2.3 Topic 1: Heating processes

In this topic, students will:

Subject matter	Guidance
Kinetic particle model and heat flow • describe the kinetic particle model of matter • define and distinguish between thermal energy, temperature, kinetic energy, heat and internal energy • explain heat transfers in terms of conduction, convection and radiation.	• **Notional time:** 2 hours • **Stimulus questions** – What is heat? – What is the difference between heat and temperature?
Temperature and specific heat capacity • use $T_K = T_C + 273$ to convert temperature measurements between Celsius and Kelvin • use digital and other measuring devices to collect data, ensuring measurements are recorded using the correct symbol, SI unit, number of significant figures and associated measurement uncertainty (absolute and percentage); all experimental measurements should be recorded in this way • explain that a change in temperature is due to the addition or removal of energy from a system (without phase change) • define *specific heat capacity* and the concept of proportionality • interpret tabulated and graphical data of heat added to a substance and its subsequent temperature change (without phase change) • solve problems involving specific heat capacity. • **Mandatory practicals** – Conduct an experiment that obtains data to be plotted on a scatter graph (with correct title and symbols, units and labels on the axes), analysed by calculating the equation of a linear trend line, interpreted to draw a conclusion, and reported on using scientific conventions and language. – Conduct an experiment that determines the specific heat capacity of a substance, ensuring that measurement uncertainties associated with mass and temperature are propagated. Where the mean is calculated (in this, and future experiments), determine the percentage and/or absolute uncertainty of the mean.	• **Notional time:** 6 hours • **Stimulus questions** – Why is it important to have the same unit of measurement internationally? – Which has more energy — a cup of coffee or a swimming pool? – What property of water makes it ideal for use as a coolant in car engines? • Students do not need to use mathematical formulas relating temperature and the average kinetic energy of the particles. • **Suggested practicals** – Conduct an experiment to investigate the precision and accuracy of different temperature measuring devices, such as analogue and digital thermometers by determining measurement uncertainty. – Conduct an experiment to investigate the proportional relationship between heat and temperature change. – Conduct an experiment to investigate the initial and final temperature of two liquids before and after they are mixed. Compare the final temperature data with a temperature value calculated theoretically by finding the percentage error. • **Formulas:** $T_K = T_C + 273$ $Q = mc\Delta T$ • **SHE:** Students could explore the development of temperature scales, e.g. Fahrenheit, Celsius and Kelvin.

Subject matter	Guidance
Phase changes and specific latent heat • explain why the temperature of the system remains the same during the process of state change; explain it in terms of the internal energy of a system and the kinetic particle model of matter • define *specific latent heat* • solve problems involving specific latent heat.	• **Notional time:** 4 hours • **Stimulus questions** – Why do you feel colder when you are wearing wet clothes? – How is it possible to boil water in a paper cup on a camp fire? • **Suggested practical:** Conduct an experiment to observe the change in temperature while heating substances before, during and after a phase change. • **Formula:** $Q = mL$
Energy conservation in calorimetry • define *thermal equilibrium* in terms of the temperature and average kinetic energy of the particles in each of the systems • explain the process in which thermal energy is transferred between two systems until thermal equilibrium is achieved, and recognise this as the zeroth law of thermodynamics • solve problems involving specific heat capacity, specific latent heat and thermal equilibrium.	• **Notional time:** 4 hours • **Stimulus question:** Does putting a coat on a snowman make it melt faster?
Energy in systems — mechanical work and efficiency • explain that a system with thermal energy has the capacity to do mechanical work • recall that the change in the internal energy of a system is equal to the energy added or removed by heating plus the work done on or by the system, and recognise this as the first law of thermodynamics and that this is a consequence of the law of conservation of energy • explain that energy transfers and transformations in mechanical systems always result in some heat loss to the environment, so that the amount of useable energy is reduced • define *efficiency* • solve problems involving finding the efficiency of heat transfers.	• **Notional time:** 2 hours • **Stimulus question:** If useable energy is reduced every time an energy transfer occurs, what implications will this have on the availability of useable energy in the future? • **Formulas:** $\Delta U = Q + W$ $\eta = \frac{\text{energy output}}{\text{energy input}} \times \frac{100}{1}\%$ • **SHE:** Students could use the concepts of energy transfers and efficiency to consider the economic and ethical implications of this science on the choice of solar panel, building design, flooring insulation, etc.
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for a research investigation.	• **Energy security and sustainability — emerging energy sources:** The science of heating processes is of key importance to the development of efficient and cost-effective technologies that use sustainable and renewable

Subject matter	Guidance
	energy sources. • **Energy balance of Earth:** Predicting global temperatures and human-induced climate change is greatly aided by new technologies and an understanding of heating processes. • **Development of thermodynamics:** The need to increase the efficiency of early steam engines led to further technological advancements (e.g. the internal combustion engine) and scientific advancements (e.g. an understanding of, and mathematical articulation of, the relationship between heating processes and mechanical work).

