P1.1 What are the risks and benefits of using radiations?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
A model of radiation can be used to describe and predict the effects of some processes in which one object affects another some distance away. One object (a source) emits radiation (of some kind). This spreads out from the source and transfers energy to other object(s) some distance away. Light is one of a family of radiations, called the electromagnetic spectrum. All radiations in the electromagnetic spectrum travel at the same speed through space.	1. describe the main groupings of the electromagnetic spectrum – radio, microwave, infrared, visible (red to violet), ultraviolet, X-rays and gamma rays, that these range from long to short wavelengths, from low to high frequencies, and from low to high energies 2. recall that our eyes can only detect a very limited range of frequencies in the electromagnetic spectrum 3. recall that all electromagnetic radiation is transmitted through space with the same very high (but finite) speed 4. explain, with examples, that electromagnetic radiation transfers energy from source to absorber	**Practical work:** • Estimate the speed of microwaves using a microwave oven. • Investigate how the intensity of radiation changes with distance from the source.
When radiation strikes an object, some may be transmitted (pass through it), or be reflected, or be absorbed. When radiation is absorbed it ceases to exist as radiation; usually it heats the absorber. Some types of electromagnetic radiation do not just cause heating when absorbed; X-rays, gamma rays and high energy ultraviolet radiation have enough energy to remove an electron from an atom or molecule (ionisation) which can then take part in other chemical reactions.	5. recall that different substances may absorb, transmit, or reflect electromagnetic radiation in ways that depend on wavelength 6. recall that in each atom its electrons are arranged at different distances from the nucleus, that such arrangements may change with absorption or emission of electromagnetic radiation, and that atoms can become ions by loss of outer electrons	**Specification links**: • Why are some materials radioactive? (P6.1) • How can radioactive materials be used safely (P6 .2). • How has our understanding of the atom developed over time? (C2.1)

P1.1 What are the risks and benefits of using radiations?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Exposure to large amounts of ionising radiation can cause damage to living cells; smaller amounts can causes changes to cells which may make them grow in an uncontrolled way, causing cancer. Oxygen is acted on by radiation to produce ozone in the upper atmosphere. This ozone absorbs ultraviolet radiation, and protects living organisms, especially animals, from its harmful effects. Radio waves are produced when there is an oscillating current in an electrical circuit. Radio waves are detected when the waves cause an oscillating current in a conductor.	7. recall that changes in molecules, atoms and nuclei can generate and absorb radiations over a wide frequency range, including: a) gamma rays are emitted from the nuclei of atoms b) X-rays, ultraviolet and visible light are generated when electrons in atoms lose energy c) high energy ultraviolet, gamma rays and X-rays have enough energy to cause ionisation when absorbed by some atoms d) ultraviolet is absorbed by oxygen to produce ozone, which also absorbs ultraviolet, protecting life on Earth e) infrared is emitted and absorbed by molecules
Different parts of the electromagnetic spectrum are used for different purposes due to differences in the ways they are reflected, absorbed, or transmitted by different materials.	8. describe how ultra-violet radiation, X-rays and gamma rays can have hazardous effects, notably on human bodily tissues
Developments in technology have made use of all parts of the electromagnetic spectrum; every development must be evaluated for the potential risks as well as the benefits (IaS4). Data and scientific explanations of mechanisms, rather than opinion, should be used to justify decisions about new technologies (IaS3).	9. give examples of some practical uses of electromagnetic radiation in the radio, microwave, infrared, visible, ultraviolet, X-ray and gamma ray regions of the spectrum **10. recall that radio waves can be produced by, or can themselves induce, oscillations in electrical circuits**

Linked learning opportunities

Ideas about Science:
- Use the radiation model to predict and explain the behaviour of electromagnetic radiation (IaS3).

Practical work
- Investigate absorption, transmission and reflection of electromagnetic radiation e.g. absorption of ultraviolet by sunscreens, reflection and absorption of microwaves, or mobile phone signals.

Ideas about Science
- Discuss the different risks and benefits of technologies that use electromagnetic radiation (IaS4).

P1.2 What is climate change and what is the evidence for it?

<table>
<tr><th>Teaching and learning narrative</th><th colspan="2">Assessable learning outcomes
Learners will be able to:</th></tr>
<tr><td rowspan="2">All objects emit electromagnetic radiation with a principal frequency that increases with temperature. The Earth is surrounded by an atmosphere which allows some of the electromagnetic radiation emitted by the Sun to pass through; this radiation warms the Earth's surface when it is absorbed. The radiation emitted by the Earth, which has a lower principal frequency than that emitted by the Sun, is absorbed and re-emitted in all directions by some gases in the atmosphere; this keeps the Earth warmer than it would otherwise be and is called the greenhouse effect.

One of the main greenhouse gases in the Earth's atmosphere is carbon dioxide, which is present in very small amounts; other greenhouse gases include methane, present in very small amounts, and water vapour. During the past two hundred years, the amount of carbon dioxide in the atmosphere has been steadily rising, largely the result of burning increased amounts of fossil fuels as an energy source and cutting down or burning forests to clear land.

Computer climate models provide evidence that human activities are causing global warming. As more data is collected using a range of technologies, the model can be refined further and better predictions made (IaS3).</td><td>1.</td><td>explain that all bodies emit radiation, and that the intensity and wavelength distribution of any emission depends on their temperatures</td></tr>
<tr><td>2.</td><td>explain how the temperature of a body is related to the balance between incoming radiation, absorbed radiation and radiation emitted; illustrate this balance, using everyday examples including examples of factors which determine the temperature of the Earth</td></tr>
</table>

Linked opportunities

Specification Links

- What is the evidence for climate change? (C1.2)

Practical work:

- Investigate climate change models – both physical models and computer models.

Ideas about Science

- Use ideas about the way science explanations are developed when discussing climate change (IaS3).
- Use ideas about correlation and cause when discussing evidence for climate change (IaS3).

P1.3 How do waves behave?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
A wave is a regular disturbance that transfers energy in the direction that the wave travels, without transferring matter. For some waves (such as waves along a rope), the disturbance of the medium as the wave passes is at right-angles to its direction of motion. This is called a transverse wave. For other waves (such as a series of compression pulses on a slinky spring), the disturbance of the medium as the wave passes is parallel to its direction of motion. This is called a longitudinal wave. The speed of a wave depends on the medium it is travelling through. Its frequency is the number of waves each second that are made by the source. The wavelength of waves is the distance between the same points on two adjacent disturbances. The ways in which light and sound waves reflect and refract when they meet at an interface between two materials can be modelled with water waves. A wave model for light and sound can be used to describe and predict some behaviour of light and sound.	1. describe wave motion in terms of amplitude, wavelength, frequency and period 2. describe evidence that for both ripples on water surfaces and sound waves in air, it is the wave and not the water or air itself that travels 3. describe the difference between transverse and longitudinal waves 4. describe how waves on a rope are an example of transverse waves whilst sound waves in air are longitudinal waves 5. define wavelength and frequency 6. recall and apply the relationship between speed, frequency and wavelength to waves, including waves on water, sound waves and across the electromagnetic spectrum: wave speed (m/s) = frequency (Hz) × wavelength (m) M1a, M1c, M3c, M3d 7. a) describe how the speed of ripples on water surfaces and the speed of sound waves in air may be measured b) describe how to use a ripple tank to measure the speed/frequency and wavelength of a wave *PAG4* 8. a) describe the effects of reflection and refraction of waves at material interfaces b) describe how to measure the refraction of light through a prism *PAG8* c) describe how to investigate the reflection of light off a plane mirror *PAG8*	**Ideas about Science** • Use the wave model to predict and explain the observed behaviour of light (IaS3). **Practical work**: • Carry out experiments to measure the speed of waves on water and the speed of sound in air.

