant, and the gradient is equal to the speed.

b) $\text{average speed} = \dfrac{30}{3.4} = 8.8\,\text{km/h}$

c) He slowed down.

d)



e) Tina has run about 24 km.

9 m/s^2

10 **a)** $\text{acceleration} = \dfrac{\text{change of velocity}}{\text{time}}$

b) **i)** $a = \dfrac{v-u}{t} = \dfrac{30}{2} = 15\,\text{m/s}^2$

ii) $a = \dfrac{v-u}{t} = \dfrac{1}{0.001} = 1000\,\text{m/s}^2$

11 a) $a = \frac{v - u}{t}$

$= \frac{-12}{4}$

$= -3\,\text{m/s}^2$

b) $\text{area} = \left(\frac{1}{2} \times 12 \times 8\right) + (12 \times 8) + \left(\frac{1}{2} \times 12 \times 4\right)$

$= 48 + 96 + 24$

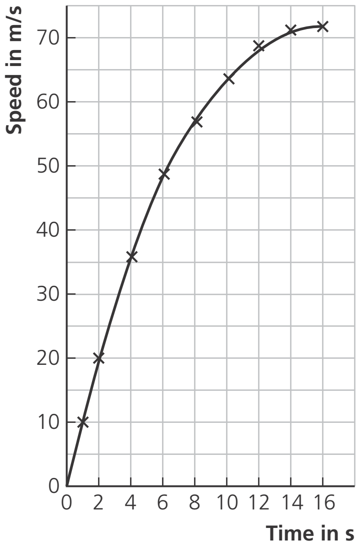
$= 168\,\text{m}$

c) average speed $= \frac{d}{t}$

$= \frac{168}{20}$

$= 8.4\,\text{m/s}$

12 a)



b) i) 0

ii) $10\,\text{m/s}^2$

c) About 800 m

13 Cheetah 30 m/s
Train $0\,\text{m/s}^2$
Aircraft 60 m/s
Car crash 0.2 s

14 a) speed $= \frac{400}{6}$

$= 67\,\text{m/s}$

b) $a = \frac{150}{6}$

$= 25\,\text{m/s}^2$

15 $v^2 - u^2 = 2as$

$60^2 - 0 = 2 \times 2.5 \times s$

$s = \frac{3600}{5}$

$= 720\,\text{m}$

16 Her weight is the same size as the air resistance.

17 An object falls at its terminal velocity when the drag acting on it upwards is the same size as the weight acting downwards.

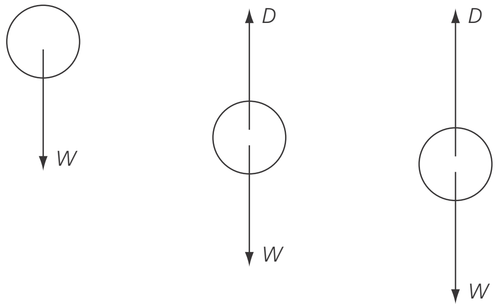
18 Air resistance on the sheet of paper is large so the paper falls slowly. When screwed into a ball, the air resistance is much less, so the paper ball accelerates.

19 a) 5 m/s

b) As she falls faster, the air resistance (or drag) on her increases. So the resultant force on her decreases and therefore so does the acceleration ($F = ma$).

c) 1000 m

d)



20 $F = ma$ and $a = \frac{F}{m}$, so the lower the mass the greater the acceleration for the force provided.

21 The shot is massive, so the force we can apply only accelerates it slowly. Since the mass of the tennis ball is low, we can accelerate it faster.

22 a) $F = ma$

$= 8 \times 2.5$

$= 20\,\text{N}$

b) $a = \frac{F}{m}$

$= \frac{15}{3}$

$= 5\,\text{m/s}^2$

c) $m = \frac{F}{a}$

$= \frac{10}{4}$

$= 2.5\,\text{kg}$

23 $a = \frac{F}{m}$

Because the mass is so large, the deceleration is very slow.

24 a) $a = \frac{v - u}{t}$

$= \frac{32 - 84}{1.3}$

$= -40\,\text{m/s}^2$

b) $F = ma$

$= 730 \times 40$

$= 29\,200\,\text{N}$

25 a) $g = \frac{W}{m}$

$= \frac{48\,000}{30\,000}$

$= 1.6\,\text{N/kg}$

b) i) 63 000 N – 48 000 N = 15 000 N

ii) $a = \frac{F}{m}$

$= \frac{15000}{30000}$

$= 0.5\ \text{m/s}^2$

26 The passenger needs a force for him to accelerate with the train. A force can be exerted if he is holding on to a seat or a rail. Without a force, he stays where he is (inertia); then he loses his balance.

27 The car has brakes whereas the parcel does not have brakes. So the parcel keeps moving forwards until it is slowed by contact with the floor in front of it.

28 a) You exert a force on the wall; it exerts an equal and opposite force back again.

b) You push the water backwards; the water pushes you forwards.

c) There is very little friction between you and the ice so the ice does not provide a forwards force to enable you to move forwards.

29 850 N

30 a) i) Thinking distance is the distance a car travels while the driver moves his foot from the accelerator to the brake, as the driver reacts to a hazard ahead.

ii) Braking distance is the distance a car travels while braking.

iii) Stopping distance is the distance a car travels from when the driver starts to react until it comes to a complete stop when braking.

b) stopping distance = thinking distance + braking distance

31 An icy road.

32 a) Missing words: force; speed.

b) mobile phone.

33 The surface can be made rougher.

34 a) When the tread is less, the braking distance is increased.

b) The data shows that the braking distance is always greater on the concrete surface.

35 a) The braking distance increases from 23 m to 36 m when you travel at 40 mph instead of 30 mph.

b) At 20 mph the stopping distance is only 12 m – half the stopping distance at 30 mph. This means a pedestrian is much safer in a crowded town centre.

c) Speed 48 km/h $= \frac{48000\ \text{m}}{3600\ \text{s}}$

$= 13.3\ \text{m/s}$

distance = speed × time

$9 = 13.3 \times t$

$t = \frac{9}{13.3}$

$= 0.68\ \text{s}$

36 $v^2 - u^2 = 2as$

a) 20 mph = 32 km/h

$= \frac{32000\ \text{m}}{3600\ \text{s}}$

$= 8.9\ \text{m/s}$

$v^2 = 2as$

$8.9^2 = 2a \times 6$

$= \frac{8.9^2}{12}$

$= 6.6\ \text{m/s}^2$

b) 60 mph = 96 km/h

$= \frac{96000}{3600}$

$= 26.7\ \text{m/s}$

$v^2 = 2as$

$26.7^2 = 2a \times 55$

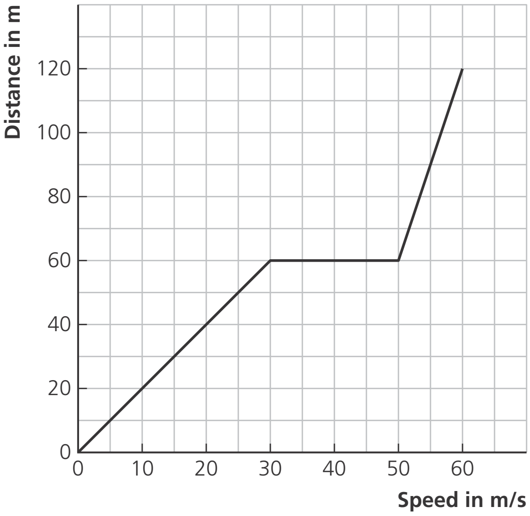
$= \frac{26.7^2}{110}$

$= 6.5\ \text{m/s}^2$

Note that, in each case, you must work in m/s and use the braking distance, because the deceleration takes place over the braking distance.

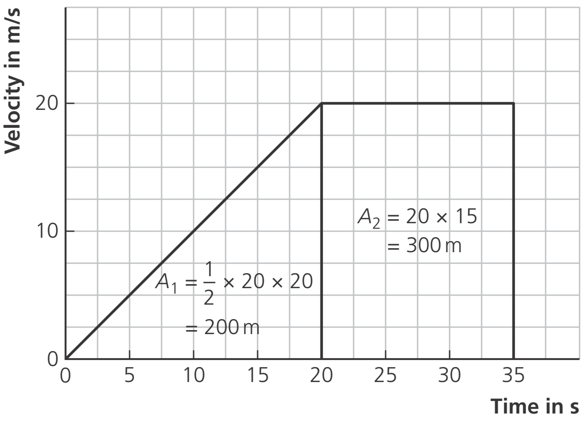
Show you can

Page 229



The gradient of the graph is the man's speed.

Page 232



The acceleration over the first 20 seconds is calculated as follows:

$$a = \frac{v - u}{t}$$
$$= \frac{20}{20}$$
$$= 1\,\text{m/s}^2$$

The distance travelled is the 'area' under the graph, which is the area of the triangle, A_1, and the rectangle, A_2.

$$A_1 = \frac{1}{2} \times 20 \times 20 = 200\,\text{m}$$
$$A_2 = 20 \times 15 = 300\,\text{m}$$

So the total distance travelled = 500 m

Page 239

You can answer this question by summarising 'Required practical 19' pages 238–39, or by explaining how you did this practical yourself.

Page 240

Newton's first law of motion states that an object remains at rest or continues to move in a straight line at a constant speed, unless acted on by an unbalanced force (page 236). There are many demonstrations to choose. For example:

You can hang a 1 N weight (about 100 g mass) on a spring balance. Then explain that the weight stays at rest because the weight down (1 N) is balanced by the (1 N) pull of the spring upwards.

Drop a cupcake holder, which falls at a constant speed. Weight is balanced by air resistance.

Set up an air track. Show that a slider, when pushed, moves at a constant speed – there is no force pushing the slider and air resistance is very small.

Page 241

Newton's third law states that to every force there is an equal and opposite force.

If you lean against a wall, you exert a force on it. You do not fall over because the wall pushes you back. Or you can lean against another person – you each feel the force.

Set up two small polystyrene balls or two balloons. Then charge them with the same sign of charge. They exert a force on each other, as shown in Figure 33.55.

Connect two dynamic trolleys, of the same mass, with springs. Mark the centre between them. Pull the trolleys apart, then release them. They return to the central place, showing that each exerts the same force on the other. [Newton's law also works, of course, for trolleys with different masses, but they move different distances.]

Page 244

Information to answer this question is included under 'thinking distance' on page 242 and 'braking distance' on page 243.

Practical

Page 233 – Light gates

2 The light gates need to be adjusted to measure the time taken for the diameter of the ball to pass through. So the light gates need to be at the height of the centre of the ball.
   a) 0.52 m/s
   b) 0.69 m/s

3 $a = \frac{v_B - v_A}{t}$

$$= \frac{0.69 - 0.52}{0.23}$$
$$= 0.74\ \text{m/s}^2$$

Page 233– Ticker timer

1 50 cm/s or 0.5 m/s
2 0.1 m/s

Page 235– Terminal velocity and surface area

3 Consider a safe place to drop the parachute – do not stand on a stool balanced high on a bench. Drop a small mass.
4 You need to measure the distance the parachute falls and the time taken to fall. Repeat the measurements.
5 You can gauge the speed as it falls. Better than that, you can repeat the experiment dropping from a different height and check that the speed is the same.
6 Area of the parachute.
7 Distance the parachute falls; weight of the figure.

Required Practical 19

Page 238

1 The time used to calculate the velocity is taken while the trolley is still accelerating.

2 The values for acceleration would have been slightly greater as the effect of friction would have been reduced.

3 Both mass and accelerating force are variables that affect the acceleration of an object. If both are changed at the same time it is not possible to tell what effect each has on the acceleration.

Chapter review questions

1 a) A to B – the gradient is steeper.

b) i) 100 s

ii) 1500 m

iii) 1000 m

c) $$\text{speed} = \frac{d}{t} = \frac{1500}{100} = 15\text{ m/s}$$

2 a) $$\text{speed} = \frac{d}{t}$$
$$45 = \frac{d}{30}$$
$$d = 30 \times 45 = 1350\text{ m}$$

b) $$\text{speed} = \frac{d}{t}$$
$$45 = \frac{9000}{t}$$
$$t = \frac{9000}{45} = 200\text{ s}$$

3 a) i) 23 m/s – 5 m/s = 18 m/s

ii) $$a = \frac{v-u}{t} = \frac{18}{6} = 3\text{ m/s}^2$$

b) i) $$a = \frac{v-u}{t} = \frac{15-23}{20} = -0.4\text{ m/s}^2$$

ii) $$F = ma = 1500 \times 0.4 = 600\text{ N}$$

4 When the arms are spread out and loose clothing worn, the skydiver provides a larger surface area. Then the drag is bigger for a particular speed. The skydiver reaches terminal velocity when drag balances the weight. This balance occurs at a lower speed when the area is larger.

5 a) $$a = \frac{v-u}{t}$$
$$= \frac{80}{40} \quad \text{[choose any point on the graph]}$$
$$= 2\text{ m/s}^2$$

b) Distance covered equals the area under the graph.

$$d = \frac{1}{2} \times 90 \times 45$$

a) work = $F \times d$
$= 400 \times 80$
$= 32\,000$ J

b) work = $F \times d$
$= 470 \times 3.6$
$= 1692$ J
$= 1700$ J (to 2 sf)

c) No work is done because the object has not been moved.

d) work = $F \times d$
$= 60\,000 \times 3000$
$= 1.8 \times 10^8$ J or 180 MJ

7 a) 700 N – drag and weight balance.

b) There is now a resultant force of 800 N upwards, so she slows down until the drag again balances the weight.

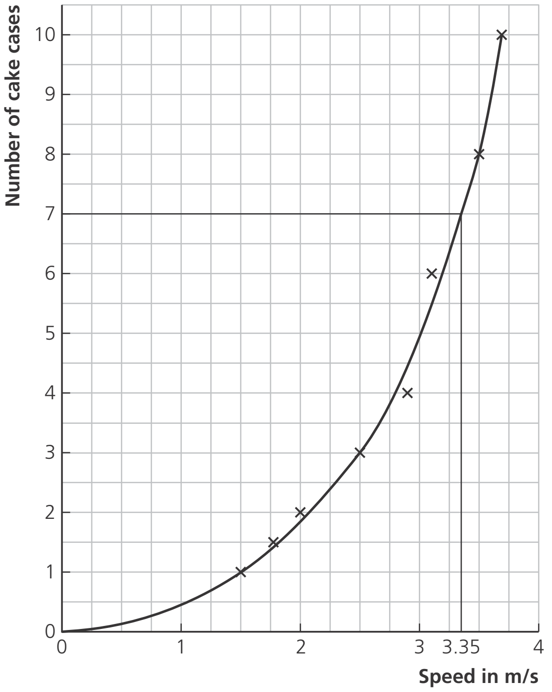
8 momentum = $m \times v$
$195\,000 = m \times 6.5$
$m = 30\,000$ kg

9 a) To reduce the effect of random timing errors.

b)

Number of cake cases	Time of fall in s	Average time in s	Average speed in m/s
1	2.7, 2.6, 2.6	2.63	1.5
1.5	2.2, 2.3, 2.2	2.23	1.8
2	2.0, 2.0, 1.9	1.97	2.0
3	1.5, 1.6, 1.7	1.60	2.5
4	1.4, 1.4, 1.4	1.40	2.9
6	1.3, 1.3, 1.2	1.27	3.1
8	1.1, 1.1, 1.2	1.13	3.5
10	1.1, 1.1, 1.0	1.07	3.7

c)



d) This is difficult to do as the exact line of the curve is hard to predict.
But the answer lies in the range 3.3 s to 3.4 s.

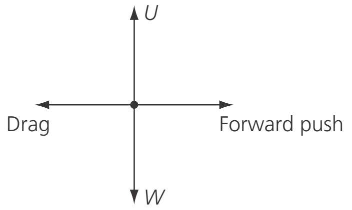
e) The graph suggests that the terminal velocity of the cake cases increases with their weight.

f) Since they fall at a constant speed, the drag is the same size as the weight. So we can conclude that drag increases with speed.

10 There are many factors; here are some you might have found.
Cars have many safety features: seat belts, crumple zones, air bags, side impact bars.
We have an MOT test to ensure: safe tyres, safe brakes and many other safety features.
There are speed limits.
We have hazard warning signs.
There are crash barriers at corners.
We have hazard lights and fog lights on our cars.
There are barriers in towns to protect pedestrians.
There are pedestrian crossings.
We have traffic lights.
There are well-designed junctions and roundabouts.
There are laws about driving with drink and drugs in our bodies.
There are laws about dangerous and careless driving, with penalties.
We have driving tests – first introduced in 1935.
We educate people to drive carefully and raise awareness of how dangerous driving can be.
Lorry drivers and bus drivers have to take a more advanced test.
Motor cyclists have to wear crash helmets.
We have cycle and bus lanes.

Practice questions

1 a)



The four forces are:
Forwards push from the water (shown)
Drag backwards *[1 mark]*
Weight (*W*) *[1 mark]*
Upthrust (*U*) *[1 mark]*

b) i) $\text{speed} = \frac{\text{distance}}{\text{time}}$

$= \frac{1500}{1200}$

$= 1.25\ \text{m/s}$ *[1 mark]*

ii) $\text{speed} = \frac{\text{distance}}{\text{time}}$

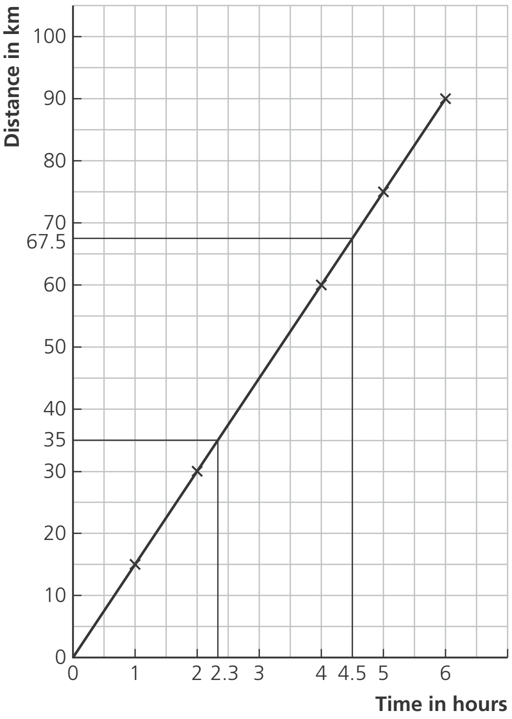
$= \frac{51\,500}{6800}$ *[1 mark]*

$= 7.6\ \text{m/s}$ *[1 mark]*

Add all the distances, then divide by the sum of the times.

c) The gradient of the graph is the speed.
For 700 s he went at a constant speed.
Then he slowed down, then went quickly again, before slowing down towards the end.
[1 mark for each point (up to 3)].

2 a)



Label axes
Accurate points
Straight line

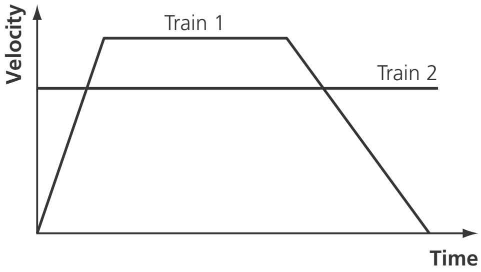
b) i) 67.5 km
ii) 2.3 hours

c) $\text{speed} = \dfrac{\text{distance}}{\text{time}}$

3 a) The train is slowing down.
OR The gradient of the graph is negative.

b) The distance travelled is the area under the graph.
[Areas A + B + C]

c)



[1 mark for a constant velocity. 1 mark for a velocity between 0.5 and 0.9 of the original velocity.]

4 a) i) F is bigger because the lorry accelerates in the direction of the resultant force. (F–B). *[1 mark]*

ii) resultant force = mass × acceleration *[1 mark]*

iii) $F = ma$
$15\,000 = 12\,500 \times a$ *[1 mark]*

$$a = \frac{15\,000}{12\,500}$$
$$= 1.2\ \text{m/s}^2$$

[1 mark for answer, 1 for unit]
You must include the correct unit.

b) i) The driver is distracted. *[1 mark]*
Or The driver is under the influence of alcohol or drugs.
Or Some drivers are just slower than others.

ii) An icy road. *[1 mark]*
Or Worn tyres.
Or The road surface – water or mud.
Or Worn brakes.
Or The speed of the car.
Or Having a heavy load in the car.

c) The driver's reaction time does not depend on the speed. *[1 mark]*
The councillor should have said the braking distance is less at 20 mph. *[1 mark]*

5 a) stopping distance = thinking distance + braking distance *[1 mark]*

b) The graph shows:
the thinking distance is proportional to the speed *[1 mark]*
the braking distance increases rapidly at high speeds. *[1 mark]*

c) About 30 m. *[1 mark]*

d) For the minimum stopping distance, you need to take the smallest distance found in the test. *[1 mark]*

e) i) There is no change to the thinking distance. *[1 mark]*
This just depends on the reaction time of the driver. *[1 mark]*

ii) The braking distance increases, because there is a smaller braking force on the car, so its deceleration is less. *[2 marks]*

6 a) $\text{acceleration} = \dfrac{\text{change of speed}}{\text{time}}$

$= \dfrac{78}{60}$ *[1 mark]*

$= 1.3\ \text{m/s}^2$
[1 mark for answer, 1 for unit]

b) As the speed increases, the drag (air resistance) on the plane increases. *[1 mark]*
So the resultant force on the plane decreases. *[1 mark]*
Acceleration decreases, because:
resultant force = mass × acceleration. *[1 mark]*

c) Distance = area under the graph *[1 mark]*
The area is about 30 squares. *[1 mark]*
1 square = 10 m/s × 10 s = 100 m
So distance = 30 × 100
= 3000 m [1 mark]

7 a) $\text{acceleration} = \dfrac{\text{change of speed}}{\text{time}}$

$= \dfrac{4}{8}$ *[1 mark]*

$= 0.5\ \text{m/s}^2$
[1 mark for answer, 1 for unit]

b) resultant force = mass × acceleration
$60 - R = 80 \times 0.5$ *[1 mark]*
$60 - R = 40$ *[1 mark]*
$R = 20\ \text{N}$ *[1 mark]*

8 a) i) The length of the card. *[1 mark]*

ii) If the track is tilted, gravity will slow down or speed up the glider. Friction would slow the glider down. *[1 mark]*

b) **i)** A vector has direction as well as size (or magnitude). *[1 mark]*

ii) momentum = $m \times v$

$= 2.4 \times 0.6$ *[1 mark]*

$= 1.44$ kg m/s *[1 mark]*

You must have the correct unit.

iii) Zero.

Working scientifically: Understanding variables

Pages 253

1 The 500 g mass has inertia; it is also an example of Newton's third law of motion.

2 **a)** Type of material used for the crumple zone.

b) How far the 500 g mass moved forwards before stopping.

3 The area and thickness of the materials used to model the crumple zone.

6 Waves

Overview

Specification points

4.6.1 Waves in air, fluids and solids, 4.6.2 Electromagnetic waves and 4.6.3 Black body radiation

Textbook chapter references

AQA GCSE (9-1) Physics: Chapter 6 pages 180–219

AQA GCSE (9-1) Combined Science Trilogy 2: Chapter 34 pages 254–73

AQA GCSE (9-1) Combined Science Trilogy: Chapter 34 pages 610–29

Recommended number of lessons: 22

Chapter overview	
AQA required practical(s)	Physics – RP8 CS Trilogy – RP20 Physics –RP9 Physics – RP10 CS Trilogy – RP21
Contains higher-tier material	Yes
Contains physics-only material	Yes

Useful Teaching and Learning resources

- Learning outcomes
- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–3
- Key terms
- Key concept: Converting times
- Animation: Radiation journeys
- Animation: Uses and dangers of electromagnetic radiation
- Animation: Waves and energy across the spectrum
- Animation: Formation of images
- Personal tutor: Waves and communication
- Personal tutor: Medical applications of physics
- Practical: Identifying the suitability of apparatus to measure the frequency, wavelength and speed of waves in a liquid
- Teacher and technician notes: Identifying the suitability of apparatus to measure the frequency, wavelength and speed of waves in a liquid
- Practical: Identifying the suitability of apparatus to measure the frequency, wavelength and speed of waves in a solid
- Teacher and technician notes: Identifying the suitability of apparatus to measure the frequency, wavelength and speed of waves in a solid
- Practical: Investigating the reflection of light from different surfaces
- Teacher and technician notes: Investigating the reflection of light from different surfaces
- Practical: Investigating the refraction of light through different materials
- Teacher and technician notes: Investigating the refraction of light through different materials
- Practical: Investigating how the amount of infrared radiation radiated by a surface depends on the nature of the surface
- Teacher and technician notes: Investigating how the amount of infrared radiation radiated by a surface depends on the nature of the surface
- Practical video: Measuring the wave speed, frequency and wavelength of waves in a liquid
- Practical video: Measuring the wave speed, frequency and wavelength of waves in a solid
- Practical video: Investigating the effect of changing surfaces on the emission of infrared radiation
- Practical video: Investigating reflection
- Practical video: Investigating refraction
- Homework tasks (a) and (b)
- Quick quizzes 1–4
- Answers for homework tasks
- Answers to all questions
- Half-term test 4.6: Waves

Useful prior learning

In most schools, students will have covered some of the ideas in the discrete topics of light and sound. If there has been coordination between these topics, it is likely that at least some of the ideas have been well understood. Other contexts may include work on earthquakes (in geography as well as science lessons), energy (when discussing thermal radiation) and music. In summary:

- Sound waves are mechanical waves which travel through a medium such as air or water.
- Light waves are examples of electromagnetic waves which travel very quickly. These waves are able to travel through a vacuum as well as media such as air or glass.

When you drop a stone into a pond you see water ripples spreading outwards from the place where the stone landed (with a splash). As the ripples spread, the water surface moves up and down. These ripples are examples of waves.

The water ripples transfer energy and information. The energy moves outwards from the centre but the water itself does not move outwards. The shape of the waves provides us with the information about where the stone landed (if we did not see it land).

Common misconceptions

Students often think of sound and electromagnetic (EM) waves as being broken down into separate, naturally occurring categories. They consider ultrasound to be different in kind to audible sound, rather than simply a matter of degree. This persists even after they have learned that what one person can hear is often inaudible for another. This is encouraged by textbooks and sources which describe EM waves as being of seven distinct types. Whenever possible, remind them of other examples where human categories are used to make descriptions easier (acid/alkalis, varieties of vertebrate and so on).

For light, the biggest issue is often with colour. Quite apart from colour-blindness (which affects 1 in 12 boys, 1 in 200 girls and so on average 1 in every classroom, *who will often be undiagnosed*), how we describe colour in physics is very different to art or everyday life. Even the ‘primary colours’ are different! Depending on how this was taught at KS3 you may find this particularly easy or particularly difficult to resolve. Whenever possible, including ‘of light’ in your descriptions will reinforce the principle, especially if you can contrast this with ‘of pigment’. Discussing this with a friendly art department colleague may help.

