Physics

Subject Outline
Stage 1 and Stage 2

This subject outline has been accredited. It is provided in draft, pre-edited form for planning purposes and for use at the implementation workshops.

The published version of this subject outline will be available online early in Term 4.

The redeveloped Board-accredited Stage 1 subject outline will be taught from 2017. The redeveloped Board-accredited Stage 2 subject outline will be taught from 2018.

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INTRODUCTION

SUBJECT DESCRIPTION

Physics may be undertaken as a 10-credit subject or a 20-credit subject at Stage 1 and as a 20-credit subject at Stage 2.

The study of Physics is constructed around using qualitative and quantitative models, laws, and theories to better understand matter, forces, energy, and the interaction among them. Physics seeks to explain natural phenomena, from the subatomic world to the macrocosmos, and to make predictions about them. The models, laws, and theories in physics are based on evidence obtained from observations, measurements, and active experimentation over thousands of years.

By studying physics, students understand how new evidence can lead to the refinement of existing models and theories and to the development of different, more complex ideas, technologies, and innovations.

Through further developing skills in gathering, analysing, and interpreting primary and secondary data to investigate a range of phenomena and technologies, students increase their understanding of physics concepts and the impact that physics has on many aspects of contemporary life.

By exploring science as a human endeavour, students develop and apply their understanding of the complex ways in which science interacts with society, and investigate the dynamic nature of physics. They explore how physicists develop new understanding and insights, and produce innovative solutions to everyday and complex problems and challenges in local, national, and global contexts.

In Physics students integrate and apply a range of understanding, inquiry, and scientific thinking skills that encourage and inspire them to contribute their own solutions to current and future problems and challenges, and pursue scientific pathways, for example in engineering, renewable energy generation, communications, materials innovation, transport and vehicle safety, medical science, scientific research, and the exploration of the universe.

CAPABILITIES

The capabilities connect student learning within and across subjects in a range of contexts. They include essential knowledge and skills that enable people to act in effective and successful ways.

The SACE identifies seven capabilities. They are:

- literacy
- numeracy
- information and communication technology capability
- critical and creative thinking
- personal and social capability
- ethical understanding
- intercultural understanding.

Literacy

In this subject students develop their literacy capability by, for example:

- interpreting the work of scientists across disciplines using physics knowledge
- critically analysing, and evaluating primary and secondary data
- extracting physics information presented in a variety of modes
- using a range of communication formats to express ideas logically and fluently, incorporating the terminology and conventions of physics
- synthesising evidence-based arguments

- using appropriate structures to communicate for specific purposes and audiences.

Numeracy

In this subject students develop their numeracy capability by, for example:

- solving problems using calculations and critical thinking skills
- measuring with appropriate instruments
- recording, collating, representing, and analysing primary data
- accessing and interpreting secondary data
- identifying and interpreting trends and relationships
- calculating and predicting values by manipulating data and using appropriate scientific conventions.

Information and communication technology capability

In this subject students develop their information and communication capability by, for example:

- locating and accessing information
- collecting, analysing, and representing data electronically
- modelling concepts and relationships
- using technologies to create new ways of thinking about science
- communicating physics ideas, processes, and information
- understanding the impact of ICT on the development of physics and its application in society
- evaluating the application of ICT to advance understanding and investigations in physics.

Critical and creative thinking

In this subject students develop critical and creative thinking by, for example:

- analysing and interpreting problems from different perspectives
- constructing, reviewing, and revising hypotheses to design-related investigations
- interpreting and evaluating data and procedures to develop logical conclusions
- analysing interpretations and claims, for validity and reliability
- devising imaginative solutions and making reasonable predictions
- envisaging consequences and speculating on possible outcomes
- recognising the significance of creative thinking on the development of physics knowledge and applications.

Personal and social capability

In this subject students develop their personal and social capability by, for example:

- understanding the importance of physics knowledge on health and well-being, both personally and globally
- making decisions and taking initiative while working independently and collaboratively
- planning effectively, managing time, following procedures effectively, and working safely
- sharing and discussing ideas about physics issues developments, and innovations while respecting the perspectives of others
- recogising the role of their own beliefs and attitudes in gauging the impact of physics in society.

Ethical understanding

In this subject students develop their ethical understanding by, for example:

- considering the implications of their investigations on organisms and the environment
- making ethical decisions based on an understanding of physics principles
- using data and reporting the outcomes of investigations accurately and fairly
- acknowledging the need to plan for the future and to protect and sustain the biosphere
- recognising the importance of their responsible participation in social, political, economic, and legal decision-making.

Intercultural understanding

In this subject students develop their intercultural understanding by, for example:

- recognising that science is a global endeavour with significant contributions from diverse cultures
- respecting different cultural views and customs while valuing scientific evidence
- being open-minded and receptive to change in the light of scientific thinking based on new information
- understanding that the progress of physics influences and is influenced by cultural factors.

ABORIGINAL AND TORRES STRAIT ISLANDER KNOWLEDGE, CULTURES, AND PERSPECTIVES

In partnership with Aboriginal and Torres Strait Islander communities, and schools and school sectors, the SACE Board of South Australia supports the development of high-quality learning and assessment design that respects the diverse knowledge, cultures, and perspectives of Indigenous Australians.

The SACE Board encourages teachers to include Aboriginal and Torres Strait Islander knowledge and perspectives in the design, delivery, and assessment of teaching and learning programs by:

- providing opportunities in SACE subjects for students to learn about Aboriginal and Torres Strait Islander histories, cultures, and contemporary experiences
- recognising and respecting the significant contribution of Aboriginal and Torres Strait Islander peoples to Australian society
- drawing students' attention to the value of Aboriginal and Torres Strait Islander knowledge and perspectives from the past and the present
- promoting the use of culturally appropriate protocols when engaging with and learning from Aboriginal and Torres Strait Islander peoples and communities.

HEALTH AND SAFETY

It is the responsibility of the school to ensure that duty of care is exercised in relation to the health and safety of all students and that school practices meet the requirements of the *Work Health and Safety Act 2012,* in addition to relevant state, territory, or national health and safety guidelines. Information about these procedures is available from the school sectors.

The following safety practices must be observed in all laboratory work:

- Use equipment only under the direction and supervision of a teacher or other qualified person.
- Follow safety procedures when preparing or manipulating apparatus.
- Use appropriate safety gear when preparing or manipulating apparatus.

Particular care must be taken when using electrical apparatus, ionising and non-ionising radiation, and lasers, but care must not be limited to these items.

Stage 1 Physics

LEARNING SCOPE AND REQUIREMENTS

LEARNING REQUIREMENTS

The learning requirements summarise the knowledge, skills, and understanding that students are expected to develop and demonstrate through their learning in Stage 1 Physics.

In this subject, students are expected to:

1. apply science inquiry skills to design and conduct physics investigations, using appropriate procedures and safe, ethical working practices
2. obtain, record, represent, analyse, and interpret the results of physics investigations
3. evaluate procedures and results, and analyse evidence to formulate and justify conclusions
4. develop and apply knowledge and understanding of physics concepts in new and familiar contexts
5. explore and understand science as a human endeavour
6. communicate knowledge and understanding of physics concepts, using appropriate terms, conventions, and representations.

CONTENT

Stage 1 Physics may be undertaken as a 10-credit or a 20-credit subject.

Integration of science inquiry skills, science as a human endeavour, and science understanding

The three strands of science inquiry skills, science as a human endeavour, and science understanding are integrated throughout student learning in this subject.

The topics in Stage 1 Physics provide the framework for developing integrated programs of learning through which students extend their skills, knowledge, and understanding of these three strands of science.

The topics are structured in two columns: science understanding, and possible contexts. The contexts are suggestions for possible inquiry approaches, and are neither comprehensive nor exclusive. Teachers may select from these and are encouraged to consider other inquiry approaches according to local needs and interests.

Programming

The following topics provide the framework for learning in Stage 1 Physics:

- Topic 1: Linear Motion and Forces
- Topic 2: Electric Circuits
- Topic 3: Heat
- Topic 4: Energy and Momentum
- Topic 5: Waves
- Topic 6: Nuclear Models and Radioactivity

For a 10-credit subject, students study a selection of aspects of at least three of these topics.

For a 20-credit subject, students study a selection of aspects of all six topics.

The topics selected can be sequenced and structured to suit individual cohorts of students. Topics can be studied in their entirety or in part, taking into account student interests and preparation for pathways into future study of physics. For example, *Topic 2: Electric Circuits* is valuable for students intending to seek an electrical apprenticeship and *Topic 3: Heat* can prepare students for a VET course in refrigeration.

Note that the topics are not necessarily designed to be of equivalent length – it is anticipated that teachers may allocate more time to some than others.

In designing a Stage 1 Physics program for students who intend to study Physics at Stage 2 the information in the following table should be considered. This table shows Stage 1 subtopics that introduce key ideas that are later used in particular Stage 2 subtopics.

Stage 1 subtopic	Stage 2 subtopic
1.1 Motion under Constant Acceleration	1.1 Projectile Motion 1.2 Forces and Momentum 1.3 Uniform Circular Motion and Gravitation 2.2 Motion of Charged Particles in Electric Fields
1.2 Forces	1.2 Forces and Momentum 1.3 Circular Motion and Gravitation 2.1 Electric Fields 2.2 Motion of Charged Particles in Electric Fields 2.4 Motion of Charged Particles in Magnetic Fields
2.1 Potential Difference and Electric Current	2.1 Electric Fields 2.3 Magnetic Fields 2.5 Electromagnetic Induction
4.1 Energy	2.2 Motion of Charged Particles in Electric Fields 3.2 Wave-Particle Duality
4.2 Momentum	1.2 Forces and Momentum 3.2 Wave-Particle Duality
5.1 Wave Model	3.1 Wave Behaviour of Light 3.2 Wave-Particle Duality 3.3 Structure of the Atom
5.3 Light	3.1 Wave Behaviour of Light 3.2 Wave-Particle Duality
6.1 The Nucleus	3.4 Standard Model
6.2 Radioactive Decay	2.4 Motion of Charged Particles in Magnetic Fields 3.4 Standard Model

Within each topic, the *Science Understanding* column sets out the concepts and ideas that guide teaching, learning, and assessment in this subject.

The following symbols in the *Possible Contexts* are used in the right-hand column:

 indicates a possible teaching and learning strategy for science understanding

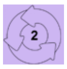
 indicates a possible science inquiry activity

 indicates a possible focus on science as a human endeavour

In addition, throughout the topics there are recurring themes that draw on the application of some of the overarching concepts in physics. As different concepts are being explored, students develop new and different understanding by discussing these applications and the concepts from which they are derived, from fresh perspectives.

The selected overarching concepts in physics are denoted as follows:

Innovations and Applications in Physics



Models and Representations in Physics (including waves, fields)

Interactions and Conservation

Properties of Matter

Science Inquiry Skills

In Physics investigation is an integral part of the learning and understanding of concepts, by using scientific methods to test ideas and develop new knowledge.

Practical investigations must involve a range of both individual and collaborative activities during which students extend the science inquiry skills described in the table that follows.

Practical activities may take a range of forms, such as developing models and simulations that enable students to develop a better understanding of particular concepts. They include laboratory and field studies during which students develop investigable questions and/or testable hypotheses, and select and use equipment appropriately to collect data. The data may be observations, measurements, or other information obtained during the investigation. Students display and analyse the data they have collected, evaluate procedures, describe their limitations, consider explanations for their observations, and present and justify conclusions appropriate to the initial question or hypothesis.

For a 10-credit subject, it is recommended that a minimum of 8–10 hours of class time would involve practical activities.

For a 20-credit subject, it is recommended that a minimum of 16–20 hours of class time would involve practical activities.

Science inquiry skills are also fundamental to students investigating the social, ethical, and environmental impacts and influences of the development of scientific understanding and the applications, possibilities, and limitations of science. These skills enable students to critically analyse the evidence they obtain so that they can present and justify a conclusion.

The science inquiry skills set out in the left-hand column guide teaching, learning, and assessment in this subject, and are supported by ideas for possible contexts, in the right-hand column.

Science Inquiry Skills	Possible Contexts
Scientific methods enable systematic investigation to obtain measureable evidence. • Deconstruct the parts of a problem to determine the most appropriate method for investigation. • Design investigations, including: – hypothesis or inquiry question – types of variables ➢ dependent ➢ independent ➢ factors held constant (how and why they are controlled) ➢ factors that may not be able to be controlled (and why not) – materials required – the procedure to be followed – the type and amount of data to be collected – identification of ethical and safety considerations.	Develop inquiry skills by, for example: - designing investigations that require investigable questions and imaginative solutions (with or without implementation) - critiquing proposed investigations - using the conclusion of one investigation to propose subsequent experiments - changing an independent variable in a given procedure and adapting the method - researching, developing, and trialling a method - improving an existing procedure - identifying options for measuring the dependent variable - researching hazards related to the use and disposal of physics materials - developing safety audits - identifying relevant ethical

Science Inquiry Skills	Possible Contexts
	and/or legal considerations in different contexts.
Obtaining meaningful data depends on conducting investigations using appropriate procedures and safe, ethical working practices. • Conduct investigations, including: – selection and safe use of appropriate materials, apparatus, and equipment – collection of appropriate primary or secondary data (numerical, visual, descriptive) – individual and collaborative work.	Develop inquiry skills by, for example: - identifying equipment, materials, or instruments fit for purpose - practising techniques and safe use of apparatus - comparing resolution of different measuring tools - distinguishing between and using primary and secondary data.
Results of investigations are presented in a well-organised way to allow them to be interpreted. • Present results of investigations in appropriate ways, including – use of appropriate SI units, symbols – construction of appropriately labelled tables – drawing of graphs, linear, non-linear, lines of best fit as appropriate – use of significant figures.	Develop inquiry skills by, for example: - practising constructing tables to tabulate data, including column and row labels with units - identifying the appropriate representations to graph different data sets - selecting axes and scales, and graphing data - clarifying understanding of significant figures using, for example: http://www.astro.yale.edu/astro120/SigFig.pdf https://www.hccfl.edu/media/43516/sigfigs.pdf https://www.physics.uoguelph.ca/tutorials/sig_fig/SIG_dig.htm - comparing data from different sources to describe as quantitative, qualitative.
Scientific information can be presented using different types of symbols and representations. • Select, use, and interpret appropriate representations, including: – mathematical [algebraic] relationships – diagrams and multi-image representations – formulae to explain concepts, solve problems, and make predictions.	Develop inquiry skills by, for example: - writing formulae - using formulae; deriving and rearranging formulae - constructing vector diagrams - drawing and labelling diagrams - sketching field diagrams - recording images - constructing flow diagrams.
Analysis of the results of investigations allows them to be interpreted in a meaningful way. • Analyse data, including: – multi-image representations – identification and discussion of trends, patterns, and relationships – interpolation/extrapolation through the axes where appropriate – selection and use of evidence and	Develop inquiry skills by, for example: - analysing data sets to identify trends and patterns - determining relationships between independent and dependent variables, including mathematical relationships, e.g. slope, linear, inverse relationships where relevant.

Science Inquiry Skills	Possible Contexts
scientific understanding to make and justify conclusions.	- discussing inverse and direct proportionality - using graphs from different sources, e.g. CSIRO or ABS, to predict values other than plotted points - calculating means, standard deviations, percent error, where appropriate.
Critical evaluation of procedures and outcomes can determine the meaningfulness of conclusions. • Evaluate the procedures and results to identify sources of uncertainty, including: – random and systematic errors – replication – sample size – accuracy – precision – validity – reliability – effective control of variables. • Discuss the impact that sources of uncertainty have on experimental results. • Recognise the limitations of conclusions.	Develop inquiry skills by, for example: - - evaluating procedures and data sets provided by the teacher to determine and hence comment on the limitations of possible conclusions - using an example of an investigation report to develop report-writing skills. Useful websites: http://www.nuffieldfoundation.org/practical-physics/designing-and-evaluating-experiments http://physics.appstate.edu/undergraduateprograms/laboratory/resources/error-analysis http://www.physics.gatech.edu/~em92/Lab/physlab/admin1/labpractice.html
Effective scientific communication is clear and concise. • Communicate to specific audiences and for specific purposes using: – appropriate language – terminology – conventions.	Develop inquiry skills by, for example: - reviewing scientific articles or presentations to recognise conventions - developing skills in referencing and/or footnoting - distinguishing between reference lists and bibliographies - opportunities to practise scientific communication in written, oral, and multimedia formats, e.g. presenting a podcast or writing a blog.

Science as a Human Endeavour

The *Science as a Human Endeavour* strand highlights science as a way of knowing and doing, and explores the use and influence of science in society.

By exploring science as a human endeavour, students develop and apply their understanding of the complex ways in which science interacts with society, and investigate the dynamic nature of physics. They explore how physicists develop new understanding and insights, and produce innovative solutions to everyday and complex problems and challenges in local, national, and global contexts. In this way, students are encouraged to think scientifically and make connections between the work of others and their own learning. This enables them to explore their own solutions to current and future problems and challenges.

Students understand that the development of science concepts, models, and theories is a dynamic process that involves analysis of evidence and sometimes produces ambiguity and uncertainty. They consider how and why science concepts, models, and theories are continually reviewed and reassessed as new evidence is obtained and as emerging technologies enable new avenues of investigation. They understand that scientific advancement involves a diverse range of individual scientists and teams of scientists working within an increasingly global community of practice.

Students explore how scientific progress and discoveries are influenced and shaped by a wide range of social, economic, ethical, and cultural factors. They investigate ways in which the application of science may provide great benefits to individuals, the community, and the environment, but may also pose risks and have unexpected outcomes. They understand how decision-making about socio-scientific issues often involves consideration of multiple lines of evidence and a range of needs and values. As critical thinkers they appreciate science as an ever-evolving body of knowledge that frequently informs public debate, but is not always able to provide definitive answers.

Science as a Human Endeavour underpins the contexts, approaches, and activities in this subject, and must be integrated into all teaching and learning programs.

Science as a Human Endeavour in the study of physics encompasses:

1. Communication and Collaboration

- Science is a global enterprise that relies on clear communication, international conventions, and review and verification of results.
- International collaboration is often required in scientific investigation.

2. Development

- Development of complex scientific models and/or theories often requires a wide range of evidence from many sources and across disciplines.
- New technologies improve the efficiency of scientific procedures and data collection and analysis; this can reveal new evidence that may modify or replace models, theories, and processes.

3. Influence

- Advances in scientific understanding in one field can influence and be influenced by other areas of science, technology, engineering, and mathematics.

- The acceptance and use of scientific knowledge can be influenced by social, economic, cultural, and ethical considerations.

4. Application and Limitation

- Scientific knowledge, understanding, and inquiry can enable scientists to develop solutions, make discoveries, design action for sustainability, evaluate economic, social, and environmental impacts, offer valid explanations, and make reliable predictions.
- The use of scientific knowledge may have beneficial or unexpected consequences; this requires monitoring, assessment, and evaluation of risk, and provides opportunities for innovation.
- Science informs public debate and is in turn influenced by public debate; at times, there may be complex, unanticipated variables or insufficient data that may limit possible conclusions.

Topic 1: Linear Motion and Forces

The study of Physics is the pursuit of understanding the physical world and the laws that govern it. One starting point for developing an understanding of matter, energy, forces, and the relationship that each has to another is the motion of physical bodies. While the motion of objects is instantly recognisable, the laws governing this motion can be subtle and often counterintuitive. In their study of Stage 1 Physics, students build on aspects of physics studied previously and then explore fundamental concepts and relationships in motion such as displacement, velocity, and acceleration, and the principles upon which each is founded.

In the first part of this topic, students acquire the skills and understanding to describe and explain motion in a variety of formats, including algebraic and graphical representations. They use the equations of motion and various graphical methods to elicit quantitative and qualitative information about moving objects that undergo constant acceleration and hence further build their literacy and numeracy skills.

Following the study of motion under constant acceleration, students consolidate their understanding of forces and the effect that forces have on the motion of objects, using Newton’s Laws of Motion.

Throughout this topic the importance of the concepts and laws in explaining physical phenomena is emphasised and their role in providing a foundation for contemporary applications is also highlighted. Students explore the limitations of the models and ways in which concepts can inform and explain existing, developing, and emerging technologies.

Critical thinking and an understanding of linear motion and forces enables students to devise solutions and make reasonable predictions.

Subtopic 1.1: Motion under Constant Acceleration

In this subtopic students become familiar with examples of motion under constant acceleration and with the use of notation, units, prefixes, and representations in physics. Students develop an awareness of the differences between vertical and horizontal motion under constant acceleration, with an emphasis on motion under the acceleration due to gravity.