P1.3 How do waves behave?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Refraction of light and sound can be explained by a change in speed of waves when they pass into a different medium; a change in the speed of a wave causes a change in wavelength since the frequency of the waves cannot change, and that this may cause a change in direction.	**9. recall that waves travel in different substances at different speeds and that these speeds may vary with wavelength**	
	10. explain how refraction is related to differences in the speed of the waves in different substances	
	11. recall that light is an electromagnetic wave	
	12. recall that electromagnetic waves are transverse	

P1.4 What happens when light and sound meet different materials? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
A beam of light is reflected from a smooth surface, such as a mirror, in a single beam which makes the same angle with the normal as the incident beam (specular reflection). Light is scattered in all directions from an uneven surface. Light is refracted at the boundary between glass (and water and Perspex) and air; this property is exploited in prisms and lenses. When a beam of white light is passed through a prism, the emerging light beam is spread out showing the colours of the spectrum. This can be explained using the wave model, different colours have different wavelengths; different wavelengths travel at different speeds when passing through glass, water or Perspex. What we perceive as white light is a mixture of different colours, ranging in wavelength from violet light (shortest visible wavelength) to red light (longest visible wavelength). A coloured filter works by allowing light of one or more wavelength through (transmission) and absorbing light of the other wavelengths. An object appears white if it scatters all the colours of light that fall on it, and black if it scatters none (and absorbs all). It appears coloured if it scatters light of some colours and absorbs light of other colours. Its observed colour is that of the light it scatters.	1. construct and interpret two-dimensional ray diagrams to illustrate specular reflection by mirrors *qualitative only* M5a, M5b 2. construct and interpret two-dimensional ray diagrams to illustrate refraction at a plane surface and dispersion by a prism *qualitative only* M5a, M5b 3. use ray diagrams to illustrate the similarities and differences between convex and concave lenses *qualitative only* 4. describe the effects of transmission, and absorption of waves at material interfaces 5. explain how colour is related to differential absorption, transmission, and scattering **6. describe, with examples, processes in which sound waves are transmitted though solids** **7. explain that transmission of sound through the bones in the ear works over a limited frequency range, and the relevance of this to human hearing**

Linked learning opportunities

Practical work:

- Trace light rays through glass blocks, prisms and lenses and when reflected from mirrors.
- Investigate the effects of looking at coloured object through coloured filters.
- Investigate the transmission of light and sound across interfaces.

2

P1.4 What happens when light and sound meet different materials? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Sound travels better through solids and liquids than through air. The small bones in the middle ear transmit the sound waves from the air outside to the inner ear. The bones transmit frequencies most efficiently in the range 1 kHz and 3 kHz. **The ways in which sound waves are transmitted, reflected and refracted as they pass through liquids and solids are exploited in ultrasound imaging in medicine, in exploring the structure of the Earth and in using SONAR to explore under water.**	**8. explain, in qualitative terms, how the differences in velocity, absorption and reflection between different types of waves in solids and liquids can be used both for detection and for exploration of structures which are hidden from direct observation, notably:** **a) in our bodies (ultrasound imaging)** **b) in the Earth (earthquake waves)** **c) in deep water (SONAR)**	
	9. show how changes, in speed, frequency and wavelength, in transmission of sound waves from one medium to another, are inter-related M1c, M3c	

Chapter P2: Sustainable energy

Overview

Energy supply is one of the major issues that society must address in the immediate future.

Citizens are faced with complex choices and a variety of messages from energy supply companies, environmental groups, the media, scientists and politicians. Some maintain that renewable resources are capable of meeting our future needs, some advocate nuclear power, and some argue that drastic lifestyle changes are required. Decisions about energy use, whether at a personal or a national level, need to be informed by a quantitative understanding of the situation, and this is an underlying theme of the chapter.

Topic P2.1 quantifies the energy used by electrical devices introduces calculations of efficiency and considers ways of reducing dissipation in a variety of contexts. In Topic P2.2 national data on energy sources introduces a study of electricity generation and distribution; nuclear power generation, the burning of fossil fuels and renewable resources are compared and contrasted. Electrical safety in the home and a review the energy choices available to individuals, organisations and society are also included.

Learning about energy before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- have compared energy uses and costs in domestic contexts, including calculations using a variety of units
- have considered a variety of processes that involve transferring energy, including heating, changing motion, burning fuels and changing position in a field.

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

P2.1 How much energy do we use?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Energy is considered as being stored in a limited number of ways: chemical, nuclear, kinetic, gravitational, elastic, thermal, electrostatic and electromagnetic and can be transferred from one to another by processes called working and heating. Electricity is a convenient way to transfer energy from source to the consumer because it is easily transmitted over distances and can be used to do work in many ways, including heating and driving motors which make things move or to lift weights. When energy is used to do work some energy is usually wasted in doing things other than the intended outcome, it is dissipated into the surroundings, ultimately into inaccessible thermal stores. The power of an appliance or device is a measure of the amount of energy it transfers each second, i.e. the rate at which it transfers energy.	1. describe how energy in chemical stores in batteries, or in fuels at the power station, is transferred by an electric current, doing work on domestic devices, such as motors or heaters 2. explain, with reference to examples, the relationship between the power ratings for domestic electrical appliances, the time for which they are in use and the changes in stored energy when they are in use 3. recall and apply the following equation in the context of energy transfers by electrical appliances: energy transferred (J, kWh) = power (W, kW) × time (s, h) M3b, M3c, M3d 4. describe, with examples, where there are energy transfers in a system, that there is no net change to the total energy of a closed system *qualitative only* 5. describe, with examples, system changes, where energy is dissipated, so that it is stored in less useful ways 6. explain ways of reducing unwanted energy transfer e.g. through lubrication, thermal insulation 7. describe the effects, on the rate of cooling of a building, of thickness and thermal conductivity of its walls *qualitative only*

Linked learning opportunities

Practical work
- Compare the power consumption of a variety of devices and relate it to the changes in stored energy.
- Investigate the effects of insulation on the rate of cooling.

Maths
- Calculate the cost of energy supplied by electricity given the power rating, the time and the cost per kWh (IaS2.2).

P2.1 How much energy do we use?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Sankey diagrams are used to show all the energy transfers in a system, including energy dissipated to the surroundings; the data can be used to calculate the efficiency of energy transfers.	8. recall and apply the equation: efficiency = useful energy transferred ÷ total energy transferred to calculate energy efficiency for any energy transfer, and **describe ways to increase efficiency** M1c	
	9. interpret and construct Sankey diagrams to show understanding that energy is conserved M4a	

P2.2 How can electricity be generated?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	
The main energy resources that are available to humans are fossil fuels (oil, gas, coal), nuclear fuels, biofuels, wind, hydroelectric, tides and from the Sun. In most power stations generators produce a voltage across a wire by spinning a magnet near the wire. Often an energy source is used to heat water; the steam produced drives a turbine which is coupled to an electrical generator. Other energy sources drive the generator directly. The mains supply to our homes is an alternating voltage, at 50 Hz, 230 volts, but electricity is distributed through the National Grid at much higher voltages to reduce energy losses. Transformers are used to increase the voltage for transmission and then decrease the voltage for domestic use. Most mains appliances are connected by a 3 core cable, containing live, neutral and earth wires. The demand for energy is continually increasing and this raises issues about the availability and sustainability of energy sources and the environmental effects of using these sources. The introduction and development of new energy sources may provide new opportunities but also introduce technological and environmental challenges. The decisions about the energy sources that are used may be different for different people in different contexts (IaS4).	1.	describe the main energy resources available for use on Earth (including fossil fuels, nuclear fuel, biofuel, wind, hydroelectricity, the tides and the Sun)
	2.	explain the differences between renewable and non-renewable energy resources
	3.	compare the ways in which the main energy resources are used to generate electricity M2c
	4.	recall that the domestic supply in the UK is a.c., at 50 Hz and about 230 volts and explain the difference between direct and alternating voltage
	5.	recall that, in the National Grid, transformers are used to transfer electrical power at high voltages from power stations, to the network and then used again to transfer power at lower voltages in each locality for domestic use
	6.	recall the differences in function between the live, neutral and earth mains wires, and the potential differences between these wires; hence explain that a live wire may be dangerous even when a switch in a mains circuit is open, and explain the dangers of providing any connection between the live wire and any earthed object
	7.	explain patterns and trends in the use of energy resources in domestic contexts, workplace contexts, and national contexts M2c

Linked learning opportunities

Specification links
- What determines the rate of energy transfer in a circuit? (P3.4)
- **What is the process inside a generator? (P3.7)**

Practical work
- Investigate factors affecting the output from solar panels and wind turbines.

Maths
- Use ideas about probability in the context of risk.
- Extract and interpret information about electricity generation and energy use presented in a variety of numerical and graphical forms.

Ideas about Science
- Discuss the risks and benefits of different ways of generating electricity and why different decisions on the same issue might be appropriate (IaS4.3–4.6, 4.11).

Chapter P3: Electric circuits

Overview

Known only by its effects, electricity provides an ideal vehicle to illustrate the use and power of scientific models. During the course of the 20th century, electrical engineers completely changed whole societies, by designing systems for electrical generation and distribution, and a whole range of electrical devices.

