**Physics Module 7: the nature of light**

## Table of contents

[Table of contents 2](#_Toc41896809)

[Teaching the year 12 modules 3](#_Toc41896810)

[Course overview 3](#_Toc41896811)

[Module summary 5](#_Toc41896812)

[Big ideas 5](#_Toc41896813)

[Evidence: discovery and justification 5](#_Toc41896814)

[Science is interconnected 6](#_Toc41896815)

[Measurement 6](#_Toc41896816)

[Relationships to other modules 7](#_Toc41896817)

[Core concepts 7](#_Toc41896818)

[The electromagnetic spectrum 7](#_Toc41896819)

[Early models of light 8](#_Toc41896820)

[The quantum model of light 9](#_Toc41896821)

[Special relativity 10](#_Toc41896822)

[Opportunities for extended concepts 11](#_Toc41896823)

[Exploring Maxwell’s equations 11](#_Toc41896824)

[Where is all the antimatter? 11](#_Toc41896825)

[How to take a photo of a black hole 12](#_Toc41896826)

[Investigating polarisation 12](#_Toc41896827)

[Alternative conceptions and misconceptions 12](#_Toc41896828)

[Symmetry in special relativity 12](#_Toc41896829)

[Relativistic momentum 13](#_Toc41896830)

[Conceptual difficulties 13](#_Toc41896831)

[Light-years and electron volts 13](#_Toc41896832)

[Suggested teaching strategies 14](#_Toc41896833)

[Suggested order of topics 14](#_Toc41896834)

[Suggested investigations 20](#_Toc41896835)

[Appendices 21](#_Toc41896836)

[Appendix one: Models of light 21](#_Toc41896837)

[Appendix two: Sample question 21](#_Toc41896838)

[Appendix three: The nature of light investigation handbook 25](#_Toc41896839)

[Resources 38](#_Toc41896840)

## Teaching the year 12 modules

The new Stage 6 Physics course was implemented in NSW schools in 2018-2019. This syllabus incorporates new content and learning activities such as Depth Studies. The syllabus is designed around inquiry questions and formal assessment tasks emphasise the skills for working scientifically.

The Year 12 course provides avenues for students to apply the concepts they were introduced to in Year 11 to motion in two dimensions, electromagnetism, theories of light, the atom and the Universe.

Therefore, pedagogies that promote inquiry and deep learning should be employed in the Physics classroom. The challenge presented by the additional content and the change in pedagogical approach were the catalysts for the preparation of these module guides for Stage 6. These guides are intended to assist teachers deliver Physics effectively by outlining overarching concepts (big ideas), core and extended ideas, strategies for teaching the modules, uncovering of alternative conceptions, and strategies to address them. The guides support the teacher in facilitating the development of deep knowledge structures, such as the relationships between concepts. The module guides do not cover all aspects of the syllabus, as that was not within the scope of the project.

It is essential that teachers note that the module guides do not substitute the syllabus, but only support teachers to teach it. The information contained in these documents are correct at the time of publication. While every effort has been made to eliminate errors, any errors or omission that are identified after the release of these documents will be corrected and released as resource updates. It is recommended that teachers access the [Curriculum website](https://education.nsw.gov.au/teaching-and-learning/curriculum/key-learning-areas/science/stage-6/physics) for the latest version of these documents.

## Course overview

The Year 11 course introduces fundamental concepts of motion, forces, fields, energy and momentum. It provides opportunities for students to develop skills in Working Scientifically, including skills related to the quantitative analysis and modelling of physical systems.

The Year 12 course further develops these concepts and applies them to the analysis of phenomena and technologies that are relevant to society and to contemporary physics. The Law of conservation of energy, along with the development of theories and models form common themes across each of the modules. The role of scientific investigation and evidence in advancing our understanding is explored in detail in Modules 7 and 8.

Inquiry questions are included in the course content and are used to frame the syllabus. The depth of understanding required to fully address the inquiry questions may vary. This allows for differentiation of the course content to cater for the diversity of learners.

During the teaching of the Year 11 course, it is expected that students have been provided opportunities to develop all seven of the Working Scientifically skills. Ideally, these would be embedded into the teaching of the Knowledge and Understanding components of the course. In preparation for the Year 12 course, students in Year 11 could benefit from work that engages them in the following areas:

* Propose hypotheses, design and conduct valid and reliable practical investigations that effectively use technologies to collect and analyse data. Teachers should look for opportunities to engage students in these beyond where the syllabus explicitly states the need to conduct a practical investigation.
* Construct and analyse graphical data for both primary and secondary sources. This should include describing relationships between variables, particularly time-varying quantities such as displacement and velocity. Emphasis should be placed on extracting qualitative and quantitative information from the gradient and/or the area under a graph.
* Evaluate and improve the quality of data collected. Students should be encouraged to recognise errors, uncertainty and limitations in the data they collect. Practical investigations provide opportunities to practice quantifying errors, including the calculation of absolute and relative errors, along with techniques such as the use of a line-of-best fit to minimise the impact of random errors in measurement.
* Assess the uses, benefits and limitations of various types of scientific models. Models are a powerful tool in science, allowing phenomena to be more easily explained and predicted by capturing and highlighting only the most important features of a system. For example, when analysing gravitational potential energy (GPE) in Module 2, it is beneficial to employ a model in which acceleration due to gravity is a constant 9.8 ms-2 and arbitrarily set at the Earth’s surface. This model is suitable for analysing the motion of objects close to the Earth’s surface including projectiles, pendulums and rollercoasters. However, students should also be encouraged to consider the limitations of such models. For example, the model above would not be appropriate, or effective, for analysing the motion of satellites as acceleration due to gravity cannot reasonably be considered constant over large distances.
* Study the rates of change of quantities including displacement, velocity, temperature and energy to support deeper insights into physical phenomena. Rates of change are particularly important to the understanding of electromagnetism in Year 12.
* Collect relevant information from secondary sources and determine the accuracy, reliability and validity. Many of the investigations will require students to obtain information from the Internet or other sources. Students will benefit from learning how to access suitable information and appreciate how new evidence can change prevailing views.
* Developing an awareness of the interconnectedness of physics concepts, including the application of conservation of energy and momentum to the understanding of diverse phenomena.
* Developing confidence in the selection and manipulation of units for physical quantities. Students should be provided opportunities to practice converting units, along with calculating and communicating quantities using scientific notation.
* Creating and analyse diagrams that represent vector quantities including free-body, field and ray diagrams. Students should develop confidence in resolving 2-dimensional vectors into their components and in adding multiple vectors to find the resultant.

## Module summary

The theories and models about light have evolved over time; through general wave behaviour, electromagnetic waves and quantum properties and these have set the foundation for special relativity.

This topic is a set on the foundations of Module 6 Electromagnetism, the unification of electricity and magnetism. Completion of this module provides a suitable introduction into the quantum physics component of Module 8 From the Universe to the Atom

Module 7 explores the following inquiry questions:

* **IQ7-1**: What is light?
* **IQ7-2**: What evidence supports the classical wave model of light and what predictions can be made using this model?
* **IQ7-3**: What evidence supports the particle model of light and what are the implications of this evidence for the development of the quantum model of light?
* **IQ7-4:** How does the behaviour of light affect concepts of time, space and matter?