2.4 Topic 2: Ionising radiation and nuclear reactions

In this topic, students will:

Subject matter	Guidance
Nuclear model and stability • describe the nuclear model of the atom characterised by a small nucleus surrounded by electrons • explain why protons in the nucleus repel each other • define the *strong nuclear force* • explain the stability of a nuclide in terms of the operation of the strong nuclear force over very short distances, electrostatic repulsion, and the relative number of protons and neutrons in the nucleus.	• **Notional time:** 2 hours • Students are not required to identify the Bohr (or other historical) model of the atom at this stage. • Students should use the ${}^{A}_{Z}\mathrm{X}$ nomenclature. • **SHE:** Students could know that the development of models of the atom often required a wide range of evidence from multiple individuals and across disciplines.
Spontaneous decay and half-life • explain natural radioactive decay in terms of stability • define *alpha radiation*, *beta positive radiation*, *beta negative radiation* and *gamma radiation* • describe alpha, beta positive, beta negative and gamma radiation, including the properties of penetrating ability, charge, mass and ionisation ability • explain how an excess of protons, neutrons or mass in a nucleus can result in alpha, beta positive and beta negative decay • solve problems involving balancing nuclear equations	• **Notional time:** 6 hours • Students are not expected to give reasons for the presence of an electron neutrino or electron antineutrino in the relevant decay equations. • Students are not required to demonstrate an understanding of exponential decay in the form e^{-kt}. However, students should be able to recognise exponential decay graphs and know that each species of radionuclide has a specific half-life. They should be able to use these graphs to estimate half-lives. • **Suggested practical:** Conduct an experiment or simulation investigating

Subject matter	Guidance
• represent spontaneous alpha, beta positive and beta negative decay using decay equations, e.g. $^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}^{2+} + \gamma$ $^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + {}^{0}_{-1}e + \bar{\nu}_e + \gamma$ $^{102}_{50}\mathrm{Sn} \rightarrow {}^{102}_{49}\mathrm{In} + {}^{0}_{+1}e + \nu_e + \gamma$ • explain how a radionuclide will, through a series of spontaneous decays, become a stable nuclide • define *half-life* • solve radioactive decay problems involving whole numbers of half-lives.	shielding effects and/or the relationship between intensity and distance from a radioactive source. • **Formula:** $N = N_o(\frac{1}{2})^n$ • **SHE:** Students could explore – how advances in scientists' understanding of the properties of nuclear radiation have influenced medical treatment and imaging – the use of scientific knowledge to predict beneficial and/or harmful or unintended consequences, e.g. choosing appropriate radioisotopes for medical imaging, carefully storing nuclear waste – how scientific knowledge of radioactive decay can enable scientists to offer valid explanations and make reliable predictions in radiometric dating of materials.
Energy and mass defect • describe energy in terms of electron volts (eV) and joules (J) • define *artificial transmutation* • distinguish between artificial transmutations and natural radioactive decay • define *nuclear fission* • explain a neutron-induced nuclear fission reaction, including references to extra neutrons produced from many of these reactions • research nuclear safety, considering the suitability of using the sources of information in terms of their credibility • explain a fission chain reaction • define *nuclear fusion* • define *mass defect*, *binding energy* and *binding energy per nucleon* • recall Einstein's mass–energy equivalence relationship • solve problems involving Einstein's mass–energy equivalence relationship • explain that more energy is released per nucleon in nuclear fusion than in nuclear fission because a greater percentage of the mass is transformed into energy.	• **Notional time:** 5 hours • Students should represent nuclear fission with nuclear equations similar to spontaneous decay equations, e.g. $^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 3\,{}^{1}_{0}\mathrm{n}$ + energy • A specific example of a fission chain reaction is not required in the explanation. • Students could represent nuclear fusion with nuclear equations, e.g. $^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$ + energy. • **Formula:** $\Delta E = \Delta mc^2$ • **Stimulus question:** Should Australia generate power using nuclear fission? • **SHE:** Students could explore the possibility of nuclear fission-based power production replacing fossil fuels to generate electricity.
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for a	• **Radioisotopes and radiometric dating:** An understanding of nuclear processes has led to the use of new analytical tools (e.g. radiometric dating) to

Subject matter	Guidance
research investigation.	understand past events. • **Harnessing nuclear power:** The health and environmental risks associated with the use of nuclear fission must be considered along with the environmental and cost benefits of lowering fossil fuel consumption. • **Nuclear fusion in stars:** Energy production in stars was attributed to gravity until the knowledge of nuclear reactions led to the understanding that energy production in stars is due to nuclear fusion.

2.5 Topic 3: Electrical circuits

In this topic, students will:

Subject matter	Guidance
Current, potential difference and energy flow • recall that electric charge can be positive or negative • recall that electric current is carried by discrete electric charge carriers • recall the law of conservation of electric charge • recall that electric charge is conserved at all points in an electrical circuit and recognise this as Kirchhoff's current law • define *electric current*, *electrical potential difference* in a circuit, and *power* • solve problems involving electric current, electric charge and time • explain that the energy inputs in a circuit equal the sum of energy output from loads in the circuit and recognise this as Kirchhoff's voltage law • recall that the energy available to electric charges moving in an electrical circuit is measured using electrical potential difference • solve problems involving electrical potential difference • explain why electric charge separation produces an electrical potential difference (no calculations required to demonstrate this) • solve problems involving power.	• **Notional time:** 4 hours • **Syllabus link:** Students should be able to recall the existence of electrons as negatively charged particles and protons as positively charged particles, and use the concept of electrostatic repulsion (Unit 1 Topic 2: Ionising radiation and nuclear reactions). • **Formulas:** $I = \frac{q}{t}$ $V = \frac{W}{q}$ $P = \frac{W}{t}$ • **SHE:** Students could explore how – 'conventional current' has been accepted as the international convention; consistent use now ensures clear communication of ideas and findings across the globe – increases in the use of household electrical devices during extreme weather (heat in Australian summers or cold in European winters) creates supply problems causing brownouts and power failures.