In this chapter, learners learn how scientists visualise what is going on inside circuits and predict circuit behaviour. Topic P3.1 introduces the idea of electric charge and electric fields. In Topic P3.2, models of charge moving through circuits driven by a voltage and against a resistance are introduced. A more general understanding of voltage as potential difference is then developed in Topic P3.3, which then continues with an exploration of the difference between series and parallel circuits, leading on to investigating the behaviour of various components in d.c. series circuits. Topic 3.4 concentrates on quantifying the energy transferred in electric circuits and how this is determined by both the potential difference and the current.

A reminder of earlier work on magnets and magnetic fields in Topic P3.5 leads into an introduction to the electric motor in Topic P3.6. Applications of electromagnetism and, in particular the electric motor, have revolutionised people's lives in so many ways – from very small motors used in medical contexts, to very large motors used to propel ships or pump water in pumped storage schemes. In Topic P3.7, the process of electromagnetic induction is placed in the context of power generation and the use of transformers in power distribution.

Learning about electric circuits before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- be familiar with the basic properties of magnets, and use these to explain and predict observations
- know that there is a magnetic field close to any wire carrying an electric current
- be aware of the existence of electric charge, and understand how simple electrostatic phenomena can be explained in terms of the movement of electrons between and within objects
- understand the idea of an electric circuit (a closed conducting loop containing a battery) that conducts an electric current and be able to predict the current in branches of a parallel circuit
- understand the idea of voltage as a measure of the 'strength' of a battery or power supply
- know that electrical resistance is measured in ohms and can be calculated by dividing the voltage across the component by the current through it
- know that the power ratings of electrical appliances are related to the rate at which the appliances transfers energy.

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

P3.1 What is electric charge? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	
When two objects are rubbed together they become charged, because electrons are transferred from one object to the other. Electrons are negatively charged. Objects with similar charges repel, and objects with opposite charges attract. Around every electric charge there is an electric field; in this region of space the effects of charge can be felt; when another charge enters the field there is an interaction between them and both charges experience a force.	1.	describe the production of static electricity, and sparking, by rubbing surfaces, and evidence that charged objects exert forces of attraction or repulsion on one another when not in contact
	2.	explain how transfer of electrons between objects can explain the phenomenon of static electricity
	3.	explain the concept of an electric field and how it helps to explain the phenomenon of static electricity

Linked learning opportunities
Practical work • Demonstrate that there are forces between charged objects and that the effect diminishes with increasing distance between the charges.

P3.2 What determines the current in an electric circuit?

<table>
<tr><th>Teaching and learning narrative</th><th>Assessable learning outcomes
Learners will be required to:</th></tr>
<tr><td rowspan="7">An electric current is the rate of flow of charge; in an electric circuit the metal conductors (the components and wires) contain many charges that are free to move. When a circuit is made, the battery causes these free charges to move, and these charges are not used up but flow in a continuous loop.

In a given circuit, the larger the potential difference across the power supply the bigger the current. Components (for example, resistors, lamps, motors) resist the flow of charge through them; the resistance of connecting wires is usually so small that it can be ignored. The larger the resistance in a given circuit, the smaller the current will be.

Representational models of electric circuits use physical analogies to help think about how an electric circuit works, and to predict what happens when a variable is changed (IaS3).</td><td>1. recall that current is a rate of flow of charge, that for a charge to flow, a source of potential difference and a closed circuit are needed and that a current has the same value at any point in a single closed loop</td></tr>
<tr><td>2. recall and use the relationship between quantity of charge, current and time:
charge (C) = current (A) × time (s)
M1c, M3b, M3c, M3d</td></tr>
<tr><td>3. recall that current (I) depends on both resistance (R) and potential difference (V) and the units in which these quantities are measured</td></tr>
<tr><td>4. a) recall and apply the relationship between I, R, and V, to calculate the currents, potential differences and resistances in d.c. series circuits:
potential difference (V) = current (A) × resistance (Ω)
M1c, M3b, M3c, M3d
b) describe an experiment to investigate the resistance of a wire and be able to draw the circuit diagram of the circuit used
PAG7</td></tr>
<tr><td>5. recall that for some components the value of R remains constant (fixed resistors) but that in others it can change as the current changes (e.g. heating elements, lamp filaments)</td></tr>
<tr><td>6. a) use graphs to explore whether circuit elements are linear or non-linear and relate the curves produced to their function and properties
M4c, M4d
b) describe experiments to investigate the I-V characteristics of circuit elements. To include: lamps, diodes, LDRs and thermistors. Be able to draw circuit diagrams for the circuits used
PAG6</td></tr>
<tr><td>7. represent circuits with the conventions of positive and negative terminals, and the symbols that represent common circuit elements, including filament lamps, diodes, LDRs and thermistors</td></tr>
</table>

Linked learning opportunities

Ideas about Science
- Identify limitations in analogies used to represent electric circuits (IaS3).

Practical work
- Design and construct electric circuits to investigate the electrical properties of range of circuit components.

2

P3.3 How do series and parallel circuits work?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
When electric charge flows through a component (or device), work is done by the power supply and energy is transferred from it to the component and/or its surroundings. Potential difference measures the work done per unit charge. In a series circuit the charge passes through all the components, so the current through each component is the same and the work done on each unit of charge by the battery must equal the total work done by the unit of charge on the components. The potential difference (p.d.) is largest across the component with the greatest resistance and a change in the resistance of one component will result in a change in the potential differences across all the components. In a parallel circuit each charge passes through only one branch of the circuit, so the current through each branch is the same as if it were the only branch present and the work done by each unit of charge is the same for each branch and equal to the work done by the battery on each charge. The current is largest through the component with the smallest resistance, because the same battery p.d. causes a larger current to flow through a smaller resistance than through a bigger one. When two or more resistors are placed in series the effective resistance of the combination (equivalent resistance) is equal to the sum of their resistances, because the battery has to move charges through all of them. Two (or more) resistors in parallel provide more paths for charges to move along than either resistor on its own, so the effective resistance is less. Some components are designed to change resistance in response to changes in the environment e.g. the resistance of an LDR varies with light intensity, the resistance of a thermistor varies with temperature; these properties used in sensing systems to monitor changes in the environment.	1. relate the potential difference between two points in the circuit to the work done on, or by, a given amount of charge as it moves between these points potential difference (V) = work done (energy transferred) (J) ÷ charge (C) M1c, M3b, M3c, M3d 2. a) describe the difference between series and parallel circuits: to include ideas about how the current through each component and the potential difference across each component is affected by a change in resistance of a component b) describe how to practically investigate the brightness of bulbs in series and parallel circuits. Be able to draw circuit diagrams for the circuits used *PAG7* 3. explain, why, if two resistors are in series the net resistance is increased, whereas with two in parallel the net resistance is decreased *qualitative only* 4. solve problems for circuits which include resistors in series, using the concept of equivalent resistance M1c, M3b, M3c, M3d 5. explain the design and use of d.c. series circuits for measurement and testing purposes including exploring the effect of: a) changing current in filament lamps, diodes, thermistors and LDRs b) changing light intensity on an LDR c) changing temperature of a thermistor (NTC only)	**Ideas about Science** • Link the features of a model or analogy to features in an electric circuit, identify evidence for specific aspects of a model and limitations in representations of a model (IaS3). **Practical work** • Use d.c. series circuits, including potential divider circuits to investigate the behaviour of a variety of components. • Design and construct electric circuits to use a sensor for a particular purpose.

P3.4 What determines the rate of energy transfer in a circuit?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
The energy transferred when electric charge flows through a component (or device), depends on the amount of charge that passes and the potential difference across the component. The power rating (in watts, W) of an electrical device is a measure of the rate at which an electrical power supply transfers energy to the device and/or its surroundings. The rate of energy transfer depends on both the potential difference and the current. The greater the potential difference, the faster the charges move through the circuit, and the more energy each charge transfers. The National Grid uses transformers to step down the current for power transmission. The power output from a transformer cannot be greater than the power input, therefore if the current increases, the potential difference must decrease. Transmitting power with a lower current through the cables results in less power being dissipated during transmission.	1. describe the energy transfers that take place when a system is changed by work done when a current flows through a component
	2. explain, with reference to examples, how the power transfer in any circuit device is related to the energy transferred from the power supply to the device and its surroundings over a given time: power (W) = energy (J) ÷ time (s) M1c, M3b, M3c, M3d
	3. recall and use the relationship between the potential difference across the component and the total charge to calculate the energy transferred in an electric circuit when a current flows through a component: energy transferred (work done) (J) = charge (C) × potential difference (V) M1c, M3b, M3c, M3d
	4. recall and apply the relationships between power transferred in any circuit device, the potential difference across it, the current through it, and its resistance: power (W) = potential difference (V) × current (A) power (W) = (current (A))^2 × resistance (Ω) M1c, M3b, M3c, M3d
	5. use the idea of conservation of energy to show that when a transformer steps up the voltage, the output current must decrease and vice versa a) select and use the equation: potential difference across primary coil × current in primary coil = potential difference across secondary coil × current in secondary coil M1c, M3b, M3c, M3d
	6. explain how transmitting power at higher voltages is more efficient way to transfer energy

Linked learning opportunities
Practical work • Compare the power consumption of a variety of devices and relate it to the current passing through the device.