It is important that students recognise that although each wavelength of light in the visible part of the spectrum is associated with a particular colour, our eyes also trick us by treating combinations of light as if they are one single wavelength. So 700 nm light appears red, 530 nm light appears green, and a combination is, to our eyes, the same as yellow light with a wavelength of 580 nm. This is about the detector, not the physics – the combined beam does not have a single wavelength matching yellow.

Students will often struggle to understand what is being displaced for EM waves. They may expect the speed to be the same in all materials; because the speed is still so much higher than anything else encountered, we often ignore the real but small drop in speed when light travels through gases, liquids or solids.

One difficulty with sound waves is that although students are *told* they are longitudinal, their representation on an oscilloscope is like a transverse wave. Being explicit about the position on the y-axis as being a measure of the displacement from the equilibrium position will help. In many ways, this is best modelled in solids first as it avoids the confusing factor of the particles in a gas moving randomly as well as the wave causing movement in a particular direction.

Preparation

If using the **T&L Prior knowledge catch-up student sheet**, it may be helpful to have students add in explanations of waves they have used in other topics and subjects. In the longer term, discussing the use of technical terms with colleagues in music and geography may avoid issues, and improve learning by ensuring that students experience consistency. The **T&L Prior knowledge catch-up teacher sheet** discusses some standard examples that students are likely to have encountered at KS3.

This specification includes some examinable material that was previously implicit, having been taught at KS3. In particular, this includes the work on colour which can often cause confusion. If teaching in the order of the GCSE specification, it is likely the concepts will need to be at least reviewed, and possibly retaught.

The **T&L Topic overview**, once more, is a useful preview but it is probably best used in small chunks after a few lessons. Removing a few words and issuing a printed copy clearly marked as ‘Find the mistakes’ would be a good way to test student recall of basic ideas.

NB The lesson plan for this chapter involves some repetition because of the difference between the Trilogy and Physics content. In particular, your choices about the order of reflection and refraction will depend on whether your students will be completing Required Practical 9. Several lessons can be omitted as the content is covered during the discussion of the practicals.

Waves: Lesson 1

Learning outcomes

1 Recap previous teaching of waves, including in music, geography, etc.
2 Define longitudinal and transverse waves.
3 Explain waves using diagrams.

Suggested lesson plan

Starter

Students could write down key words for waves that they remember from previous work. Explicitly recognise those referring to subjects other than science.

Main

Define waves as a way of transferring energy with no *permanent* movement of the medium. (Emphasising the permanent part is helpful when students point out that physical waves do move the material, as you can explain that the movement is temporary, i.e. displacement.)

A useful model for all waves is to break down events by considering the transmitter or source, the medium and the detector. For physical waves, the source will be some vibrating object. Anything that is made to vibrate by the medium can be thought of as the detector; it doesn't have to be set up deliberately to detect.

It is often useful to demonstrate the two kinds of waves using a slinky and to check student recall of the definitions. Emphasise the temporary movement or displacement of the medium (coils of the slinky); along the direction of travel for longitudinal waves and at a right angle for transverse waves. Comparing a 'shoulder barge' and a Mexican wave is almost expected by students; over-enthusiastic pushing is of course an example of amplification.

Students should draw diagrams and accompany them with notes. If a list of waves is provided, students can divide them between the two categories by considering the direction of displacement.

Plenary
Have students identify the medium for each of the wave examples given. Be prepared for EM waves to cause confusion; they are transverse but the displacement is a change in strength of the electric and magnetic fields.

Support
As a lesson recapping KS3 content there should be no real issues here; if EM waves cause difficulties, reassure students that they will be covered in more detail in a future lesson.

Extension
Students could consider how each kind of wave could be measured by the effect on the detector.

Homework
Use Test yourself questions 1–4 from page 182 (*256; 612*) of the textbook.

Wave properties and equation: Lesson 2

Learning outcomes

1. Define key terms using diagrams.
2. Use ripple tank and/or simulations to explore links between quantities.
3. Use the equation to solve problems.

Suggested lesson plan

Starter
If using **T&L Lesson starter 1**, be aware that there are, of course, many other possible questions that match the suggested answers. Instead of using the slides on the board, the text could be copied and given out so that all students have one of the six possibilities and must find a matching partner.

Main
Repeat the exercise with the slinky from the previous lesson to show longitudinal and transverse waves. Use a photo of a transverse wave and label the *wavelength* λ and *amplitude* A. Make clear that the amplitude is measured from the middle or equilibrium point.

A ripple tank, although sometimes awkward to set up, is often very helpful as a comparison. Students will recognise that measuring the height of the water wave is challenging to say the least! The arrangement is, however, easier for showing how the time *period* and *frequency* can be calculated. It may be worth doing measurements in tens:

- Measure the time for ten waves to pass a given point then divide by ten to find period T.
- Count the number of waves passing a point in ten seconds, then divide by ten to find frequency f.

Linking frequency and period is straightforward, but students may need reminding to use the correct units in the equation: $T = 1/f$. This is a step towards the wave equation, which will be a recurring theme through the topic:
wave speed = frequency × wavelength ($v = f\lambda$)

This should be defined and explained, with opportunities for practice that use different waves and so different realistic values. The equation may help to show why the units for frequency, hertz, are also described as s^{-1} in some textbooks.

Plenary
Check recall of the different symbols, quantities and units. It may be worth adding preparation for a repeat test to the student homework.

Support
Ensure that students use the correct symbols; T is specifically for the time period of a wave, but students are used to measuring time from the previous topic and describing it as t. It is important students can measure both wavelength and amplitude correctly, as the start and end points are not clear to novices.

Extension
Some students may be able to give a good explanation of the reasoning behind the wave

equation; ask them to explain an analogy using bus routes in terms of frequency, spacing and speed.

Homework
Use Test yourself questions 5–9 from page 184 (*258; 614*) of the textbook.

Required practical 8(*20*): Measuring and calculating wave properties: Lesson 3

Learning outcomes

1. Discuss demonstration measuring speed of sound.
2. Use provided equipment to measure speed of other waves.

Suggested lesson plan

Starter
Compare two equations for speed; $v = d/t$ and $v = f\lambda$. Ask students how they might measure the quantities for waves.

Main
There are several methods that can be used to measure the speed of sound; if time allows this could be an additional lesson. Alternatively, the practicals could be set up as a circus (which will reduce problems with equipment shortages). A centimetre of water in a Gratnells^{TM} tray can produce reasonable ripples; a laminated sheet of squared paper at the bottom makes measuring the distance travelled in a second much easier. Students could also take measurements with the slinky; they can measure the speed of *compressions* and *rarefactions* to show that longitudinal waves follow the same rules.

The required practical methods are described well in the **T&L** worksheets: **Practical: Identifying the suitability of apparatus to measure the frequency, wavelength and speed of waves in a liquid** and **Practical: Identifying the suitability of apparatus to measure the frequency, wavelength and speed of waves in a solid**. The matched **Teacher and technician notes** have the answers to student questions but are not designed to include too much additional detail.

Plenary
Ask students to describe patterns in the data; this could be their own or a sample set displayed for the class.

Support
The difficulties are likely to be with the apparatus, as the analysis is planned for the next lesson. At each point, the students should focus on the measurements taken and the devices available.

Extension
Ask students to suggest improvements to the methods supplied that will allow more accurate and precise readings to be taken. Discuss sources of error and how these can be reduced.

Homework
Use Test yourself questions 10 and 11 from page 187 (*261; 617*) of the textbook. Depending on which practicals have been completed, you may wish to set some discussion points about the methods, based on the student resources.

Measuring and calculating wave properties (debrief): Lesson 4

Learning outcomes

1. Discuss physical factors affecting wave speed.
2. Explain speed change across a boundary.
3. Annotate diagrams with key terms.

Suggested lesson plan

Starter
If using **T&L Lesson starter 2**, it would be best to give printed copies of the first slide (the answer grid) to students; otherwise they may spend more time drawing it out than considering the answers.

Main
Students may need to finish the analysis of the data collected previously; if equipment is limited, you may wish to extend the circus of activities over the two lessons and students can do the analysis in parallel with practicals.

Show how wave speeds can be affected by the medium; stretching out a slinky is a quick way to do this. If the wave speed increases, so does the wavelength. Students should recognise that, because of the relationship described by the wave equation, this means that the frequency is reduced.

Students may remember that the speed of sound in different states of matter varies, and this is a good model to show how the displacement is passed on more or less effectively. Students can record examples of increased or decreased speed for different kinds of wave and how it affects the wave characteristics. Figure 6.16 on page 188 of the Student book (Physics only) (and available from the **T&L Diagram bank**) is a useful one to guide discussions.

Define a boundary between materials, or between uniform regions within a material, as a place where the wave speed may change. Later lessons will use this concept for understanding refraction and reflection, including contexts such as ultrasound.

It's hard to do too much practice with the wave equation, so this would be a good use of time in the lesson if the newer concepts are secure.

Plenary
T&L Quick quiz 1 will be useful here; it finishes with a question about the speed of EM waves changing when entering a material which obviously cannot be *measured* in a lesson but students should encounter the principle.

Support
Where possible, reinforce that we use observable waves (slinky, ripples) to check the ideas but the principles apply to all waves. It's just that some are much harder to measure, either because of detectors or just because the values of characteristics are so large/small compared to human perspectives.

Extension
Students may be able to explain changes in observable wave characteristics, for example recognising that when sound travels from a low density gas (e.g. helium in the lungs) to a higher density one (air) it means that:

1. speed decreases
2. wavelength decreases
3. frequency increases (squeakier sound).

Homework
As well as Test yourself question 12 from page 188 of the textbook (Physics only), you may wish to include more practice questions of the wave equation or a review of wave vocabulary (emission, absorption, transmission, reflection, refraction) from KS3.

Reflection, absorption, transmission and refraction: Lesson 5 (Physics only)

Learning outcomes

1. Distinguish between key terms for behaviour of light.
2. Use a diagram to show possible results of light meeting a surface.

Suggested lesson plan

Starter
Test recall of key terms, linking emit/transmit/absorb to the source/medium/detector model.

Main
Please note: Refraction is covered on pages 195–196 (*263–264; 619–620*) of the textbook as the specification treats it as a common feature of all electromagnetic (EM) waves. This is of course true, but these plans contrast it directly with reflection for a lesson limited to visible light. There are many different ways to sequence these ideas and what you choose will depend on your students; this lesson will probably be used as an alternative for lessons 6–8 (required practical and analysis) to summarise the concepts for students *not* following the triple course.

Use mirrors and glass/Perspex blocks to investigate the behaviour of light from a ray box or similar. Students should be familiar with the principles from KS3, so the focus should be on clear and correct descriptions of the behaviour. If the light sources are bright enough (and the room can be dark enough – careful planning for 'lights-off' work is always a good idea) then students should see that when meeting a boundary, some light is reflected and some is transmitted, and possibly refracted. Discussions of the proportion reflected/transmitted can be assisted by referring to anti-reflection coatings on glasses.

It may be a good idea to use Test yourself questions 13–17 from page 190 of the textbook (Physics only) in the lesson while students have support with drawing the diagrams.

Students should draw a large, clear diagram showing not only the behaviour of a ray of light, but annotating it with the terms used to describe this, including *angle of incidence*, *normal*, *angle of reflection*, *angle of refraction*. It may be better to show reflection and refraction separately as long as students understand that often both will occur. General principles should be recorded, some of which students will recall from previous work; the angle of reflection is equal to the angle of incidence for a plane (flat) mirror, and light is refracted towards the normal when going into a denser material and away from the normal when going into a less dense one.

Ensure students understand that although different waves will all be reflected and refracted, by how much will depend on the conditions. 'Shiny' surfaces reflect visible light, but water waves will reflect from any hard surface. X-rays are transmitted through objects that are opaque to visible light, and so on.

Plenary
Ask students to explain what is happening when a person wearing glasses sees a tree reflected in a

mirror, using the key terms. You may wish to break the stages down for them:

1 Sun emits light.
2 Light is transmitted through space and the atmosphere.
3 Light is reflected from a tree.
4 Light is reflected from a mirror.
5 Light is refracted by glasses.
6 Light is absorbed by a retina.

Support
The representation of waves can cause difficulties for students, particularly since terms such as *wave*, *ray* and *beam* are often used interchangeably. It may help to clarify that wave describes the whole model, a ray is the single line (which should have an arrow to show direction) representing one part of the light's route, and a beam is the widening collection of rays that spread out as they travel. The *wave front* is sometimes shown as a series of lines perpendicular to the direction of travel, and can be thought of as representing the 'peaks' and 'troughs' of the light.

Extension
Encourage students to use clear explanations of each stage and correct words. Ask them to explain how refraction is a particular example of transmission when the surface is at an angle to the direction of the wave front.

Homework
Students may need to finish the Test Yourself questions on page 190 of the textbook. Reviewing work on sound waves may also be helpful as a preview for the next lesson (assuming they are following the Trilogy route).

Required practical 9: Investigating reflection and refraction of light: Lesson 6 (Physics only)

Learning outcomes

1 Use supplied method to compare angles of incidence, reflection and refraction.
2 Display data in graphs, marking anomalies clearly.

Suggested lesson plan

Starter
This lesson and the two following are a more investigative approach covering the content in the planned lesson 5. The intention is for lessons 6–8 to be used for the triple (Physics) route while lesson 5 offers a summary for those following the Trilogy course, who can then move on to lesson 9 as time is likely to be short.

Main
T&L worksheets **Practical: Investigating the reflection of light from different surfaces** and **Practical: Investigating the refraction of light through different materials** will be good guides for student work. You may choose to complete one practical and the analysis in one lesson, and follow up with the other. This may depend on the availability of a lab with blackout blinds.

If at all possible, students should have the opportunity to compare refraction in different materials. They could be challenged to distinguish between glass and Perspex based on the different amounts of refraction; this will require careful measurements. It may be easier for students if semi-circular blocks can be used as, if orientated correctly, there is only refraction at one boundary (see http://practicalphysics.org/law-refraction.html for a method, but ignore the maths analysis).

Students may see results tables for the reflection practical as a waste of time, but it is worth insisting on it. The **T&L Teacher and technician notes** give answers to the questions, which may be saved for the follow-up lesson.

The methods on pages 197–198 of the textbook include some useful discussion of uncertainty and the sources of error.

Plenary
With care, refraction and reflection can be demonstrated with a laser pointer. Ask students how the change of light source will affect a) patterns observed and b) uncertainty in the values measured.

Support
Some students will need to take time with the methods; setting up the apparatus so all readings can be taken without moving the glass/Perspex blocks is time well spent.

Extension
Discuss how it is easy to 'see' the angle that you expect when the pattern seems so obvious. It can be possible to set up the experiment so the student recording the reflected angle does not know the incident angle; would the results be more 'honest' in this case?

Homework
Students could start the analysis based on the questions provided on the **T&L Practical** worksheets.

Investigating reflection and refraction of light (debrief): Lesson 7 (Physics only)

Learning outcomes

1. Discuss uncertainty in the results and how to reduce this.
2. Explain refraction in terms of changing wave speed at the boundary.

Suggested lesson plan

Starter
Recap the practical methods from the previous lesson.

Main
Define *uncertainty* as the difference between the *mean* and either the highest or lowest value recorded. Students could rewrite some of the paragraphs on pages 34 and 35 of the **Student book** for the refraction method. This would be a good opportunity to review the difference between *systematic* and *random errors*, and why *precise* readings are not necessarily *accurate*. (If a recap is required, remember that this is covered in the 'Working Scientifically' section on pages 34–35 of the textbook).

Students should draw a large, clear diagram summarising the behaviour of a ray of light and annotating with the terms used to describe this including *angle of incidence*, *normal*, *angle of reflection*, *angle of refraction*. It may be better to show reflection and refraction separately as long as students understand that often both will occur. General principles should be recorded, some of which students will recall without prompting; the angle of reflection is equal to the angle of incidence for a plane (flat) mirror, and light is refracted towards the normal when going into a denser material and away from the normal when going into a less dense one.

The explanation on pages 195–196 of the textbook will be a good model for student notes. In particular, it provides the opportunity to discuss refraction in water waves. Spending time to consider the change in speed as the reason for refraction may help to show why some waves show a much greater effect than others. Animations are very helpful here as they can show clear links between different waves; a good place to start might be: https://phet.colorado.edu/en/simulation/bending-light

Plenary
Explain the twinkling of stars by discussing the changing refraction of light due to movement of high and low density regions in the atmosphere. This is why the stars appear steadier when at altitude, and why satellites offer better data for astronomers.

Support
The explanation for refraction is much easier to apply to water waves which have an observable 'width'. Students will need to link this model to light and other waves using the idea of a wave-front, even though it is not something they experience.

Extension
Ask students to consider the possible applications of a material with such a slow speed of light that it takes hours, days or even years for light to pass through. What would you see through it? (This is an idea from science fiction, although work with Bose–Einstein condensates has seen light slowed down to walking pace.)

Homework
Use Test yourself questions 26–28 from page 196 of the textbook.

Diagrams and calculations: Lesson 8 (Physics only)

Learning outcomes

1. Draw diagrams for reflection at a surface and label with key features.
2. Show that angles of incidence and reflection are equal for a plane mirror.
3. Explain why a mirror image is virtual.

Suggested lesson plan

Starter
Display a curved mirror and ask students to bullet point how they would investigate the angles of reflection.

Main
Please note: If following the triple (Physics) route you may choose to combine this material with the previous lesson; effectively it is the analysis for the reflection part of the required practical.

Although not on the specification, having students draw a scale diagram with measured angles of incidence and reflection is a good way to review the practical. The rays should be labelled and any errors discussed. Try providing a deliberately poor-quality mirror to show that only a good surface gives the exact match they intuitively expect. Ensure that they use the correct symbol for a mirror (straight line with shading) and that rays have arrows to show direction. This may be a good point at which to remind students of the difference between luminous and non-luminous objects, and that we see most objects because they reflect light from other sources, some of which is detected by our eyes. This will be a useful foundation for the discussions of colour later on.

Students should record key facts from the information on pages 188 and 189 in the textbook. In particular, discussion of the meaning of the word 'virtual' when applied to images is important as it will feature in the later work on lenses. If an image is *real* then a screen placed at that point will display the image. We can't place a screen 'in' the mirror, so reflections are an example of a *virtual* image.

It may be a good idea to use Test yourself questions 13–17 from page 190 of the textbook in the lesson while students have support with drawing the diagrams.

Plenary
Review all key terms for wave behaviour; students could match words and definitions, or improve definitions provided with ambiguities.

Support
Reflection as a principle is straightforward and not significantly different from the treatment at KS3. The concept of virtual images is likely to cause much more confusion. It's worth having some counter-examples ready as many of the definitions found on a quick google search are unhelpful to a novice.

Extension
Encourage students to give more examples of reflection in waves other than light; they should be able to recognise both similarities and differences.

Homework
If the questions have not been completed, these can be set; an alternative might be to ask students to review previous work on sound in preparation for the next lesson.

Sound: Lesson 9 (Physics only)

Learning outcomes

1 Recap wave properties.
2 Complete observations on varied experiments in 'sound circus'.
3 Record normal audible range and factors that can reduce this.

Suggested lesson plan

Starter
Students should demonstrate recall of definitions; they could match definitions to the terms, or correct or improve definitions provided.

Main
A range of small practicals is a good way for students to link the various wave properties to observable characteristics. Providing prompt questions for each one will guide their understanding. Some to try might be:

- bell in bell jar (or micro-scale version)
- tuning fork with water
- string telephone
- microphone with oscilloscope
- signal generator and loudspeaker (clingfilm and cornflour/water optional)
- cardboard tubes, hard surface and ticking clock – show reflection at equal angles.

Discussing the details of the ear offers a good opportunity to compare the transmission of sound in gas, solid and liquid materials. The compressions and rarefactions of the material can be modelled with a slinky; students often find it easier to link this to sound travelling in solids before the more abstract nature of regions of gas or liquid. Ensure that students link the displacement back and forth, along the direction of wave travel, to the vertical shift on the oscilloscope trace.

Although students will have experienced it before, the auditory range demonstration is helpful to define ultrasound before next lesson. Comparing auditory ranges is useful as students should be aware that 20 kHz is a nominal limit for human hearing, rather than a universal value. A brief discussion of factors affecting the range – the main evidence suggests that the hairs in the cochlea are damaged over time, exacerbated by loud sounds – is unlikely to stop them listening to music through headphones, but still worthwhile.

Plenary
T&L Quick quiz 2 would be a good check of the topic so far and finishes with a question about ultrasound.

Support
One of the biggest challenges for students with sound is to reconcile the description of them as longitudinal with the oscilloscope representation which appears transverse. If video footage of a slinky wave next to a ruler is slowed down, students could plot measured displacement of each frame to show an equivalent line.

Extension
Ask students to link previous ideas about changes of wave speed to the transmission of sound through the different parts of the ear.

Homework
Students should choose several of the demonstrations to explain, using the key terms from the starter.

Ultrasound and seismic waves: Lesson 10 (Physics only)

Learning outcomes

1. Explain uses of ultrasound in medicine and undersea exploration.
2. Use diagrams to explain points where seismic waves arrive on the surface.

Suggested lesson plan

Starter
Show students ultrasound (ideally not an ante-natal one) and X-ray images side-by-side. Ask them to identify which is made using a longitudinal wave (ultrasound is a longitudinal physical wave, X-rays are transverse electromagnetic radiation).

Main
You may have chosen to have students prepare for this lesson as homework, in which case the focus can be shifted to treating the questions as review and exam practice. Alternatively, students could present information to classmates explaining different aspects of the concepts.

Remind students of the source/medium/detector model for waves. A single reflection from a hard surface is a good starting point for ultrasound, like that shown in Figure 6.30(b) on page 192 of the textbook or from the **T&L Diagram bank**. Provide time data and show how the speed equation can be used to find the total distance travelled; students should be aware that, for many ultrasound examples, this is a *return* journey. The speed of sound in sea water can be approximated as 1500 m/s.

So for example:

- An ultrasound pulse from a ship is detected 0.75 s after transmission: $s = vt = 1500 \times 0.75 = 1125$ m.
- If the pulse travels 1125 m in the journey to the sea bottom and back, the depth is half this: 562.5 m.

Before considering medical uses, it may be worth reminding students that nuclear radiation can be used for diagnostic and therapeutic purposes; this is also true for ultrasound but only diagnosis is discussed in the specification. There will be multiple reflections of the pulse to consider as each tissue boundary will produce a signal. Between this and the varying speeds in different body tissues, it becomes clear that ultrasound imaging requires a lot of calculation, which is naturally all done by computer software. The non-destructive nature of ultrasound should be emphasised as a major advantage. Asking 'who has had an ultrasound?' is often best avoided as the immediate assumption is for ante-natal scans; it is worth pointing out that it is very useful for diagnosing soft tissue damage, as the resolution between muscle, ligament and tendon is much clearer than X-rays, and for the movements of the heart.

When considering our understanding of the Earth's structure, particular attention should be paid to how the different behaviour of longitudinal P-waves and transverse S-waves have given information about boundaries. On a smaller scale, the same principles are used for local high-resolution scans in archeology and geology using artificial sources; clips from *Time Team* regularly feature geophysicists explaining this.

Plenary
Students could be given information about echolocation in marine mammals and asked to explain why noise pollution from shipping and the oil industry is thought to be a problem.

Support
Some students may assume that X-rays and ultrasound imaging are the same; emphasise that ultrasound uses reflections while with X-rays we look at what is absorbed (by bone) and transmitted (through everything else). You may need to explicitly remind students of the wave equation before some of the questions are attempted; this is a good opportunity to remind them that the exams will include material across all topics.

Extension
Students could discuss why liquids cannot transmit transverse waves with reference to the particle model. (Answer: because the particles are not connected along the direction of travel, there is no reason why a perpendicular force will be passed on.)

Homework
In some way, it is likely that you will want to use Test yourself questions 19–22 from page 193 of the textbook. Some questions may need scaffolding, particularly those using mathematical approaches.

The ‘colours’ of the EM spectrum: Lesson 11

Learning outcomes

1 Recap frequency/wavelength.
2 List properties of all EM waves.
3 List main bands.

Suggested lesson plan

Starter

Ask students to recall the meaning of f (frequency) and λ (wavelength) and the relationship between them. They should be able to define and explain the wave equation: $v = f\lambda$.

Main

You may wish to combine this lesson with the one following if preferred; alternatively, students could complete a guided research project in small groups, each reporting back on one of the seven bands.

The nature of electromagnetic waves is abstract compared with waves which affect a material medium. When students ask, the best explanation is that instead of the position of a material being displaced (e.g. sound waves) the strength of electrical and magnetic fields are changed.

Students should record the common features of electromagnetic waves; some of these are common to all waves. Explain that for electromagnetic (EM) waves the symbol c is often used in place of v, to remind us that they all travel in a vacuum at the same speed of 300 million m/s. Providing example values so they can check this also serves to refresh their memories of the use of the equation and the necessary unit prefixes.

Remind students of the auditory range and the arbitrary nature of the values chosen. It is useful for them to bear this in mind when examining the values chosen to separate bands of the EM spectrum. The properties change gradually rather than at specific values, in most cases. Even the visible spectrum is based on the average human eye, as many animals can see into what we describe as infra-red (e.g. snakes) or ultraviolet (e.g. bees).

Students will need to recall the bands in order and know that gamma rays are at the low wavelength/high frequency end, compared with radio waves which are at the high wavelength/low frequency end. Various mnemonics exist, some of which are more classroom-suitable than others. Give an example property of each band with the promise that more will be coming.

Plenary

Have students identify which bands have been relevant to their day: radio/micro for phones, IR for remote controls, visible for sight, UV for bank note checking (sunblock if summer). X-rays and gamma are unlikely to be suggested (although food may have been gamma sterilised).

Support

Some students will struggle with the idea that these bands are defined by us for convenience rather than being natural divisions. Asking them what the difference is between red and orange light may help.

Extension

Some students will want to know more about the true nature of EM waves; this would be an opportunity to discuss how models are used in science. The wave model of EM radiation is based on changing electrical and magnetic fields which are propagated through a vacuum. In materials, the speed is slower, as each time electrons are encountered they absorb the wave, vibrate and then emit a wave with the same properties.

Homework

Use Test yourself questions 23–25 from page 195 (*questions 12–14 from page 263; 619*) of the textbook. You may wish to set some additional questions using the wave equation, so that students gain familiarity with the scales involved. If so, ensure that they have reviewed prefixes for SI units as both the very small (nano-, micro-, milli-) and very large (kilo-, mega-, giga-) will be needed for EM examples; see page 64 (*316*) of the textbook for a list and explanation.

