Accreditation Period

Units 1 and 2

2023–2027

Units 3 and 4

2024–2027

Victorian Certificate of Education

Physics

Study Design

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

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Important information

Accreditation period

Units 1–4: 1 January 2023 – 31 December 2027

Implementation of this study commences in 2023.

Other sources of information

The *VCAA Bulletin* is the only official source of changes to regulations and accredited studies. The Bulletin also regularly includes advice on VCE studies. It is the responsibility of each VCE teacher to refer to each issue of the Bulletin. The Bulletin is available as an e-newsletter via free subscription on the VCAA website.

To assist teachers in developing courses, the VCAA publishes online Support materials (incorporating the previously known *Advice for teachers*).

The current *VCE and VCAL Administrative Handbook* contains essential information on assessment processes and other procedures.

VCE providers

Throughout this study design the term ‘school’ is intended to include both schools and other VCE providers.

Copyright

Schools may use this VCE study design in accordance with the VCAA educational allowance, including making copies for students and use within the school’s secure online teaching and learning environment. For details, access the full VCAA copyright policy on the VCAA website.

Introduction

Scope of study

The study of VCE Physics involves investigating, understanding and explaining the behaviour of physical phenomena in the Universe. Models, including mathematical models, are used to explore, simplify and predict how physical systems behave at varying scales from the very small (quantum and particle physics) through to the very large (astronomy and cosmology). Beginning with classical ideas and considering their limitations, and then being introduced to more modern explanations of the world, provides a novel lens through which students experience the world around them, drawing on their natural curiosity and wonder.

Conceptual understanding is developed as students study topics including light, atomic physics, radiation, thermal physics, electricity, fields, mechanics, quantum physics and the nature of energy and matter. Students are given agency through a choice of options and in designing and undertaking their own investigations.

An important feature of undertaking a VCE science study is the opportunity for students to engage in a range of scientific investigation methodologies, to develop key science skills, and to interrogate the links between theory, knowledge and practice. Students work collaboratively as well as independently on a range of tasks involving experiments, fieldwork, case studies, classification and identification, modelling, simulations, literature reviews, and the development of a product, process or system. Knowledge and application of the safety and ethical guidelines associated with undertaking investigations is integral to the study of VCE Physics.

As well as increasing their understanding of scientific processes, students develop insights into how knowledge in physics has changed, and continues to change, in response to new evidence, discoveries and thinking. They develop capacities that enable them to critically assess the strengths and limitations of science, respect evidence-based conclusions and gain an awareness of the ethical contexts of scientific endeavours. Students consider how science is connected to innovation in addressing contemporary physics challenges.

Through the study of VCE Physics students continue to develop skills to describe, explain, analyse and mathematically model diverse physical phenomena.

Rationale

VCE Physics enables students to use observations, experiments, measurements and mathematical analysis to develop qualitative and quantitative explanations for phenomena occurring from the subatomic scale to macroscopic scales. They explore the big ideas that changed the course of thinking in physics such as relativity and quantum physics. While much scientific understanding in physics has stood the test of time, many other areas continue to evolve, leading to the development of more complex ideas and technological advances and innovation. In undertaking this study, students develop their understanding of the roles of careful and systematic observation, experimentation and modelling in the development of theories and laws. They undertake practical activities and apply physics principles to explain and quantify phenomena.

In VCE Physics, students develop and extend a range of scientific inquiry skills including practical experimentation, research and analytical skills, problem-solving skills including critical and creative thinking, and communication skills. Students pose questions, formulate hypotheses, conduct investigations, and analyse and critically interpret qualitative and quantitative data. They assess the limitations of data, evaluate methodologies and results, justify their conclusions, make recommendations and communicate their findings. Students investigate and evaluate physics-related issues and the impacts of physics research both locally and globally and communicate their views from a position informed by their knowledge of physics.

VCE Physics provides for continuing study pathways within the discipline and can lead to a range of careers. Physicists may undertake research and development in specialist areas including acoustics, astrophysics and cosmology, atmospheric physics, computational physics, communications, education, engineering, geophysics, instrumentation, lasers and photonics, medical diagnosis and treatment, nuclear science, optics, pyrotechnics and radiography. Physicists also work in cross-disciplinary areas such as bushfire research, climate science, forensic science, materials science, neuroscience, remote sensing, renewable energy generation, sports science and transport and vehicle safety.

Aims

This study enables students to:

- apply physics models, theories and concepts to describe, explain, analyse and make predictions about diverse physical phenomena
- understand and use the language and methodologies of physics to solve qualitative and quantitative problems in familiar and unfamiliar contexts

and more broadly to:

- develop attitudes that include curiosity, open-mindedness, creativity, flexibility, integrity, attention to detail and respect for evidence-based conclusions
- develop an understanding of the cooperative, cumulative, iterative and interdisciplinary nature of science as a human endeavour, including its possibilities, limitations and sociocultural, economic, political and legal influences and consequences
- develop a range of individual and collaborative science inquiry skills through a variety of investigation methodologies in the laboratory and field, refining investigations to improve data quality
- understand the research, ethical and safety guidelines that govern the study and practice of the discipline and apply these guidelines to generate, collate, analyse, critically evaluate and report data
- analyse and interpret qualitative and quantitative data to provide evidence, recognising patterns, relationships and limitations of data
- develop an informed and critical perspective, as local and global citizens, on contemporary science-based issues
- develop knowledge and understanding of key models, concepts, theories and laws of science to explain scientific processes and phenomena, and apply this understanding in familiar and unfamiliar situations, including personal, sociocultural, environmental and technological contexts
- communicate clearly and accurately an understanding of the discipline using appropriate terminology, conventions and formats.

Structure

The study is made up of four units, structured under a series of curriculum-framing questions that reflect the inquiry nature of the discipline.

- Unit 1: How is energy useful to society?
- Unit 2: How does physics help us to understand the world?
- Unit 3: How do fields explain motion and electricity?
- Unit 4: How have creative ideas and investigation revolutionised thinking in physics?

Each unit deals with specific content contained in areas of study and is designed to enable students to achieve a set of outcomes for that unit. Each outcome is described in terms of key knowledge and is complemented by a set of key science skills.

Entry

There are no prerequisites for entry to Units 1, 2 and 3. Students must undertake Unit 3 and Unit 4 as a sequence. Students entering Unit 3 without Units 1 and/or 2 may be required to undertake additional preparation as prescribed by their teacher. Units 1–4 are designed to a standard equivalent to the final two years of secondary education. All VCE studies are benchmarked against comparable national and international curriculum.

Duration

Each unit involves at least 50 hours of scheduled classroom instruction.

Changes to the study design

During its period of accreditation minor changes to the study will be announced in the *VCAA Bulletin*. The Bulletin is the only source of changes to regulations and accredited studies. It is the responsibility of each VCE teacher to monitor changes or advice about VCE studies published in the Bulletin.

Monitoring for quality

As part of ongoing monitoring and quality assurance, the VCAA will periodically undertake an audit of VCE Physics to ensure the study is being taught and assessed as accredited. The details of the audit procedures and requirements are published annually in the *VCE and VCAL Administrative Handbook*. Schools will be notified if they are required to submit material to be audited.

Safety and wellbeing

The study may involve the handling of potentially hazardous substances and the use of potentially hazardous equipment. 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 undertaking the study. Teachers and students should observe appropriate safety precautions when undertaking practical activities. All laboratory work should be supervised by the teacher. It is the responsibility of principals to ensure that their schools comply with health and safety requirements.

Relevant acts, regulations and codes include:

- *Occupational Health and Safety Act 2004* (Vic)
- *Occupational Health and Safety Regulations 2017* (Vic)
- *Occupational Health and Safety Management Systems* (AS/NZS ISO 45001:2018)
- *Dangerous Goods (Storage and Handling) Regulations 2021* (Vic)
- Code of Practice for the Storage and Handling of Dangerous Goods 2013
- Hazardous Substances Compliance Code, Edition 2, 2019 (Vic)
- *Electrical Safety Act 1998* (Vic)

Teachers should ensure they access up-to-date versions of all acts, regulations and codes.

In Victoria, the relevant legislation for electrical safety is the *Electricity Safety Act 1998* and associated regulations. Only persons who hold an appropriate current electrical license are permitted to carry out electrical work on products or equipment that require voltages greater than 50 volts AC or 120 volts ripple-free DC. This requirement means that students are not permitted to carry out any electrical work on the internal components of electrical products or equipment that operates above 50 volts AC or 120 volts ripple-free DC.

Students are permitted to work with approved apparatus, appliances and testing equipment that operate at voltages up to 240 volts (which may include appliances such as electric drills or electric soldering irons); however, they must not access or modify any component on such apparatus or appliances.

Any product that requires voltages up to 50 volts AC or 120 volts DC in a supervised class must comply with Wiring Rules (AS/NZS 3000:2000) and General requirements for electrical equipment (AS/NZS 3100:2002).

Employability skills

This study offers a number of opportunities for students to develop employability skills. The Support materials provide specific examples of how students can develop employability skills during learning activities and assessment tasks.

Legislative compliance

When collecting and using information, the provisions of privacy and copyright legislation, such as the Victorian *Privacy and Data Protection Act 2014* and *Health Records Act 2001*, and the federal *Privacy Act 1988* and *Copyright Act 1968*, must be met.

Child Safe Standards

Schools and education and training providers are required to comply with the Child Safe Standards made under the Victorian *Child Wellbeing and Safety Act 2005*. Registered schools are required to comply with *Ministerial Order No. 1359 Implementing the Child Safe Standards – Managing the Risk of Child Abuse in Schools and School Boarding Premises*. For further information, consult the websites of the Victorian Registration and Qualifications Authority, the Commission for Children and Young People and the Department of Education and Training.

Assessment and reporting

Satisfactory completion

The award of satisfactory completion for a unit is based on the teacher's decision that the student has demonstrated achievement of the set of outcomes specified for the unit. Demonstration of achievement of outcomes and satisfactory completion of a unit are determined by evidence gained through the assessment of a range of learning activities and tasks.

Teachers must develop courses that provide appropriate opportunities for students to demonstrate satisfactory achievement of outcomes.

The decision about satisfactory completion of a unit is distinct from the assessment of levels of achievement. Schools will report a student's result for each unit to the VCAA as S (satisfactory) or N (not satisfactory).

Levels of achievement

Units 1 and 2

Procedures for the assessment of levels of achievement in Units 1 and 2 are a matter for school decision. Assessment of levels of achievement for these units will not be reported to the VCAA. Schools may choose to report levels of achievement using grades, descriptive statements or other indicators.

Units 3 and 4

The VCAA specifies the assessment procedures for students undertaking scored assessment in Units 3 and 4. Designated assessment tasks are provided in the details for each unit in VCE study designs.

The student's level of achievement in Units 3 and 4 will be determined by School-assessed Coursework (SAC) as specified in the VCE study design, and external assessment.

The VCAA will report the student's level of achievement on each assessment component as a grade from A+ to E or UG (ungraded). To receive a study score the student must achieve two or more graded assessments in the study and receive an S for both Units 3 and 4. The study score is reported on a scale of 0–50; it is a measure of how well the student performed in relation to all others who took the study. Teachers should refer to the current *VCE and VCAL Administrative Handbook* for details on graded assessment and calculation of the study score. Percentage contributions to the study score in VCE Physics are as follows:

- Unit 3 School-assessed Coursework: 30 per cent
- Unit 4 School-assessed Coursework: 20 per cent
- End-of-year examination: 50 per cent.

Details of the assessment program are described in the sections on Units 3 and 4 in this study design.

Authentication

Work related to the outcomes of each unit will be accepted only if the teacher can attest that, to the best of their knowledge, all unacknowledged work is the student's own. Teachers need to refer to the current *VCE and VCAL Administrative Handbook* for authentication rules and strategies.

Cross-study specifications

Key science skills

The key science skills are a core component of the study of VCE Physics and apply across Units 1 to 4 in all areas of study. In designing teaching and learning programs for each unit and in assessing student learning for each outcome, teachers should ensure that students are given the opportunity to develop, use and demonstrate these skills in a variety of contexts, including when undertaking their own investigations and when evaluating the research of others. As the complexity of key knowledge increases from Units 1 to 4, and as opportunities are provided to undertake investigations, students should aim to demonstrate the key science skills at a progressively higher level.

The key science skills are common to all VCE science studies and have been contextualised in the following table for VCE Physics.