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Resistance

- define *resistance*
- recall and solve problems using Ohm's Law
- compare and contrast ohmic and non-ohmic resistors
- interpret graphical representations of electrical potential difference versus electric current data to find resistance using the gradient and its uncertainty.
- **Mandatory practical:** Conduct an experiment that measures electric current through, and electrical potential difference across an ohmic resistor in order to find resistance.
  - Write a research question.
  - Suggest modifications to the methodology used in class to improve the outcome.
  - Collect sufficient data.
  - Consider safety and manage risks.

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- **Notional time:** 4 hours
- Students should be able to recognise the characteristics of ohmic and non-ohmic resistors in terms of the gradient of an electrical potential difference – electric current graph. For ohmic resistors, students should be able to determine the resistance from the gradient.
- **Suggested practical:** Conduct an experiment to compare ohmic and non-ohmic resistors.
- **Formula:** $R = \frac{V}{I}$

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Circuit analysis and design

- define *power dissipation* over resistors in a circuit
- solve problems involving electrical potential difference, electric current, resistance and power
- recall resistor, voltmeter, ammeter, cell, battery, switch and bulb circuit diagram symbols
- recognise series and parallel connections of components in electrical circuits
- solve problems involving finding equivalent resistance, electrical potential difference and electric currents in series and parallel circuits
- design simple series, parallel and series/parallel circuits.

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- **Notional time:** 6 hours.
- Students should be able to recognise and draw the following symbols.

- **Suggested practicals**
  - Conduct an experiment to investigate series and parallel circuits.
  - Conduct an experiment to design and build simple circuits for specific 'real-life' purposes.
- **Formulas:** $P = VI$
$P = I^2R$
$V_t = V_1 + V_2 + \cdots V_n$
$R_t = R_1 + R_2 + \cdots R_n$
$I_t = I_1 + I_2 + \cdots I_n$
$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}$
- **Syllabus link:** Students should be able to integrate the concepts of circuit design, power dissipation, thermodynamics and efficiency to investigate the use of electricity in heating elements.

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Subject matter	Guidance
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for a research investigation.	• **Electrical energy in the home:** Developing new household electrical devices, improving the efficiency of existing devices and ensuring consistency of electrical standards all require international cooperation between scientists, engineers and manufacturers. • **Powering the digital age:** Computers, smartphones and the internet have changed the world, but none would be possible without a reliable supply of electricity. • **Electric lighting:** Concerns about sustainable energy usage and global warming have led to international research and development to improve the energy efficiency of electric lighting.

3.3 Topic 1: Linear motion and force

In this topic, students will:

Subject matter	Guidance
Vectors • define the terms *vector* and *scalar*, and use these terms to categorise physical quantities, e.g. velocity and speed • calculate resultant vectors through the addition and subtraction of two vectors in one dimension.	• **Notional time:** 4 hours • **Stimulus question:** If I start in the middle of the oval and walk 100 metres, where could I end up? • Vectors could be represented in the following ways: F, $\tilde{F}$ and $\vec{F}$ $\longrightarrow$ • Students should recognise that quantities that do not require a direction to complete their definition, such as energy, are scalars.
Linear motion • define the terms *displacement*, *velocity* and *acceleration* • compare and contrast instantaneous and average velocity • describe the motion of an object by interpreting a linear motion graph • calculate and interpret the intercepts and gradients (and their uncertainties) of displacement–time and velocity–time graphs, and the areas under velocity–time and acceleration–time graphs • solve problems involving the equations of uniformly accelerated motion in one dimension • recall that the acceleration due to gravity is constant near the Earth's surface. • **Mandatory practical:** Conduct an experiment to verify the value of acceleration due to gravity on the Earth's surface. *All* data sets that suggest a non-linear relationship, data (e.g. t^2 versus s) should be linearised and plotted, allowing for the calculation of the equation of a linear trend line. An evaluation of the experimental process undertaken, and of the conclusions drawn, will require students to – discuss the reliability and validity of the experimental process with reference to the uncertainty and limitations of the data – identify justifiable sources of imprecision and inaccuracy – suggest improvements or extensions to the experiment using the uncertainty and limitations identified. • **Mandatory practical:** Conduct an experiment that requires students to	• **Notional time:** 6 hours • **Stimulus question:** The hare and the tortoise — how is it that the slow-moving tortoise beat the faster hare? • Areas under graphs should be found using simple geometry, not calculus. • Students should be able to determine average velocity using a graph and an equation. However, students only need to determine instantaneous velocity for linear graphs or using an equation. • Students should use $g = 9.8\ m\ s^{-2}$ as the accepted value. • **Formulas:** $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$

