

Accreditation Period

Units 1 and 2

**2016–2022**

Units 3 and 4

**2017–2022**

Victorian Certificate of Education

# PHYSICS

STUDY DESIGN



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# Important information

## Accreditation period

Units 1 and 2: 1 January 2016 – 31 December 2022

Units 3 and 4: 1 January 2017 – 31 December 2022

Implementation for Units 1 and 2 of this study commences in January 2016.

Implementation for Units 3 and 4 of this study commences in January 2017.

## Sources of information

The [VCAA Bulletin](#) is the only official source of changes to regulations and accredited studies. The *VCAA Bulletin* also regularly includes advice on VCE studies. It is the responsibility of each VCE teacher to refer to each issue of the *VCAA Bulletin*. The *VCAA Bulletin* is available as an e-newsletter via free subscription on the VCAA's website at: [www.vcaa.vic.edu.au](http://www.vcaa.vic.edu.au).

To assist teachers in developing courses, the VCAA publishes online the *Advice for teachers*, which includes teaching and learning activities for Units 1–4, and advice on assessment tasks and performance level descriptors for School-assessed Coursework in Units 3 and 4.

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

VCE schools may reproduce parts of this study design for use by teachers. The full VCAA Copyright Policy is available at: [www.vcaa.vic.edu.au/Footer/Pages/Copyright.aspx](http://www.vcaa.vic.edu.au/Footer/Pages/Copyright.aspx).

# Introduction

## Scope of study

Physics seeks to understand and explain the physical world. It examines models and ideas used to make sense of the world and which are sometimes challenged as new knowledge develops. By looking at the way matter and energy interact through observations, measurements and experiments, physicists gain a better understanding of the underlying laws of nature.

VCE Physics provides students with opportunities to explore questions related to the natural and constructed world. The study provides a contextual approach to exploring selected areas within the discipline including atomic physics, electricity, fields, mechanics, thermodynamics, quantum physics and waves. Students also have options for study related to astrophysics, bioelectricity, biomechanics, electronics, flight, medical physics, nuclear energy, nuclear physics, optics, sound and sports science. Students examine classical and contemporary research, models and theories to understand how knowledge in physics has evolved and continues to evolve in response to new evidence and discoveries. An understanding of the complexities and diversity of physics leads students to appreciate the interconnectedness of the content areas both within physics, and across physics and the other sciences.

An important feature of undertaking a VCE science study is the opportunity for students to engage in a range of inquiry tasks that may be self-designed, develop key science skills and interrogate the links between theory and practice. In VCE Physics inquiry methodologies can include laboratory experimentation, local and remote data logging, simulations, animations and literature reviews. Investigation in physics is diverse and may take many forms including the design, building, testing and evaluation of a device; the investigation of the operation of a device; creating a solution to a scientific or technological problem; and the investigation of a physical phenomenon. Students work collaboratively as well as independently on a range of tasks. They pose questions, formulate hypotheses and collect, analyse and critically interpret qualitative and quantitative data. They analyse the limitations of data, evaluate methodologies and results, justify conclusions, make recommendations and communicate their findings. Students investigate and evaluate issues, changes or alternative proposals by considering both shorter and longer term consequences for the individual, environment and society. Knowledge of the safety considerations associated with physics investigations is integral to the study of VCE Physics.

As well as an increased understanding of scientific processes, students 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, social and political contexts of scientific endeavours.

## Rationale

Physics is a natural science based on observations, experiments, measurements and mathematical analysis with the purpose of finding quantitative explanations for phenomena occurring from the subatomic scale through to the planets, stellar systems and galaxies in the Universe. While much scientific understanding in physics has stood the test of time, many other areas continue to evolve. In undertaking this study, students develop their understanding of the roles of careful and systematic experimentation and modelling in the development of theories and laws. They undertake practical activities and apply physics principles to explain and quantify both natural and constructed phenomena.

In VCE Physics students develop a range of inquiry skills involving practical experimentation and research, analytical skills including critical and creative thinking, and communication skills. Students use scientific and cognitive skills and understanding to analyse contemporary physics-related issues and to communicate their views from an informed position.

VCE Physics provides for continuing study pathways within the discipline and leads to a range of careers. Physicists may undertake research and development in specialist areas including acoustics, astrophysics and cosmology, atmospheric physics, computational physics, education, energy research, engineering, instrumentation, lasers and photonics, medical physics, nuclear science, optics, pyrotechnics and radiography. Physicists also work in cross-disciplinary areas such as bushfire research, climate science, forensic science, geology, materials science, neuroscience and sports science.

## 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:

- understand the cooperative, cumulative, evolutionary and interdisciplinary nature of science as a human endeavour, including its possibilities, limitations and political and sociocultural influences
- develop a range of individual and collaborative science investigation skills through experimental and inquiry tasks in the field and in the laboratory
- develop an informed perspective on contemporary science-based issues of local and global significance
- apply their scientific understanding to familiar and to unfamiliar situations, including personal, social, environmental and technological contexts
- develop attitudes that include curiosity, open-mindedness, creativity, flexibility, integrity, attention to detail and respect for evidence-based conclusions
- understand and apply the research, ethical and safety principles that govern the study and practice of the discipline in the collection, analysis, critical evaluation and reporting of data
- communicate clearly and accurately an understanding of the discipline using appropriate terminology, conventions and formats.

## Structure

The study is made up of four units:

Unit 1: What ideas explain the physical world?

Unit 2: What do experiments reveal about the physical world?

Unit 3: How do fields explain motion and electricity?

Unit 4: How can two contradictory models explain both light and matter?

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 key science skills.

The study is structured under a series of curriculum framing questions that reflect the inquiry nature of the discipline.

## Entry

There are no prerequisites for entry to Units 1, 2 and 3. Students must undertake Unit 3 prior to undertaking Unit 4. Students entering Unit 3 without Units 1 and/or 2 may be required to undertake additional preparation as prescribed by their teacher. Units 1 to 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 over the duration of a semester.

## Changes to the study design

During its period of accreditation minor changes to the study will be announced in the [VCAA Bulletin](#). The *VCAA 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 *VCAA 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

This 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 work. All laboratory work should be supervised by the teacher. It is the responsibility of schools to ensure that they comply with health and safety requirements.

Relevant acts and regulations include:

- *Occupational Health and Safety Act 2004*
- *Occupational Health and Safety Regulations 2007*
- *Occupational Health and Safety Management Systems (AS/NZ 4801)*
- *Dangerous Goods (Storage and Handling) Regulations 2012*
- *Dangerous Goods Storage and Handling Code of Practice 2000*
- *Hazardous Substances Code of Practice 2000*
- *Electrical Safety Act 1998*

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 licence 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 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 appliance.

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 *Advice for teachers* companion document provides 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.

# 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 the VCE study designs.

The student's level of achievement in Units 3 and 4 will be determined by School-assessed Coursework (SACs) and/or School-assessed Tasks (SATs) as specified in the VCE study designs, 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 and receive 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: 21 per cent
- Unit 4 School-assessed Coursework: 19 per cent
- End-of-year examination: 60 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 procedures.