Key science skill	VCE Physics Units 1–4
Develop aims and questions, formulate hypotheses and make predictions	• identify, research and construct aims and questions for investigation • identify independent, dependent and controlled variables in experiments • formulate hypotheses to focus investigations • predict possible outcomes of investigations
Plan and conduct investigations	• determine appropriate investigation methodology: case study; classification and identification; experiment; fieldwork; literature review; modelling; product, process or system development; simulation • design and conduct investigations: select and use methods appropriate to the selected investigation methodology, including consideration of equipment and procedures, taking into account potential sources of error and causes of uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated • work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications in a logbook
Comply with safety and ethical guidelines	• demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks • apply relevant occupational health and safety guidelines while undertaking practical investigations • demonstrate ethical conduct when undertaking and reporting investigations
Generate, collate and record data	• systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources • record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data • organise and present data in useful and meaningful ways, including tables and graphs
Analyse and evaluate data and investigation methods	• process quantitative data using appropriate mathematical relationships and units • use appropriate numbers of significant figures in calculations • construct graphs that show the relationship between variables • extrapolate to determine graph intercepts of significance • construct linearised graphs and identify the significance of the gradient (using relationships relevant to the key knowledge outlined in the areas of study)

Key science skill	VCE Physics Units 1–4
	• identify and analyse experimental data qualitatively, handling, where appropriate, concepts of: accuracy, precision, repeatability, reproducibility, resolution and validity of measurements; and errors (random and systematic) • identify outliers, and contradictory, provisional or incomplete data • repeat experiments to evaluate the precision of data • evaluate investigation methods and possible causes of error and uncertainty, and suggest how precision can be improved, and how uncertainty can be reduced
Construct evidence-based arguments and draw conclusions	• distinguish between opinion and evidence, and between scientific and non-scientific ideas • evaluate data to determine the degree to which the evidence supports the aim of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation • evaluate data to determine the degree to which the evidence supports or refutes the initial prediction or hypothesis • use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with evidence and relevant to the question under investigation • identify, describe and explain the limitations of conclusions, including identification of further evidence required • discuss the implications of research findings
Analyse, evaluate and communicate scientific ideas	• use appropriate physics terminology, representations and conventions, including standard abbreviations, graphing conventions, vector diagrams, algebraic equations, significant figures, uncertainty bars and units of measurement • discuss relevant physics information, ideas, concepts, theories and models and the connections between them • analyse and explain how models and theories are used to organise and understand observed phenomena and concepts related to physics, identifying limitations of selected models/theories • critically evaluate and interpret a range of scientific and media texts (including journal articles, mass media communications and opinions in the public domain), processes, claims and conclusions related to physics by considering the quality of available evidence • analyse and evaluate physics-related societal issues taking into account the influence of social, economic, legal and political factors relevant to the selected issue • use clear, coherent and concise expression to communicate to specific audiences and for specific purposes in appropriate scientific genres, including scientific reports and posters • acknowledge sources of information and assistance, and use standard scientific referencing conventions

Scientific investigation

Students undertake scientific investigations across Units 1 to 4 of this study. Scientific investigations may be undertaken in groups, but all work for assessment must be completed individually.

All VCE science studies include scientific investigations that are student-designed. In approving student-designed investigation topics, teachers and schools must ensure that an investigation proposed by a student for a VCE Physics assessment task is not able to be presented as an assessment task in another VCE study at the school.

Scientific investigation methodologies

Scientific investigations can be undertaken in a variety of ways depending on the aim of the investigation and the question under investigation. For the purposes of VCE Physics, the planning and conducting of scientific investigations will require consideration of the following investigation methodologies:

- **Case study**: An investigation of a particular event or problem that contains a real or hypothetical situation and includes the complexities that would be encountered in the real world. Case studies can take various forms: historical, involving the analysis of causes and consequences, and discussion of knowledge learned from the situation; a real situation or a role-play of an imagined situation, where plausible recommendations are to be made; or problem-solving, where developing a new design, methodology or method is required.
- **Classification and identification**: Classification is the arrangement of phenomena, objects or events into manageable sets, whereas identification is a process of recognition of phenomena as belonging to particular sets or possibly being part of a new or unique set. This methodology is common in physics fields such as astrophysics and the development of classification categories for stars.
- **Experiment**: A procedure undertaken to demonstrate a known fact, test a hypothesis or make a discovery. It may include investigating the relationship between an independent variable and a dependent variable, controlling all other variables, as part of the scientific method.
- **Fieldwork**: Fieldwork involves students undertaking their own investigation to solve a problem or to investigate an issue at a specific location. Students may note the context of the site and the relevance of the site to an investigation, prediction and/or hypothesis prior to recording site data for later processing. The generation of site-specific data should be recorded in the student's logbook.
- **Literature review**: Involves the collation and analysis of secondary data related to other people's scientific findings and/or viewpoints in order to answer a question or provide background information to help explain observed events, or as preparation for an investigation to generate primary data.
- **Modelling**: Involves the construction of: a physical model, such as a small-scale or large-scale representation of an object; a conceptual model, which represents a system involving concepts that help people know, understand or simulate the system; or a mathematical model, which describes a system using mathematical equations that involve relationships between variables and that can be used to make predictions.
- **Product, process or system development**: Design of an artefact, process or system to meet a human need, which may involve technological applications in addition to scientific knowledge and procedures.
- **Simulation**: A process of using a model to study the behaviour of a real or theoretical system. The modelling and manipulation of variables in a real system is useful because often the variables cannot be controlled as the system may be too complex, too large or small, too fast or slow, not accessible or too dangerous.

Logbooks

Students undertaking this study must maintain a logbook of practical activities in each of Units 1 to 4 for recording, authentication and assessment purposes. All items in the logbook must be dated and clearly documented.

The logbook is submitted as a requirement for satisfactory completion in each of Units 1 to 4. Teachers must regularly sight and monitor the logbook, particularly for the student-designed practical and/or research investigations in Outcomes 2 and 3 of Unit 2, and Outcome 2 of Unit 4.

The logbook may be maintained in hard copy or electronic form.

Unit 4 Scientific poster

In Unit 4, Area of Study 2, students demonstrate their science communication skills by presenting the findings of a student-designed scientific investigation and the significance of these findings to both technical and non-technical audiences. The poster may be produced electronically or in hard-copy format and should not exceed 600 words. Tables, graphs, image captions, references and acknowledgements, etc. are not included in the word count.

Posters are not limited to a particular paper size or number of panels. The priorities for the communication should be conciseness, clarity and legibility.

Students will use the following scientific poster format when reporting on their investigation:

<table>
<tr><td colspan="3">Title
Student name</td></tr>
<tr><td>Introduction

Methodology and methods

Results</td><td rowspan="1">Communication statement reporting the key finding of the investigation as a one-sentence summary</td><td>Discussion

Conclusion</td></tr>
<tr><td colspan="3">References and acknowledgements</td></tr>
</table>

The centre of the poster will occupy between 20 to 25 per cent of the poster space and will be a one-sentence summary of the major finding of the investigation that answers the investigation question.

The presentation format of the poster will include the following sections:

Poster section	Content
Title	Question under investigation
Introduction	Brief explanation or reason for undertaking the investigation, including a clear aim, a hypothesis and/or prediction and relevant background physics concepts
Methodology and methods	Brief outline of the selected methodology used to address the investigation question
	Summary of data generation method(s) and data analysis method(s)
Results	Presentation of generated data/evidence in appropriate format to illustrate trends, patterns and/or relationships
Discussion	Interpretation and evaluation of analysed primary data
	Identification and evaluation of limitations in data and methods, and suggested improvements
	Evaluation of results in terms of relevant physics concepts
	Linking of results to investigation question and to the aim to evaluate and explain whether the investigation data and findings support the hypothesis
Conclusion	Conclusion (including its limitation) that provides a response to the investigation question
	Identification of the extent to which the analysis has answered the investigation question, with no new information being introduced
	Implications of the investigation and/or suggestions as to further investigations that may be undertaken
References and acknowledgements	Referencing and acknowledgement of all quotations and sourced content relevant to the investigation

Students record in their logbooks all elements of their investigation planning, comprising identification and management of relevant risks, recording of raw data, and preliminary analysis and evaluation of results, including identification of outliers and their subsequent treatment. Both the student's poster and logbook entries are assessed as part of Unit 4, Area of Study 2.

Critical and creative thinking

Responding effectively to environmental, social and economic challenges requires young people to be creative, innovative, enterprising and adaptable, with the motivation, confidence and skills to use critical and creative thinking purposefully.

Critical and creative thinking are embedded in key science skills and applied across the VCE sciences during learning experiences where students develop questions and hypotheses, design and undertake investigations, make reasoned predictions, generate and evaluate knowledge, clarify concepts and ideas, seek possibilities, consider alternatives and consequences, make evidence-based decisions, devise real or imagined solutions, and solve problems.

Students may engage in scientific investigations involving both primary and secondary data after they identify an aim and methodology, and develop a specific investigation method that includes consideration of a relevant procedure and equipment. A commitment to accuracy, precision and integrity in observation is an important precursor to critical thinking when generating primary data.

Problem solving of any kind requires initial deconstruction to identify an appropriate methodology, followed by consideration of potential risks, and perseverance in adopting different strategies to develop a solution or to reach a conclusion.

In VCE Physics students are exposed to a discipline that challenges ideas and that through experimental investigation may lead to modifying and improving existing knowledge. What is known today builds on what was known in the past and forms the basis of what may be discovered in the future.

Students critically evaluate models used to explain physical phenomena. Ideas in physics encompass the concrete through to the intangible. In order to conceptualise theories, students are required to extend their understanding beyond the visible, to imagine and extend their thinking to view the Universe through entirely new perspectives. They are exposed to the creativity of physicists whose novel ideas have revolutionised thinking in physics. They are challenged to view the Universe as these great minds conceptualised it and to wonder at the creative ability of these scientists to be able to generate such ideas.

Ethical understanding

Ethical understanding is applied across Units 1 to 4 of the VCE sciences. Students apply an ethical understanding when they undertake their own investigations, analyse their own and others' data, and identify and investigate issues relating to the application of scientific knowledge in society. Applying the knowledge and skills of ethical understanding enables students to:

- consider the implications of their own and others' investigations on living and non-living things and the environment
- apply integrity when recording and reporting the outcomes of their own investigations, and when using their own and others' data
- reach a position about science-related ethical issues based on an understanding of ethical concepts and scientific knowledge and skills, considering current and future needs
- recognise the importance of values, and of sociocultural, economic, political and legal factors in responsible science-related decision-making.

Individual and collaborative scientific endeavour

Scientific endeavour is commonly a collaborative, and often global, undertaking that draws on the knowledge and skills of individuals. Units 1 to 4 of VCE Physics provides students with opportunities to manage themselves and their interactions with others through activities that include discussions about scientific concepts, problem-solving and decision-making, and to undertake individual and group practical work.

In working individually, students should be encouraged to plan and manage their time effectively, work safely, make responsible decisions and constructively handle challenging situations.

When working with others, students are expected to actively participate, share ideas, and offer viewpoints and suggestions while respecting the perspectives of others. In group work, students should identify collective goals and make use of strategies to work effectively as a group member to complete tasks and solve problems.

Students learn to seek, value and act on feedback when undertaking both individual and collaborative endeavours.

Aboriginal and Torres Strait Islander knowledge, cultures and history

Aboriginal and Torres Strait Islander peoples have diverse cultures, social structures and a history of unique, complex knowledge systems. In VCE Physics, students consider how science thinking can be informed and enhanced by considering how Aboriginal and Torres Strait Islander peoples have developed and refined their own knowledge about the world through: observation, using all the senses; prediction and hypothesis testing, including trial-and-error; and making generalisations within specific contexts including the management of thermal related factors, the construction and use of tools, toys and building structures, and understandings of Earth and space.

Teachers are encouraged to include Aboriginal and Torres Strait Islander knowledge and perspectives in the design and the delivery of teaching and learning programs related to VCE Physics. Many local Aboriginal and Torres Strait Islander communities have protocols that they have developed in relation to education. The Victorian Koorie community-preferred education model enables teachers to focus inclusively on supporting students to consider Victorian Koorie education matters, and systematically support students to learn about local, regional, state and national Aboriginal and Torres Strait Islander perspectives. VCE studies involve a focused extension of this model and include a broader application of national and international perspectives.

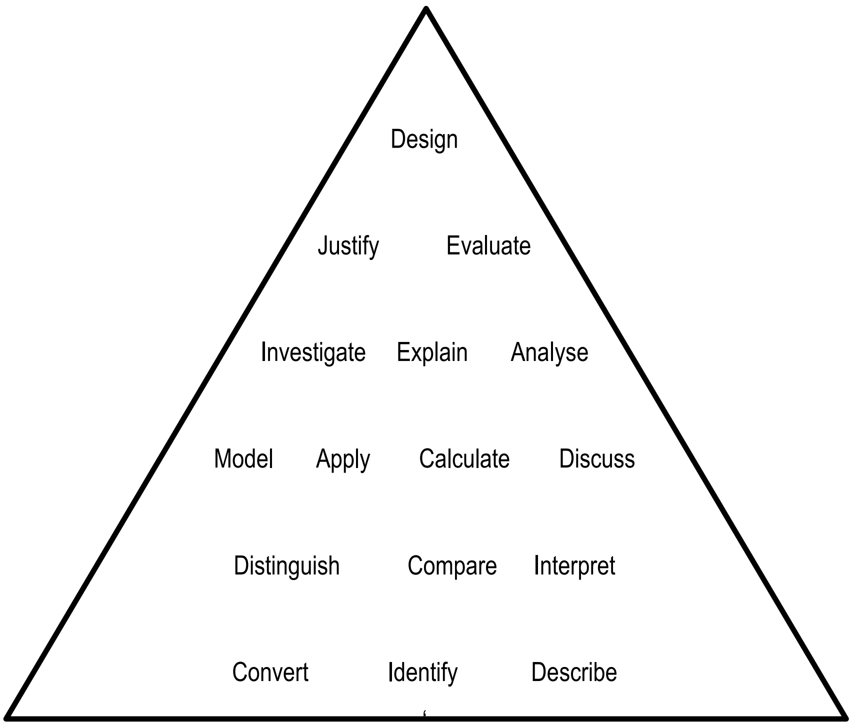
Protocols for Koorie education in Victorian schools, developed through the Yalca policy, and other resources relating to the inclusion of Aboriginal and Torres Strait Islander knowledge and perspectives may be accessed at www.vaeai.org.au/documents/

Characteristics of this study

Use of verbs in key knowledge

The points listed in the key knowledge for each area of study In the *VCE Physics Study Design* are activated by one of sixteen verbs. The verbs provide a guide to the depth of treatment required for the key knowledge.