## Big ideas

### Evidence: discovery and justification

Along with Module 8, this module builds strong relationships between theories and models and the experimental evidence that led to their discovery and subsequent acceptance. The use of new evidence to make distinctions between competing theories is highlighted by the models of light championed by Newton and Huygens. The nature of light is then further challenged by new observations in the photoelectric effect.

The provisional nature of scientific knowledge is embodied in Newton’s famous statement “If I have seen further it is by standing on the shoulders of giants”, and is demonstrated though both Maxwell’s unification of electricity and magnetism and Einstein’s explanation of the photoelectric effect.

Einstein’s two postulates of special relativity demonstrate a pathway to discovery that is highly important to modern physics, the axiomatic method. Beginning with a small set of postulates, assumed truths not requiring evidential support, a logical process is followed to derive testable predictions. Einstein used a set of thought experiments to draw out testable predictions as the logical consequences of his postulates. Special relativity makes several surprising predictions based on the assumption of the constancy of the speed of light in a vacuum, including time dilation, length contraction, a limitation of the maximum velocity of particles and the mass-energy equivalence. In contrast to many classical theories, these predictions were made many decades in advance of the technologies required to put them to the test.

### Science is interconnected

Scientific theories do not exist in isolation, instead, they are better considered as making up a ‘web of belief’. Core ideas are those that have survived numerous experimental tests or those which have wide ranging links across the web. New observations may easily challenge peripheral or not widely connected ideas such as the ether model for the transmission of light. By contrast, core ideas such as the law of conservation of energy have wide ranging application and importance and are often preserved by adjusting other parts of the web if required. Chadwick’s discovery of the neutron, investigated in Module 8, is just such an example of how a strong belief in conservation laws led to the proposal of a previously unobserved particle.

Module 7 explores the dramatic consequences of disturbing the centre of this web. Changes to our understanding of the behaviour of light, making the speed of light in a vacuum an absolute constant, challenges our concepts of space, time and matter. It has turned these quantities on their heads, for example, the speed of light, previously thought to be relative to the motion of the observer, is now held as an absolute constant. To make room for this to be true, space, time and matter must now be relative quantities affected by the frame of reference of the observer. This change heralded the birth of Modern Physics and has successfully predicted and been confirmed across wide ranging phenomena.

### Measurement

The ability to make precise and accurate measurement is central to scientific inquiry. Experimental observations may lead to the development of theories and laws and are required in their validation. Beginning in 1799, with the deposition of platinum standards representing the meter and kilogram in Paris, efforts have been made to create a single, coherent system of measurements throughout the world. This led to the establishment of the International System of Units (SI). Initial efforts relied on the production of artefacts to represent fundamental units with all measurements being compared to these artefacts or copies thereof. More recently, the demands for increased precision imposed by research into phenomena on the smallest scales of time and space has driven the 2019 SI redefinition. As of May 20, 2019, all SI base units will be defined in terms of seven fundamental constants, with each constant assigned an exact numerical value in the process. More information regarding the International System of Units is available from the [International Bureau of Weights and Measures (BIPM)](https://www.bipm.org/utils/common/pdf/si-brochure/SI-Brochure-9-concise-EN.pdf) and also from the [UK’s National Measurement Institute (NPL)](https://www.npl.co.uk/si-units).

Many of the historical efforts measure the speed of light using the displacement-time relationship, , were plagued by errors. These stemmed from the high speed of light, the inability to observe its travel over large distances and the lack of technology to precisely measure small increments of time. The wave nature of light provides an alternate method of measuring its speed. By creating standing waves and applying the wave equation, ,, the accuracy of measurements of the velocity of light is instead dependent on measurements of distance and the frequency of radiation used. Students are guided through several key efforts to measure the speed of light and should consider how each attempted to improve accuracy by overcoming some of these issues or by exploiting the wave nature of light.

The role of new technologies and inventive methodologies for measurement are further explored in relation to the photoelectric effect and in validating predictions made by special relativity.

## Relationships to other modules

Modules 7 and 8 include a significant overlap in concepts relating to quantum phenomena. From Module 8, the emission spectra concepts in the IQ8-3, (Quantum Mechanical Nature of the Atom) could be brought forward to be taught along with IQ7-3 (Light: Quantum Model ). As Module 8 has five topics, this will improve the balance of concepts between the two modules.

In Module 6, students explore the [SI definition of the ampere](https://www.nist.gov/si-redefinition/ampere-introduction) at [nsit.gov](https://www.nist.gov/si-redefinition/introduction-redefining-worlds-measurement-system). While the 2017 syllabus, (IQ6-2) refers to a superseded definition of the ampere, investigating recent revisions in the standards of measurement is an opportunity to familiarise students with issues in the measurement of time and distance included in this module.

Students investigate the experimental validation of time dilation provided by observations of cosmic-origin muons at the Earth’s surface. In order to appreciate the subtleties of how the observations provide evidence of time dilation, students will require a basic understanding of radioactive decay and half-life. These concepts are included in Module 8.

## Core concepts

### The electromagnetic spectrum

Maxwell’s contribution to the classical theory of electromagnetism was in the unification of the then separate theories of electricity and magnetism, creating a single system of four equations. They showed that electric and magnetic forces are not separate, only different manifestations of the electromagnetic force. His equations also introduce a symmetry between the creation of electric and magnetic fields and include Gauss’ law, Gauss’ law for magnetism, Faraday’s law and Ampere’s law.

From his equations, Maxwell was able to show that electromagnetic fields could travel as self-propagating waves, allowing them to propagate in a vacuum. His equations predicted that there was a spectrum of electromagnetic waves of varying frequencies and wavelengths but with an absolute speed given by the expression a fact that would later challenge the principle of relativity by seemingly providing an avenue to determine absolute motion without the need for an external frame of reference.

Historical and contemporary methods to measure the speed of light are investigated in this module. Notable historical examples that could be investigated include:

* Galileo, using shuttered lanterns
* Roemer, studying eclipse patterns of Jupiter’s moons
* Fizeau, using a rotating toothed wheel and mirror
* Michelson, using an octagonal mirror

It would be reasonable to only cover in detail, the efforts of Roemer and Fizeau as they demonstrate methods of improving accuracy of measurements, compared to Galileo’s lanterns by increasing the distance light travels and by improving the precision of time measurements respectively.

Modern methods generally exploit the wave properties of light and rely on the ability to produce lasers of a known and stable frequency, along with the ability to measure their wavelength accurately. These methods highlighted the 1960 definition of the meter as the limiting factor in the uncertainty around the speed of light. This led ultimately to the redefinition of the meter in 1983 to be “the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second”. Therefore, the speed of light was assigned a fixed and exact value as detailed in [Speed of Light From Direct Frequency and Wavelength Measurements](https://nvlpubs.nist.gov/nistpubs/sp958-lide/191-193.pdf), from the [Journal of Research of the NIST](https://www.nist.gov/)

Studies of the spectra emitted by stars have yielded insights into their composition and other properties. This is further explored in Module 8.

### Early models of light

This module explores the differing models of light presented by Newton (published in 1704) and Huygens (published 1690) along with the evidence supporting them. Observations of the reflection and refraction of light can be explained sufficiently with both models, acting as a suitable example of underdetermination by data. This is where available evidence is unable to make distinctions between competing hypotheses. However, Newton’s and Huygen’s explanations of refraction did make different and potentially testable claims about the speed of light in water: Newton’s explanation suggested light sped up as it entered the water and Huygen’s suggesting it slowed down. This was later tested by Foucault (1850), the results of which favoured the Huygen’s wave model. Young’s double slit experiment (1801) and Malus’s discovery of the polarisation of light (1808) subsequently provided convincing evidence of light’s wave-like nature.