# Cross-study specifications

## Units 1–4: Key science skills

The development of a set of key science skills is a core component of the study of VCE Physics and applies across Units 1 to 4 in all areas of study. In designing teaching and learning programs and in assessing student learning for each unit, teachers should ensure that students are given the opportunity to develop, use and demonstrate these skills in a variety of contexts 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	<ul style="list-style-type: none"> <li>determine aims, hypotheses, questions and predictions that can be tested</li> <li>identify independent, dependent and controlled variables</li> </ul>
Plan and undertake investigations	<ul style="list-style-type: none"> <li>determine appropriate type of investigation: conduct experiments; design-build-test-evaluate a device; explore operation of a device; solve a scientific or technological problem; perform simulations; access secondary data, including data sourced through the internet that would otherwise be difficult to source as raw or primary data through a laboratory or a classroom</li> <li>select and use equipment, materials and procedures appropriate to the investigation, taking into account potential sources of error and uncertainty</li> </ul>
Comply with safety and ethical guidelines	<ul style="list-style-type: none"> <li>apply ethical principles when undertaking and reporting investigations</li> <li>apply relevant occupational health and safety guidelines while undertaking practical investigations</li> </ul>
Conduct investigations to collect and record data	<ul style="list-style-type: none"> <li>work independently and collaboratively as appropriate and within identified research constraints</li> <li>systematically generate, collect, record and summarise both qualitative and quantitative data</li> </ul>
Analyse and evaluate data, methods and scientific models	<ul style="list-style-type: none"> <li>process quantitative data using appropriate mathematical relationships, units and number of significant figures</li> <li>organise, present and interpret data using tables, line graphs, correlation, line of best fit, calculations of mean and fitting an appropriate curve to graphical data, including the use of error bars on graphs</li> <li>take a qualitative approach when identifying and analysing experimental data with reference to accuracy, precision, reliability, validity, uncertainty and errors (random and systematic)</li> <li>explain the merit of replicating procedures and the effects of sample sizes to obtain reliable data</li> <li>evaluate investigative procedures and possible sources of bias, and suggest improvements</li> <li>explain how models are used to organise and understand observed phenomena and concepts related to physics, identifying limitations of the models</li> </ul>

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Key science skill	VCE Physics Units 1–4
Draw evidence-based conclusions	<ul style="list-style-type: none"><li>• determine to what extent evidence from an investigation supports the purpose of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation</li><li>• draw conclusions consistent with evidence and relevant to the question under investigation</li><li>• identify, describe and explain the limitations of conclusions, including identification of further evidence required</li><li>• critically evaluate various types of information related to physics from journal articles, mass media and opinions presented in the public domain</li><li>• discuss the implications of research findings and proposals</li></ul>
Communicate and explain scientific ideas	<ul style="list-style-type: none"><li>• use appropriate physics terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement</li><li>• discuss relevant physics information, ideas, concepts, theories and models and the connections between them</li><li>• identify and explain formal physics terminology about investigations and concepts</li><li>• use clear, coherent and concise expression</li><li>• acknowledge sources of information and use standard scientific referencing conventions</li></ul>

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## 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. Students maintain a logbook of practical activities in each unit of this study for recording, authentication and assessment purposes.

Students communicate findings for the investigation in Outcome 3, Unit 4 of this study in a scientific poster. The poster may be produced electronically or in hard copy format and should not exceed 1000 words. Students must select information carefully so that they meet the word limit. The production quality of the poster will not form part of the assessment.

The following template is to be used by students in the development of the scientific poster for the investigation undertaken.

Section	Content and activities
Title	Question under investigation is the title
Introduction	Explanation or reason for undertaking the investigation, including a clear aim, a hypothesis and/or prediction and relevant background physics concepts
Methodology	Summary that outlines the methodology used in the investigation and is authenticated by logbook entries Identification and management of relevant risks, including the relevant health, safety and ethical guidelines followed in the investigation
Results	Presentation of collected data/evidence in appropriate format to illustrate trends, patterns and/or relationships
Discussion	Analysis and evaluation of primary data Identification of outliers and their subsequent treatment Identification of limitations in data and methods, and suggested improvements Linking of results to relevant physics concepts
Conclusion	Conclusion that provides a response to the question
References and acknowledgments	Referencing and acknowledgment of all quotations and sourced content as they appear in the poster

# Unit 1: What ideas explain the physical world?

Ideas in physics are dynamic. As physicists explore concepts, theories evolve. Often this requires the detection, description and explanation of things that cannot be seen. In this unit students explore how physics explains phenomena, at various scales, which are not always visible to the unaided human eye. They examine some of the fundamental ideas and models used by physicists in an attempt to understand and explain the world. Students consider thermal concepts by investigating heat, probe common analogies used to explain electricity and consider the origins and formation of matter.

Students use thermodynamic principles to explain phenomena related to changes in thermal energy. They apply thermal laws when investigating energy transfers within and between systems, and assess the impact of human use of energy on the environment. Students examine the motion of electrons and explain how it can be manipulated and utilised. They explore current scientifically accepted theories that explain how matter and energy have changed since the origins of the Universe.

Students undertake quantitative investigations involving at least one independent, continuous variable.

## Area of Study 1

### How can thermal effects be explained?

In this area of study students investigate the thermodynamic principles related to heating processes, including concepts of temperature, energy and work. 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 in order to consider debates related to climate science.

## Outcome 1

On completion of this unit the student should be able to apply thermodynamic principles to analyse, interpret and explain changes in thermal energy in selected contexts, and describe the environmental impact of human activities with reference to thermal effects and climate science concepts.

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

#### Thermodynamics principles

- convert temperature between degrees Celsius and kelvin
- describe the Zeroth Law of Thermodynamics as two bodies in contact with each other coming to a thermal equilibrium
- describe temperature with reference to the average kinetic energy of the atoms and molecules within a system
- investigate and apply theoretically and practically the First Law of Thermodynamics to simple situations:  $Q = U + W$
- explain internal energy as the energy associated with random disordered motion of molecules
- distinguish between conduction, convection and radiation with reference to heat transfers within and between systems

- 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:  $Q = mL$
- explain why cooling results from evaporation using a simple kinetic energy model.

### Thermodynamics and climate science

- identify regions of the electromagnetic spectrum as radio, microwave, infrared, visible, ultraviolet, x-ray and gamma waves
- describe electromagnetic radiation emitted from the Sun as mainly ultraviolet, visible and infrared
- calculate the peak wavelength of the re-radiated electromagnetic radiation from Earth using Wien's Law:  $\lambda_{\text{max}} T = \text{constant}$
- compare the total energy across the electromagnetic spectrum emitted by objects at different temperatures such as the Sun
- describe power radiated by a body as being dependent on the temperature of the body according to the Stefan-Boltzmann Law,  $P \propto T^4$
- explain the roles of conduction, convection and radiation in moving heat around in Earth's mantle (tectonic movement) and atmosphere (weather)
- model the greenhouse effect as the flow and retention of thermal energy from the Sun, Earth's surface and Earth's atmosphere
- explain how greenhouse gases in the atmosphere (including methane, water and carbon dioxide) absorb and re-emit infrared radiation
- analyse changes in the thermal energy of the surface of Earth and of Earth's atmosphere
- analyse the evidence for the influence of human activity in creating an enhanced greenhouse effect, including affecting surface materials and the balance of gases in the atmosphere.