The following ‘cognitive triangle’ shows the hierarchical nature of the cognitive processes associated with the use of these verbs within the study design.



Note: In the cognitive triangle, higher order cognitive processes encompass capacities of those cognitive processes that appear below them.

Treatment of data

Data may be presented by students in tables or graphs. The following guidelines apply to VCE Physics:

Tabulation of data	Graphing of data
Data tables should include: • a title • similar data in columns, i.e. data is represented in columns rather than rows • units in the column header • the *powers of 10* in the column header for very small or very large numbers • consistent representation of decimal places in data columns (unless the measuring method has changed) • replicate measurements and the calculated average in separate columns or rows as appropriate.	Graphs should include: • a title • axes labels with units • axes labels with powers of ten (if relevant) • the independent variable on the horizontal axis (unless other conventions or usefulness override this) • uncertainty bars on data points (if provided with a numerical representation of the uncertainty) • a smooth trend line (straight or curved) through data points Note: • when variables are directly proportional, the graphed result is expected to be a linear relationship passing through the origin (0,0) • extrapolation should be represented by dashed lines.

When interpreting graphs, students should consider:

- the physical meaning of the gradient of linear graphs (expected student knowledge should be limited to concepts that the student has previously encountered in their physics or science studies)
- that not all graphs will necessarily pass through the origin (0,0)
- that the origin may only be included as a data point if authentically measured.

Terms used in this study

For the purposes of this study design and associated assessment, the following definitions will apply. The Support materials provide additional guidance and should be used in conjunction with this study design.

Terms for force

The use of specific terms in physics can assist conceptual understanding of ideas. With consideration to avoiding the development of student alternative conceptions, clear explanations are given for the following terms concerning force.

- **Use of 'force due to gravity'**

  For the purposes of the *VCE Physics Study Design* the force due to gravity will be referred to as F_g and no reference will be made to weight or weightlessness (or zero gravity or related terms).

- **Terminology for force, $\mathbf{F_{on\ A\ by\ B}}$**

  Objects are often described as 'having' force or reference is sometimes made to the force 'of' an object. Such descriptions can lead to an alternative conception that if an object is moving it is because the object 'has' force. This alternative conception can exist in tandem with students knowing that if an object is moving at constant velocity then the forces on it are balanced.

  This alternative conception may be dealt with by considering the momentum of an object in the first instance. An object that is moving 'has' momentum. If the momentum is changing then there is a force 'acting on' the object. The *VCE Physics Study Design* considers the motion of an object in terms of the object and the forces acting 'on' it. Questions in physics generally require that students identify all of the forces acting 'on' an object. Consistent with this is the notation of describing the force 'on' an object 'by' a second object. Hence $F_{\text{on A by B}}$. The emphasis is on the object on which the forces are acting.

- **Normal force**

  The accepted term for a force in the normal direction between two surfaces in contact is 'normal force'. Teachers should note that the expressions 'reaction force' and 'normal reaction force' perpetuate misunderstandings in terms of the connection of the term 'reaction' to Newton's third law. Firstly, the term 'reaction' in this law applies to force-pairs in all types of forces, not just the normal contact forces (so, friction along the direction of the plane of contact is an action-reaction force pair, but not normal to the plane). Second, there is no distinction about which of the pair of forces is the 'action' and which is the 'reaction'. The term 'reaction' is validly used when carefully describing so-called 'action-reaction' force pairs in relation to Newton's third law and, if used, should be restricted to that usage. Ideally, this terminology should be avoided, and Newton's third law be described as forces existing in pairs, thus avoiding the need for an 'instigator' or 'receiver' of force.

Measurement terms

A major aim of science is to develop explanations that are supported by evidence for natural phenomena and events. This involves evaluating the quality and quantity of evidence and, before conclusions are drawn from data, considering questions such as: 'Can I rely on the data I have generated when drawing conclusions?', and, 'Does the difference between one measurement and another indicate a real change in what is being measured?'.

When analysing and discussing investigations of a quantitative nature, the following terms require consideration:

- **True value**: The value that would be found if the quantity could be measured perfectly.
- **Uncertainty**: The true value is expected to lie in the interval expressed as mean ± uncertainty. For example, for the measurement result 20 ± 1 mm, the 'uncertainty' is 1 mm and the 'interval' is between 19 to 21 mm.
- **Accuracy**: A measurement value is considered to be accurate if it is judged to be close to the true value of the quantity being measured. Accuracy is a qualitative term; a measurement value or measurement result may be described, for example, as being 'less accurate' or 'more accurate' when compared with a true value.
- **Precision**: A measure of the repeatability or reproducibility of scientific measurements and refers to how close two or more measurements are to each other. A set of precise measurements will have values very close to the mean value of the measurements. Precision gives no indication of how close the measurements are to the true value and is therefore a separate consideration to accuracy. The spread of individual measured values provides an indication of the (final) measurement's precision.
- **Measurement result**: Refers to a final result, usually the average of several measurement values. A measurement result may also include an estimate of uncertainty, but for VCE Physics purposes students are not required to determine an estimate of uncertainty.
- **Repeatability**: The closeness of the agreement between the results of successive measurements of the same quantity being measured in an experiment, carried out under the same conditions of measurement. These conditions include the same observer, the same measurement procedure, the same measuring instrument used under the same conditions, the same location, and replicate measurements on the same or similar objects over a short period of time. Experiments that use subjective human judgment/s or that involve small sample sizes may yield results that may not be repeatable. Repeatability can be used to evaluate the quality of data in terms of the precision of measurement results. Ideally, measurements should be repeated where possible to produce a measurement result.
- **Reproducibility**: The closeness of the agreement between the results of measurements of the same quantity being measured, carried out under changed conditions of measurement. These changed conditions involving replicate measurements on the same or similar objects include a different observer, different method of measurement, different measuring instrument, different location, different conditions of use, and different time. The purposes of reproducing experiments include checking of claimed precision and uncovering of any systematic errors that may affect accuracy from one or other experiments/groups. Experiments that use subjective human judgment/s or that involve small sample sizes or insufficient measurements may also yield results that may not be reproducible. Reproducibility links closely to the accuracy of an experiment. Reproducibility can also be used to evaluate the quality of data in terms of the precision of measurement results.
- **Resolution:** The smallest change in the quantity being measured that causes a perceptible change in the value indicated on the measuring instrument, for example, the resolution of a ruler may be 1 mm while the resolution of a stop watch may be 0.1 s.
- **Validity**: A valid experiment investigates what it sets out and/or claims to investigate. Both experimental design and the implementation should be considered when evaluating validity. An experiment and its associated data may not be valid, for example, if the investigation is flawed and controlled variables have been allowed to change. Data may not be valid, for example, if there is observer bias.

Measurement errors, uncertainty, significant figures and outliers

Measurements of quantities are made with the aim of finding the true value of that quantity. In reality, it is impossible to obtain the true value of any quantity since there will always be variations and errors.

For the purposes of this study:

- The term ‘measurement error’ is used to describe the difference between a measurement result and the ‘true’ value.
- The uncertainty of a measurement is often represented as an interval, for example, 20 ± 1 mm. When represented on a graph, the interval is described as an ‘uncertainty bar’.
- Random errors affect the precision of a measurement and may be present in all measurements. Random errors are unpredictable variations in the measurement process and result in a spread of readings.
- Systematic errors cause readings to differ from the true value in a systematic manner so when a particular value is measured repeatedly, the error is the same. Systematic errors result from limitations in the instrument itself or incorrect calibration, or inappropriate methods (including parallax).
- Repeated measurements are made to reduce the effect of random errors (and reduce likelihood of mistakes).
- Mistakes (sometimes called personal errors) should not be included in reporting and analysis. Rather, the experiment should be repeated correctly.
- Significant figures should be considered in all calculations. The following guidelines apply to VCE Physics:
  - all digits in numbers expressed in standard form are significant, e.g. 4.320×10^{-6} has 4 significant figures
  - all non-zero numbers are significant, e.g. 42.3 has 3 significant figures
  - zeros between two non-zero numbers are significant, e.g. 4.302 has four significant figures
  - leading zeros are not significant, e.g. 0.0043 has 2 significant figures
  - trailing zeros to the right of a decimal point are significant, e.g. 42.00 has 4 significant figures
  - for numbers less than 1, 0.4 has 1 significant figure, 0.04 also has 1 significant figure whereas 0.40 has 2 significant figures and 0.400 has 3 significant figures
  - whole numbers written without a decimal point will have the same number of significant figures as the number of digits, with the assumption that the decimal point occurs at the end of the number, e.g. 400 has 3 significant figures. Therefore, a measured distance of 100 m will be considered as having three significant figures.
- Outliers are data points or observations that differ significantly from other data points or observations. Outliers in data must be further analysed and accounted for, rather than being automatically dismissed, as an ethical approach to dealing with data. Repeating readings may be useful in further examining an outlier, for example, to determine whether the outlier is a personal mistake.
- Determining uncertainty for a set of measurements is beyond the scope of VCE Physics because it requires understanding of instrument characteristics for systematic errors, and of probability for random errors.
- For the purposes of VCE Physics, students should be able to:
  - recognise the representation of uncertainty as mean ± uncertainty (for example, ‘the temperature is 20 ± 2 ^{o}C’) or graphically as uncertainty bars
  - draw uncertainty bars given a numerical representation of the uncertainty
  - state the numerical value for uncertainty given a graphical representation of an uncertainty bar.

Formula sheet

The VCE Physics Formula Sheet available on the VCAA website should be considered to be an integral part of the study design and not just reserved for use during the external examination. The formula sheet contains useful formulas, data and other information. It is recommended that the formula sheet be used in teaching and learning and for school-based assessments.

Unit 1: How is energy useful to society?

In this unit students examine some of the fundamental ideas and models used by physicists in an attempt to understand and explain energy. Models used to understand light, thermal energy, radioactivity, nuclear processes and electricity are explored. Students apply these physics ideas to contemporary societal issues: communication, climate change and global warming, medical treatment, electrical home safety and Australian energy needs.

Area of Study 1

How are light and heat explained?

In this area of study, students study light using the wave model and thermal energy using a particle model forming an understanding of the fundamental physics ideas of reflection, refraction and dispersion. They use these to understand observations made of the world such as mirages and rainbows. They investigate energy transfers and explore how light and thermal energy relate to one another. They apply light ideas to explain how light is used through optical fibres in communication, and how physics is used to inform global warming and climate change.

Outcome 1

On completion of this unit the student should be able to model, investigate and evaluate the wave-like nature of light, thermal energy and the emission and absorption of light by matter.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 1 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Electromagnetic radiation

- identify all electromagnetic waves as transverse waves travelling at the same speed, c, in a vacuum as distinct from mechanical waves that require a medium to propagate
- identify the amplitude, wavelength, period and frequency of waves
- calculate the wavelength, frequency, period and speed of travel of waves using: $\lambda = \frac{v}{f} = vT$
- explain the wavelength of a wave as a result of the velocity (determined by the medium through which it travels) and the frequency (determined by the source)
- describe electromagnetic radiation emitted from the Sun as mainly ultraviolet, visible and infrared
- compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and compare the different uses each has in society
- investigate and analyse theoretically and practically the behaviour of waves including:
  - refraction using Snell's Law: $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ and $n_1 v_1 = n_2 v_2$
  - total internal reflection and critical angle including applications: $n_1 \sin(\theta_c) = n_2 \sin(90°)$
- investigate and explain theoretically and practically colour dispersion in prisms and lenses with reference to refraction of the components of white light as they pass from one medium to another
- explain the formation of optical phenomena: rainbows; mirages
- investigate light transmission through optical fibres for communication

Thermal energy

- convert between Celsius and kelvin scales
- describe how an increase in temperature corresponds to an increase in thermal energy (kinetic and potential energy of the atoms) of a system:
  - distinguish between conduction, convection and radiation with reference to heat transfers within and between systems
  - explain why cooling results from evaporation using a simple kinetic energy model
- investigate and analyse theoretically and practically the energy required to:
  - raise the temperature of a substance: $Q = mc\Delta T$
  - change the state of a substance: $Q = mL$

Interaction of thermal energy and electromagnetic radiation

- calculate the peak wavelength of the radiated electromagnetic radiation using Wien's Law: $\lambda_{max}T = \text{constant}$
- compare the total energy across the electromagnetic spectrum emitted by objects at different temperatures
- apply concepts of energy transfer, energy transformation, temperature change and change of state to climate change and global warming.

Area of Study 2

How is energy from the nucleus utilised?