2

P3.5 What are magnetic fields?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Around any magnet there is a region, called the magnetic field, in which another magnet experiences a force. The magnetic effect is strongest at the poles. The field gets gradually weaker with distance from the magnet. The direction and strength of a magnetic field can be represented by field lines. These show the direction of the force that would be experienced by the N pole of a small magnet, placed in the field. The magnetic field around the Earth, with poles near the geographic north and south, provides evidence that the core of the Earth is magnetic. The N-pole of a magnetic compass will point towards the magnetic north pole. Magnetic materials (such as iron and nickel) can be induced to become magnets by placing them in a magnetic field. When the field is removed permanent magnets retain their magnetisation whilst other materials lose their magnetisation. When there is an electric current in a wire, there is a magnetic field around the wire; the field lines form concentric circles around the wire. Winding the wire into a coil (solenoid) makes the magnetic field stronger, as the fields of each turn add together. Winding the coil around an iron core makes a stronger magnetic field and an electromagnet that can be switched on and off. In loudspeakers and headphones the magnetic field produced due to a current through a coil interacts with the field of a permanent magnet. The 19th century discovery of this electromagnetic effect led quickly to the invention of a number of magnetic devices, including electromagnetic relays, which formed the basis of the telegraph system, leading to a communications revolution (IaS4.1).	1. describe the attraction and repulsion between unlike and like poles for permanent magnets 2. describe the characteristics of the magnetic field of a magnet, showing how strength and direction change from one point to another 3. explain how the behaviour of a magnetic compass is related to evidence that the core of the Earth must be magnetic 4. describe the difference between permanent and induced magnets 5. describe how to show that a current can create a magnetic effect 6. describe the pattern and directions of the magnetic field around a conducting wire 7. recall that the strength of the field depends on the current and the distance from the conductor 8. explain how the magnetic effect of a solenoid can be increased **9. explain how a solenoid can be used to generate sound in loudspeakers and headphones** *(separate science only)*

Linked learning opportunities

Specification links
- Sound waves (P1.4).

Practical work
- Use plotting compasses to map the magnetic field near a permanent bar magnet, between facing like/opposite poles of two magnets, a single wire, a flat coil of wire and a solenoid.
- Investigate the relationship between the number of turns on a solenoid and the strength of the magnetic field.
- **Build a loudspeaker.**

Ideas about Science
- Developments of electromagnets have led to major changes in people's lives, including applications in communications systems, MRI scanners and on cranes in scrapyards.

P3.6 How do electric motors work?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
The magnetic fields of a current-carrying wire and a nearby permanent magnet will interact and the wire and magnet exert a force on each other. This is called the 'motor effect'. **If the current-carrying wire is placed at right angles to the magnetic field lines, the force will be at right angles to both the current direction and the lines of force of the field. The direction of the force can be inferred using Fleming's left-hand rule.** **The size of the force is proportional to the length of wire in the field, the current and the strength of the field.** **The motor effect can result in a turning force on a rectangular current-carrying coil placed in a uniform magnetic field; this is the principle behind all electric motors.** **The invention and development of practical electric motors have made an impact on almost every aspect of daily life (IaS4.1).**	**1. describe the interaction forces between a magnet and a current-carrying conductor to include ideas about magnetic fields** **2. show that Fleming's left-hand rule represents the relative orientations of the force, the conductor and the magnetic field** **3. select and apply the equation that links the force (F) on a conductor to the strength of the field (B), the size of the current (I) and the length of conductor (l) to calculate the forces involved:** **force (N) = magnetic field strength (T) × current (A) × length of conductor (m)** M1b, M1c, M3b, M3c, M3d **4. explain how the force on a conductor in a magnetic field is used to cause rotation in the rectangular coil of a simple electric motor** ⓘ ***Detailed knowledge of the construction of motors not required***

Linked learning opportunities

Practical work
- Investigate the motor effect for a single wire in a magnetic field and apply the principles to build a simple electric motor.
- Build a simple electric motor and explain how it works.

Ideas about Science
- Describe and explain examples of uses of electric motors that have made significant improvements to people's lives. (IaS4.1).

2

P3.7 What is the process inside an electric generator? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Mains electricity is produced using the process of electromagnetic induction. When a magnet is moving into a coil of wire a potential difference is induced across the ends of the coil; if the magnet is moving out of the coil, or the other pole of the magnet is moving into it, there is a potential difference induced in the opposite direction. If the ends of the coil are connected to make a closed circuit, a current will flow round the circuit. In a moving coil microphone sound waves cause a diaphragm to vibrate. The diaphragm is attached to a coil which is in the field of a permanent magnet. Sounds make the coil vibrate, inducing a changing potential difference across the ends of the coil. This potential difference drives a changing current in an electric circuit. **In a generator, a magnet or electromagnet is rotated within a coil of wire to induce a voltage across the ends of the coil.** **The induced voltage across the coil of an alternating current (a.c.) generator (and hence the current in an external circuit) changes during each revolution of the magnet or electromagnet.** **To generate a d.c. split-ring commutator is used so that the current always passes from the same side of the generator.**	**1.** **recall that a change in the magnetic field around a conductor can give rise to an induced potential difference across its ends, which could drive a current** **2.** **explain the action of a moving coil microphone in converting the pressure variations in sound waves into variations in current in electrical circuits** **3.** **recall that the direction of the induced potential difference drives a current which generates a second magnetic field that would oppose the original change in field** **4.** **use ideas about electromagnetic induction to explain a potential difference/time graph showing the output from an alternator being used to generate a.c.** **5.** **explain how an alternator can be adapted to produce a dynamo to generate d.c., including explaining a potential difference/time graph** **6.** **explain how the effect of an alternating current in one circuit in inducing a current in another is used in transformers** **7.** **describe how the ratio of the potential differences across the two circuits of a transformer depends on the ratio of the numbers of turns in each**

Linked learning opportunities

Specification links
- How can electricity be generated? (P2.2)
- Sound waves (P1.4).

Practical work
- Investigate electromagnetic induction in transformers and generators.

Ideas about Science
- Describe and explain examples of technological applications of science that have made significant positive differences to people's lives (IaS4).
- Identify examples of risks which arise from a new scientific or technological advance (IaS4).

P3.7 What is the process inside an electric generator? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
A changing magnetic field caused by changes in the current in one coil of wire can induce a voltage in a neighbouring coil. **A simple transformer has two coils of wire wound on an iron core; a changing current in one coil of a transformer will cause a changing magnetic field in the iron core, which in turn will induce a changing potential difference across the other transformer coil.** **The discovery of electromagnetic induction and the subsequent development of power generators transformed the way we live, although with new developments in technology there are often unintended consequences (IaS4).**	**8. apply the equations linking the potential differences and numbers of turns in the two coils of a transformer, to the currents and the power transfer involved and relate these to the advantages of power transmission at high voltages:** **a) potential difference across primary coil × current in primary coil = potential difference across secondary coil × current in secondary coil** **b) potential difference across primary coil ÷ potential difference across secondary coil = number of turns in primary coil ÷ number of turns in secondary coil** M1c, M3b, M3c	

2

Chapter P4: Explaining motion

Overview

Simple but counterintuitive concepts of forces and motion, developed by Galileo and Newton, can transform young people's insight into everyday phenomena. These ideas also underpin an enormous range of modern applications, including spacecraft, urban mass transit systems, sports equipment and rides at theme parks.

Topic P4.1 reviews the idea of forces: identifying, describing and using forces to explain simple situations. Topic P4.2 looks at how speed is measured and represented graphically and introduces the vector quantities of velocity and displacement. The relationships between distance, speed, acceleration and time are an example of simple mathematical modelling that can be used to predict the speed and position of a moving object.

The relationship between forces and motion is developed in Topic P4.3, where resultant forces and changes in momentum are described. These ideas are then applied in the context of road safety.

Topic P4.4 considers how we can describe motion in terms of energy transfers.