Within this module, this topic is the best opportunity to conduct practical investigations, with opportunities to demonstrate the wave nature of light using diffraction and polarisation experiments.

### The quantum model of light

The photoelectric effect was first observed by Heinrich Hertz in 1887, and subsequent observations provided evidence to support the quantum (or photon) model of light as proposed by Einstein in 1905. When applied to the quantum models of light, the law of conservation of energy correctly predicts aspects of black body radiation and the photoelectric effect. These quantum models have in common the exchange of energies in discrete packets or quanta. In module 8, this is further applied to account for the hydrogen spectrum and is the basis for the Bohr model of the atom.

The photoelectric effect describes the emission of electrons from a metal surface when it is irradiated with radiation of a sufficiently high frequency. The emitted electrons are called ‘photoelectrons’ and their emission results in the production of a ‘photocurrent’. The key observations leading to the development of a quantum model of light were:

1. The existence of a threshold frequency, , where only frequencies above this threshold will produce a photocurrent, regardless of intensity. The threshold frequency is dependent on the metal surface.
2. The energy of photoelectrons is independent of the intensity of the light source.
3. The magnitude of the photocurrent is proportional to the intensity of the light source.

The first two of the above observations could not be accounted for by the electromagnetic wave theory of light. A quantum model of light can explain all three observations. The basic postulates of this model are:

1. Electromagnetic waves consist of discrete, massless units called photons. A photon travels in vacuum at the speed of light,
2. Each photon has an energy proportional to its frequency. , where is the frequency of the wave and is a universal constant called Planck’s constant. The value of Planck’s constant is . In other words, electromagnetic waves consist of discrete ‘chunks’ of energy.

When applied to the photoelectric effect, this model predicts the maximum kinetic energy of photoelectrons and is represented mathematically by:

Where is the work function of the given metal surface. The threshold frequency, , is defined by as this leads to photoelectrons with zero kinetic energy. For frequencies higher than the threshold frequencies, the maximum kinetic energy of photoelectrons is equal to the difference between the photon energy and the work function.

### Special relativity

Scientific evidence and its role in developing and validating theories is explored in this topic. It should be noted when analysing and evaluating the evidence confirming or denying Einstein’s two postulates of special relativity (SR), that it is not an expectation that students provide evidence that denies either postulate. However, it is expected that evidence relating to each postulate is analysed.

Galileo’s thought experiment illustrates how evidence could be collected to support what was later known as the Principle of Relativity. In the early seventeenth century, the popular view of our solar system was that the Earth was stationary at its centre because we did not observe any of the expected effects of racing through space at very high speeds. Galileo used his ship as a model for the Earth in order to demonstrate that it is impossible to detect the motion of the Earth using observations within its inertial frame. That is, experiments conducted on a ship at rest, or moving at constant velocity, would produce identical results. This would make it impossible to use experiments of motion, or any other experiments, to distinguish between the two inertial frames.

Maxwell’s prediction of a constant speed for light, albeit very high, provided a potential experimental method for distinguishing between inertial frames. By measuring the speed of light in an inertial frame and comparing it to the predicted speed, one could determine their absolute motion.

Einstein’s second postulate states that all inertial frames of reference are equivalent. This extends the equivalence of physical laws in inertial frames of reference to include not just Newton’s laws of motion, but all physical laws particularly those relating to electromagnetic phenomena. Thus, the Michelson-Morley experiment (1887) could be considered to provide evidence for both postulates.

Einstein predicted phenomena, including time dilation and length contraction, would occur as a logical consequence of the two postulates for SR. He demonstrated these through a range of thought experiments at a time when technological limitations made it practically impossible to observe the phenomena experimentally. Suitable thought experiments for time dilation and length contraction involve the use of a ‘light clock’ placed inside a train carriage that is moving at a constant velocity relative to an observer on the platform of a train station. The orientation of the light clock relative to the motion (either perpendicular or parallel) allows the respective phenomena to be investigated.

Students are required to follow up these thought experiment with examples of suitable experimental validation of each phenomenon. Of the suggested examples, the cosmic-muon observations and Hafele-Keating experiment are sensible choices due to the wide range of learning resources available for student use.

Other predictions arising from SR are included in this topic (relativistic momentum and mass-energy equivalence), however, students are not required to analyse evidence that supports them. Instead, they are required to draw out some of their observed practical consequences and applications.

## Opportunities for extended concepts

### Exploring Maxwell’s equations

The mathematics of Maxwell’s equations is beyond what is required in high school, however, the physics described by each equation is relevant to the Year 12 Physics course. [Activity 3 in the Fields resource](https://resources.perimeterinstitute.ca/collections/lesson-compilations/products/fields), produced by the Perimeter Institute provides a set of classroom activities that consolidates concepts covered in Module 6. It also explores the significance of Maxwell’s equations in terms of the unification of electricity and magnetism, the prediction of a speed for light waves and the subsequent development of Special Relativity by Einstein. The teacher background section has additional detail in its discussion of the relevant mathematics.

### Where is all the antimatter?

The equation is known as the mass-energy equivalence. It has many interpretations, for example, it could describe the energy required to create a given quantity of mass, or the equivalent energy stored in a mass. Studying the application of this equivalence to particle-antiparticle interactions, provides an opportunity to explore an important open question in physics; Where is all the antimatter?

Cosmological models describing the transformation of radiation into matter following the ‘Big Bang’ predict that the Universe should contain equal quantities of matter and antimatter.

* Consider applying to the transformation of radiation to matter, for example an electron. If a photon (neutral charge) were to transform into an electron (negatively charged), it would violate the law of conservation of charge.
* Instead, the process occurs through ‘pair-production’. That is, a photon (or another neutrally charged boson) transforms by creating a particle-antiparticle pair. In this case, the photon transforms to produce an electron and its antiparticle, a positron. Each has equal and opposite charge ensuring that conservation of charge is upheld.

This is true for all such transformations, so we could rewrite the initial equation as

,

where is the symbol for antimatter. We have not yet found (or are likely to find) any significant amounts of antimatter in our galaxy or in any other observable galaxy. One possible explanation for the observed imbalance of matter and antimatter is that their properties may not be precisely symmetric, for example they may each interact differently with gravity. This possibility is currently being investigated by researchers at the Antimatter factory at CERN as described in [Entering the Antimatter Factory at CERN](https://www.newscientist.com/article/mg21328584-000-entering-the-worlds-premier-antimatter-factory/) by [New Scientist Magazine](https://www.newscientist.com/subject/physics/).

Pair production in bubble chambers is also a key piece of evidence for the existence of particles other than protons, neutrons and electrons, which is explored further in Module 8.

### How to take a photo of a black hole

The TED video [How to take a photo of a black hole Katie Bouman](https://www.youtube.com/watch?v=BIvezCVcsYs&feature=youtu.be) (duration 12:51) describes the capturing of the first image of a black hole in 2019. This topic is a great example of the application of diffraction limits and interferometry. It is a compelling case for the importance of models to aid explanation and the application of computer algorithms to aid scientific observation.