In this area of study, students build on their understanding of energy to explore energy that derives from the nuclei of atoms. They learn about the properties of the radiation from the nucleus and the effects of this radiation on human cells and tissues and apply this understanding to the use of radioisotopes in medical therapy.

Students explore the transfer of energy from the nucleus through the processes of fission and fusion and apply these ideas to evaluate the viability of nuclear energy as an energy source for Australia.

Outcome 2

On completion of this unit the student should be able to explain, apply and evaluate nuclear radiation, radioactive decay and nuclear energy.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 2 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Radiation from the nucleus

- explain nuclear stability with reference to the forces in the nucleus including electrostatic forces, the strong nuclear force and the weak nuclear force
- model radioactive decay as random decay with a particular half-life, including mathematical modelling with reference to whole half-lives
- describe the properties of α, β^-, β^+ and γ radiation
- explain nuclear transformations using decay equations involving α, β^-, β^+ and γ radiation
- analyse decay series diagrams with reference to type of decay and stability of isotopes

- explain the effects of α, β and γ radiation on humans, including:
  - different capacities to cause cell damage
  - short- and long-term effects of low and high doses
  - ionising impacts of radioactive sources outside and inside the body
  - calculations of absorbed dose (gray), equivalent dose (sievert) and effective dose (sievert)
- evaluate the use of medical radioisotopes in therapy including the effects on healthy and damaged tissues and cells

Nuclear energy

- explain, qualitatively, nuclear energy as energy resulting from the conversion of mass
- explain fission chain reactions including:
  - the effect of mass and shape on criticality
  - neutron absorption and moderation
- compare the processes of nuclear fusion and nuclear fission
- explain, using a binding energy curve, why both fusion and fission are reactions that release energy
- investigate the viability of nuclear energy as an energy source for Australia.

Area of Study 3

How can electricity be used to transfer energy?

Modelling is a useful tool in developing concepts that explain physical phenomena that cannot be directly observed. In this area of study, students develop conceptual models to analyse electrical phenomena and undertake practical investigations of circuit components. Concepts of electrical safety are developed through the study of safety mechanisms and the effect of current on humans. Students apply and critically assess mathematical models during experimental investigations of DC circuits. They explore electrical safety and the use of transducers to transfer energy in common devices.

Outcome 3

On completion of this unit the student should be able to investigate and apply a basic DC circuit model to simple battery-operated devices and household electrical systems, apply mathematical models to analyse circuits, and describe the safe and effective use of electricity by individuals and the community.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 3 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Concepts used to model electricity

- apply concepts of charge (Q), electric current (I), potential difference (V), energy (E) and power (P), in electric circuits
- analyse and evaluate different analogies used to describe electric current and potential difference
- investigate and analyse theoretically and practically electric circuits using the relationships: $I = \frac{Q}{t}$, $V = \frac{E}{Q}$, $P = \frac{E}{t} = VI$

- justify the use of selected meters (ammeter, voltmeter, multimeter) in circuits
- apply the kilowatt-hour (kW h) as a unit of energy

Circuit electricity

- model resistance in series and parallel circuits using:
  - current versus potential difference (I–V) graphs
  - resistance as the potential difference to current ratio, including R = constant for ohmic devices
  - equivalent resistance in arrangements in
    - series: $R_{\text{equivalent}} = R_1 + R_2 + ... + R_n$ and
    - parallel: $\frac{1}{R_{\text{equivalent}}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$
- calculate and analyse the equivalent resistance of circuits comprising parallel and series resistance
- analyse circuits comprising voltage dividers
- model household (AC) electrical systems as simple direct current (DC) circuits
- compare power transfers in series and parallel circuits
- explain why the circuits in homes are mostly parallel circuits

Using electricity

- investigate and apply theoretically and practically concepts of current, resistance, potential difference (voltage drop) and power to the operation of electronic circuits comprising resistors, light bulbs, diodes, thermistors, light dependent resistors (LDRs), light-emitting diodes (LEDs) and potentiometers (quantitative analysis restricted to use of $I = \frac{V}{R}$ and $P = VI$)
- investigate practically the operation of simple circuits containing resistors, variable resistors, diodes and other non-ohmic devices
- describe energy transfers and transformations with reference to resistors, light bulbs, diodes, thermistors, light dependent resistors (LDRs), light-emitting diodes (LEDs) and potentiometers in common devices

Electrical safety in the home

- model household electricity connections as a simple DC circuit comprising fuses, switches, circuit breakers, loads and earth
- compare the operation of safety devices including fuses, circuit breakers and residual current devices (RCDs)
- describe the causes, effects and first aid treatment of electric shock and identify the approximate danger thresholds for current and duration.

Assessment

The award of satisfactory completion for a unit is based on whether the student has demonstrated the set of outcomes specified for the unit. Teachers should use a variety of learning activities and assessment tasks that provide a range of opportunities for students to demonstrate the key science skills and key knowledge in the outcomes.

The areas of study, including the key science skills and key knowledge listed for the outcomes, should be used for course design and the development of learning activities and assessment tasks. Assessment must be a part of the regular teaching and learning program and should be completed mainly in class and within a limited timeframe.

All assessments at Units 1 and 2 are school-based. Procedures for assessment of levels of achievement in Units 1 and 2 are a matter for school decision.

For this unit students are required to demonstrate achievement of three outcomes. As a set these outcomes encompass all areas of study in the unit.

Suitable tasks for assessment of Outcomes 1, 2 and 3 may be selected from the following:

- a report of a laboratory or fieldwork activity including the generation of primary data
- reflective annotations related to one or more practical activities from a logbook
- an analysis and evaluation of generated primary and/or collated secondary data
- a critique of an experimental design, process or apparatus
- a modelling or simulation activity
- a report of the design, building, testing and evaluation of a device
- an explanation of a selected physics device, design or innovation
- a physics-referenced response to an issue
- a report of a selected physics phenomenon
- a media analysis/response
- an infographic
- problem-solving involving physics concepts and/or skills
- a report of an application of physics concepts to a real-world context
- an analysis, including calculations, of physics concepts applied to real-world contexts
- comparison and evaluation of two solutions to a problem, two explanations of a physics phenomenon or concept, or two methods and/or findings from practical activities
- a scientific poster.

Where teachers allow students to choose between tasks they must ensure that the tasks they set are of comparable scope and demand.

Practical work

Practical work is a central component of learning and assessment and may include activities such as laboratory experiments, fieldwork, simulations, modelling and other direct experiences as described in the scientific investigation methodologies on page 13. A minimum of fifteen hours of class time should be devoted to student practical activities and scientific investigations across Areas of Study 1, 2 and 3.

Unit 2: How does physics help us to understand the world?

In this unit students explore the power of experiments in developing models and theories. They investigate a variety of phenomena by making their own observations and generating questions, which in turn lead to experiments.

In Area of Study 1, students investigate the ways in which forces are involved both in moving objects and in keeping objects stationary and apply these concepts to a chosen case study of motion.

In Area of Study 2, students choose one of eighteen options related to climate science, nuclear energy, flight, structural engineering, biomechanics, medical physics, bioelectricity, optics, photography, music, sports science, electronics, astrophysics, astrobiology, Australian traditional artefacts and techniques, particle physics, cosmology and local physics research. The selection of an option enables students to pursue an area of interest through an investigation and using physics to justify a stance, response or solution to a contemporary societal issue or application related to the option.

A student-adapted or student-designed scientific investigation is undertaken in Area of Study 3. The investigation involves the generation of primary data and draws on the key science skills and key knowledge from Area of Study 1 and/or Area of Study 2.

Area of Study 1

How is motion understood?

In this area of study, students describe and analyse graphically, numerically and algebraically the energy and motion of an object, using specific physics terminology and conventions. They consider the effects of balanced and unbalanced forces on motion and investigate the translational and rotational forces on static structures. Students apply mathematical models during experimental investigations of motion, and apply their understanding of motion and force through a case study.

Outcome 1

On completion of this unit the student should be able to investigate, analyse, mathematically model and apply force, energy and motion.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 1 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Concepts used to model motion

- identify parameters of motion as vectors or scalars
- analyse graphically, numerically and algebraically, straight-line motion under constant acceleration:
  $v = u + at,\ v^2 = u^2 + 2as,\ s = \frac{1}{2}(u+v)t,\ s = ut + \frac{1}{2}at^2,\ s = vt - \frac{1}{2}at^2$
- analyse, graphically, non-uniform motion in a straight line
- apply concepts of momentum to linear motion: $p = mv$

Forces and motion

- explain changes in momentum as being caused by a net force: $\Delta p = F_{net}\Delta t$
- model the force due to gravity, F_g, as the force of gravity acting at the centre of mass of a body, $F_{\text{on body by Earth}} = mg$, where g is the gravitational field strength (9.8 N kg^{-1} near the surface of Earth)
- model forces as vectors acting at the point of application (with magnitude and direction), labelling these forces using the convention 'force on A by B' or $F_{\text{on A by B}} = -F_{\text{on B by A}}$
- apply Newton's three laws of motion to a body on which forces act: $a = \frac{F_{net}}{m}$, $F_{\text{on A by B}} = -F_{\text{on B by A}}$
- apply the vector model of forces, including vector addition and components of forces, to readily observable forces including the force due to gravity, friction and normal forces

Energy and motion

- apply the concept of work done by a force using:
  - work done = force × displacement: $W = Fs\cos\theta$, where force is constant
  - work done = area under force vs distance graph
- investigate and analyse theoretically and practically Hooke's Law for an ideal spring: $F = -kx$, where x is extension
- analyse and model mechanical energy transfers and transformations using energy conservation:
  - changes in gravitational potential energy near Earth's surface: $E_g = mg\Delta h$
  - elastic potential energy in ideal springs: $E_s = \frac{1}{2}kx^2$
  - kinetic energy: $E_k = \frac{1}{2}mv^2$
- analyse rate of energy transfer using power: $P = \frac{E}{t}$
- calculate the efficiency of an energy transfer system: $\eta = \frac{\text{useful energy out}}{\text{total energy in}}$
- analyse impulse in an isolated system (for collisions between objects moving in a straight line): $F\Delta t = m\Delta v$
- investigate and analyse theoretically and practically momentum conservation in one dimension

Equilibrium

- calculate torque, $\tau = r_{\perp} F$
- analyse translational and rotational forces (torques) in simple structures in translational and rotational equilibrium

Application of motion

- investigate the application of motion concepts through a case study, for example, through motion in sport, vehicle safety, a device or a structure.

Area of Study 2

Options: How does physics inform contemporary issues and applications in society?

In this area of study, students develop a deeper understanding of an area of interest within diverse areas of physics. They select from eighteen options, explore the related physics and use this physics to form a stance, opinion or solution to a contemporary societal issue or application. In their explorations, a range of investigation methodologies may be used by students.

Outcome 2

On completion of this unit the student should be able to investigate and apply physics knowledge to develop and communicate an informed response to a contemporary societal issue or application related to a selected option.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 2 and the related key science skills on pages 11 and 12 of the study design.

Options

Eighteen options are available for selection in Area of Study 2. Each option is based on a different observation of the physical world. One option is to be selected by the student from the following:

- How does physics explain climate change?
- How do fusion and fission compare as viable nuclear energy power sources?
- How do heavy things fly?
- How do forces act on structures and materials?
- How do forces act on the human body?
- How is radiation used to maintain human health?
- How does the human body use electricity?
- How can human vision be enhanced?
- How is physics used in photography?
- How do instruments make music?
- How can performance in ball sports be improved?
- How can AC electricity charge a DC device?
- How do astrophysicists investigate stars and black holes?
- How can we detect possible life beyond Earth's Solar System?
- How can physics explain traditional artefacts, knowledge and techniques?
- How do particle accelerators work?
- How does physics explain the origins of matter?
- How is contemporary physics research being conducted in our region?

Option 2.1: How does physics explain climate change?

In this option students focus on communicating physics understanding in the context of climate change. In preparing their communication related to a selected contemporary societal issue or application, students examine the environmental impacts of Earth's thermal systems and human activities with reference to the effects on surface materials, the emission of greenhouse gases and the contribution to the enhanced greenhouse effect. They analyse the strengths and limitations of the collection and interpretation of thermal data to consider debates related to climate science. Contexts for student exploration may include: the impact that humans are having on Earth's surface; an evaluation of the evidence related to climate change informed by physics; the effect of human activity on the changing albedo of Earth; a physics-based comparison of the effect of industry vs the individual on global warming; a physics-informed response to an argument presented in the media about climate change; or a physics-based response to a political stance taken in the media about climate change.

Key knowledge

The physics of climate change

- describe the transformation of radiation as it passes through the atmosphere, is absorbed and re-emitted by Earth
- explain how greenhouse gases in the atmosphere (including methane, water and carbon dioxide) absorb and re-emit infrared radiation and the impact on global warming
- compare the total energy across the electromagnetic spectrum emitted by objects at different temperatures such as the Sun
- calculate the peak wavelength of the re-radiated electromagnetic radiation from Earth using Wien's Law: $\lambda_{max}T =$ constant
- describe power radiated by a body as being dependent on the temperature of the body according to the Stefan-Boltzmann Law, $P \propto T^4$
- analyse the evidence for the influence of human activity in creating an enhanced greenhouse effect, including the change in the materials that comprise the surface of Earth and the balance of gases in the atmosphere

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.2: How do fusion and fission compare as viable nuclear energy power sources?