Science Understanding	Possible Contexts
Linear motion with constant velocity is described in terms of relationships between measureable scalar and vector quantities, including displacement, distance, speed, and velocity • Solve problems using $v = \frac{s}{t}$. • Interpret solutions to problems in a variety of contexts. • Explain and solve problems involving the instantaneous velocity of an object. Acceleration is a change in motion. Uniformly accelerated motion is described in terms of relationships between measurable scalar and vector quantities, including displacement, speed, velocity, and acceleration. • Solve problems using equations	*This connects to the concept of acceleration used in the Stage 1 Sub-topic 1.2: Forces and the Stage 2 subtopics 1.1: Projectile Motion, 1.2 Forces and Momentum, 1.3 Uniform Circular Motion and Gravitation and 2.2 Motion of Charged Particles in Electric Fields.* Compare current definitions of units with other systems of measurement such as imperial measure, and consider the benefits and limitations of each. Discuss the nature and difference between scalar and vector quantities, and how each explains different aspects of motion. Discuss velocity vectors for an object moving in a curved path, to understand instantaneous velocity. Investigate the physical interpretation of negative velocities and accelerations in

Science Understanding	Possible Contexts
for constant acceleration and $a = \frac{\Delta v}{\Delta t}$. • Interpret solutions to problems in a variety of contexts. • Make reasonable and appropriate estimations of physical quantities in a variety of contexts.	context. Use SI units and common prefixes such as kilo (k), milli (m) and micro (μ) in practical activities to develop an awareness of reasonable estimates of physical quantities. Extend understanding and use of the equations $v = \frac{s}{t}$ and $a = \frac{\Delta v}{\Delta t}$. This could include the vector equations $\vec{v} = \frac{\Delta \vec{s}}{\Delta t}$ and $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$.
	Explore and clarify the relationship between velocity and acceleration using the computer interactive 'The Maze Game' https://phet.colorado.edu/
	Investigate the development and use of the SI units. Analyse the significance of the development of internationally agreed definitions of absolute measures of time, mass, and distance, and the challenges facing scientists since the introduction of SI units.
Graphical representations can be used qualitatively and quantitatively to describe and predict aspects of linear motion. • Use graphical methods to represent linear motion, including the construction of graphs showing: - position *versus* time - velocity *versus* time - acceleration *versus* time. • Use graphical representations to determine quantities such as position, displacement, distance, velocity, and acceleration. • Use graphical techniques to calculate the instantaneous velocity and instantaneous acceleration of an object.	Demonstrate how the gradient of a displacement *versus* time graph can be shown to be equivalent to the velocity of the object. Relate the gradient of a velocity *versus* time graph to the acceleration of the object. Use the area under the graph to determine the distance and displacement of an object. Construct different graphical representations using sections from popular movies or television shows. Those with 'chase' scenes may be particularly effective. Graphical representations can be constructed using data from professional athletes. Construct position *versus* time graphs and velocity *versus* time graphs using trolleys on an inclined plane. Consider the accelerations of different masses. Use motion sensors or other multi-image technology to collect data. Refer to computer interactive 'The Moving Man' https://phet.colorado.edu/ Connect and investigate different graphical representations by calculating gradients and areas. For example: - use a position *versus* time graph to construct a velocity

Science Understanding	Possible Contexts
	versus time graph. - use a velocity *versus* time graph to construct an acceleration *versus* time graph.
	Work out how to determine the instantaneous velocity and instantaneous acceleration from non-linear graphs, using mathematical techniques.
Equations of motion quantitatively describe and predict aspects of linear motion. • Solve and interpret problems using the equations of motion: $v = v_0 + at$ $s = v_0 t + \frac{1}{2}at^2$ $v^2 = {v_0}^2 + 2as$. Vertical motion is analysed by assuming that the acceleration due to gravity is constant near Earth's surface. The constant acceleration due to gravity near the surface of the Earth is approximately $g = 9.80 ms^{-2}$. • Solve problems for objects undergoing vertical motion because of the acceleration due to gravity in the absence of air resistance. • Explain the concept of free-falling objects and the conditions under which free-falling motion may be approximated. • Describe qualitatively the effects that air resistance has on vertical motion. Use equations of motion and graphical representations to determine the acceleration due to gravity.	Show how equations can be derived using different methods: - $v = v_0 + at$ using the definition of acceleration - $s = v_0 t + \frac{1}{2}at^2$ using a velocity *versus* time graph - $v^2 = {v_0}^2 + 2as$ algebraically. Calculate and analyse the acceleration due to gravity on the moon using NASA footage showing a hammer and feather being dropped simultaneously. Use and discuss appropriate estimations. Use stop motion animation to illustrate an understanding of motion. Footage of objects in motion may be analysed using tracking software.
	Further develop scientific inquiry skills by investigating different aspects of projectile motion in sport. Experimentally determine the acceleration due to gravity by recording an object falling against an appropriate scale using a ticker-timer, motion sensor, or other multi-image applications. Use data to construct a velocity time graph. Design investigations to determine if mass has any effect on vertical acceleration. Investigate side-show rides to measure and calculate physical quantities. Investigate what quantities make a ride enjoyable and how these are maximised. Consider factors such as g-force, acceleration, average speeds. Mobile devices could have suitable sensors and applications to record measurements.
	Explore the principles behind different methods used to determine the speed of an object and evaluate the benefits and limitations of each method.

Science Understanding	Possible Contexts
	Examples include radars and laser guns, point-to-point cameras. Decide the best location for point-to-point cameras to identify speeding vehicles. Investigate the methods used to determine the gait and speed of dinosaurs based on their tracks (such as that devised by Robert Alexander).which contribute to better understanding of early life on earth Conduct experiments and analyse data based on this work.

Subtopic 1.2: Forces

Students apply Newton's Laws of Motion to a variety of contexts. Students investigate how these laws have influenced design and safety in different contexts such as cars, boats, submarines, playground equipment, and air and space transport. Through experiments and activities, students build a sound understanding of forces in the physical world, including those relating to various kinds of resistance and friction.

Science Understanding	Possible Contexts
A force ($\vec{F}$) is any action which causes motion to change ($\vec{a}$). Uniform motion is a state of motion in which the body travels with a constant speed (in a straight line). Rest is a state of uniform motion in which the speed of the body is zero. To change the state of motion of an object, a net force must be applied.	*This connects to the concept of force used in the Stage 1 subtopic 4.1: Energy and 4.2: Momentum and the Stage 2 subtopics 1.2 Forces and Momentum, 1.3 Circular Motion and Gravitation, 2.1 Electric Fields, 2.2 Motion of Charged Particles in Electric Fields and 2.4 Motion of Charged Particles in Magnetic Fields.* Review understanding of forces.
Newton's Three Laws of Motion describe the relationship between the force or forces acting on an object, modelled as a point mass, and the motion of the object due to the application of the force or forces. Newton's First Law: An object will remain at rest, or continue in its motion, unless acted upon by an unbalanced force: • Explain Newton's First Law using the concept of inertia. • Use Newton's First Law to explain the motion of objects in a variety of contexts. • Describe and explain the motion of an object falling in a uniform gravitational field with air resistance. Newton's Second Law: If an unbalanced	Refer to computer interactive 'Forces in 1 dimension' https://phet.colorado.edu/ Discuss the concepts of weight and weightlessness in different contexts, e.g. on the surface of the earth, on the moon, inside a moving elevator, International Space Station. Discuss the motion of spacecraft in an essentially frictionless environment. Study satellites in circular orbits with acceleration but constant speed. Discuss motion in different circumstances, for example, on an inclined plane, thick liquids, or rigid objects.
	Use computer Interactive 'Forces and Motion: Basics' and 'Forces and Motion' https://phet.colorado.edu/ Investigate Newton's First Law by

Science Understanding	Possible Contexts
force acts upon an object, the object will accelerate in the direction of the net force. This can be given mathematically as: $\vec{a} = \frac{\vec{F}}{m}$. • Solve problems involving $\vec{F} = m\vec{a}$. • Explain the difference between mass and weight. Newton's Third Law: When two objects interact, they exert forces on each other equal in magnitude and opposite in direction. The forces are identified in pairs, and the accelerations of each object will differ if the objects differ in mass: • Use Newton's Third Law to solve problems. • Identify pairs of forces in a variety of contexts, including the normal reaction force. • Describe and explain motion where Newton's Third Law occurs. • Use Newton's Laws to explain the motion of spacecraft. Undertake experiments to investigate the relationship between acceleration and either force or mass.	moving objects of different mass over surfaces of very low friction. This may include: air tracks, ice, or layers of ball bearings. Investigate the relationships between terminal speeds and forces in a variety of contexts. Design and carry out individual or group investigations involving dropping objects in different fluids to observe and quantify non-uniform acceleration. Use computer Interactive 'Masses and Springs' https://phet.colorado.edu/ Investigate spring constants using Hooke's Law. Design experiments to investigate the effect of multiple springs. Students could test elastic bands, spaghetti, noodles, or confectionery to compare differences in results. Use an air track, light gate, and slotted masses to investigate relationship between forces and acceleration. Investigate different types of air or water rockets. The design may be manipulated and the effect on the rockets' motion determined. Determine the coefficient of kinetic friction by measuring the acceleration of a moving object as it comes to rest. Design, build, and evaluate structures individually or in groups.
	Investigate and assess the wide range of evidence from many sources that have contributed to the current understanding of motion. Investigate the influence that an understanding of the balance of forces has on the design of ancient and modern buildings, bridges, and other forms of engineering. Investigate and discuss the application of Newton's Laws of Motion in the development of various safety features involving people or objects in motion. Evaluate their social and economic impacts.

Topic 2: Electric Circuits

This topic extends students' knowledge and understanding of the concepts of circuit electricity. It explores the concept of electric charge and the requirements for electric current and introduces the concepts of potential difference, current, resistance electric power, and efficiency. These concepts are applied to direct current (DC) electric circuit and form the essential understanding for Stage 2, Topic 2: Electricity and Magnetism when discussing the production of magnetic fields and the generation and transmission of electricity.

Students extend their numeracy skills when problem solving in this topic and their personal and social capability is fostered by considering electrical safety devices and the impact of electrical energy use on the local and global environment.

2.1 Potential Difference and Electric Current

The existence of charged subatomic particles is used to explain the charging of objects. These ideas are extended to include potential difference and current, describing how the energy used to separate the charges enables an electric current in a closed circuit. The measurement of potential difference and current is introduced.

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td rowspan="3">Atoms contain positively-charged protons and negatively-charged electrons.
Two objects become charged when electrons are transferred from one object to another or redistributed on an object.
Two like charges exert repulsive forces on each other, whereas two unlike charges exert attractive forces on each other.
Describe electric forces between like and opposite charges.
Explain various phenomena involving interactions of charge.
Explain how electrical conductors allow charges to move freely through them, whereas insulators do not.
Energy is required to separate positive and negative charges and this charge separation produces an electrical potential difference that can be used to drive current in circuits.
The energy available to charges moving in an electrical circuit is measured using electric potential difference (voltage). This is defined as the change in potential energy per unit charge between two defined points in the circuit and is measured using a voltmeter.
Describe how a voltmeter is used in an electric circuit.
Explain the purpose of measuring potential difference in electric circuit.
Describe how electrical safety is increased through the use of</td><td>This connects to the concept of work in the Stage 1, Subtopic 4.1: Energy and Stage 2, Subtopic 2.2: Motion of charged particles in electric fields.
It connects to the concepts of charge in Stage 2, Subtopic 2.1: Electric Fields and electric current used in the Stage 2 subtopics 2.3: Magnetic Fields and 2.5: Electromagnetic Induction.</td></tr>
<tr><td>Activities could include using:
- Van de Graaf generator
- Perspex and ebonite rods
- an electroscope
- balloons.
Investigate electrical discharges such as:
- lighting
- spark plugs
- piezo igniters.
Measure the total potential difference across a circuit and the potential difference across individual components.</td></tr>
<tr><td>Explore the application of potential differences Examples include: x-ray production in medical imaging and particle accelerators.
Discuss the social and economic impacts, for example access to and affordability of such medical treatment in different parts of the world.
Discuss innovative applications and limitations of semi-conductors (e.g. photovoltaic cells in solar panels, LEDs)</td></tr>
</table>

Science Understanding	Possible Contexts
➢ fuses or circuit breakers ➢ residual current devices	and superconductors (e.g. maglev trains, MRI). Explore beneficial and unexpected consequences of large scale electricity production and transmission taking into account that much of the world's energy reserves are used to provide the energy needed to drive electric current. Research the safety aspects of working with electric circuits and the use of testing devices.
Electric current is carried by discrete charge carriers. Charge is conserved at all points in an electrical circuit. • Distinguish between electron current and conventional current. Electric current is the rate of flow of charge. • Solve problems involving $I = \frac{q}{t}$. An ammeter is used to measure the electrical current at a point in a circuit. It is placed in series with the electrical component through which the current is to be measured.	Use a water-flow analogy to facilitate students' understanding of this concept. Observe how the conductivity of metals, molten and aqueous ionic compound and ionised gases provide evidence for a variety of charge carriers.
	Measure the total current in a circuit and the current at various places in the circuit.

2.2 Resistance

Resistance is described and the factors affecting the resistance of a conductor are investigated. Ohm's Law is introduced, investigated, and applied. The concept of ohmic and non-ohmic conductors is also explored.

Science Understanding	Possible Contexts
Resistance for ohmic and non-ohmic components is defined as the ratio of potential difference across the component to the current in the component. The resistance of a conductor depends on its length, area of cross-section, temperature, and the type of the material of which it is composed. Resistance is constant for ohmic resistors, which conform to Ohm's law. Ohm's Law states that current is directly proportional to the potential difference providing the temperature of the conductor remains constant.	Computer interactive: Resistance in a wire from: http://phet.colorado.edu/en/simulation/resistance-in-a-wire Ohm's Law is used when exploring electrical power, energy transmission, and the need for transformers.
	Investigate the factors affecting the resistance of conductors such as the length of conductor, resistivity, or cross-sectional area. Investigate the relationship between current and potential difference for a variety of conductors, including graphical analysis.

Science Understanding	Possible Contexts
• Solve problems involving $R = \frac{V}{I}$.	Assess the economic, social, and environmental impacts of electrical safety devices, such as circuit breakers, fuses, and fuse wire.

2.3 Circuit Analysis

Students are introduced to series, parallel, and composite (series/parallel) circuits and their construction. They analyse circuits to determine resistance, potential difference, and current.

Science Understanding	Possible Contexts
Circuit analysis and design involve calculation of the potential difference across, the current in, and the power supplied to, components in series, parallel and series/parallel circuits. The current is equal in each series component. • Solve problems involving $V_t = V_1 + V_2 + ..V_n$ and $R_t = R_1 + R_2 + ..R_n$. for components in series. The potential difference is equal across each parallel component. • Solve problems involving $I_t = I_1 + I_2 + ..I_n$ and $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + ..\frac{1}{R_n}$ Undertake experiments to investigate current, resistance or potential difference in series and parallel circuits using various circuit elements.	Computer interactives: Explore electric circuits using http://www.physicsclassroom.com/Physics-Interactives/Electric-Circuits
	Students construct, test, and analyse a variety of electrical circuits. Use circuit construction kits, for example, from http://phet.colorado.edu/en/simulation/circuit-construction-kit-ac

2.4 Electrical Power

Students study electrical power, connecting the Electric Circuits topic to the Stage 1, Subtopic 4.2: Momentum. Calculations of electric power enable connections to be made to the Stage 1, Topic 3: Heat. The concept of efficiency is introduced in the context of electric circuits, enabling it to be applied in a range of situations in the Stage 1, Subtopic 4.1: Energy. Concepts of power and efficiency are related to the electricity production and transmission application.

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td rowspan="3">Power is the rate at which energy is transformed by a circuit component.
• Solve problems involving
– $P = \frac{\Delta E}{t}$
– $P = VI$
and the use of Ohm’s Law formula.
• Solve problems involving the cost of electrical energy, using kilowatt hours.

Electrical circuits enable electrical energy to be transferred efficiently over large distances and transformed into a range of other useful forms of energy including thermal and kinetic energy, and light.
• Solve problems involving
$efficiency = \frac{useful\ energy\ /\ power\ output}{total\ energy\ /\ power\ input}$</td><td>This connects to the use of the concept power in the Stage 1, Topic 4: Energy and Momentum.
Explore electrical power and the use of appliances.
Compare local and large-scale electricity generation in terms of their efficiency, convenience, and effect on the local and global environment.</td></tr>
<tr><td>Investigate the efficiency and running cost of a range of electrical appliances.</td></tr>
<tr><td>Analyse the energy losses that occur as electrical energy is fed through transmission lines from the generator to the consumer, the high voltage used in transmission.
Explore competing electric power transmission and storage systems such as large and small scale electricity production, innovative home energy storage technology. Evaluate benefits and limitations of each.</td></tr>
</table>

Topic 3: Heat

In this topic, students extend their understanding of the concepts of energy, its transformations, transfer, and conservation by focusing on heat. Students explore the concepts of heat, temperature, thermal energy, and the different methods through which heat is transferred within a system. They study the change of state and the increase in temperature of a substance when heated from both qualitative and quantitative ways, extending their literacy and numeracy skills.

Possible contexts that can be used to develop these concepts include internal combustion engines, heating and cooling systems, and weather systems.

Students develop an understanding of the importance of heating and cooling systems on health and well-being, both personally and globally.

3.1 Heat and Temperature

Students develop their understanding of the link between the temperature of matter and the kinetic energy of its particles. They investigate the flow of energy and explain it in terms of conduction, convection, and radiation. They explore applications of the expansion of materials due to the motion of their particles.

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td rowspan="2">Thermal energy is made up of the combined potential energy and the kinetic energy that is due to the vibration of the particles within the object.
The particles within objects with higher temperatures have a higher average kinetic energy.
An increase in the temperature of an object is due to an increase in its thermal energy.
• Describe the links between temperature, vibrating particles, and thermal energy.
Temperature can be measured with different scales (common ones being degrees Celsius, degrees Fahrenheit and Kelvin).
As the temperature decreases the average kinetic energy of the particles drops until the lower limit (known as ‘absolute zero’) is reached.
When a hot object is put into contact with a cooler object some of the thermal energy transfers between the objects. This flow of energy is referred to as heat.
If the objects remain in contact then eventually the objects will reach the same temperature, putting the objects into ‘thermal equilibrium’.
• Describe heat as the flow of energy from hot to cooler objects.
• Describe thermal equilibrium.</td>
<td>Demonstrate and describe different temperature scales: Celsius, degrees Fahrenheit, and Kelvin scales. Include those used to measure air temperature and the temperature of stars like the Sun.
Discuss absolute zero.
Compare the temperatures of a range of different objects, e.g. body temperature, boiling water, ice, light bulb, sun, liquid nitrogen, a warm room.
Observe random motion of particles using a smoke cell and light source and view through a microscope.
Plot graphs of temperature versus time using thermometers made by students. Compare with commercially made thermometers.
Use simulation experiments:
https://phet.colorado.edu/en/simulation/energy-forms-and-changes</td></tr>
<tr><td>Conduct an investigation to determine the value of absolute zero.
Compare the change in temperature in a volume of water when a small, hot object is added as opposed to adding a large, warm object.
Refer to http://youtu.be/wTi3Hn09OBs
Construct thermometers. These can be made with coloured liquids (alcohol) in thin tubes or straws that expand as temperature increases.</td></tr>
</table>

Science Understanding	Possible Contexts
	How to build a thermometer link: http://www.energyquest.ca.gov/projects/thermometer.html Investigate daily temperature changes using temperature maps on Bureau of Meteorology website: http://www.bom.gov.au/climate/outlooks/#/temperature/maximum/median/seasonal/0
	Explore the international conventions involving different temperature scales and analyse the significance of using a consistent system. Examples may include Imperial, Fahrenheit, Celsius, and Kelvin. Research on the influence of engineering and technology of the development of the world's most sensitive thermometers, e.g. https://www.adelaide.edu.au/news/news70922.html 7
Heat transfer can occur through conduction, convection, and radiation. • Explain how heat transfer can occur through conduction, convection, and radiation. • Describe examples of each heat transfer processes. Most solids, liquids, and gases expand when heated. • Describe applications of the expansion of matter due to heat transfer.	Use a conductivity star made of 4 different metals to demonstrate the different thermal conductivities of different metals. Show that water is a poor conductor by boiling water at the top of a test tube while ice at the bottom of the tube does not melt.
	Explore the conduction of heat in a metal bar with small pieces of wax holding pins, and with one end of the bar being heated. (Graph distance and time.) Investigate convection currents with potassium permanganate crystals in water. Carry out investigations to explore gas and /or metallic expansion.
	Analyse ways in which the use of poor conductors can have social and economic advantages, e.g. air in feather and down quilts, building insulation. Explore how an understanding of heat transfer during climate cycles (such as ocean currents or air currents) and their effects on weather can enable scientists to make predictions and design action for sustainability. *Note the link with Earth and Environmental Science, Stage 2, Topic*

Science Understanding	Possible Contexts
	4: Climate Change. Explore the social, economic, and environmental impacts of applications of thermal expansion, for example: – thermostat control of heaters, irons, kettles – engineering of bridge building – turbines (particularly in power stations) driven by steam. Investigate changing technologies involving heat engines, including steam engines (external combustion), diesel engines and petrol engines (internal combustion), Stirling engine and innovations to reduce their environmental impact.

3.2 Specific Heat Capacity

Students explore the amount of energy required to increase the temperature of various materials. This can then be linked to the properties and uses of materials.