Further explanation of this momentous event can be found at [How to understand the black hole image](https://www.youtube.com/watch?v=zUyH3XhpLTo&feature=youtu.be) (duration 9:18) by [Veritasium](https://www.youtube.com/channel/UCHnyfMqiRRG1u-2MsSQLbXA) and [How scientists captured the first image of a black hole](https://www.jpl.nasa.gov/edu/news/2019/4/19/how-scientists-captured-the-first-image-of-a-black-hole/) at [NASA’s Jet Propulsion Laboratory](https://www.jpl.nasa.gov/edu/news/).

### Investigating polarisation

When investigating polarisation, students could test a range of alternative light sources including polarised and unpolarised light. Modelling light using the components of its electric field can be used to explain linear and circular polarisation. The following videos may provide a useful introduction.

* [Circular polarisation](https://www.youtube.com/watch?v=ycY2mUZHS84&feature=youtu.be) (duration 4:39) at [UCLAphysicsvideo](https://www.youtube.com/channel/UCXWBuswk0HFXgqJw3MXT1Ow) -using a physical model and demonstrations
* [Polarisation of light](https://www.youtube.com/watch?v=8YkfEft4p-w&feature=youtu.be)  (duration 19:50) 3D animations explaining circularly polarised, linearly polarised and unpolarised light
* [Circular polarisation](https://www.youtube.com/watch?v=Fu-aYnRkUgg&feature=youtu.be) (duration 1:36) - animations of the components of the electric field

## Alternative conceptions and misconceptions

### Symmetry in special relativity

When discussing time dilation, students will often make statements such as “time slows down when you are moving close to the speed of light” or “moving clocks run slow”. Whilst these statements are commonly used as memory strategies, they can reinforce the false notion that there is a reference frame in which we can measure the ‘actual time’. This may lead to some incorrect logic as described below.

Student A is in a spaceship moving at a high velocity relative to student B, who is standing on an asteroid. Students generally recognise that student B will observe less time to have passed on a clock moving with student A compared to the time recorded on a clock that is stationary in their reference frame. However, students holding the conception of an absolute reference frame may then incorrectly assert that “because moving clocks run slow, stationary clocks run fast”, and fail to recognise the symmetry between the reference frames of students A and B.

The concept of ‘actual time’ is based on the notion that there is a preferred or universal inertial frame to which all time and space measurements can be compared. This of course, is addressed in Einstein’s second postulate “all inertial frames of reference are equivalent”. Special relativity requires us to give up on time and space as absolute quantities, but it allows us to accurately determine how these values are transformed when viewed from a different inertial frame of reference. In many ways, it validates any inertial frame of reference as a suitable place to investigate the laws of physics.

Further reading on student conceptions of special relativity, including the presentation of a concept inventory of the topic, can be sourced from the article [The relativity concept inventory: development, analysis and results](https://arxiv.org/pdf/1302.7094.pdf) is referenced in the resources. It also contains a short set of quiz questions targeted at identifying specific student conceptions.

### Relativistic momentum

The 2017 changes to the Stage 6 Physics syllabus have removed the formula for calculating mass dilation and replaced it with the associated concept of relativistic momentum. This change is welcomed because in Special Relativity the mass is invariant, a quantity that never changes. Instead, as an object approaches the speed of light, it is its momentum that approaches infinity from the perspective of a stationary observer.

## Conceptual difficulties

The topic is very abstract and requires the preunderstanding of wave properties including refraction and superposition. Students require a high level of mathematical competence to manipulate the formulae used in this topic. Investigations in this topic require the graphing and evaluation of data along with the manipulation of unfamiliar units.

### Light-years and electron volts

The standard unit of energy, the joule (J), has been used throughout the Stage 6 Physics course to describe the energies involved in mechanical and electrical systems. However, when describing energies on the atomic and subatomic scales, the electron-volt (eV) is a far more suitable unit.

An electron-volt is defined as the work done on a single electron as it is accelerated through a potential difference of 1 volt with . Students can verify the work done by applying the knowledge they developed during the first topic in the Electromagnetism module. Students will be required to interpret and communicate energies using the electron-volt and be capable of converting between eV and J.

Additionally, problem solving in the Special relativity topic will often require students to recognise light-years (ly) as a unit of distance where

.

Fortunately, it is not generally expected that students make conversions between light-years and other units of measurement.

## Suggested teaching strategies

### Suggested order of topics

1. Light: Wave Model
   1. Newton and Huygens
   2. Experimental evidence from diffraction and polarisation
2. Light: Quantum Model
   1. Spectroscopy (from Electromagnetic Spectrum topic)
   2. Blackbody radiation including Wien’s Law and Planck’s contribution
   3. Photoelectric effect evidence
   4. Einstein’s explanation – the photon model of light
3. Electromagnetic Spectrum
   1. Maxwell’s classical theory of electromagnetism
   2. Prediction of the absolute speed of light in a vacuum
   3. Historical and modern methods used to determine the speed of light experimentally
4. Light and Special Relativity
   1. Einstein’s postulates
   2. Thought experiments and subsequent experimental evidence
   3. Further applications and examples – relativistic momentum and

Modules 7 and 8 share concepts in quantum physics and Module 8, IQ8-3 Quantum Mechanical Nature of Atom can be brought forward and taught with Module 7, IQ7-3 Light: quantum model. As Module 8 has five topics, this may reduce the pressure experienced towards the end of Year 12.

Student understanding of the role that historical evidence played in the changing models of light can be supported by student investigation. A range of sample investigations are outlined in the Nature of light investigation handbook which is included in the appendix. It outlines opportunities for students to conduct investigations using first-hand and simulated data. Skills addressed in these learning activities include conducting investigations, processing and analysing primary and secondary data, and communicating ideas to a general audience.

#### Light: Wave model

During this unit students will explore the wave behaviour of light, diffraction, interference and polarisation. This topic provides a range of opportunities for students to complete first-hand investigations and to analyse evidence collected from historical investigations.

##### Models of light

The Olympus webpage, [Light: Particle or a wave?](https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/particleorwave/) provides a detailed introduction to the debate over the nature of light, highlighting the division between the models proposed by Newton and Huygens in the early Eighteenth Century. A sample student activity based on this resource can be found in the appendix.

##### Diffraction

The diffraction of light can be demonstrated using purpose-built single and double slit slides, diffraction gratings, or even using a CD. Comparing the diffraction patterns produced from a collimated source such as a discharge tube to that from a monochromatic source like a laser could be a useful starting point for discussions of diffraction. It should be noted that the distance to the respective maxima is proportional to the wavelength, with red appearing on the outside of the diffraction pattern.

Possible approaches to investigating the diffraction equation include:

* providing students with the wavelength of a laser and dimensions of diffraction grating and ask them to predict the spacing between maxima before observing
* predict the wavelength of laser light from observations of the diffraction pattern produced
* modify or repeat either of the above approaches in order to improve accuracy
* change the dimensions and/or orientation of the grating or slit and predict qualitatively or quantitatively the result
* for a given diffraction pattern, predict and sketch an apparatus likely to have produced it.

##### Polarisation

Students can conduct first-hand practical investigations to verify Malus’s Law. Light meters on mobile phones along with small sheets of polarised film with protractors pinned in the middle could be used to collect data to verify Malus’s Law. It is an opportunity for students develop skills in planning investigations and problem solving.