In this option students focus on communicating physics understanding in the context of fission and fusion reactions. Fission and fusion are nuclear reactions that produce relatively large quantities of energy from comparatively small quantities of fuel. In preparing their communication related to a selected contemporary societal issue or application, students explore fission and fusion reactions as power sources. Contexts for student exploration may include: the validity of arguments in the media that relate to nuclear energy as a source of power; the viability of using fission and fusion nuclear power as an energy source including a comparison and evaluation of its benefits and risks; or a comparison of fusion and fission reactions in terms of the availability of reactants, the percentage of the mass that is transformed into energy and environmental impacts.

Key knowledge

The physics of nuclear fusion and fission reactions

- explain nuclear fusion reactions of proton-proton and deuterium-tritium with reference to:
  - reactants, products and energy production
  - availability of reactants
  - energy production compared with mass of fuel
- explain nuclear fission reactions of ^{235}U and ^{239}Pu with reference to:
  - fission initiation by slow and fast neutrons respectively
  - products of fission including typical unstable fission fragments and energy
  - radiation produced by unstable fission fragments
- describe neutron absorption in ^{238}U, including formation of ^{239}Pu
- describe the energy transfers and transformations in the systems that convert nuclear energy into thermal energy for subsequent power generation
- explain the risks and benefits for society of using nuclear energy as a power source

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.3: How do heavy things fly?

In this option students focus on communicating physics understanding in the context of flight. In preparing their communication related to a selected contemporary societal issue or application, students explore the aerospace principles that underpin the development of controlled powered flight and the application of these principles to aerospace design. Students observe how different forces affect flight. They investigate the principles of aerodynamics and flight control and how these principles are utilised in the design and operation of aircraft. Contexts for student exploration may include: how aircraft can generate lift when flying upside down; the change in aerodynamic behaviour at supersonic speeds, including compressibility, shock wave formation and increase in drag; or applications of flight concepts beyond conventional aircraft such as improving lift in boomerangs, kites or helicopters.

Key knowledge

The physics of flight

- model the forces acting on an aircraft in flight as:
  - the force due to gravity, acting at the centre of mass
  - thrust
  - lift: $F_L = \frac{1}{2}C_L \rho v^2 A$, acting at the centre of pressure
  - drag: $F_D = \frac{1}{2}C_D \rho v^2 A$, acting at the centre of pressure
- explain the production of aerodynamic lift with reference to:
  - Bernoulli's principle and pressure differences
  - conservation of momentum and downwash
- compare contributions to aerodynamic drag, including skin friction, form and lift-induced
- explain the production of thrust with reference to Newton's laws of motion
- apply balance of forces and torques with reference to Newton's laws of motion to the different stages of flight and the control of the aircraft

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.4: How do forces act on structures and materials?

In this option students focus on communicating physics understanding in the context of materials and their use in structures. In preparing their communication related to a selected contemporary societal issue or application, students investigate the translational and rotational forces on structures and the effects these have on the stress and strain experienced by the material of the structure. They analyse structures and evaluate the suitability of materials used in structures. Contexts for student exploration may include: a case study of a piece of contemporary architecture; physical testing of materials and structures for purpose; designing for greater stability of structures; or an evaluation of the use of contemporary materials in structures such as ceramics, superalloys or composites.

Key knowledge

The physics of structures and materials

- identify different types of external forces due to loads such as compression, tension and shear, that can act on a body, including gravitational forces
- analyse the stability of structures using translational and rotational forces (torques) and identify that gravitational forces act at the centre of mass

- calculate the stress and strain resulting from the application of compressive and tensile forces and loads to materials in structures, $\sigma = F/A$, $\varepsilon = \Delta l/l$
- analyse the behaviour of materials under load in terms of extension and compression, including Young's modulus, $E = \sigma/\varepsilon$, area under stress versus strain graphs and the elastic or plastic behaviour of materials under load
- evaluate the suitability of different materials for use in structures, comparing tensile and compressive strength and stiffness or flexibility under load

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.5: How do forces act on the human body?

In this option students focus on communicating physics understanding in the context of materials and structures that make up the human body. In preparing their communication related to a selected contemporary societal issue or application, students investigate the mechanical theories and concepts related to living systems with emphasis on the human body, particularly its movement, structure and function. Students observe the effects of forces acting upon a material and evaluate data relating to changes to the material. They investigate properties of structures and materials in the human body and in the development and design of prosthetics. Contexts for student exploration may include: a case study of the forces on a body during a physical movement in sport or dance; an investigation of the development of artificial materials and structures for use in prosthetics; a case study of external prostheses for the replacement of lost limbs or internal prostheses such as hip or valve replacements; an evaluation of the challenges with implanting materials within the human body; or a comparison of the performance of artificial limbs with natural limbs with reference to function and longevity.

Key knowledge

The physics of forces on the human body

- apply centre of mass calculations to a body or system: $x_m = \dfrac{x_1 m_1 + x_2 m_2 + \dots + x_n m_n}{m_1 + m_2 + \dots + m_n}$
- investigate and apply theoretically and practically translational forces (gravitational, compressive, tensile and shear) and torques
- calculate the stress and strain resulting from the application of compressive and tensile forces and loads to materials in organic structures including bone and muscle using: $\sigma = \dfrac{F}{A}$ and $\varepsilon = \dfrac{\Delta l}{l}$
- analyse the behaviour of living tissue under load with reference to extension and compression, including Young's modulus, $E = \dfrac{\sigma}{\varepsilon}$, area under stress versus strain graphs and the elastic or plastic behaviour of materials under load

- investigate the suitability of different materials for use in the human body, including bone, tendons and muscle, by comparing tensile and compressive strength and stiffness, toughness, and flexibility under load
- evaluate the development, performance and challenges of using artificial materials and structures in prosthetics, including external prostheses for the replacement of lost limbs, and internal prostheses such as hip or valve replacements

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.6: How is radiation used to maintain human health?

In this option students focus on communicating physics understanding in the context of nuclear physics. In preparing their communication related to a selected contemporary societal issue or application, students explore how the use of electromagnetic radiation and particle radiation are applied in medical diagnosis and treatment. They learn about the production and simple interpretation of images of the human body produced by a variety of imaging techniques used to observe or monitor the functioning of the human body. Contexts for student exploration may include: the effects of α, β and γ radiation on humans such as different capacities to cause cell damage and the short-term and long-term effects of low and high doses; the use of medical radioisotopes in therapy including the effects on healthy and damaged tissues and cells; an evaluation of the cost of medical imaging and the consequences in terms of equity; physics research that led to the development of technology such as matter and anti-matter annihilation; an evaluation of the risks and benefits of imaging techniques; or an investigation in new research that will potentially lead to better imaging.

Key knowledge

The physics of medical radiation

- describe how X-rays for medical use are produced including the distinction between soft and hard X-rays
- describe how medical radioisotopes may be produced by neutron bombardment and high energy collisions
- compare ionising and non-ionising radiation with reference to how each affects living tissues and cells
- compare the processes of, and images produced by, medical imaging using two or more of X-rays, computed tomography (CT), γ radiation, magnetic resonance imaging (MRI), single photon emission computed tomography (SPECT) and positron emission tomography (PET)
- describe applications of medical radioisotopes in imaging and diagnosis
- relate the detection and penetrating properties of α, β and γ radiation to their use in different medical applications

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.7: How does the human body use electricity?

In this option students focus on communicating physics understanding in the context of the production of potential difference and subsequent currents in the human body. In preparing their communication related to a selected contemporary societal issue or application, students explore the role of electrical responses in nerve transmission, in sensation, and in the heart to understand concepts including resistance, the generation of action potentials and neural transmission. They consider the effects of current through the body. Students use this physics to form a stance, opinion or solution to a selected contemporary societal issue or application. Contexts for student exploration may include: the operation of defibrillators; biomedical diagnosis using electrocardiograms (ECGs) or electroencephalograms (EEGs); the electrodermal response and its use in polygraphs or biotherapy feedback; neuroplasticity; the detection of light and perception of colour by photoreceptors in the eye; or the use of the brain to control electrical devices.

Key knowledge

The physics of the use of electricity in the human body

- compare charge carriers in the human body (specifically Na^+, K^+, Ca^{2+}, Mg^{2+}, PO_4^{3-} and Cl^- ions) with those in metals (specifically electrons)
- describe the nervous system as the control of the function of the human body through electrical processes of nerve cells (through an action potential) and chemical transfer between nerve cells (through neurotransmitters diffusing across synapses)
- model an action potential as a short-lasting electrical event across the cell membrane in response to a stimulus, including reference to the roles of ion channels (leakage and voltage gated) in changing membrane potentials during the processes of depolarisation, repolarisation, hyperpolarisation and return to resting state
- explain heart beat with reference to the production of a potential difference and model heart beat with reference to the action of the nodes in atrial and ventricular muscles as the source of the electric signal, the staggering of signals from the atrial and ventricular muscles, and time delay before both muscles can contract again
- describe the effects of current through, and potential difference across, the human body
- explain why people have different electrical resistances with reference to comparison of the resistances in human bone, fat, muscle, nerves and skin

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations

- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.8: How can human vision be enhanced?

In this option students focus on communicating physics understanding in the context of human vision. In preparing their communication related to a selected contemporary societal issue or application, students observe the behaviour of light, investigate reflection and refraction, and apply these concepts to the operation of cameras, lenses, telescopes, microscopes and the human eye. Contexts for student exploration may include: the effects of aging on the human eye and the consequences for vision; the treatment of cataract blindness including the use of intraocular lenses; the mechanism of the operation of the bionic eye; an evaluation of the quality of sunglasses for specific purposes; or exploring new technologies that have improved the collection of visual information from beyond Earth.

Key knowledge

The physics of human vision

- describe image formation using pinhole cameras and convex and concave lenses
- calculate image positions for thin lenses using either accurate ray tracing scale diagrams and/or the thin lens equation: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
- calculate image sizes in pinhole and simple lens cameras: $M = -\frac{v}{u}$
- explain the operation of simple two-lens telescopes and microscopes
- model and explain human vision as refraction at a spherical surface with an adjusting lens and explain accommodation in the human eye including the effects of ageing
- distinguish between short-sightedness and long-sightedness, and explain their correction by concave and convex lenses, respectively
- apply the power of a lens: $P = \frac{1}{f}$ to eye glasses
- investigate sunglasses including the function of polarised lenses, photochromatic lenses and the benefits and possible damaging effects of tinted lenses

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.9 How is physics used in photography?

In this option students focus on communicating physics understanding in the context of photography. They observe the behaviour of light in the formation of images. In preparing their communication related to a selected contemporary societal issue or application, students apply these concepts to the operation of lenses and traditional cameras and compare these with image formation using a digital camera. Contexts for student exploration may include: camera design to improve image formation; the effect of digital photography on society; the comparison of quality of image formation between traditional and digital cameras; or the developments in technology that have led to better imaging by digital cameras and smart phones.

Key knowledge

The physics of photography

- describe image formation using pinhole cameras and convex and concave lenses
- calculate image positions for thin lenses using either accurate ray tracing scale diagrams and/or the thin lens equation: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
- calculate image sizes in pinhole and simple lens cameras: $M = -\frac{v}{u}$
- explain the operation of a simple two-lens camera
- investigate the effect on image formation by polarising lenses, colour filters and aperture size and shutter speed
- compare image formation by a traditional camera and a digital camera

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.10: How do instruments make music?

In this option students focus on communicating physics understanding in the context of sound production or music. In preparing their communication related to a selected contemporary societal issue or application, students examine how the wave model is applied in the design and development of musical instruments. They explore concepts including sound intensity, sound intensity levels, resonance and timbre. Contexts for student exploration may include: the human voice box as a resonance chamber with vibration provided by the vocal chords; the effects of sound and why certain chord progressions and cadences are more appealing to the human ear than others; the frequency response curve and change in hearing ability with increasing age; how cochlear implants work; or psychoacoustics.

Key knowledge

The physics of sound production and music

- describe sound as the transmission of energy via longitudinal pressure waves and distinguish between sound intensity (W m^{-2}) and sound intensity level (dB)
- calculate sound intensity at different distances from a source using an inverse square law
- explain resonance and identify it as related to the natural frequency of an object, and analyse the unique sound of an instrument as a consequence of multiple resonances created by the instrument and described as timbre
- investigate factors that influence natural frequency including shape and material and explain how this relates to instruments
- investigate and explain a variety of musical instruments with reference to the similarities and differences of sound production between instrument types (brass, string, woodwind and percussion) and how they compare with the human voice
- analyse, for strings and open and closed resonant tubes, the fundamental and subsequent harmonics and apply this analysis to selected musical instruments

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.11: How can performance in ball sports be improved?

In this option students focus on communicating physics understanding in the context of ball sports. In preparing their communication related to a selected contemporary societal issue or application, students examine mechanics concepts including Newton's laws of motion. They observe and analyse motion in one and two dimensions, study associated collisions and explore the factors that maximise the projection of the ball in various sports. Contexts for student exploration may include: ideas applied in a selected sport of interest or the comparison of a range of ball sports. They may focus on, for example: the swing of a racquet, club, stick or ball; the throw, pitch or hurl of a ball; or the kick of a ball. They may study the relative influence of dynamics factors that affect the performance of the equipment used in ball sports, the effect of the use of different materials, or the aerodynamics of ball shapes (round, ovoid) and surface textures (smooth or dimpled).