Properties of EM waves: Lesson 12

Learning outcomes

1 Recap drawing ray diagrams.
2 Apply key terms to waves other than visible light.

Suggested lesson plan

Starter

Ask students to list key terms describing wave behaviour and give examples of how they apply to sound and (visible) light.

Main

Students following the triple (Physics) course will be familiar enough with wave behaviour so that this lesson can probably be combined with the previous one.

If possible, demonstrate reflection and refraction of visible light. Students should be able to explain the processes involved. Extend this to discuss how each part of the electromagnetic (EM) spectrum can be reflected or refracted in the right circumstances. You will also want to cover the ideas of transmission and absorption, and, in particular, the effect on a material when EM radiation is absorbed; this is covered in more detail later, so you could summarise now by listing the induction of an alternating current, heating and ionisation.

Give examples of diagrams and use this to review the drawing of ray diagrams; the same rules apply but different materials are required to get the same effect with different parts of the spectrum. Reinforce that we use visible light as an introduction because it is an easily observable example, rather than because it is somehow special or different.

Plenary
Ask students to explain why mobile phones have poor signal in the middle of tunnels but work near the ends. (Answer: the material of the tunnel is a good absorber of the radio waves but they may be reflected from close to the ends in some circumstances.)

Support
The ideas here should cause few problems; as in the previous lesson, be ready to guide those who struggle with the scale involved in describing the quantities of wavelength and frequency.

Extension
Ask students why you can get sunburn on a cold day, and why feeling warm at the beach does not necessarily mean that you need more sunblock. (Answer: warming is caused by the infra-red part of the sunlight while sunburn is caused by ultraviolet or UV. The two often go together, but not always. This is an excellent example of why *correlation* does not always imply *causation*.)

Homework
Use Test yourself questions 23–25 on page 195 (*questions 12–14 from page 263; 619*) of the textbook, if not already completed.

Required practical 10(*21*): Investigating emission and absorption: Lesson 13

Learning outcomes

1 Complete practical as described.
2 Display results as a bar chart.

Suggested lesson plan

Starter
Ask students to identify source, medium and detector for various examples of waves, including at least one from the electromagnetic spectrum. When discussing this example, be sure to use the words *emit* and *absorb* and check student understanding of these.

Main
Available equipment will determine how students collect data on emission and absorption of infra-red radiation; students should be encouraged to make specific predictions, in terms of measurable values, for the apparatus provided. As a comparison, sample data for the method described on page 202 (*269; 625*) of the textbook could be provided. Students could watch **T&L Practical video: Investigating the effect of changing surfaces on the emission of infrared radiation** and script an equivalent version if the method in school is different. Collecting data for this practical is very quick, so repeating the readings will be a good opportunity to reinforce understanding of random error and the use of means.

The same method is described in the **T&L Teacher and technician notes** and **Practical: Investigating the amount of infra-red radiation radiated by a surface depends on the nature of the surface**; you may wish to adapt the latter.

Unusually for the Physics required practicals, the independent variable is *discrete* which means that a bar chart is the appropriate way to display the results. Page 179 from the textbook (Physics only) discusses the reasoning for this choice. (Students could also collect data for temperature against time as a recap of the work on dissipation in the Energy topic, but, if so, it must be made clear that this is for a different purpose.)

Plenary
Students can discuss how they would test whether the same pattern is seen for absorption rather than emission of infra-red.

Support
Students may be surprised by the difference between matt and shiny black; it may be worth having more examples of the different textures to prompt discussion.

Extension
Students could be asked to compare this method with others, and explore how different measuring devices will affect the result.

Homework
Even if students have followed a different method, if sample data is provided it should be easy for them to complete the questions on the approach described on page 202 (*269; 625*) of the textbook.

Investigating emission and absorption (debrief): Lesson 14

Learning outcomes

1 Describe uses of different surfaces in terms of their IR behaviour.
2 Recap house insulation applications.
3 Research how these ideas apply to other parts of the EM spectrum.

Suggested lesson plan

Starter
Students should describe the pattern obtained from the previous lesson and consider whether they are *repeatable* or *reproducible*.

Main
Ensure that students record the general rule that, for infra-red, dark matt surfaces are good emitters and absorbers while white or shiny surfaces are bad emitters and absorbers. Ask students to consider reflection as the opposite to absorption.

Return to the ideas of house insulation covered in the Energy topic. Some methods of house insulation reduce conduction and convection, but students should be able to recognise cases where infra-red emission or absorption has been considered. The use of solar panels (as distinct from solar cells, which are photovoltaic and not to do with heating) to preheat water entering a boiler is another useful context.

If available, an IR thermometer can be used to check the infra-red emissions from different surfaces; this works best from outside the lab, comparing values for doors, walls, windows and roof. False-colour images showing differences for many objects are easy to find online. Students should be able to make links to work done in biology, regarding mammals and birds staying warm, and reptiles, in particular, maximising IR absorption.

Plenary
Students should be able to link the ideas about reflection, emission and absorption to other parts of the electromagnetic spectrum. Once more, the emphasis should be on similar behaviour (because they are all EM waves) but happening in different materials and surfaces.

Support
Any issues are likely to be with recall of past learning rather than the ideas themselves. This is a good chance to reinforce the idea of steady review work rather than leaving it all to the last minute; discussing regular retrieval practice as a way to avoid catastrophe can only be a good thing.

Extension
Show students a (picture of) microwave shielding, with holes in it; why is this an effective reflector? (Answer: the wavelength of the microwave radiation is too large for it to pass through.)

Homework
Students should read ahead and fill in a table showing uses and hazards of different bands of EM radiation.

More properties: Lesson 15

Learning outcomes

1 Describe link between emitted waves and alternating current (HT only).
2 List dangers of high energy waves.
3 Recap radiation dose and context.

Suggested les son plan

Starter
Ask students to explain how, in terms of physics, their mobile phone receives a signal.

Main
Although the details of the process of transmitters and aerials for EM radiation are only required for higher tier, the basics will be useful for all students. Students should record the idea that the frequency of the wave emitted or absorbed will match that of the alternating current. Many animations are available to represent what happens, but Figure 6.44 (*34.23*) on page 198 (*265; 621*) of the textbook (also available from the **T&L Diagram bank**) is at a reasonable level, and the bullet points over the page could usefully be turned into a flow chart. Reinforce that although the term ‘radio waves’ is often used, this applies (1) to the radio *and* micro-wave bands (2) to signals used for TV, radio and mobile phone signals. It may be worth pointing out that there is heating of the aerial at the same time.

Students could explore the information from **T&L Animation: Radiation journeys,** which allows clear comparisons between bands to be made. Point out that the absorption effects can often be classified into heating (most bands to some degree), the induction of an alternating current (mostly radio and micro) and ionisation (gamma, X-ray and ultraviolet). The high frequency end is also high-energy which is why these bands are considered more hazardous; gamma, in particular, as one kind of nuclear radiation, is associated with health risks. Students may remember that exposure is measured in sieverts (or more often millisieverts), a unit applied to X-rays as well as gamma. No numbers are needed, but the idea of a cost-benefit analysis for medical scans may be a good way to consider the social context of these medical options.

Students should be able to link their understanding from Chapter 4 (*18*) Atomic structure to the ideas here. It may be interesting for them to see how their understanding of 'radiation', often used as a vague term in everyday life, has improved since then. In particular, they should be able to recognise that although mobile phones and similar (WiFi, Bluetooth, etc.) involve EM radiation, without any ionisation there is little credible link to the damage associated with cancer. No matter what some newspapers claim.

Plenary
Students can now write a response to a claim in the local newspaper that putting a mobile phone mast next to school would be a health risk.

Support
Be aware that, for some students, cancer and similar health risks are not a theoretical possibility. The abstract nature of EM waves is often challenging; repeating that the model we use is one way to think about them, and successfully predicts many observed features, may help.

Extension
Ask students to explain how mobile phones can work without aerials. (Answer: they do have aerials – but they are small enough to be inside the case.)

Homework
If students will be presenting ideas to each other next lesson about the uses of EM radiation, they will need to be assigned a band to research and produce summary materials for.

Using EM waves: Lesson 16

Learning outcomes

1 Compare uses of different bands.
2 Link specific characteristics to particular uses (HT only).

Suggested lesson plan

Starter
Students should now be able to answer most of **T&L Lesson starter 3**; those areas where they hesitate will hopefully encourage them to pay close attention in the lesson.

Main
This would be a good lesson for students to present ideas to each other, with the opportunity to make structured notes. The information on pages 200–201 (*266–268; 622–624*) of the Student book cover the specification well, but a wider scope would probably be helpful as students will need to do more thinking.

Wherever possible, student should make explicit links between the uses described and the characteristic of that band of electromagnetic (EM) radiation; according to the specification this is required only for HT, but all students will benefit as it explains the limitations more thoroughly. At the least, students should be able to describe the absorption effects.

It may help to demonstrate and explain *fluorescence*, using a UV source and objects which absorb this to emit visible light. Students may be familiar with this from TV shows, in particular, crime dramas.

Contrasting the uses of X-ray and gamma radiation for diagnosis (transmission images and medical tracers) with treatment (radiotherapy) will show how important dose can be. As ever, be aware that students may have personal or family experience with these uses.

Plenary
Use **T&L Quick quiz 3** to review these ideas and others.

Support
Emphasise that although we use the microwave band for communications and cooking, they are different parts of this band! As discussed previously, most parts of the EM spectrum will produce some heating when absorbed; those used in cooking are chosen for an exaggerated effect on water.

Extension
Students could consider why mobile phones rely on several distinct parts of the radio/micro bands. (Answer: the main reason is range. Microwaves are used from cell tower to satellite and back. Different companies use different ranges, including around 800, 1800 and 2600 MHz. Wifi and Bluetooth operate at 2.4 GHz, NFC at 13.56 MHz. They do *not* need to recall these.)

Homework
T&L Animation: Uses and dangers of electromagnetic radiation is a helpful reminder that can be reviewed at home, perhaps as support for completing Test yourself questions 29–31 on page 203 (*questions 17–19 on page 268; 624*) of the textbook.

For combined science students, as this is the end of the topic, students should prepare for the **T&L Half-term test 4.6: Waves** using the Chapter review questions (pages 270; 626) and the Practice questions (pages 271; 671). **Homework tasks (a)** and **(b)** may also be useful if not already used.

Drawing diagrams for refractive lenses: Lesson 17 (Physics only)

Learning outcomes

1. Recap ray diagrams.
2. Explain the effect of varying thickness, referring to speed changes.
3. Define convex and concave shapes.

Suggested lesson plan
Starter
Show students a diagram with several possible 'refracted' rays; ideally one should carry straight on and one should bend the 'wrong' way at the boundary. Can they explain why only one line is possible?

Main
This lesson and the one following can be challenging ones for students. The ideas are difficult conceptually, and there are both mathematical aspects and principles for diagrams which must be understood. The plan here is based on drawing the diagrams first and exploring the effects of lenses, which, if structured carefully, can be very dramatic for students. The following lesson involves more careful comparison of the characteristics of the two categories. Many other approaches are, of course, possible.

A good starting point is to use a semi-circular block or a lens with one flat, one convex side before students explore symmetrical lenses. Ray boxes with multiple slits will show the effect of the different thicknesses of glass/Perspex. Ensure that students recognise that the narrow beams represent a simplified version of reality, and that a ray diagram is simpler again. They should draw the ray diagram for this situation and annotate it.

If available, students can adjust arrangements to show the beams converging with a half-convex lens, travelling as parallel beams, then converging further to a point after a second half-convex lens. This helps to separate the effects at each boundary of the lens. Bringing them together to make a regular convex lens is then straightforward. The discussions of refraction on page 196 of the textbook may be a useful reminder.

Students should explore the effect of lenses on parallel beams; the terms *converging* for *convex* lenses and *diverging* for *concave* lenses should be introduced. You may wish to define the *principal focus* (probably for a convex lens only for now) as where the parallel rays meet, and the *principal axis* as the line through the centre of the lens, perpendicular to the lens itself.

Plenary
If a strong light source is available, using a convex lens to burn paper is a powerful demonstration which students should be able to explain in terms of beams of light.

Support
In many ways, the best approach when introducing lenses is to give some suggestions and then let students try out different arrangements. Using the multiple slits means that students can actually see something very similar to the beam diagrams we draw; the reality is a close match to the representation. Use this link to make explanations clear in terms of beams coming together or spreading out.

Extension
Have students place a screen at different points before and after the principal focus; this will raise questions about magnification and inversion that will be investigated more thoroughly next lesson.

Homework
Students could examine the lenses of glasses, their own or family members, to consider whether they are convex (thick in the middle) or concave (thin in the middle). To reduce chromatic aberration spectacle lenses are not symmetrical but the words are still used in the same way.

Comparing convex and concave lenses: Lesson 18 (Physics only)

Learning outcomes

1. Describe the images using a range of correct vocabulary.
2. Derive/check the magnification equation.
3. Use diagrams to explain the use of a magnifying glass.

Suggested lesson plan

Starter

Compare diagrams of the beams for a convex lens and a concave lens, reminding students of the principle focus (Figure 6.54 on page 203 and Figure 6.59 on page 206 of the textbook (Physics only), also available from the **T&L Diagram bank**). Draw lines back from the diverging beams to show how a concave lens can also be considered as having a principal focus. Label the distance from this to the centre of the lens as the *focal length*.

Main

Explain that when considering the effect of a lens on light travelling from an object, we consider a few example rays (as distinct from beams) of light. This is what we mean by a ray diagram, and there are some rules we follow to make life much easier. Point out that, when drawing these on a board, it is harder than on paper; you may wish to work on a demonstration desk to model more closely what they will be doing. It can really help students to follow a numbered method, starting with drawing the principal axis and lens. They can then draw the most important rays, starting at the top of the object:

- The first travels parallel to the principal axis until the lens then bends to pass through the principal focus on the opposite side.
- The second travels in a single straight line through the centre of the lens and onwards.
- An optional third travels through the principal focus before the lens, then bends at the lens to travel parallel to the principal axis.

Students should record the characteristics of the image produced by placing a screen at various points after the lens and recognise that there are distinct changes at the focal length. They should be encouraged to be systematic when investigating different positions of the object and the screen. Any image that can be projected on a screen is real; they can then choose from *upright* or *inverted*, and *magnified* or *diminished* to describe it further. The magnification of a lens is a simple ratio of image height divided by object height and so has no units.

If a student looks through a lens at an object which is closer than the focal length, the rays we draw do not meet. Instead, they appear to come from further away. This kind of image is a *virtual* one and is *upright* and *magnified*. This is how magnifying glasses are used.

Concave lenses also produce a virtual image; to the observer, it appears that the object is closer to the lens, upright and *diminished*. This is true whether the object is beyond or within the focal length.

T&L Animation: Formation of images may be a useful way for students to explore a simulated lens and the images that result from different combinations. Using this or similar simulations (this one from PhET for example: https://phet.colorado.edu/en/simulation/legacy/geometric-optics) *before* they have tried out the practical risks them seeing it all as unreal; they are better as a follow-up, either in lessons or as homework.

Plenary

With support, students should now be able to fill in a summary table for the characteristics of images with various combinations of lens and distance.

Support

There is a lot for students to remember here; if they are struggling, the best thing is to reinforce the main points of drawing the diagrams and how the image formed can then be described.

Extension

Students can be encouraged to consider the difference between the small effects seen when a screen is moved within one range, to the sudden effect of moving beyond the focal length (or double the focal length).

Homework

Students can now attempt Test yourself questions 32–38 on page 207 of the textbook.

Making a spectrum: Lesson 19 (Physics only)

Learning outcomes

1. Use a prism to show colours from white light.
2. Discuss continuous nature of spectrum obtained and the common colours identified.
3. Explain spectra from reflection.

Suggested lesson plan

Starter

It may be worth digressing into biology briefly to point out that no two people will see or describe colours in exactly the same way; the difference between blue-green and green-blue is a very personal one. Bear in mind that, on average, one student in every classroom will have some form of colour-blindness but this is often undiagnosed.

Main

Students should be challenged to produce a spectrum using a bright light source and a prism. Although a short activity, it can be pointed out that they are literally repeating one of Newton's experiments. It should be noted that the blue/purple end is refracted more than the red component, summed up with the mnemonic 'blue bends best'.

There is no reason in terms of physics to divide the spectrum into seven colours; most humans cannot reliably distinguish a colour between blue and violet. Newton's beliefs included a reverence for the number seven and this may explain his choice. In terms of physics, sunlight is a mixture of many distinct wavelengths making up a continuous spectrum, which, when together, our eyes report as white. The atmosphere filters out some wavelengths more than others, both within the visible range and others, e.g. ultraviolet.

Place the visible spectrum in the context of all electromagnetic waves; you may wish to demonstrate the infra-red detected past the end of the 'visible' spectrum.

Remind students of reflection and explain that, previously, all examples have been of *specular reflection* from a smooth, shiny surface. A rough or cloudy surface will reflect or *scatter* light in many directions; this is called *diffuse reflection*. Opaque objects, which transmit no light, may still absorb some. We find that, in most cases, some wavelengths are absorbed and some reflected.

You may wish to introduce the idea of mixing colours of light, being very careful with language.

Plenary
Review the terms used and have students match words and definitions.

Support
Students who have reduced colour vision may not have realised it before now; you may wish to suggest a trip to the optician. The ideas otherwise are unlikely to cause problems although this is not true of the next lesson, which uses a model of colour mixing which is necessarily abstract.

Extension
Students should recognise that specific wavelengths are detected as specific colours, and that this idea corresponds to the different parts of the radio and microwave bands discussed in previous lessons.

Homework
As the end of the topic is approaching, students should be given opportunities to review earlier work. Terms and definitions, with examples of the waves which have now been covered in more detail, would be a good way to do this.

Mixing colours of light: Lesson 20 (Physics only)

Learning outcomes

1. Distinguish between primary colours of pigment and those of light.
2. Explore colour mixing rules.
3. Answer questions on light being mixed or filtered based on RGB.

Suggested lesson plan

Starter
Students could recap the visible spectrum from last lesson, or begin with a diagram of the eye; the important feature to consider is not the lens but the retina. Students do not need to recall any characteristics of the cells but it may help them to understand why the colours we detect are not necessarily caused by particular wavelengths.

Main
Colour perception is a much more complex idea than students may expect, and there are many aspects that are far beyond the reasoning needed at GCSE. Much of it relates more to psychology than the physics. Be aware that the filters available in school are rarely mono-chromatic so allow a mixture of wavelengths through; even if one combination works well, it is unlikely that the whole set will be consistent. A better plan is often to demonstrate with one checked set of filters.

Remind students that objects are seen by us because they reflect or *scatter* light towards our eyes. What we perceive as white light (e.g. sunlight) is a mixture of many wavelengths. Some of these are *absorbed* by objects; others are reflected. (The same idea applies to filters, which absorb some and *transmit* others.)

A useful model, based on how the human eye detects light, uses three sample wavelengths: one corresponds to blue light, one green, and one red. We consider which of these is reflected or absorbed by an object. The combination is *perceived* by our eyes/brains as being another colour, as follows:

- Red and green light in equal amounts are interpreted by the eye/brain as *yellow*.
- Red and blue light in equal amounts are interpreted by the eye/brain as *magenta* (purple).
- Blue and green light in equal amounts are interpreted by the eye/brain as *cyan* (turquoise).

These are not the same rules as used in art to describe primary colours (red, blue, yellow) which are pigments or dyes which are mixed. Students should record that red, green and blue are the primary colours of light and how they can be mixed to produce the perception of the secondary colours: yellow, magenta and cyan. A perfect reflector appears white and a perfect absorber appears black.

Model the process of breaking down a described beam of light into the three primary colours (red, green and blue, R, G, B) and how different parts of this are absorbed or reflected, changing how the object appears. Students should attempt some questions following this process.

Plenary
T&L Quick quiz 4 focuses on lenses and colours of light.

Support
Some of the combinations will seem impossible to students, until they are demonstrated. It helps to make clear that the rules discussed are for light, not pigments; that way, they can treat them as a special case rather than a replacement for what they have used in art since primary school.

Extension
Ask students to predict and explain the apparent colour of light obtained by mixing a bright blue source and a dim green source. (Answer: cyan, but much closer to blue, because of the signal received by the eye/brain.)

Homework
Use Test yourself questions 39–43 on page 209 of the textbook.

Defining a black body: Lesson 21 (Physics only)

Learning outcomes

1 Recap emission/absorption of IR.
2 Define a 'perfect' black body.

Suggested lesson plan

Starter
Display a Leslie cube and ask students to predict and explain the readings if a thermometer is placed near each surface.

Main
Discuss the infra-red emitted and absorbed by an object in the room. Without assigning values, students should be aware that hot objects will be emitting more than they absorb, and that this is reversed for cold objects.

Students should be aware that, above a few hundred degrees Celsius, objects will emit some visible light along with the infra-red. The important feature is that the net radiation emitted per second, which can be considered as the power of an energy transfer, increases with the temperature difference between the object and the surroundings. A range of wavelengths will be emitted but the hotter the object, the shorter the end of the range will be.

Define the *perfect black body* as one which absorbs all electromagnetic radiation; it will also be the best possible emitter. In reality, we often describe a 'black body' as a perfect emitter and absorber for a particular range, e.g. visible or infra-red.

Plenary
Consider emission spectra for an object at a high temperature and demonstrate the decrease in minimum wavelength when the temperature increases; simulations such as the one available from PhET are helpful here: https://phet.colorado.edu/en/simulation/legacy/blackbody-spectrum

Support
Some students may need reminding that a low wavelength implies a high frequency, and that high frequency EM radiation has more energy.

Extension
Ask students to explain why film references to 'the cold of space' are inaccurate and why this is linked to the fact that exploration vessels would have to be polished to a high shine. (Answer: as a vacuum, space is, in fact, an almost perfect insulator. The biggest problem is to cool down the interior, as humans are excellent heaters. The Apollo capsules needed to be highly polished to avoid the crew being cooked by sunlight, visible and otherwise.

Homework
Use Test yourself questions 44–46 on page 212 of the textbook.

Temperature of the Earth: Lesson 22 (Physics only)

Learning outcomes

1 Consider effects of emission and absorption on temperature.
2 Consider factors affecting temperature of Earth's surface, at specific points and overall.

Suggested lesson plan

Starter
Explain to students that on a recent Duke of Edinburgh's expedition, a participant went missing. How could the helicopter search for them and why would this be easier on a cold day? (Giving a

medical physics context is an excellent opportunity to discuss careers.)

Main

It should be obvious to students that emission from an object will mean it cools, while absorption means the temperature will increase. A short discussion will allow students to expand this model to account for *net* emission or absorption being the important quantity to consider. The information summed up in Figure 6.71 on page 211 of the textbook (and available from the **T&L Diagram bank**) shows how two objects at the same temperature may be behaving differently in terms of absorbed, emitted and reflected radiation.

Although it is not listed in the Physics specification, a vitally important context here is, of course, climate change. It is not only one students will be familiar with (Chemistry Topic 9, Chemistry of the atmosphere) but one with huge social and political implications.

Students may be able to add to the factors discussed that affect the Earth's temperature. As well as cloud cover, most scientists accept that ice at the poles is responsible for reflecting at least some of the incident radiation back into space. One concern is that once the ice starts to melt, more incident radiation will be absorbed leading to a further increase in temperature.

Students should be able to explain the higher temperature of the equator than the poles in terms of the angle of incidence (NB: the Earth's axial tilt is not well depicted in the textbook diagram), as well as the different effects of cloud cover during the day and at night. A short digression into the different air temperatures in nearby regions of the atmosphere being responsible for wind may help students make sense of the overall picture.

The Test yourself questions 44 to 47 on page 212 of the textbook are a good way for them to demonstrate the necessary understanding,

Plenary

Ask students to explain the cooling of coffee in a cup in terms of changing amounts of emitted and absorbed radiation over time.

Support

The main idea here can be described as balance; if they are unsure, remind students to compare absorbed and emitted radiation, taking account of any information about an object being an imperfect black body.

Extension

Some students will recognise the difficulties in measuring the Earth's temperature in any meaningful way; you should be able to make clear that the vast weight of evidence supports an increase in global temperatures, unevenly distributed, which is both caused by humans and responsible for a growing number of extreme weather events.

Homework

Students should prepare for the **T&L Half-term test 4.6: Waves** using the Chapter review questions (pages 213–214) and the Practice questions (pages 215–217). **Homework tasks (a)** and **(b)** may also be useful if not already used.

Answers

AQA GCSE (9-1) Physics

Test yourself on prior knowledge

1 **a)** Seismic waves.
  b) Mechanical waves travelling on a rope.
  c) Examples of electromagnetic waves other than light, X-ray, radio waves, etc.

2 **a)** Seismic waves cause the ground to move – this energy can knock down buildings. We can work out where the centre of the earthquake was (information).
  b) Energy is transmitted in the vibrations of the rope. Information could be carried in a code of pulses.
  c) Radio waves carry energy in oscillating electric and magnetic fields. Radio waves carry information – TV and radio signals.

3 There is a time lag between hearing the thunder and seeing the lightning.

Test yourself

1 **a)** Draw a diagram like Figure 6.2 on page 181.
  b) Draw a diagram like Figure 6.4 on page 182.

2 In a longitudinal wave, areas of compression are the parts where the spring coils are close together (or an area of greater pressure in a sound wave).
A rarefaction occurs where coils of the slinky are further apart or, in sound, where the air pressure is less.

3 **a)** Up and down.
  b) The balls also move up and down.

4 A slinky transfers energy – we can feel a pulse being transmitted from one end to another. We could use a code (Morse code for example) to transmit a message down a slinky.

5 The pulses on rope A have a higher amplitude and a higher frequency than the pulses on rope B.

6 **a)** These are all one wavelength.
  b) This is the amplitude of the wave.
  c) **i)** 2 m
    ii) 30 cm
    iii) 3.5 m

7 $f = \frac{1}{T}$

a) 4 Hz

b) 100 Hz

8 $v = f\lambda$

$0.4 = f \times 0.08$

$f = 5\text{ Hz}$

9 Copy Figure 6.4 Page 182. One wavelength is the distance between two neighbouring compressions or neighbouring rarefactions.