Learning about forces and motion before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- describe motion using words and with distance–time graphs
- use the relationship average speed = distance ÷ time
- identify the forces when two objects in contact interact; pushing, pulling, squashing, friction, turning
- use arrows to indicate the different forces acting on objects, and predict the net force when two or more forces act on an object
- know that the forces due to gravity, magnetism and electric charge are all non-contact forces
- understand how the forces acting on an object can be used to explain its motion.

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

P4.1 What are forces?

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*
Force arises from an interaction between two objects, and when two objects interact, both always experience a force and that these two forces form an interaction pair. The two forces in an interaction pair are the same kind of force, equal in size and opposite in direction, and act on different objects (Newton's third law). Friction is the interaction between two surfaces that slide (or tend to slide) relative to each other: each surface experiences a force in the direction that prevents (or tends to prevent) relative movement. There is an interaction between an object and the surface it is resting on: the object pushes down on the surface, the surface pushes up on the object with an equal force, and this is called the normal contact force. In everyday situations, a downward force acts on every object, due to the gravitational attraction of the Earth. This is called its weight. It can be measured (in N) using a spring (or top-pan) balance. The weight of an object is proportional to its mass. Near the Earth's surface, the weight of a 1 kg object is roughly 10 N. The Earth's gravitational field strength is therefore 10 N/kg. Newton's insight that linked the force that causes objects to fall to Earth with the force that keeps the Moon in orbit around the Earth led to the first universal law of nature.	1. recall and apply Newton's third law 2. recall examples of ways in which objects interact: by gravity, electrostatics, magnetism and by contact (including normal contact force and friction) 3. describe how examples of gravitational, electrostatic, magnetic and contact forces involve interactions between pairs of objects which produce a force on each object 4. represent interaction forces as vectors 5. define weight 6. describe how weight is measured 7. recall and apply the relationship between the weight of an object, its mass and the gravitational field strength: weight (N) = mass (kg) × gravitational field strength (N/kg) M1c, M3b, M3c

Linked opportunities

Practical work

- Investigate the effect of different combinations of surfaces on the frictional forces.

Ideas about science

- Explain how Newton's discovery of the universal nature of gravity is an example of the role of imagination in scientific discovery (IaS3).

2

P4.2 How can we describe motion?

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*	*Linked opportunities*
The motion of a moving object can be described using the speed the object is moving, the direction it is travelling and whether the speed is changing. The distance an object has travelled at a given moment is measured along the path it has taken. The displacement of an object at a given moment is its net distance from its starting point together with an indication of direction. The velocity of an object at a given moment is its speed at that moment, together with an indication of its direction. Distance and speed are scalar quantities; they give no indication of direction of motion. Displacement and velocity are vector quantities, and include information about the direction. In everyday situations, acceleration is used to mean the change in speed of an object in a given time interval. Distance–time graphs and speed-time graphs can be used to describe motion. The average speed can be calculated from the slope of a distance–time graph. The average acceleration of an object moving in a straight line can be calculated from a speed-time graph. The distance travelled can be calculated from the area under the line on a speed-time graph.	1. recall and apply the relationship: average speed (m/s) = distance (m) ÷ time (s) M1a, M1c, M3b, M3c, M3d 2. recall typical speeds encountered in everyday experience for wind, and sound, and for walking, running, cycling and other transportation systems 3. a) make measurements of distances and times, and calculate speeds b) describe how to use appropriate apparatus and techniques to investigate the speed of a trolley down a ramp M2b, M2f *PAG3* 4. make calculations using ratios and proportional reasoning to convert units, to include between m/s and km/h M1c, M3c 5. explain the vector–scalar distinction as it applies to displacement and distance, velocity and speed 6. a) recall and apply the relationship: acceleration (m/s^2) = change in speed (m/s) ÷ time taken (s) M1c, M3b, M3c, M3d b) explain how to use appropriate apparatus and techniques to investigate acceleration *PAG3* 7. select and apply the relationship: $(\text{final speed (m/s)})^2 - (\text{initial speed(m/s)})^2 = 2 \times \text{acceleration (m/s}^2) \times \text{distance (m)}$ M1a, M1c, M3b, M3c, M3d	**Practical work**: • Use a variety of methods to measure distances, speeds and times and to calculate acceleration. • Compare methods of measuring the acceleration due to gravity. **Ideas about Science** • Use mathematical and computational models to make predictions about the motion of moving objects (IaS3). • Explore using simple computer models to predict motion of a moving object.

P4.2 How can we describe motion?

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*	*Linked opportunities*
The mathematical relationships between acceleration, speed, distance, and time are a simple example of a computational model. The model can be used to predict the speed and position of an object moving at constant speed or with constant acceleration.	8. draw and use graphs of distances and speeds against time to determine the speeds and accelerations involved	
	9. interpret distance–time and velocity–time graphs, including relating the lines and slopes in such graphs to the motion represented M4a, M4b, M4c, M4d	
	10. interpret enclosed areas in velocity – time graphs M4a, M4b, M4c, M4d, M4f	
	11. recall the value of acceleration in free fall and calculate the magnitudes of everyday accelerations using suitable estimates of speeds and times	

P4.3 What is the connection between forces and motion?

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*	*Linked opportunities*
When forces act on an object the resultant force is the sum of all the individual forces acting on it, taking their directions into account. **If a resultant force acts on an object, it causes a change of momentum in the direction of the force.** **The size of the change of momentum of an object is proportional to the size of the resultant force acting on the object and to the time for which it acts (Newton's second law).** For an object moving in a straight line: a. if the resultant force is zero, the object will move at constant speed in a straight line (Newton's first law). b. if the resultant force is in the direction of the motion, the object will speed up (accelerate). c. if the resultant force is in the opposite direction to the motion, the object will slow down. **In situations involving a change in momentum (such as a collision), the longer the duration of the impact, the smaller the average force for a given change in momentum.** In situations where the resultant force on a moving object is not in the line of motion, the force will cause a change in direction. **If the force is perpendicular to the direction of motion the object will move in a circle at a constant speed – the speed doesn't change but the velocity does. For example, a planet in orbit around the Sun – gravity acts along the radius of the orbit, at right angles to the planet's path.**	1. describe examples of the forces acting on an isolated solid object or system 2. describe, using free body diagrams, examples where several forces lead to a resultant force on an object and the special case of balanced forces (equilibrium) when the resultant force is zero *qualitative only* **3. use scale drawings of vector diagrams to illustrate the addition of two or more forces, in situations when there is a net force, or equilibrium** ⓘ ***Limited to parallel and perpendicular vectors only*** M4a, M5a, M5b **4. recall and apply the equation for momentum and describe examples of the conservation of momentum in collisions:** **momentum (kg m/s) = mass (kg) × velocity (m/s)** M1c, M3b, M3c, M3d **5. select and apply Newton's second law in calculations relating force, change in momentum and time:** **change of momentum (kg m/s) =** **resultant force (N) × time for which it acts (s)** M1c, M3b, M3c, M3d 6. apply Newton's first law to explain the motion of objects moving with uniform velocity and also the motion of objects where the speed and/or direction changes **7. explain with examples that motion in a circular orbit involves constant speed but changing velocity** ***qualitative only***	**Practical work** • Investigate factors that might affect human reaction times. • Investigate the use of crumple zones to reduce the stopping forces.

P4.3 What is the connection between forces and motion?

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*	*Linked opportunities*
In some situations a resultant force acts to make an object rotate about a fixed point (pivot). The rotational effect is called the moment of the force; the further the force acts from the pivot, the greater the turning effect. Levers and gears are used to transmit rotational forces.	8. describe examples in which forces cause rotation *(separate science only)*	
	9. define and calculate the moment of examples of rotational forces using the equation: moment of a force (N m) = force (N) × distance (m) (normal to direction of the force) *(separate science only)* M1c, M3b, M3c, M3d	**Practical work** • **Investigate forces that cause rotation, including the use of levers and gears.**
	10. explain, with examples, how levers and gears transmit the rotational effects of forces *(separate science only)*	
The mass of an object can be thought of as the amount of matter in an object – the sum of all the atoms that make it up. Mass is measured in kilograms. The mass of an object is also a measure of its resistance to any change in its motion (its inertia); using this definition the inertial mass is the ratio of the force applied to the resulting acceleration. **Newton wrote about how the length of time a force acted on an object would change the object's 'amount of motion', and the way he used the term makes it clear that he is describing what we now call momentum, this has led to Newton's second law being expressed in two ways – in terms of change in momentum and in terms of acceleration.** Newton's explanation of motion is one of the great intellectual leaps of humanity. It is a good example of the need for creativity and imagination to develop a scientific explanation of something that had been observed and discussed for many years (IaS3).	**11. explain that inertial mass is a measure of how difficult it is to change the velocity of an object and that it is defined as the ratio of force over acceleration**	
	12. recall and apply Newton's second law relating force, mass and acceleration: force (N) = mass (kg) × acceleration (m/s^2) M1c, M3b, M3c, M3d	**Ideas about Science** • Explain why Newton's explanation of motion is an example of the need for creative thinking in developing new scientific explanations (IaS3).
	13. Use and apply equations relating force, mass, velocity, acceleration, and **momentum** to explain relationships between the quantities M3b, M3c, M3d	

P4.3 What is the connection between forces and motion?