Subject matter	Guidance
construct and interpret displacement–time and velocity–time graphs with resulting data. Where appropriate, students should use vertical error bars when plotting data. This ensures that they can determine the uncertainty of the gradient and intercepts using minimum and maximum lines of best fit.	
Newton's laws of motion • define Newton's three laws of motion and give examples of each • identify forces acting on an object • construct free-body diagrams representing forces acting on an object • determine the resultant force acting on an object in one dimension • solve problems using each of Newton's three laws of motion • define the terms *momentum* and *impulse* • recall the principle of conservation of momentum • solve problems involving momentum, impulse, the conservation of momentum and collisions in one dimension • determine and interpret the area under a force–time graph.	• **Notional time:** 6 hours • **Stimulus question:** Can physics help athletes perform better? • Students should be able to label forces such as the force due to gravity (weight), the normal force, tension, friction, drag and applied forces. • Students should be able to use free-body diagrams to calculate forces. However, they are not required to calculate drag and friction forces directly using the formulas $F_D = \frac{1}{2}\rho v^2 C_D A$ and $F_f = \mu F_N$. • In Unit 2, students are not required to determine resultant forces from constituent forces acting in more than one dimension. • Areas under graphs should be found using simple geometry, not calculus. • **Formulas:** $a_{net} = \frac{F_{net}}{m}$ $p = mv$ $\sum mv_{before} = \sum mv_{after}$ • **SHE:** Students could appreciate that Ptolemy, Aristotle, Copernicus, Galileo and Newton developed many complex models and theories describing motion and force. The development of these models and theories required a wide range of evidence, some of which was provided by predecessors.
Energy • define the terms *mechanical work*, *kinetic energy* and *gravitational potential energy* • solve problems involving work done by a force • solve problems involving kinetic energy and gravitational potential energy • determine and interpret the area under a force–displacement graph • interpret meaning from an energy–time graph • define the terms *elastic collision* and *inelastic collision* • compare and contrast elastic and inelastic collisions	• **Notional time:** 6 hours • Areas under graphs should be found using simple geometry, not calculus. • Problems may include collisions of two objects or explosions and involve previously studied formulas. • **Suggested practical:** Conduct an experiment to investigate a linear elastic collision between two objects. • **Formulas:** $W = \Delta E$ $W = Fs$

Subject matter	Guidance
• solve problems involving elastic collisions and inelastic collisions.	$E_k = \frac{1}{2}mv^2$ $\Delta E_p = mg\Delta h$ $\sum \frac{1}{2}mv_{before}^2 = \sum \frac{1}{2}mv_{after}^2$
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for a research investigation.	• **Road safety and technology:** Knowledge of forces and motion has led to improvements in car safety through the development and use of devices such as seatbelts, crumple zones and airbags. • **Sports science:** Biomechanics applies the laws of force and motion to gain greater understanding of athletic performance through direct measurement, computer simulations and mathematical modelling. • **Development and limitations of Newton's laws:** Newton's laws provided an explanation for a range of previously unexplained physical phenomena and were confirmed by multiple experiments performed by a multitude of scientists.

3.4 Topic 2: Waves

In this topic, students will:

Subject matter	Guidance
Wave properties • recall that waves transfer energy • define the term *mechanical wave* • compare the terms *transverse wave* and *longitudinal wave* • describe examples of transverse and longitudinal waves, such as sound, seismic waves and vibrations of stringed instruments • recall the terms *compression*, *rarefaction*, *crest*, *trough*, *displacement*, *amplitude*, *period*, *frequency*, *wavelength* and *velocity*, identifying them on graphical and visual representations of a wave • interpret and calculate the amplitude, period, frequency and wavelength from graphs of transverse and longitudinal waves • solve problems involving the wavelength, frequency, period and velocity of	• **Notional time:** 7 hours • Students should be able to use their understanding of reflection and refraction to solve problems involving the apparent position of objects that are under water and to explain the shape of the sun at sunset. • Simple waves are those whose wavefronts are moving 180° to each other, e.g. waves moving in opposite directions in a string, or sound waves in a pipe. • **Suggested practical:** Conduct an experiment to investigate the behaviour of both longitudinal waves and transverse waves on springs in relation to reflection from fixed and free ends and transmission/reflection at a medium boundary. • **Formulas:** $v = f\lambda$

Subject matter	Guidance
a wave • define the terms *reflection*, *refraction*, *diffraction* and *superposition* • using the wave model of light, explain phenomena related to reflection and refraction • describe the reflection and refraction of a wave at a boundary between two media • apply the principle of superposition to determine the resultant amplitude of two simple waves • explain constructive interference and destructive interference of two simple waves • explain the formation of standing waves in terms of superposition with reference to constructive and destructive interference, and nodes and antinodes.	$f = \frac{1}{T}$
Sound • solve problems involving standing wave formation in pipes open at both ends, closed at one end, and on stretched strings • define the concept of resonance in a mechanical system • define the concept of natural frequency • identify that energy is transferred efficiently in resonating systems.	• **Notional time:** 6 hours • The lowest frequency will be referred to as the fundamental (or first harmonic). All other modes are referred to as harmonics, not overtones. • **Suggested practicals:** – Conduct an experiment to investigate fundamental and harmonic wavelengths in pipes. – Conduct an experiment to calculate the speed of sound in air at a specific temperature. • **Formulas:** $L = n\frac{\lambda}{2}$ $L = (2n-1)\frac{\lambda}{4}$
Light • recall that light is not modelled as a mechanical wave, because it can travel through a vacuum • recall that a wave model of light can explain reflection, refraction, total internal reflection, dispersion, diffraction and interference • describe polarisation using a transverse wave model • use ray diagrams to demonstrate the reflection and refraction of light • solve problems involving the reflection of light on plane mirrors	• **Notional time:** 10 hours • Students do not need to use the lens or mirror formula to determine location. Only one lens or mirror should be used at a time. • Students should be able to construct ray diagrams to find the location, orientation and size of an image formed by a single concave lens and a single convex lens. • Students should know that intensity is proportional to the square of amplitude.