10 You can time how long it takes for a pulse to be reflected out and down the slinky. If it takes 2 s to travel up and down twice:

$$v = \frac{d}{t}$$

$$= \frac{4 \times 5}{2}$$

$$= 10\text{ m/s}$$

11 $d = v \times t$

$t = 4.2 \times 1\text{ ms}$

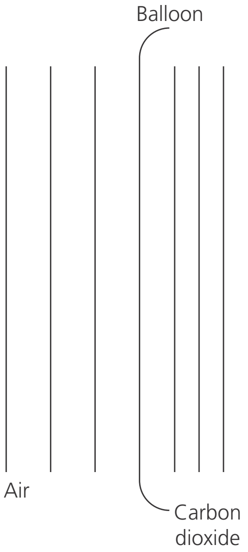
$= 4.2\text{ ms}$

$d = 330 \times 0.0042$

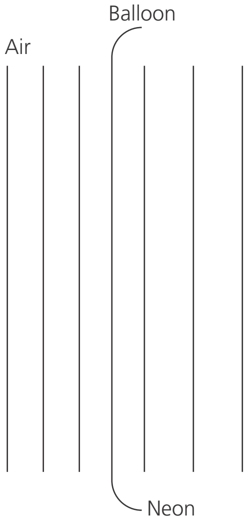
$= 1.39\text{ m}$

12 a) The frequency stays the same – this is the number of waves per second.

b) i)



ii)

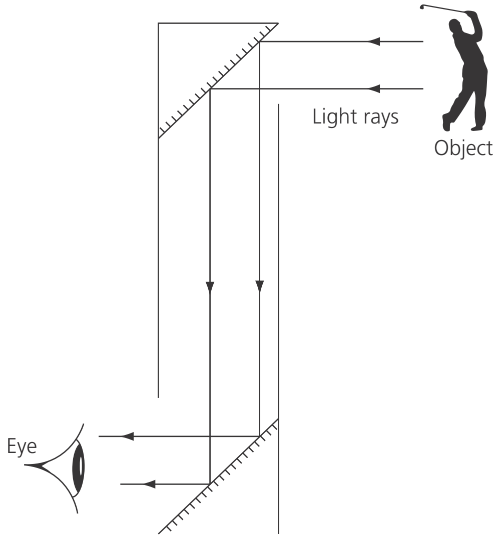


13 A plane mirror is a flat mirror – the glass is all in one plane.

14 a) 5 m behind the mirror.

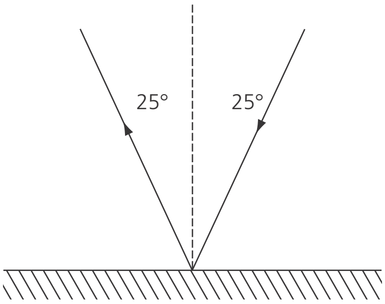
b) 4 m/s

15 a)



b) The image is the right way up and the right way round. (There have been two reflections.)

16

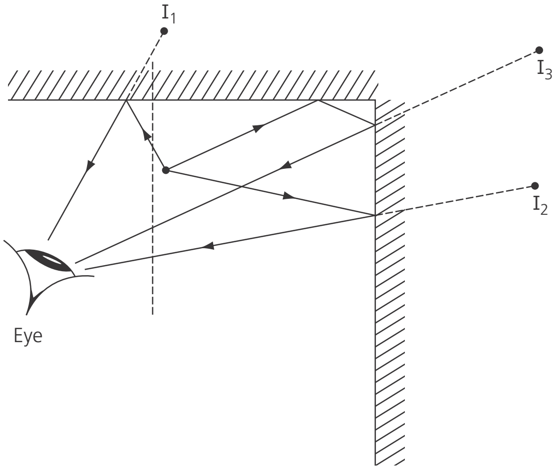


17 a) The panels have pyramid shapes which reflect the sound sideways. This reduces the energy moving forwards to the side of the room.

b) The soft foam absorbs energy.

18 a) 3

b)



This is very difficult to draw well, but follow these hints.

- Draw the image positions first. I_1 and I_2 are the same distance behind the mirror as the coin is in front. I_3 is the sum of these two image displacements.
- Now draw the rays as if they have come from the images.
- In drawing the rays for I_3, it helps to know that the ray from the coin and the ray from the image must be parallel.

19 a) Ultrasound is a sound wave with a frequency above our range of hearing (above 20 kHz).

b) The waves are reflected off the baby, and a computer builds up an image from the echoes.

20 $v = f\lambda$

$1600 = 5\,000\,000\lambda$

$\lambda = \dfrac{1600}{5\,000\,000}$

$= 0.00032\text{ m}$ or 0.32 mm

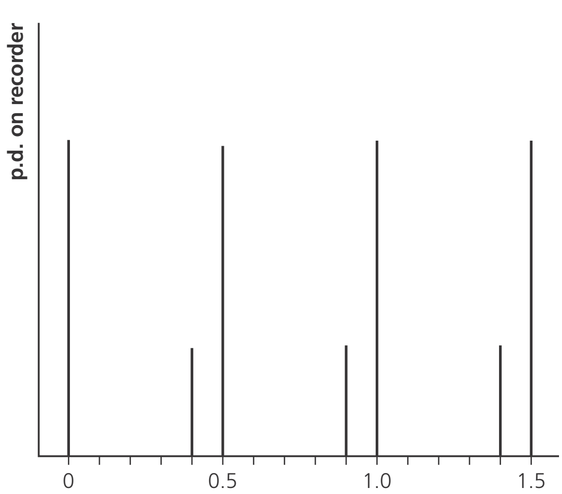
21 a) $d = 2 \times 150 = 300\text{ m}$

$d = vt$

$300 = v \times 0.2$

$v = 1500\text{ m/s}$

b)



c) $v = f\lambda$

$1500 = 50\,000 \times \lambda$

$\lambda = \dfrac{1500}{50\,000}$

$= 0.03\text{ m}$

22 a) Ultrasound is reflected off the bottom of the rail as well as the crack.

b) $t = 50 \times 10^{-6}$ s to travel twice the thickness of the rail.

$d = v \times t$

$= 6000 \times 50 \times 10^{-6}$

$= 0.3\text{ m}$

so the rail is 0.15 m thick

c) The crack is 3/5 × 0.15 m or 0.09 m below the surface.

23
- All travel at 3×10^8 m/s (speed of light) in a vacuum.
- They carry energy (in oscillating electric and magnetic fields).
- They carry information.
- They can be characterised by a frequency.
- They can be characterised by a wavelength.
- They refract when entering a different medium.
- They can be reflected off surfaces.
- They all have uses.
- They can call be dangerous at high intensity – (less so with radio waves).

24 Refraction – When waves are transmitted from one medium to another, the waves change speed and can also change the direction of travel.

Reflection – When waves are incident on the surface of a different medium, some (or all) of the energy is reflected back into the original medium. (The angle of reflection equals the angle of incidence.)

Absorption – When energy is absorbed from a wave, the amplitude of the wave (and therefore the energy carried by the wave) reduces. For example, infrared radiation is absorbed by meat in an oven. The wave energy is transferred into the meat which cooks.

Transmission – When an electromagnetic wave is transmitted through a medium, there is little absorption. For example, glass transmits light – we can see through glass.

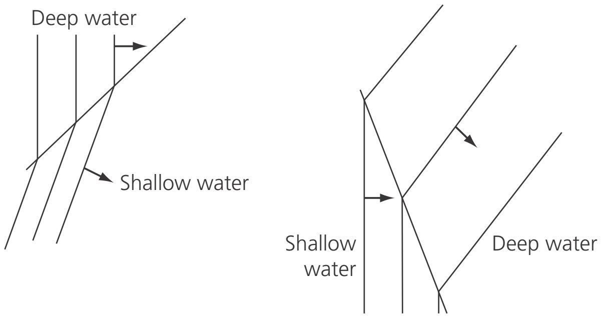
25 a)

$$v = f\lambda$$
$$3 \times 10^8 = 10^8 \lambda$$
$$\lambda = \frac{3 \times 10^8}{10^8}$$
$$= 3\,\text{m}$$

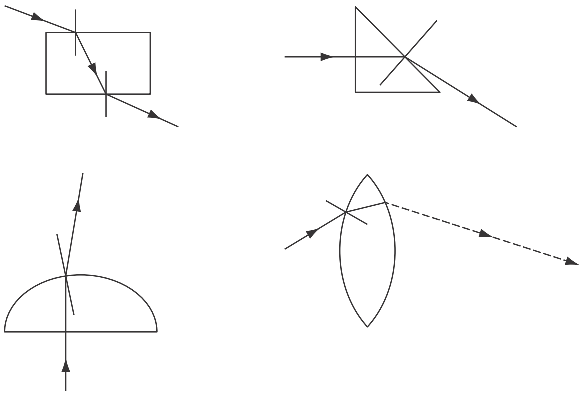
b)

$$f = \frac{3 \times 10^8}{1500}$$
$$= 200\,\text{kHz}$$

26



27



28 P-waves refract towards the normal as they pass from the mantle into the outer core.

29 X-rays and gamma rays.

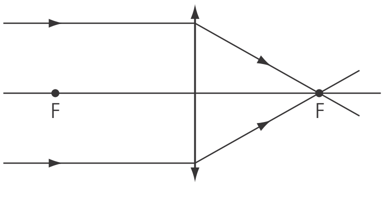
30 a) Radio waves.

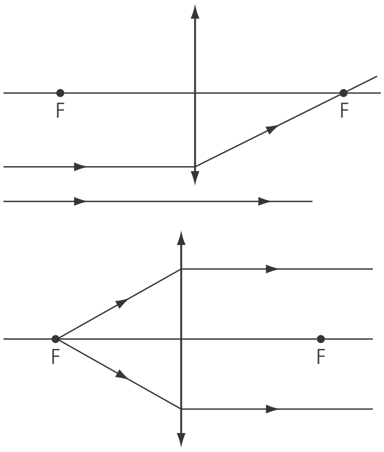
b) Ultraviolet. Ultraviolet radiation is most likely to cause skin cancer as we are exposed to it from the Sun. But large doses of X-rays or gamma rays could also cause skin cancer.

c) X-rays.

31 Choose from Pages 199–201.

32





33 a) Rays *appear* to diverge from a virtual focus, as opposed to a real focus where the rays converge to that point.

b) A concave lens always produces a diminished image.

34 a) i) A real image can be projected on to a screen, because rays converge to form that image.

ii) A virtual image can only be seen by the person looking through a lens (or at a mirror). The rays appear to come from the image.

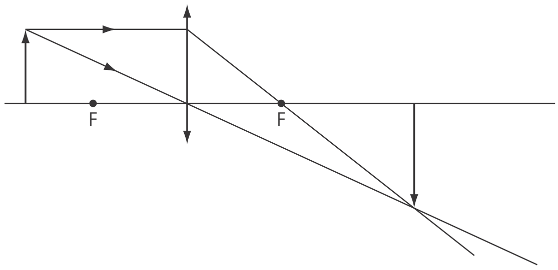
b) Virtual.

35 A, D

36 Figure 6.56: M = 0.84

Figure 6.58: M = 2.65

37 a)

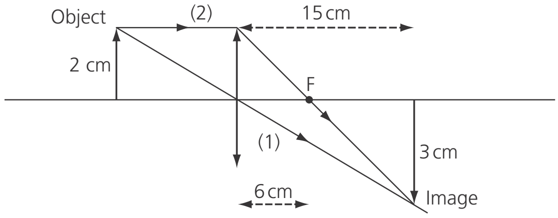


b) i) Real.

ii) Magnified.

iii) Inverted.

38 a)



- Draw an image 3 cm high (e.g.).
- Draw ray 1. This must pass through the centre of the lens and the top of the image. Extend it back to the object which must be 2 cm high (the magnification is × 1.5).
- Draw ray 2. This is parallel to the principal axis and is refracted through the focal point, and on to the top of the inverted image.

b) 6 cm.

39 a) Blue.

b) Black.

c) Black.

40

Colour of light	Shoes	Trousers	Shirt	Cap
White	red	green	blue	black and white
Red	red	black	black	black and red
Blue	black	black	blue	black and blue
Green	black	green	black	black and green

41 A colour corresponds to a particular colour of light. For example, wavelength *x* is green light. If an object absorbs *x* the object looks black. If wavelength *x* is reflected, we see green.

42 Different coloured lights travel at different speeds in glass. (Red light travels a little faster than green or blue light; green light travels a little faster than blue light.)

43 a) $v = f\lambda$

$$3 \times 10^8 = f \times 6.5 \times 10^{-7}$$

$$f = \frac{3 \times 10^8}{6.5 \times 10^{-7}}$$

$$= 4.6 \times 10^{14}\ \text{Hz}$$

b) $v = f\lambda$

$$3 \times 10^8 = 5.2 \times 10^{14}\lambda$$

$$\lambda = \frac{3 \times 10^8}{5.2 \times 10^{14}}$$

$$= 5.8 \times 10^{-7}\ \text{m}$$

44 Missing words: infrared, visible.

45 A hot piece of metal emits radiation and some of this is visible light. The colour of the light is related to the temperature of the metal.

46 A perfect black body emits as much radiation as it absorbs, when it is at a steady temperature.

47 Base your diagrams on Figure 6.72, page 211.

Show you can

Page 182

You can demonstrate the transmission of energy on a slinky. You can feel the energy of the pulse arriving, but the slinky does not pile up at the end.

Page 184

These terms are shown in Figure 6.8 on page 183.

Page 190

You can follow the instructions on page 189 to complete this task.

Page 193

You can complete this task by summarising the information about seismic waves on page 192.

Page 203

A high frequency alternating current makes electrons oscillate up and down inside the transmitting aerial. This sends an electromagnetic wave which transfers energy in its oscillating electric and magnetic fields. These fields then make electrons oscillate up and down in the receiving aerial, so that a current is produced and detected.

Page 207

This construction is to be found on page 206, Figure 6.58.

Page 212

In the day, clouds reflect infrared radiation from the Sun. So less radiation reaches the surface of the Earth and it remains cooler. At night, there is no Sun, but infrared radiation leaves the Earth's surface. Clouds can reflect this radiation back, so we feel warmer.

Practicals

Page 186

There are no questions set within this practical.

Page 197

1 With random errors the plotted data points are scattered about the line of best fit.

2 Repeat the measurement several times and then calculate a mean (average).

Page 202

1 Amount of infrared detected will depend on distance. So distance is a variable that must be controlled.

2 The type of surface is a categoric variable.

Chapter review questions

1 a) i) In a longitudinal wave, the vibrations in the medium are parallel to the direction of energy transfer.

ii) In a transverse wave, the vibrations in the medium are perpendicular to the direction of energy transfer.

b) Longitudinal: longitudinal waves on a slinky spring, sound waves, P-waves in an earthquake.
Transverse: transverse waves on a slinky spring, water ripples, electromagnetic waves, S-waves in an earthquake.

2 a) Infrared radiation (also visible light and ultraviolet).

b) Microwaves.

c) Ultraviolet (this is also dangerous and can cause cancer).

3 a) $T = \frac{1}{f}$

$= \frac{1}{512}$

$= 0.002\,\text{s}$ or $2\,\text{ms}$

b) $v = f\lambda$

$330 = 512 \times \lambda$

$\lambda = \frac{330}{512}$

$= 0.64\,\text{m}$

4 a) An echo occurs when sound is reflected off a large solid object – a cliff, for example.

b) $d = \text{speed} \times \text{time}$

$= 330 \times 4$

$= 1320\,\text{m}$

so the cliff is $\frac{1}{2} \times 1320 = 660\,\text{m}$ away as the sound has to travel there and back.

5 a) 20 cm

b) 60 cm

c) $T = \frac{2}{5}$

$= 0.4\,\text{s}$

d) $f = \frac{1}{T}$

$= \frac{1}{0.4}$

$= 2.5\,\text{Hz}$

e) One wavelength = 60 cm

f) $v = f\lambda$

$= 2.5 \times 0.6$

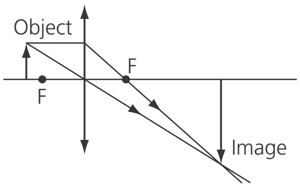
$= 1.5\,\text{m/s}$

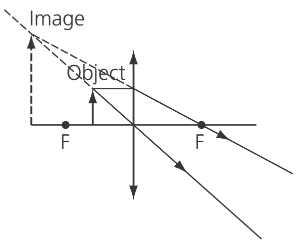
or $v = \frac{\lambda}{T}$

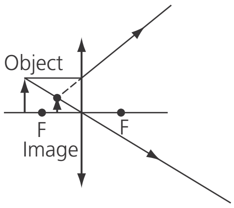
$= \frac{0.6}{0.4}$

$= 1.5\,\text{m/s}$

6 a)







b) i) Real, inverted, magnified.

ii) Virtual, the right way up, magnified.

iii) Virtual, the right way up, diminished.

c) These are approximate answers, because what you measure depends on exactly how you drew the figures.

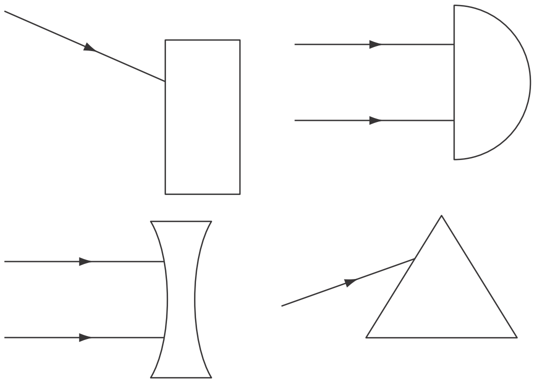
$$\text{magnification} = \frac{\text{image height}}{\text{object height}}$$

i) 2.4

ii) 2.2

iii) 0.4

7



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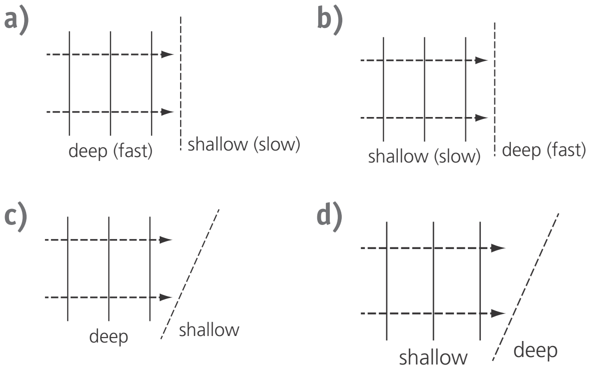

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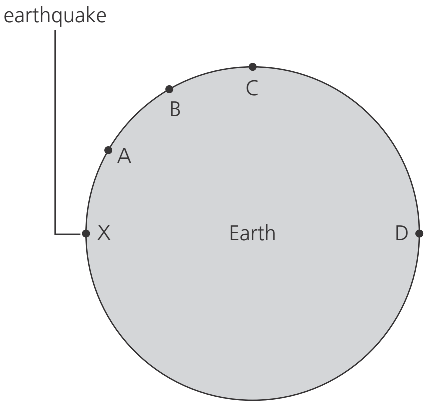


The Earth has a liquid core in its centre and a solid mantle outside. Transverse waves cannot travel through the liquid core, so they only reach points, A, B and C; they cannot reach D. So only longitudinal waves reach D.

Practice questions

1 a) Missing words: transmits, absorbs. *[2 marks]*

b) Killing cancer cells. *[1 mark]*

c) 40 *[2 marks]*

2 a) Magnified and virtual. *[1 mark] [1 mark]*

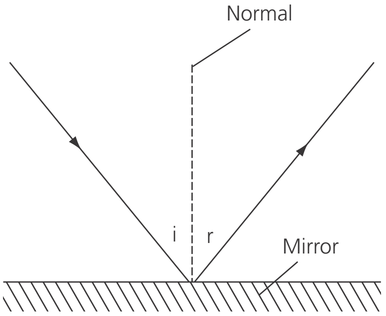
b) $\text{magnification} = \dfrac{\text{image height}}{\text{object height}}$

$= \dfrac{2.1\,\text{cm}}{6.7\,\text{cm}}$ *[1 mark]*

$= 3$ *[1 mark]*

3 a) The image in a plane mirror is virtual. *[1 mark]*
The angle of incidence equals the angle of reflection. *[1 mark]*

b) i) and **ii)**



[2 mark] [1 mark]

4 a) Sound waves are longitudinal waves.
A vibrating source of sound causes compressions and expansions in the air. *[1 mark] [1 mark]*
The vibrations in the air move backwards and forwards along the direction in which the sound travels. *[1 mark]*

b) i) 0.01 s *[1 mark]*

ii) $\text{speed} = \dfrac{\text{distance}}{\text{time}}$ *[1 mark]*

c) i) Student 1: $0.44 + 0.46 + 0.44 + 0.48 + 0.43 = 2.25$

$\text{average} = \dfrac{2.25}{5}$

$= 0.45\,\text{s}$ *[1 mark]*

Student 2: $0.5 + 0.6 + 0.4 + 0.4 + 0.6 = 2.5$

$\text{average} = \dfrac{2.5}{5}$

$= 0.5\,\text{s}$ *[1 mark]*

ii) $\text{speed} = \dfrac{\text{distance}}{\text{time}}$

$\text{speed} = \dfrac{150}{0.45}$

$= 333\,\text{m/s}$

or 330 m/s to 2 s.f. [Student 1] *[1 mark]*

$\text{speed} = \dfrac{150}{0.5}$

$= 300\,\text{m/s}$ to 1 s.f. [Student 2] *[1 mark]*

5 a) A: Visible light. *[1 mark]*
B: X-rays. *[1 mark]*

b) Infrared. *[1 mark]*

c) Microwaves. *[1 mark]*

d) Gamma rays. *[1 mark]*

e) Choose any two, for example:

i) Gamma rays, X-rays, ultraviolet.
Each of these radiations can cause cancer. *[1 mark]*
Infrared radiation can burn you. *[1 mark]*
Too much light can damage your eye, and even cause blindness. *[1 mark]*

ii) Ultraviolet. You can reduce your exposure to UV radiation by keeping out of the Sun, or by putting on sunblock cream. *[1 mark]*
X-rays. Radiographers wear lead aprons and keep away from X-ray machines. *[1 mark]*

6 a) White light is made up of all the colours. The red flower reflects the red light but absorbs all the other colours. *[2 marks]*

b) i) Red. *[1 mark]*

ii) Black. *[1 mark]*

7 a) i) D *[1 mark]*

ii) C *[1 mark]*

b) Transverse. *[1 mark]*
Although the wave oscillates up and down, the energy is transferred along the surface of the water at right angles to the surface. *[1 mark]*

c) $f = \dfrac{1}{4}$ *[1 mark]*

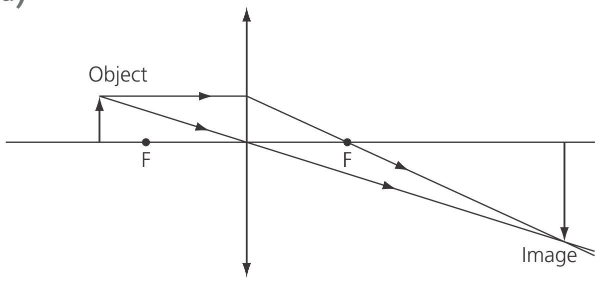
$= 0.25\,\text{Hz}$ *[1 mark]*

8 a) Ultrasound is a sound wave which has a frequency above our range of hearing. *[1 mark]*

b) distance = speed × time
= 1500 × 1.2 *[1 mark]*
= 1800 m *[1 mark]*
so water depth = 900 m *[1 mark]*

c) Ultrasound can be used for forming images of a foetus or body organs. *[1 mark]*

9 a)



Each ray. *[1 mark] [1 mark]*
Correctly drawn image. *[1 mark]*

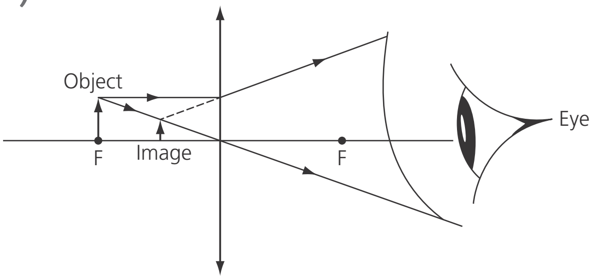
b) The image is: inverted *[1 mark]*
real *[1 mark]*
magnified. *[1 mark]*

c) $$\text{magnification} = \frac{\text{image height}}{\text{object height}}$$ *[1 mark]*

$$= \frac{1.5}{1}$$

$$= 1.5$$ *[1 mark]*

10 a)



Two rays. *[1 mark] [1 mark]*
One extended backwards. *[1 mark]*
Virtual image. *[1 mark]*

b) A virtual image only appears to be there. In this case, the rays diverge and the eye 'thinks' the rays have come from the virtual image position. *[1 mark]*
A real image can be projected onto a screen for everyone to see. *[1 mark]*

11 a) A longitudinal wave transfers energy with vibrations backwards and forwards along the direction of travel. *[1 mark]*
A transverse wave transfers energy with vibrations at right angles to the direction of travel. *[1 mark]*

b) S-waves cannot travel through the liquid, so they are all reflected. *[2 marks]*

c) P-waves travel more slowly in the liquid core. We can see this because they are refracted towards the normal. *[1 mark]*
[1 mark]

Working scientifically

1 $2.44\,\text{ms} = 2.44 \times 10^6\,\text{ns}$
2 Systematic error.
3 So they could go through the process of peer review.
4 Opinions.
5 When there is no doubt about the evidence, it is not contradicted by other evidence.
6 Probably not – it is only a small sample from the very large numbers of mobile phone users throughout the world.

AQA GCSE (9-1) Combined Science

Test yourself on prior knowledge

1 Seismic waves.
Mechanical waves travelling on a rope.
Examples of electromagnetic waves other than light, X-ray, radio waves, etc.
2 Seismic waves cause the ground to move – this energy can knock down buildings. We can work out where the centre of the earthquake was (information).
Energy is transmitted in the vibrations of the rope. Information could be carried in a code of pulses.
Radio waves carry energy in oscillating electric and magnetic fields. Radio waves carry information – TV and radio signals.
3 There is a time lag between hearing the thunder and seeing the lightning.

Test yourself

1 **a)** Draw a diagram like Figure 34.2 page 255.
b) Draw a diagram like Figure 34.4 page 256.
2 In a longitudinal wave, areas of compression are the parts where the spring coils are close together (or an area of greater pressure in a sound wave).
A rarefaction occurs where coils of the slinky are further apart or, in sound, where the air pressure is less.
3 **a)** Up and down.
b) The balls also move up and down.
4 A slinky transfers energy – we can feel a pulse being transmitted from one end to another.
We could use a code (Morse code for example) to transmit a message down a slinky.
5 The pulses on rope A have a higher amplitude and a higher frequency than the pulses on rope B.
6 **a)** These are all one wavelength.
b) This is the amplitude of the wave.
c) **i)** 2 m
ii) 30 cm
iii) 3.5 m
7 $f = \frac{1}{T}$
a) 4 Hz
b) 100 Hz
8 $v = f\lambda$
$0.4 = f \times 0.08$
$f = 5\,\text{Hz}$
9 Copy Figure 34.10 page 258. Distance b–f or d–g represent one wavelength. One wavelength is the distance between two neighbouring compressions or neighbouring rarefactions.