### Issues related to thermodynamics

- apply thermodynamic principles to investigate at least one issue related to the environmental impacts of human activity with reference to the enhanced greenhouse effect:
  - proportion of national energy use due to heating and cooling of homes
  - comparison of the operation and efficiencies of domestic heating and cooling systems: heat pumps; resistive heaters; reverse-cycle air conditioners; evaporative coolers; solar hot water systems; and/or electrical resistive hot water systems
  - possibility of homes being built that do not require any active heating or cooling at all
  - use of thermal imaging and infrared thermography in locating heating losses in buildings and/or system malfunctions; cost savings implications
  - determination of the energy ratings of home appliances and fittings: insulation; double glazing; window size; light bulbs; and/or electrical gadgets, appliances or machines
  - cooking alternatives: appliance options (microwave, convection, induction); fuel options (gas, electricity, solar, fossil fuel)
  - automobile efficiencies: fuel options (diesel petrol, LPG and electric); air delivery options (naturally aspirated, supercharged and turbocharged); and fuel delivery options (common rail, direct injection and fuel injection)
- explain how concepts of reliability, validity and uncertainty relate to the collection, interpretation and communication of data related to thermodynamics and climate science.

## Area of Study 2

### How do electric circuits work?

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.

### Outcome 2

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 2 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
- explore 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  $R = \text{constant}$  for ohmic devices
  - equivalent effective resistance in arrangements in
    - series:  $R_T = R_1 + R_2 + \dots + R_n$  and
    - parallel:  $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$
- calculate and analyse the effective resistance of circuits comprising parallel and series resistance and 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 transducers.

**Electrical safety**

- model household electricity connections as a simple 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 treatment of electric shock in homes and identify the approximate danger thresholds for current and duration.

## Area of Study 3

### What is matter and how is it formed?

In this area of study students explore the nature of matter, and consider the origins of atoms, time and space. They examine the currently accepted theory of what constitutes the nucleus, the forces within the nucleus and how energy is derived from the nucleus.

## Outcome 3

On completion of this unit the student should be able explain the origins of atoms, the nature of subatomic particles and how energy can be produced by atoms.

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****Origins of atoms**

- describe the Big Bang as a currently held theory that explains the origins of the Universe
- describe the origins of both time and space with reference to the Big Bang Theory
- explain the changing Universe over time due to expansion and cooling
- apply scientific notation to quantify and compare the large ranges of magnitudes of time, distance, temperature and mass considered when investigating the Universe
- explain the change of matter in the stages of the development of the Universe including inflation, elementary particle formation, annihilation of anti-matter and matter, commencement of nuclear fusion, cessation of fusion and the formation of atoms.

### Particles in the nucleus

- explain nuclear stability with reference to the forces that operate over very small distances
- describe the radioactive decay of unstable nuclei with reference to half-life
- model radioactive decay as random decay with a particular half-life, including mathematical modelling with reference to whole half-lives
- apply a simple particle model of the atomic nucleus to explain the origin of  $\alpha$ ,  $\beta^-$ ,  $\beta^+$  and  $\gamma$  radiation, including changes to the number of nucleons
- explain nuclear transformations using decay equations involving  $\alpha$ ,  $\beta^-$ ,  $\beta^+$  and  $\gamma$  radiation
- analyse decay series diagrams with reference to type of decay and stability of isotopes
- relate predictions to the subsequent discoveries of the neutron, neutrino, positron and Higgs boson
- describe quarks as components of subatomic particles
- distinguish between the two types of forces holding the nucleus together: the strong nuclear force and the weak nuclear force
- 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 they will annihilate each other to create radiation.

### Energy from the atom

- explain nuclear energy as energy resulting from the conversion of mass:  $E = mc^2$
- compare the processes of nuclear fusion and nuclear fission
- explain, using a binding energy curve, why both fusion and fission are reactions that produce energy
- explain light as an electromagnetic wave that is produced by the acceleration of charges
- describe the production of synchrotron radiation by an electron radiating energy at a tangent to its circular path
- model the production of light as a result of electron transitions between energy levels within an atom.

## 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 knowledge and key skills in the outcomes.

The areas of study, including the key knowledge and key science skills 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.

Suitable tasks for assessment may be selected from the following:

*For Outcomes 1, 2 and 3*

- an annotated folio of practical activities
- data analysis
- design, building, testing and evaluation of a device
- an explanation of the operation of a device

- 
- a proposed solution to a scientific or technological problem
  - a report of a selected physics phenomenon
  - a modelling activity
  - a media response
  - a summary report of selected practical investigations
  - a reflective learning journal/blog related to selected activities or in response to an issue
  - a test comprising multiple choice and/or short answer and/or extended response.

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

Practical work is a central component of learning and assessment. As a guide, between 3½ and 5 hours of class time should be devoted to student practical work and investigations in each of Areas of Study 1 and 2 and to investigations in Area of Study 3 involving the use of secondary data and/or modelling.

# Unit 2: What do experiments reveal about the physical 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. Students make direct observations of physics phenomena and examine the ways in which phenomena that may not be directly observable can be explored through indirect observations.

In the core component of this unit students investigate the ways in which forces are involved both in moving objects and in keeping objects stationary. Students choose one of twelve options related to astrobiology, astrophysics, bioelectricity, biomechanics, electronics, flight, medical physics, nuclear energy, nuclear physics, optics, sound and sports science. The option enables students to pursue an area of interest by investigating a selected question.

Students design and undertake investigations involving at least one independent, continuous variable. A student-designed practical investigation relates to content drawn from Area of Study 1 and/or Area of Study 2 and is undertaken in Area of Study 3.

## Area of Study 1

### How can motion be described and explained?

In this area of study students observe motion and explore the effects of balanced and unbalanced forces on motion. They analyse motion using concepts of energy, including energy transfers and transformations, and apply mathematical models during experimental investigations of motion. Students model how the mass of finite objects can be considered to be at a point called the centre of mass. They describe and analyse graphically, numerically and algebraically the motion of an object, using specific physics terminology and conventions.

## Outcome 1

On completion of this unit the student should be able to investigate, analyse and mathematically model the motion of particles and bodies.

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:  
 $v = u + at$ ,  $v^2 = u^2 + 2as$ ,  $s = \frac{1}{2}(u + v)t$ ,  $s = ut + \frac{1}{2}at^2$ ,  $s = vt - \frac{1}{2}at^2$
- graphically analyse 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:  $F_{net} = \frac{\Delta p}{\Delta t}$
- model the force due to gravity,  $F_g$ , as the force of gravity acting at the centre of mass of a body,  $F_g = mg$ , where  $g$  is the gravitational field strength ( $9.8 \text{ N kg}^{-1}$  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 reaction forces
- calculate torque:  $\tau = r_{\perp} F$
- investigate and analyse theoretically and practically translational forces and torques in simple structures that are in rotational equilibrium.

**Energy and motion**

- apply the concept of work done by a constant force using:
  - work done = constant force  $\times$  distance moved in direction of force:  $W = Fs$
  - work done = area under force-distance graph
- investigate and analyse theoretically and practically Hooke's Law for an ideal spring:  $F = -k\Delta x$
- analyse and model mechanical energy transfers and transformations using energy conservation:
  - changes in gravitational potential energy near Earth's surface:  $E_g = mg\Delta h$
  - potential energy in ideal springs:  $E_s = \frac{1}{2}k\Delta x^2$
  - 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 (momentum transfer) in an isolated system (for collisions between objects moving in a straight line):  $I = \Delta p$
- investigate and analyse theoretically and practically momentum conservation in one dimension.

**Area of Study 2****Options**

Twelve 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:

- What are stars?
- Is there life beyond Earth's Solar System?
- How do forces act on the human body?
- How can AC electricity charge a DC device?
- How do heavy things fly?
- How do fusion and fission compare as viable nuclear energy power sources?
- How is radiation used to maintain human health?
- How do particle accelerators work?
- How can human vision be enhanced?