Students could be assigned the task of collecting evidence to verify Malus’s Law. After plotting their initial data for intensity versus analyser angle, students should identify the need for increased sampling resolution around the points of maximum intensity in order to verify the sinusoidal nature of the relationship. More advanced students could be guided in manipulating variables to produce and linear relationship.

#### Electromagnetic Spectrum

##### Maxwell’s equations

Maxwell’s equations represented the unification of our models of electric and magnetic phenomena into an overarching theory of electromagnetism. His work not only explained existing phenomena using a common language and mathematical framework, it provided new insights into the nature and behaviour of light.

Whilst the mathematics of the four equations is beyond the scope of this course, students can be encouraged to understand the physical significance of each equation. Using worded descriptions of each and associating each with a diagram will provide a suitable depth of understanding for most students. An example of suitable descriptions can be found on [Lumen learning](https://courses.lumenlearning.com/physics/chapter/24-1-maxwells-equations-electromagnetic-waves-predicted-and-observed/) and [Fields: Activity 3](https://resources.perimeterinstitute.ca/collections/lesson-compilations/products/fields?variant=29797321965646), from the Perimeter Institute (see resources).

##### Measuring the speed of light

Investigating historical and contemporary methods used to determine the speed of light can be used to build skills in Working Scientifically, particularly in planning investigations and analysing data and information. This investigation can also be used to highlight the importance of technologies in ensuring the accuracy of measurements.

Students draw on their prior understanding of measuring speed developed in Module 1 to analyse Galileo’s method involving two shuttered lanterns separated across hilltops.

Students could:

* make predictions of the time taken for light to travel between hilltops and consider the limitations imposed by the technologies available at the time
* investigate questions including “How far apart would the lanterns need to be in order to accurately measure the speed of light using a stopwatch? Using your pulse?”
* plan a thought experiment to determine the speed of light using a stopwatch, mirrors or other simple technologies.

Subsequent methods, including those used by Roemer, Foucault and Fitzeau could then be analysed in terms of:

* improvements in technologies used to accurately measure distance and time
* increasing accuracy compared to the accepted value for the speed of light, and in some cases
* the exploitation of lights wave-like properties for interferometry or the formation of standing waves.

A sample question, marking guidelines and sample response are included in the appendix and could be set as a research assignment or as revision. Further reading on these and other methods is available from [Las Cumbres Observatory](https://lco.global/spacebook/light/speed-light/), [PHYSCLIPS](https://www.animations.physics.unsw.edu.au/light/nature-of-light/index.html#1.3) and the [National Institute of Standards and Technology (NIST)](https://web.archive.org/web/20090813061018/http:/nvl.nist.gov/pub/nistpubs/sp958-lide/191-193.pdf).

##### Spectroscopy

Handheld spectroscopes allow students to clearly observe the spectra from a variety of sources. Observing reflected sunlight and incandescent filaments (and changing the supplied voltage) allows students to qualitatively explore the relationship between surface temperature and the spectrum produced.

Analysing the spectrum of a star to gather information about its properties generally requires students to identify key features of each spectra and correctly link them to inferences about the star’s properties. Features include:

* the peak wavelength
* patterns of absorption lines
* doppler shifting and broadening of spectral lines

Further reading, including detailed examples, is provided by [Australian Telescope National Facility](https://www.atnf.csiro.au/outreach/education/senior/astrophysics/spectra_info.html) and [Lumen learning](https://courses.lumenlearning.com/astronomy/chapter/using-spectra-to-measure-stellar-radius-composition-and-motion/).

[Activity 2: The signature of the stars](https://resources.perimeterinstitute.ca/collections/astrophysics-cosmology/products/the-expanding-universe?variant=17163100102) produced by the Perimeter Institute, includes a rich set of data driven activities for students to explore the information contained in the light from stars. Students will be guided through the analysis and display of spectral plots and develop an understanding of the evidence for an expanding Universe provided by the spectra of distant galaxies and Type 1a supernovas. Consequently, this activity is a suitable bridge between concepts in Modules 7 and 8.

##### Extension

A star analyser (typically costing around $250), combined with a telescope or DLSR camera can be used to capture and analyse the spectra of stars in the night sky. Detailed spectra can then be quickly processed and analysed using free software.

#### Light: Quantum model

##### Black body radiation

To investigate Wien’s Law, students could collect simulated data using the [PhET simulation, Blackbody spectrum](https://phet.colorado.edu/en/simulation/legacy/blackbody-spectrum). By varying the temperature (T) and measuring the peak wavelength (), students can plot versus to verify the law.

Observations of black body radiation could not be explained using Maxwell’s classical electromagnetic theory. Students should appreciate that attempts to explain and predict the shape of the black body radiation curve observed for hot objects were unable to completely match the experimental observations. Attempts to explain the spectrum, including Wien’s theory, which was only accurate at short wavelengths and deviated at longer wavelengths, whilst the Rayleigh-Jeans theory suffered from the opposite problem. The ultraviolet catastrophe predicted by the Rayleigh-Jeans theory serves as a clear example to students of the failure of classical theories to explain black body radiation.

Planck proposed an empirical formula (that is, a formula that is supported by experimental observations but not necessarily supported by theory). The details of his formula are beyond the scope of this course, however the success of his formula in describing the black body spectrum led him to make a bold suggestion that changed the direction of scientific thinking.

He proposed that the energy distributed among the oscillations of atoms within molecules (which were thought to be the source of the radiation) was not continuous but instead consist of a finite number of tiny discrete amounts each related to the frequency of oscillation. His proposal suggested that the energy of any oscillation could only take on a whole number multiple of some small value, , or;

Where is Planck’s constant , is the frequency, and ….

Consider using analogies to reinforce the distinction between the continuous and discrete natures of the respective classical and quantum models of energy. The Cosmos magazine article, [Quantum physics for the terminally confused](https://cosmosmagazine.com/physics/quantum-physics-terminally-confused) (accessed 02/04/2020) outlines some useful examples, including using the placing of a jar of peanut butter on a shelf in the cupboard, and notably the inability to place it between shelves, to represent the quantisation of energy.

##### Photoelectric effect

Definitions and correct terminology relating to the photoelectric effect are outlined in the core concepts section of this module guide. Explicitly introducing this terminology will support students in creating concise explanations relating to the photoelectric effect.

Students will apply their knowledge of the behaviour of charged particles in electric fields to understand how the maximum kinetic energy of photoelectrons is measured.

Investigations and explanations of the photoelectric effect can be supported with simulations such as [PhET Photoelectric effect](https://phet.colorado.edu/en/simulation/photoelectric) . Simulations allow students to visualise the energies of photoelectrons and the application of a stopping voltage.

Students should be given opportunities to practice analysing plots of maximum kinetic energy of photoelectrons versus the frequency of incident light. This should include investigating the significance of the x and y-intercepts and gradient, along with the interpretation of the scaled units of each axis. Students could be guided in applying the general formula for a straight line, , to demonstrate the directly proportional relationship between frequency and photon energy. However, if finding Planck’s constant using the gradient, consider the units of energy.