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td rowspan="3">Energy can be added to or removed from a system without causing a change of state. The energy that is added or removed causes a change in temperature ΔT.
The change in temperature depends on the mass of the object, m, the amount of heat transferred to or from the object Q and the nature of the material (its ‘specific heat capacity’ c). These variables are linked through the formula: $Q = mc\Delta T$.
• Describe and explain specific heat capacity.
• Solve problems using the formula $Q = mc\Delta T$.</td><td>Experimental determination of specific heat capacity.</td></tr>
<tr><td>Investigate whether salt concentration affects the specific heat capacity of salt-water.
Use calorimeters to investigate the specific heat capacity of common materials, such as cubes of wood, plastic, and metal.</td></tr>
<tr><td>Explore the significance to engineering of an understanding of specific heat capacity, for example, in metal parts in an engine.
Discuss the significance of the high specific heat capacity of water in climate homeostasis. Note the link with Earth and Environmental Science, Stage 2, Topic 4: Climate Change.</td></tr>
</table>

3.3 Change of State

Students explore the amount of energy absorbed or released during changes of state. They also explain changes of state using the particle model. The constant temperature during a change of state can be linked to applications.

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td rowspan="3">Matter commonly exists in three states: solid, liquid, and gas.
To change a solid to a liquid (melting) and to change a liquid to a gas (boiling) requires the input of energy.
This energy breaks the bonds between atoms or molecules but does not change the temperature and is thus known as latent heat.
• Describe and explain latent heat.
• Explain the difference between evaporation and boiling, using the particle model.
The amount of latent heat required (Q) depends upon the nature of the substance (specifically, its latent heat capacity (L)) and the mass of the substance m, and is calculated using $Q = mL$.
During the change of state from a gas to a liquid (condensation) or from a liquid to a solid (freezing/solidification) heat is released due to the formation of bonds between atoms or molecules.
• Solve problems using the formula $Q = mL$.
Some substances change from solid to gas (sublimation) or from gas to solid (deposition) without going through a liquid phase.
Undertake experiments to determine the specific heat capacity or latent heat of different materials.</td>
<td>Discuss:
– characteristics of 3 common states of matter
– change of state using particle models and particle motion
– other states of matter such as plasma.
Discuss the difference between scalding burns and steam burns.</td></tr>
<tr><td>Investigate the latent heat of fusion of ice.
Investigate the properties of liquids that make them suitable radiator coolants.</td></tr>
<tr><td>Explore how an understanding of body temperature control mechanisms such as sweating can lead to innovations, for example, in sports science.
Compare evaporative and refrigerative cooling of buildings and evaluate the benefits and limitations of each.
Research pressure differences which can cause change of states / temperatures of refrigerants in refrigerators and evaluate its significance in food preservation.
Explore the importance to life on Earth of water existing in all three states.
Note the link with Earth and Environmental Science, Stage 1, Topic 5: Importance of the Hydrosphere</td></tr>
</table>

Topic 4: Energy and Momentum

This topic draws on content covered in Stage 1, Topic 1: Linear Motion and Forces and extends the study of motion to include energy and momentum. Conservation laws form the basis of many fundamental principles in physics, and a sound understanding of what these laws mean, and their implications, are essential to understand the physical world. This topic emphasises the law of the conservation of energy and the law of the conservation of momentum.

The concept of Energy is used as a means to explain and predict the behaviours of different objects under different physical conditions. Students should be familiar with energy processes and transformations from previous learning in science. The first subtopic begins by exploring energy, work, and the relationship between the two. Students discuss abstract scientific definitions and how they might be used in the physical world. They consider different forms of energy, with a number of these forms suitable for quantitative analysis. Students also study the rate at which energy is used. As they discuss and explain these concepts, students further develop their literacy and numeracy skills.

Through the subtopic covering momentum, students extend their understanding of the relationship that exists between force and the motion of an object. There is a focus on interactions in one dimension between objects such as those that occur during collisions and explosions. This topic lends itself to a variety of experiments and investigations, including pendulum motion, and energy transfer and efficiency, enabling students to use their creativity and creative thinking to construct, review, and revise hypotheses.

Personal and social capability is strengthened by better understanding the physics of collisions and exploring innovative ways of increasing safety and reducing injury in vehicles and sports.

Subtopic 4.1: Energy

Students use mathematical relationships to determine and measure quantities based on work done, conservation of energy, and power. They investigate the efficiency of different mechanical systems and explore emerging technologies in sustainable energy generation.

Science Understanding	Possible Contexts
The work done on an object is equivalent to the change in energy of that object. When a force is applied to an object causing a displacement over a distance, work is done. • Explain work in terms of an applied force. • Solve problems using $W = \Delta E$ and $W = Fs$ where the displacement is parallel to the force.	*This connects to the concept of energy used in the Stage 1 subtopic 6.4: Induced Nuclear Reactions and the Stage 2 subtopics 2.2 Motion of Charged Particles in Electric Fields and 3.2: Wave-Particle Duality.* Investigate the work done on an object when the net force acting on the object is not in the direction of the displacement, using trigonometric calculations, $W = Fs\cos\theta$.
Energy exists in a number of different forms. • Describe different forms of energy including kinetic, elastic, gravitational potential, rotational kinetic, heat, and electrical.	Connect to work done when a projectile with air resistance moves through air. Show how the relationship $W = \Delta E$ can be derived using the definition of force and $E_k = \frac{1}{2}mv^2$.
Energy can be transferred from one object to another or transformed into different forms of energy. • Describe examples of energy	Demonstrate energy transfers using a steam engine, combustion engine, or other similar engines. Investigate the relationship between

Science Understanding	Possible Contexts
being transferred from one object to another. • Describe examples of energy being transformed. Explain qualitatively the meaning and some applications of various forms of energy, including kinetic energy and potential energy. • Solve problems using $E_k = \frac{1}{2}mv^2$ and $E_p = mgh$. • Describe energy transfers between objects and within different mechanical systems. Energy is conserved when transferred from one object to another in an isolated system. • Solve problems using the conservation of energy. Describe and explain the energy losses that occur in systems involving energy transfers. Power is defined as the rate at which work is done and is equivalent to the rate at which energy is used. • Solve problems using $P = \frac{W}{t}$ and $P = Fv$ • Interpret solutions to calculate involving power in context.	power and mechanical advantage using simple machines. *The concept of efficiency can be developed here; it is also covered in Stage 1, Subtopic 2.4: Electrical Power.* Utilise computer interactive 'Energy forms and changes' https://phet.colorado.edu/ *The simple harmonic motion of pendulums links to Stage 1, Topic 5: Waves.*
	Design and conduct individual or group experiments to determine the efficiency of different systems involving energy transfers. Test the conservation of energy by recording and measuring objects falling from different heights and recording their speed as they hit the ground. Design and build a 'gravity car' – a car that uses a falling weight to transfer energy to wheel rotation. Investigate the motion of pendulums, demonstrating the law of conservation of energy.
	Explore the difficulty of developing international conventions to define concepts such as energy and work to facilitate communication and collaboration. Assess the economic advantage of efficiency in different mechanical systems and any implications for developing or emerging technology such as regenerative brakes.

Subtopic 4.2: Momentum

Students explore the relationship between force and momentum through this subtopic. They use the concept of momentum to reformulate the definition of a force as the rate of change of momentum, and examine impulse.

Students use the relationship between change in momentum (impulse) and force to explore the implications for existing technology, particularly in terms of safety in vehicles. They also apply this to spacecraft propulsion on Earth and the potential of propulsion in space, for example in probe and potential human space exploration. Students use the conservation of momentum to predict and explain physical phenomena, and may use that to investigate the forensic methods applied to analysing accidents. Students use technology to analyse and present experiments throughout this topic.

Science Understanding	Possible Contexts
Momentum is a property of moving objects, which depends on their mass and velocity. Momentum can be expressed mathematically as $\vec{p} = m\vec{v}$. Momentum may be transferred from one object to another when a force acts over a time interval. The rate of change of momentum of an object with respect to time is equal to the net force acting upon the object. This can be expressed mathematically as: $\vec{F} = \frac{\Delta \vec{p}}{\Delta t}$ The impulse of an object is equal to $F\Delta t$, and consequently equals the change in momentum. • Use Newton's Second Law in the form $\vec{F} = m\vec{a}$ to derive the formula: $\vec{F} = \frac{\Delta \vec{p}}{\Delta t}$. • Solve problems involving changes in momentum and impulse (for one dimension). • Draw and interpret graphs of force *versus* time.	*This connects to the concept of momentum used in the Stage 2 subtopics 1.2: Forces and Momentum and 3.2: Wave-Particle Duality.* Analyse the safety mechanisms of modern vehicles using concepts of impulse and momentum. Analyse the elasticity of bungee cords using the concept of impulse. *The focus in Stage 1 should be on one-dimensional situations. Two-dimensional situations are studied in Stage 2 Physics.*
	Compare the difficulty in stopping objects of different masses and speeds as a way to introduce the concept of momentum. Use simple experiments and demonstrations such as dropping eggs enclosed in student-designed cases to demonstrate basic concepts of impulse in context.
	Analyse the social and economic advantages of minimising the risk of injury by extending the time of a collision, for example seatbelts, airbags, bicycle helmets, boxing gloves, softball gloves, and safety nets. Explore applications in which an understanding of maximising the time during which the force acts leads to an increase in speed. Examples include: long rowing strokes, use of a woomera for throwing. Evaluate ways in which increasing the gain in speed through maximising the force applied is used in sport science. Examples include: force applied with tennis racquets or golf clubs, kicking balls, and other ball sports. Design a new piece of equipment.
In an isolated system, the total momentum is conserved. • Use the conservation of momentum to solve problems in a variety of contexts. An elastic collision is one in which the total initial kinetic energy equals the total final kinetic energy. In an inelastic collision some kinetic energy is transformed. • Describe the difference between	*The focus in Stage 1 should be on one-dimensional situations. Two-dimensional situations are studied in Stage 2 Physics.* Use water powered or air rockets to describe the conservation of momentum. This may be extended to include systems of variable mass. Investigate Newton's Cradle to explain that the conservation of momentum and the conservation of energy are both required to explain its motion.

Science Understanding	Possible Contexts
an elastic collision and an inelastic collision using examples. • Solve problems involving one-dimensional collisions, using $E_k = \frac{1}{2}mv^2$ and $\vec{p} = m\vec{v}$. • Describe the energy transformations during inelastic collisions. Undertake experiments to investigate the conservation of energy or conservation of momentum.	Refer to computer interactive ‘Collision Lab’ https://phet.colorado.edu/
	Conduct experiments involving collisions, using various recording technology such as motion sensors, and video. Use data and photographs from simulated accidents to make reasonable assumptions about their causes. Design and investigate collisions with minimal friction, using an air track with various recording technologies. Analyse video footage of explosions to further understand momentum in two dimensions. Investigate non-contact collisions by attaching magnets to trolleys.
	Assess the technical and practical challenges associated with the development of spacecraft and the ways in which the conservation of momentum may be applied to spacecraft. Analyse the effect of the conservation of momentum in traffic accidents and hence determine factors that may have led to a collision.. Evaluate the social and economic impacts.

Topic 5: Waves

In this topic, students understand how the wave model can be used to describe, explain, and predict the transfer of energy through matter and space.

Students investigate a range of mechanical waves, and compare them with light waves. This leads to an understanding of a number of wave-related phenomena, including reflection, refraction, resonance, diffraction, polarisation, dispersion, and interference. Students also learn about the electromagnetic spectrum.

Possible contexts that can be investigated include sound, music and acoustics, earthquakes and seismic waves; optics, lasers, and fibre optics; and wireless communications.

An insight into the rapidly increasing range of new technology for data storage and transmission extends students' personal and social capability as they recognise its global impact on health and well-being. They develop an understanding of the increased capacity of technology to communicate and explore some of the social, environmental, and economic impacts of scientific research in this area.

5.1 Wave Model

Students develop their understanding of the wave model as a theory that can be used to describe the transfer of energy through matter and space. They investigate various properties of waves and the relationships between them.

Science Understanding	Possible Contexts
Waves are periodic oscillations that transfer energy from one point to another. In longitudinal waves the direction of oscillation is parallel to the direction of the wave velocity. In transverse waves the direction of oscillation is perpendicular to the propagation of the wave. • Represent transverse waves graphically and analyse the graphs. • Describe waves in terms of measurable quantities, including amplitude, wavelength (λ), frequency (f), period (T), and velocity (v). • Solve problems using: - $f = 1/T$ - $v = f\lambda$.	*This connects to the concept of waves used in the Stage 2 subtopics 3.1 Wave Behaviour of Light and 3.2 Wave - Particle Duality.* Show longitudinal and transverse waves in a slinky spring or wave machine. Discuss longitudinal waves in terms of compressions and rarefactions. Demonstrate and explain the Doppler effect and formation of sonic booms at supersonic speeds. Phet – Sound and Waves – (https://phet.colorado.edu/en/simulations/category/physics/sound-and-waves) Discuss difference in time between seeing lightning and hearing thunder.
	Investigate sound and vibrations, e.g. tuning fork in water, speaker cone. Analyse wave representations using technology, such as oscilloscopes or smartphone apps. Measure sound levels and relate them to the amplitude of the waves. Explore the relationships between the frequency and period of oscillators (such as pendulums and springs), and investigate factors that affect these quantities (such as string length).

Science Understanding	Possible Contexts
	Investigate velocity of various waves (sound, seismic, light) in various media (air, water, solids).
	Ascertain the economic, social, and environmental impacts of applications of the Doppler effect. Examples include: - detecting red-shift and blue-shift stars - radar guns - doppler radar - reading weather patterns using a stationary transmitter in weather station and moving object, e.g. storm system - using sound waves to produce image of heart (Doppler Echocardiogram).

5.2 Mechanical Waves

Students use the wave model to describe and explain many phenomena that are observed in everyday life. They investigate wave behaviour and explore various applications of waves.

Science Understanding	Possible Contexts
Mechanical waves such as sound and seismic waves transfer energy through a physical medium. The natural frequency is the rate at which an object vibrates when it is disturbed by an outside force. A forced vibration occurs when a wave forces an object to vibrate at the same frequency as the wave. Resonance is the large amplitude vibration that occurs in the object when the forced vibration is the same as its natural frequency. • Explain a range of wave-related phenomena, including echoes, refraction, and resonance, using the mechanical wave model. • Use the principle of superposition of waves to explain a range of interference phenomena, including standing waves and beats.	Test human hearing frequency range. Use a bell jar to show that sound does not travel through a vacuum. Use a large isolated solid wall to demonstrate echoes and reverberation. Discuss bats using echo location for navigation. Discuss concept of harmonics in musical instruments. Demonstrate resonance with a singing rod. Use the concept of resonance to tune a guitar. View videos of and discuss the Tacoma Narrows Bridge failure. Demonstrate the concept of beats, using tuning forks, musical instruments, or ICT. Visually compare the shape of the waves of different musical instruments (shown on an oscilloscope or other technology). Use Phet – Sound and Waves – (https://phet.colorado.edu/en/simulations/category/physics/sound-and-waves)

Science Understanding	Possible Contexts
	Analyse standing waves mathematically using: - $l = n\frac{\lambda}{2}$ for strings attached at both ends and for pipes open at both ends - $l = (2n-1)\frac{\lambda}{4}$ for pipes closed at one end. Investigate: - the effect of different tensions or lengths on the vibrating frequency, using, for example, strings or air columns - the effect of the density of the medium on the speed of sound - interference patterns in a ripple tank - the formation of standing waves in strings and pipes - the production of beats - the resonant frequency of an oscillator, such as a loudspeaker or spring, and the factors that affect the resonant frequency.
	Evaluate the benefits, limitations, and ethical considerations of using technology in contexts such as: - voice recognition - medical imaging using ultrasound - sonar in submarines, depth sounders and locating fish - acoustic and building design - resonance in built structures - automated home systems. Evaluate the significance of using seismic waves to determine epicentre of an earthquake. *Note the link to Stage 1 Earth and Environmental Science, Topic 3: Processes in the Geosphere.*

5.3 Light

Students develop their understanding of the wave-like properties of light and other forms of electromagnetic radiation. They are introduced to the concept of oscillating electric and magnetic fields to model the behaviour of light and other forms of electromagnetic radiation. They investigate light and other forms electromagnetic radiation and explore applications based on the wave model.

Science Understanding	Possible Contexts
Light is the visible part of the electromagnetic spectrum – a spectrum that also includes radio waves, microwaves, infrared, and ultraviolet radiations, x-rays, and gamma rays. Electromagnetic waves can be modelled as a transverse wave that can travel through a vacuum. Refraction is the change in direction of propagation of a wave as its speed changes. Diffraction is the bending/spreading of waves as they pass through an aperture or past a sharp edge. The plane of polarisation of an electromagnetic wave is the plane defined by the direction of travel and the oscillating electric field. • Describe reflection and refraction, using the ray model of light. • Explain a range of light-related phenomena, including reflection, refraction, total internal reflection, diffraction, and polarisation, using the wave model. Undertake experiments to investigate reflection or refraction of light using different media	*This connects to the concept of waves used in the Stage 2 subtopics 3.1 Wave Behaviour of Light and 3.2 Wave - Particle Duality.* Demonstrate transmission of a mobile phone signal into an evacuated bell jar. Observe spectra of various light sources through a spectrometer or prism. Refer to Phet – Light and Radiation (https://phet.colorado.edu/en/simulations/category/physics/light-and-radiation) Use Snell's Law to quantitatively describe refraction of light, using: $\frac{\sin i}{\sin r} = \frac{v_1}{r_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$. Demonstrate transmission of light through optical fibres.
	Use light box or laser to investigate reflection, refraction, total internal reflection, and the optics of concave and convex lens and curved and flat mirrors. Investigate polarisation of light, using filters.
	Analyse the interaction between science and technology with advances in: - optics of camera lenses, telescopes, and binoculars - optometry (spectacles and corrective laser surgery) - the uses of optic fibres in medicine and communication - applications of polarisation (such as 3D glasses, sunglasses) - the uses of radio waves and microwaves in communication (such as wifi, mobile phones, and space communication) - heating using microwaves - the uses of x-rays and gamma rays in diagnostic and therapeutic medicine - Laser Airborne Depth Sounding (LADS). Assess the economic and health impacts of ultraviolet radiation exposure.

Topic 6: Nuclear Models and Radioactivity

In this topic, students build on their understanding of the basic structure of the nucleus and the uses of radiation to develop an understanding of the concepts involved in the complex structure of the nucleus, stable and unstable nuclei, radioactivity, nuclear fission and nuclear fusion. This includes the concepts of nuclear force, nuclear reactions, radioactive decays, and mass-energy equivalence.. They recognise that science is a global endeavour with significant contributions coming from many people.

Possible contexts that can be investigated include nuclear reactors, medical uses for radioisotopes, positron emission tomography, radioactive dating, high-energy particle accelerators, and developments in technology, engineering, and communication.

Students extend their ethical understanding by considering the impact of radioactive material on the environment and the importance of planning for the future, protecting and sustaining the biosphere. They explore the way that science informs public debate about nuclear power and is in turn influenced by public debate.

6.1 The Nucleus

Students develop an understanding of the structure of the atom and the nucleus, and the forces that exist within the nucleus. They also learn how to use represent various nuclei.

Science Understanding	Possible Contexts
The basic structure of an atom comprises a small central nucleus consisting of protons and neutrons (nucleons) surrounded by electrons. Atomic nuclei can be described using their chemical symbol (X), mass number (A), atomic number (Z), and number of neutrons (N). A common representation is: ${}^{A}_{Z}X$ • Describe the structure of an atom, including the relative size and location of the nucleons and electrons. • Describe the structure of various nuclei from their symbol and vice-versa.	*This connects to the concept of the nucleus used in the Stage 2 subtopic 3.4: Standard Model.* Review the structure of the atom. Use online interactives to build an atom: https://phet.colorado.edu/en/simulation/build-an-atom Explore other atomic models, the evidence that supported those models, and the limitations of each model.
Isotopes are atoms of the same element that have different mass numbers. • Identify isotopes of an element based on their composition. • Explain why isotopes of the same element are chemically identical but have different physical properties. The nucleus is held together by a strong, attractive nuclear force. • Describe the properties of the strong nuclear force, including its short range. • Describe the balance between the electrostatic force and strong	Determine the value of the collaborative work of many scientists in the discovery of the nucleus and modifications made to their models in the light of new information. Research the benefits and limitations of the medical and industrial uses of different isotopes. Discuss monitoring and risk evaluation. Research how the heavy-water content of ancient ice provides information about climate change and enables scientists to make predictions.

Science Understanding	Possible Contexts
nuclear force in stable nuclei. • Use the properties of the electrostatic force and strong nuclear force to explain why some isotopes are unstable. • Locate stable and unstable nuclei on an N *versus* Z graph.	

6.2 Radioactive decay

Students learn about the factors that determine whether a nucleus is stable or unstable and undergoes radioactive decay. They also learn how the composition of the nucleus determines the type of decay that will occur.