- How do instruments make music?
- How can performance in ball sports be improved?
- How does the human body use electricity?

## Option 2.1: What are stars?

Observations of the night sky have changed over time from using just the naked eye to the use of sophisticated instruments. This option involves the examination of the birth, life and death of stars in the Universe. Students explore how the properties of starlight can provide information, including the star's distance from Earth, its temperature, composition, age and future.

### Outcome 2.1

On completion of this unit the student should be able to apply concepts of light and nuclear physics to describe and explain the genesis and life cycle of stars, and describe the methods used to gather this information.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Astronomical measurement

- explain the use of electromagnetic radiation in collecting information about the Universe
- identify all electromagnetic waves as travelling at the same speed,  $c$ , in a vacuum
- calculate wavelength, frequency, period and speed of light:  $c = f\lambda$ ,  $T = \frac{1}{f}$
- identify spectroscopy as a tool to investigate the light from stars, and interpret and analyse spectroscopic data with reference to the properties of stars
- apply methods used for measurements of the distances to stars and galaxies (standard candles, parallax, red shift) to analyse secondary data.

##### Classification of stars

- describe the Sun as a typical star, including size, mass, energy output, colour and information obtained from the Sun's radiation spectrum
- identify the properties of stars, including luminosity, radius and mass, temperature and spectral type, and explain how these properties are used to classify stars
- explain nuclear fusion as the energy source of a star including:  $E = mc^2$
- distinguish between the different nuclear fusion phenomena that occur in stars of various sizes.

##### Stellar life cycle

- apply the Hertzsprung–Russell diagram as a tool to describe the evolution and death of stars with differing initial mass
- relate the formation of stars to the formation of galaxies and planets
- describe future scenarios for a star, including white dwarfs, neutron stars and black holes
- 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
- compare the Milky Way galaxy to other galaxies with different shape, colour or size
- explain and analyse how the chemical composition of stars and galaxies is used to determine their age
- investigate selected aspects of stellar life cycles by interpreting and applying appropriate data from relevant databases.

## Option 2.2: Is there life beyond Earth's Solar System?

In this option 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.

### Outcome 2.2

On completion of this unit the student should be able to apply concepts of light and atomic physics to describe and analyse the search for life beyond Earth's Solar System.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Information from beyond Earth's Solar System

- identify the spectrum of electromagnetic radiation as the basis for all observations of the Universe
- explain how emission and absorption line spectra are produced with reference to the transition of electrons between energy levels of the atom
- 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
- describe how planets can be identified by using the common centre of mass and the gravitational effect of a planetary system on a star.

##### Locating extrasolar planets

- compare methods of exoplanet detection including astrometric, radial velocity, transit method and microlensing, referring to databases that differentiate for size, eccentricity and radius
- explain and apply Doppler shift including spectral shift and 'wobble' of planetary systems using:  $\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$
- investigate how the composition of an exoplanet can be determined using spectral analysis.

##### Conditions for life beyond Earth's Solar System

- explain the presence of liquid water as determining the habitable zones of a star system and the most likely place for life
- explain the origins of life in the Universe as having come from organic molecules in space, or as originating on Earth or an Earth-like planet through reactions of elements and compounds.

##### Possibility of life beyond Earth's Solar System

- explain the use of the Fermi paradox to question the possibility of life outside Earth's Solar System and identify its counter arguments
- apply the Drake equation:  $N = R^* f_p n_c f_l f_i f_c L$ , as a way of predicting the likelihood of life existing in the Universe by making reasonable assumptions based on evidence and speculation
- 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 why the radio spectrum is the best section of the electromagnetic spectrum to search the sky for possible ETI signals, including the cosmic radio window and the use of radio astronomy in the search
- explain the nature of information that humans transmit beyond Earth to signal that intelligent life exists on Earth.

## Option 2.3: How do forces act on the human body?

This option involves the application of mechanical theories and concepts 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 context of the human body and in the development and design of prosthetics.

### Outcome 2.3

On completion of this unit the student should be able to analyse the physical properties of organic materials including bone, tendons and muscle, and explain the uses and effects of forces and loads on the human body.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Forces in the human body

- identify different types of external forces, including gravitational forces, that can act on a body to create compression, tension and shear
- apply centre of mass calculations to a body or system:  $x_m = \frac{x_1 m_1 + x_2 m_2 + \dots + x_n m_n}{m_1 + m_2 + \dots + m_n}$
- investigate and apply theoretically and practically translational forces and torques ( $\tau = r_{\perp} F$ ) in simple lever models of human joints under load.

##### Materials in the human body

- 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:  $\sigma = \frac{F}{A}$  and  $\varepsilon = \frac{\Delta l}{l}$
- compare the behaviour of living tissue under load with reference to extension and compression, including Young's modulus:  $E = \frac{\sigma}{\varepsilon}$
- investigate how the behaviour of living tissue under load compares with common building materials, including wood and metals
- 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
- calculate the potential energy stored in a material under load (strain energy) using area under stress versus strain graph
- investigate the elastic or plastic behaviour of materials under load, for example skin and membranes.

##### Materials used to replace body parts

- investigate the development of artificial materials and structures for use in prosthetics, including external prostheses for the replacement of lost limbs, and internal prostheses such as hip or valve replacements
- identify the difficulties and problems with implanting materials within the human body
- compare the performance of artificial limbs with natural limbs with reference to function and longevity.



## Option 2.4: How can AC electricity charge a DC device?

This option investigates 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. 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.

### Outcome 2.4

On completion of this unit the student should be able to construct, test and analyse circuits that change AC voltage to a regulated DC power supply, and explain the use of transducers to transfer energy.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### 240 V AC to 6 V DC

- 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
- analyse systems, including fault diagnosis, following selection and use of appropriate test equipment
- interpret a display on an oscilloscope with reference to voltage as a function of time.

#### Data transfer

- 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
- evaluate the use of circuits for particular purposes using technical specifications related to potential difference (voltage drop), current, resistance, power, temperature and illumination
- compare different light sources (bulbs, LEDs, lasers) for their suitability for data transfer
- explain the use of optical fibres for short and long distance telecommunications.

## Option 2.5: How do heavy things fly?

This option enables students to 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.

### Outcome 2.5

On completion of this unit the student should be able to apply concepts of flight to investigate and explain the motion of objects through fluids.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

## Key knowledge

### Aerodynamics

- model the forces acting on an aircraft in flight as lift, drag, the force due to gravity and thrust
- identify aerodynamic forces as arising from the movement of fluid over an object
- 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 changes in aerodynamic behaviour at supersonic speeds, including compressibility, shock wave formation and increase in drag
- explain the production of thrust with reference to Newton's laws of motion
- investigate how it is possible for an aircraft to generate lift when flying upside down.

### Manipulating flight

- calculate lift and drag forces acting on an aircraft:
  - lift:  $F_L = \frac{1}{2} C_L \rho v^2 A$
  - drag:  $F_D = \frac{1}{2} C_D \rho v^2 A$
- investigate theoretically and practically the variation of lift coefficient with angle of attack, including identification of stall
- model aerodynamic forces as acting at the centre of pressure and the force due to gravity as acting at the centre of mass
- calculate the torque applied by a force acting on an aircraft:  $\tau = r_{\perp} F$
- describe the roles of the rudder, elevator and ailerons as the primary control surfaces on an aircraft
- apply balance of forces and torques with reference to Newton's laws of motion to:
  - controlling an aircraft in roll, pitch and yaw
  - stages of flight, including takeoff, climb, cruise, descent, landing and manoeuvres
- explain the possible advantages and difficulties in designing an unconventional aircraft, such as a flying wing.