Subject matter	Guidance
• define Snell's Law • solve problems involving the refraction of light at the boundary between two mediums • recall that the speed of light in a vacuum is $c = 3 \times 10^8 m\ s^{-1}$ • contrast the speed of light and the speed of mechanical waves • define the concept of intensity • solve problems involving the proportional relationship between intensity of light and the inverse-square of the distance from the source. • **Mandatory practical:** Conduct an experiment to determine the refractive index of a transparent substance.	• **Suggested practical:** Conduct an experiment to verify the law of reflection. • **Formulas:** $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$ $I \propto \frac{1}{r^2}$ • **SHE:** The Michelson–Morley experiment with light demonstrated the wave properties of light and that it travelled through a vacuum, disproving the luminiferous aether theory.
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for a research investigation.	• **Monitoring earthquakes and tsunamis:** Knowledge of different types of waves, and their motion through the ocean and the continents, allows prediction of the possible extent of damage or the timing of a tsunami. • **Noise pollution and acoustic design:** Using an understanding of the behaviour of sound waves, acoustical engineering can reduce noise pollution by planning structures that absorb sound waves or that do not reflect and amplify sound in an unwanted way. • **Development of the wave theory of light:** From the late 17th century through to the 1860s, scientists continued to refine their understanding of light and its wave-like behaviour through experimentation.

4.3 Topic 1: Gravity and motion

In this topic, students will:

Subject matter	Guidance
Vectors • use vector analysis to resolve a vector into two perpendicular components • solve vector problems by resolving vectors into components, adding or subtracting the components and recombining them to determine the resultant vector.	• **Notional time:** 2 hours • **Syllabus link:** Students should be able to define the term *vector* and determine the addition and subtraction of two vectors in one dimension (Unit 2 Topic 1: Linear motion and force).
Projectile motion • recall that the horizontal and vertical components of a velocity vector are independent of each other • apply vector analysis to determine horizontal and vertical components of projectile motion • solve problems involving projectile motion. • **Mandatory practical:** Conduct an experiment to determine the horizontal distance travelled by an object projected at various angles from the horizontal.	• **Notional time:** 4 hours • Students do not need to account for the effect of drag on either horizontal or vertical motion. • **Formulas:** $v_y = gt + u_y$ $s_y = \frac{1}{2}gt^2 + u_y t$ $v_y^2 = 2gs_y + u_y^2$ $v_x = u_x$ $s_x = u_x t$ • **Syllabus link:** Students should be able to recall that the acceleration due to gravity is constant near the Earth's surface and solve problems involving the equations of uniformly accelerated motion in one dimension (Unit 2 Topic 1: Linear motion and force).
Inclined planes • solve problems involving force due to gravity (weight) and mass using the mathematical relationship between them • define the term *normal force* • describe and represent the forces acting on an object on an inclined plane through the use of free-body diagrams • calculate the net force acting on an object on an inclined plane through vector analysis.	• **Notional time:** 4 hours • Forces acting on an object on an inclined plane include force due to gravity (weight), the normal force, tension, frictional force and applied force. Calculation of frictional force using $F_f = \mu F_N$ is not required. • **Suggested practical:** Conduct an experiment to investigate the parallel component of the weight of an object down an inclined plane at various angles. • **Formula:** $F_g = mg$ • **Syllabus link:** Students should be able to define Newton's three laws of motion

Subject matter	Guidance
	and describe examples of each (Unit 2 Topic 1: Linear motion and force).
Circular motion • describe uniform circular motion in terms of a force acting on an object in a perpendicular direction to the velocity of the object • define the concepts of average speed and period • solve problems involving average speed of objects undergoing uniform circular motion • define the terms *centripetal acceleration* and *centripetal force* • solve problems involving forces acting on objects in uniform circular motion.	• **Notional time:** 4 hours • **Stimulus question:** How can you travel at a constant speed yet be accelerating? • **Suggested practical:** Conduct an experiment to investigate the net forces acting on an object undergoing horizontal circular motion on a string. • **Formulas:** $v = \frac{2\pi r}{T}$ $a_c = \frac{v^2}{r}$ $F_{net} = \frac{mv^2}{r}$
Gravitational force and fields • recall Newton's Law of Universal Gravitation • solve problems involving the magnitude of the gravitational force between two masses • define the term *gravitational fields* • solve problems involving the gravitational field strength at a distance from an object.	• **Notional time:** 4 hours • **Suggested practical**: Conduct an experiment (using simulations) to investigate the gravitational force between two objects by varying the mass and distance. • **Formulas:** $F = \frac{GMm}{r^2}$ $g = \frac{F}{m} = \frac{GM}{r^2}$ • **SHE:** Students could explore the international collaboration required in the discovery of gravity waves and associated technologies, e.g. Laser Interferometer Gravitational Wave Observatory (LIGO). • **Syllabus link:** Students should be able to consider how gravity keeps planets in orbit around the sun (Unit 2 Topic 1: Linear motion and force).
Orbits • recall Kepler's laws of planetary motion • solve problems involving Kepler's third law • recall that Kepler's third law can be derived from the relationship between Newton's Law of Universal Gravitation and uniform circular motion.	• **Notional time:** 4 hours • **Stimulus question:** What is the difference between the heliocentric and geocentric models of the solar system? • **Suggested practical:** Conduct an experiment to investigate the relationship between orbital radius and mass for orbiting objects (simulation). • **Formula:** $\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$