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*	Linked opportunities
Ideas about force and **momentum** can be used to explain road safety measures, such as stopping distances, car seatbelts, crumple zones, air bags, and cycle and motorcycle helmets. Improvements in technology based on Newton's laws of motion (together with the development of new materials) have made all forms of travel much safer.	14. explain methods of measuring human reaction times and recall typical results	**Ideas about Science** • Describe and explain examples of how application of Newton's laws of motion have led developments in road safety (IaS4). • Discuss people's willingness to accept risk in the context of car safety and explain ways in which the risks can be reduced (IaS4).
	15. explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies and the implications for safety M2c	
	16. explain the dangers caused by large decelerations **and estimate the forces involved in typical situations on a public road**	
	17. given suitable data, estimate the distance required for road vehicles to stop in an emergency, and describe how the distance varies over a range of typical speeds *(separate science only)* M1c, M1d, M2c, M2h, M3b, M3c	
	18. in the context of everyday road transport, use estimates of speeds, times and masses to calculate the accelerations and forces involved in events where large accelerations occur *(separate science only)* M1d, M2b, M2h, M3c	

P4.4 How can we describe motion in terms of energy transfers?

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*	*Linked opportunities*
Energy is always conserved in any event or process. Energy calculations can be used to find out if something is possible and what will happen, but not explain why it happens. The store of energy of a moving object is called its kinetic energy. As an object is raised, its store of gravitational potential energy increases, and as it falls, its gravitational potential energy decreases. When a force moves an object, it does work on the object, energy is transferred to the object; when work is done by an object, energy is transferred from the object to something else, for example: • when an object is lifted to a higher position above the ground, work is done by the lifting force; this increases the store of gravitational potential energy. • when a force acting on an object makes its velocity increase, the force does work on the object and this results in an increase in its store of kinetic energy. If friction and air resistance can be ignored, an object's store of kinetic energy changes by an amount equal to the work done on it by an applied force; in practice air resistance or friction will cause the gain in kinetic energy to be less than the work done on it by an applied force in the direction of motion, because some energy is dissipated through heating.	1. describe the energy transfers involved when a system is changed by work done by forces including: a) to raise an object above ground level b) to move an object along the line of action of the force 2. recall and apply the relationship to calculate the work done (energy transferred) by a force: work done (Nm or J) = force (N) × distance (m) (along the line of action of the force) M1a, M3b, M3c, M3d 3. recall the equation and calculate the amount of energy associated with a moving object: kinetic energy (J) = 0.5 × mass (kg) × $(\text{speed (m/s)})^2$ M1a, M3b, M3c, M3d 4. recall the equation and calculate the amount of energy associated with an object raised above ground level gravitational potential energy (J) = mass (kg) × gravitational field strength (N/kg) × height (m) M1a, M3b, M3c, M3d 5. make calculations of the energy transfers associated with changes in a system, recalling relevant equations for mechanical processes M1a, M1c, M3c 6. calculate relevant values of stored energy and energy transfers; convert between newton-metres and joules M1c, M3c	**Specification links:** • **P2 Sustainable energy.** **Practical work** • Use datalogging software to calculate the efficiency of energy transfers when work is done on a moving object. • Measure the work done by an electric motor lifting a load, and calculate the efficiency.

2

P4.4 How can we describe motion in terms of energy transfers?

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*	*Linked opportunities*
Calculating the work done when climbing stairs or lifting a load, and the power output, makes a link back to the usefulness of electrical appliances for doing many everyday tasks.	7. describe all the changes involved in the way energy is stored when a system changes, for common situations: including an object projected upwards or up a slope, a moving object hitting an obstacle, an object being accelerated by a constant force, a vehicle slowing down	
	8. explain, with reference to examples, the definition of power as the rate at which energy is transferred (work done) in a system	
	9. recall and apply the relationship: power (W) = energy transferred (J) ÷ time (s) M1a, M3b, M3c, M3d	

Chapter P5: Radioactive materials

Overview

The terms 'radiation' and 'radioactivity' are often interchangeable in the public mind. Because of its invisibility, radiation is commonly feared. A more objective evaluation of risks and benefits is encouraged through developing an understanding of the many practical uses of radioactive materials.

Topic P5.1 begins by considering the evidence of a nuclear model of the atom, including Rutherford's alpha particle scattering experiment. It then uses the nuclear model to explain what happens during radioactive decay. The properties of alpha, beta and gamma radiation are investigated and ideas about half-life are developed. In Topic P5.2 learners learn about the penetration properties of ionising radiation which leads to a consideration of the use of radioactive materials in the health sector, and how they can be handled safely. In the context of health risks associated with irradiation and/or contamination by radioactive material, they also learn about the interpretation of data on risk.

Topic P5.3 describes nuclear fission and nuclear fusion. Learners have the opportunity to learn more about the issues that surround decisions about the best way to generate electricity.

Learning about the radioactivity before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- recall that in each atom its electrons are arranged at different distances from the nucleus
- recall that gamma rays are emitted from the nuclei of atoms
- be able to describe how ionising radiation can have hazardous effects, notably on human bodily tissues.

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers. All other statements will be assessed in both Foundation and Higher Tier papers.

P5.1 What is radioactivity?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
An atom has a nucleus, made of protons and neutrons, which is surrounded by electrons. The modern model of the atom developed over time as scientists rejected earlier models and proposed new ones to fit the currently available evidence. Each stage relied on scientists using reasoning to propose models which fitted the evidence available at the time. Models were rejected, modified and extended as new evidence became available (IaS3). After the discovery of the electron in the 19th century by Thomson scientists imagined that atoms were small particles of positive matter with the negative electrons spread through, like currants in a cake. This was the model used until 1910 when the results of the Rutherford-Geiger-Marsden alpha particle scattering experiment provided evidence that a gold atom contains a small, massive, positive region (the nucleus). Atoms are small – about 10^{-10} m across, and the nucleus is at the centre, about a hundred-thousandth of the diameter of the atom. Each atom has a nucleus at its centre and that nucleus is made of protons and neutrons. For an element, the number of the protons is always the same but the number of neutrons may differ. Forms of the same element with different numbers of neutrons are called the isotopes of the element. Interpreting the unexpected results of the Rutherford-Geiger-Marsden experiment required imagination to consider a new model of the atom.	1. describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller than that of the atom and with almost all of the mass in the nucleus 2. describe how and why the atomic model has changed over time to include the main ideas of Dalton, Thomson, Rutherford and Bohr 3. recall the typical size (order of magnitude) of atoms and small molecules 4. recall that atomic nuclei are composed of both protons and neutrons, and that the nucleus of each element has a characteristic positive charge 5. recall that nuclei of the same element can differ in nuclear mass by having different numbers of neutrons, these are called isotopes 6. use the conventional representation to show the differences between isotopes, including their identity, charge and mass 7. recall that some nuclei are unstable and may emit alpha particles, beta particles, or neutrons, and electromagnetic radiation as gamma rays 8. relate emissions of alpha particles, beta particles, or neutrons, and gamma rays to possible changes in the mass or the charge of the nucleus, or both

Linked learning opportunities

Specification links
- How has our understanding of the structure of atoms developed over time? (C2.1)

Ideas about Science
- Explain how the development of the nuclear model of the atom is an example of how scientific explanations become accepted (IaS3).

Practical work
- Collect data to calculate the half-life of a radioactive isotope.
- Use a random event such as dice-throwing to model radioactive decay.