### Applications of flight

- apply aerodynamics principles beyond conventional aircraft to investigate practically and/or theoretically at least one of:
  - strategies to improve the efficiency of cars by reducing drag area ( $C_D A$ )
  - the design and use of aerofoil shapes to produce forces in propellers, wind turbines, racing cars or submarines
  - improving lift in boomerangs, kites or helicopters
  - the production of thrust using propellers, jet engines and rockets.

## Option 2.6: How do fusion and fission compare as viable nuclear energy power sources?

Fission and fusion are nuclear reactions that produce relatively large quantities of energy from comparatively small quantities of fuel. This option enables students to compare the production of energy from fission and fusion reactions. They study a model of the atom that explains the source of the large amounts of energy produced. Students explore the viability of using nuclear power as an energy source and evaluate its benefits and risks.

### Outcome 2.6

On completion of this unit the student should be able to apply the concepts of nuclear physics to describe and analyse nuclear energy as a power source.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Energy from the nucleus

- 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  $^{235}\text{U}$  and  $^{239}\text{Pu}$  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  $^{238}\text{U}$ , including formation of  $^{239}\text{Pu}$
- explain fission chain reactions including:
  - the effect of mass and shape on criticality
  - neutron absorption and moderation

##### Nuclear energy as a power source

- compare nuclear fission and fusion with reference to:
  - energy released per nucleon and percentage of the mass that is transformed into energy
  - availability of reactants
  - limitations as a source of energy for electricity production
  - environmental impact
- analyse fission and fusion with reference to their viabilities as energy sources
- 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.

## Option 2.7: How is radiation used to maintain human health?

In this option students use concepts of nuclear physics to 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.

### Outcome 2.7

On completion of this unit the student should be able to use nuclear physics concepts to describe and analyse applications of electromagnetic radiation and particle radiation in medical diagnosis and treatment.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Radiation and the human body

- distinguish between electromagnetic radiation and particle 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
- analyse decay series diagrams of medical radioisotopes with reference to type of decay and stability of isotopes
- compare ionising and non-ionising radiation with reference to how each affects living tissues and cells
- explain the effects of  $\alpha$ ,  $\beta$  and  $\gamma$  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).

##### The use of radiation in diagnosis and treatment of human illness and disease

- compare the processes of, and images produced by, medical imaging using two or more of X-rays, computed tomography (CT),  $\gamma$  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
- explain the use of medical radioisotopes in therapy including the effects on healthy and damaged tissues and cells
- relate the detection and penetrating properties of  $\alpha$ ,  $\beta$  and  $\gamma$  radiation to their use in different medical applications
- analyse the strengths and limitations of a selected contemporary diagnostic or therapeutic radiation technique.

## Option 2.8: How do particle accelerators work?

In this option students explore the function and use of particle accelerators to produce radiation and to collide particles. 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 allows theories of the early Universe to be developed and challenged. Students investigate the development of, and comparisons between, various accelerator technologies. Particle accelerators and colliders include the Australian Synchrotron and the Large Hadron Collider.

## Outcome 2.8

On completion of this unit the student should be able to apply the principles related to the behaviour of charged particles in the presence of electric and magnetic fields to describe and analyse the use of accelerator technologies in high energy physics.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

### Key knowledge

#### Particle accelerators and the production of light

- distinguish between the use of particle accelerators to produce synchrotron light and to collide particles
- distinguish between the capabilities of a particle collider and the capabilities of the Australian Synchrotron
- 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.

#### Accelerator technology and the development of modern particle physics

- 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
- describe the products of collisions with reference to symbol, charge, rest energy and lifespan
- compare the physical designs and purposes of particle detectors at the Large Hadron Collider including ATLAS, CMS, ALICE and LHCb.

#### Current and future applications of accelerator technology for society

- 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
- describe at least one application of particle accelerators selected from:
  - materials analysis and modification which results in the improvement of consumer products such as heat-shrinkable film and chocolate
  - implanting of ions in silicon chips to make them more effective in electronic products such as computers and smart phones
  - nuclear energy applications such as the use of thorium as an alternative fuel for the production of nuclear energy or the treatment of nuclear waste
  - pharmaceutical research involving the analysis of protein structure leading to the development of new pharmaceuticals to treat major diseases
  - DNA research involving the analysis of protein metabolism leading to the development of new antibiotics
  - medical applications such as the production of a range of radioisotopes for medical diagnostics and treatments or cancer therapy through the use of particle beams
  - use of spectrometry in environmental monitoring or the use of blasts of electrons in the treatment of pollution such as contaminated water, sewage sludge and gases from smokestacks
  - use of particle accelerators in a selected experiment or scientific endeavour
- investigate current and proposed future directions of collider technologies.

## Option 2.9: How can human vision be enhanced?

In this option 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.

### Outcome 2.9

On completion of this unit the student should be able to apply a ray model of light and the concepts of reflection and refraction to explain the operation of optical instruments and the human eye, and describe how human vision can be enhanced.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Behaviour of light

- identify that light travels in straight lines in a uniform medium
- investigate and apply theoretically and practically the two laws of reflection at a plane surface:
  - the angle of incidence is equal to the angle of reflection
  - the incident ray, reflected ray and the normal at the point of incidence are coplanar
- investigate theoretically and practically refraction using Snell's Law,  $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ .

##### Manipulating light for a purpose

- 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.

##### Light and the eye

- model and explain human vision as refraction at a spherical surface with an adjusting lens
- 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
- explain accommodation in the human eye including the effects of ageing
- investigate and explain the treatment of cataract blindness including the use of intraocular lenses
- investigate the operation of the bionic eye.

## Option 2.10: How do instruments make music?

In this option students explore models and ideas about sound in the contexts of music and hearing. Students examine how the wave model is applied in the design and development of musical instruments including the voice. They investigate the effects of sound and consider why certain chord progressions and cadences are more appealing to the human ear than others.

### Outcome 2.10

On completion of this unit the student should be able to apply a wave model to describe and analyse the production of sound in musical instruments, and explain why particular combinations of sounds are more pleasing to the human ear than others.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Concepts used to model sound

- describe sound as the transmission of energy via longitudinal pressure waves
- analyse sound using wavelength, frequency and speed of propagation of sound waves:  $v = f\lambda$
- 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
- analyse a standing wave as the superposition of a travelling wave and its reflection.

##### Sound production

- explain resonance and identify it as related to the natural frequency of an object
- investigate factors that influence natural frequency including shape and material and explain how this relates to instruments
- investigate and explain the human voice box as a resonance chamber with vibration provided by vocal cords
- 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
- analyse the unique sound of an instrument as a consequence of multiple resonances created by the instrument and described as timbre
- investigate how the amount of diffraction around an obstacle varies with the size of the obstacle and the wavelength of the sound.

##### Sound detection

- describe the structure of the human ear with reference to the transfer and amplification of vibrations
- interpret the frequency response curve of the human ear
- differentiate between pitch, timbre and loudness
- identify the representation of timbre as a combination of specific frequencies
- describe how particular musical intervals can be represented as ratios of their frequencies, and how consonant frequencies tend to have simple ratios
- investigate the phenomenon of beats.
- investigate an aspect of contemporary research in psychoacoustics.