10 You can time how long it takes for a pulse to be reflected out and down the slinky. If it takes 2 s to travel up and down twice:

$$v = \frac{d}{t}$$

$$= \frac{4 \times 5}{2}$$

$$= 10\,\text{m/s}$$

11 $d = v \times t$

$t = 4.2 \times 1\,\text{ms}$

$= 4.2\,\text{ms}$

$d = 330 \times 0.0042$

$= 1.39\,\text{m}$

12 All travel at 3×10^8 m/s (speed of light) in a vacuum.
They carry energy (in oscillating electric and magnetic fields).
They carry information.
They can be characterised by a frequency.
They can be characterised by a wavelength.
They refract when entering a different medium.
They can be reflected off surfaces.
They all have uses.
They can call be dangerous at high intensity – (less so with radio waves).

13 Refraction. When waves are transmitted from one medium to another, the waves change speed and can also change the direction of travel.
Reflection. When waves are incident on the surface of a different medium, some (or all) of the energy is reflected back into the original medium. (The angle of reflection equals the angle of incidence.)
Absorption. When energy is absorbed from a wave, the amplitude of the wave (and therefore the energy carried by the wave) reduces. For example, infrared radiation is absorbed by meat in an oven. The wave energy is transferred into the meat which cooks.
Transmission. When an electromagnetic wave is transmitted through a medium, there is little absorption. For example, glass transmits light – we can see through glass.

14 a) $v = f\lambda$

$3 \times 10^8 = 10^8 \lambda$

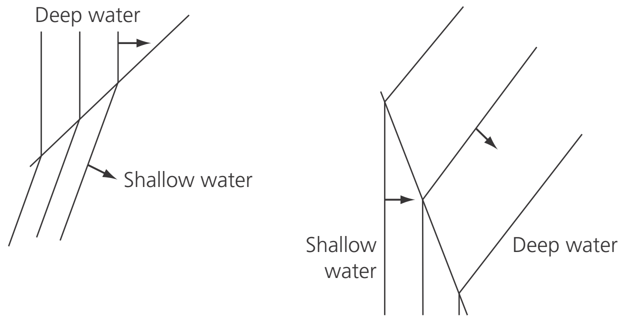
$$\lambda = \frac{3 \times 10^8}{10^8}$$

$$= 3\,\text{m}$$

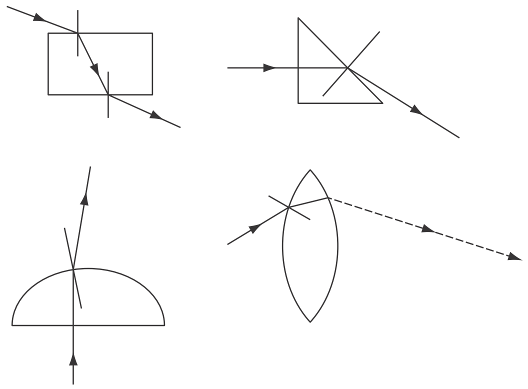
b) $$f = \frac{3 \times 10^8}{1500}$$

$$= 200\,\text{kHz}$$

15



16



17 X-rays and gamma rays.

18 a) Radio waves.

b) Ultraviolet. Ultraviolet radiation is most likely to cause skin cancer as we are exposed to it from the Sun. But large doses of X-rays or gamma rays could also cause skin cancer.

c) X-rays.

19 Choose from Pages 267–68.

Show you can

Page 256

You can demonstrate the transmission of energy on a slinky. You can feel the energy of the pulse arriving, but the slinky does not pile up at the end.

Page 258

These terms are shown in Figure 34.8 page 257.

Page 268

A high frequency alternating current makes electrons oscillate up and down inside the transmitting aerial. This sends an electromagnetic wave which transfers energy in its oscillating electric and magnetic fields. These fields then make electrons oscillate up and down in the receiving aerial, so that a current is produced and detected.

Practical

Page 269

1 Amount of infrared detected will depend on distance. So distance is a variable that must be controlled.

2 The type of surface is a categoric variable.

Chapter review questions

1 a) In a longitudinal wave, the vibrations in the medium are parallel to the direction of energy transfer.
In a transverse wave, the vibrations in the medium are perpendicular to the direction of energy transfer.

b) Longitudinal: longitudinal waves on a slinky spring, sound waves, P-waves in an earthquake.
Transverse: transverse waves on a slinky spring, water ripples, electromagnetic waves, S-waves in an earthquake.

2 a) Infrared radiation (also visible light and ultraviolet).

b) Microwaves.

c) Ultraviolet (this is also dangerous and can cause cancer).

3 a) $T = \frac{1}{f}$

$= \frac{1}{512}$

$= 0.002\,\text{s}$ or $2\,\text{ms}$

b) $v = f\lambda$

$330 = 512 \times \lambda$

$\lambda = \frac{330}{512}$

$= 0.64\,\text{m}$

4 a) An echo occurs when sound is reflected off a large solid object – a cliff, for example.

b) $d = \text{speed} \times \text{time}$

$= 330 \times 4$

$= 1320\,\text{m}$

so the cliff is $\frac{1}{2} \times 1320 = 660\,\text{m}$ away as the sound has to travel there and back.

5 a) 20 cm

b) 60 cm

c) $T = \frac{2}{5}$

$= 0.4\,\text{s}$

d) $f = \frac{1}{T}$

$= \frac{1}{0.4}$

$= 2.5\,\text{Hz}$

e) One wavelength = 60 cm

f) $v = f\lambda$

$= 2.5 \times 0.6$

$= 1.5\,\text{m/s}$

or $v = \frac{\lambda}{T}$

$= \frac{0.6}{0.4}$

$= 1.5\,\text{m/s}$

Practice questions

1 a) Missing words: transmits; absorbs. *[2 marks]*

b) Killing cancer cells. *[1 mark]*

c) 40 *[2 marks]*

2 a) Sound waves are longitudinal waves. *[1 mark]*
A vibrating source of sound causes compressions and expansions in the air. *[1 mark]*
The vibrations in the air move backwards and forwards along the direction in which the sound travels. *[1 mark]*

b) i) 0.01 s *[1 mark]*

ii) $\text{speed} = \frac{\text{distance}}{\text{time}}$ *[1 mark]*

c) i) Student 1: $0.44 + 0.46 + 0.44 + 0.48 + 0.43$

$= 2.25$

$\text{average} = \frac{2.25}{5}$

$= 0.45\,\text{s}$ *[1 mark]*

Student 2: $0.5 + 0.6 + 0.4 + 0.4 + 0.6 = 2.5$

$\text{average} = \frac{2.5}{5}$

$= 0.5\,\text{s}$ *[1 mark]*

ii) $\text{speed} = \frac{\text{distance}}{\text{time}}$

$\text{speed} = \frac{150}{0.45}$

$= 333\,\text{m/s}$

or 330 m/s (to 2 sf) [Student 1] *[1 mark]*

$\text{speed} = \frac{150}{0.5}$

$= 300\,\text{m/s}$ (to 1 sf) [Student 2] *[1 mark]*

3 a) A: Visible light. *[1 mark]*
B: X-rays. *[1 mark]*

b) Infrared. *[1 mark]*

c) Microwaves. *[1 mark]*

d) Gamma rays. *[1 mark]*

e) Choose any two, for example:

i) Gamma rays, X-rays, ultraviolet.
Each of these radiations can cause cancer. *[1 mark]*
Infrared radiation can burn you. *[1 mark]*

Too much light can damage your eye, and even cause blindness. *[1 mark]*

ii) Ultraviolet. You can reduce your exposure to UV radiation by keeping out of the Sun, or by putting on sunblock cream. *[1 mark]*
X-rays. Radiographers wear lead aprons and keep away from X-ray machines. *[1 mark]*

4 White light is made up of all the colours. The red flower reflects the red light but absorbs all the other colours. *[2 marks]*

5 **a)** **i)** D *[1 mark]*
ii) C *[1 mark]*
b) Transverse. *[1 mark]*
Although the wave oscillates up and down, the energy is transferred along the surface of the water at right angles to the surface. *[1 mark]*

c) $f = \frac{1}{4}$ *[1 mark]*

$= 0.25\,\text{Hz}$ *[1 mark]*

Working scientifically: Communication in science

Pages 272–73

1 $2.44\,\text{ms} = 2.44 \times 106\,\text{ns}$
2 Systematic error.
3 So they could go through the process of peer review.
4 Opinions.
5 When there is no doubt about the evidence, it is not contradicted by other evidence.
6 Probably not – it is only a small sample from the very large numbers of mobile phone users throughout the world.

7 Magnetism and electromagnetism

Overview

Specification points

4.7.1 Permanent and induced magnetism, magnetic forces and fields, 4.7.2 The motor effect and 4.7.3 Induced potential, transformers and the National Grid

Textbook chapter references

AQA GCSE (9-1) Physics: Chapter 7 pages 220–46

AQA GCSE (9-1) Combined Science Trilogy 2: Chapter 35 pages 274–86

AQA GCSE (9-1) Combined Science Trilogy: Chapter 35 pages 630–42

Recommended number of lessons: 13

Chapter overview	
AQA required practical(s)	N/A
Contains higher-tier material	Yes
Contains physics-only material	Yes

Useful Teaching and Learning resources

- Learning outcomes
- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–3
- Key terms
- Personal tutor: Transformers
- Homework tasks (a) and (b)
- Quick quizzes 1–4
- Answers for homework tasks
- Answers to all questions
- Half-term test 4.7: Magnetism and electromagnetism

Useful prior learning

- Some materials are magnetic. The most common magnetic materials are iron and steel.
- Magnets have two poles, north and south.
- Magnets attract magnetic materials at a distance. Magnetism is a non-contact force.
- Two like poles repel each other: a north pole repels a north pole; a south pole repels a south pole.
- Two unlike poles attract: a north pole attracts a south pole.

It is likely that students will recognise some links to previous GCSE work; in particular, references to generating electricity, non-contact forces and electrostatic fields will feature.

Common misconceptions

Students will often unify their mental models of magnetism and electrostatic forces. This is useful if guided; if they are not provided a structure which encompasses both effects they are likely to make mistakes which cause problems. In particular, they may find it difficult that there is no quantity of ‘magnetic-ness’ as a parallel to mass and charge.

Younger students will often assume that all metals are magnetic; hopefully work done at KS3 will have remedied this. When electromagnetism is encountered, it is worth ensuring that their understanding is clear. It is not that the copper wire becomes magnetic, but the current flowing in the wire which causes a magnetic field.

The actual causes of magnetic attraction and repulsion are very abstract. That doesn’t mean that they should not be introduced, but check that students realise that there is no way their lab experiments can shed light on this level of physics. Instead, the observable effects must be considered and shown to be consistent with underlying causes. As part of this, discussions of magnetic flux density are likely to cause some difficulties. Proper discussion of this quantity is reserved for A-level, so the best thing is to make an explicit parallel between magnetic flux density, B, and gravitational field strength, g, treating B as simply ‘magnetic field strength’ measured in tesla, T.

Connections between force, current and field are necessarily complex. Using a flow chart to recognise causes and effects in each case can be very helpful for students, starting with current or motion as appropriate.

When transformers are taught, students should make a clear distinction between the two electrical circuits. The principle of conservation of energy, along with $P = IV$, will help them to see how the quantities on the two sides are related. Some sources will use subscripts p and s (primary and secondary) for the coils, others i and o (input and output). Using 1 and 2 makes life much easier in some ways.

Preparation

The **T&L Prior knowledge catch-up student sheet** should be a quick way to reassure students that they have a good foundation for the topic to follow. It doesn’t examine their understanding of motors, which is probably for the best as this has also been addressed in a variable way. As the **T&L Prior knowledge catch-up teacher sheet** points out, students must recognise that repulsion, not attraction is the only true test of a magnet. Some

Institute of Physics (IOP) practicals are suggested but you may choose to save this guidance for the appropriate point in these lessons.

The exam specification makes it clear that work previously assumed from KS3 is now potentially examinable. This should make a relatively small difference but it does mean that the first six slides of the **T&L Topic overview** can be used immediately as most of it should be vaguely familiar, if not recalled fluently.

Poles and fields: Lesson 1

Learning outcomes

1 Describe attraction and repulsion.
2 Show a magnetic field (Fe filings).

Suggested lesson plan

Starter
Provide key words (e.g. iron, nickel, cobalt, steel, copper, wood, force, field, attract, repel, north pole, south pole) and have students write summary sentences of KS3 work.

Main
The focus here is to check understanding of the basics that were covered at KS3. You may feel, depending on student responses to the **T&L Prior knowledge catch-up student sheet,** that you can move on, or you could combine this work with the next lesson.

Students should be able to recall that only a few metals are attracted to magnets; we call these magnetic. Two magnets will show *attraction* and *repulsion*, depending on the orientation of the *poles*. Iron filings scattered around a bar magnet will show the shape of the *magnetic field*, but students should be aware that this extends into three dimensions. The closer together the lines are, the stronger the field; this can be checked by seeing that the dense lines near the poles are where the field has the strongest attractive or repulsive effect.

It may be worth reminding students of electrostatic fields and making an explicit parallel between them and the rules for magnetic and gravitational fields. Magnetic north and south poles take the place of positive and negative charges; fundamental properties of particles much too small to see that have effects we can detect, in the form of forces that can be attractive or repulsive. We don't measure the 'magneticness' of an object directly, but indirectly we can compare field strength.

- Gravitational fields affect anything with mass, but the force is always attractive.
- Electric fields attract or repel charged objects, depending on the magnitude and direction of the charge.
- Magnetic fields attract or repel north or south poles.

Ensure that students understand the difference between *permanent* and *induced* magnets; only objects made of magnetic materials (iron, steel, nickel or cobalt) can have induced magnetism. This is distinct from *electromagnetism*, which we sometimes say has been induced in any situation where a current flows.

Plenary
Students could correct the statements in **T&L Lesson starter 1** to check understanding. Alternatively, you could show them the electromagnetism apparatus and ask them to predict factors affecting the strength of the force caused.

Support
As review material, this should not cause any problems for most students. If questions are asked about what is happening, focus on the interaction of magnetic fields to cause attraction or repulsion between two magnets.

Extension
Some students are likely to be frustrated by what they see as vague explanations of the mechanism. The best response to this is to encourage them to see magnetic field behaviour as a parallel to electric fields. The attraction and repulsion seen in electrostatics was seen, measured and understood long before the nature of electrons was understood. The property of particles which makes them magnetic is another fundamental characteristic, but one which is much harder to describe in words. They can investigate the idea of electron spin but are unlikely to find it adds to their understanding of observed effects.

Homework
Use Test yourself questions 1–4 from page 223 (*277; 633*) of the textbook.

Making electromagnets: Lesson 2

Learning outcomes

1 Explain effect on compass.
2 Investigate strength.

Suggested lesson plan

Starter

Use **T&L Lesson starter 1** to check previous lesson's work (if not used as a plenary).

Main

This lesson has been included as a foundation for the later work on electromagnetism; you may choose to combine it with the next lesson, probably as a demonstration, or to omit it entirely.

Investigating factors affecting the strength of an electromagnet will depend on appropriate equipment in school. A rheostat will need to be in series with the coil so that the current can be kept consistent; otherwise it is likely that every power supply will end the lesson with a blown fuse.

It is important that students are clear about the nature of the magnetic field. Some will assume that the wire becomes magnetic, or that it only works with a soft iron core. A better model for them to consider is that the current flowing, in any kind of wire, will cause a magnetic field to be produced. In a very real way it is the current, not the wire itself, which is magnetic.

Students should record the evidence supporting their intuitive predictions that a higher current and greater number of coils both increase the strength of the magnetic field. A soft iron core also increases the strength but is not necessary.

Holding a plotting compass close to the solenoid will show that there is a magnetic field, and some students may recognise that it follows the same pattern as a bar magnet. Further discussion of this is included in the following lesson plan but some overlap is inevitable.

Plenary

Students should complete a flow chart showing that a current in the wire causes a magnetic field which then causes attraction (for magnetic materials) and/or repulsion (for other magnets, permanent or otherwise).

Support

For many students, the difficulty in this sequence (and that explored in the following lesson) is the move from the magnetic field around a single wire, to that observed around a solenoid. Various approaches are useful here but animations are probably the most reliable.

Extension

Students who grasp the idea here could be asked to consider the implication for moving charges. What can we say about a moving electron, for example? (Answer: treated as a tiny current, this suggests there will be a magnetic field caused by the motion.)

Homework

Students should review the terms used and their definitions.

(Induced) magnetic fields: Lesson 3

Learning outcomes

1 Predict/explain field around wire.
2 Extend this to a solenoid.

Suggested lesson plan

Starter

Students can complete a quick recall test for the definitions, based on the homework set at the end of the previous lesson.

Main

This lesson may be combined with the previous one if time is short and students show a good level of understanding.

Demonstrating the electric field around a straight wire is an important step for students building a mental model. The circles of iron filings cannot show the direction of the field, but students will logically suggest that reversing the direction of current will reverse the field direction. Plotting compasses can be used to show this, and that this can be modelled with the right hand grip rule. (See Figure 7.15 (*35.15*) on page 224 (*278; 634*) of the textbook, also available from the **T&L Diagram bank**.)

Students should draw the result of this experiment, annotating the diagram to explain the dot and cross notation and the arrows to show N to S field direction. This can be compared with the bar-magnet-type magnetic field observed around a *solenoid*, which should also be drawn; students need to understand the observations, but the geometry which explains the effect is not required. Animations may help with this, but a good mental model is to compare students walking down a corridor and up a spiral staircase.

Students should understand that although we may describe the field around a solenoid as an electromagnetic field, this is just to remind us that the magnetic field exists because of the electric current. The effects – attraction and repulsion – are exactly the same. What makes them useful is that the strength can be controlled easily and quickly, simply by changing the current. It is worth noting that high currents will cause heating, which is why many electrical devices will be warm in use; this is why for strong magnetic fields using a large number of coils is a better approach.

The use of electromagnets that exert a specific force depending on the current can be introduced using *relays*. Figure 7.18 on page 226 of the textbook (Physics only) is of a car starter but a similar approach is used in a circuit breaker. The important thing to note is that because the force can be determined based on the properties of the electromagnet, such a device can be built into a mechanical system. It will behave in predictable ways to oppose a spring or similar, depending on the value of current in the circuit.

Plenary
The work of the previous lessons can be checked by using **T&L Quick quiz 1**.

Support
If students struggle with the logic underlying the magnetic field of a solenoid, reassure them that the mechanism is not needed. What they will need to recall is the resulting field, which can be memorised and demonstrated with iron filings or plotting compasses.

Extension
Some students will be able to see the value of a circuit breaker which acts to prevent a high current without any destruction (unlike a fuse). Ask them to consider the other situations where limiting the current in a circuit that humans encounter (car engines, bank vaults, cranes) is a good idea.

Homework
Use Test yourself questions 5–9 from page 226 (*questions 5–8 on pages 279–280; 635–636*) of the textbook.

Force on a wire: Lesson 4

Learning outcomes

1 Define magnetic flux density.
2 Use $F = BIL$ equation.

Suggested lesson plan

Starter
Students should be able to answer the questions in **T&L Lesson starter 2**.

Main
NB technically, the equation used here would use a lower case l for length. As this is easily confused with I for current, the notation here follows the common substitution of L.

Ensuring that students realise that the lines of magnetic flux are a model, rather than a physical reality, discuss how we use them to represent the strength of a magnetic field. This may be a good opportunity to recap the diagrams showing the magnetic field around wires and solenoids. Define B as the *magnetic flux density* aka the magnetic field strength, measured in tesla (T). They should record explicitly that the value will vary depending on how far from the poles of a magnet it is measured.

Ask students to suggest factors that will affect the force acting on a wire because of a given magnetic field. As well as suggesting the field strength, with prompting they should recall that the force is actually acting on the moving charges; there are several ways they can express this. Provide the equation $F = BIL$ and be clear that, in most cases, the charges are contained in the wire so that is what the force is observed to act on. You may need to clarify that the length of wire involved is the length within the permanent magnetic field. What is actually happening is that the permanent magnetic field and the electromagnetic field caused by the moving charges are interacting.

Provide worked examples with realistic values for the magnetic flux density. Students should appreciate that 1 tesla is a strong field; lab magnets will be less than a tenth of this and the Earth's magnetic field has a value of 25–65 μT.

Plenary
Show students the apparatus for the motor effect, and ask them to predict what will happen when the circuit is completed. Then leave them in suspense.

Support
If students are unsure about the equation, it is likely to be because they struggle to understand why the length of wire is important. Remind them that the magnetic field acts on all the moving charges, and a longer wire has more charges.

Extension
Ask students to consider the limitations of the model: the equation assumes that the same magnetic flux density acts on the whole length of wire, and nothing else. What might cause the effect to be larger or smaller?

Homework
More questions could be set for practice or students could be asked to review all quantities discussed, with symbols and units, as well as those in the Electricity topic.

The motor effect: Lesson 5

Learning outcomes

1 Explain, use Fleming's left-hand rule.
2 Apply to moving wires demos.

Suggested lesson plan

Starter

Ask students to make a fresh prediction for the demonstration, explaining their ideas with reference to forces.

Main

There are several possible demonstrations of the motor effect; it can often be worth saving the most dramatic for a whole-class demonstration, rehearsing your questions and ensuring students are looking for the right effects. Some versions will require a strong permanent magnet; alternatively, the Earth's magnetic field is enough to cause a long strip of aluminium foil to 'flick' when a current flows briefly. (If you leave it connected the fuse of the powerpack tends to blow, but by switching on and off in time it can be made to swing to and fro.) Details at Practical Physics: http://practicalphysics.org/flemings-left-hand-rule-using-earths-magnetic-field.html.

Once the basic principle is established, use other demonstrations to check the perpendicular arrangement of current, field and force. For some variants, students can feel the movement of the wire as well as seeing it. Although recall of Fleming's left-hand rule is not required, students do need to recognise that each vector is at right angles to the other. The standard mnemonic is helpful for this:

- First finger: Field
- seCond finger: Current (alternatively use Curse finger: Current)
- thuMb: Motion (alternatively use Thumb: Thrust)

Students should be able to apply this to predict the motion for each following example. Ensuring a range of field and current directions will help to check that they are making thoughtful predictions; once motion is observed once for an arrangement, it requires no understanding to predict opposite movement if current or field are reversed.

Students should record a summary of the factors affecting the size of the force acting on the conductor and recognise that this is described by the equation from the previous lesson ($F = BIL$). You may need to explicitly state that if the field and current are parallel, rather than at right angles, there is no force. Students may then recognise that the forces calculated, for right angle arrangements, are the maximum possible; if angles are between 0 and 90, the force will be somewhere in between too.

Plenary

Provide values for students to work out the force acting on a mains overhead cable ($I = 500\,\text{A}$, $L = 200\,\text{m}$, taking Earth's magnetic field as $B = 50\,\mu\text{T}$ gives $F = BIL = 5\,\text{N}$). Even without calculating the weight of the cable (200 m of 300 mm^2 CSA cable will have a mass of approximately 500 kg so 5 kN), students should recognise this force is irrelevant, being equivalent to 500 g.

Support

As with many other concepts in this topic, it is often useful to remind students to check if a force is due to one magnetic field (which means it must be attractive) or two magnetic fields, which can be permanent or temporary i.e. electromagnetic.

Extension

Examples could be considered – perhaps by showing animations rather than 'live' – where the conductor is fixed in place so it is the magnet which moves.

Homework

Use Test yourself questions 10–13 from page 229 (*questions 9–12 on page 282; 638*) of the textbook.

Motors and loudspeakers: Lesson 6 (some Physics only)

Learning outcomes

1 Label important parts of a motor.
2 Apply this to coil in a loudspeaker.

Suggested lesson plan

Starter

Recap factors affecting the force acting on a current-carrying conductor.

Main

The equipment available will determine whether you feel the time needed for students to build a motor is worthwhile. If unreliable, the apparatus will be a distraction rather than a learning opportunity.

Students should be able to label the features of a d.c. motor, paying particular attention to the split-ring commutator. Understanding this will require a clear mental model of how the force acts on the current flowing, rather than the wire itself. You may wish to use a version of Figure 7.27 (*35.26*) on page 230 (*283; 639*) of the textbook and available from the **T&L Diagram bank**. If demonstrating a motor, it can help to show the force acting at various points, by starting it with the coil at different orientations compared with the magnet.

Students should be able to use the ideas reviewed during the starter to suggest factors which will increase the speed of rotation. You may need to point out that friction and air resistance will reduce this speed. (Students could be asked why *speed*, not *velocity* is correct here; remind them if needed that circular movement implies a changing direction.)

Students should record examples of electric motors (whether mains or battery-powered) in everyday use.

The material on loudspeakers is Physics only. Demonstrate a loudspeaker cone in action, ideally connected to a signal generator and oscilloscope. Emphasise that the signal, in this case, is a changing potential difference which produces a directly proportional current in the wire. The frequency of the alternating potential difference is therefore equal to the resulting frequency of the moving loudspeaker.

Plenary
T&L Quick quiz 2 covers ideas from the last few lessons.

Support
Take time to break down the sequence of events, noting changes of direction of the force, so the need for and function of the split-ring commutator is clear. Animations or slow-motion video can be useful here.

Extension
Ask students to explain why most battery-operated motors (e.g. in remote control cars) slow down as the battery ‘runs out’. (Answer: the potential difference supplied and resulting current is not consistent.)

Homework
Use Test yourself questions 14–18 from page 231 (*questions 13–16 on page 284; 640*) of the textbook.

Combined Science students can now complete **T&L Homework tasks (a)** and **(b)** as preparation for the **T&L Half-term test 4.7: Magnetism and electromagnetism**. From the textbook there are also the Chapter review questions (page 285; 641) and the Practice questions (page 286; 642).

Inducing potential: Lesson 7 (Physics only)

Learning outcomes

1 Factors affecting induced p.d. (practical).
2 Explain the use of a solenoid.

Suggested lesson plan

Starter
Provide a flowchart with missing information, starting with potential difference causing current in a wire and finishing with movement of the wire in a magnetic field due to the motor effect.

Main
Set up the practical shown on page 232 of the textbook or similar. Demonstrate that current is induced when the wire is moved within the magnetic field. Before anything else, ensure they realise that this implies that a potential difference has been *induced*. (You may wish to remind them of other ways in which a potential difference can be set up, for example by a chemical reaction in a cell or light falling on a photovoltaic cell.) Define this as the *generator effect*.

Students should predict the effect of changing the direction or speed of motion then test it out if equipment is available. Linking back to the previous lessons, you should show that if the motion is parallel to the magnetic field there is no current observed. Emphasise that it is the motion of the wire which induces the potential difference.

Demonstrate the effect of dropping a magnet through a coil of wire. The reduction in speed of the magnet (due to the force acting against motion) may not be obvious to students unless compared with a dropped lump of metal which is not magnetic; this demonstration of Lenz’s Law is dramatic and surprising, so makes a good starting point for the ideas explained on page 233 of the textbook.

If possible, demonstrate the potential difference of a turbine spinning near a solenoid as an oscilloscope trace (see Figure 7.33 on page 233 of the textbook, or from the **T&L Diagram bank**). Discuss how the flow rate can be worked out once the device is calibrated and how this is used in enclosed tubes, e.g. oil pipelines.