P5.1 What is radioactivity?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Some substances emit ionising radiation all the time and are called radioactive. The ionising radiation (alpha, beta, gamma, and neutron) is emitted from the unstable nucleus of the radioactive atoms, which as a result become more stable. Alpha particles consist of two protons and two neutrons, and beta particles are identical to electrons. Gamma radiation is very high frequency electromagnetic radiation.	9. use names and symbols of common nuclei and particles to write balanced equations that represent the emission of alpha, beta, gamma, and neutron radiations during radioactive decay M1b, M1c, M3c	
	10. explain the concept of half-life and how this is related to the random nature of radioactive decay	
Radioactive decay is a random process. For each radioactive isotope there is a different constant chance that any nucleus will decay. Over time the activity of radioactive sources decreases, as the number of undecayed nuclei decreases.	**11. calculate the net decline, expressed as a ratio, in a radioactive emission after a given (integral) number of half-lives** M1c, M3d	
The time taken for the activity to fall to half is called the half-life of the isotope and can be used to calculate the time it takes for a radioactive material to become relatively safe.	12. interpret activity-time graphs to find the half-life of radioactive materials M1c, M2g, M4a, M4c	

2

P5.2: How can radioactive materials be used safely?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Ionising radiation can damage living cells and these may be killed or may become cancerous, so radioactive materials must be handled with care. In particular, a radioactive material taken into the body (contamination) poses a higher risk than the same material outside as the material will continue to emit ionising radiation until it leaves the body. Whilst ionising radiation can cause cancer, it can also be used for imaging inside the body and to kill cancerous cells. Doctors and patients need to consider the risks and benefits when using ionising radiation to treat diseases.	1. recall the differences in the penetration properties of alpha particles, beta particles and gamma rays 2. recall the differences between contamination and irradiation effects and compare the hazards associated with each of these 3. describe the different uses of nuclear radiations for exploration of internal organs, and for control or destruction of unwanted tissue 4. explain how ionising radiation can have hazardous effects, notably on human bodily tissues 5. explain why the hazards associated with radioactive material differ according to the radiation emitted and the half-life involved

Linked learning opportunities

Specification links:

- What are the risks and benefits of using electromagnetic radiations? (P1.2)

Practical work

- Collect and interpret data to show the penetration properties of ionising radiations.

Ideas about Science

- Discuss ideas about correlation and cause in the context of links between ionising radiation and cancer (IaS3).
- Discuss the uses of ionising radiation, with reference to its risks and benefits (IaS4).

P5.3 How can radioactive materials be used to provide energy? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Nuclear fuels are radioactive materials that release energy during changes in the nucleus. In nuclear fission a neutron splits a large and unstable nucleus (such as some isotopes of uranium and plutonium) into two smaller parts, roughly equal in size, releasing more neutrons, which may go on to make further collisions. Energy is released from the nucleus, carried away as kinetic energy of the particles and also by gamma radiation. This release of energy from the nuclear store is analogous to that released from the chemical store of explosives like TNT but it is considerably larger. If brought close enough together, hydrogen nuclei can fuse into helium nuclei, releasing energy, and this is called nuclear fusion. The demand for energy is continually increasing and nuclear fuels are an alternative energy source to fossil fuels. The risks and benefits need to be compared when making decisions about how to generate electricity.	1. recall that some nuclei are unstable and may split into two nuclei and that this is called nuclear fission 2. relate the energy released during nuclear fission to the emission of ionising radiation and the kinetic energy of the resulting particles 3. explain how nuclear fission can lead to further fission events in a chain reaction 4. describe the process of nuclear fusion and recall that in this process some of the mass may be converted into the energy of radiation

Linked learning opportunities

Specification links:

- How should electricity be generated? (P3.2)

Ideas about Science

- Discuss the risks and benefits of generating electricity using nuclear fission. Suggest reasons why different decisions on the same issue might be appropriate in view of differences in personal, social, or economic context (IaS4).

2

Chapter P6: Matter – models and explanations

Overview

Richard Feynman said: "If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied." (*Six Easy Pieces*, p.4)

In this chapter the particle model described by Feynman is used to predict and explain some properties of matter. Topic P6.1 explores the relationship between energy and temperature and the ways in which energy transfer transforms matter. Topic P6.2 considers how the particle model explains the differences in densities between solids, liquids and gases and the effect of heating both in terms of temperature changes and changes of state. Topic P6.3 considers the behaviour of materials under stress and how the particle model can explain differences in behaviour. Topic 6.4 deals with pressure, and how it varies in fluids (liquids and gases), with the particle model used to explain the law discovered by Robert Boyle. Finally, in Topic P6.5 ideas about forces and also the particle model are considered in the context of planets, moons and satellites in their orbit, and the formation of the solar system, before briefly describing the early stage of the Universe and the Big Bang.

Learning about matter and particles before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- be able to use a particulate model of matter to explain states of matter and changes of state
- have investigated stretching and compressing materials and identifying those that obey Hooke's law
- be able to describe how the extension or compression of an elastic material changes as a force is applied, and make a link between the work done and energy transfer during compression or extension
- have investigated pressure in liquids and related this to floating and sinking
- be able to relate atmospheric pressure to the weight of air overhead.

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

P6.1 How does energy transform matter?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
It took the insight of a number of eighteenth and nineteenth century scientists to appreciate that heat and work were two aspects of the same quantity, which we call energy. Careful experiments devised by Joule showed that equal amounts of mechanical work would always produce the same temperature rise. Energy can be supplied to raise the temperature of a substance by heating using a fuel, or an electric heater, or by doing work on the material. Mass – the amount of matter in an object – depends on its volume and the density of the material of which it consists. The temperature rise of an object when it is heated depends on its mass and the amount of energy supplied. Different substances store different amounts of energy per kilogram for each °C temperature rise – this is called the specific heat capacity of the material.	1. a) define density b) describe how to determine the densities of solid and liquid objects using measurements of length, mass and volume M1c, M5c *PAG1*
	2. recall and apply the relationship between density, mass and volume to changes where mass is conserved: density (kg/m^3) = mass (kg) ÷ volume (m^3) M1a, M1b, M1c, M3c
	3. describe the energy transfers involved when a system is changed by heating (in terms of temperature change and specific heat capacity)
	4. define the term specific heat capacity and distinguish between it and the term specific latent heat
	5. a) select and apply the relationship between change in internal energy of a material and its mass, specific heat capacity and temperature: change in internal energy (J) = mass (kg) × specific heat capacity (J/kg°C) × change in temperature (°C) M1a, M1c, M3d b) explain how to safely use apparatus to determine the specific heat capacity of materials *PAG5*

Linked learning opportunities

Specification links
- How much energy do we use? (P2.1)
- What determines the rate of energy transfer in a circuit? (P3.4)
- How can we describe motion in terms of energy transfers? (P4.4)

Practical work
- Devise a method to measure the density of irregular objects.
- Measure the specific heat capacity of a range of substances such as water, copper, aluminium.
- Measure the latent heat of fusion of a substance in the solid state and the latent heat of vaporisation of a substance in the liquid state.
- Show that the same amount of work always results in the same temperature rise.
- Collect data, plot and interpret graphs that show how the temperature of a substance changes when heated by a constant supply of energy.

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P6.1 How does energy transform matter?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
When a substance in the solid state is heated its temperature rises until it reaches the melting point of the substance, but energy must continue to be supplied for the solid to melt. Its temperature does not change while it melts, and the change in density on melting is very small. Similarly as a substance in the liquid state is heated its temperature rises until it reaches boiling point; its temperature does not change, although energy continues to be supplied while it boils. The change in density on boiling is very great; a small volume of liquid produces a large volume of vapour. Different substances require different amounts of energy per kilogram to change the state of the substance – this is called the specific latent heat of the substance.	6. select and apply the relationship between energy needed to cause a change in state, specific latent heat and mass: energy to cause a change of state (J) = mass (kg) × specific latent heat (J/kg) M1a, M1c, M3d 7. describe all the changes involved in the way energy is stored when a system changes, and the temperature rises, for example: a moving object hitting an obstacle, an object slowing down, water brought to a boil in an electric kettle 8. make calculations of the energy transfers associated with changes in a system when the temperature changes, recalling or selecting the relevant equations for mechanical, electrical, and thermal processes M1a, M1c, M2a, M3b, M3c, M3d

Linked learning opportunities

Ideas about Science

- Describe and explain how careful experimental strategy can yield high quality data (IaS1).
- Describe and explain an example of how a developing a new scientific explanation takes creative thinking (IaS3).