#### Light and special relativity

Students can be introduced to Special relativity and Einstein’s thought experiments using the hands-on investigation developed by the Perimeter Institute. [Activity 4 in the Contemporary Physics lesson](https://resources.perimeterinstitute.ca/collections/featured/products/contemporary-physics?variant=29797467160654) compilation guides students to investigate time using the models of Newton and Einstein using printed templates, drawing pins and string. A video guide, along with printable student materials and worked solutions are included in the lesson compilation.

Paul Hewitt has recorded a series of explanatory videos for physics students, his collection of [Hewitt Drew-It!](http://phyz.org/hewittdrewit/spth.html) videos on the Special theory of relativity use diagrams and examples to introduce this topic including time dilation and length contraction.

[Visual physics online’s](http://www.physics.usyd.edu.au/teach_res/hsp/sp/mod7/m7MuonDecay.pdf) discussion of evidence for time dilation and length contraction outlines relevant evidence at a level of depth appropriate for Year 12 students.

When quantitatively introducing the impact of relative motion on measurements of time, length and momentum, it can be useful to begin by determining the relativistic (or Lorentz) factor . Students can explore the magnitude of this factor for different relative velocities to develop an appreciation of relativistic speed, that is, the speed at which relativistic effects become significant or need to be accounted for.

Investigating the mass-energy equivalence, , can be used to build connections with concepts in Module 8. Consider using examples that relate to Module 8 content such as the transformation of radiation into matter via pair-production (for example, electron-positron production) and the release of energy from hydrogen fusion in stars. Quantitative analysis of these processes can support questioning and problem solving such as estimating stellar lifetimes and will be applied later when studying the properties of the nucleus topic.

## Suggested investigations

A range of suggested investigations for this module, beyond those described in the teaching strategies have been compiled in the Nature of light investigation handbook, which has been included as an appendix to this guide.

## Appendices

### Appendix one: Models of light

The Olympus webpage, [Light: Particle or a wave?](https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/particleorwave/) introduces a debate over the nature of light, highlighting the division between the models proposed by Newton and Huygens in the early eighteenth century. Use the information in this website, or gather your own to complete the following.

1. Outline the models of Newton and Huygens, support your responses with diagrams

|  |  |
| --- | --- |
| Newton’s model | Huygen’s model |
|  |  |

1. Complete the table below to summarise the evidence supporting and/or distinguishing between the models of light proposed by Newton and Huygens.

|  |  |  |  |
| --- | --- | --- | --- |
| Phenomena | Newton’s model | Huygens Model | Role as evidence |
| Refraction |  |  |  |
| Reflection |  |  |  |
| Diffraction, including Young’s double slit experiment |  |  |  |
| Polarisation |  |  |  |
| Photoelectric effect (optional at this stage) |  |  |  |

1. Construct a timeline showing the development of ideas and analyse the relationships between evidence and understanding. Include the publication of their respective models along with the finding of new experimental evidence. How many years are there between events?

### Appendix two: Sample question

Question 22 is part of the Year 12 Physics problem set published on the [Curriculum website](https://education.nsw.gov.au/teaching-and-learning/curriculum/key-learning-areas/science/stage-6/physics).

#### Question 22 (6 marks)

In your studies in Physics, you investigated historical and contemporary methods used to determine the speed of light. Outline **two** of the methods that you investigated and compare how each method minimised error and uncertainty to improve the accuracy of their measurement of the speed of light.

##### Marking criteria

|  |  |
| --- | --- |
| Criteria | Mark |
| * describes **two** methods used to determine the speed of light * demonstrates a thorough understanding of error, uncertainty and accuracy in first-hand investigations * relates features of each method to the improved accuracy of the measurement of the speed of light | 6 |
| * describes **two** methods used to determine the speed of light * demonstrates an understanding of **two** of the following: error, uncertainty and accuracy, in first-hand investigations * relates features of each method to the improved accuracy of the measurement of the speed of light | 5 |
| * outlines a method used to determine the speed of light * demonstrates a sound understanding of at least **one** of the following: error, uncertainty and accuracy, in first-hand investigations * relates a feature of one of the methods to the improved accuracy of the measurement of the speed of light | 3-4 |
| outlines a method used to determine the speed of light  **or**  demonstrates a sound understanding of error, uncertainty OR accuracy in first-hand investigations | 2 |
| provides a general description of how the speed of light could be measured  **or**  identifies a basic understanding of error, uncertainty OR accuracy | 1 |

##### **Sample answer**

Errors and uncertainty can limit the accuracy of measurements made in first-hand investigations. The magnitude of the quantities to be measured, coupled with the technologies used to measure them will affect the accuracy of the results obtained in an investigation.

Methods used to measure the speed of light generally involve either:

* the simultaneous measurements of distance and time to calculate the speed as , or
* using wave properties of light to create standing waves, requiring measurements of distance (wavelength) and frequency to calculate speed using the wave equation (

When attempting to measure the speed of light, accuracy can be judged by the extent to which the measured value for the speed of light agrees with its true value ().

#### Method 1 1840’s, Fizeau and a rotating cog

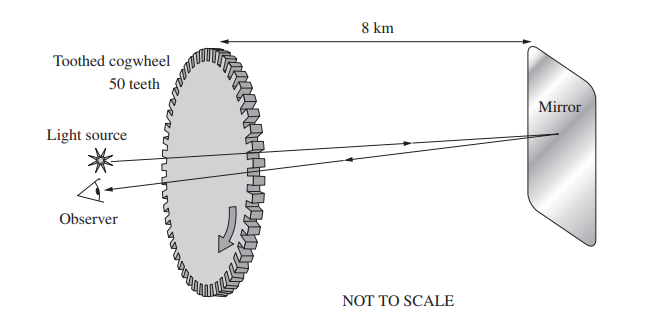
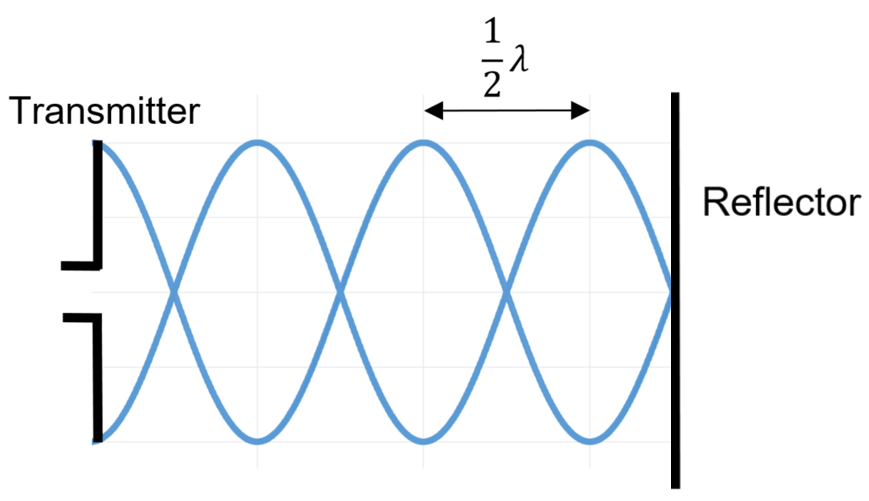


Image credit: Mod 5 – Question 15 [NESA](https://educationstandards.nsw.edu.au/wps/wcm/connect/9274d565-a5bf-451f-8d70-e7deca19d820/physics-2017-additional-sample-hsc-questions.pdf?MOD=AJPERES&CVID=)

In his experiment, intense light was shone at a mirror 8 km away. The light beam was broken up by a rotating cog, as shown above. The speed of rotation was adjusted until the reflected light been could no longer be seen returning through the gaps between the teeth of the cogs. At this point, the cog will have rotated through exactly the angle required for a tooth to block the part of the returning light in the time it took to travel the 16 km round trip to the mirror and back.