Plenary
Return to the flowchart used in the starter and have students produce a version that reverses cause and effect.

Support
Emphasise that whether it is the magnetic field or position of the wire that is changing, a potential difference is induced. The following lesson will allow them to consolidate their understanding of both the uses of this and the factors affecting the characteristics of the induced potential difference.

Extension
Ask students to explain how they could work out the strength of the magnetic field caused by the induced current. (This could be calculated by rearranging $F = BIL$ if the opposing force can be measured.)

Homework
Use Test yourself questions 19–21 from page 233 of the textbook.

Alternators: Lesson 8 (Physics only)

Learning outcomes

1 Describe the oscilloscope trace.
2 List factors increasing induced p.d.

Suggested lesson plan

Starter
Check previous lesson content using the application questions described in **T&L Lesson starter 3**.

Main
You may wish to combine this lesson with the one following, so that a clear contrast can be made between *alternators* (which produce alternating current) and *dynamos* (which produce direct current).

Demonstrate the oscilloscope trace showing induced potential difference of a coil in a magnetic field. Show how the trace changes when the speed of rotation is changed. Depending on the apparatus, the use of a bulb in the circuit will show how the brightness changes over time for lower speeds. (If an LED is used, the flickering will be clearer as no light will be produced for half of each cycle.) Remind students that the *maximum* or *peak potential difference* is not the same as the *effective potential difference*.

Students should recognise that, no matter what the orientation, no potential difference is induced if the coils are stationary. Figure 7.34 (page 234 of the textbook, and available from the **T&L Diagram bank**) makes a useful link between the oscilloscope trace and the various positions, but it should be emphasised that this only applies as snapshots of a *moving* coil.

As well as listing the four methods of increasing the induced potential difference (rotating the coil faster, using stronger magnets, using more turns of wire, and wrapping the wire round a soft iron core), students should be able to explain why the only one affecting the frequency is the rotation speed. Remind them that mains supply in the UK is at 50 Hz, implying an alternator spinning at 3000 rpm. This is not what happens; instead, the alternating potential difference produced by the alternator is converted into direct potential difference (by a rectifier) then converted back at the appropriate value (by an inverter). NB: This process is not on the specification.

Plenary
Ask students to apply the factors increasing induced potential difference to the design of a power station turbine.

Support
As before, a slow-motion video of the turning coil matched to the oscilloscope trace, or an animation which can be paused, will help students link the cause and effect. Ensure that students describe the magnet appropriately; some will replace ‘stronger’ with ‘bigger’ which will lose them exam marks.

Extension
Students should recognise that the factors cannot all simply be increased for a power station, for example we cannot make the wind blow faster to increase rotation speed. Stronger magnets are likely to be bigger and heavier. How might they find out the best compromise for any situation?

Homework
Depending on the lesson arrangements, students could read ahead to cover material on dynamos and microphones; the Test yourself questions on page 236 of the textbook will then check their understanding.

Dynamo: Lesson 9 (Physics only)

Learning outcomes

1 Explain use of split ring commutator.
2 Recap power stations.

Suggested lesson plan

Starter
It may be useful to use **T&L Quick quiz 3** here, as it reminds students of the use of oscilloscope traces in recent contexts.

Main
It is possible the ideas from this lesson will either have been covered as an extension to the last one, or set as homework.

Remind students of the split-ring commutator as used within a d.c. motor and show how it can be used with a spinning coil in a magnetic field to induce a potential difference in a constant direction. Define a *dynamo* as a spinning coil that induces a *direct potential difference*. Contrast the oscilloscope trace with that for the alternator. Emphasise that there is still a changing potential difference, but that it is steadier as the sign is consistent. If a bulb is part of the circuit, some flickering may be seen if the speed is low enough. Students will recognise that the factors affecting the value are the same as the alternator.

Provide examples of oscilloscope traces and have students distinguish between alternator and dynamo patterns, as well as reading off values for peak potential difference induced and frequency.

Discussion of power stations will depend on time available, but students should be aware that, in most cases, alternators are preferred as a.c. is easier to manipulate with transformers (covered in a later lesson). It is more important for students to apply their understanding of the factors to a real-life situation; it is unlikely that they will have used dynamo bike lights, but the same principles are used to charge car batteries while driving and in regenerative braking, used to slow some electric and hybrid vehicles in addition to friction brakes.

Plenary
Demonstrate a wind-up torch to students and ask them to explain what is happening in terms of induced potential difference.

Support
Apart from any difficulties in reading values from the oscilloscope traces, students should have no difficulty here. Provide reminders where needed that amplitude is measured from the zero line, and that the time must be measured for a complete cycle (two peaks for d.c., one positive peak and one negative for a.c.).

Extension
A standard phone charger provides a current of one amp and is used for 4–6 hours; ask students to consider the practicality of charging a phone using a hand-cranked charger. (Answer: less than ideal)

Homework
If this has been taught as a distinct lesson, it may be worth treating the microphones work as a self-study opportunity and having students complete the Test yourself questions on page 236 of the textbook for checking.

Microphones: Lesson 10 (Physics only)

Learning outcomes

1 Recap use of a loudspeaker.
2 Describe microphone function.
3 Draw a flow chart including an amplifier.

Suggested lesson plan

Starter
Give a mixed up list of observations for a loudspeaker (change in potential difference, change in current, change in strength of electromagnetic field, force between coil and magnet, movement, emission of sound wave) and have students put them in order with explanations about each stage.

Main
Compare the use of a signal generator and loudspeaker with a microphone and oscilloscope; it should be possible to show the two signals on the same trace to compare the emitted and detected waves. Students should recognise the process involved as the reverse of a loudspeaker, with the electrical signal being induced by movement of the coils within a magnetic field.

Students could annotate a diagram of a microphone with the distinct stages, using this as an opportunity to revise the properties of sound waves.

The use of amplification should be discussed; the signal (not the sound) undergoes amplification when the amplitude is increased without changing the frequency. This higher amplitude signal is then used to drive a loudspeaker which produces a louder sound.

Plenary
Students could consider why mobile phone microphones and speakers produce poorer quality sound than larger ones.

Support
Encourage students to see this as a simple example of an induced potential difference; comparing the diagrams (or if available, deconstructed models) of a microphone and loudspeaker will help them to understand the process.

Extension
Ask students to explain situations where the signal is transferred between microphone and loudspeaker as an electromagnetic wave, e.g. Bluetooth speaker used to broadcast audio from a phone call.

Homework
If not yet done, Test yourself questions 22–23 from page 236 of the textbook.

Investigating transformers: Lesson 11 (Physics only)

Learning outcomes

1 Sequence p.d., current, field.
2 Factors affecting output p.d.

Suggested lesson plan

Starter
Recap the ideas covered in the Electricity topic, for example by having students label a version of Figure 2.45 (page 55 of the textbook or available from the Electricity section of the **T&L Diagram bank**).

Main
NB: Most schools will have a transformers kit, but they are often quite temperamental. It is worth checking available equipment and having a few selected pairs of coils ready with the appropriate meters.

Remind students that a changing current in a wire causes a magnetic field. Contrast this with induction, where a wire in a changing magnetic field has a potential difference (and therefore current) induced.

If possible, first demonstrate the effect of a transformer by switching a direct current on, then off. If set up correctly this will cause the ammeter on the secondary coil to flick one way then the other. It will quickly return to zero and you can remind students that only a changing magnetic field will induce a potential difference and therefore current. Repeating with an alternating current will give a steady value on the secondary coil.

The investigation as described on page 237 of the textbook will only be practical if the equipment is available and you are confident students are reliable. You may choose instead, to demonstrate the effect with carefully chosen combinations of coil sets. One way to provide a prompt for yourself is to pre-draw the results table, on the board or electronically, with the values added.

It is important that students recognise that there is no electrical connection between the two circuits. Instead, the changing magnetic field caused by the primary current induces a secondary current; the laminated soft iron core means the magnetic field is shared effectively and there is nearly 100% efficiency. The maths is covered in the following lesson but it is likely that students will start to recognise some factors affecting secondary values quickly.

As noted in the preamble, there are different forms of notation used to differentiate between values in the two coils; *primary* and *secondary* (subscripts p and s) and less often *input* and *output*. Students may prefer to use 1 and 2 as subscripts but should know what will be presented in exam questions. Potential difference (V) and current (I) will be familiar and n for number of turns of wire on a coil is straightforward.

Plenary
Returning to the National Grid diagram from the starter, define a step-up transformer as one which has more turns on the secondary coil than the primary.

Support
You may need to round the values obtained so that the relationships are clearer; some students may struggle with the idea that there are two distinct circuits. Emphasise that the potential difference in the secondary coil is induced by the changing magnetic field, not directly by the primary potential difference.

Extension
Ask students to explain why a direct current supply to the primary coil will only produce a current in the secondary coil when it is turned on or off. (Answer: this is when the current is changing.)

Homework
T&L Personal tutor: Transformers may be useful if students can access it from home. Ensure that they know that the last slide about switch-mode transformers, although relevant to the devices they use as home, is no longer required for the specification.

Explaining transformers: Lesson 12 (Physics only)

Learning outcomes

1 Work through maths examples.
2 Solve problems independently.

Suggested lesson plan

Starter
Students should annotate a diagram showing primary and secondary coils on a soft iron core.

Main
Ensure that students have labelled quantities correctly (V_P, I_P and n_P for the primary or input coil, V_S, I_S and n_S for the secondary or output.)

A good start is to show that the ratio between potential differences (V_S/V_P) is equal to the ratio between numbers of turns (n_S/n_P). This relationship is easiest to appreciate when the ratio is an integer such as 2, 5 or 10. Proportional reasoning here will help students, but you must emphasise that the link is between the ratios, not the actual values directly. In principle, two transformers with a 1 : 2 ratio will work the same no matter how many actual turns are on each coil.

(If the equipment is available, students could check this with various combinations that 'should' double the output potential difference).

Model the working needed to find a 'missing' value when three of the four are provided for potential difference and number of turns. (A good starter might be the Example at the top of page 237 of the textbook). Give some questions for students to complete independently.

Before considering the current, remind students of the principle of conservation of energy. Because electrical current is best considered as a pathway, rather than a store, this means we can think of the power as being conserved. Students may need to be reminded of $P = VI$ but should then be able to recognise that if the efficiency is 100% $V_P I_P = V_S I_S$. This can be rearranged – being careful with subscripts – to show that the ratio for current is the opposite to that for potential difference: $I_P / I_S = V_S / V_P$.

In simple terms, this means that whatever multiple is used for potential difference must be used to divide the current value. A *step-up transformer*, it should be emphasised, increases potential difference. The current is *reduced*. Model the working needed, emphasising the need to take care with subscripts. It is worth students noting that they can always predict the comparison (larger than, smaller than) as a simple check.

Return to the examples and provide either primary or secondary current, and have students calculate the other current value for each.

Plenary
T&L Quick quiz 4 finishes with a question about how scientists work within society, which may be a useful link to the next lesson.

Support
All the way through, students have learned that increasing the potential difference means increasing the current. This habit will cause problems for some when dealing with transformers until they grasp the fact that power must be conserved between the two coils.

Extension
Using one of the earlier examples, ask students to work out the potential difference and current on the secondary coil if the efficiency is only 95%. Ask them to predict what happens to the rest of the energy. (Answer: it causes heating of the soft iron core.)

Homework
Use Test yourself questions 24–27 from page 239 of the textbook.

Transformers in the National Grid: Lesson 13 (Physics only)

Learning outcomes

1 Recap parts of National Grid.
2 Explain efficiency reasons for step-up and step-down transformers.

Suggested lesson plan

Starter
Review example values for the potential difference and current at different points of the National Grid; Figure 7.42 on page 238 of the textbook (also available from the **T&L Diagram bank**) may be a useful resource.

Main
Although the national grid has been covered in several approaches, the focus here is on the mathematical reasoning which makes high voltage transmission necessary. Students should recall that high voltages are dangerous because they can cause sparks; these can start fires and if a person provides the route to earth they are likely to be injured. (Higher currents are more dangerous, but a lower voltage would mean you don't have to stay so far away from the cables.)

Remind students of the electrical power equation $P = VI$. A simple filament bulb demonstrates that the wire heats the room when current flows, but even good conductors have noticeable resistance if the wire is long enough. Substituting in the relationship of Ohm's law ($V = IR$) gives the more useful equation for power 'lost': $P = I^2R$. Students need to recall this for the exam but should record the derivation as a reminder: three equations for the 'price' of two.

Use a worked example, either with your own numbers or those in the textbook, and ensure that students understand that the reduced heating effect means higher efficiency in terms of electrical power. (Point out that this translates, as is often the case, to lower costs.) If values of 23 kV at the generator and 230 kV across the pylons are used, the numbers lend themselves to a turns calculation for the transformers too. Explain that the numbers provided are simplified and that the voltage is stepped down in several stages, the last one being the substations they see on local streets.

Plenary

Ask students to estimate the power 'loss' for a similar cable in America which is 2000 km long (ten times as far). Hopefully they will recognise that the resistance (and so the power loss) will be multiplied by the same factor; this explains why more than one power station is needed.

Support

Students may be surprised by the low value of resistance for a long cable; showing them images of the cable itself (e.g. 300 mm^2 cross sectional area) may help.

Extension

Ask students to explain why we don't simply use a better conductor to reduce the resistance, rather than going through the hassle of transformers. (Answer: although better conductors exist, they are expensive. Even copper cables get stolen – see the Darwin Awards website for unfortunate yet funny stories of this – so replacing them with silver is impractical, to say the least.)

Homework

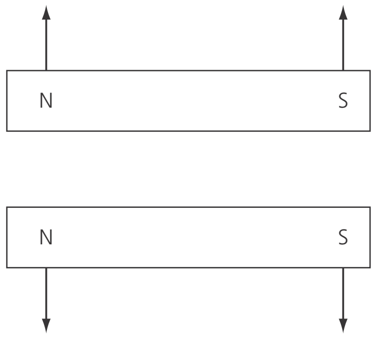
Students can now complete **T&L Homework tasks (a)** and **(b)** as preparation for the **T&L Half-term test 4.7: Magnetism and electromagnetism**. From the textbook there are also the Chapter review questions (pages 240–241) and the Practice questions (pages 242–244).

Answers

AQA GCSE (9-1) Physics

Test yourself on prior knowledge

1



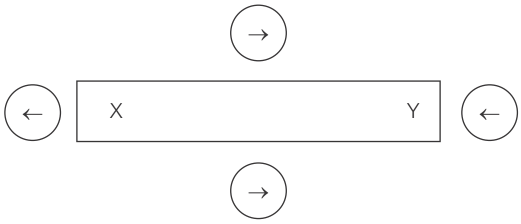
2 Missing words: magnetises, south, north, weight.

3 The head of each nail is magnetised south. Since like poles repel each other, the pins repel and stick out sideways.

Test yourself

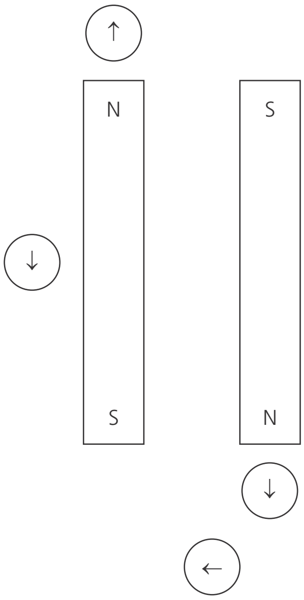
1 Steel pin, iron nail.

2 a)



b) X is north; Y is south. The compass needle points away from X and towards Y.

3



4 a) A permanent magnet always produces a magnetic field. It has two poles, north and south.

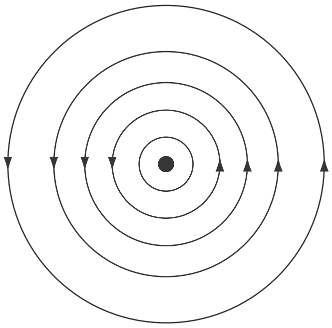
b) Some materials become magnetic, when placed in a magnetic field. These are induced magnets.

5
- Increase the current.
- Increase the number of turns.
- Put the turns closer together.
- Insert iron into the turns.

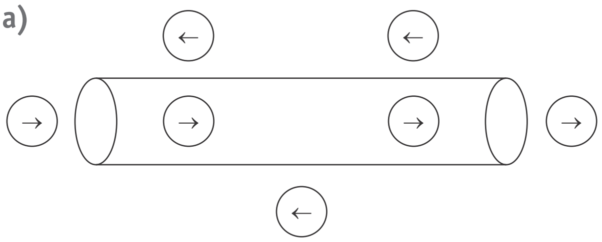
6 To ensure that the current flows through each turn, without the current crossing from coil to coil or flowing through the iron.

7 A, C, D, E, B.

8



9 a)



b) The left end.

c) The compasses all change direction by 180°.

d) The field will be the same shape as Figure 7.16, Page 225; but the direction of the field depends on the direction of the current.

10 Increasing the magnetic field strength; increasing the current in the wire.

11 Placing the wire so that the current is parallel to the magnetic field.

12 a) ↓

b) ↓

c) →

d) →

13 $F = BIL$

$= 2 \times 4.5 \times 0.2$

$= 1.8\,\text{N}$

14 BC is parallel to the magnetic field so there is no force on the wire.

15
- Increase the current.
- Increase the number of turns.
- Increase the strength of the magnets.

16 a) The force on the coil reverses direction.

b) The coil and cone oscillate from right to left.

c) i) The frequency of the vibrations increases.

ii) The amplitude of the oscillations increases and therefore the sound level.

17 a) i) Down.

ii) Up.

b) Anticlockwise as we look at it (from the end AD).

c) When it is vertical.

18 a) i) This is reversed.

ii) This is reversed.

iii) The direction of the force stays the same.

b) Both a.c. and d.c. supplies cause the coil to rotate. The a.c. supply works because both the current direction and magnet polarity reverse, but the rotation force is not changed.

[See Question 12 on Page 229.]

c) The parallel supply allows different currents to be supplied to the magnet and coil.

19 Move the wire faster; use stronger magnets.

20 a) Zero.

b) When the north pole is pushed in, the meter deflects to the right – Figure 7.32 a).

i) left

ii) right

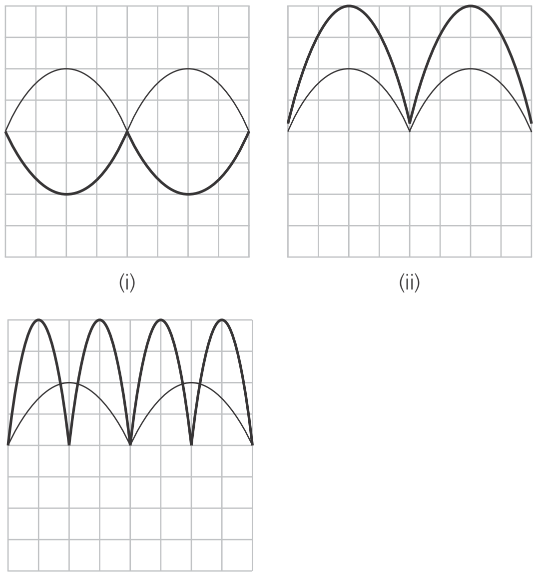
iii) left

21 When a north pole approaches, there is a positive p.d. induced and therefore a negative p.d. induced as the north pole goes away. This happens the other way round when a south pole approaches and then goes away from the coil.

22 a) At A, C, E the coil is vertical.

At B and D the coil is horizontal.

b)



(i)

(ii)

(iii)

23 When the sound is louder, the amplitude of the vibrations in the air is greater. Then the diaphragm moves with greater amplitude; this means that the coil moves faster past the magnet, and so induces a larger p.d.

24 a) The ammeter kicks when the switch is closed, then reads zero.

b) The ammeter kicks.

c) The ammeter reads zero.

d) The ammeter kicks, but in the opposite direction to parts a) and b).

25

Primary turns	Secondary turns	Primary p.d. in volts	Secondary p.d. in volts	Step up or step down
100	20	15	3	step down
400	10 000	10	250	step up
1000	50	240	12	step down
15 000	5000	33 000	11 000	step down

26 Phone or computer charger; electric shaver; low voltage lighting; electric train set.

27 For a p.d. to be induced in a coil, there must be a changing magnetic field. A d.c. supply produces a constant magnetic field, so a p.d.

will not be induced in a secondary coil by a d.c. supply to the primary. An a.c. supply in the primary produces a changing magnetic field in the secondary coil, which induces an alternating p.d.

28 A high p.d. allows power to be transmitted at low currents: power = p.d. × current, so by using a transformer to step up the p.d. the current is reduced.
The power dissipated by the wires carrying the current is: I^2R. So at low current less power is dissipated.

Show you can

Page 223

First you need one permanent magnet which is then used to test unknown magnetic materials. If a material is a permanent magnet, it has a north and a south pole; one pole will be attracted to your test magnet and one pole will be repelled. Induced magnets will always be attracted to your test magnet.

Page 226

You wrap many turns of the insulated wire around the nail. When the wire is connected to a battery or power pack (d.c. supply), the nail becomes an electromagnet. Then the induced magnet (the nail) can pick up paper clips.

Page 231

You need to refer to Figure 7.27 on Page 230. When the coil passes the vertical position, the two halves of the commutator change contact from one brush to the other. This changes the direction of the current in the coil, so that the forces on the coil continue to make it turn. You will need to draw your own diagram to illustrate this.

Page 236

You need to connect the ends of the coil to a sensitive ammeter. Then a current may be induced by moving a magnet in and out of the coil. The current is made as large as possible by:

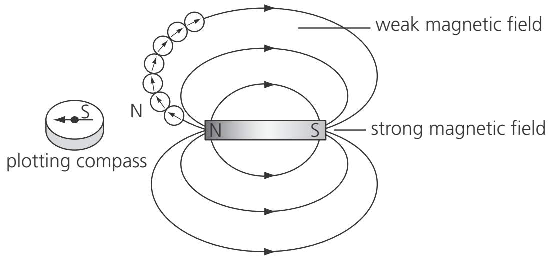
- using a strong magnet
- moving the magnet as quickly as possible
- putting many turns of wire on the coil
- putting some iron in the coil, which will also be magnetised by the moving magnet.

Page 239

Transformers only work on a.c. because a changing magnetic field is needed to induce a p.d. in the secondary coil. The transformer allows us to step up the p.d. on the power lines and to reduce the current flowing. A low current reduces the loss of energy in heating the power lines.

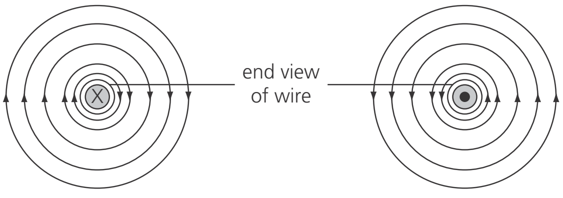
Chapter review questions

1 a)

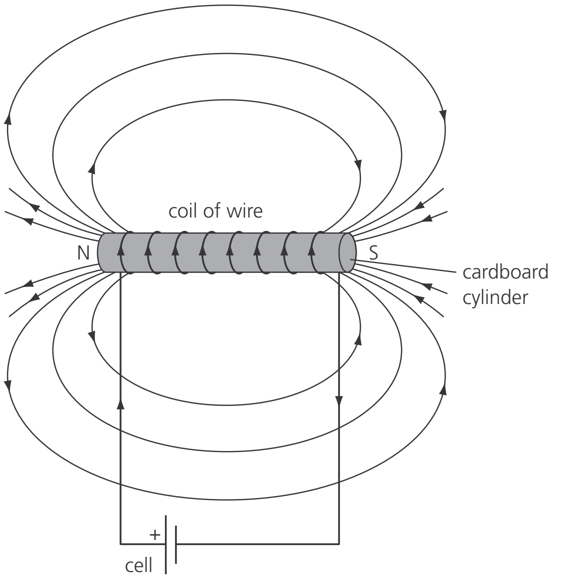


b) You can use the compass as shown above to trace out the pattern of field lines.

2 a)



b)



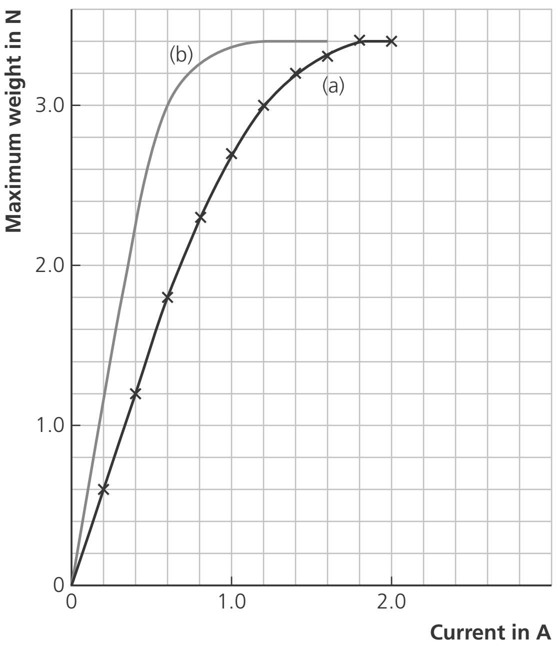
3 a) A light emitting diode is a diode that emits light when a current flows through it.

b) This is to ensure that current only flows one way into the battery when it is being charged.

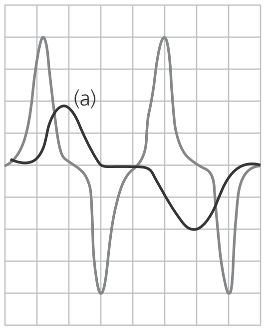
c) Shaking the magnet in the coil generates an alternating p.d. But the diode only allows the p.d. to drive a current into the battery one way.

d) One position is for charging the battery; one is off; one is for using the battery to light the LED.

4



5 a)



b) The magnet must be moving near to the coil for a p.d. to be induced.

6 a) $\frac{V_2}{V_1} = \frac{N_2}{N_1}$

$\frac{V_2}{230} = \frac{5}{500}$

$V_2 = \frac{230}{100}$

2.3 V

b) $V = IR$

$2.3 = I \times 0.02$

$I = \frac{2.3}{0.02}$

$= 115\,\text{A}$

c) $P = VI$

$= 2.3 \times 115$

$= 264.5\,\text{W}$ (265 W)

d) $P = \frac{E}{t}$

$265 = \frac{15\,000}{t}$

$t = \frac{15\,000}{265}$

$= 57\,\text{s}$

7 a) $\frac{V_2}{V_1} = \frac{N_2}{N_1}$

$\frac{400\,000}{25\,000} = \frac{N_2}{10\,000}$

$16 = \frac{N_2}{10\,000}$

$N_2 = 160\,000$

b) $V_1I_1 = V_2I_2$

$25\,000 \times 800 = 400\,000 \times I_2$

$I_2 = \frac{25 \times 8}{4}$

$= 50\,\text{A}$

c) The power dissipated on the power lines is calculated using:

$P = I^2R$

So by using a high p.d. the current carried by the lines is small. Thus I^2 is reduced and the power dissipated is reduced.