Key knowledge

The physics of ball sports

- investigate and calculate theoretically and practically the transfer of momentum in elastic and inelastic collisions (limited to two dimensions) including the use of the coefficient of restitution, *e*
- investigate and apply theoretically and practically the coefficients of static and kinetic friction to sliding and rolling balls to calculate speeds using Newton's laws of motion and the equations of constant acceleration

- explain rolling of spherical objects using angular and linear speeds: $v = r\omega$.
- calculate air resistance (drag) and terminal velocity: $v_{terminal} = \sqrt{\frac{2mg}{C_D \rho A}}$, where C_D is the drag coefficient, ρ is the gas density, A is the frontal area
- investigate and apply theoretically and practically the equations of constant acceleration to calculate the flight of objects through the air (neglecting air resistance) in two dimensions
- model and describe qualitatively the flight of:
  - a ball through the air when air resistance is not neglected
  - spinning sports balls with reference to the Magnus effect

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.12: How can AC electricity charge a DC device?

In this option students focus on communicating physics understanding in the context of AC to DC electricity conversion. In preparing their communication related to a selected contemporary societal issue or application, students investigate the processes involved in transforming the alternating current delivered by the electrical supplier into low voltage direct current for use with small current electrical devices. In preparing their communication, students investigate a variety of circuits to explore processes including transformation, rectification, smoothing and regulation. They use a variety of instruments to observe the effects of electricity. Contexts for student exploration may include: the importance of reliable power sources for new technologies; an evaluation of light sources (bulbs, LEDs, lasers) for their suitability for data transfer; the limitations and benefits of using fibre optics for communication; an investigation of contemporary technologies making data transfer expedient; or investigating advancements in technology to smooth signals.

Key knowledge

The physics of using AC electricity to charge a DC device

- analyse the role of the transformer in the power supply system including the analysis of voltage ratio: $\frac{N_1}{N_2} = \frac{V_1}{V_2}$ (not including induction or its internal workings)
- explain the use of diodes in half-wave and full-wave bridge rectification
- explain the effect of capacitors with reference to voltage drop and current change when charging and discharging (time constant for charging and discharging, $\tau = RC$) leading to smoothing for DC power supplies
- describe the use of voltage regulators including Zener diodes and integrated circuits
- apply the use of heat and light sensors such as thermistors and light-dependent resistors (LDRs) to trigger an output device such as lighting or a motor
- compare different light sources (bulbs, LEDs, lasers) for their suitability for data transfer

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.13: How do astrophysicists investigate stars and black holes?

In this option students focus on communicating physics understanding in the context of stellar investigations. Observations of the night sky have changed over time from using just the naked eye to the use of sophisticated instruments. In preparing their communication related to a selected contemporary societal issue or application, students examine the birth, life and death of stars in the Universe. They explore how the properties of starlight can provide information, including the star's distance from Earth, its temperature, composition, age and future. Contexts for student exploration include: the challenges of detecting information about the stars; the quality of the stellar information; the change of knowledge resulting from improved collection of information; evaluation of data from stars; how space research led to the hypothesis and subsequent identification of black holes; or the evaluation of the efficiency of research in contemporary stellar astronomy.

Key knowledge

The physics of stars

- apply methods used to investigate the light from stars and for measurements of the distances to stars and galaxies
- identify the properties of stars, including luminosity, radius and mass, temperature and spectral type, and explain how these properties are used to classify stars
- distinguish between the different nuclear fusion phenomena that occur in stars of various sizes
- apply the Hertzsprung–Russell diagram as a tool to describe the evolution and death of stars with differing initial mass
- explain the event horizon of a black hole and use $r_s = \frac{2GM}{c^2}$ to calculate the Schwarzschild radius
- describe the effects of the gravitational fields of black holes on space and time

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- use physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.14: How can we detect possible life beyond Earth's Solar System?

In this option students focus on communicating physics understanding of the search for life beyond the Solar System. In preparing their communication related to a selected contemporary societal issue or application, students are introduced to ways that the question about life beyond Earth's Solar System is investigated by astronomers. Students consider the likelihood of life, including intelligent life, beyond the Solar System, the methods used to find suitably habitable planets, and how the search for life beyond the Solar System is conducted. They examine how telescopes are deployed to observe starlight from across our galaxy and to detect possible signals from other life. Contexts for student exploration could include: the challenges of detecting information about extra-terrestrial life; the quality of the information used to detect extra-terrestrial life; the change of knowledge resulting from improved collection of information; evaluation of data from beyond the Solar System; extreme habitats; or an evaluation of the ethics related to the location of intelligent life beyond the Solar System.

Key knowledge

The physics of life beyond the Solar System

- identify spectroscopy as a tool to investigate the light from stars, and interpret and analyse spectroscopic data with reference to information from beyond our Solar System
- compare methods of exoplanet detection including astrometric, radial velocity, transit method and microlensing, referring to databases that differentiate for size, eccentricity and radius, and by observing the gravitational effect of a planetary system on a star
- explain and apply Doppler shift including spectral shift and 'wobble' of planetary systems using:
  $$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$
- explain the use of the Fermi paradox and the Drake equation to question the possibility of life outside Earth's Solar System and of predicting the likelihood of life existing in the Universe
- distinguish between targeted and untargeted searches for extra-terrestrial intelligence (ETI), and describe optimising strategies including where to look and how to 'listen' with reference to choice of frequency and bandwidth
- explain the nature of information that humans transmit beyond Earth to signal that intelligent life exists on Earth

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.15: How can physics explain traditional artefacts, knowledge and techniques?

In this option students focus on communicating physics understanding in the context of an exploration of the artefacts, knowledge and techniques used by Aboriginal and Torres Strait Islander peoples. In preparing their communication related to a selected contemporary societal issue or application, students research artefacts, knowledge and techniques and select one for detailed analysis. They develop a greater appreciation and understanding of Aboriginal and Torres Strait Islander peoples' knowledge, cultures and history through applying physics concepts to explain the operation, behaviour or understanding of their chosen artefacts, knowledge or techniques. Contexts for student exploration could include: flight concepts that apply to the boomerang and the mirroring of its shape in modern aircraft's wings; aerodynamics of returning and non-returning boomerangs; explanations of how stars are used as seasonal indicators or in navigation; stress-strain graphs related to the physical properties of artefacts made from different grass types and using different weaving techniques; the ergonomics of the design of bicornual baskets; or comparisons of the engineering of different fish traps such as eel traps and barramundi traps.

Key knowledge

The physics of local traditional artefacts, knowledge and techniques

- apply appropriate protocols to access information and to then select one or more Aboriginal and Torres Strait Islander peoples' traditional artefacts, knowledge or techniques, for example a weapon, structure, building material, native fauna, native flora, land management technique, hunting technique, dance, artwork or story
- investigate Aboriginal and Torres Strait Islander peoples' descriptions and explanations of the chosen artefacts, knowledge or techniques
- identify and discuss the physics ideas that are used in the descriptions and explanations of Aboriginal and Torres Strait Islander peoples' artefacts, knowledge or techniques
- apply physics ideas to the understanding and explanation of the chosen artefacts, knowledge or techniques

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.16: How do particle accelerators work?

In this option students focus on communicating physics understanding in the context of particle accelerators. The use of particle accelerators has allowed observations to be made of particles that may once have existed in nature but are no longer present. Investigation of these particles enables theories of the early Universe to be developed and challenged. In preparing their communication related to a selected contemporary societal issue or application, students explore the function and use of particle accelerators to produce radiation and to collide particles. Students investigate the development of, and comparisons between, various accelerator technologies. Particle accelerators and colliders include the Australian Synchrotron and the Large Hadron Collider. Contexts for student exploration could include: an exploration of how research into particle physics has led to the development of consumer products such as heat shrinkable film or the improvement of silicon chips for use in smart phones; evaluation of current and proposed future directions of collider technologies; or a comparison of particle accelerators in various continents including the Asia-Pacific region.

Key knowledge

The physics of particle accelerators

- distinguish between the use of particle accelerators to produce synchrotron light and to collide particles
- explain the general purpose of the electron linac, circular booster, storage ring and beamlines in the Australian Synchrotron
- explain, using the characteristics of brightness, spectrum and divergence, why for some experiments synchrotron radiation is preferable to laser light and radiation from X-ray tubes
- explain the evolution of collider technology including:
  - particles involved in the collision event
  - the increasing energies attained since the 1950s
- evaluate the role of colliders in the development of the Standard Model of particle physics, including reference to subatomic structure and processes
- explain how the immense amount of data collected by the Large Hadron Collider is stored and analysed, and the associated role particle detectors have had in the development of information processing technologies

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.17: How does physics explain the origins of matter?

In this option students focus on communicating physics understanding in the context of theories that explain the origins of matter. In preparing their communication related to a selected contemporary societal issue or application, students explore the nature of matter, and consider the origins of atoms, time and space. They examine the currently accepted scientific theory of the origins of the Universe and the Standard Model to explain how matter has changed over time. Contexts for student exploration can include: the limitations of models used to explain the origins of matter; the process of the discovery of cosmic background radiation; evaluation of current and proposed future directions of theories related to knowledge about the origins of the Universe; investigation of the nature of the development of scientific knowledge, from predicting the existence of a particle from theory through to building technology and the subsequent discovery of the particle; or an investigation into the nature of collaboration and relationships between countries in the pursuit of scientific knowledge.

Key knowledge

The physics of the origins of matter

- describe the Big Bang as a currently held theory that explains the origins of both time and space, and evaluate evidence for the Big Bang including the identification of cosmic background radiation
- explain the changes of matter during the different stages of the Universe over time due to expansion and cooling
- relate predictions to the subsequent discoveries of the neutron, neutrino, positron and Higgs boson
- compare the nature of leptons, hadrons, mesons and baryons
- explain that for every elementary matter particle there exists an antimatter particle of equal mass and opposite charge, and that if a particle and its antiparticle come into contact the particles will annihilate each other to create radiation
- describe the contribution that the detection of gravitational waves has made to understanding of the Universe

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Option 2.18: How is contemporary physics research being conducted in our region?

In this option students focus on communicating physics understanding in the context of cutting-edge research that is based in Victoria, Australia or Oceania. In preparing their communication related to a selected contemporary societal issue or application, students investigate how research involves both individual and collaborative endeavours, as well as the application of critical and creative thinking. They identify key physics concepts to provide a physics-related response to their chosen area of physics research. They research and analyse the limitations, challenges and consequences of local contemporary physics research. Contexts for student exploration can include: research at the Australian Synchrotron; space research; dark matter research; medical research involving radiation; materials research; or nuclear fusion research.

Key knowledge

The physics of local scientific research

- investigate cutting-edge research that is based in Victoria, Australia or Oceania
- select one area of local physics research and follow protocols to access information related to current research in the selected area
- identify the physics related to the chosen research
- explain how physics understanding has led to the development of the selected research
- explain how critical and creative thinking shapes the application of physics concepts related to the selected research

- analyse the extent to which both individual contribution and collaboration are involved in the selected research
- evaluate how the chosen physics research may change the way we live

Communicating physics

- evaluate validity of sources of information
- apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations
- apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations
- discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application
- apply physics understanding to justify a stance, opinion or solution to the selected issue or application.

Area of Study 3

How do physicists investigate questions?

Systematic experimentation is an important aspect of physics inquiry. In this area of study, students adapt or design and then conduct a scientific investigation to generate appropriate primary qualitative and/or quantitative data, organise and interpret the data, and reach and evaluate a conclusion in response to the research question.

Research questions may relate to different scientific methodologies that involve the generation of primary data, controlled experiments, fieldwork, correlational studies, classification and identification, modelling, and the development of a product, process or system. Students may extend their knowledge and skills related to understanding motion by designing and undertaking investigations such as, ‘What are the energy transformations during a theme park ride?’, ‘What are the forces experienced by a netballer’s ankle?’, ‘Is momentum conserved in a football tackle?’ and ‘What is the optimal design of the lightest capsule that is able to prevent an egg breaking during a drop?’. Video analysis can be used to investigate questions such as, ‘Is kinetic energy conserved in a pole vault?’. Questions may be used as a starting point for the investigation, such as ‘Does the shape of the cornea or the material of the lens have a greater effect on refraction?’, ‘How do the structures of winged seeds affect their dispersal?’ and ‘How do buttresses affect the stability of a church?’, or further questions may be posed that have arisen from the options in Unit 2, Area of Study 2.

The student-adapted or student-designed scientific investigation relates to knowledge and skills developed in Area of Study 1 and/or Area of Study 2.