Science Understanding	Possible Contexts
Unstable nuclei will undergo radioactive decay in which particles and/or electromagnetic radiation are emitted.	*This connects to the concept of the nucleus used in the Stage 2 Subtopics 2.4: Motion of Charged Particles in Magnetic Fields and 3.4: Standard Model.* Discuss how large unstable nuclei may undergo nuclear fission rather than one of the three radioactive decays. Utilise the Australian Government ARPANSA website: http://www.arpansa.gov.au/radiationprotection/basics/radioactivity.cfm
	Explore examples of the collaborative work that has led to the discovery of radioactive elements and discuss the subsequent development of a range of applications.
In alpha decay, an unstable nucleus emits an alpha particle, ${}^{4}_{2}\alpha$. Alpha decay typically occurs for nuclei with Z > 83. The general equation for an alpha decay is given by: ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$ • Write equations for the decay of heavy nuclei by alpha decay.	Simulate alpha decay: https://phet.colorado.edu/en/simulation/alpha-decay Demonstrate the use of a cloud chamber to detect alpha radiation. Investigate the decay series of unstable nuclei to form stable nuclei.
	Explore the benefits and unexpected consequences of using alpha decay in, for example, quantum tunnelling (in a scanning tunnelling microscope) or in smoke alarms.
In beta minus decay, an unstable nucleus emits an electron (${}^{0}_{-1}e$). Beta minus decay occurs when a nucleus	Simulate Beta decay: https://phet.colorado.edu/en/simulation/beta-decay Demonstrate the use of a cloud

Science Understanding	Possible Contexts
has an excess of neutrons, and involves the decay of a neutron into a proton, electron, and antineutrino. This is shown by the equation: $n \rightarrow p + e^{-} + \overline{\nu}_e$. The general equation for beta minus decay of an unstable nucleus is shown by the equation: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \overline{\nu}_e$. In beta plus decay, an unstable nucleus emits a positron (${}^{0}_{+1}e$). Beta plus decay occurs when a nucleus has an excess of protons, and involves the decay of a proton into a neutron, positron, and neutrino. This is shown by the equation: $p \rightarrow n + e^{+} + \nu_e$. The general equation for beta plus decay of an unstable nucleus is given by: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + \nu_e$. • Describe the structure of unstable nuclei that causes each type of beta decay. • Write the equations for the decay of nuclei by beta minus and beta plus decay. • Use the conservation of charge to explain the emission of an electron in the decay of a neutron into a proton. • Use the conservation of charge to explain the emission of a positron in the decay of a proton into a neutron.	chamber to detect beta radiation. Explore how the knowledge of conservation of momentum enables scientists to predict the presence of new particles such as neutrinos. Evaluate the benefits and risks of the use of beta decay in industry and medicine.
In gamma decay, an unstable nucleus emits high-energy gamma rays (γ). Gamma decay occurs when a nucleus is left with excess energy after an alpha or beta decay. The general equation for a gamma decay is given by: ${}^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + n\gamma$ where *n* is the number of high-energy gamma rays emitted. • Write equations for the decay of unstable nuclei involving the emission of gamma rays.	Explore industrial, scientific, and medical uses of gamma emitters such as Tc-99 and assess the risks and their management.
The type of decay an unstable nucleus will undergo can be predicted based on the	

Science Understanding	Possible Contexts
number of protons and neutrons within the nucleus. • Use the atomic and mass numbers to predict the type of decay for an unstable nucleus. • Use the location on an N *versus* Z graph to predict the type of decay for an unstable nucleus.	
The particles emitted in radioactive decay have sufficient energy to ionise atoms. The properties of the particles and/or radiation emitted in the different types of radioactive decay result in different penetration of matter. • Describe the effects of ionising radiation on living matter. • Describe methods of minimising exposure to ionising radiation. • Compare and contrast the ionising ability and penetration through matter of alpha, beta, and gamma radiations.	Discuss the protection for workers handling radioactive materials.

6.3 Radioactive half-life

Students learn about the rate of radioactive decay. They explore how this is related to the activity of radioactive samples, and the implications of this for managing radioactive materials. Students also investigate how the rate of decay can be used to determine the age of artefacts.

Science Understanding	Possible Contexts
The number of radioactive nuclei in a sample of a given isotope decreases exponentially with time. Half-life is the time required for half of the radioactive nuclei in a sample to decay. Half-life of radioactive nuclei is independent of both the physical state and the chemical state of the material. The activity of a radioactive substance is the number of radioactive nuclei that decay per unit time. • Relate the activity of a sample to the number of radioactive nuclei present, and hence explain how it decreases exponentially with time. • Use data to estimate the half-life of radioactive nuclei. • Use data to estimate the activity or number of radioactive nuclei of a	Investigate radioactive dating using: https://phet.colorado.edu/en/simulation/radioactive-dating-game Refer to radiocarbon dating online interactive: http://www.pbs.org/wgbh/nova/tech/radiocarbon-dating.html
	Simulate radioactive decay using dice, or similar random events. Use a Geiger counter to detect radioactive emissions from different sources such as radioactive sources, bananas, concrete, bricks, and computers. Plot decay graphs and determine half-life.
	Explore the benefits and limitations of radioactive dating, including: - carbon dating to determine age

Science Understanding	Possible Contexts
sample at different times. • Estimate the age of a sample based on the relative activity or the relative amounts of radioactive nuclei or their decay products. The range of products of nuclear decay and their long half-lives mean that nuclear waste must be stored for long periods • Explain the requirements for the safe storage of nuclear waste.	of various artefacts and remains. - uranium to lead ratio to determine age of rocks, comets. Research the issues associated with storing radioactive waste generated by the nuclear power and medical industries.

6.4 Induced Nuclear Reactions

Students discuss the characteristics of induced nuclear fission reactions and apply them to the example of a nuclear fission reactor used for the generation of electrical power. The concept of mass-energy equivalence is used to explain the source of the energy produced in nuclear reactions.

Students also examine the fusion reactions in stars, and consider some advantages and disadvantages of fusion as a future source of power.

They explore nuclear reactions that are used to produce isotopes for scientific, medical, and industrial purposes. These isotopes can either be produced using neutrons from a nuclear reactor or using particle accelerators.

Science Understanding	Possible Contexts
Nuclear fission can be induced in some heavy nuclei by the capture of a neutron. The nucleus splits into two nuclei and several neutrons. The total mass of the reactants in a fission reaction is greater than that of the products, releasing energy given by $E = \Delta mc^2$, where Δm is the mass of the reactants minus the mass of the products. Given the relevant masses (in kg), calculate the energy released per fission reaction. On average, more than one neutron is emitted in nuclear fission. This leads to the possibility that these neutrons will induce further fissions, resulting in a chain reaction. • Relate the starting, normal operation, and stopping of a nuclear reactor to the nature of the chain reaction.	Demonstrate the chain reaction using a simulation. (www.phet.colorado.edu/en/simulation/nuclear-fission). Discuss how nuclear fission releases energy in the form of gamma rays and kinetic energy. Explain fission in terms of short-range nuclear-attractive forces and long-range electric-repulsive forces. Discuss how neutrons are slowed down as a result of collisions with a moderator. Explain why it is necessary to increase the fraction of ^{235}U in order to achieve a chain reaction because the fraction of ^{235}U in naturally occurring uranium is small. The process is called 'enrichment'.
The neutrons emitted as a result of nuclear fission have high speeds. ^{235}U undergoes fission with slow neutrons. Hence to induce fission in these nuclei the neutrons must be slowed down. Many neutrons are absorbed by surrounding nuclei, or escape and cause no further	Assess the economic, social, and environmental impacts of the Manhattan Project.. Investigate the way in which science informs public debate and is in turn influenced by public debate over the use of nuclear weapons. Analyse the economic and social

Science Understanding	Possible Contexts
fissions. • Explain why neutrons have to be slowed down in order to produce fission in ^{235}U . Enrichment increases the proportion of U235 in Uranium fuel • Describe how enrichment enables a chain reaction to proceed. • Use a diagram of a reactor to locate and discuss the function of the principal components of a water-moderated fission power reactor.	benefits and the consequences of enrichment of isotopes of uranium from the ore. Explore the innovations which use neutron beams from nuclear reactors to produce radioisotopes for use in medicine and industry.
Energy released during nuclear fission reactions can be harnessed for use in power generation. • Explain the use of nuclear fission in power production. • Describe some of the risks associated with the use of nuclear energy for power production.	Use a nuclear power plant simulator to gain an understanding of how the fission process is controlled. (https://esa21.kennesaw.edu/activities/nukeenergy/nuke.htm)
	Explore the beneficial or unexpected consequences of nuclear power and assess its monitoring, assessment, and risk. Explore public debate about nuclear power. Discuss some of the advantages and disadvantages of nuclear fission over fossil fuel power stations.
Nuclear fusion is the process in which two nuclei combine into a single nucleus. • Explain why high temperatures are needed for nuclear fusion to occur. The energy absorbed or released is given by $E = \Delta mc^2$, where Δm is the difference in mass between the reactants and the products. • Given the relevant masses (in kg), calculate the energy released per fusion reaction.	Discuss the role of gravity in generating conditions necessary for fusion to begin to occur and how the process is sustained within a star such as our sun.
	Compare the availability of fuel for fission and fusion reactions. Examine the reasons it is not currently possible to use fusion for electricity generation. Compare the processes needed to safely control a fission and fusion reaction. Research attempts by scientists to produce sustainable fusion and predict possible outcomes. Research the birth and life cycle of stars and the detection of gravitational waves created by colliding black holes and assess the available evidence. Identify the conditions in the interiors of the sun and other stars that allow nuclear fusion to take place, and hence how nuclear fusion is their main energy conversion process. Envisage the ways this may be harnessed. Discuss the advantages and disadvantages of nuclear fusion over

Science Understanding	Possible Contexts
	nuclear fission as a future source of power.

ASSESSMENT SCOPE AND REQUIREMENTS

At Stage 1, assessment is school-based.

EVIDENCE OF LEARNING

The following assessment types enable students to demonstrate their learning in Stage 1 Physics.

- Assessment Type 1: Investigations Folio
- Assessment Type 2: Skills and Applications Tasks

For a 10-credit subject, students provide evidence of their learning through four assessments. Each assessment type should have a weighting of at least 20%.

Students complete:

- at least one practical investigation
- one science as a human endeavour investigation
- at least one skills and applications task.

For a 20-credit subject, students provide evidence of their learning through eight assessments. Each assessment type should have a weighting of at least 20%.

Students complete:

- at least two practical investigations
- two science as a human endeavour investigations
- at least two skills and applications tasks.

ASSESSMENT DESIGN CRITERIA

The assessment design criteria are based on the learning requirements and are used by teachers to:

- clarify for the student what he or she needs to learn
- design opportunities for the student to provide evidence of his or her learning at the highest level of achievement.

The assessment design criteria are the specific features that:

- students should demonstrate in their learning
- teachers look for as evidence that students have met the learning requirements.

For this subject, the assessment design criteria are:

- investigation, analysis, and evaluation
- knowledge and application.

The specific features of these criteria are described below.

The set of assessments, as a whole give students opportunities to demonstrate each of the specific features by the completion of study of the subject.

Investigation, Analysis, and Evaluation

The specific features are as follows:

IAE1 Design of a physics investigation.

IAE2 Obtaining, recording, and representation of data, using appropriate conventions and formats.

IAE3 Analysis and interpretation of data and other evidence to formulate and justify conclusions.

IAE4 Evaluation of procedures and their effect on data.

Knowledge and Application

The specific features are as follows:

KA1 Demonstration of knowledge and understanding of physics concepts.

KA2 Development and application of physics concepts in new and familiar contexts.

KA3 Exploration and understanding of the interaction between science and society.

KA4 Communication of knowledge and understanding of physics concepts and information, using appropriate terms, conventions, and representations.

SCHOOL ASSESSMENT

Assessment Type 1: Investigations Folio

For a 10-credit subject, students undertake at least one practical investigation and one investigation with a focus on science as a human endeavour.

For a 20-credit subject, students undertake at least two practical investigations and two investigations with a focus on science as a human endeavour.

Students inquire into aspects of physics through practical discovery and data analysis, or by selecting, analysing, and interpreting information.

Practical Investigations

As students design and safely carry out investigations, they further develop their science inquiry skills by:

- deconstructing the parts of a problem to determine the most appropriate method for investigation
- formulating investigable questions and hypotheses
- selecting and using appropriate equipment, apparatus, and techniques
- identifying variables
- collecting, representing, analysing, and interpreting data
- evaluating procedures and considering their impact on results
- drawing conclusions
- communicating their knowledge and understanding of concepts.

Practical investigations are conducted both individually and collaboratively. For each investigation, students present an individual report. Students should be given the opportunity to investigate a question or hypothesis for which the outcome is uncertain.

A practical report should include:

- introduction with relevant physics concepts, a hypothesis and variables, or investigable question
- materials/apparatus, method/procedure outlining steps to be taken*
- identification and management of safety and/or ethical risks*
- results*
- analysis of results, identifying trends, and linking results to concepts
- evaluation of procedures and data, identifying sources of uncertainty
- conclusion.

The report should be a maximum of 1000 words, if written, or a maximum of 6 minutes for an oral presentation or the equivalent in multimodal form.

*The materials/apparatus, method/procedure outlining steps to be taken, identification and management of safety and/or ethical risks, and results sections are excluded from the word count.

Suggested formats for presentation of a practical investigation report include:

- a written report
- a multimodal product.

Science as a Human Endeavour Investigation

Students investigate a contemporary example of how science interacts with society. This may focus on one or more of the aspects of science as a human endeavour described on pages 13 and 14 and may draw on a context suggested in the topics or relate to a new context.

Students consider, for example:

- how humans seek to improve their understanding and explanation of the natural world
- how working scientifically is a way of obtaining knowledge that allows for testing scientific claims
- how scientific theory can change in the light of new evidence
- how technological advances change ways of working scientifically
- links between advances in science and their impact and influence on society
- how society influences scientific research
- physics in sport
- emerging physics-related careers and pathways
- 'blue sky' research leading to new technologies.

Students access information from different sources, select relevant information, analyse their findings, explain the connection to science as a human endeavour, and develop and explain their own conclusions from the investigation.

Possible starting points for the investigation could include, for example:

- the announcement of a discovery in the field of biological science
- an expert's point of view on a controversial innovation
- a TED talk based on a biological development
- an article from a scientific publication (e.g. Cosmos)
- public concern about an issue that has environmental, social, economic, or political implications.

The science as a human endeavour investigation should be a maximum of 1000 words if written or a maximum of 6 minutes for an oral presentation, or the equivalent in multimodal form.

For this assessment type, students provide evidence of their learning in relation to the following assessment design criteria:

- investigation, analysis, and evaluation
- knowledge and application.

Assessment Type 2: Skills and Applications Tasks

For a 10-credit subject, students undertake at least one skills and applications task.

Students may undertake more than one skills and applications task, but least one should be under the direct supervision of the teacher. The supervised setting (e.g. classroom, laboratory, or field) should be appropriate to the task.

For a 20-credit subject, students undertake at least two skills and applications tasks. Students may undertake more than two skills and applications tasks, but least two should be under the direct supervision of the teacher. The supervised setting (e.g. classroom, laboratory, or field) should be appropriate to the task.

Skills and applications tasks allow students to provide evidence of their learning in tasks that may:

- be applied, analytical, and/or interpretative
- pose problems in new and familiar contexts
- involve individual or collaborative assessments, depending on task design.

A skills and applications task may require students to, for example: solve problems; design an investigation to test a hypothesis or investigable question; consider different scenarios in which to apply their knowledge and understanding; graph, tabulate, and/or analyse data; evaluate procedures and identify their limitations; formulate and justify conclusions; represent information diagrammatically or graphically; use physics terms, conventions, and notations.

Skills and applications tasks should be designed to enable students to apply their science inquiry skills, demonstrate knowledge and understanding of key physics concepts and learning, and explain connections with science as a human endeavour. Problems and scenarios should be set in a relevant context, which may be practical, social, or environmental.

Skills and applications tasks may include, for example:

- modelling or representing concepts
- developing simulations
- practical skills
- graphical skills
- a multimodal product
- an oral presentation
- participation in a debate
- an extended response
- responses to short-answer questions
- a structured interview
- an excursion report
- a response to science in the media.

For this assessment type, students provide evidence of their learning in relation to the following assessment design criteria:

- investigation, analysis, and evaluation
- knowledge and application.

PERFORMANCE STANDARDS

The performance standards describe five levels of achievement, A to E.

Each level of achievement describes the knowledge, skills and understanding that teachers refer to in deciding how well a student has demonstrated his or her learning on the basis of the evidence provided.

During the teaching and learning program the teacher gives students feedback on their learning, with reference to the performance standards.

At the student's completion of study of a subject, the teacher makes a decision about the quality of the student's learning by:

- referring to the performance standards
- taking into account the weighting of each assessment type
- assigning a subject grade between A and E.

Performance Standards for Stage 1 Physics

	Investigation, Analysis, and Evaluation	Knowledge and Application
A	Designs a logical, coherent, and detailed, physics investigation. Obtains, records, and represents data, using appropriate conventions and formats accurately and highly effectively. Systematically analyses and interprets data and evidence to formulate logical conclusions with detailed justification. Critically and logically evaluates procedures and their effects on data.	Demonstrates deep and broad knowledge and understanding of a range of physics concepts. Develops and applies physics concepts highly effectively in new and familiar contexts. Critically explores and understands in depth the interaction between science and society. Communicates knowledge and understanding of physics coherently with highly effective use of appropriate terms, conventions, and representations.
B	Designs a well-considered and clear physics investigation. Obtains, records, and displays findings of investigations, using appropriate conventions and formats mostly accurately and effectively. Logically analyses and interprets data and evidence to formulate suitable conclusions with reasonable justification. Logically evaluates procedures and their effects on data.	Demonstrates some depth and breadth of knowledge and understanding of a range of physics concepts. Develops and applies physics concepts mostly effectively in new and familiar contexts. Logically explores and understands in some depth the interaction between science and society. Communicates knowledge and understanding of physics mostly coherently with effective use of appropriate terms, conventions, and representations.
C	Designs a considered and generally clear physics investigation. Obtains, records, and displays findings of investigations, using generally appropriate conventions and formats with some errors but generally accurately and effectively. Undertakes some analysis and interpretation of data and evidence to formulate generally appropriate conclusions with some justification. Evaluates procedures and some of their effects on data.	Demonstrates knowledge and understanding of a general range of physics concepts. Develops and applies physics concepts generally effectively in new or familiar contexts. Explores and understands aspects of the interaction between science and society. Communicates knowledge and understanding of physics generally effectively, using some appropriate terms, conventions, and representations.
D	Prepares the outline of a physics investigation. Obtains, records, and displays findings of investigations, using conventions and formats inconsistently, with occasional accuracy and effectiveness. Describes data and undertakes some basic interpretation to formulate a basic conclusion. Attempts to evaluate procedures or suggest an effect on data.	Demonstrates some basic knowledge and partial understanding of physics concepts. Develops and applies some physics concepts in familiar contexts. Partially explores and recognises aspects of the interaction between science and society. Communicates basic physics information, using some appropriate terms, conventions, and/or representations.
E	Identifies a simple procedure for a physics investigation. Attempts to record and display some descriptive results of an investigation, with limited accuracy or effectiveness. Attempts to describe results and/or interpret data to formulate a basic conclusion. Acknowledges that procedures affect data.	Demonstrates limited recognition and awareness of physics concepts. Attempts to develop and apply physics concepts in familiar contexts. Attempts to explore and identify an aspect of the interaction between science and society. Attempts to communicate information about physics.

ASSESSMENT INTEGRITY

The SACE Assuring Assessment Integrity Policy outlines the principles and processes that teachers and assessors follow to assure the integrity of student assessments. This policy is available on the SACE website (wwww.sace.sa.edu.au) as part of the SACE Policy Framework.

The SACE Board uses a range of quality assurance processes so that the grades awarded for student achievement in the school assessment are applied consistently and fairly against the performance standards for a subject, and are comparable across all schools.

Information and guidelines on quality assurance in assessment at Stage 1 are available on the SACE website (www.sace.sa.edu.au).

SUPPORT MATERIALS

SUBJECT-SPECIFIC ADVICE

Online support materials are provided for each subject and updated regularly on the ACE website (www.sace.sa.gov.au) Examples of support materials are sample learning and assessment plans, annotated assessment tasks, annotated student responses, and recommended resource materials.

ADVICE ON ETHICAL STUDY AND RESEARCH

Advice for students and teachers on ethical study and research practices is available in the guidelines on the ethical conduct of research in the SACE on the SACE website. (www.sace.sa.edu.au).

Stage 2 Physics

LEARNING SCOPE AND REQUIREMENTS

LEARNING REQUIREMENTS

The learning requirements summarise the knowledge, skills, and understanding that students are expected to develop and demonstrate through their learning in Stage 2 Physics.

In this subject, students are expected to:

1. apply science inquiry skills to design and conduct physics investigations, using appropriate procedures and safe, ethical working practices
2. obtain, record, represent, and analyse, and interpret the results of physics investigations
3. evaluate procedures and results, and analyse evidence to formulate and justify conclusions
4. develop and apply knowledge and understanding of physics concepts in new and familiar contexts
5. explore and understand science as a human endeavour
6. communicate knowledge and understanding of physics concepts, using appropriate terms, conventions, and representations.

CONTENT

Stage 2 Physics is a 20-credit subject.

Integration of science inquiry skills, science as a human endeavour, and science understanding

The three strands of science inquiry skills, science as a human endeavour, and science understanding are integrated throughout student learning in this subject.