Practice questions

1 a) Steel. *[1 mark]*

b) Gravity. *[1 mark]*

c) A permanent magnet will attract one end of another permanent magnet and then repel the other end. An unmagnetised iron bar will become magnetised by a magnet, but there will always be an attraction between the bar and the magnet. *[1 mark]* *[1 mark]* *[1 mark]*

2 a) Missing words:

primary *[1 mark]*

magnetic field *[1 mark]*

induces *[1 mark]*

a current *[1 mark]*

secondary. *[1 mark]*

b) Increase the number of turns on the secondary coil. *[1 mark]*

Reduce the number of turns on the primary coil. *[1 mark]*

Put an iron bar across the top of the iron c-core. *[1 mark]*

3 a) There is a force down on one side of the coil (left), and there is a force up on the other side of the coil (right). This turns the coil. *[2 marks]*

The split ring commutator keeps the current flowing in the same sense, so that the coil always has forces to turn it in the same direction. *[1 mark]*

b) Stronger magnets. *[1 mark]*

Larger current from batteries with a higher p.d. *[1 mark]*

c) Reverse the magnets. *[1 mark]*

Reverse the battery. *[1 mark]*

4 a) Step up. *[1 mark]*

b) So that each turn produces a magnetic field of its own, (in the primary) and/or in the secondary, each turn has a p.d. induced across it. *[1 mark]* for either

c) i) Iron. *[1 mark]*

ii) So that the core can be magnetised by the current in the primary coil. *[1 mark]*

5 a) Move the trolley to the right. *[1 mark]*
Switch the magnets round. *[1 mark]*
Move the magnets to the left. *[1 mark]*
Any 2 of these.

b) Use stronger magnets. *[1 mark]*
Move the trolley faster. *[1 mark]*

c) Zero. *[1 mark]*

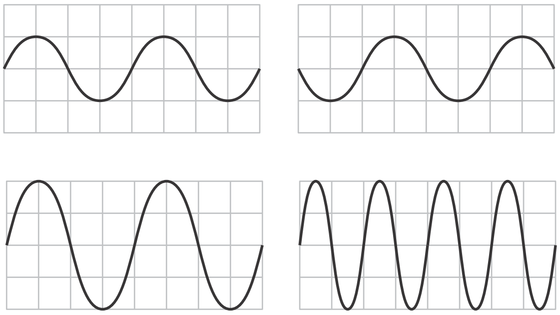
6 a) i) The wire moves to the right. *[1 mark]*
[Use the left hand rule.]

ii) The direction of the movement is reversed so the wire moves to the left. *[2 marks]*
[You will get carry through marks here; if you said in part a) that the wire moves to the left, then you get 2 marks for saying it moves to the right in part ii).]

b) i) As the magnet turns, there is a changing magnetic field through the coil. *[1 mark]*
When there is a changing field through a coil, a p.d. is induced across its ends. *[1 mark]*

ii) The magnetic field switches direction. So the p.d. switches direction too. *[1 mark]*

c)



[1 mark] *[2 marks]* *[2 marks]*

d) Iron increases the strength of the magnetic field in the coil, so inducing a larger p.d. *[1 mark]*

7 a) The wheel makes the magnet spin inside the coil. *[1 mark]*
Now there is a changing magnetic field in the coil, which induces a p.d. across the coil. *[1 mark]*
An alternating p.d. is induced as the direction of the changing field reverses with each spin of the magnet. *[1 mark]*

b) The faster the magnet spins, the greater the induced p.d.
When the p.d. is larger, a greater current flows through the lamp. *[1 mark]*

c) When the magnet is stationary, no p.d. is induced in the coil. *[1 mark]*

8 a) When the switch is closed, a current flows which magnetises the coil. *[1 mark]*
Now the iron bolt is magnetised by the field, so that it is attracted towards the coil. *[1 mark]*
The attractive force is large enough to compress the spring and to pull the bolt out of the door. *[1 mark]*

b) Use a higher p.d. on the battery. *[1 mark]*
Put more turns of wire on the coil. *[1 mark]*
Replace the springs with weaker ones. *[1 mark]*

9 a) i) The moving magnet produces a changing magnetic field in the coil. When the field is changing, a p.d. is induced. *[1 mark]*

ii) The needle is deflected in the opposite direction. *[1 mark]*

iii) Move the magnet faster. *[1 mark]*
Use a stronger magnet. *[1 mark]*
Put more turns of wire onto the coil. *[1 mark]*

b) When the current is switched on, a magnetic field is produced in the coil. As this field grows, it induces a current which flows one way through the meter. *[1 mark]*
When the current is switched off, the field drops, and the current flows the other way in the coil. *[1 mark]*
With a.c. in the second coil, the field is always changing and so an a.c. p.d. is induced in the left-hand coil. *[1 mark]*

10 a) When the magnet moves, there is a changing magnetic field in the coil, which induces a p.d. across the coil. *[1 mark]*

b) The magnet moves first one way then the other. *[1 mark]*
[No mark for saying the magnetic field changes direction – it does not.]

c) At A the magnet is moving fastest. *[1 mark]*

d) At B the magnet is stationary, having just reached the top (or bottom) of its oscillation. *[1 mark]*

e) Using a stronger magnet. *[1 mark]*
Putting more turns of wire on the coil. *[1 mark]*

Working scientifically

1 The transformer allows the p.d. of an a.c. supply to be increased. This increases the efficiency of the distribution system making it economically viable to link power stations to towns a long distance apart.

2 Examples of possible ethical issues include:
- the unequal use of energy resources is unfair
- decisions made now may have consequences for the future
- everyone should have fair access to global energy resources.

3 Provides an essential link to what is happening outside a person's immediate area. People made more aware of national and global events. May be used for entertainment.

4 It would take far too long to wind up the device for it to be of use. To operate the desktop computer for 1 minute would take 40 minutes of winding. To operate the electric kettle for 1 minute would take 10 hours of winding. A person cannot wind a generator for more than a few minutes before they would get tired.

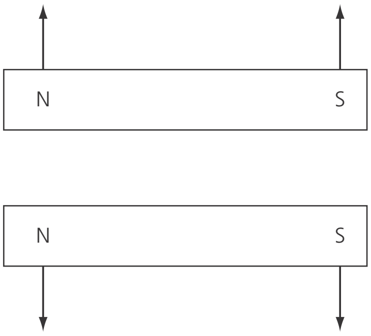
5 Examples of possible economic implications include:
- do not have to pay for electricity
- can work inside and earn money.

Examples of possible environmental implications include:
- less electricity needs to be generated so less pollution (from fossil fuelled power stations) fewer plastic bottles end up in landfill sites.

AQA GCSE (9-1) Combined Science

Test yourself on prior knowledge

1



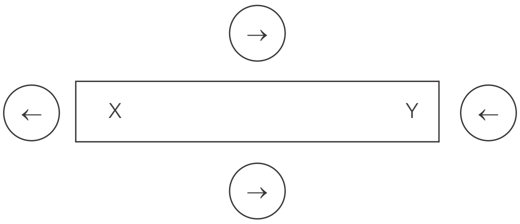
2 Missing words: magnetises; south; north; weight.

3 The head of each nail is magnetised south. Since like poles repel each other, the pins repel and stick out sideways.

Test yourself

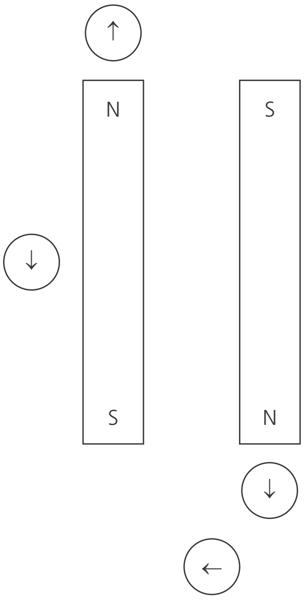
1 steel pin, iron nail.

2 a)



b) X is north; Y is south. The compass needle points away from X and towards Y.

3



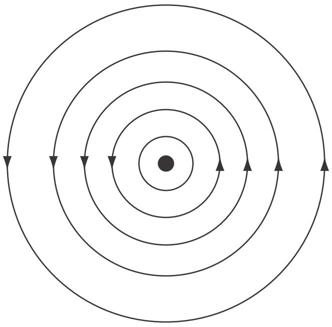
4 a) A permanent magnet always produces a magnetic field. It has two poles, north and south.

b) Some materials become magnetic, when placed in a magnetic field. These are induced magnets.

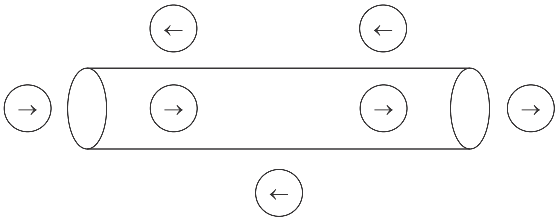
5 Increase the current.
Increase the number of turns.
Put the turns closer together.
Insert iron into the turns.

6 To ensure that the current flows through each turn, without the current crossing from coil to coil or flowing through the iron.

7



8 a)



b) The left end.

c) The compasses all change direction by 180°.

d) The field will be the same shape as Figure 35.16 page 279; but the direction of the field depends on the direction of the current.

9 Increasing the magnetic field strength; increasing the current in the wire.

10 Placing the wire so that the current is parallel to the magnetic field.

11 a) ↓

b) ↓

c) →

d) →

12 $F = BIL$

$= 2 \times 4.5 \times 0.2$

$= 1.8\,\text{N}$

13 BC is parallel to the magnetic field so there is no force on the wire.

14 Increase the current.
Increase the number of turns.
Increase the strength of the magnets.

15 a) i) Down.

ii) Up.

b) Anticlockwise as we look at it (from the end AD).

c) When it is vertical.

16 a) i) This is reversed.

ii) This is reversed.

iii) The direction of the force stays the same.

b) Both a.c. and d.c. supplies cause the coil to rotate. The a.c. supply works because both the current direction and magnet polarity reverse, but the rotation force is not changed. [See Question 11 on Page 282.]

c) The parallel supply allows different currents to be supplied to the magnet and coil.

Show you can

Page 277

First you need one permanent magnet which is then used to test unknown magnetic materials. If a material is a permanent magnet, it has a north and a south pole; one pole will be attracted to your test magnet and one pole will be repelled. Induced magnets will always be attracted to your test magnet.

Page 280

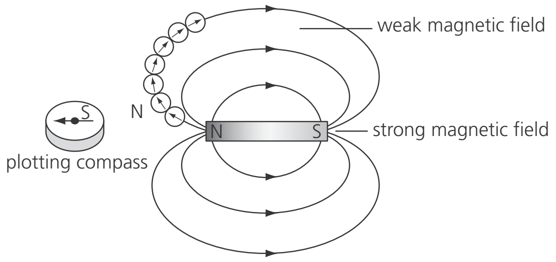
You wrap many turns of the insulated wire around the nail. When the wire is connected to a battery or power pack (d.c. supply), the nail becomes an electromagnet. Then the induced magnet (the nail) can pick up paper clips.

Page 284

You need to refer to Figure 35.26 page 283. When the coil passes the vertical position, the two halves of the commutator change contact from one brush to the other. This changes the direction of the current in the coil, so that the forces on the coil continue to make it turn. You will need to draw your own diagram to illustrate this.

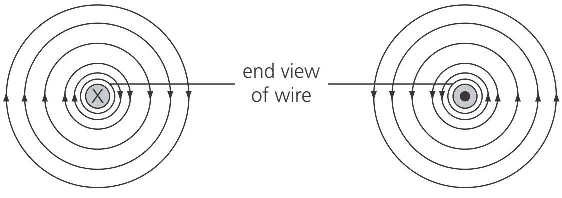
Chapter review questions

1 a)

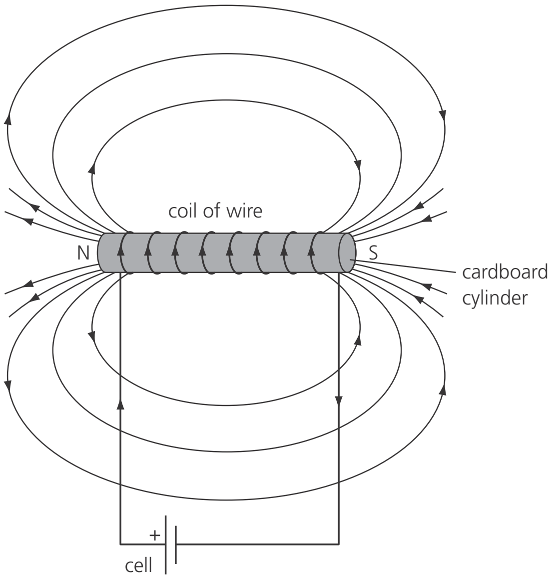


b) You can use the compass as shown above to trace out the pattern of field lines.

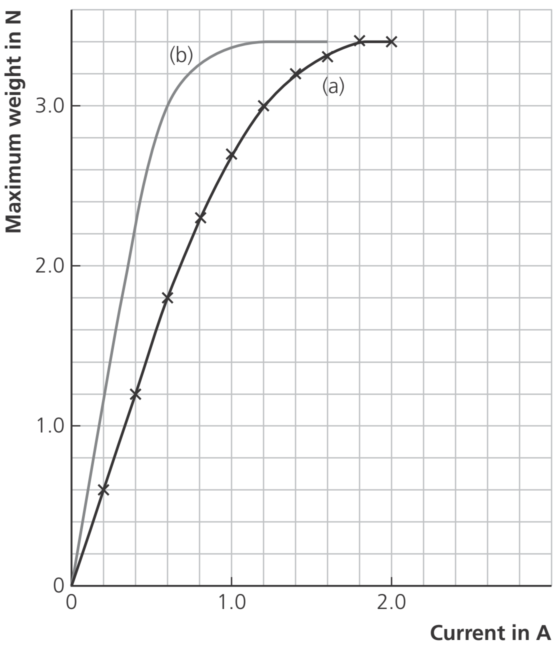
2 a)



b)



3



Practice questions

1 **a)** Steel *[1 mark]*

b) Gravity *[1 mark]*]

c) A permanent magnet will attract one end of another permanent magnet and then repel the other end. *[1 mark]*

An unmagnetised iron bar will become magnetised by a magnet, *[1 mark]*but there will always be an attraction between the bar and the magnet. *[1 mark]*

2 An induced magnet only becomes magnetic when placed in a magnetic field (it is a temporary magnet). *[1 mark]*

3 **a)** The area around a magnet which is affected by the magnet's magnetic force. *[1 mark]*

b) The magnetic field is strongest near the poles of the magnet / the magnetic field decreases with distance away from the poles of the magnet. *[1 mark]*

c) Field lines run from north to south. *[1 mark]*

The magnetic field will be circular (and perpendicular to the wire). *[1 mark]*

The magnetic field gets weaker further away from the wire. *[1 mark]*

4 Any three from

- Using a larger current
- Using more turns of wire
- Putting the turns closer together
- Adding an iron core into the middle of the solenoid *[3 marks]*

5 **a)** There is a force down on one side of the coil (left), and there is a force up on the other side of the coil (right). This turns the coil. *[2 marks]*

The split ring commutator keeps the current flowing in the same sense, so that the coil always had forces to turn it in the same direction. *[1 mark]*

b) Stronger magnets. *[1 mark]*

Larger current from batteries with a higher p.d. *[1 mark]*

c) Reverse the magnets. *[1 mark]*

Reverse the battery. *[1 mark]*

6 **a)** The wire moves to the right. *[1 mark]*

[Use the left hand rule.]

b) The direction of the movement is reversed so the wire moves to the left. *[2 marks]*

[You will get carry through marks here; if you said in part a) that the wire moves to the left, then you get 2 marks for saying it moves to the right in part b).]

8 Space physics

Overview

Specification points
4.8.1 Solar system, stability of orbital motions, satellites, 4.8.2 Red-shift

Textbook chapter references
AQA GCSE (9-1) Physics: Chapter 8 pages 247–64

Recommended number of lessons: 8

Chapter overview	
AQA required practical(s)	N/A
Contains higher-tier material	Yes
Contains physics-only material	Yes (entire chapter)

Useful Teaching and Learning resources

- Prior knowledge catch-up student sheet
- Prior knowledge catch-up teacher sheet
- Topic overview
- Lesson starters 1–3
- Key terms
- Homework task
- Quick quizzes 1–4
- Answers for homework task
- Answers to all questions
- Half-term test 4.8: Space physics

Useful prior learning

- The Sun is a star that radiates energy and light. There are many other stars in the sky.
- The Earth is a planet that orbits the Sun.
- The Moon is a natural satellite that orbits around the Earth, approximately once a month.
- There are eight planets and several dwarf planets which orbit around the Sun.

As you might expect, some of the ideas discussed in this topic will draw on student knowledge from previous topics, in particular, Chapter 4 Atomic structure and Chapter 6 Waves. Although orbits are mentioned, students will not need a mathematical understanding, as circular motion is no longer examined.

Common misconceptions

The main area of difficulty is not a misconception as such, but a natural human difficulty with the numbers involved. Just as with atomic scales or the time needed for evolution, humans struggle to put the values discussed into any meaningful context. It is very hard to draw any diagrams to scale, for example, and the projected death of our Sun in five billion years may seem imminent, despite this being a thousand times longer than the human race as a species distinct from chimpanzees.

For some students, this topic will also raise contradictions with a non-scientific point of view: their own religious faith. As with topics about evolutionary theory, the focus should be on accepting the evidence collected and the conclusions they lead to, rather than believing one approach over the other. As a contrast, some students may want to ask about alien life, intelligent or otherwise, and whether the moon landings were faked!

The idea of the expanding universe will be challenging for some students. Partly this is because of red-shift, which is better described as ‘radio-shift’; all electromagnetic waves from a receding source have a longer wavelength, closer to the radio end of the spectrum. The main difficulty is that as well as stellar objects moving apart, space itself is expanding. Students may be reassured when you explain that this idea is completely counter-intuitive for *everyone*.

Preparation

It should not take long to use the **T&L Prior knowledge catch-up student sheet** to check student recall of KS3 work. Many students will have a much greater understanding, from personal interest in the science or preference for science fiction in some form. This does, of course, mean that some will have absorbed misconceptions to address. You will need to emphasise that details of conditions on planets in the Solar System will not be expected.

Unless your school offers Astronomy (as a course or through an extra-curricular club) it is unlikely that there will be many opportunities for practical work. You may instead choose to develop some modelling opportunities; these will offer a double benefit as not only will students improve their grasp of the concepts, but you can discuss the strengths and weaknesses of models from a Working Scientifically perspective.

The **T&L Topic overview** is understandably text-heavy and should be saved for points when a summary is needed. Asking students to write down questions about space and the universe that they would like answering is an interesting strategy, although many of your answers will start with ‘We’re only going to introduce this topic, but…’.

Our sun and the planets: Lesson 1

Learning outcomes

1 Luminous sun, reflecting objects.
2 List/model inner and outer planets.
3 Recall other objects orbiting sun.

Suggested lesson plan

Starter

T&L Lesson starter 1 is a quick True/False exercise that will allow you to gauge student confidence.

Main

Define *luminous* objects as those which *emit* (visible) light, compared with *non-luminous* ones which simply reflect it. Students may recall that stars are effectively fusion reactors so the emission is a *pathway* for energy travelling from a *nuclear store*.

The *Solar System* is how we describe the objects that orbit our closest star, the Sun. At one point, these were described as planets (some with *moons*) and *comets*; we now consider some, such as Pluto, to be *dwarf planets*.

Recap the order of the planets and Pluto. The rocky inner planets are separated from the gas giants by the asteroid belt. Various models are available to show the scale involved, but you can improvise with string and clothes pegs, or chalk if the playground is available. Details of the playground demonstration can be found here: http://invigorate.royalsociety.org/media/16587/how%20big%20is%20the%20solar%20system.pdf. Just as with the atom, students will be surprised by just how big the gaps are.

Values are not required but an appreciation of the scale (Pluto orbits at around 50 times the radius of Earth's orbit) is helpful. Any model should confirm to students, as their intuition would suggest, that more distant planets take longer to orbit. Define a year as the time taken for one complete orbit but point out that we describe all other planets in terms of Earth days (24 hours) and years (365.25 days) for convenience.

Define comets as objects with non-circular orbits and dwarf planets as objects with enough mass (and gravity) to be roughly spherical, orbiting approximately in circles.

Plenary

Ask students which planets we have visited via machines (lots) and in person (none). Even a mission to Mars is a challenge; can they explain why? (Answers should focus on travel time, with consequences for food, water, air and fuel. The last is actually less of an issue as once moving, there would be little deceleration in space as resistive forces are effectively zero.)

Support

Students who are intimidated by the values should be reassured; you may wish to provide data in astronomical units which make it much easier to understand the context. (1 astronomical unit, or AU, is the radius of the Earth's orbit, approximately 150 million kilometres.)

Extension

Students should recognise that there is no connection between the number of moons or length of day, and the distance a planet is from the Sun. You could provide data for surface temperature which does show a relationship, although Venus is an anomaly – and a lesson in the result of a runaway greenhouse effect.

Homework

Students could read ahead, but a better plan might be to set review homework for previous topics. By now, time will be short and providing a structure is almost always useful.

Gravity and galaxies: Lesson 2

Learning outcomes

1 Explain how gravity causes orbits.
2 Appreciate relative scales of Solar System and galaxies.

Suggested lesson plan

Starter

Demonstrate a mass spinning on a string. Ask students to explain how this model describes the Sun and Earth. (Centre object = Sun, tension in string = gravitational attraction, small mass = Earth.)

Main

You may have chosen to combine this lesson with the previous one, depending on student confidence when faced with the **T&L Prior knowledge catch-up student sheet** activity.

Remind students that forces – in the case of the planets, a gravitational force – cause acceleration, but that this can involve either a change in magnitude or direction. An orbiting object travels at (fairly) constant speed but with changing direction, so it moves in a circle. This is seen at different scales, and we can 'zoom in and out' to consider them:

- the Moon and artificial satellites orbit the Earth
- the Earth and other planets orbit our Sun
- the Sun and many other stars orbit the galactic centre.

Define a *galaxy* as a collection of stars that share a central point – in many cases, we have good evidence that this is a black hole. Our galaxy, the Milky Way, appears as a bright stripe of densely packed stars when seen on a clear night. Figure 8.6 on page 250 of the textbook (and available from the **T&L Diagram bank**) shows what it would look like, from an external point of view. There are many shapes of galaxy and some beautiful images are available online. Students could research the different kinds and compare estimates of the numbers involved, which will vary widely. (Useful ranges to consider: 100-400 billion stars in the Milky Way, hundreds of billions of galaxies in the universe.)

Plenary
It can be really useful to consider a single image of the night sky and have students think about what is missing. Any star that does not emit visible light is, by definition, invisible, and some are too faint to be seen with the naked eye. The Hubble Deep Field image – actually a composite of many images taken at different times and different wavelengths – shows just how many stars are in an apparently 'empty' patch of sky.

Support
The sheer scale of numbers involved can be daunting for students; arguably, any who are not bemused by the scale have not understood what they imply. Balancing the awe and wonder of these ideas with the facts that students need to recall can be a challenge.

Extension
Some students may be interested to consider the eccentric orbit of comets, and how the speed changes depending on how close to the Sun they are. (Fast near the sun, slow when further away.)

Homework
Use Test yourself questions 1–5 from page 251 of the textbook.

Birth of a star: Lesson 3

Learning outcomes

1 Recall fusion process.
2 Use vocabulary for star formation.
3 Describe radiation pressure in main sequence stage.

Suggested lesson plan

Starter
Ask students to imagine an alien visitor who can only stay for a few seconds. They take photos of the local high street at a weekend, recording the images of many residents as they go about their day. How might such a set of photos allow them to model the life cycle of the human species? (Answer: although in that time nobody ages, a large enough sample would have people at every age of life. There would be enough similarities to describe a pattern, and the presence of pregnant women, babies and children, adults and seniors, would fit together in a fairly average lifespan.)

Main
The aim for this lesson and the one following is for students to understand a simplified model of the possible changes a star may go through; a diagram similar to Figure 8.9 on page 252 of the textbook (and available from the **T&L Diagram bank**) will probably be a useful structure for them.

Describe the collapse of a *nebula* due to gravity to form a *protostar*. Define stellar *ignition* as the start of nuclear *fusion* – nuclear equations are not needed but may be a useful reminder of notation – and the point we use as the 'birth' of a *main sequence* star. Although not strictly necessary, reminding them of the equation that describes the process is often helpful: $\Delta E = \Delta mc^2$.

It is worth students describing the processes on an atomic level; they can link the effects back to several topics covered in previous chapters, including Particle Model of Matter (Chapter 3), Atomic Structure (Chapter 4) and Waves (Chapter 6). In the past, this has been a common exam question and students should be able to interpret a flow chart of the process, or write coherent sentences explaining what is happening.

Students should recognise the opposing forces of inward gravitational attraction (because of mass) and outward radiation pressure (because of the heat of fusion) that find equilibrium. They should appreciate that the timescales for each stage vary widely depending on the mass and radius of the (proto)star.

Plenary
T&L Quick quiz 1 covers the ideas so far; a couple of terms are used that may not be covered until the following lesson (*supernova*, *black hole*) but students may be able to figure them out from context.

Support
Ensure that students have brief, clear summaries of the stages covered. The level required is straightforward; the ambiguous stages (e.g. the time taken for light to be emitted from the different layers of the star) are not covered or expected.

Extension
Ask students to explain the nuclear fusion process in more detail; although this is not required by the specification, it will reinforce the ideas about atomic structure that were covered previously.

Homework
Students should review the ideas covered so far, and could read ahead to consider the common pathways possible (depending on the size of the star).

Death of a star: Lesson 4

Learning outcomes

1 Consider fusion fuel depletion.
2 Understand factors changing result.
3 Complete flow chart (birth to death).

Suggested lesson plan

Starter
Students should annotate a diagram to explain the equilibrium between gravitational attraction and radiation pressure in a main sequence star.

Main
Remind students of the process leading to a main sequence star. Discuss the equilibrium and what will happen when there is less hydrogen as a fuel for fusion. Explain how the temperature increases and this means fusion of heavier elements can occur, in a *red giant* or *red super giant*. The Sun is about halfway through its 10-billion-year lifespan, and after five billion years may spend up to another billion as a cooling red giant.

It is worth pausing here to explain that the temperatures reached – and the elements produced – will depend on the size of the star. This is not a choice, but a consequence of the mass present. Using a diagram with notes to explain the factors which cause a star to undergo particular changes may help. Students should understand that there are other, less common possibilities. They should understand that only stars much larger than the Sun will explode in a *supernova*, and that what is left behind (*neutron star* or *black hole*) again depends on the mass present.