Subject matter	Guidance
	• **SHE:** Students could – explore the difficulties experienced by scientists who supported a heliocentric model of the solar system and the hindrances to the acceptance of their discoveries by society – consider the international collaboration required to monitor the orbits of satellites, and the management of space debris. • **Syllabus link:** Students should be able to recall the Law of Conservation of Energy (Unit 1 Topic 1: Heating processes).
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for a research investigation.	• **Forensic science:** Forensic evidence is often used in court. However, despite messages in the popular media, forensic science cannot always provide sufficient conclusive evidence to lead to convictions. • **Artificial satellites:** Knowledge of orbital heights and speeds allows satellites to be best positioned for observation of weather, natural phenomena, traffic and military movements. • **Developing understanding of planetary motion:** From Ptolemy to Newton, the accepted model of the solar system slowly shifted under the influence of carefully collected and analysed data.

4.4 Topic 2: Electromagnetism

In this topic, students will:

Subject matter	Guidance
Electrostatics • define Coulomb's Law and recognise that it describes the force exerted by electrostatically charged objects on other electrostatically charged objects • solve problems involving Coulomb's Law • define the terms *electric fields*, *electric field strength* and *electrical potential energy* • solve problems involving electric field strength • solve problems involving the work done when an electric charge is moved in an	• **Notional time:** 7 hours • **Suggested practical**: Conduct an experiment to investigate the effects of electrostatic charge on various materials, e.g. on trickling water, Coulomb meter. • **Formulas:** $F = \frac{1}{4\pi\varepsilon_o}\frac{Qq}{r^2}$ $\frac{1}{4\pi\varepsilon_o} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

Subject matter	Guidance
electric field.	$E = \frac{F}{Q} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$ $V = \frac{\Delta U}{q}$ • **Syllabus links** – Students should be able to recall that electric charge can be positive or negative, define electrical potential difference, and solve problems involving electric potential (Unit 1 Topic 3: Electrical circuits). – Students should be able to describe examples of each of Newton's three laws of motion (Unit 2 Topic 1: Linear motion and force). – Students should be able to determine the addition and subtraction of vectors in two dimensions (Unit 3 Topic 1: Gravity and motion).
Magnetic fields • define the term *magnetic field* • recall how to represent magnetic field lines, including sketching magnetic field lines due to a moving electric charge, electric currents and magnets • recall that a moving electric charge generates a magnetic field • determine the magnitude and direction of a magnetic field around electric current-carrying wires and inside solenoids • solve problems involving the magnitude and direction of magnetic fields around a straight electric current-carrying wire and inside a solenoid • recall that electric current-carrying conductors and moving electric charges experience a force when placed in a magnetic field • solve problems involving the magnetic force on an electric current-carrying wire and moving charge in a magnetic field. • **Mandatory practicals** – Conduct an experiment to investigate the force acting on a conductor in a magnetic field. – Conduct an experiment to investigate the strength of a magnet at various distances.	• **Notional time:** 7 hours • **Formulas:** $B = \frac{\mu_o I}{2\pi r}$ $\mu_o = 4\pi \times 10^{-7}\ T\ A^{-1}\ m$ $B = \mu_o nI$ $F = BILsin\theta$ $F = qvBsin\theta$ • **Syllabus links** – Students should be able to recall that electric charge is conserved at all points in an electrical circuit (Unit 1 Topic 3: Electrical circuits). – Students should be able to describe examples of each of Newton's three laws of motion (Unit 2 Topic 1: Linear motion and force). – Students should be able to determine the addition and subtraction of vectors in two dimensions (Unit 3 Topic 1: Gravity and motion).