Outcome 3

On completion of this unit the student should be able to draw an evidence-based conclusion from primary data generated from a student-adapted or student-designed scientific investigation related to a selected physics question.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 3 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Investigation design

- apply the physics concepts specific to the selected investigation and explain their significance, including definitions of key terms, and physics representations
- evaluate the characteristics of the scientific methodology relevant to the investigation, selected from: experiment; fieldwork, classification and identification, modelling, simulation, and the development of a product, process or system
- apply techniques of primary qualitative and quantitative data generation relevant to the investigation
- identify and apply concepts of accuracy, precision, repeatability, reproducibility, resolution, and validity of data in relation to the investigation
- identify and apply health, safety and ethical guidelines relevant to the selected scientific investigation

Scientific evidence

- distinguish between an aim, a hypothesis, a model, a theory and a law
- identify and explain observations and experiments that are consistent with, or challenge, current models or theories
- describe the characteristics of primary data
- evaluate methods of organising, analysing and evaluating primary data to identify patterns and relationships including scientific error, causes of uncertainty, and limitations of data, methodologies and methods
- model the scientific practice of using a logbook to authenticate generated primary data

Science communication

- apply the conventions of scientific report writing including scientific terminology and representations, standard abbreviations, units of measurement, significant figures and acknowledgement of references
- apply the key findings of the selected investigation and their relationship to key physics concepts.

Assessment

The award of satisfactory completion for a unit is based on whether the student has demonstrated the set of outcomes specified for the unit. Teachers should use a variety of learning activities and assessment tasks that provide a range of opportunities for students to demonstrate the key science skills and key knowledge in the outcomes.

The areas of study, including the key science skills and key knowledge listed for the outcomes, should be used for course design and the development of learning activities and assessment tasks. Assessment must be a part of the regular teaching and learning program and should be completed mainly in class and within a limited timeframe.

All assessments at Units 1 and 2 are school-based. Procedures for assessment of levels of achievement in Units 1 and 2 are a matter for school decision.

For this unit students are required to demonstrate achievement of three outcomes. As a set these outcomes encompass all areas of study in the unit.

Suitable tasks for assessment may be selected from the following:

For *Outcomes 1 and 2*

- a report of a laboratory or fieldwork activity including the generation of primary data
- reflective annotations related to one or more practical activities from a logbook
- an analysis and evaluation of generated primary and/or collated secondary data
- a critique of an experimental design, process or apparatus
- a modelling or simulation activity
- a report of the design, building, testing and evaluation of a device
- an explanation of a selected physics device, design or innovation
- a physics-referenced response to an issue
- a report of a selected physics phenomenon
- a media analysis/response
- an infographic
- problem-solving involving physics concepts and/or skills
- a report of an application of physics concepts to a real-world context
- an analysis, including calculations, of physics concepts applied to real-world contexts
- comparison and evaluation of two solutions to a problem, two explanations of a physics phenomenon or concept, or two methods and/or findings from practical activities
- a scientific poster.

Where teachers allow students to choose between tasks they must ensure that the tasks they set are of comparable scope and demand.

For *Outcome 3*

- a report of a practical investigation (student-designed or adapted) using an appropriate format, for example a scientific poster, practical report, oral communication or digital presentation.

Practical work

Practical work is a central component of learning and assessment and may include activities such as laboratory experiments, fieldwork, simulations, modelling and other direct experiences as described in the scientific investigation methodologies on page 13. A minimum of ten hours of class time should be devoted to student practical activities and scientific investigations across Areas of Study 1 and 2. For Area of Study 3, a minimum of seven hours of class time should be devoted to undertaking, and communicating findings of, the student-adapted or student-designed scientific investigation.

Unit 3: How do fields explain motion and electricity?

In this unit students use Newton's laws to investigate motion in one and two dimensions. They explore the concept of the field as a model used by physicists to explain observations of motion of objects not in apparent contact. Students compare and contrast three fundamental fields – gravitational, magnetic and electric – and how they relate to one another. They consider the importance of the field to the motion of particles within the field. Students examine the production of electricity and its delivery to homes. They explore fields in relation to the transmission of electricity over large distances and in the design and operation of particle accelerators.

A student-designed practical investigation involving the generation of primary data and including one continuous, independent variable related to fields, motion or light is undertaken either in Unit 3 or Unit 4, or across both Units 3 and 4, and is assessed in Unit 4, Outcome 2. The design, analysis and findings of the investigation are presented in a scientific poster format as outlined on pages 14 and 15.

Area of Study 1

How do physicists explain motion in two dimensions?

In this area of study, students use Newton's laws of motion to analyse linear motion, circular motion and projectile motion. Newton's laws of motion give important insights into a range of motion both on Earth and beyond through the investigations of objects on land and in orbit. They explore the motion of objects under the influence of a gravitational field on the surface of Earth, close to Earth and above Earth. They explore the relationships between force, energy and mass.

Outcome 1

On completion of this unit the student should be able to investigate motion and related energy transformations experimentally, and analyse motion using Newton's laws of motion in one and two dimensions.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 1 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Newton's laws of motion

- investigate and apply theoretically and practically Newton's three laws of motion in situations where two or more coplanar forces act along a straight line and in two dimensions
- investigate and analyse theoretically and practically the uniform circular motion of an object moving in a horizontal plane: $\left(F_{net} = \frac{mv^2}{r}\right)$, including:
  - a vehicle moving around a circular road
  - a vehicle moving around a banked track
  - an object on the end of a string
- model natural and artificial satellite motion as uniform circular motion

- investigate and apply theoretically Newton's second law to circular motion in a vertical plane (forces at the highest and lowest positions only)
- investigate and analyse theoretically and practically the motion of projectiles near Earth's surface, including a qualitative description of the effects of air resistance
- investigate and apply theoretically and practically the laws of energy and momentum conservation in isolated systems in one dimension

Relationships between force, energy and mass

- investigate and analyse theoretically and practically impulse in an isolated system for collisions between objects moving in a straight line: $F\Delta t = m\Delta v$
- investigate and apply theoretically and practically the concept of work done by a force using:
  - work done = force × displacement
  - work done = area under force vs distance graph (one dimensional only)
- analyse transformations of energy between kinetic energy, elastic potential energy, gravitational potential energy and energy dissipated to the environment (considered as a combination of heat, sound and deformation of material):
  - kinetic energy at low speeds: $E_k = \frac{1}{2}mv^2$; elastic and inelastic collisions with reference to conservation of kinetic energy
  - elastic potential energy: area under force-distance graph including ideal springs obeying Hooke's Law: $E_s = \frac{1}{2}kx^2$
  - gravitational potential energy: $E_g = mg\Delta h$ or from area under a force-distance graph and area under a field-distance graph multiplied by mass.

Area of Study 2

How do things move without contact?

Field models are used to explain the behaviour of objects when there is no apparent contact. In this area of study, students examine the similarities and differences between three fields: gravitational, electric and magnetic. Students explore how positions in fields determine the potential energy of, and the force on, an object. They investigate how concepts related to field models can be applied to construct motors, maintain satellite orbits and to accelerate particles including in a synchrotron.

Outcome 2

On completion of this unit the student should be able to analyse gravitational, electric and magnetic fields, and apply these to explain the operation of motors and particle accelerators, and the orbits of satellites.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 2 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Fields and interactions

- describe gravitation, magnetism and electricity using a field model
- investigate and compare theoretically and practically gravitational, magnetic and electric fields, including directions and shapes of fields, attractive and repulsive effects, and the existence of dipoles and monopoles

- investigate and compare theoretically and practically gravitational fields and electrical fields about a point mass or charge (positive or negative) with reference to:
  - the direction of the field
  - the shape of the field
  - the use of the inverse square law to determine the magnitude of the field
  - potential energy changes (qualitative) associated with a point mass or charge moving in the field
- investigate and apply theoretically and practically a field model to magnetic phenomena, including shapes and directions of fields produced by bar magnets, and by current-carrying wires, loops and solenoids
- identify fields as static or changing, and as uniform or non-uniform

Effects of fields

- analyse the use of an electric field to accelerate a charge, including:
  - electric field and electric force concepts: $E = k\frac{Q}{r^2}$ and $F = k\frac{q_1 q_2}{r^2}$
  - potential energy changes in a uniform electric field: $W = qV$, $E = \frac{V}{d}$
  - the magnitude of the force on a charged particle due to a uniform electric field: $F = qE$
- analyse the use of a magnetic field to change the path of a charged particle, including:
  - the magnitude and direction of the force applied to an electron beam by a magnetic field: $F = qvB$, in cases where the directions of *v* and *B* are perpendicular or parallel
  - the radius of the path followed by an electron in a magnetic field: $qvB = \frac{mv^2}{r}$, where $v << c$
- analyse the use of gravitational fields to accelerate mass, including:
  - gravitational field and gravitational force concepts: $g = G\frac{M}{r^2}$ and $F_g = G\frac{m_1 m_2}{r^2}$
  - potential energy changes in a uniform gravitational field: $E_g = mg\Delta h$
- analyse the change in gravitational potential energy from area under a force vs distance graph and area under a field vs distance graph multiplied by mass

Application of field concepts

- apply the concepts of force due to gravity and normal force including in relation to satellites in orbit where the orbits are assumed to be uniform and circular
- model satellite motion (artificial, Moon, planet) as uniform circular orbital motion: $a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$
- describe the interaction of two fields, allowing that electric charges, magnetic poles and current carrying conductors can either attract or repel, whereas masses only attract each other
- investigate and analyse theoretically and practically the force on a current carrying conductor due to an external magnetic field, $F = nIlB$, where the directions of I and B are either perpendicular or parallel to each other
- investigate and analyse theoretically and practically the operation of simple DC motors consisting of one coil, containing a number of loops of wire, which is free to rotate about an axis in a uniform magnetic field and including the use of a split ring commutator
- investigate, qualitatively, the effect of current, external magnetic field and the number of loops of wire on the torque of a simple motor
- model the acceleration of particles in a particle accelerator (including synchrotrons) as uniform circular motion (limited to linear acceleration by a uniform electric field and direction change by a uniform magnetic field).

Area of Study 3

How are fields used in electricity generation?

The production, distribution and use of electricity has had a major impact on the way that humans live. In this area of study, students use empirical evidence and models of electric, magnetic and electromagnetic effects to explain how electricity is produced and delivered to homes. They explore the transformer as critical to the performance of electrical distribution systems in minimising power loss.

Outcome 3

On completion of this unit the student should be able to analyse and evaluate an electricity generation and distribution system.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 3 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Generation of electricity

- calculate magnetic flux when the magnetic field is perpendicular to the area, and describe the qualitative effect of differing angles between the area and the field: $\Phi_B = B_{\perp}A$
- investigate and analyse theoretically and practically the generation of electromotive force (emf) including AC voltage and calculations using induced emf: $\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$, with reference to:
  - rate of change of magnetic flux
  - number of loops through which the flux passes
  - direction of induced emf in a coil
- explain the production of DC voltage in DC generators and AC voltage in alternators, including the use of split ring commutators and slip rings respectively
- describe the production of electricity using photovoltaic cells and the need for an inverter to convert power from DC to AC for use in the home (not including details of semiconductors action or inverter circuitry)

Transmission of electricity

- compare sinusoidal AC voltages produced as a result of the uniform rotation of a loop in a constant magnetic field with reference to frequency, period, amplitude, peak-to-peak voltage $(V_{\text{p–p}})$ and peak-to-peak current $(I_{\text{p–p}})$
- compare alternating voltage expressed as the root-mean-square (rms) to a constant DC voltage developing the same power in a resistive component
- analyse transformer action with reference to electromagnetic induction for an ideal transformer: $\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
- analyse the supply of power by considering transmission losses across transmission lines.

School-based assessment

Satisfactory completion

The award of satisfactory completion for a unit is based on whether the student has demonstrated the set of outcomes specified for the unit. Teachers should use a variety of learning activities and assessment tasks to provide a range of opportunities for students to demonstrate the key science skills and key knowledge in the outcomes.

The areas of study and key knowledge and relevant key science skills listed for the outcomes should be used for course design and the development of learning activities and assessment tasks.

Assessment of levels of achievement

The student's level of achievement in Unit 3 will be determined by School-assessed Coursework. School-assessed Coursework tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe.

Where teachers provide a range of options for the same School-assessed Coursework task, they should ensure that the options are of comparable scope and demand.

The types and range of forms of School-assessed Coursework for the outcomes are prescribed within the study design. The VCAA publishes Support materials for this study, which includes advice on the design of assessment tasks and the assessment of student work for a level of achievement.

Teachers will provide to the VCAA a numerical score representing an assessment of the student's level of achievement. The score must be based on the teacher's assessment of the performance of each student on the tasks set out in the following table.

Contribution to final assessment

School-assessed Coursework for Unit 3 will contribute 30 per cent to the study score.

<table>
<tr><th>Outcomes</th><th>Marks allocated</th><th>Assessment tasks</th></tr>
<tr><td>Outcome 1
Investigate motion and related energy transformations experimentally, and analyse motion using Newton’s laws of motion in one and two dimensions.</td><td>40</td><td rowspan="3">For Outcomes 1, 2 and 3
For each outcome, one task selected from:
application of physics concepts to explain a model, theory, device, design or innovation
analysis and evaluation of primary and/or secondary data, including data plotting, identified assumptions or data limitations, and conclusions
problem-solving, applying physics concepts and skills to real-world contexts
comparison and evaluation of two solutions to a problem, two explanations of a physics phenomenon or concept, or two methods and/or findings from practical activities.
Each task can only be selected once across Units 3 and 4.
For each task the time allocated should be approximately 50 minutes for a written response and 5 minutes for a multimodal or oral presentation.</td></tr>
<tr><td>Outcome 2
Analyse gravitational, electric and magnetic fields, and apply these to explain the operation of motors and particle accelerators, and the orbits of satellites.</td><td>40</td></tr>
<tr><td>Outcome 3
Analyse and evaluate an electricity generation and distribution system.</td><td>40</td></tr>
<tr><td>Total marks</td><td>120</td><td></td></tr>
</table>

Practical work

Practical work is a central component of learning and assessment and may include activities such as laboratory experiments, fieldwork, simulations, modelling and other direct experiences as described in the scientific investigation methodologies on page 13. A minimum of fifteen hours of class time should be devoted to student practical work and investigations across Areas of Study 1, 2 and 3.