The topics in Stage 2 Physics provide the framework for developing integrated programs of learning through which students extend their skills, knowledge, and understanding of these three strands of science.

The topics are structured in two columns: science understanding, and possible contexts. The contexts are suggestions for possible inquiry approaches, and are neither comprehensive nor exclusive. Teachers may select from these and are encouraged to consider other inquiry approaches according to local needs and interests.

Programming

The following topics provide the framework for learning in Stage 2 Physics:

- Topic 1: Motion and Relativity
- Topic 2: Electricity and Magnetism
- Topic 3: Light and Atoms

Students study all three topics. The topics can be sequenced and structured to suit individual cohorts of students.

The left-hand column in the *Science Inquiry Skills*, the *Science Understanding* in the topics, and *Science as a Human Endeavour*, form the basis of teaching, learning, and assessment in this subject.

The following symbols in the *Possible Contexts* are used in the right-hand column:

 indicates a possible teaching and learning strategy for science understanding

 indicates a possible science inquiry activity

indicates a possible focus on science as a human endeavour.

In addition, throughout the topics there are recurring themes that draw on some of the big ideas in physics and their applications. As different concepts are being explored, students develop new and different understanding by discussing these big ideas and their applications from fresh perspectives.

The selected big ideas in physics are denoted as follows:

Innovations in Physics

Models and Representations in Physics (including waves, fields)

Interactions and Conservation

Properties of matter

Science Inquiry Skills

In Physics investigation is an integral part of the learning and understanding of concepts, by using scientific methods to test ideas and develop new knowledge.

Practical investigations must involve a range of both individual and collaborative activities, during which students extend the science inquiry skills described in the table that follows.

Practical activities may take a range of forms, such as developing models and simulations that enable students to develop a better understanding of particular concepts. They include laboratory and field studies, during which students develop investigable questions and/or testable hypotheses, and select and use equipment appropriately to collect data. The data may be observations, measurements, or other information obtained during the investigation. Students display and analyse the data they have collected, evaluate procedures, and describe their limitations, consider explanations for their observations, and present and justify conclusions appropriate to the initial question or hypothesis.

It is recommended that a minimum of 16–20 hours of class time would involve practical activities.

Science inquiry skills are also fundamental to students investigating the social, ethical, and environmental impacts and influences of the development of scientific understanding and the applications, possibilities, and limitations of science. These skills enable students to critically consider the evidence they obtain, so that they can present and justify a conclusion.

The left-hand column in the *Science Inquiry Skills*, along with the *Science Understanding* in the topics and *Science as a Human Endeavour*, form the basis of teaching, learning, and assessment in this subject. They are supported by ideas for possible contexts, in the right-hand column.

Science Inquiry Skills	Possible Contexts
Scientific methods enable systematic investigation to obtain measureable evidence. • Deconstruct the parts of a problem to determine the most appropriate method	Develop inquiry skills by, for example: - designing investigations that require investigable questions and imaginative solutions (with

Science Inquiry Skills	Possible Contexts
for investigation. • Design investigations, including: – hypothesis or inquiry question – types of variables ➢ dependent ➢ independent ➢ factors held constant (how and why they are controlled) ➢ factors that may not be able to be controlled (and why not) – materials required – the procedure to be followed – the type and amount of data to be collected – identification of ethical and safety considerations.	or without implementation) - critiquing proposed investigations - using the conclusion of one investigation to propose subsequent experiments - changing an independent variable in a given procedure and adapting the method - researching, developing, and trialling a method - improving an existing procedure - identifying options for measuring the dependent variable - researching hazards related to the use and disposal of physics materials - developing safety audits - identifying relevant ethical and/or legal considerations in different contexts.
Obtaining meaningful data depends on conducting investigations using appropriate procedures and safe, ethical working practices. • Conduct investigations, including: – selection and safe use of appropriate materials, apparatus, and equipment – collection of appropriate primary or secondary data (numerical, visual, descriptive) – individual and collaborative work.	Develop inquiry skills by, for example: - identifying equipment, materials, or instruments fit for purpose - practising techniques and safe use of apparatus - comparing resolution of different measuring tools - distinguishing between and using primary and secondary data.
The results of investigations are presented in a well-organised way to allow them to be interpreted. • Present results of investigations in appropriate ways, including – use of appropriate SI units, symbols – construction of appropriately labelled tables – drawing of graphs, linear, non-linear, lines of best fit as appropriate – use of significant figures.	Develop inquiry skills by, for example: - practising constructing tables to tabulate data with column and row labels with units - identifying the appropriate representations to graph different data sets - selecting axes and scales, and graphing data - clarifying understanding of significant figures using, for example: http://www.astro.yale.edu/astro120/SigFig.pdf https://www.hccfl.edu/media/43516/sigfigs.pdf https://www.physics.uoguelph.ca/tutorials/sig_fig/SIG_dig.htm - comparing data from different sources to describe as

Science Inquiry Skills	Possible Contexts
	quantitative, qualitative.
Scientific information can be presented using different types of symbols and representations. • Select, use, and interpret appropriate representations, including: – mathematical [algebraic] relationships – diagrams and multi-image representations – formulae. to explain concepts, solve problems and make predictions.	Develop inquiry skills by, for example: - writing formulae - using formulae; deriving and rearranging formulae - constructing vector diagrams - drawing and labelling diagrams - sketching field diagrams - recording images - constructing flow diagrams.
The analysis of the results of investigations allows them to be interpreted in a meaningful way. • Analyse data, including: – multi-image representations – identification and discussion of trends, patterns, and relationships – interpolation/extrapolation through the axes where appropriate – selection and use of evidence and scientific understanding to make and justify conclusions.	Develop inquiry skills by, for example: - analysing data sets to identify trends and patterns - determining relationships between independent and dependent variables, including mathematical relationships, e.g. slope, linear, inverse relationships where relevant. - discussing inverse and direct proportionality - using graphs from different sources, e.g. CSIRO or ABS, to predict values other than plotted points - calculating means, standard deviations, percent error, where appropriate.
Critical evaluation of procedures and outcomes can determine the meaningfulness of conclusions. • Evaluate the procedures and results to identify sources of uncertainty, including: – random and systematic errors – replication – sample size – accuracy – precision – validity – reliability – effective control of variables. • Discuss the impact that sources of uncertainty have on experimental results. • Recognise the limitations of conclusions.	Develop inquiry skills by, for example: - evaluating procedures and data sets provided by the teacher to determine and hence comment on the limitations of possible conclusions - using an example of an investigation report to develop report-writing skills.. Useful websites: http://www.nuffieldfoundation.org/practical-physics/designing-and-evaluating-experiments http://physics.appstate.edu/undergraduateprograms/laboratory/resources/error-analysis http://www.physics.gatech.edu/~em92/Lab/physlab/admin1/labpractice.html
Effective scientific communication is clear and concise. • Communicate to specific audiences and for specific purposes using: – appropriate language	Develop inquiry skills by, for example: - reviewing scientific articles or presentations to recognise conventions - developing skills in referencing

Science Inquiry Skills	Possible Contexts
− terminology − conventions.	and/or footnoting - distinguishing between reference lists and bibliographies - opportunities to practise scientific communication in written, oral, and multimedia formats, e.g. presenting a podcast or writing a blog.

Science as a Human Endeavour

The *Science as a Human Endeavour* strand highlights science as a way of knowing and doing, and explores the use and influence of science in society.

By exploring science as a human endeavour, students develop and apply their understanding of the complex ways in which science interacts with society, and investigate the dynamic nature of physics. They explore how physicists develop new understanding and insights, and produce innovative solutions to everyday and complex problems and challenges in local, national, and global contexts. In this way, students are encouraged to think scientifically and make connections between the work of others and their own learning. This enables them to explore their own solutions to current and future problems and challenges.

Students understand that the development of science concepts, models, and theories is a dynamic process that involves analysis of evidence and sometimes produces ambiguity and uncertainty. They consider how and why science concepts, models, and theories are continually reviewed and reassessed as new evidence is obtained and as emerging technologies enable new avenues of investigation. They understand that scientific advancement involves a diverse range of individual scientists and teams of scientists working within an increasingly global community of practice.

Students explore how scientific progress and discoveries are influenced and shaped by a wide range of social, economic, ethical, and cultural factors. They investigate ways in which the application of science may provide great benefits to individuals, the community, and the environment, but may also pose risks and have unexpected outcomes. They understand how, decision-making about socio-scientific issues often involves consideration of multiple lines of evidence and a range of needs and values. As critical thinkers, they appreciate science as an ever-evolving body of knowledge that frequently informs public debate, but is not always able to provide definitive answers.

Science as a Human Endeavour underpins the contexts, approaches, and activities in this subject, and must be integrated into all teaching and learning programs.

Science as a Human Endeavour in the study of physics encompasses:

1. Communication and Collaboration

- Science is a global enterprise that relies on clear communication, international conventions, and review and verification of results.
- International collaboration is often required in scientific investigation.

2. Development

- Development of complex scientific models and/or theories often requires a wide range of evidence from many sources and across disciplines.
- New technologies improve the efficiency of scientific procedures and data collection and analysis. This can reveal new evidence that may modify or replace models, theories, and processes.

3. Influence

- Advances in scientific understanding in one field can influence and be influenced by other areas of science, technology, engineering, and mathematics.
- The acceptance and use of scientific knowledge can be influenced by social, economic, cultural, and ethical considerations.

4. Application and Limitation

- Scientific knowledge, understanding, and inquiry can enable scientists to develop solutions, make discoveries, design action for sustainability, evaluate economic, social, and environmental impacts, offer valid explanations, and make reliable predictions.
- The use of scientific knowledge may have beneficial or unexpected consequences; this requires monitoring, assessment, and evaluation of risk, and provides opportunities for innovation.
- Science informs public debate and is in turn influenced by public debate; at times, there may be complex, unanticipated variables or insufficient data that may limit possible conclusions.

Topic 1: Motion and Relativity

This topic builds upon the concepts of forces and energy developed in Stage 1 Physics. There is a particular focus on the relationships between force and acceleration in different contexts. Students investigate the effect of the acceleration due to gravity on the motion of projectiles using the vector nature of gravitational force. They describe, explain, and interpret projectile motion using qualitative and quantitative methods. Newton's Laws of Motion are used to introduce the vector nature of momentum. This enhances their numeracy capability.

The conservation of momentum is used to identify subatomic particles – particles that support the Standard Model covered in Stage 2, Topic 3: Light and Atoms. Centripetal acceleration is introduced and Newton's Law of Universal Gravitation is used to explain the nature of the acceleration due to gravity and extend the concept of centripetal acceleration to contemporary applications such as satellites. Centripetal acceleration also has strong connections to the motion of particles in cyclotrons covered in Stage 2,Topic 2: Electricity and Magnetism. Newton's Law of Universal Gravitation is also used to explain Kepler's Laws of Planetary Motion: the laws that govern the motion of satellites, comets, planets and star systems.

The fundamental concepts of classical physics serve as an entry point to modern physics, in particular, the Theory of Special Relativity, formulated by Einstein. Students investigate the relationship between matter and energy at high speeds, and explore the experiments, both from Einstein's time and more recently, that confirm the postulates of special relativity.

Subtopic 1.1: Projectile Motion

Students are introduced to the theories and quantitative methods used to describe, determine, and explain projectile motion both in the absence of air resistance and in media with resistive forces.

Students study projectile motion through a range of investigations to understand how the principles are applied in the contexts of sports, vehicle designs, and terminal speed.

Science Understanding	Possible Contexts
Uniformly accelerated motion is described in terms of relationships between measurable scalar and vector quantities, including displacement, speed, velocity, and acceleration. Motion under constant acceleration can be described quantitatively using the following equations: - $v = v_0 + at$ - $s = v_0 t + \frac{1}{2}at^2$ - $v^2 = v_0^2 + 2as$.	*Explanation of the difference between scalar and vector quantities and methods of measurement of these quantities is covered in Stage 1, Topic 1: Linear Motion and Forces.* *This uses the concept of acceleration developed in Stage 1, Subtopic 1.1: Motion under Constant Acceleration.* Use trigonometric calculations and scale diagram to determine quantities, using vector addition and subtraction. Given a diagram showing the path of a projectile, draw vectors to show the forces acting on the projectile, as well as the acceleration and velocity vectors.
Projectile motion can be analysed quantitatively by treating the horizontal and vertical components of the motion independently. • Construct, identify, and label displacement, velocity, and acceleration vectors. • Use vector addition and subtraction	Use a projectile launcher to investigate the effect of launch angle or launch height on range.

Science Understanding	Possible Contexts
to calculate net vector quantities. • Resolve velocity into vertical and horizontal components. • Determine the velocity at any point, using trigonometric calculations or a scale diagram.	
An object experiences a constant gravitational force near the surface of the Earth, which causes it to undergo uniform acceleration. • Explain that the acceleration of a projectile is always downwards and independent of its mass. • Explain that in the absence of air resistance, the horizontal component of the velocity is constant. The equations of motion are used to calculate measurable quantities for objects undergoing projectile motion. • Calculate the time of flight and maximum height of a projectile. • Calculate the horizontal range of a projectile. • Explain qualitatively that the maximum range occurs at 45° for projectiles that land at the same height from which they were launched. • Describe the relationship between launch angles that result in the same range. • Describe and explain the effect of launch height, speed, and angle on the time of flight and the maximum range of a projectile. • Analyse multi-image representations of projectile paths.	Demonstrate the independence of acceleration due to gravity on mass using NASA footage of dropping a hammer and feather on the Moon. https://www.youtube.com/watch?v=5C5_dOEyAfk Investigate the 'monkey and the hunter' problem both quantitatively and qualitatively. Use video footage to analyse projectile motion in a variety of contexts. Analyse the constant horizontal component of the velocity qualitatively and quantitatively, using various recording technologies. Model and demonstrate that the maximum range occurs at an angle other than 45° when the launch height is different to the landing height. In terms of projectile motion, analyse footage of students undertaking a sport like shot-put. Use concepts from projectile motion to analyse sporting activities such as aerial jump skiing, golf, javelin, shot-put, and various ball sports.
When a body moves through a medium such as air, the body experiences a drag force that opposes the motion of the body. • Explain the effects of speed, cross-sectional area, and density of the medium on the drag force on a moving body. • Explain that terminal velocity occurs when the magnitude of the drag force results in zero net force on the moving body. • Describe situations such as skydiving and the maximum speed	Determine the terminal velocity of a spherical object by dropping it into a viscous liquid. Determine the drag coefficients by dropping coffee filters or cupcake holders. By manipulating the mass and recording the time taken to reach the ground, use the air resistance formula to calculate the drag coefficient. Discuss the conclusions of experiments comparing swimming in syrup with swimming in water: http://www.nature.com/news/2004/040920/full/news040920-2.html.

Science Understanding	Possible Contexts
of racing cars where terminal velocity is achieved. • Describe and explain the effects of air resistance on the vertical and horizontal components of the velocity, maximum height, and range of a projectile. • Describe and explain the effects of air resistance on the time for a projectile to reach the maximum height or to fall from the maximum height.	Explore examples of the way that scientists have been able to develop solutions affecting aerodynamics (such as shape, texture, and spin) of different objects like balls, planes, cars.

Subtopic 1.2: Forces and Momentum

Students learn to use force and acceleration vectors to discuss Newton's Laws of Motion and are introduced to the vector nature of momentum. They explain the law of the conservation of momentum in terms of Newton's Laws and develop skills in vector addition and subtraction within this context.

Science Understanding	Possible Contexts
Momentum is a property of moving objects; it is conserved in an isolated system and may be transferred from one object to another when a force acts over a time interval. Newton's Second Law of Motion can be expressed as two vector relations, $\vec{F} = m\vec{a}$ and $\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$, where $\vec{p} = m\vec{v}$ is the momentum of the object. • Derive $\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$ by substituting the defining formula for acceleration $(\vec{a} = \frac{\Delta\vec{v}}{\Delta t})$ into Newton's second law of motion $\vec{F} = m\vec{a}$ for particles of fixed mass. (The net force $\vec{F}$ and hence the acceleration $\vec{a}$ are assumed to be constant. Otherwise, average or instantaneous quantities apply.) • Draw vector diagrams in which the initial momentum is subtracted from the final momentum, giving the change in momentum $\Delta\vec{p}$. • Solve problems (in both one dimension and in two dimensions)	*Many of these ideas have been introduced in Stage 1 through one-dimensional situations. The focus here should be on two-dimensional situations.* Consider the development of the discovery of neutrinos. *This uses the concepts of acceleration and force developed in the Stage 1, Subtopics 1.1: Motion under Constant Acceleration and 1.2 Forces and Momentum.*
	Use the conservation of momentum to determine the speed of a projectile by firing it into a trolley.
	Investigate how the use of the law of conservation of momentum was used to predict the existence of neutrinos. Explore perspectives in the public debate about economics of space exploration. Is government funding likely to be maintained? Research the most appropriate types of spacecraft propulsion for journeys to different destinations,

Science Understanding	Possible Contexts
using the formulae $\vec{F} = m\vec{a}$, $\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$ and $\vec{p} = m\vec{v}$. Newton's Third Law of Motion, $\vec{F}_1 = -\vec{F}_2$ in conjunction with the Second Law expressed in terms of momentum, implies that the total momentum of a system of two interacting particles, subject only to the force of each one on the other, is conserved. • Derive an formula expressing the conservation of momentum for two interacting particles by substituting $\vec{F}_1 = \frac{\Delta\vec{p}_1}{\Delta t}$ and $\vec{F}_2 = \frac{\Delta\vec{p}_2}{\Delta t}$ into $\vec{F}_1 = -\vec{F}_2$. • Use the law of the conservation of momentum to solve problems in one and two dimensions. • Analyse multi-image representations to solve conservation of momentum problems, using only situations in which the mass of one object is an integral multiple of the mass of the other object(s). The scale of the representations and the flash rate can be ignored. The conservation of momentum can be used to explain the propulsion of spacecraft, ion thrusters, and solar sails. • Use the conservation of momentum to describe and explain the change in momentum and acceleration of spacecraft due to the emission of gas particles or ionised particles. • Use the conservation of momentum to describe and explain how the reflection of particles of light (photons) can be used to accelerate a solar sail. • Use vector diagrams to compare the acceleration of a spacecraft, using a solar sail where photons are reflected with the acceleration of a spacecraft, using a solar sail where photons are absorbed.	considering technical challenges and speculative technologies.

Subtopic 1.3: Circular Motion and Gravitation

Students investigate the circular motion that results from centripetal acceleration in a variety of contexts, including satellites and banked curves. Students are introduced to the concepts of Newton’s Law of Universal Gravitation and Kepler’s Laws of Planetary Motion.

They explore extra-terrestrial phenomena that can be explained using Newton’s Law of Universal Gravitation and Kepler’s Laws of Planetary Motion.

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr>
<td rowspan="3">An object moving in a circular path at a constant speed undergoes uniform circular motion. This object undergoes centripetal acceleration, which is directed towards the centre of the circle.
The magnitude of the centripetal acceleration is constant for a given speed and radius and given by $a=\frac{v^2}{r}$.
The relationship $v=\frac{2\pi r}{T}$ relates the speed, v, to the period, T, for a fixed radius.
• Solve problems involving the use of the formulae $a=\frac{v^2}{r}$ and $v=\frac{2\pi r}{T}$ and $\vec{F}=m\vec{a}$.
• Use vector subtraction to show that the change in the velocity $\Delta\vec{v}$, and hence the acceleration, of an object over a very small time interval is directed towards the centre of the circular path.
On a flat curve, the friction force between the tyres and the road causes the centripetal acceleration. To improve safety, some roads are banked at an angle above the horizontal.
• Draw a diagram showing the force vectors (and their components) for a vehicle travelling around a banked curve.
• Explain how a banked curve reduces the reliance on friction to provide centripetal acceleration.</td>
<td>This uses the concepts of acceleration and force developed in the Stage 1, Subtopics 1.1: Motion under Constant Acceleration and 1.2 Forces.
Describe situations in which the centripetal acceleration is caused by a tension force, a frictional force, a gravitational force, or a normal force.</td>
</tr>
<tr><td>Investigate the force causing centripetal acceleration, using a tube, stopper, washers, and connecting string.
Find and test the speed required for a marble to ‘loop the loop’, using flexible railing or a slot car set.</td></tr>
<tr><td>Explore the benefits and limitations in the design and use of banked curves, such as velodromes, motor racing circuits, amusement park rides, and high-speed train tracks.</td></tr>
<tr>
<td>Objects with mass produce a gravitational field in the space that surrounds them.
An object with mass experiences a gravitational force when it is within the gravitational field of another mass.
Gravitational field strength g is defined as</td>
<td>Use Newton’s Law of Universal Gravitation to determine variations in acceleration due to gravity at different points on the surface of the Earth. For example, compare the gravitational acceleration at sea level to the top of Mt Everest.
Use Newton’s Law of Universal Gravitation to find the point between the</td>
</tr>
</table>

Science Understanding	Possible Contexts
the net force per unit mass at a particular point in the field. This definition is expressed quantitatively as $g = \frac{F}{m}$, hence it is equal to the acceleration due to gravity. All objects with mass attract one another with a gravitational force; the magnitude of this force can be calculated using Newton's law of universal gravitation. • Use Newton's Law of Universal Gravitation and Second Law of Motion to calculate the value of the acceleration due to gravity g on a planet or moon. Every particle in the universe attracts every other particle with a force that is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them. The force between two masses, m_1 and m_2, separated by distance, r, is given by: $F = G\frac{m_1 m_2}{r^2}$ • Solve problems using Newton's Universal Law of Gravitation. • Use proportionality to discuss changes in the magnitude of the gravitational force on each of the masses as a result of a change in one or both of the masses and/or a change in the distance between them. • Explain that the gravitational forces are consistent with Newton's Third Law.	Earth and the moon where the net gravitational force is zero. Explore how scientists use the gravitational force to indirectly detect the existence of stars, planets, moons, black holes, and other celestial bodies, and predict the existence of dark matter. Explore the collaborative science that lead to the detection of gravitational waves. (e.g. [http://www.ligo.org-/science/GW-Sources.php](http://www.ligo.org/science/GW-Sources.php))
Many satellites orbit the Earth in circular orbits. • Explain why the centres of the circular orbits of Earth satellites must coincide with the centre of the Earth. • Explain that the speed, and hence the period, of a satellite moving in a circular orbit depends only on the radius of the orbit and the mass of the central body (m_2) about which the satellite is orbiting and not on the mass of the satellite.	Use Kepler's Laws to explain the motion of comets and predict times when they may be seen. Use data giving the orbital radii and periods of Saturn's (or other planets') natural satellites to determine the mass of Saturn. Use similar techniques to determine the mass of the sun. Explore the geometric definition of an ellipse and its relation to planetary and satellite motion. Investigate the eccentricities of planets within the solar system to explore how Kepler's Laws may be modelled as uniform circular motion.