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

In this option students investigate the physics of ball sports using mechanics concepts including Newton's laws of motion. Students 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. Students may explore ideas in a selected sport of interest or may choose a range of ball sports to investigate.

### Outcome 2.11

On completion of this unit the student should be able to apply concepts of linear, rotational and fluid mechanics to explain movement in ball sports.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Motion of sports balls

- 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:  $v = r\omega$ .

##### Maximising flight

- model and describe qualitatively the energy transfers in the action of a double pendulum in at least one of the following:
  - the swing of a racquet, club, stick or bat
  - the throw, pitch or hurl of a ball
  - the kick of a ball
- calculate air resistance (drag) and terminal velocity:  $F_d = \frac{1}{2} C_d \rho v^2 A$
- 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
- analyse and explain the relative influence of dynamics factors that affect the performance of equipment in ball sports.



## Option 2.12: How does the human body use electricity?

In this option students focus on the production of potential difference and subsequent currents in the human body. They explore the role of electricity in nerve transmission, in sensation, and in the heart. The effects of current through the body are considered, including the operation of artificial stimulators and the use of heart defibrillators to restore heart beat. Students investigate an issue related to the production or use of electricity by the body.

### Outcome 2.12

On completion of this unit the student should be able to explain the electrical behaviour of the human body and apply electricity concepts to biological contexts.

To achieve this outcome the student will draw on key knowledge outlined below and apply the key science skills on [pages 11 and 12](#) of the study design.

#### Key knowledge

##### Electrical signals in the human body

- compare charge carriers in the human body (specifically  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{PO}_4^{3-}$  and  $\text{Cl}^-$  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)
- describe electrical signalling in the body as occurring through electrical pulses
- 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
- 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.

##### Effects of electricity applied to the body

- describe the general principle of operation of artificial stimulators such as heart pacemakers and cochlear implants
- describe the effects of current through, and potential difference across, the human body
- relate various sensations (tingling, taste) to amplitude of current flowing through the body
- explain how a defibrillator works by storing electric charge for rapid production of large-amplitude current to restore heart rhythm.

##### Applications of electricity involving the human body

- apply concepts of resistance and capacitance to current and the frequency of pulses (time constant for charging and discharging,  $\tau = RC$ )
- apply concepts of current, resistance, potential difference (voltage drop), capacitance and power to the human body (quantitative analysis restricted to use of  $I = \frac{V}{R}$  and  $P = VI$ )
- explain why people have different electrical resistances with reference to comparison of the resistances in human bone, fat, muscle, nerves and skin
- apply electricity concepts to describe one of:
  - use of potential difference in biomedical diagnosis with reference to electrocardiograms (ECGs) and/or electroencephalographs (EEGs)
  - the galvanic skin response and its use in polygraphs and/or biotherapy feedback devices

- neuroplasticity after spinal cord injury and use of activity-based therapies
- use of the brain, through activated muscles, to control remote devices
- cauterisation of wounds through resistive heating
- action potentials involved in detecting light by photoreceptors (three types of cones for colour; rods for detecting light and dark changes, shapes and movement).

## Area of Study 3

### Practical investigation

Systematic experimentation is an important aspect of physics inquiry. In this area of study students design and conduct a practical investigation related to knowledge and skills developed in Area of Study 1 and/or Area of Study 2.

The investigation requires the student to develop a question, plan a course of action that attempts to answer the question, undertake an investigation to collect the appropriate primary qualitative and/or quantitative data, organise and interpret the data, and reach a conclusion in response to the question. The student designs and undertakes an investigation involving two independent variables one of which should be a continuous variable. A practical logbook must be maintained by the student for recording, authentication and assessment purposes.

### Outcome 3

On completion of this unit the student should be able to design and undertake an investigation of a physics question related to the scientific inquiry processes of data collection and analysis, and draw conclusions based on evidence from collected data.

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

- the physics concepts specific to the investigation and their significance, including definitions of key terms, and physics representations
- the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the selected investigation, including experiments (thermodynamics, construction of electric circuits, mechanics), and/or the evaluation of a device; precision, accuracy, reliability and validity of data; and identification of uncertainty
- identification and application of relevant health and safety guidelines
- methods of organising, analysing and evaluating primary data to identify patterns and relationships including sources of error and uncertainty, and limitations of data and methodologies
- observations and experiments that are consistent with, or challenge, current physics models or theories
- the nature of evidence that supports or refutes a hypothesis, model or theory
- the key findings of the selected investigation and their relationship to key physics concepts
- the conventions of scientific report writing including physics terminology and representations, symbols, equations and formulas, units of measurement, significant figures, standard abbreviations and acknowledgment of references.

## 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 knowledge and key skills in the outcomes.

The areas of study, including the key knowledge and key skills 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*

- an annotated folio of practical activities
- data analysis
- design, building, testing and evaluation of a device
- an explanation of the operation of a device
- a proposed solution to a scientific or technological problem
- a report of a selected physics phenomenon
- a modelling activity
- a media response
- a summary report of selected practical investigations
- a reflective learning journal/blog related to selected activities or in response to an issue
- a test comprising multiple choice and/or short answer and/or extended response.

*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.

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

Practical work is a central component of learning and assessment. As a guide, between 3½ and 5 hours of class time should be devoted to student practical work and investigations for each of Areas of Study 1 and 2. For Area of Study 3, between 7 and 10 hours of class time should be devoted to undertaking the investigation and communicating findings.

# Unit 3: How do fields explain motion and electricity?

In this unit students explore the importance of energy in explaining and describing the physical world. They examine the production of electricity and its delivery to homes. Students consider the field model as a construct that has enabled an understanding of why objects move when they are not apparently in contact with other objects. Applications of concepts related to fields include the transmission of electricity over large distances and the design and operation of particle accelerators. They explore the interactions, effects and applications of gravitational, electric and magnetic fields. Students use Newton's laws to investigate motion in one and two dimensions, and are introduced to Einstein's theories to explain the motion of very fast objects. They consider how developing technologies can challenge existing explanations of the physical world, requiring a review of conceptual models and theories. Students design and undertake investigations involving at least two continuous independent variables.

A student-designed practical investigation related to waves, fields or motion is undertaken either in Unit 3 or Unit 4, or across both Units 3 and 4, and is assessed in Unit 4, Outcome 3. The findings of the investigation are presented in a scientific poster format as outlined in the template on [page 13](#).

## Area of Study 1

### How do things move without contact?

In this area of study students examine the similarities and differences between three fields: gravitational, electric and magnetic. Field models are used to explain the motion of objects when there is no apparent contact. Students explore how positions in fields determine the potential energy of an object 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.

### Outcome 1

On completion of this unit the student should be able to analyse gravitational, electric and magnetic fields, and use 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 1 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 fields, 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 vector 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 a low-velocity electron in a magnetic field:  $qvB = \frac{mv^2}{r}$
- 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:  $E_g = mg\Delta h$
  - the change in gravitational potential energy from area under a force-distance graph and area under a field-distance graph multiplied by mass.

**Application of field concepts**

- apply the concepts of force due to gravity,  $F_g$ , and normal reaction force,  $F_N$ , including 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,  $F = nIB$ , 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
- model the acceleration of particles in a particle accelerator (limited to linear acceleration by a uniform electric field and direction change by a uniform magnetic field).