External assessment

The level of achievement for Units 3 and 4 is also assessed by an end-of-year examination, which will contribute 50 per cent to the study score.

Unit 4: How have creative ideas and investigation revolutionised thinking in physics?

A complex interplay exists between theory and experiment in generating models to explain natural phenomena. Ideas that attempt to explain how the Universe works have changed over time, with some experiments and ways of thinking having had significant impact on the understanding of the nature of light, matter and energy. Wave theory, classically used to explain light, has proved limited as quantum physics is utilised to explain particle-like properties of light revealed by experiments. Light and matter, which initially seem to be quite different, on very small scales have been observed as having similar properties. At speeds approaching the speed of light, matter is observed differently from different frames of reference. Matter and energy, once quite distinct, become almost synonymous.

In this unit, students explore some monumental changes in thinking in Physics that have changed the course of how physicists understand and investigate the Universe. They examine the limitations of the wave model in describing light behaviour and use a particle model to better explain some observations of light. Matter, that was once explained using a particle model, is re-imagined using a wave model. Students are challenged to think beyond how they experience the physical world of their everyday lives to thinking from a new perspective, as they imagine the relativistic world of length contraction and time dilation when motion approaches the speed of light. They are invited to wonder about how Einstein's revolutionary thinking allowed the development of modern-day devices such as the GPS.

A student-designed practical investigation involving the generation of primary data and including one continuous, independent variable related to fields, motion or light is undertaken either in Unit 3 or Unit 4, or across both Units 3 and 4, and is assessed in Unit 4, Outcome 2. The design, analysis and findings of the investigation are presented in a scientific poster format as outlined on pages 13 and 14.

Area of Study 1

How has understanding about the physical world changed?

In this area of study, students learn how understanding of light, matter and motion have changed over time. They explore how major experiments led to the development of theories to describe these fundamental aspects of the physical world.

When light and matter are probed, they appear to have remarkable similarities. Light, previously described as an electromagnetic wave, appears to exhibit both wave-like and particle-like properties. Findings that electrons behave in a wave-like manner challenged thinking about the relationship between light and matter.

Students consider the limitations of classical mechanics as they explore Einstein's view of the Universe. They consider postulates as distinct from theories and explore ideas related to objects moving at speeds approaching the speed of light. They use special relativity to explore length contraction and time dilation as observations are made by observers in different frames of reference, and the interrelationship between matter and energy.

Outcome 1

On completion of this unit the student should be able to analyse and apply models that explain the nature of light and matter, and use special relativity to explain observations made when objects are moving at speeds approaching the speed of light.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 1 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Light as a wave

- describe light as a transverse electromagnetic wave which is produced by the acceleration of charges, which in turn produces changing electric fields and associated changing magnetic fields
- identify that all electromagnetic waves travel at the same speed, c, in a vacuum
- explain the formation of a standing wave resulting from the superposition of a travelling wave and its reflection
- analyse the formation of standing waves (only those with nodes at both ends is required)
- investigate and explain theoretically and practically diffraction as the directional spread of various frequencies with reference to different gap width or obstacle size, including the qualitative effect of changing the $\frac{\lambda}{w}$ ratio, and apply this to limitations of imaging using electromagnetic waves
- explain the results of Young's double slit experiment with reference to:
  - evidence for the wave-like nature of light
  - constructive and destructive interference of coherent waves in terms of path differences: $n\lambda$ and $\left(n+\frac{1}{2}\right)\lambda$ respectively, where n = 0,1, 2,…
  - effect of wavelength, distance of screen and slit separation on interference patterns: $\Delta x = \frac{\lambda L}{d}$ when *L>>d*

Light as a particle

- apply the quantised energy of photons: $E = hf = \frac{hc}{\lambda}$
- analyse the photoelectric effect with reference to:
  - evidence for the particle-like nature of light
  - experimental data in the form of graphs of photocurrent versus electrode potential, and of kinetic energy of electrons versus frequency
  - kinetic energy of emitted photoelectrons: $E_{k\,max} = hf - \phi$, using energy units of joule and electron-volt
  - effects of intensity of incident irradiation on the emission of photoelectrons
- describe the limitation of the wave model of light in explaining experimental results related to the photoelectric effect

Matter as particles or waves

- interpret electron diffraction patterns as evidence for the wave-like nature of matter
- distinguish between the diffraction patterns produced by photons and electrons
- calculate the de Broglie wavelength of matter: $\lambda = \frac{h}{p}$

Similarities between light and matter

- discuss the importance of the idea of quantisation in the development of knowledge about light and in explaining the nature of atoms
- compare the momentum of photons and of matter of the same wavelength including calculations using: $p = \frac{h}{\lambda}$
- explain the production of atomic absorption and emission line spectra, including those from metal vapour lamps
- interpret spectra and calculate the energy of absorbed or emitted photons: $E = hf$
- analyse the emission or absorption of a photon by an atom in terms of a change in the electron energy state of the atom, with the difference in the states' energies being equal to the photon energy: $E = hf = \frac{hc}{\lambda}$
- describe the quantised states of the atom with reference to electrons forming standing waves, and explain this as evidence for the dual nature of matter
- interpret the single photon and the electron double slit experiment as evidence for the dual nature of light and matter

Einstein's special theory of relativity

- describe the limitation of classical mechanics when considering motion approaching the speed of light
- describe Einstein's two postulates for his special theory of relativity that:
  - the laws of physics are the same in all inertial (non-accelerated) frames of reference
  - the speed of light has a constant value for all observers regardless of their motion or the motion of the source
- interpret the null result of the Michelson-Morley experiment as evidence in support of Einstein's special theory of relativity
- compare Einstein's special theory of relativity with the principles of classical physics
- describe proper time (t_0) as the time interval between two events in a reference frame where the two events occur at the same point in space
- describe proper length (L_0) as the length that is measured in the frame of reference in which objects are at rest
- model mathematically time dilation and length contraction at speeds approaching *c* using the equations: $t = \gamma t_0$ and $L = \frac{L_0}{\gamma}$ where $\gamma = \frac{1}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}}$
- explain and analyse examples of special relativity including that:
  - muons can reach Earth even though their half-lives would suggest that they should decay in the upper atmosphere
  - particle accelerator lengths must be designed to take the effects of special relativity into account
  - time signals from GPS satellites must be corrected for the effects of special relativity due to their orbital velocity

Relationship between energy and mass

- interpret Einstein's prediction by showing that the total 'mass-energy' of an object is given by: $E_{tot} = E_k + E_0 = \gamma mc^2$ where $E_0 = mc^2$, and where kinetic energy can be calculated by: $E_k = (\gamma - 1)mc^2$
- apply the energy-mass relationship to mass conversion in the Sun, to positron-electron annihilation and to nuclear transformations in particle accelerators (details of the particular nuclear processes are not required).

Area of Study 2

How is scientific inquiry used to investigate fields, motion or light?

Students undertake a student-designed scientific investigation in either Unit 3 or Unit 4, or across both Units 3 and 4. The investigation involves the generation of primary data relating to fields, motion or light. The investigation draws on knowledge and related key science skills developed across Units 3 and 4 and is undertaken by students in the laboratory and/or in the field.

When undertaking the investigation students are required to apply the key science skills to develop a question, state an aim, formulate a hypothesis and plan a course of action to answer the question, while complying with safety and ethical guidelines. Students then undertake an investigation to generate primary quantitative data, analyse and evaluate the data, identify limitations of data and methods, link experimental results to scientific ideas, discuss implications of the results, and draw and evaluate a conclusion in response to the question. Students are expected to design and undertake an investigation involving one continuous independent variable. The presentation format for the investigation is a scientific poster constructed according to the structure outlined on page 13. A logbook is maintained by the students for record, assessment and authentication purposes.

Outcome 2

On completion of this unit the student should be able to design and conduct a scientific investigation related to fields, motion or light, and present an aim, methodology and method, results, discussion and a conclusion in a scientific poster.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 2 and the related key science skills on pages 11 and 12 of the study design.

Key knowledge

Investigation design

- identify the physics concepts specific to the investigation and explain their significance, including definitions of key terms and physics representations
- explain the characteristics of the selected scientific methodology and method including: techniques of primary qualitative and quantitative data generation relevant to the selected investigation; and appropriateness of the use of independent, dependent and controlled variables in the selected scientific investigation
- identify and apply concepts of accuracy, precision, repeatability, reproducibility, resolution and validity of data; and the identification of, and distinction between, error and uncertainty
- identify and apply health, safety and ethical guidelines relevant to the selected investigation

Scientific evidence

- discuss the nature of evidence that supports or refutes a hypothesis, model or theory
- apply methods of organising, analysing and evaluating primary data to identify patterns and relationships including: the physical significance of the gradient of linearised data; causes of uncertainty; use of uncertainty bars; and assumptions and limitations of data, methodologies and methods
- model the scientific practice of using a logbook to authenticate generated primary data

Science communication

- apply the conventions of science communication: scientific terminology and representations; symbols, equations and formulas; standard abbreviations; significant figures; and units of measurement
- apply the conventions of scientific poster presentation, including succinct communication of the selected scientific investigation, and acknowledgement of references
- explain the key findings and implications of the selected investigation.

School-based assessment

Satisfactory completion

The award of satisfactory completion for a unit is based on whether the student has demonstrated the set of outcomes specified for the unit. Teachers should use a variety of learning activities and assessment tasks to provide a range of opportunities for students to demonstrate the key science skills and key knowledge in the outcomes.

The areas of study and key knowledge and relevant key science skills listed for the outcomes should be used for course design and the development of learning activities and assessment tasks.

Assessment of levels of achievement

The student's level of achievement in Unit 4 will be determined by School-assessed Coursework. School-assessed Coursework tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe.

Where teachers provide a range of options for the same School-assessed Coursework task, they should ensure that the options are of comparable scope and demand.

The types and range of forms of School-assessed Coursework for the outcomes are prescribed within the study design. The VCAA publishes Support materials for this study, which includes advice on the design of assessment tasks and the assessment of student work for a level of achievement.

Teachers will provide to the VCAA a numerical score representing an assessment of the student's level of achievement. The score must be based on the teacher's assessment of the performance of each student on the tasks set out in the following table.

Contribution to final assessment

School-assessed Coursework for Unit 4 will contribute 20 per cent to the study score.

Outcomes	Marks allocated	Assessment tasks
Outcome 1 Analyse and apply models that explain the nature of light and matter, and use special relativity to explain observations made when objects are moving at speeds approaching the speed of light.	**40**	**For Outcome 1** One task selected from: • application of physics concepts to explain a model, theory, device, design or innovation • analysis and evaluation of primary and/or secondary data, including data plotting, identified assumptions or data limitations, and conclusions • problem-solving, applying physics concepts and skills to real-world contexts • comparison and evaluation of two solutions to a problem, two explanations of a physics phenomenon or concept, or two methods and/or findings from practical activities. Each task can only be selected once across Units 3 and 4. For each task the time allocated should be approximately 50 minutes for a written response and 5 minutes for a multimodal or oral presentation.
Outcome 2 Design and conduct a scientific investigation related to fields, motion or light, and present an aim, methodology and method, results, discussion and a conclusion in a scientific poster.	**40**	**For Outcome 2** Communication of the design, analysis and findings of a student-designed and student-conducted scientific investigation through a structured scientific poster and logbook entries. The poster should not exceed 600 words.
Total marks	**80**	

Practical work

Practical work is a central component of learning and assessment and may include activities such as laboratory experiments, fieldwork, simulations, modelling and other direct experiences as described in the scientific investigation methodologies on page 13. A minimum of five hours of class time should be devoted to student practical activities and investigations in Area of Study 1. For Area of Study 2, a minimum of ten hours of class time should be devoted to designing and undertaking the student-designed scientific investigation and communicating findings.

External assessment

The level of achievement for Units 3 and 4 is also assessed by an end-of-year examination.

Contribution to final assessment

The examination will contribute 50 per cent to the study score.

End-of-year examination

Description

The examination will be set by a panel appointed by the VCAA. All the key knowledge that underpin the outcomes in Units 3 and 4 and key science skills are examinable.

Conditions

The examination will be completed under the following conditions:

- Duration: 2.5 hours.
- Date: end-of-year, on a date to be published annually by the VCAA.
- VCAA examination rules will apply. Details of these rules are published annually in the *VCE and VCAL Administrative Handbook*.
- The examination will be marked by assessors appointed by the VCAA.

Further advice

The VCAA publishes specifications for all VCE examinations on the VCAA website. Examination specifications include details about the sections of the examination, their weighting, the question format(s) and any other essential information. The specifications are published in the year prior to implementation of the revised Unit 3 and 4 sequence together with any sample material.