The rotating cog is the technology used to make precise measurements of time with relatively low uncertainty. Placing the mirror 8 km away increases the time the light takes to travel. Together, this reduces the relative error in the time measurement and supports a reasonably accurate measurement of the speed of light. He measured c≈, which is within 5% of its true value.

#### Method 2 1894 – Hertz and the speed of radio waves using standing waves



Hertz measured the speed of radio waves (predicted by Maxwell as part of the EM spectrum that includes light and travels at speed, c, in a vacuum). He created a standing wave by reflecting radio waves back towards the transmitter, as shown in the diagram. The distance between adjacent anti-nodes was measured using a ring with a small gap across which a spark would jump. This distance was equal to ½ the wavelength. The frequency of waves could not be directly measured and was instead calculated from the transmitter circuit details. By applying the wave equation, the velocity could then be determined.

The static nature of the node-antinode pattern removed the need to make measurements at short time intervals, which plagued earlier efforts. Random errors in distance measurements for determining the wavelength could be minimised by recording the distance between a larger number of successive anti-nodes and dividing the result accordingly. His measurement for the speed of radio waves (and therefore light) was highly accurate and supported Maxwell’s earlier predictions.

Answers could also include:

Galileo’s shuttered lanterns, Roemer’s eclipse patterns, Foucault’s rotating mirror, Michelson’s octagonal mirror, Michelson-Morley interferometer.

### Appendix three: The nature of light investigation handbook

#### Teachers Guide

Having an accessible practical equipment list allows you to copy and paste straight into your school’s software or template for completing risk assessments. The risk assessment tables included with each investigation have been partially completed to demonstrate their use. Teachers and students could complete these tables as part of their risk assessment practice.

It is not a syllabus requirement that these investigations be conducted as practical investigations. However, simple investigations involving the collection of first-hand (or simulated) data can improve student engagement and support the development of a variety of Working Scientifically skills.

#### Equipment required

##### Investigation one: measuring the speed of light

* microwave
* ruler
* bar of chocolate
* calculator

##### Investigation two: spectroscopy

* a compact disc (CD)
* a cardboard tube (30cm long 10cm in diameter)
* two flat circular pieces of cardboard large enough to cover each end of the tube
* razor knife or box-cutter
* tape
* fluorescent light
* saw
* cutting guide (scaled for a 3-inch tube) [PDF included](https://www.exploratorium.edu/sites/default/files/snacks/CD-Spectroscope-Cutting-Guide.pdf)
* access to a printer

##### Investigation three: black body radiation

* [PhET simulation: Blackbody spectrum](https://phet.colorado.edu/en/simulation/blackbody-spectrum)

##### Investigation four: diffraction of light

* red laser pointer (<1 mW)
* retort stand and clamps
* narrow slit attachment (alternatively, you can make your own with pencils)
* graph paper
* sticky tape
* a very dark room

##### Investigation five: Young’s double slit experiment

* red laser pointer (<1 mW)
* retort stand and clamps
* double slit attachment (alternatively, you can make your own with pencils)
* graph paper
* sticky tape
* a very dark room

#### Method

##### Investigation one: measuring the speed of light

All you need to do this experiment is a microwave, ruler, bar of chocolate and a calculator. You could also use cheese, marshmallows, or choc drops. Remember to check for food allergies. Adapted from Shadwick, B., 2020. Surfing NSW Physics Modules 5 & 6: Brian Shadwick: 9780855837068.

**Aim**

To measure the speed of light using a microwave

**Background knowledge**

The typical frequency of a microwave oven is around 2450MHz = 2450000000Hz

Check the service plate on the back of the microwave for the frequency used and adjust your calculations accordingly

Where:

Be familiar with Galileo’s experiment of first trying to measure the speed of light and Roemer who proved that light travels at a finite speed. You could reproduce Galileo’s experiment in a dark room with torches.

This investigation exploits the wave properties of light to measure its velocity. In this way, it is like the method employed by Heinrich Hertz in measuring the speed of radio waves.

When waves are reflected back towards their source, the waves interfere to create [standing waves](https://www.physicsclassroom.com/class/waves/Lesson-4/Formation-of-Standing-Waves) with alternating nodes (positions of zero displacement) and antinodes (positions which vibrate between maximum positive and negative displacements). The distance between any two consecutive antinodes, or nodes, is equal to half the wavelength of component waves.

Draw a diagram of a standing wave pattern in the space below. Label the nodes and antinodes along with a wavelength.

##### Risk assessment for investigation one

|  |  |  |
| --- | --- | --- |
| Identify hazard | Evaluate risk | Control measure used |
|  |  |  |
|  |  |  |
|  |  |  |

**Method**

1. Remove turntable from microwave. The chocolate must be stationary when heated.
2. Put a plate upside down over the rotor to ensure chocolate remains stationary.
3. Place a bar of chocolate upside down, ensuring the middle of the chocolate is as close as possible to the centre of the microwave.
4. Set the timer for 30 seconds. **Note**: This is too long, but you can open manually to stop.
5. Start the microwave and heat chocolate until it starts to melt in two or three places- usually around 20 seconds.
6. Open the door as soon as you see the melted hot spots form on the chocolate
7. Carefully take the chocolate out of the microwave.
8. Measure the distance between the centre of the melted spots, as accurately as you can.
9. This distance represents half the wavelength of the microwaves (**Note**: remember to change to metres).
10. Repeat the experiment 3 times and calculate the average wavelength of the microwaves.

**Results**

* apply the formula , and your measured wavelength to determine the speed of microwaves
* compare your answers to the accepted value ()
* calculate your percentage error in your experiment from
* write a brief discussion of your results including suggestions of how you could improve the accuracy of the investigation.

##### Investigation two: CD Spectrometry

A spectroscope splits light up so that the different components are spread out allowing the intensity of light at different waves to be observed.

Adapted from Exploratorium. 2020. CD Spectroscope. [online] Available at: [exploratorium.edu/snacks/cd-spectroscope](https://www.exploratorium.edu/snacks/cd-spectroscope) [Accessed 25 March 2020].

**Aim**

Observe light at different wavelengths by turning an old CD into a spectroscope to analyse light. You may be surprised by what you see.

**Background knowledge**

Visible light is composed of a spectrum of electromagnetic waves, each component having its own wavelength. A spectroscope disperses the component wavelengths, separating and displaying them so that they can be studied. CD’s can be used to build a spectroscope as the circular tracks that information is recorded on are so close together that they can act as a diffraction grating for light.

When the light enters the tube, its spectrum is spread out perpendicular to the CD tracks. Therefore, the slit and the viewing hole are located at right angles. Each component is diffracted according to its wavelength which spreads out the colours. For you to see the spectrum, the light must diffract off the CD and be directed at your eye. Adjusting the tilt of the CD allows you to align the spectrum so that it can be viewed.