Science Understanding	Possible Contexts
- Derive the formula $v=\sqrt{\frac{GM}{r}}$ for the speed, v, of a satellite moving in a circular orbit of radius, r, about a spherically symmetric mass M, given that its gravitational effects are the same as if all its mass were located at its centre. Kepler's Laws of Planetary Motion describe the motion of planets, their moons, and other satellites. Kepler's First Law of planetary motion: All planets move in elliptical orbits with the Sun at one focus. Kepler's Second Law of Planetary Motion: The radius vector drawn from the sun to a planet sweeps equal areas in equal time intervals. - Describe Kepler's first two Laws of Planetary Motion. - Use these first two Laws to describe and explain the motion of comets, planets, moons, and other satellites. Kepler's Third Law of Planetary Motion shows that the period of any satellite depends upon the radius of its orbit. For circular orbits Kepler's Third Law can be expressed as: $T^2=\frac{4\pi^2}{GM}r^3$. - Derive: $T^2=\frac{4\pi^2}{GM}r^3$. - Solve problems using the mathematical form of Kepler's Third Law for circular orbits. - Solve problems involving the use of the formulae $v=\sqrt{\frac{GM}{r}}$, $v=\frac{2\pi r}{T}$ and $T^2=\frac{4\pi^2}{GM}r^3$. - Explain why a satellite in a geostationary orbit must have an orbit in the Earth's equatorial plane, with a relatively large radius and in the same direction as the Earth's rotation. - Explain the differences between polar, geostationary, and equatorial orbits. Justify the use of each orbit for different applications. - Perform calculations involving orbital periods, radii, altitudes above the	Track satellites in real time at http://www.n2yo.com/?s=00050 Analyse how the models for the motion of planets, stars, and other bodies were modified in the light of new evidence. Research the benefits, limitations, and/or unexpected consequences of the uses of satellites. Examples include: the Hubble Space Telescope, the International Space Station, GPS satellites, and decommissioned satellites. Use Kepler's Laws to analyse the orbits of recently discovered exoplanets with highly elliptical orbits, such as HD 80606 b and HD 20782. Consider how the effect of these orbits on the composition and temperature changes on these exoplanets can also be investigated. Useful website: http://news.mit.edu/2016/highly-eccentric-extreme-weather-exoplanet-0328 http://www.sci-news.com/astronomy/hd20782b-exoplanet-highly-eccentric-orbit-03718.html Investigate how Kepler's Laws can be used to estimate the mass of black holes, including Sagittarius A* - the black hole hypothesised to exist within the Milky Way Galaxy. Useful website: http://curious.astro.cornell.edu/about-us/95-the-universe/galaxies/general-questions/512-do-stars-orbits-in-galaxies-obey-kepler-s-laws-intermediate http://io9.gizmodo.com/the-video-that-revealed-the-black-hole-at-the-center-of-1114918644

Science Understanding	Possible Contexts
surface, and speeds of satellites, including examples that involve the orbits of geostationary satellites.	

Subtopic 1.4: Einstein’s Relativity

Students explore how Einstein’s Special Theory of Relativity can be used to explain the behaviour of objects at high speeds. The theory is based on two postulates: the postulate of the constancy of the speed of the light and the postulate that there is no preferred frame of reference. Students describe, predict, and calculate some of the counter-intuitive consequences of the theory as well as explore some of the experiments that support the theory.

Science Understanding	Possible Contexts
Motion can only be measured relative to an observer; length and time are relative quantities that depend on the observer’s frame of reference. Observations of objects travelling at very high speeds cannot be explained by Newtonian physics. Einstein’s Special Theory of Relativity predicts significantly different results to those of Newtonian physics for velocities approaching the speed of light. The Special Theory of Relativity is based on two postulates: – that the speed of light in a vacuum is an absolute constant – that the laws of physics are the same in all inertial reference frames. In relativistic mechanics, there is no absolute length or time interval. Two events that appear simultaneous for a stationary observer may not be for an observer in motion. Time in a moving reference frame is dilated according to $t=\gamma t_0$, where $\gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$, is the Lorentz factor. • Solve problems using $t=\gamma t_0$ and Lorentz factor formula. • Explain the effects of time dilation on objects moving at relativistic speeds. Some subatomic particles exist in the	Investigate different frames of reference, for example: – the motion of a ball being thrown vertically inside a moving train from the perspective of a stationary person on the train can be compared to an observer standing on the ground. – the motion of a projectile moving with the same horizontal speed as a moving vehicle (relative to the ground) can be compared using perspectives from the ground and the moving vehicle. Use graphical representations of the motion of Mars to demonstrate and explain its retrograde motion to show different frames of reference. Use the expression for relativistic momentum to explain why it is impossible for an object to travel faster than light. https://www.youtube.com/watch?v=wteiuxyqtoM Explore the time dilation effects that have been measured experimentally with atomic cesium clocks. Use the twin paradox to describe time dilation and the implications for long-distance space travel. Discuss the difficulties surrounding providing experimental evidence of length contraction. There is an indirect way to measure the relativistic effects of length contraction in relation to magnetism: https://www.youtube.com/watch?v=1TKS

Science Understanding	Possible Contexts
laboratory for very short time periods before decaying. These same particles are detected as part of cosmic ray showers in the atmosphere, travelling at relativistic speeds close to the speed of light. Time dilation effects allow these particles to travel significant distances without decay. Given the laboratory lifetime of a subatomic particle and its relativistic speed: • calculate time dilation factors. • using calculations, compare the distance travelled by subatomic particles when incorporating relativistic effect.	fAkWWN0 The book *Mr Tomkins in Wonderland* by George Gamow provides an accessible qualitative description of special relativity if it were experienced at low speeds. Investigate how relativistic effects are taken into consideration in GPS systems. http://www.brighthub.com/science/space/articles/32969.aspx#disqus_thread http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit5/gps.html
An object moving at relativistic speeds always appears shorter to an observer in a different frame of reference, and the length is given by: $l = \frac{l_0}{\gamma}$, where l_0 is the length in the observer's frame of reference. • Solve problems using $l = \frac{l_0}{\gamma}$ • Explain the effects of length contraction on objects moving at relativistic speeds. Mass in a moving reference frame is increased according to: $m = \gamma m_o$, where m_o is the mass in the observer's frame of reference. • Solve problems using $m = \gamma m_o$, and $p = mv$ • Explain the effects of increasing mass on objects moving at relativistic speeds.	Explore how new evidence led scientists to modify models to account for high speed particles which exhibited properties that were inconsistent with Newtonian physics. In what way has the evidence from different sources such as X-rays from binary star systems and other experiments on moving gamma radiation sources supported Einstein's second postulate of relativity?

Topic 2: Electricity and Magnetism

This topic builds on the concepts of circuit electricity developed in Stage 1, Topic 2: Electric Circuits and projectile and circular motion developed in Stage 2, Topic 1: Motion and Relativity. It introduces students to the use of the concept of fields in physics. The conventions adopted to represent fields pictorially show the magnitude and direction of the relevant field vectors at points within the field. Students discuss forces between stationary charges and analyse the motion of charged particles in uniform electric fields is analysed quantitatively, in one and two dimensions. They make comparisons with projectile motion, as described in Stage 2, Topic 1: Motion and Relativity.

Students examine moving charges, first in electric currents and then in a vacuum. A magnetic field is shown to exist in each case. This magnetic field can exert a force on another electric current or a charge moving in a vacuum. In the latter case the force can cause the charge to move uniformly in a circle. The quantitative analysis of this motion involves the ideas of uniform circular motion developed in Stage 2, Topic 1: Motion and Relativity.

The limitation on the maximum energy of the ions exiting a cyclotron due to relativistic effects builds on concepts introduced in Stage 2, Topic 1: Motion and Relativity. The production of high intensity and frequency light in a synchrotron links this topic to the production of electromagnetic radiation in Stage 2, Topic 3: Light and Atoms.

Data capture, storage, transmission, and reproduction rely on electricity and magnetism and can be used as the context through students can develop their information and communication technology capability.

Examples of the application of electricity and magnetism in medical physics include the use of shielding of NMR rooms, the use of linear accelerators and X-ray tubes, and the production of medical radioisotopes. Each of these settings extends the personal and social capability as they better understand the importance of physics to health and well-being.

Calculations involving electrostatic forces and the motion of charged particles in electric and magnetic fields extend the numeracy capabilities of students.

Subtopic 2.1 Electric Fields

Students are introduced to two fundamental postulates of electrostatics: Coulomb's Law and the principle of superposition. The electric field at a point in space is defined and used, with Coulomb's Law, to derive an expression for the electric field at a distance from a point charge. In this topic the charges are assumed to be in a vacuum (or, for practical purposes, air).

Students explore several important electric field distributions, including those used in a wide range of applications.

Science Understanding	Possible Contexts
Electrostatically charged objects exert forces upon one another; the magnitude of these forces can be calculated using Coulomb's Law. • Solve problems involving the use of $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$. • Using proportionality, discuss changes in the magnitude of the	*This uses the concepts of force developed in the Stage 1, Subtopic 1.2: Forces and charge in Subtopic 2.1: Potential Difference and Electric Current.* Compare and contrast Coulomb's Law with Newton's Law of Universal Gravitation. Use a van de Graaf generator to demonstrate repulsion between like charges.

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td>force on each of the charges as a result of a change in one or both of the charges and/or a change in the distance between them.
Explain that the electric forces are consistent with Newton’s Third Law.</td><td>Explore an example of the development of complex models using evidence from many sources using the video: Coulomb’s Law. : https://youtu.be/B5LVoU_a08c</td></tr>
<tr><td>When more than two point charges are present, the force on any one of them is equal to the vector sum of the forces due to each of the other point charges.
Use vector addition in one dimension or with right-angled, isosceles, or equilateral triangles to calculate the magnitude and direction of the force on a point charge due to two other point charges.</td><td>The Principle of Superposition is a key concept in this topic and in Stage 2, Topic 3, Light and Atoms. It is essential here when sketching electric field diagrams, particularly of two charges or two parallel plates.</td></tr>
<tr><td rowspan="2">Point charges and charged objects produce electric fields in the space that surrounds them. A charged object in an electric field experiences an electric force.
The direction and number of electric field lines per unit area represent the direction and magnitude of the electric field.
Sketch the electric field lines:
– for an isolated positive or negative point charge and for two point charges
– between and near the edges of two finite oppositely charged parallel plates.
A positively charged body placed in an electric field will experience a force in the direction of the field; the strength of the electric field is defined as the force per unit charge
Solve problems involving the use of: $\vec{E} = \vec{F}/q$.
Using Coulomb’s Law, derive the formula: $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$.
Solve problems using: $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$, for one or two point charges.</td><td>Computer interactive: Electric Fields and Charges from https://phet.colorado.edu/en/simulation/charges-and-fields
Demonstrate electric fields using HT power supply or van de Graaf generator.
Explore applications of electric fields, such as:
– electrostatic loudspeakers
– shark shields
– capacitors.</td></tr>
<tr><td>Use electric field sensors to map electric fields and explore the relationship between electric field strength and distance from charged conductors.</td></tr>
<tr><td>There is no electric field inside a hollow conductor of any shape, provided that there is no charge in the cavity.
Sketch the electric field produced by a hollow spherical charged conductor.</td><td>Assess the benefits and limitations of applications of electrostatic shielding. Examples include:
– Faraday cages
– microwave ovens
– Nuclear Magnetic Resonance</td></tr>
</table>

Science Understanding	Possible Contexts
	imaging rooms – coaxial and USB cables – difficulties with mobile phone reception.
Electric fields are strongest near sharp points on conductors. These fields may be large enough to ionise the polar and non-polar molecules in the air in the vicinity of the sharp points, resulting in charge movement away from the conductor. This is called a ‘corona discharge’. • Sketch the electric field produced by a charged pear-shaped conductor. • Describe how the large electric field in the vicinity of sharp points may ionise the air.	Demonstrate Corona discharges using van de Graaf generator. Explore problems for which scientists have developed practical solutions by making use of strong electric fields. Examples include: – photocopier (charging drum and charging/discharging paper) – lightning rod – electrostatic precipitator – spark plugs.

Subtopic 2.2 Motion of Charged Particles in Electric Fields

Students are introduced to the concept of work done by an electric field on a charged particle. The potential difference between two points in an electric field is defined and used to determine the work, and hence energy changes, of charged particles moving in uniform electric fields in a vacuum.

Students use mathematical relationships to determine the electric force and hence the resulting motion of charged particles in uniform electric fields. Students use the electric field and electric force concepts to explore the motion of ions in particle accelerators, such as a cyclotron.

Science Understanding	Possible Contexts
Electric fields store electric potential energy. When a charged body moves or is moved from one point to another in an electric field and its potential energy changes, work is done on or by the field. The electric potential difference ΔV between two points is the work done per unit charge on a small positive test charge moved between the points, provided that all other charges remain undisturbed. The electronvolt (eV) is a unit of measurement which describes the energy carried by a particle. It is the work done when an electron moves through a potential difference of 1 volt. • Solve problems involving the use of $W = q\Delta V$. • Convert energy from joules into electronvolts and vice versa. The magnitude of the electric field (away	*This uses the concepts of force developed in the Stage 1, Subtopic 1.2 Forces and energy in Stage 1, Subtopic 4.1 Energy.* Use the concepts of work done and gravitational potential energy to introduce the concepts of electric potential energy and potential difference. *The energy conversions relating to this concept have relevance to several other sections in the subject outline, including:* - *Stage 2, Subtopic 1.2: Forces and Momentum: ion thrusters* - *Stage 2, Subtopic 3.2: Wave-Particle Duality: particle accelerators, X-ray production, the photoelectric effect, the Davisson-Germer experiment* - *Stage 2, Topic 3.3: The Structure of the Atom - production of line emission spectra.*

Science Understanding	Possible Contexts
from the edges) between two oppositely charged parallel plates a distance *d* apart, where ΔV is the potential difference between the plates, is given by the formula: $E = \Delta V/d$ • Solve problems involving the use of $E = \Delta V/d$.	The meaning of the formula $W = q\Delta V$ should be emphasised in each context. Discuss the convenience of the different energy units (J and eV) in different circumstances.
The force on a charged particle moving in a uniform electric field is constant in magnitude and direction, thus producing a constant acceleration. • Derive the formula $\vec{a} = \frac{q\vec{E}}{m}$ symbols for the acceleration of a charged particle in an electric field. • Solve problems using $\vec{a} = \frac{q\vec{E}}{m}$ and the equation of motion for the movement of charged particles parallel or antiparallel to a uniform electric field. • Describe the motion of charged particles parallel or antiparallel to a uniform electric field. In a cyclotron, the electric field in the gap between the dees increases the speed of the charged particles. • Describe how an electric field between the dees can transfer energy to an ion passing between them. • Describe how ions could be accelerated to high energies if they could be made repeatedly move across an electric field. • Calculate the energy transferred to an ion each time it passes between the dees. • Explain why the ions do not gain kinetic energy when inside the dees.	Explore solutions to scientific problems developed using the motion of charges parallel or antiparallel to electric fields, such as: – linear accelerators – electron guns (e.g. in electron microscopes, oscilloscopes) – ion thrusters (e.g. in spacecraft propulsion) – X-ray tubes (e.g. in medicine).
When a charged particle moves at an angle to the uniform electric field the component of the velocity perpendicular to the field remains constant. • Compare the motion of a projectile in the absence of air resistance with the motion of a charged particle in a uniform electric field. • Solve problems for the motion of charged particles that enter a uniform electric field at an angle.	*Reinforce the concepts and processes introduced in the Stage 2, Subtopic 1.2 Projectile Motion.* Investigate the motion of electrons in an electric field using Teltron tubes.

Subtopic 2.3 Magnetic Fields

Students are introduced to the concept that a moving charge produces a magnetic field in addition to its electric field. The magnetic field strength at a point in space is defined and used. The interaction between magnetic fields and electric currents is described and used to define the strength of the magnetic field in terms of the force on current-carrying conductors.

Science Understanding	Possible Contexts
Magnetic fields are associated with moving charges, such as charges in an electric current. Current-carrying conductors produce magnetic fields; these fields are utilised in solenoids. Magnetic field lines can be used to represent the magnetic field. The direction of the magnetic field depends on the direction of the moving charge that is producing the magnetic field. The magnitude of magnetic field strength B at any point is represented by the number of lines crossing a unit area perpendicular to the field in the vicinity of the point. • Sketch and/or interpret the magnetic field lines produced by an electric current flowing in a straight conductor, a loop, and a solenoid.	*This uses the concept of electric current developed in the Stage 1, Subtopic 2.1 Potential Difference and Electric Current.* Demonstrate magnetic field lines around permanent magnets, current carrying conductors, and solenoids.
	Investigate electromagnets and their uses. Determine the direction of magnetic fields using a 'right-hand rule'. Investigate factors affecting magnetic field strength near a solenoid.
The magnitude of the magnetic field strength in the vicinity of a current-carrying conductor is given by $B=\frac{\mu_0 I}{2\pi r}$, where r is the radial distance to the conductor. • Solve problems involving the use of $B=\frac{\mu_0 I}{2\pi r}$.	Compare and contrast the factors affecting gravitational field strength, electric field strength, and magnetic field strength.
	Use sensors to measure the magnitude of the magnetic field strength at different distances from or different currents in conductors, loops, and solenoids.

Subtopic 2.4 Motion of Charged Particles in Magnetic Fields

The interaction of current-carrying conductors and magnetic fields is extended to the interaction of moving charged particles and uniform magnetic fields. Students investigate applications of the magnetic force on a current-carrying conductor.

Students explore the velocity dependence of the magnetic force on a moving charged particle, comparing this with the electric force. They discuss the circular path of charged particles moving at right angles to a uniform magnetic field, and apply their understanding to the deflection of ions in applications such as a cyclotron.

Science Understanding	Possible Contexts
Magnets, magnetic materials, moving charges, and current-carrying conductors	*This uses the concept of force developed in Stage 1, Subtopic 1.2: Forces and the concept of circular motion in Stage 2,*

Science Understanding	Possible Contexts
experience a force in a magnetic field. The force on a current element that is parallel or antiparallel to a magnetic field is zero. The magnetic force depends on both the magnitude and the direction of the velocity of the particle. The direction of the force on a current-carrying conductor or an individual charged particle moving at any angle θ to a uniform magnetic field depends on the direction of the magnetic field and the direction of charge movement. • Determine the direction of one of: - force - magnetic field - charge movement, given the direction of the other two. • Solve problems involving the use of $F = IlB\sin\theta$ for a current-carrying conductor and $F = qvB\sin\theta$ for a moving charged particle. A charged particle moving at right angles to a uniform magnetic field experiences a force of constant magnitude at right angles to the velocity. The force changes the direction but not the speed of the charged particle and hence it moves with uniform circular motion. • Explain how the velocity-dependence of the magnetic force on a charged particle causes the particle to move with uniform circular motion when it enters a uniform magnetic field at right angles. • Derive $r = mv/qB$ for the radius r of the circular path of an ion of charge q and mass m that is moving with speed v at right angles to a uniform magnetic field of magnitude B. • Solve problems involving the use of $r = mv/qB$.	*Subtopic 1.3: Circular Motion and Gravitation.* Demonstrate the production of sound in loudspeakers. Use a current balance to determine the force on current-carrying conductors due to an external magnetic field. Investigate the motion of charges using Teltron tube or fine beam apparatus. Use Teltron tubes to measure the charge to mass ratio of electrons. Evaluate the economic, social, and environmental impacts of some applications of charges moving within magnetic fields, such as: – moving coil loudspeaker – synchrotron – mass spectrometer – electric motors – use of magnetic fields in electron microscopes. – maglev trains.
Cyclotrons are used to accelerate ions to high speed. The high speed ions are collided with other nuclei to produce radioisotopes that can be used in medicine and industry. • Discuss the importance of being able to generate radioisotopes in a timely manner near the location they are required.	Discuss the advantages and disadvantages of generating radioisotopes in a cyclotron compared to a nuclear reactor. Make recommendations for particular contexts. Debate the need for both cyclotrons and nuclear reactors in the production of radioisotopes; including the relationship between public debate and science. Discuss the importance of the cyclotron in the SAMHRI facility.