Subject matter	Guidance
Electromagnetic induction • define the terms *magnetic flux*, *magnetic flux density*, *electromagnetic induction*, *electromotive force* (*EMF*), Faraday's Law and Lenz's Law • solve problems involving the magnetic flux in an electric current-carrying loop • describe the process of inducing an EMF across a moving conductor in a magnetic field • solve problems involving Faraday's Law and Lenz's Law • explain how Lenz's Law is consistent with the principle of conservation of energy • explain how transformers work in terms of Faraday's Law and electromagnetic induction.	• **Notional time**: 7 hours • **Stimulus question:** How is electricity made? • **Suggested practicals** – Conduct an experiment to investigate the induction of an electric current using a magnet and coil. – Conduct an experiment to investigate the induced EMF from an AC generator. • **Formulas:** $\emptyset = BAcos\theta$ $emf = -\frac{n\Delta(BA_{\perp})}{\Delta t}$ $emf = -n\frac{\Delta\phi}{\Delta t}$ $I_pV_p = I_sV_s$ $\frac{V_p}{V_s} = \frac{n_p}{n_s}$ • **Syllabus links** – Students should be able to recall the Law of Conservation of Energy (Unit 1 Topic 1: Heating processes). – Students should be able to recall that electric charge is conserved at all points in an electrical circuit (Unit 1 Topic 3: Electrical circuits). – Students should be able to determine the addition and subtraction of vectors in two dimensions (Unit 3 Topic 1: Gravity and motion). • **SHE:** Students could explore – how scientific knowledge has been used to develop methods of renewable energy production (e.g. wind and wave power generation) – scientific evidence about the risks of electromagnetic phenomena and associated technologies (e.g. wi-fi and mobile phones) as reported in the media – the international collaboration involved in the development of the Square Kilometre Array (SKA) and the associated technologies.

Subject matter	Guidance
Electromagnetic radiation • define and explain electromagnetic radiation in terms of electric fields and magnetic fields.	• **Notional time:** 2 hours • **Syllabus links** – Students should be able to recall the properties of gamma radiation (Unit 1 Topic 2: Ionising radiation and nuclear reactions). – Students should be able to recall the properties of waves (Unit 2 Topic 2: Waves).
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for a research investigation.	• **Medical imaging:** Due to the strong magnetic fields used in MRI machines, many safety procedures must be followed, such as excluding patients with some metallic implants from receiving MRI scans. • **The Square Kilometre Array:** The Square Kilometre Array (SKA), a joint scientific project between Australia, New Zealand and South Africa, aims to gather information to advance our knowledge of dark matter, dark energy, cosmic magnetism and general relativity. • **Superconductivity:** A series of discoveries caused a number of theories to be put forward to explain superconductivity, but it was not until the late 1950s that a complete atomic scale theory of superconductivity was proposed.

5.3 Topic 1: Special relativity

In this topic, students will:

Subject matter	Guidance
Special relativity • describe an example of natural phenomena that cannot be explained by Newtonian physics, such as the presence of muons in the atmosphere • define the terms *frame of reference* and *inertial frame of reference* • recall the two postulates of special relativity • recall that motion can only be measured relative to an observer • explain the concept of simultaneity • recall the consequences of the constant speed of light in a vacuum, e.g. time dilation and length contraction • define the terms *time dilation*, *proper time interval*, *relativistic time interval*, *length contraction*, *proper length*, *relativistic length*, *rest mass* and *relativistic momentum* • describe the phenomena of time dilation and length contraction, including examples of experimental evidence of the phenomena • solve problems involving time dilations, length contraction and relativistic momentum • recall the mass–energy equivalence relationship • explain why no object can travel at the speed of light in a vacuum • explain paradoxical scenarios such as the twins' paradox, flashlights on a train and the ladder in the barn paradox.	• **Notional time:** 16 hours • **Formulas:** $t = \frac{t_o}{\sqrt{(1-\frac{v^2}{c^2})}}$ $L = L_o\sqrt{(1-\frac{v^2}{c^2})}$ $p_v = \frac{m_o v}{\sqrt{(1-\frac{v^2}{c^2})}}$ $\Delta E = \Delta mc^2$ • **Syllabus links** – Students should be able to define momentum and impulse, solve problems on momentum and impulse, recall Newton's laws of motion, and solve problems using Newton's laws of motion (Unit 2 Topic 1: Linear motion and force). – Students should be able to recall the speed of light (Unit 2 Topic 2: Waves). • **SHE:** Students could explore how technologies such as satellites have dramatically increased the size, accuracy, and geographic and temporal scope of datasets with which scientists work. They should also be aware that satellites provide experimental evidence that supports the phenomena of time dilation.

Subject matter	Guidance
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for the research investigation.	• **Development of the special theory of relativity:** Albert Einstein's work on special relativity built upon the work of scientists such as Maxwell and Lorentz, while subsequent studies by Max Planck, Hermann Minkowski and others led to the development of relativistic theories of gravitation, mass–energy equivalence and quantum field theory. • **Ring laser gyroscopes and navigation:** Ring laser gyroscopes (RLG) are inertial guidance systems that do not rely on signals from an external source, but from instruments on board a moving object and are used in helicopters, ships, submarines and missiles for accurate navigation. • **Nuclear reactors:** Special relativity leads to the idea of mass–energy equivalence, which has been applied in nuclear fission reactors.