P6.2 How does the particle model explain the effects of heating?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
The particle model of matter describes the arrangements and behaviours of particles (atoms and molecules); it can be used to predict and explain the differences in properties between solids, liquids and gases. In this model: • All matter is made of very tiny particles. • There is no other matter except these particles (in particular, no matter between them). • Particles of any given substance are all the same. • Particles of different substances have different masses. • There are attractive forces between particles. These differ in strength from one substance to another. • In the solid state, the particles are close together and unable to move away from their neighbours. • In the liquid state, the particles are also close together, but can slide past each other. • In the gas state, the particles are further apart, and can move freely. The particle model is an example of how scientists use models as tools for explaining observed phenomena. The particle model can be used to describe and predict physical changes when matter is heated. • The particles are always moving: in the solid state, they are vibrating; in the liquid state, they are vibrating and jostling around; in the gas state, they are moving freely in random directions. • A substance in the gas state exerts pressure on its container because the momentum of the particles changes when they collide with walls of the container. • The hotter something is, the higher its temperature is and the faster its particles are vibrating or moving. Careful experimentation and mathematical analysis showed that the temperature of a substance was linked to the kinetic energy of its atoms or molecules.	1. explain the differences in density between the different states of matter in terms of the arrangements of the atoms or molecules 2. use the particle model of matter to describe how mass is conserved, when substances melt, freeze, evaporate, condense or sublimate, but that these physical changes differ from chemical changes and the material recovers its original properties if the change is reversed 3. use the particle model to describe how heating a system will change the energy stored within the system and raise its temperature or produce changes of state 4. explain how the motion of the molecules in a gas is related both to its temperature and its pressure: hence explain the relationship between the temperature of a gas and its pressure at constant volume *qualitative only*	**Ideas about Science** • Use the particle model to explain familiar or unfamiliar phenomena and make predictions (IaS3).

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P6.3 How does the particle model relate to material under stress?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
When more than one force is applied to a solid material it may be compressed, stretched or twisted. When the forces are removed it may return to its original shape or become permanently deformed. These effects can be explained using ideas about particles in the solid state. A substance in the solid state is a fixed shape due to the forces between the particles. Compressing or stretching the material changes the separation of the particles, and the forces between the particles. Elastic materials spring back to their original shape. If the forces are too large the material becomes plastic and is permanently distorted. For some materials, the extension is proportional to the applied force, but in other systems, such as rubber bands, the relationship is not linear, even though they are elastic. When work is done by a force to compress or stretch an spring or other simple system, energy is stored, this energy can be recovered when the force is removed.	1. explain, with examples, that to stretch, bend or compress an object, more than one force has to be applied 2. describe **and use the particle model to explain** the difference between elastic and plastic deformation caused by stretching forces 3. a) describe the relationship between force and extension for a spring and other simple systems b) describe how to measure and observe the effect of forces on the extension of a spring M2b, M2f *PAG2* 4. describe the difference between the force-extension relationship for linear systems and for non-linear systems 5. recall and apply the relationship between force, extension and spring constant for systems where the force-extension relationship is linear force exerted by a spring (N) = extension (m) × spring constant (N/m) M1c, M3b, M3c 6. a) calculate the work done in stretching a spring or other simple system, by calculating the appropriate area on the force-extension graph M4f b) describe how to safely use apparatus to determine the work done in stretching a spring 7. select and apply the relationship between energy stored, spring constant and extension for a linear system: energy stored in a stretched spring (J) = ½ × spring constant (N/m) × (extension (m))^2 M1c, M3b, M3c, M3d	**Practical work** • Investigate the force-extension properties of a variety of materials, identifying those that obey Hooke's law, those that behave elastically, and those that show plastic deformation.

P6.4 How does the particle model relate to pressures in fluids? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
An object immersed in a fluid (a liquid or a gas) experiences forces acting at right angles to all its surfaces due to the pressure of the fluid. The pressure of the fluid is due to collisions of the particles of the fluid with the surface of the object. The particles of gas in a container collide with the surfaces of the container, exerting a pressure. If the volume of the container is increased, the particles have further to travel between collisions and the pressure of the gas falls. When a gas is compressed the particles are much closer together and will collide with the walls of the container more frequently, exerting a greater outward pressure. The atmosphere of the Earth exerts a pressure perpendicular to the surface of any object in it, and this pressure is the same in all directions at a particular height. Atmospheric pressure decreases with height above the surface of the Earth. The pressure at a point in a fluid increases with depth, because it is caused by the gravitational force on the fluid above that point. A fluid with greater density will experience a greater gravitational force and so exert a greater pressure.	1. recall that the pressure in fluids causes a force normal to any surface 2. recall and apply the relationship between the force, the pressure, and the area in contact: pressure (Pa) = force normal to a surface (N) ÷ area of that surface (m^2) M3b, M3c 3. recall that gases can be compressed or expanded by pressure changes and that the pressure produces a net force at right angles to any surface 4. use the particle model of matter to explain how increasing the volume in which a gas is contained, at constant temperature, can lead to a decrease in pressure 5. select and apply the equation: pressure × volume = constant (for a given mass of gas at constant temperature) M1c, M3b, M3c, M3d 6. describe a simple model of the Earth's atmosphere and of atmospheric pressure, and explain why atmospheric pressure varies with height above the surface **7. explain why pressure in a liquid varies with depth and density**	Practical work • **Investigate the relationship between density of an immersed object and density of the fluid and the net force on the object.** • **Devise an experiment to show that pressure in a fluid varies with depth.** • **Investigate the relationships between the pressure of a gas and its volume and its temperature.**

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P6.4 How does the particle model relate to pressures in fluids? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Because pressure increases with depth, the force on the lower surface of an immersed object will be greater than the force on the upper surface, resulting in a net force upwards. This explains why the apparent weight of an object immersed in a liquid is less than its weight in air. It was Dalton's careful study of the atmosphere and gases that led to him giving a quantitative significance to the atomic theory which provides the basis for the particle model of matter.	**8. select and apply the equation to calculate the differences in pressure at different depths in a liquid:** **pressure = density × gravitational field strength × depth** M1c, M3c **9. explain how the increase in pressure with depth in a fluid leads to an upwards force on a partially submerged object** **10. describe and explain the factors which influence whether a particular object will float or sink**	

P6.5 How can scientific models help us understand the Big Bang? (*separate science only*)

Teaching and learning narrative	Assessable learning outcomes *Learners will be able to:*	Linked opportunities
The gravitational interaction between the planets and the Sun keeps the planets in (almost) circular orbits around the Sun, all in the same direction. Similarly, it is the gravitational interaction between a planet and its moons or artificial satellites that keeps them in orbit.	1. recall the main features of our solar system, including the similarities and distinctions between the planets, their moons, and artificial satellites	**Specification links** • **Nuclear fusion (P5.3).** **Practical work** • Investigate the relationship between the force, speed and radius of path for an object moving in a circle. **Ideas about Science** • Use the development of the 'Big Bang' model of the beginning of the Universe as an example of how scientific explanations become accepted (IaS3).
The force needed to keep an object moving in a circle depends on the speed of the object and the radius of the circle. The greater the speed and/or the smaller the radius, the greater the force needed. If a satellite or planet slows down, it will be pulled in to a smaller radius orbit.	**2. explain, for the circular orbits, how the force of gravity can lead to changing velocity of a planet but unchanged speed**	
	3. explain how, for a stable orbit, the radius must change if this speed changes *qualitative only*	
The solar system was formed over long periods from clouds of gases and dust drawn together by the force of gravity. When a force is used to compress a gas, work is done on the gas, leading to an increase in temperature.	4. recall that the solar system was formed from dust and gas drawn together by gravity	
During the formation of a star such as the Sun, a cloud of gas is pulled together by gravity, its temperature increases and the hydrogen nuclei gain sufficient energy to fuse into helium nuclei, releasing more energy.	**5. use the particle model of matter to explain how doing work on a gas can increase its temperature (e.g. bicycle pump, in stars)**	
The Universe contains thousands of millions of galaxies. The light coming from distant galaxies shows a red-shift that suggests that distant galaxies are moving away from us. The further away a galaxy is, the faster it is moving away from us; this suggests that space itself is expanding. Scientists' explanation for these observations is that the Universe began with a 'Big Bang' about 14 thousand million years ago.	6. explain how the Sun was formed when collapsing cloud of dust and gas resulted in fusion reactions, leading to an equilibrium between gravitational collapse and expansion due to the fusion energy	
The acceptance of the 'Big Bang' model to describe the early stages of the Universe depends on the interpretation of observations, as more observations were made, the theory became more secure.	7. explain the red-shift of light from galaxies which are receding *qualitative only*	
Telescope designs have improved over the last 100 years, and modifications have made it possible to observe regions of the electromagnetic spectrum other than visible light. Placing these instruments outside the atmosphere has improved the range and quality of data obtained, and these improved data have increased the confidence in the 'Big Bang' model (IaS3).	8. explain that the relationship between the distance of each galaxy and its speed is evidence of an expanding universe model	
	9. explain how the evidence of an expanding universe leads to the 'Big Bang' model	

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