Science Understanding	Possible Contexts
	Investigate medical uses and disadvantages of radioisotopes for diagnostic and therapeutic purposes, for example, PET scanners, Boron Neutron Capture Therapy. Investigate benefits and limitations of using radioisotopes in industry, for example, in quality assurance processes. Discuss the safe storage and disposal of radioactive materials.
The magnetic field within the dees of a cyclotron causes the charged particles to travel in a circular path, so that they repeatedly pass through the electric field. • Describe the nature and direction of the magnetic field needed to deflect ions into a circular path in the dees of a cyclotron. • Derive the formula $T = 2\pi m / qB$ for the period T of the circular motion of an ion, and hence show that the period is independent of the speed of the ion. • Derive the formula $E_K = q^2B^2r^2 / 2m$ for the kinetic energy E_K of the ions emerging at radius r from a cyclotron. • Use the formula $E_K = q^2B^2r^2 / 2m$ to show that E_k is independent of the potential difference across the dees and, for given ions, depends only on the magnetic field and the radius of the cyclotron. • Solve problems involving the use of $T = 2\pi m / qB$ and $E_k = q^2B^2r^2 / 2m$.	Study the production and use of radioisotopes, for medical or industrial use. Explore the limitation on the energy of a charged particle emerging from a cyclotron due to relativistic effects.

Subtopic 2.5 Electromagnetic Induction

Students are introduced to the concepts of magnetic flux and induced electromotive force. They use Faraday's Law and Lenz's Law to investigate and explain a range of applications, such as electrical generators, induction stoves, and transformers.

Science Understanding	Possible Contexts
Magnetic flux Φ is defined as the product of magnetic field strength and the area perpendicular to the magnetic fields $A\perp$: $\phi = BA_{\perp}$ • Solve problems involving the use of $\phi = BA_{\perp}$.	*This uses the concept of electric current developed in Stage 1, Subtopic 2.1: Potential Difference and Electric Current.*

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td rowspan="3">Electromagnetic induction is the process in which a changing magnetic flux induces a potential difference in a conductor.
The induced potential difference is referred to as an electromotive force (emf).
The changing magnetic flux is due to relative movement of the conductor or variation of the magnetic field strength.
Faraday's Law states the induced emf is equal to the rate of change of the magnetic flux. Lenz's Law states that the induced emf creates a current in a direction that opposes the change in magnetic flux producing the emf. Hence: $emf = \Delta\phi / \Delta t$
For *n* conducting loops the induced emf is given by $emf = n\Delta\phi / \Delta t$.
• Solve problems involving the induction of an emf in a straight conductor.
• Solve problems involving the induction of an emf in n conducting loops.
• Use Lenz's Law to determine the direction of the current produced by the induced emf.
• Explain Lenz's Law in terms of conservation of energy.
• Explain the production of eddy currents in terms of Lenz's Law.
Generators use a fixed magnet to generate emfs in rotating conducting loops for electricity production.
• Identify the main components of a generator.
• Explain how generators can be used to produce electric current.
Transformers allow generated voltage to be either increased or decreased before it is used. A transformer consists of a primary coil (with n_p turns) with a potential difference V_p and a secondary coil (with n_s turns) with a potential difference V_s. The relationship between the potential differences is given by the formula: $\frac{V_p}{V_s} = \frac{n_p}{n_s}$.
• Describe the purpose of transformers in electrical circuits.
• Compare step-up and step-down transformers.
• Explain, in terms of the potentially large energy losses that occur as energy is fed through transmission</td>
<td>Computer interactives:
– Faraday's Law from https://phet.colorado.edu/en/simulation/faradays-law
– Faraday's Electromagnetic Lab from https://phet.colorado.edu/en/simulation/faraday.
Demonstrate an induction coil and floating ring, Ruhmkorff Coil and spark, magnet falling through a copper pipe.</td></tr>
<tr><td>Investigate induced emf and currents using data loggers.
Investigate the output of a hand-turned generator.
Compare the structure and function of a generator to an electric motor.</td></tr>
<tr><td>Explore the benefits and limitations of applications of electromagnetic induction, such as:
– reading data from computer hard drives
– induction cooktops
– electromagnetic (eddy-current) braking
– maglev trains
– security systems
– vehicle detection at traffic lights
– metal detectors
– minesweepers.
Assess economic, social, and environmental impacts of power generation by:
– mechanically powered torches
– domestic and industrial electricity power stations
– alternators in vehicles.
Analyse changes that have resulted from the use of transformers in contexts, such as:
– step-up and step-down transformers in electrical power transmission
– step-down transformers in home appliances
– induction coil in vehicles.</td></tr>
</table>

Science Understanding	Possible Contexts
lines from the generator to the consumer, the high voltage used in transmission. • Solve problems involving the use of: $\frac{V_p}{V_s} = \frac{n_p}{n_s}$.	

Topic 3: Light and Atoms

Light, and other forms of electromagnetic radiation, represent one of the most important forms of energy transfer. Analysis of light is crucial to developing an understanding of the structure of matter. The mass-energy equivalence also explains the large amount of energy that can be produced in nuclear reactions.

Light and matter exhibit the characteristics of both waves and matter. Interference patterns can be explained using the wave model of light and the applications of interference enhance students' understanding of information and communication technology.

The wave model of light cannot explain phenomena such as the behaviour of light at relatively low intensities and the photoelectric effect. To explain these phenomena, light must be considered in terms of the photon model. The production of X-rays is also explained in terms of photons. The interference of electrons is used to introduce the concept of the wave behaviour of particles. By describing and explaining these phenomena, students extend their literacy capability.

The emission and absorption of light by matter can be used to explain the structure of the atom and concepts such as fluorescence, stimulated emission, and black body radiation.

The ethical understanding of students will be strengthened as they recognise the need to make ethical decisions based on their further understanding of ionising radiation.

Sub-topic 3.1: Wave Behaviour of Light

Students explore applications that use oscillating charges to radiate electromagnetic waves, which propagate at the speed of light. They discuss the link between electromagnetism and light and relate the frequency and polarisation of television and radio waves to the frequency and direction of oscillation of the electrons in an antenna.

Students use the wave model of light to explain interference and diffraction. Diffraction is treated qualitatively as a precursor to a more extended quantitative treatment of the interference of light from two slits. This is extended to the transmission diffraction grating and its uses.

Science Understanding	Possible Contexts
Oscillating charges produce electromagnetic waves of the same frequency as the oscillation; electromagnetic waves cause charges to oscillate at the frequency of the wave. • Explain the transmission and reception of radio or television in terms of the frequency of oscillation of the electrons in the transmitting and receiving antennae.	*This uses the concept of waves developed in the Stage 1, Subtopics 5.1: Wave Model and 5.3 Light.* Demonstrate the polarisation of microwaves. Utilise computer interactive showing production and transmission of electromagnetic waves: Phet.colorado.edu/en.simulation/legacy/radio-waves.
Electromagnetic waves are transverse waves made up of mutually perpendicular, oscillating electric and magnetic fields. • Relate the orientation of the receiving antenna to the plane of polarisation of radio or television waves.	Explore examples of new technologies enabled by an understanding of electromagnetic waves: – data recording, storage, transmission and reproduction – AM and FM radio/TV – mobile phone transmission, Bluetooth, WiFi – orientation of transmitting and receiving antennae – synchrotron radiation.

Science Understanding	Possible Contexts
Monochromatic light is light composed of a single frequency with waves that radiate in all directions away from the source. Coherent wave sources are wave sources that maintain a constant phase relationship with each other. • Describe what is meant by two wave sources being in phase or out of phase. • Explain why light from an incandescent source is neither coherent nor monochromatic.	Illustrate examples of wave sources that are in phase and out of phase.
	Observe spectra of light from various sources (e.g. incandescent globe, fluorescent globe, vapour lamp, LED) through spectroscope.
When two or more electromagnetic waves overlap, the resultant electric and magnetic fields at a point can be determined using the principle of superposition. When the waves at a point are in phase, 'constructive interference' occurs. When the waves at a point are out of phase, 'destructive interference' occurs. • Describe constructive and destructive interference in terms of the principle of superposition.	Illustrate examples of constructive and destructive interference. Investigate interference patterns produced by light using, for example, thin films, multiple wave-sources, and multiple layers of nanoparticles.
	Explore opportunities for innovation provided by applying the interference of electromagnetic waves in applications such as Blu-ray players and anti-reflective surfaces.
For two monochromatic sources in phase, the waves at a point some distance away in a vacuum: - constructively interfere when the path difference from the sources to the point is $m\lambda$ - destructively interfere when the path difference from the sources to the point is $(m+1/2)\lambda$ where m is an integer and λ is the wavelength. • Use a geometrical construction to identify the locations of maximum and minimum amplitude due to the interference of light from two wave sources of the same frequency. • Explain the maximum and minimum amplitudes in terms of constructive and destructive interference.	Demonstrate two-source interference pattern using a ripple tank or two-source simulation application. (https://phet.colorado.edu/en/simulation/wave-interference) Illustrate regions of constructive and destructive interference on two-source diagram.
	Explore the effect of frequency/ wavelength on two-source interference pattern.
Young's double slit experiment can be used to demonstrate the wave behaviour of light. The formulae $d\sin\theta = m\lambda$ and $\Delta y = \lambda L/d$. can be used to analyse the interference pattern, where d is the distance between the slits θ is the angular position of the	Demonstrate two-slit interference pattern using laser and diffraction grating slide or simulation. (https://phet.colorado.edu/en/simulation/wave-interference)
	Investigate the effect of slit separation on two-slit interference pattern. Determine the wavelength from two-

Science Understanding	Possible Contexts
maximum, Δy is the distance between adjacent minima or maxima on the screen, and L is the slit-to-screen distance. • Describe how two-slit interference is produced in the laboratory using a coherent light source or using a single slit between a light source and the double slit. • Describe how diffraction of the light by the slits in a two-slit interference apparatus allows the light to overlap and hence interfere. • Sketch a graph of the intensity distribution for two-slit interference of monochromatic light. (Consider only cases where the slit separation is much greater than the width of the slits.) • Explain the bright fringes of a two-slit interference pattern in terms of constructive interference, and the dark fringes in terms of destructive interference. • Solve problems involving the use of $d\sin\theta = m\lambda$ and $\Delta y = \lambda L/d$. • Determine the wavelength of monochromatic light from measurements of the two-slit interference pattern.	source interference pattern. Research the ways in which multiple lines of evidence have led to an understanding of the wave-particle duality of light.
The interference pattern produced by light passing through a transmission diffraction grating demonstrates the wave behaviour of light. Transmission diffraction gratings can be used to analyse the spectra of various light sources. The formula $d\sin\theta = m\lambda$ can be used to analyse the interference pattern. • Describe how diffraction by the very thin slits in a grating allows the light from the slits to overlap and hence interfere to produce significant intensity maxima at large angles. • Derive $d\sin\theta = m\lambda$ for the intensity maxima in the pattern produced by a transmission diffraction grating, where d is the distance between the slits in the grating and θ is the angular position of the mth maximum (m specifies the order of the maximum). • Solve problems involving the use of	Demonstrate interference pattern produced by transmission diffraction grating, using coherent light. Illustrate $d\sin\theta = m\lambda$ geometric derivation for transmission diffraction pattern. Demonstrate interference pattern produced by transmission diffraction grating, using white light. Determine of wavelength of monochromatic source. Observe the spectra of different light sources. Explore the emerging technologies which use optical data storage; consider the interplay with technology and engineering.

Science Understanding	Possible Contexts
$d \sin\theta = m\lambda$. • Sketch a graph of the intensity distribution of the maxima produced by a grating, for monochromatic light. • Determine, from the distance between the slits in the grating, the maximum number of orders possible for a given grating and wavelength. • Describe how a grating can be used to measure the wavelength of light from a monochromatic source. • Describe and explain the white-light pattern produced by a grating. • Identify the properties of a grating that make it useful in spectroscopy.	

Subtopic 3.2: Wave-Particle Duality

Students compare the wave model of light to the particle model needed to explain the interaction of light with matter. The properties of photons are introduced and the phenomena of the photoelectric effect and X-rays are then examined and explained in terms of photons. In addition, the wave behaviour of particles, such as electrons, is also introduced. Students explore applications of photons, X-rays and the wave behaviour of particles.

Science Understanding	Possible Contexts
In interacting with matter, light behaves like particles (called 'photons'), with energy given by $E = hf$ and momentum given by $p = h/\lambda$ where h is Planck's constant, f is the frequency of the light, and λ is its wavelength. • Calculate the energy and momentum of the photons in various regions of the electromagnetic spectrum.	*This uses the concept of energy developed in the Stage 1, Subtopic 4.1 Energy and Stage 2, Subtopic 2.2: Motion of Charged Particles in Electric Fields, momentum in Stage 1, Subtopic 4.2: Momentum and waves in Stage 1, Subtopics 5.1: Wave Model and 5.3: Light.* Investigate photon by photon build-up of an interference pattern, using a simulation. (https://phet.colorado.edu/en/simulation/quantum-wave-interference) Describe how microscopic observations of the building up of an image produced by light of very low intensity demonstrate the arrival of localised bundles of energy and momentum called 'photons'. Discuss the acceleration of solar sails as the result of the reflection of photons, emphasising that photons have momentum.
	Explore ways in which engineers use an understanding of photons to design devices. Examples include: – charge coupled devices in digital cameras

Science Understanding	Possible Contexts
	– photomultiplier tube for neutrino detection inside huge underground water tanks.
When light of sufficiently high frequency is incident on matter, it may be absorbed by the matter, from which electrons are then emitted. This is called the ‘photoelectric effect’. The intensity of the incident light affects the number, but not the energy, of emitted electrons. The minimum frequency f_0 at which electrons are emitted varies with the type of material and is called the ‘threshold frequency’. The work function W of a surface is the minimum energy required to remove an electron from it. The work function W is related to the threshold frequency by $W = hf_0$. • Describe an experimental method for investigating the relationship between the maximum kinetic energy of the emitted electrons, calculated from the measured stopping voltage using $E_{K_{\max}} = eV_s$ and the frequency of the light incident on a metal surface. • Describe how Einstein used the concept of photons and the conservation of energy to explain the experimental observations of the photoelectric effect. • Deduce the formula $E_{K_{\max}} = hf - W$ where $E_{K_{\max}}$ is the maximum kinetic energy of the emitted electrons. • Plot experimental values of maximum kinetic energy versus frequency, and relate the slope and axes intercepts to the equation: $E_{K_{\max}} = hf - W$. • solve problems that require the use of $K_{\max} = hf - W$.	Discuss photoelectric experiment. (https://phet.colorado.edu/en/simulation/photoelectric) Explain why wave model of light cannot explain results of photoelectric experiment. Investigate the photoelectric effect experimentally. Explore innovations which utilise the photoelectric effect, for example: – solar cells – photocells (used as light sensors in cameras and many other automated electronic and security systems) – photomultiplier tubes used in many scientific instruments that monitor light and other electromagnetic radiation – the production of sound tracks on movie films – smoke detectors.
X-ray photons can be produced when electrons that have been accelerated to high speed interact with a target. The three main features of the spectrum of the X-rays produced in this way are: - a continuous range of frequencies (bremsstrahlung) due to the various	Investigate how the uses of X-rays are monitored, assessed, and the risks evaluated. Examples in medicine include diagnostic medicine, including CAT or CT scans Examples in industry include X-ray diffraction used in crystallography

Science Understanding	Possible Contexts
proximities of the electrons with the nuceli in the target - a maximum frequency given by $f_{\max} = e\Delta V/h$ where ΔV is the potential difference across the X-ray tube - high-intensity peaks at particular frequencies (known as characteristic X-rays). The intensity of X-rays is decreased (i.e. attenuated) as they pass through matter by scattering and absorption. • Describe the purpose of the following features of a simple X-ray tube: filament, target, high voltage supply, evacuated tube, and a means of cooling the target. • Sketch a graph of the spectrum from an X-ray tube, showing the three main features of the spectrum. • Explain the continuous range of frequencies and the maximum frequency in the spectrum of the X-rays. • Derive the formula for the maximum frequency $f_{\max} = e\Delta V/h$. • Solve problems involving the use of $f_{\max} = e\Delta V/h$. • Relate the attenuation of X-rays to the types of tissue through which they pass (e.g. soft tissue or bone). • Relate the penetrating power (hardness) of X-rays required to pass through a particular type of tissue to the energy and frequency of the X-rays, and hence to the potential difference across the X-ray tube. • Relate the minimum exposure time for X-ray photographs of a given hardness to the intensity of the X-rays, and hence to the tube current, which is determined by the filament current.	and the non-destructive analysis of art objects, X-ray microscopy of biological materials, security screening, or quality control on production lines. Explore the uses of alternative techniques for producing or detecting X-rays, including: • Synchrotron • X-ray fluorescence • X-ray lasers • X-ray astronomy. Assess the benefits and disadvantages of these in different contexts.
Particles exhibit wave behaviour with a wavelength that depends on the momentum of the particle. This de Broglie wavelength can be determined using the formula $\lambda = h/p$, where h is Planck's constant and p is the momentum of the particles. The wave behaviour of particles can be demonstrated using Young's double slit experiment and the Davisson-Germer experiment.	Discuss wave behaviour of particles and reasons why wave behaviour is only observable for small particles. Demonstrate simulation of two-slit interference of electrons. (https://phet.colorado.edu/en/simulation/quantum-wave-interference) Discuss the Davisson-Germer experiment and relate to transmission diffraction grating topic.

Science Understanding	Possible Contexts
• Solve problems involving the use of the formula $\lambda = h/p$ for electrons and other particles. • Describe two-slit interference pattern produced by electrons in double-slit experiments. • Describe the Davisson–Germer experiment, in which the diffraction of electrons by the surface layers of a crystal lattice was observed. • Compare the de Broglie wavelength of electrons with the wavelength required to produce the observations of the Davisson-Germer experiment and in two-slit interference experiments.	(https://phet.colorado.edu/en/simulation/davisson-germer)
	Explore how the wave nature of electrons has led to a diverse range of contemporary applications. Examples include: electron microscope, materials research, forensics, pharmaceutical quality control.

Subtopic 3.3: Structure of the Atom

Students investigate the production and features of line emission spectra from atomic gases to infer the structure of the atom, consisting of excited states with discrete energies.

Students describe and explain the visible continuous spectra emitted by hot objects and atomic absorption spectra.

Students are introduced to the phenomena of a population inversion and stimulated emission to provide a simple explanation of the operation of a laser. They explore the fundamental particles in the Standard Model.

Science Understanding	Possible Contexts
A continuous spectrum contains a continuous range of frequencies. Solid, liquid, or dense gaseous objects radiate a continuous spectrum, which may extend into or beyond the visible region. The process is known as incandescence. The frequency distribution, and hence the dominant colour, depends on the temperature of the object. Describe the changes in the spectrum of a filament globe as the temperature of the filament increases.	Demonstrate changes in the spectrum of an incandescent light globe as voltage increases.
	Investigate the relationship between temperature and frequency distribution, using a simulation. (https://phet.colorado.edu/en/simulation/blackbody-spectrum)
	Explore examples of the application of incandescence, such as: - red hot versus white hot - white fireworks - filament light bulbs. Propose contexts for which the use of each is appropriate.

Science Understanding	Possible Contexts
Atoms can be raised to excited states by heating or bombardment with light or particles such as electrons. The heated vapour of a pure element emits light of discrete frequencies, resulting in a line emission spectrum when the light is viewed with a spectrometer. • Describe the general characteristics of the line emission spectra of elements. • Explain how the uniqueness of the spectra of elements can be used to identify the presence of an element. • Explain the production of characteristic X-rays in an X-ray tube. The presence of discrete frequencies in the spectra of atoms is evidence for the existence of different states in atoms. The states have their own specific energies. The different energies can be represented on an energy-level diagram. When an electron makes a transition from a higher-energy state to a lower-energy state in an atom, the energy of the atom decreases and can be released as a photon. The energy of the emitted photon is given by the difference in the energy levels of the atom. An atom is in its ground state when its electrons have their lowest energy. If an electron is in any of the higher-energy states, the atom is said to be in an excited state. • Explain how the presence of discrete frequencies in line emission spectra provides evidence for the existence of states with discrete energies in atoms. • Solve problems involving emitted photons and energy levels of atoms. • Draw energy-level diagrams to represent the energies of different states in an atom. • Given an energy-level diagram, calculate the frequencies and wavelengths of lines corresponding to specified transitions.	Investigate the relationship between temperature and frequency distribution, using a simulation. (https://phet.colorado.edu/en/simulation/blackbody-spectrum) Use flame tests to identify various metal atoms. Use spectroscopes to identify gases in a fluorescent light globe. Explore advantages and disadvantage of using vapour lamps (e.g. Neon lights and sodium vapours street lamps). When is the use of one more appropriate than the other? Explore how the temperature of stars is determined from the spectrum of emitted light. How confident of their accuracy can scientists be?