## Area of Study 2

### How are fields used to move electrical energy?

The production, distribution and use of electricity has had a major impact on human lifestyles. 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 magnetic fields and the transformer as critical to the performance of electrical distribution systems.

### Outcome 2

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 2 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:  $\mathcal{E} = -N \frac{\Delta \Phi_B}{\Delta t}$ , 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.

### 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 ( $V_{p-p}$ ) and peak-to-peak current ( $I_{p-p}$ )
- compare alternating voltage expressed as the root-mean-square (rms) to a constant DC voltage developing the same power in a resistive component
- convert between rms, peak and peak-to-peak values of voltage and current
- 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
- identify the advantage of the use of AC power as a domestic power supply.

## Area of Study 3

### How fast can things go?

In this area of study students use Newton's laws of motion to analyse relative motion, circular motion and projectile motion. Newton's laws of motion give important insights into a range of motion both on Earth and beyond. At very high speeds, however, these laws are insufficient to model motion and Einstein's theory of special relativity provides a better model. Students compare Newton's and Einstein's explanations of motion and evaluate the circumstances in which they can be applied. They explore the relationships between force, energy and mass.

### Outcome 3

On completion of this unit the student should be able to investigate motion and related energy transformations experimentally, analyse motion using Newton's laws of motion in one and two dimensions, and explain the motion of objects moving at very large speeds using Einstein's theory of special relativity.

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****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.

**Einstein's theory of special relativity**

- describe Einstein's two postulates for his theory of special 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
- compare Einstein's theory of special 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:
 
$$t = t_0\gamma \text{ and } L = \frac{L_0}{\gamma} \text{ where } \gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$
- explain why muons can reach Earth even though their half-lives would suggest that they should decay in the outer atmosphere.

**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 constant force using:
  - work done = constant force  $\times$  distance moved in direction of net force
  - work done = area under force-distance graph
- analyse transformations of energy between kinetic energy, strain 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
  - strain potential energy: area under force-distance graph including ideal springs obeying Hooke's Law:  $E_s = \frac{1}{2}k\Delta x^2$
  - 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

- interpret Einstein's prediction by showing that the total 'mass-energy' of an object is given by:  
 $E_{\text{tot}} = E_{\text{k}} + E_0 = \gamma mc^2$  where  $E_0 = mc^2$ , and where kinetic energy can be calculated by:  $E_{\text{k}} = (\gamma - 1)mc^2$
- describe how matter is converted to energy by nuclear fusion in the Sun, which leads to its mass decreasing and the emission of electromagnetic radiation.

## 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 assessment tasks to provide a range of opportunities for students to demonstrate the key knowledge and key skills in the outcomes.

The areas of study and key knowledge and key 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 *Advice for teachers* 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 21 per cent to the study score.



Outcomes	Marks allocated*	Assessment tasks
<p><b>Outcome 1</b></p> <p>Analyse gravitational, electric and magnetic fields, and use these to explain the operation of motors and particle accelerators and the orbits of satellites.</p>	30	<p>At least one task (which is different from the task/s selected for Outcomes 2 and 3) selected from:</p> <ul style="list-style-type: none"> <li>• annotations of at least two practical activities from a practical logbook</li> <li>• a report of a student investigation</li> <li>• a report of a physics phenomenon</li> <li>• data analysis</li> <li>• media analysis/response</li> <li>• design, building, testing and evaluation of a device</li> <li>• an explanation of the operation of a device</li> <li>• a proposed solution to a scientific or technological problem</li> <li>• a response to structured questions</li> <li>• a reflective learning journal or blog related to selected activities or in response to an issue</li> <li>• a test (short answer and extended response) (approximately 50 minutes or not exceeding 1000 words for each task)</li> </ul>
<p><b>Outcome 2</b></p> <p>Analyse and evaluate an electricity generation and distribution system.</p>	30	<p>Analysis and evaluation of stimulus material. At least one task (which is different from the task/s selected for Outcomes 1 and 3) selected from:</p> <ul style="list-style-type: none"> <li>• annotations of at least two practical activities from a practical logbook</li> <li>• a report of a student investigation</li> <li>• a report of a physics phenomenon</li> <li>• data analysis</li> <li>• media analysis/response</li> <li>• design, building, testing and evaluation of a device</li> <li>• an explanation of the operation of a device</li> <li>• a proposed solution to a scientific or technological problem</li> <li>• a response to structured questions</li> <li>• a reflective learning journal or blog related to selected activities or in response to an issue</li> <li>• a test (short answer and extended response) (approximately 50 minutes or not exceeding 1000 words for each task)</li> </ul>
<p><b>Outcome 3</b></p> <p>Investigate motion and related energy transformations experimentally, analyse motion using Newton's laws of motion in one and two dimensions, and explain the motion of objects moving at very large speeds using Einstein's theory of special relativity.</p>	30	<p>At least one task (which is different from the task/s selected for Outcomes 1 and 2) selected from:</p> <ul style="list-style-type: none"> <li>• annotations of at least two practical activities from a practical logbook</li> <li>• a report of a student investigation</li> <li>• a report of a physics phenomenon</li> <li>• data analysis</li> <li>• media analysis/response</li> <li>• design, building, testing and evaluation of a device</li> <li>• an explanation of the operation of a device</li> <li>• a proposed solution to a scientific or technological problem</li> <li>• a response to structured questions</li> <li>• a reflective learning journal or blog related to selected activities or in response to an issue</li> <li>• a test (short answer and extended response) (approximately 50 minutes or not exceeding 1000 words for each task)</li> </ul>
<b>Total marks</b>	<b>90</b>	

\*School-assessed Coursework for Unit 3 contributes 21 per cent.

**Practical work and assessment**

Practical work is a central component of learning and assessment. As a guide, between 3½ and 5 hours of class time should be devoted to student practical work and investigations for each of 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 60 per cent to the study score.

# Unit 4: How can two contradictory models explain both light and matter?

A complex interplay exists between theory and experiment in generating models to explain natural phenomena including light. Wave theory has classically been used to explain phenomena related to light; however, continued exploration of light and matter has revealed the particle-like properties of light. On very small scales, light and matter – which initially seem to be quite different – have been observed as having similar properties.

In this unit, students explore the use of wave and particle theories to model the properties of light and matter. They examine how the concept of the wave is used to explain the nature of light and explore its limitations in describing light behaviour. Students further investigate light by using a particle model to explain its behaviour. A wave model is also used to explain the behaviour of matter which enables students to consider the relationship between light and matter. Students learn to think beyond the concepts experienced in everyday life to study the physical world from a new perspective. Students design and undertake investigations involving at least two continuous independent variables.

A student-designed practical investigation related to waves, fields or motion is undertaken either in Unit 3 or Unit 4, or across both Unit 3 and Unit 4, and is assessed in Unit 4, Outcome 3. The findings of the investigation are presented in a scientific poster format as outlined in the template on [page 13](#).

## Area of Study 1

### How can waves explain the behaviour of light?

In this area of study students use evidence from experiments to explore wave concepts in a variety of applications. Wave theory has been used to describe transfers of energy, and is important in explaining phenomena including reflection, refraction, interference and polarisation. Do waves need a medium in order to propagate and, if so, what is the medium? Students investigate the properties of mechanical waves and examine the evidence suggesting that light is a wave. They apply quantitative models to explore how light changes direction, including reflection, refraction, colour dispersion and polarisation.