Students should know that different elements in the periodic table are produced at different points:

- elements up to oxygen can be produced in smaller stars like our Sun
- elements up to iron are produced in much larger stars as they go through red super giant phase
- elements beyond iron are made in an exploding supernova.

It is worth digressing into human biology and chemistry to consider what we are made of. The carbon, nitrogen and oxygen that form most of our tissues will have formed in stars like our Sun. Calcium and phosphorus – around two kilograms in an average human – and the five grams of iron in haemoglobin are from a red super giant. If students have any gold or silver jewellery, the atoms that make it up were made when a star exploded.

If not already done, students should complete a diagram or flow chart showing the possible changes a star will go through, depending on mass.

Plenary
T&L Lesson starter 2 could be used here to check understanding. Alternatively, use **T&L Quick quiz 4** but ignore the last question.

Support
Some students may claim to be worrying about the Sun's future changes. Dealing with this may mean pointing out that the scale is rather different to those concerning life, by considering orders of magnitude in the past (values are approximate):

- 500 years ago: Shakespeare
- 5000 years ago: Pyramids built
- 50 000 years ago: Neanderthals died out (very approximately)
- 500 000 years ago: stone tools
- 5 million years ago: common ancestor with modern chimpanzees.

This last one is one thousandth of the time before a change in the Sun is observable. Students who believe in the literal truth of their religious texts will have stopped listening by now, or started an argument.

Extension
Students could consider the cyclic nature of stellar formation and how the remnants of supernovas form the nebula for another generation of stars. Around 2% of stars observed are thought to have formed in this way. Can they explain why we know our Solar System did too? (Answer: it contains elements beyond iron.)

Homework
Use Test yourself questions 6–11 from page 253 of the textbook.

Orbiting: Lesson 5

Learning outcomes

1 Explain acceleration due to direction change at constant speed.
2 Use orbital speed equation.
3 Compare natural/artificial satellites.

Suggested lesson plan

Starter
Ask students to recall the equation for the circumference of a circle ($C = 2\pi r$ or $C = \pi D$).

Main
NB: Some or all of this may have been covered as part of the Gravity and galaxies lesson.

Show an image of the orbiting planets, ideally including at least one comet, and explain that although most are at least slightly elliptical the maths is much simpler for a circular orbit. Define the terms used:

- r for radius
- v_1, v_2, etc. for velocity
- F_1, F_2, etc. for force towards the centre.

Remind students that the changing direction means that the *velocity* must also be changing, even though the value of the *speed* stays the same. It is often easier to write the words speed and velocity in calculations so the meaning is clear. This means that there must be acceleration, which is caused by the attractive force towards the central object.

Go through a worked example to calculate the orbital speed of an object (page 255 of the textbook calculates the orbital speed of both Mercury and Earth); students can then complete some practice questions. Emphasise that the radius is measured between the centres of each mass, e.g. the average value for the international space station is not 400 km (height above ground) but 6800 km (from the centre of the Earth).

Students should understand that if the speed of the orbiting object is changed, then it will move into a 'higher' or 'lower' orbit. This is used with artificial satellites to adjust the height, and if the speed is high enough the object will escape entirely.

Although no longer examined, a brief discussion of artificial satellites is often of interest. Many orbits are possible, but a geostationary orbit over the equator is a useful one as it allows a point to be fixed compared with the surface. These satellites are used for communications, including GPS and radio/TV signals.

Plenary
Students could consider the use of artificial satellites for astrophysics observations; this would be a good way to prepare them for the use of data to calculate red-shift. Alternatively, **T&L Quick quiz 3** could be used.

Support
Students should be reassured that they are not expected to recall the equations for orbital speeds. The focus should be on distinguishing between velocity (which changes) and speed (which doesn't). Diagrams will be helpful for most students, but ensure that all arrows are clearly explained.

Extension
Ask students to explain why the height of the International Space Station decreases over time and how this can be reversed. (Answer: although high up, there is still enough atmosphere to slow it down which means the height gradually decreases. The International Space Station uses fuel to boost the orbit height again.)

Homework
Use Test yourself questions 12–15 from page 255 of the textbook. If not used in the plenary, students could also complete **T&L Quick quiz 3**.

Red-shift: Lesson 6

Learning outcomes

1 Explain the Doppler effect demo.
2 Link to red-shift of observed light.
3 Solve diagram-based problems.

Suggested lesson plan

Starter
If not used previously, **T&L Lesson starter 2** would be a good way to check recall of key stages in a star's lifecycle. Alternatively, demonstrate the Doppler effect with a buzzer spinning on a string

(a similar example is shown in Figure 8.16 on page 256 of the textbook, also in the **T&L Diagram bank**).

Main
Discuss the *Doppler effect* with an audible example, ensuring that students understand the difference between 'emitted wavelength' and 'detected wavelength'. They should understand that although the source has not changed, what is detected depends on whether the distance is increasing or decreasing, and how quickly. They may point out that the amplitude (loudness) would also change, which is true; it is dependent on *distance*, however, not speed of approach or recession.

- Approaching from a distance: amplitude low, wavelength decreased compared with source
- Close by: amplitude high, wavelength the same as source
- Receding into distance: amplitude low, wavelength increased compared with source

This can be demonstrated by laying a slinky on a table and sending two transverse pulses along it. If the 'source' end is pulled away while the pulses travel, students may be able to observe a difference in the time between them. Alternatively, a Nerf^{TM} foam dart gun can be used, showing that if they are fired at a steady rate while walking away the impact rate is decreased. This may not be observable in the average lab, but students will be able to understand the principle.

Discussing emission spectra of stars will show that there is a predictable pattern to be seen; students can be reminded that this shows us which elements are present, linking back to the stellar lifecycle work. Spectra from stars can be compared, and although the same pattern is sometimes seen, it appears to be 'shifted' with all wavelengths higher by the same fraction (not the same absolute change). Images are available online or use Figure 8.17 (page 256 of the textbook or from the **T&L Diagram bank**); this is slightly simplified as the shift is linear rather than fractional.

This effect is called *red-shift* because visible light from a receding source seems more red; you may wish to remind students of how the visible spectrum fits within the larger electromagnetic spectrum. When examples are provided, make sure that some involve waves (or the black bands which have a measurable position, i.e. wavelength) outside the visible spectrum. No measurements are needed but students should be able to state whether wavelength has increased or decreased, and whether this implies recession or approach of the source.

Plenary
Provide information summarising Hubble's work, which was based on detected EM radiation from galaxies rather than individual stars. Students should match facts (light is red-shifted, further sources have bigger red-shift, and this is observed in all directions) with conclusions (galaxies are receding from us, further galaxies are moving faster, and the effect is universal).

Support
Part of the difficulty for some students is the name. Emphasise that for white light – a mixture of wavelengths – the effect does cause it to be shifted towards the red, and hence the name. For any wave emitted by a receding source, the detected wavelength will be increased (and the frequency decreased). This means that infrared, microwave and radio waves will be shifted *away* from the red part of the spectrum.

Extension
Some students will be able to explain why looking for the shifted absorption bands rather than the emitted light is more helpful (red light is red light, but the bands can be compared with known values for nearby and relatively stationary stars). Technically, the increase in wavelength is due to the expansion of space–time rather than simple motion, but the mathematical treatment is the same.

Homework
Students should review this work and that of previous topics; by now they should have an established review/revision schedule.

The big bang theory: Lesson 7

Learning outcomes

1 Recall features of red-shift.
2 Plot galaxy speeds versus distance.
3 Define dark matter, dark energy.

Suggested lesson plan

Starter
Display two spectra with different amounts of red-shift. Ask students which source is moving more quickly.

Main
NB: This lesson makes explicit the scientific evidence and accepted theory that the universe is approximately 14 billion years old. There may well be a divide between students who consider their religious texts as literal and inarguable truth

and those who see them as metaphorical. It is important to emphasise that scientists do not 'believe' theories; they *accept* them as consistent with observational evidence. The animation from the Royal Institution and voiced by Jim Al-Khalili may be helpful: http://www.rigb.org/blog/2014/november/its-just-a-theory.

Remind students of Hubble's work on red-shift showing that further galaxies are moving away from us (and each other) more quickly.

If possible, provide data for students to plot a graph of speed against distance. The units are unimportant; what matters is that students should be able to recognise the relationship. The table in https://www.britishcouncil.fr/sites/default/files/expanding-universe-british-council-science-in-schools-worksheet-for-secondary.pdf is a useful resource.

When the position and velocity of each galaxy are compared, the evidence shows that they share an origin point. It is important to note that this does *not* mean the stars all formed at the same point in time and space, but that the matter which later became stars *did*. This evidence has led to what is called the *big bang theory*. Current data suggests that this event was 13.8 billion years in the past, but the latest work suggests that the rate of expansion is changing. This can only be explained by a combination of two factors, which can be coarsely summarised as *dark matter* and *dark energy*.

Dark matter can be explained as matter which is thought to exist because of a lower historical rate of expansion, but cannot be detected (hence dark). Black holes are the major candidate. Dark energy is used to describe the increased rate of expansion despite no observed phenomena. Students should be encouraged to see these ideas as evidence for astrophysics – like all science – as a subject which changes based on new evidence, not a static collection of facts.

Plenary
Point out to students that occasionally sources are found to show *blue-shift*, with reduced rather than increased wavelength. What would this show? (Answer: they are getting closer to us or we are getting closer to them. We use this to measure the speed of rotation of the Sun, which shows red-shift at one edge and blue shift at the other.)

Support
The concepts here are straightforward despite their scope; objections are likely to be philosophical rather than practical. There is more evidence for the big bang, for example the cosmic microwave background which is pervasive electromagnetic radiation, massively red-shifted, which makes up around 1% of the static you hear on the radio between stations. This can be thought of as the echo of the original event.

Extension
Some students will want to know more about dark matter and energy; they should be directed to recent articles online as this is current work.

Homework
Use Test yourself questions 16–20 from page 257 of the textbook.

Sun at the centre: Lesson 8

Learning outcomes

1 Recap scientific method.
2 Compare models (Aristotle, Copernicus, Galileo).

Suggested lesson plan
Starter
T&L Lesson starter 3 (prompting discussions of whether the big bang theory is 'proved') would set the scene for discussion of models and their limitations. If not already used, the animation from the Royal Institution mentioned in the previous lesson would be a good start.

Main
Despite the use of the term in media and education, there is no good definition of one 'scientific method', as used by every scientist, that is meaningful. Students should be encouraged to see it as a collection of approaches that rely on collecting observations – sometimes from carefully arranged circumstances to avoid distracting factors – and suggesting models that both *explain* them and can be used to *predict* future observations. How this is applied by a botanist will be very different to a theoretical physicist!

Students can review the models suggested on pages 258 and 259 of the textbook, and should appreciate that these are *examples* of the many versions suggested over time. At each point, a model was suggested which explained many of the observations; as devices for seeing the planets and stars improved, there was more information to explain. Each model is associated with a *hypothesis*. (You may choose to act out each of the models; in particular, it may help to show that if Mars and Earth are orbiting the sun, Mars will appear to travel backwards for several months of the simulated year, demonstrated further in Figure 8.20 on page 259 of the textbook.)

When enough data has been collected to support a hypothesis, it may be described as a *theory*. Even at this point, it can still be disproved; all scientific theories *could* be disproved. That is what makes them scientific. In practice, not all evidence is treated equally. This may be because evidence goes against personal bias, government policies or religious doctrine.

Students should be encouraged to review models covered previously – using a rope to simulate electrons moving in a wire, the plum pudding versus nuclear atom, light as a wave – and link them to the appropriate hypothesis. The limits of models are interesting to consider, along with the conditions or circumstances in which they no longer match the observations. We may still use them (for example, the electron donor model, 'carrying' energy around a circuit, works fine for the maths concerned in electrical circuits) but students should be aware of their limitations.

Plenary
Ask students to describe how a Subbuteo game (or other toy) is a good or bad model for the real-life situation it imitates.

Support
Students often think of data as 'proving' or 'disproving' a hypothesis; it is better for them to recognise that, in most cases, data will be a small part of the picture, and the terms 'supporting' or 'not supporting' are more useful. Magicians in Las Vegas with a levitation trick have not *disproved* gravity; instead, they have set up a particular situation in which gravity *appears* not to apply.

Extension
A general principle in science is that extraordinary evidence is needed to support extraordinary claims; why would a classroom practical in which potential difference across a resistor is not proportional to current not be considered to disprove Ohm's law?

Homework
Use Test yourself questions 21–25 from page 260 of the textbook, as well as the Chapter review questions on page 261 and the Practice questions on page 262. Students will also need to use the **T&L Homework task** as they prepare for the **T&L Half-term test 4.8: Space physics**.

Answers

AQA GCSE (9-1) Physics

Test yourself on prior knowledge

1 Gravity.
2 A star emits energy due to nuclear reactions. A planet rotates around a star (our Sun is a star); we can see planets because they reflect the Sun's light.

Test yourself

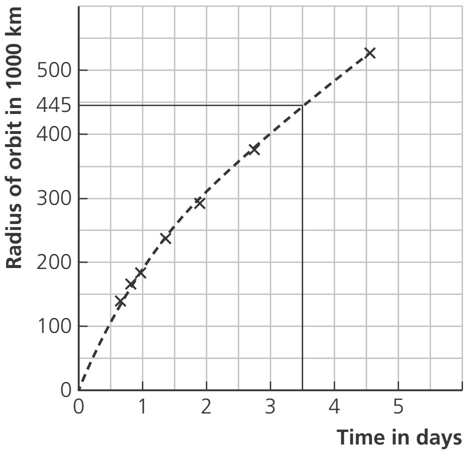
1 a) Planet; moon.
  b) Galaxy.
  c) Dwarf planet.
2 A dwarf planet orbits the Sun; a moon orbits a planet.
3 The four planets closest to the Sun are relatively small and rocky. The four outer planets are classified as gas giants; they do not have solid surfaces.
4 a) The Milky Way is a large galaxy of over 100 000 million stars. Our Sun is in the Milky Way.
  b) See Figure 8.6, page 250.
  c) Galaxies close to us include: Andromeda, Triangulum, the Large and Small Magellanic Clouds.
5 Another dwarf planet, Eris, has been discovered which is larger than Pluto. So either Eris had to be called a planet, or Pluto be reclassified as a dwarf planet.
6 a) D, A, C, B.
  b) i) Main sequence.
    ii) White dwarf, then eventually a black dwarf.
7 Nuclear fusion.
8 a) A main sequence star is a stable star that generates energy by fusing hydrogen into helium.
  b) Pressure from the fusion reaction is balanced by gravity that tends to collapse the star.
9 A white dwarf is a hot small star that has no supply of energy. It eventually cools down and stops emitting light, so it becomes black.
10 a) The nuclear fusion reaction becomes so rapid that it runs out of control like a gigantic nuclear bomb.
  b) The core can become a neutron star or a black hole.
11 Heavy atoms such as gold or uranium are only fused together in red super-giant stars, or these elements can be created in supernovae explosions. So our Solar System is made from recycled material.
12 a) A speed is a scalar quantity – we only mention size. A velocity is a speed where we define a direction – this is a vector quantity.
  b) A planet can have a constant speed in a circular orbit, but its velocity is always changing because the direction of the planet's motion is changing.

13 a) When a planet changes direction, it changes velocity. When there is a velocity change, the planet is accelerating:

$$\text{acceleration} = \frac{\text{change of velocity}}{\text{time}}$$

b) Always towards the Sun – this is the direction of the force on the planet: force = mass × acceleration.

14 a)



b) 445 000 km

15 a) i) B

ii) D

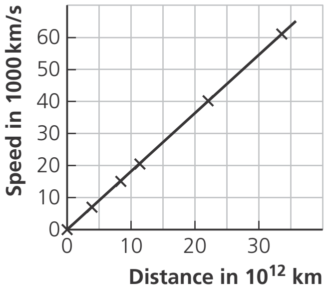
b) Gravity acts to speed the comet up from D to B. Then gravity slows the comet down from B to D.

16 Go down.

17 C

18 True: B, D.

19 a)



b) Yes, the graph suggests that the galaxies further away from us are moving faster.

c) G: 1140 × 1012 km
H: 2270 × 1014 km

20 There remains some doubt about exactly what produced the universe. But there is some clear evidence of the big bang: groups of galaxies are moving away from us in all directions – the speed of the galaxies gets bigger the further away the galaxies are; then there is background cosmic radiation that is thought to be an 'echo' of the big bang.

21 Aristotle thought that the Earth was at the centre of the universe. We now place the Sun as the centre of the Solar System, and the Sun is one of many stars in our galaxy.

22 He observed that some planets make backwards loops every year. He explained this by saying that the Earth is moving.

23 Mars appears brighter in position M_1 as it is closer to the Earth than in position M_2.

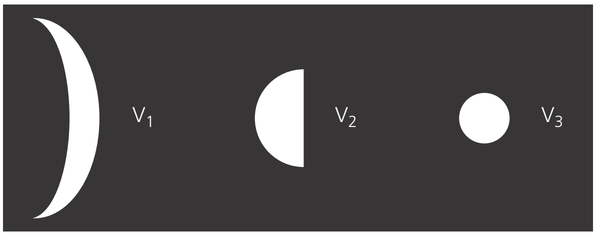
24 a) The Moons of Jupiter.

b) The moons are in orbit around Jupiter.

c) Sometimes a moon is behind the planet and cannot be seen.

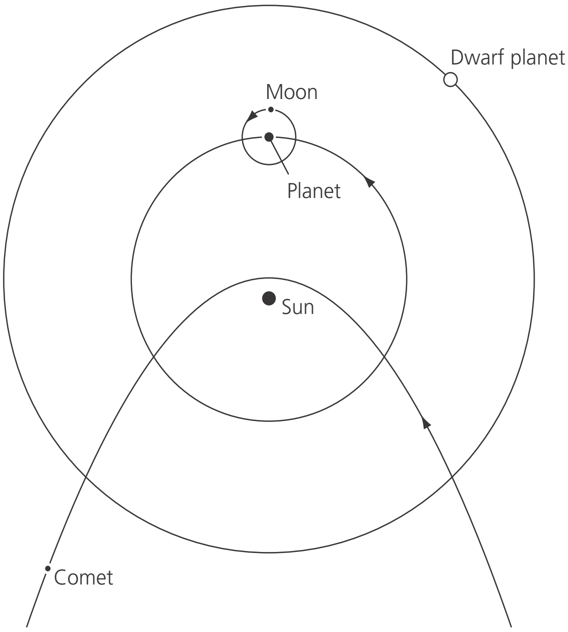
d) Io, Europe, Ganymede, Callisto.

25



Show you can...

Page 251



The four bodies mentioned so far are the Sun, planets, dwarf planets and moons. (You could also add comets.)

Page 253

You need to summarise the information on page 252. You could be asked this question in an exam; you will need to make 6 good points to earn full marks.

Page 256

Acceleration is defined by this equation:

$$\text{acceleration} = \frac{\text{change of velocity}}{\text{time}}$$

Since velocity is a vector quantity, when there is a change of direction there is a velocity change. So the Moon changes direction, its velocity changes, and it accelerates, but it does not go any faster or get closer to the Earth.

Page 258

When light from a group of galaxies is red-shifted, it means that those galaxies are moving away from us. The greater the red-shift, the faster the galaxies are moving. Measurements show that the more distant galaxies are moving faster. This leads to the idea that all the galaxies were in the same place some 13.8 billion years ago and then were thrown outwards by the big bang.

Page 260

- The planets Mars, Jupiter and Saturn appear to go backwards once a year. This cannot easily be explained by an Earth-centred model. When we place the Sun at the centre of the Solar System, the backwards motion of the planets is explained by the Earth overtaking these planets.
- Galileo provided further evidence, when he looked at planets through his telescope. He saw the phases of Venus, which shows that Venus rotates round the Sun. The variation of the brightness of Mars is also explained by its movement relative to us and the Sun.
- The moons of Jupiter can be seen to rotate around the planet. This provides a model similar to that of planets rotating around the Sun.

Chapter review questions

1 C, A, B, E, D, F

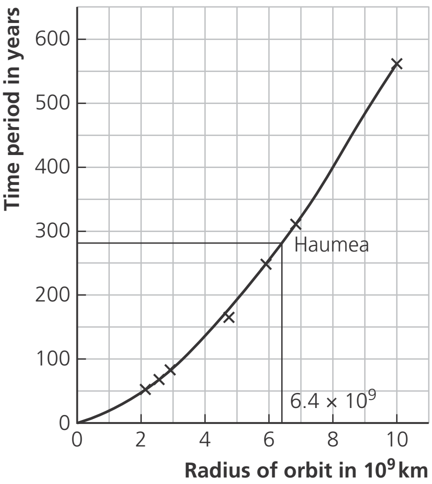
2 **a)** Gravity.
   b) Nuclear fusion.
   c) Nuclear fusion reactions in the Sun's core produce a great pressure, which resists the inward force of gravity.
   d) The planets are too small to sustain a nuclear fusion reaction.

3 **a)** **i)** Haumea is roughly spherical – the definition of a dwarf planet is that it is large enough for the effects of gravity to produce a roughly spherical shape.
   ii) Dwarf planets are simply very small planets which orbit the Sun, but they are large enough to be roughly spherical.
   iii) Size – Mercury is much larger than Haumea.
   b) Both orbit the Sun.

4 **a)** A main sequence star is a star that has nuclear fusion reactions that fuse hydrogen to form helium.
   b) A white dwarf is a hot small star. Nuclear fusion has stopped and the star is cooling down.
   c) A red giant is a very large star that is fusing helium (and other elements) into larger nuclei. Red giants are very luminous.
   d) A supernova is what we see when a large star has a runaway nuclear reaction. A supernova is a bright 'new' star. We suddenly see a bright star, but it is an old one exploding.
   e) A black hole is a collapsed star (or many collapsed stars). The gravitational pull is so large that light cannot escape from it.
   f) A galaxy is a large group of stars. Galaxies contain as many as 1000 billion stars (1012).

5 When something is moving quickly away from us, the wavelength of the radiation increases. Red light has a wavelength longer than blue light. So red-shift means that the wavelength of light has increased. These distant galaxies are moving away from us.

6 **a)**



   b) Neptune – about 4.5×10^9 km rather than 4.8×10^9 km.
   c) About 280 years.

Practice questions

1 **a)** B, C, A, E, D *[2 marks]*
   b) The outwards pressure from the fusion reaction. *[1 mark]*

2 **a)** A very large star. *[1 mark]*
   b) A black hole is very small – a point – so it is very dense because the mass of a star is concentrated in a point. Light cannot escape from it. *[1 mark]*

3 **a)** **i)** Red-shift. *[1 mark]*
   ii) Expanding. *[1 mark]*
   b) The speed of the galaxy moving away is proportional to its distance away from the Earth. *[1 mark]*
   c) **i)** Big bang theory. *[1 mark]*
   ii) All the galaxies, in all directions, are moving away from us. *[1 mark]*

4 In small stars such as the Sun, only light elements are made by nuclear fusion. Heavy elements are made in giant stars, by fusion, and are due to a supernova explosion. *[1 mark]*

When the star explodes, heavy elements are thrown out, which are then formed into new stars like the Sun (and its solar system). *[1 mark]*

5 **a)** A main sequence star is in a long state of stability. *[1 mark]*
It fuses hydrogen nuclei into helium nuclei. *[1 mark]*

b) The Milky Way is a spiral galaxy which contains about 200 000 million stars. *[1 mark]*
Our Sun is part of the Milky Way. *[1 mark]*

c) A supernova is a *gigantic explosion* caused by the collapse of a *giant star* at the end of its life cycle. *[1 mark]*

d) A neutron star is the end product of the collapse of a giant star after a supernova explosion. *[1 mark]*
All the matter has been converted into neutrons, so the star is very dense. *[1 mark]*

6 **a)** In space, there are large clouds of hydrogen. *[1 mark]*
The force of gravity acts on these clouds and causes them to collapse. *[1 mark]*
As they collapse, atoms/molecules speed up. By the time the gas has collapsed into a small ball, the gravitational potential energy of the molecules has been transferred into thermal energy. *[1 mark]*
At high temperatures, a nuclear fusion reaction can start; this is a star. *[1 mark]*

b) Hydrogen fuses to make helium nuclei. *[1 mark]*

c) When the hydrogen runs out, the star collapses. *[1 mark]*
This causes the core of the star to heat up further. *[1 mark]*
Now the fusion of helium starts. *[1 mark]*
Further collapses and heating allow heavier elements to fuse. *[1 mark]*
Eventually, the nuclear fusion runs away and there is a supernova explosion. *[1 mark]*
The explosion leaves behind a neutron star or a black hole. *[1 mark]*
Maximum 5 marks

7 **a)** From a supernova explosion of a giant star. *[1 mark]*

b) Heavier elements are made by nuclear fusion. Helium is made in small stars, and heavier elements are fused in giant stars and supernova explosions. *[1 mark]*

c) Our star is quite young in comparison with some stars. *[1 mark]*

8 **a)** Distant galaxies are moving away from us. *[1 mark]*
When something moves away from us, the wavelength of the light is stretched and becomes longer. *[1 mark]*
Red light has a longer wavelength than blue light so light from distant galaxies is shifted towards the red end of the spectrum. *[1 mark]*

b) Galaxies are moving away from us in all directions. *[1 mark]*
The further galaxies are moving faster, so their red-shift is greater. *[1 mark]*
Therefore we think that all the galaxies must have been in the same place a long time ago. So they exploded from that point. *[1 mark]*

9 **a)** Velocity is a vector, so direction matters. *[1 mark]*
Since the satellite is always changing direction, its velocity is changing. *[1 mark]*

b) $\text{acceleration} = \dfrac{\text{change of velocity}}{\text{time}}$ *[1 mark]*
So, since velocity is changing, the satellite must be accelerating. *[1 mark]*
Or there is only one force acting on the satellite – the pull of gravity. *[1 mark]*
Since $F = ma$, the force makes the satellite accelerate (towards the Earth). *[1 mark]*

c) It accelerates towards the Earth. *[1 mark]*
Gravity is this force. *[1 mark]*

Working scientifically

1 Both of these variables would affect the radius of the circle.

2 It reduces the percentage timing error, for example 4 ± 1 s is a bigger percentage error than 40 ± 1 s. It is also difficult to keep the bung moving at a totally constant speed so this will allow an average time for one rotation to be calculated.

3 Standing away from other students reduces the risk of hitting another student with the bung. If the string broke and the bung flew across the air, the goggles reduce the risk of eye injury.

4 Increasing the speed increases the radius of the circle but non-linearly (not in a straight line). However, the radius is directly proportional to the speed squared.

5 Yes; the results of other students gave the same pattern.

6 The gravity pull is not constant. The further the satellite is from the Earth, the weaker the gravity pull on the satellite.