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td>The line emission spectrum of atomic hydrogen consists of several series of lines.
• Draw, on an energy-level diagram of hydrogen, transitions corresponding to each of the series terminating at the three lowest-energy levels.
• Relate the magnitude of the transitions on an energy-level diagram to the region in the electromagnetic spectrum of the emitted photons (ultraviolet, visible, or infrared).</td><td>Observe the emission spectrum of hydrogen using a vapour lamp and spectroscope or simulation.
www.phet.colorado.edu/en/simulation/hydrogen-atom
Discuss the energy level diagram of hydrogen and relate to the line emission spectrum of hydrogen. Illustrate the transitions corresponding to the first three series of the hydrogen emission spectrum.</td></tr>
<tr><td>The ionisation energy of an atom is the minimum energy required to remove a single electron from the atom in its ground state.
• Using an energy-level diagram, determine the ionisation energy (in either joules or electronvolts) of an atom.</td><td>Compare and contrast the concept of ionisation in physics with the formation of metal ions.</td></tr>
<tr><td rowspan="2">When light with a continuous spectrum is incident on a gas of an element, discrete frequencies of light are absorbed, resulting in a line absorption spectrum.
The frequencies of the absorption lines are a subset of those in the line emission spectrum of the same element.
• Describe the line absorption spectrum of atomic hydrogen.
• On an energy-level diagram, draw transitions corresponding to the line absorption spectrum of hydrogen.
• Explain why there are no absorption lines in the visible region for hydrogen at room temperature.
• Account for the presence of absorption lines (Fraunhofer lines) in the Sun’s spectrum.</td><td>Demonstrate line absorption spectra of various elements using simulation and relate to emission spectra and energy level diagram.
(www.phet.colorado.edu/en/simulation/hydrogen-atom)
Analyse solar spectrum and discuss sources of Fraunhofer lines.</td></tr>
<tr><td>Explore how line absorption spectra can be used to make discoveries and reliable predictions about the composition and motion of stars.</td></tr>
<tr><td>When an atom absorbs a photon, it is elevated to an ‘excited state’, which has a higher energy. Excited states are generally short-lived and the atom returns spontaneously to its ground state, often by emitting a series of lower-energy photons.
The process of converting high-energy photons into a larger number of lower-energy photons is called ‘fluorescence’.
• Draw, on an energy-level diagram of hydrogen, the process of fluorescence.</td><td>Investigate innovative applications of fluorescence, such as:
- biosensors
- currency security features
- forensic science
- mineralogy
- optical brighteners
- gene identification
- defect and leak detection.
Consider the advantages and disadvantages of their use in different contexts.</td></tr>
</table>

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td rowspan="2">Lasers use the process of stimulated emission to produce electromagnetic radiation. In many lasers stimulated emission occurs from atoms that are in a higher-energy state.

When a photon with energy corresponding to a transition from a higher-energy state to a lower-energy state is incident on an atom in the higher state, it can stimulate a transition to the lower state. This results in two identical photons; the original photon and a second photon that results from the transition.
• Compare the process of stimulated emission with that of ordinary (or spontaneous) emission.

The photon emitted in stimulated emission is identical (in energy, direction, and phase) to the incident photon.
• Explain how stimulated emission can produce coherent light in a laser.

A population inversion is produced in a set of atoms whenever there are more atoms in a higher-energy state than in a lower-energy state. For practical systems, the higher-energy state must be metastable if a population inversion is to be produced.
• Explain the conditions required for stimulated emission to predominate over absorption when light is incident on a set of atoms.

The energy carried by a laser beam is concentrated in a small area and can travel efficiently over large distances, giving laser radiation a far greater potential to cause injury than light from other sources.
• Describe the useful properties of laser light (i.e. it is coherent and monochromatic, and may be of high intensity).
• Discuss the requirements for the safe handling of lasers.</td>
<td>Illustrate the process of stimulated emission on an energy level diagram or using a simulation. (www.phet.colorado.edu/en/simulation/lasers)

Discuss the properties of laser light and hence the safety precautions that must be used when handling lasers.</td></tr>
<tr><td>Research multiple lines of evidence and international communication that contributed to the development of the laser.

Explore the ways in which lasers can be used to solve problems. Examples include:
- LADS for aircraft-based hydrographic surveying
- laser cutting and welding
- laser surgery
- optical data storage
- communication using fibre optics.

Research the international collaboration and communication of scientists from several countries, including Australia, in the joint project LIGO (Laser Interferometer Gravitational-Wave Observatory) to detect gravitational waves.</td></tr>
</table>

Subtopic 3.4: Standard Model

In this subtopic students explore theories that describe the composition of subatomic particles and how interactions between those particles can then be used to describe phenomena such as electrostatic repulsion, beta decay, and positron-electron annihilation.

Science Understanding	Possible Contexts

Science Understanding

The Standard Model suggests that there are three fundamental types of particles: leptons, quarks, and gauge bosons.

Leptons, such as electrons and neutrinos, are particles that are not affected by the strong nuclear force.

Quarks are particles that exist in combinations, which form larger particles such as protons and neutrons.

Gauge bosons are particles which ‘carry’ the four fundamental forces. They are often called ‘exchange particles.’

All other particles are thought to be combinations of quarks and leptons.

- Distinguish between the three types of fundamental particles.

There are six types of quark, with different properties, such as mass and charge. Each quark has a charge of either +2/3 or -1/3.

Quark	Symbol	Charge
Up	u	2/3
Down	d	-1/3
Strange	s	-1/3
Charm	c	2/3
Top	t	2/3
Bottom	b	-1/3

Baryons are particles that consist of a combination of three quarks.

- Describe how protons and neutrons can be formed from different combinations of quarks.

Each particle is assigned a lepton number and baryon number.

The baryon number of a quark is 1/3, all other particles have a baryon number of 0.

The lepton number for a lepton is 1, all other particles have a lepton number of 0.

For every matter particle there exists an antimatter particle equivalent. When a particle and its antiparticle collide they

Possible Contexts

This uses the concept of the nucleus developed in the Stage 1, Subtopics 6.1: The Nucleus and 6.2 Radioactive Decay.

Use online interactive from Particle Data Group at Lawrence Berkerley National laboratory to develop and understanding of the Standard Model.

http://www.particleadventure.org/

Use the following resource on quarks: http://neutrinoscience.blogspot.co.uk/2015/07/pentaquark-series-what-are-quarks.html

Discuss the research using the Large Hadron Collider which has found that particles are formed from combinations of four and five quarks: http://www.symmetrymagazine.org/article/july-2015/lhc-physicists-discover-five-quark-particle.

Utilise resource on quarks, such as: http://neutrinoscience.blogspot.co.uk/2015/07/pentaquark-series-what-are-quarks.html

Discuss the adaptation of the Standard Model to include the Higgs boson, to account for the finite masses of various leptons and quarks.

Explore the change in understanding of the Standard Model in the light of new information using, for example, high-energy particle accelerators.

Explore the benefits and limitations of using positron-electron annihilation PET scanners, including for the production of gamma rays.

Research the economic and social impacts of using the cyclotron at SAHMRI to produce radioisotopes for PET scanning.

Science Understanding	Possible Contexts
annihilate, releasing energy according to the mass-energy equivalence relationship $E = \Delta mc^2$ • Perform calculations using $E = \Delta mc^2$ Antiquarks have a baryon number of -1/3 and anti-leptons have a lepton number of -1. Antiquarks have the opposite charge to their quark equivalent. Quarks and antiquarks can form mesons. The laws of the conservation of baryon number, charge, and lepton number determines the types of reactions that can occur between particles. • Use the conservation laws to determine the baryon number, lepton number, and charge of particles in reactions. • Given a reaction between particles, demonstrate that baryon number, lepton number, and charge are conserved.	

<table>
<tr><th>Science Understanding</th><th>Possible Contexts</th></tr>
<tr><td>
The Standard Model identifies four fundamental forces and gauge bosons are particles that model the interactions of these forces.
<table>
<tr><td>Force</td><td>Gauge Boson</td></tr>
<tr><td>Electromagnetic</td><td>photon</td></tr>
<tr><td>Weak Nuclear</td><td>W, Z</td></tr>
<tr><td>Strong Nuclear</td><td>gluon</td></tr>
<tr><td>Gravitational</td><td>graviton</td></tr>
</table>
The gauge boson for gravitation forces, the graviton, is still to be discovered.
• Describe the electromagnetic, weak nuclear, and strong nuclear forces in terms of gauge bosons.

Feynman diagrams show how gauge bosons mediate the fundamental forces
• Use Feynman diagrams to represent:
➢ the electromagnetic force between two electrons
➢ the weak nuclear force during beta decay
➢ the strong nuclear force between a proton and a neutron.
</td><td>
Explore how beta minus decay involves the conversion of a neutron to a proton accompanied by the production of an electron and an antineutrino.
Explore how beta plus decay involves the conversion of a proton to a neutron, accompanied by the production of an electron and an antineutrino.
Explore how beta decay can be explained in terms of the conversion of quarks.
</td></tr>
</table>

ASSESSMENT SCOPE AND REQUIREMENTS

All Stage 2 subjects have a school assessment component and an external assessment component.

EVIDENCE OF LEARNING

The following assessment types enable students to demonstrate their learning in Stage 2 Physics:

School Assessment (70%)

- Assessment Type 1: Investigations Folio (30%)
- Assessment Type 2: Skills and Applications Tasks (40%)

External Assessment (30%)

Assessment Type 3: Examination (30%).

Students provide evidence of their learning through eight assessments, including the external assessment component. Students complete:

- at least two practical investigations
- one investigation with a focus on science as a human endeavour
- at least three skills and applications tasks
- one examination.

At least one investigation or skills and applications task should involve collaborative work.

It is anticipated that from 2018 all school assessments will be submitted electronically.

ASSESSMENT DESIGN CRITERIA

The assessment design criteria are based on the learning requirements and are used by:

- teachers to clarify for the student what he or she needs to learn
- teachers and assessors to design opportunities for the student to provide evidence of his or her learning at the highest possible level of achievement.

The assessment design criteria consist of specific features that:

- students should demonstrate in their learning
- teachers and assessors look for as evidence that students have met the learning requirements.

For this subject, the assessment design criteria are:

- investigation, analysis, and evaluation
- knowledge and application.

The specific features of these criteria are described in the list below.

The set of assessments, as a whole, give students opportunities to demonstrate each of the specific features by the completion of study of the subject.

Investigation, Analysis, and Evaluation

The specific features are as follows:

IAE1 Design of a physics investigation

IAE2 Obtaining, recording, and representation of data, using appropriate conventions and formats

IAE3 Analysis and interpretation of data and other evidence to formulate and justify conclusions

IAE4 Evaluation of procedures and their effect on data.

Knowledge and Application

The specific features are as follows:

KA1 Demonstration of knowledge and understanding of physics concepts
KA2 Development and application of physics concepts in new and familiar contexts
KA3 Exploration and understanding of the interaction between science and society
KA4 Communication of knowledge and understanding of physics concepts and information, using appropriate terms, conventions and representations.

SCHOOL ASSESSMENT

Assessment Type 1: Investigations Folio (30%)

Students undertake at least two practical investigations and one investigation with a focus on science as a human endeavour. They inquire into aspects of physics through practical discovery and data analysis, and/or by selecting, analysing, and interpreting information.

Practical Investigations

As students design and safely carry out investigations, they extend their science inquiry skills by:

- deconstructing the parts of a problem to determine the most appropriate method for investigation
- formulating investigable questions and hypotheses
- selecting, trialling, and using appropriate equipment, apparatus, and techniques
- identifying variables
- collecting, representing, analysing, and interpreting data
- evaluating procedures and considering their impact on results
- drawing conclusions
- communicating their knowledge and understanding of concepts.

Practical investigations are conducted both individually and collaboratively. For each investigation, students present an individual report. Students should be given the opportunity to investigate a question or hypothesis for which the outcome is uncertain.

A practical report should include:

- introduction with relevant physics concepts, a hypothesis and variables, or investigable question
- materials/apparatus, method/procedure outlining any trials and steps to be taken*
- identification and management of safety and/or ethical risks*
- results*
- analysis of results, identifying trends, and linking results to concepts
- evaluation of procedures and data, and identifying sources of uncertainty
- conclusion.

The report should be a maximum of 1500 words or the equivalent in multimodal form.

*The materials/apparatus, method/procedure outlining trials and steps to be taken, identification and management of safety and/or ethical risks, and results sections are excluded from the word count.

Suggested formats for presentation of a practical investigation report include:

- a written report
- a multimodal product.

Science as a Human Endeavour Investigation

Students investigate a contemporary example of how science interacts with society. This may focus on one or more of the aspects of science as a human endeavour described on pages 54 and 55, and may draw on a context suggested in the topics or relate to a new context.

Students select and explore a recent discovery, innovation, issue, or advancement linked to one of the topics in physics. They analyse and synthesise information from different sources to explain the science relevant to the focus of their investigation, show its connections to science as a human endeavour, and develop and justify their own conclusions.

Possible starting points for the investigation could include, for example:

- the announcement of a discovery in the field of physics
- an expert's point of view on a controversial innovation
- a TED talk based on a biological development
- an article from a scientific publication (e.g. Cosmos)
- public concern about an issue that has environmental, social, economic, or political implications
- changes in government funding for physics-related purposes, e.g. for scientific research into decommissioned satellites and spent rocket stages, various forms of medical imaging, quantum computers and extremely high data transfer, ring laser guidance systems and their application for accurate aircraft navigation, use of nuclear isotopes for industrial or medical applications, monitoring changes in global temperature
- 'blue sky' research leading to new technologies.

Based on their investigation, students prepare a scientific communication, which must include the use of scientific terminology and:

- an introduction to identify the focus of the investigation and the aspect of science as a human endeavour that it links to
- an explanation of how the focus of the investigation illustrates the interaction between science and society
- relevant physics concepts or background
- a discussion of the potential impact or application of the focus of the investigation, e.g. further development, effect on quality of life, environmental implications, economic impact, intrinsic interest
- a conclusion with justification
- citations and referencing.

The scientific communication should be a maximum of 1500 words if written, or a maximum of 10 minutes for an oral presentation, or the equivalent in multimodal form.

This communication could take the form of, for example:

- an article for a scientific publication
- an oral or multimodal scientific presentation.

For this assessment type, students provide evidence of their learning in relation to the following assessment design criteria:

- investigation, analysis, and evaluation
- knowledge and application.

Assessment Type 2: Skills and Applications Tasks (40%)

Students undertake at least three skills and applications tasks. Students may undertake more than three skills and applications tasks within the maximum number of tasks allowed in the school assessment component, but at least three should be under the direct supervision of the teacher. The supervised setting should be appropriate to the task. Each supervised task should be a maximum of 90 minutes of class time, excluding reading time.

Skills and applications tasks allow students to provide evidence of their learning in tasks that may:

- be applied, analytical, and/or interpretative
- pose problems in new and familiar contexts
- involve individual or collaborative assessments, depending on task design.

A skills and applications task may require students to, for example: solve problems; design an investigation to test a hypothesis or investigable question; consider different scenarios in which to apply their knowledge and understanding; graph, tabulate, and/or analyse data; evaluate procedures and identify their limitations; formulate and justify conclusions; represent information diagrammatically or graphically; use physics terms, conventions, and notations.

Skills and applications tasks should be designed to enable students to apply their science inquiry skills, demonstrate knowledge and understanding of key physics concepts and learning, and explain connections with science as a human endeavour. Problems and scenarios should be set in a relevant context, which may be practical, social, or environmental.

Skills and applications tasks may include, for example:

- developing simulations
- practical skills
- graphical skills
- a multimodal product
- an oral presentation
- participation in a debate
- an extended response
- responses to short-answer questions
- a response to science in the media.

For this assessment type, students provide evidence of their learning in relation to the following assessment design criteria:

- investigation, analysis, and evaluation
- knowledge and application.

EXTERNAL ASSESSMENT

Assessment Type 3: Examination (30%)

Students undertake one 2½ hour examination.

Questions of different types cover all Stage 2 science inquiry skills and science understanding. Some questions may require students to show an understanding of science as a human endeavour or to apply their science understanding from more than one topic.

For the examination, students are given a sheet containing symbols of common quantities, the magnitude of physical constants, some mathematical relationships, and standard SI prefixes.

For this assessment type, students provide evidence of their learning in relation to the following assessment design criteria:

- investigation, analysis, and evaluation
- knowledge and application.

PERFORMANCE STANDARDS

The performance standards describe five levels of achievement, A to E.

Each level of achievement describes the knowledge, skills, and understanding that teachers and assessors refer to in deciding how well a student has demonstrated his or her learning on the basis of the evidence provided.

During the teaching and learning program the teacher gives students feedback on their learning, with reference to the performance standards.

At the student's completion of study of each school assessment type, the teacher makes a decision about the quality of the student's leaning by:

- referring to the performance standards
- assigning a grade between A+ and E- for the assessment type.

The student's school assessment and external assessment are combined for a final result, which is reported as a grade between A+ and E-.

Performance Standards for Stage 2 Physics

	Investigation, Analysis, and Evaluation	Knowledge and Application
A	Designs a logical, coherent, and detailed physics investigation. Obtains, records, and represents data, using appropriate conventions and formats accurately and highly effectively. Systematically analyses and interprets data and evidence to formulate logical conclusions with detailed justification. Critically and logically evaluates procedures and discusses their effects on data.	Demonstrates a deep and broad knowledge and understanding of a range of physics concepts. Develops and applies physics concepts highly effectively in new and familiar contexts. Critically explores and understands in depth the interaction between science and society. Communicates knowledge and understanding of physics coherently, with highly effective use of appropriate terms, conventions, and representations.
B	Designs a well-considered and clear physics investigation. Obtains, records, and displays findings of investigations, using appropriate conventions and formats mostly accurately and effectively. Logically analyses and interprets data and evidence to formulate suitable conclusions with reasonable justification. Logically evaluates procedures and their effects on data.	Demonstrates some depth and breadth of knowledge and understanding of a range of physics concepts. Develops and applies physics concepts mostly effectively in new and familiar contexts. Logically explores and understands in some depth the interaction between science and society. Communicates knowledge and understanding of physics mostly coherently, with effective use of appropriate terms, conventions, and representations.
C	Designs a considered and generally clear physics investigation. Obtains, records, and displays findings of investigations, using generally appropriate conventions and formats with some errors but generally accurately and effectively. Undertakes some analysis and interpretation of data and evidence to formulate generally appropriate conclusions with some justification. Evaluates procedures and some of their effects on data.	Demonstrates knowledge and understanding of a general range of physics concepts. Develops and applies physics concepts generally effectively in new or familiar contexts. Explores and understands aspects of the interaction between science and society. Communicates knowledge and understanding of physics generally effectively, using some appropriate terms, conventions, and representations.
D	Prepares the outline of a physics investigation. Obtains, records, and displays findings of investigations, using conventions and formats inconsistently, with occasional accuracy and effectiveness. Describes data and undertakes some basic interpretation to formulate a basic conclusion. Attempts to evaluate procedures or suggest an effect on data.	Demonstrates some basic knowledge and partial understanding of physics concepts. Develops and applies some physics concepts in familiar contexts. Partially explores and recognises aspects of the interaction between science and society. Communicates basic physics information, using some appropriate terms, conventions, and/or representations.
E	Identifies a simple procedure for a physics investigation. Attempts to record and display some descriptive results of an investigation, with limited accuracy or effectiveness. Attempts to describe results and/or interpret data to formulate a basic conclusion. Acknowledges that procedures affect data.	Demonstrates limited recognition and awareness of physics concepts. Attempts to develop and apply physics concepts in familiar contexts. Attempts to explore and identify an aspect of the interaction between science and society. Attempts to communicate information about physics.

ASSESSMENT INTEGRITY

The SACE Assuring Assessment Integrity Policy outlines the principles and processes that teachers and assessors follow to assure the integrity of student assessments. This policy is available on the SACE website (www.sace.sa.edu.au) as part of the SACE Policy Framework.

The SACE Board uses a range of quality assurance processes so that the grades awarded for student achievement, in both the school assessment and the external assessment, are applied consistently and fairly against the performance standards for a subject, and are comparable across all schools.

Information and guidelines on quality assurance in assessment at Stage 2 are available on the SACE website (www.sace.sa.gov.au)

SUPPORT MATERIALS

SUBJECT-SPECIFIC ADVICE

Online support materials are provided for each subject and updated regularly on the SACE website (www.sace.sa.edu.au). Examples of support materials are sample learning and assessment plans, annotated assessment tasks, annotated student responses, and recommended resource materials.

ADVICE ON ETHICAL STUDY AND RESEARCH

Advice for students and teachers on ethical study and research practices is available in the guidelines on the ethical conduct of research in the SACE on the SACE website (www.sace.sa.edu.au).