5.4 Topic 2: Quantum theory

In this topic, students will:

Subject matter	Guidance
Quantum theory • explain how Young's double slit experiment provides evidence for the wave model of light • describe light as an electromagnetic wave produced by an oscillating electric charge that produces mutually perpendicular oscillating electric fields and magnetic fields • explain the concept of black-body radiation • identify that black-body radiation provides evidence that electromagnetic radiation is quantised into discrete values • describe the concept of a photon • solve problems involving the energy, frequency and wavelength of a photon • describe the photoelectric effect in terms of the photon • define the terms *threshold frequency*, *Planck's constant* and *work function* • solve problems involving the photoelectric effect	• **Notional time:** 16 hours • Only a qualitative description of Young's double slit experiment and its outcomes needs to be developed to provide an explanation of the wave-like nature of light. • **Formulas:** $\lambda_{max} = \frac{b}{T}$ $E = hf$ $h = 6.626 \times 10^{-34}\ J\ s$ $E_k = hf - W$ $\lambda = \frac{h}{p}$ $n\lambda = 2\pi r$ $mvr = \frac{nh}{2\pi}$

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recall that photons exhibit the characteristics of both waves and particles
describe Rutherford’s model of the atom including its limitations
describe the Bohr model of the atom and how it addresses the limitations of Rutherford’s model
explain how the Bohr model of the hydrogen atom integrates light quanta and atomic energy states to explain the specific wavelengths in the hydrogen line spectrum
solve problems involving the line spectra of simple atoms using atomic energy states or atomic energy level diagrams
describe wave–particle duality of light by identifying evidence that supports the wave characteristics of light and evidence that supports the particle characteristics of light.
Mandatory practical: Conduct an experiment (or use a simulation) to investigate the photoelectric effect. Data such as the photoelectron energy or velocity, or electrical potential difference across the anode and cathode, can be compared with the wavelength or frequency of incident light. Calculation of work functions and Planck’s constant using the data would also be appropriate.

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$\frac{1}{\lambda} = R(\frac{1}{n_f^2} - \frac{1}{n_i^2})$

Syllabus links

Students should be able to describe the structure of atoms and recall Einstein’s mass–energy equivalence relationship (Unit 1 Topic 2: Ionising radiation and nuclear reactions).
Students should be able to recall that waves transfer energy, recall that light cannot be modelled as a mechanical wave because it can travel through a vacuum, recall that a wave model of light can explain interference and define the concept of resonance in a mechanical system (Unit 2 Topic 2: Waves).

SHE: Students could explore

the historical development of the model of the atom in terms of traditional models (Democritus, Dalton, Brownian motion, Thomson, Rutherford and Bohr, etc.)
how theories are contested, refined or replaced when new evidence challenges them, or when a new model or theory has greater explanatory power
how the approximation of Earth as a black body can be used to predict climate patterns; however, many scientists face real problems in validating their models.

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Science as a Human Endeavour (SHE)

SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for the research investigation.

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Development of the quantum model: A more elaborate quantum mechanical model of the atom, developed from work by Rutherford, Bohr, Planck and Einstein, is required to explain many observations made about atoms.
Black-body radiation and the greenhouse effect: Models of Earth’s energy balance using the concept of black-body radiation enable scientists to monitor changes in global temperature, assess the evidence for changes in climate due to the enhanced greenhouse effect and evaluate the risk posed by anthropogenic climate change.

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5.5 Topic 3: The Standard Model

In this topic, students will:

Subject matter	Guidance
The Standard Model • define the concept of an elementary particle and antiparticle • recall the six types of quarks • define the terms *baryon* and *meson* • recall the six types of leptons • recall the four gauge bosons • describe the strong nuclear, weak nuclear and electromagnetic forces in terms of the gauge bosons • contrast the fundamental forces experienced by quarks and leptons.	• **Notional time:** 5 hours • **Syllabus links** – Students should be able to describe and use the law of conservation of energy (Unit 1 Topic 1: Heating processes). – Students should be able to recall, describe and explain the properties of the nuclear model of the atom and strong nuclear forces (Unit 1 Topic 2: Ionising radiation and nuclear reactions). – Students should be able to recall, describe and explain the properties of electromagnetic forces (Unit 3 Topic 2: Electromagnetism).
Particle interactions • define the concept of lepton number and baryon number • recall the conservation of lepton number and baryon number in particle interaction • explain the following interactions of particles using Feynman diagrams – electron and electron – electron and positron – a neutron decaying into a proton • describe the significance of symmetry in particle interactions.	• **Notional time:** 8 hours • Students do not need to determine lepton and baryon number quantitatively. • Students should know that baryon number is conserved in all reactions. No calculations are required to show this. • Refer to supporting resources for instructions on how to represent particle interactions using Feynman diagrams. • **SHE:** Students could explore the history of particle physics models and theories through the development of particle accelerators and contributions from notable physicists.
Science as a Human Endeavour (SHE) • SHE subject matter will not be assessed on the external examination, but could be used in the development of claims and research questions for the research investigation.	• **Evidence for the Higgs boson particle:** The Large Hadron Collider was built to test particle physics theories and specifically to try to produce and detect the Higgs boson particle. • **Particle accelerators:** The construction of the Australian Synchrotron (a particle accelerator) involved collaboration between Australian and New Zealand science organisations, state and federal governments, and international organisations and committees, including the International Science Advisory Committee and the International Machine Advisory Committee.

Subject matter	Guidance
	• **The Big Bang theory:** There is a variety of evidence that supports the Big Bang theory, including cosmic background radiation, the abundance of light elements, and the red shift of light from galaxies that obey Hubble’s Law.