### Outcome 1

On completion of this unit the student should be able to apply wave concepts to analyse, interpret and explain the behaviour 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

##### Properties of mechanical waves

- explain a wave as the transmission of energy through a medium without the net transfer of matter
- distinguish between transverse and longitudinal waves
- identify the amplitude, wavelength, period and frequency of waves
- calculate the wavelength, frequency, period and speed of travel of waves using:  $v = f\lambda = \frac{\lambda}{T}$
- investigate and analyse theoretically and practically constructive and destructive interference from two sources with reference to coherent waves and path difference:  $n\lambda$  and  $\left(n - \frac{1}{2}\right)\lambda$  respectively

- explain qualitatively the Doppler effect
- explain resonance as the superposition of a travelling wave and its reflection, and with reference to a forced oscillation matching the natural frequency of vibration
- analyse the formation of standing waves in strings fixed at one or both ends
- 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.

### Light as a wave

- describe light as an 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
- compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and identify the distinct uses each has in society
- explain polarisation of visible light and its relation to a transverse wave model
- 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:  $n_1 \sin(\theta_c) = n_2 \sin(90^\circ)$
- 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 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  $(n - \frac{1}{2})\lambda$  respectively
  - effect of wavelength, distance of screen and slit separation on interference patterns:  $\Delta x = \frac{\lambda L}{d}$

## Area of Study 2

### How are light and matter similar?

In this area of study students explore the design of major experiments that have led to the development of theories to describe the most fundamental aspects of the physical world – light and matter.

When light and matter are probed they appear to have remarkable similarities. Light, which was 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, where matter had been modelled previously as being made up of particles.

### Outcome 2

On completion of this unit the student should be able to provide evidence for the nature of light and matter, and analyse the data from experiments that supports this evidence.

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

### Behaviour of light

- investigate and describe theoretically and practically the effects of varying the width of a gap or diameter of an obstacle on the diffraction pattern produced by light and apply this to limitations of imaging using light
- 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

- 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:  $\Delta E = hf$
- analyse the absorption of photons by atoms, with reference to:
  - the change in energy levels of the atom due to electrons changing state
  - the frequency and wavelength of emitted photons:  $E = hf = \frac{hc}{\lambda}$
- 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/electron double slit experiment as evidence for the dual nature of light/matter
- explain how diffraction from a single slit experiment can be used to illustrate Heisenberg's uncertainty principle
- explain why classical laws of physics are not appropriate to model motion at very small scales.

### Production of light from matter

- compare the production of light in lasers, synchrotrons, LEDs and incandescent lights.

## Area of Study 3

### Practical investigation

A student-designed practical investigation related to waves, fields or motion is undertaken either in Unit 3 or Unit 4, or across both Units 3 and 4. The investigation relates to knowledge and skills developed across Units 3 and 4 and is undertaken by the student through practical work.

The investigation requires the student to develop a question, formulate a hypothesis and plan a course of action to answer the question and that complies with safety and ethical guidelines. Students then undertake an experiment that involves the collection of primary quantitative data, analyse and evaluate the data, identify limitations of data and methods, link experimental results to science ideas, reach a conclusion in response to the question

and suggest further investigations that may be undertaken. The student is expected to design and undertake an investigation involving two continuous independent variables. Results are communicated in a scientific poster format according to the template provided on [page 13](#). A practical logbook must be maintained by the student for record, authentication and assessment purposes.

## Outcome 3

On completion of this unit the student should be able to design and undertake a practical investigation related to waves or fields or motion, and present methodologies, findings and conclusions in a scientific poster.

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

- independent, dependent and controlled variables
- the physics concepts specific to the investigation and their significance, including definitions of key terms, and physics representations
- the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the selected investigation, including experiments (gravity, magnetism, electricity, Newton's laws of motion, waves) and/or the construction and evaluation of a device; precision, accuracy, reliability and validity of data; and the identification of, and distinction between, uncertainty and error
- identification and application of relevant health and safety guidelines
- methods of organising, analysing and evaluating primary data to identify patterns and relationships including sources of uncertainty and error, and limitations of data and methodologies
- models and theories, and their use in organising and understanding observed phenomena and physics concepts including their limitations
- the nature of evidence that supports or refutes a hypothesis, model or theory
- the key findings of the selected investigation and their relationship to concepts associated with waves, fields and/or motion
- the conventions of scientific report writing and scientific poster presentation, including physics terminology and representations, symbols, equations and formulas, units of measurement, significant figures, standard abbreviations and acknowledgment of references.

## 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 assessment tasks to provide a range of opportunities for students to demonstrate the key knowledge and key skills in the outcomes.

The areas of study and key knowledge and key 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 *Advice for teachers* 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 19 per cent to the study score.

Outcomes	Marks allocated*	Assessment tasks
<p><b>Outcome 1</b></p> <p>Apply wave concepts to analyse, interpret and explain the behaviour of light.</p>	30	<p>At least one task (which is different from the task selected for Outcome 2) selected from:</p> <ul style="list-style-type: none"> <li>• annotations of at least two practical activities from a practical logbook</li> <li>• a report of a student investigation</li> <li>• a report of a physics phenomenon</li> <li>• data analysis</li> <li>• media analysis/response</li> <li>• design, building, testing and evaluation of a device or physical model</li> <li>• an explanation of the operation of a device or physical model</li> <li>• a proposed solution to a scientific or technological problem</li> <li>• a response to structured questions</li> <li>• a reflective learning journal or blog related to selected activities or in response to an issue</li> <li>• a test (short answer and extended response) (approximately 50 minutes or not exceeding 1000 words for each task)</li> </ul>
<p><b>Outcome 2</b></p> <p>Provide evidence for the nature of light and matter, and analyse the data from experiments that support this evidence.</p>	30	<p>Response to stimulus material. At least one task (which is different from the task selected for Outcome 1) selected from:</p> <ul style="list-style-type: none"> <li>• annotations of at least two practical activities from a practical logbook</li> <li>• a report of a student investigation</li> <li>• a report of a physics phenomenon</li> <li>• data analysis</li> <li>• media analysis/response</li> <li>• design, building, testing and evaluation of a device or model</li> <li>• an explanation of the operation of a device or model</li> <li>• a proposed solution to a scientific or technological problem</li> <li>• a response to structured questions</li> <li>• a reflective learning journal or blog related to selected activities or in response to an issue</li> <li>• a test (short answer and extended response) (approximately 50 minutes or not exceeding 1000 words for each task)</li> </ul>
<p><b>Outcome 3</b></p> <p>Design and undertake a practical investigation related to waves, fields or motion, and present methodologies, findings and conclusions in a scientific poster.</p>	35	<p>Structured scientific poster according to VCAA template. (not exceeding 1000 words)</p>
<b>Total marks</b>	<b>95</b>	

\*School-assessed Coursework for Unit 4 contributes 19 per cent.



### Practical work and assessment

Practical work is a central component of learning and assessment. As a guide, between 3½ and 5 hours of class time should be devoted to student practical work and investigations for each of Areas of Study 1 and 2. For Unit 3, between 7 and 10 hours of class time should be devoted to the investigation, related to waves, fields or motion, to be undertaken in either Unit 3 or Unit 4, or across both Unit 3 and Unit 4, including writing of the sections of the scientific poster.

## 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 60 per cent.

## End-of-year examination

### Description

The examination will be set by a panel appointed by the VCAA. All the key knowledge that underpins the outcomes in Units 3 and 4 and the cross-study 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 first year of implementation of the revised Units 3 and 4 sequence together with any sample material.