Watch [exploratorium.edu/snacks/cd-spectroscope](https://www.exploratorium.edu/snacks/cd-spectroscope) (duration 2:17)

##### Risk assessment for investigation two

|  |  |  |
| --- | --- | --- |
| Identify hazard | Evaluate risk | Control measure used |
| Light source | Bright lights may cause eye damage if viewed directly |  |
| Light source | Hot light globes may cause burns |  |
| Cutting tools |  |  |
|  |  |  |

**Method**

1. Print the cutting guide and wrap it around your tube. If needed, you can scale the guide to ensure it wraps around your tube without a gap or overlap.
2. Use a saw to cut the tube at an angle along the curved line on the cutting guide. The cut will make the CD tilt at an angle approximately 30 degrees from the end of the tube.
3. Use a razor knife or box-cutter to cut the rectangular viewing hole—the black square on the cutting guide. You can remove the cutting guide now.
4. Next, cut a clean slit less than 1 mm wide and 5 cm long in one of pieces of flat cardboard (or plastic tube cap). Tape the flat cardboard onto the end of the tube furthest from the CD—the top of the tube. Hold the tube as shown below and align the slit horizontally.
5. Tape the second flat piece of cardboard (or plastic tube cap) over the bottom end of the tube, behind the CD, to exclude any stray light.
6. Insert the CD into the CD slot, so that it reflects the light coming through the top slit into your eye.
7. Hold the tube upright and point the top slit at a fluorescent light and press your eye to the viewing hole.
8. On the CD, look for a clear, solid line of light broken up into coloured bands: this is the spectrum of light reflected from fluorescent light onto the CD.

You may need to adjust the angle at which you look through the viewing hole at the CD to find the best view of the light spectrum. Notice that the fluorescent light produces bright lines. The bright lines are the spectrum of mercury gas inside the tube. An incandescent light, by comparison, makes a continuous spectrum.

**Note**: consider trying to photograph the spectrum using a smartphone if you have one available. This will allow you to describe, analyse and compare spectra without the need to keep the light source and tube aligned. You could also share your best image with one of your peers or class.

**Results**

* Sketch the spectra produced by a range of light sources, labelling any key features, similarities or differences.
* Use the internet to find a picture of the emission spectra of common elements, that is, bright line spectra. Then try and identify the elements present in the spectra of the discharge tube you observed.
* Create a table to organise and share your results.

##### Investigation three: blackbody radiation

A blackbody is an idealised object that is a perfect absorber and emitter of radiation. That is, it is capable of absorbing and emitting all wavelengths of electromagnetic radiation, thus not reflecting any incident light. As it absorbs energy it heats up and re-radiates the energy, producing a spectrum of light that is dependent only on its temperature.

**Aim**

Use the PhET black body simulation to reproduce a blackbody radiation curve for a range of temperatures.

**Background knowledge**

The visible part of the spectrum contains electromagnetic radiation with wavelengths ranging from 400 nm (violet) to 700 nm (red).

Wien’s Law;

describes the relationship between the temperature, T, of an object and the peak wavelength (the wavelength with the highest intensity), . For hotter objects, the peak wavelength occurs at a shorter wavelength. The constant, b, known as Wien’s displacement constant, has a value of .

**Note:** the unit of Wien’s constant is metres kelvin.

##### Risk assessment for investigation three

|  |  |  |
| --- | --- | --- |
| Identify hazard | Evaluate risk | Control measure used |
|  |  |  |
|  |  |  |
|  |  |  |

**Method**

Open the [PhET simulation – Blackbody spectrum](https://phet.colorado.edu/sims/html/blackbody-spectrum/latest/blackbody-spectrum_en.html).

**Section one - the black body spectrum of an incandescent light globe**

* set the temperature of the black body to 3000 K. This is approximately the temperature of the tungsten filament of an incandescent light globe which behaves like a blackbody. Use the zoom tools so that you can observe a large peak.
* turn on “Graph Values” to assist in reading values from the blackbody spectrum.
* complete questions 1-4 in the results section

**Section two - comparing spectra of different objects**

* set the temperature to 650 K, which is approximately the temperature of a very hot oven. Notice that the RED line is the radiation emitted by the oven. The line may appear flat, but it is not.
* use the zoom tools to enlarge the blackbody curve so that it can be viewed easily.
* complete question 5
* set the temperature to about 5800 K. This is approximately the surface temperature of the sun. You may again need to adjust the zoom.
* complete questions 6-8

**Section three - the relationship between peak wavelength and temperature**

* this section explores the relationship between the peak wavelength and temperature. For the following temperatures find the peak wavelength using the ruler tool to help line up the peak with the x-axis. Enter your wavelengths in μm, that is 10-6 m.
* complete questions 9-13

**Results**

**Section one**

1. Does the light globe produce X-rays? Explain your answer.
2. Which wavelength is most intense and what colour is it?
3. Is an incandescent light globe an efficient light source? Explain and suggest alternatives which would be better.
4. From the shape of the graph, would you expect the light globe to emit radio waves? Explain your answer.

**Section two**

1. Compare the spectrum produced by the light bulb to that produced by the oven?
2. Compare the most intense wavelength (peak wavelength) produced by the light globe to the most intense produced by the sun.
3. Explain the relationship you see between the radiation emitted by the sun and the visible spectrum.
4. Is there evidence from the black body curve that the sun is producing ultraviolet radiation? Explain your answer.

**Section three**

**Note -** you cannot fill in the 3rd column until after you have graphed your data

Results table for section 3

|  |  |  |
| --- | --- | --- |
| Temperature (K) | Peak wavelength ) |  |
| 500 |  | 20 |
| 1000 |  |  |
| 1500 |  |  |
| 2000 |  |  |
| 2500 |  |  |
| 3000 |  |  |
| 3500 |  |  |
| 4000 |  |  |

1. Plot a graph of wavelength against temperature on the grid below. Make sure your axis starts at (0,0) and place temperature (the independent variable in our investigation) on the x-axis.



1. Do you get a straight line? If not, you will need to process your data by manipulating one of the variables to create a straight-line relationship. Complete the last column in the table above by calculating the inverse of the temperature values. Represent your calculated values for 1/T using the units described in the table as demonstrated in the following example.

For the first row;

Therefore, the first row of the last column would be 20.

Now redraw your graph with 1/T on the x-axis using the following grid.



1. What kind of relationship do you find between wavelength and ?
2. Write an equation including the value of the gradient for your straight-line graph.
3. The straight-line relationship you find is Wien’s law. Find the constant in this law and compare your value with the accepted value provided in the background knowledge.

##### Investigation four: diffraction of light waves

All waves can exhibit diffraction. Diffraction is the spreading out of light as it passes around the edge of an obstacle or through a narrow slit. Early observations of the diffraction of light provided key evidence to support the wave model of light proposed by Huygens over Newton’s particle model.

**Aim**

Observe the change in direction of the travel of waves as they pass through an opening.

**Background knowledge**

Simply stated, Huygen’s (pronounced HOY-guns) model of light is based on the proposal that:

Each point of a wavefront acts as a source of secondary wavelets that expand forward from that point.

[Huygen’s model of light video](https://www.youtube.com/watch?v=_03sfhb7Mvg) (duration 6:42) successfully explains reflection, refraction and diffraction.

Some key features of diffraction patterns produced by single slit diffraction are described below.

The width of the central band is double the width of the band on either side of it. The intensity of the maxima, that is the brightness, diminishes quickly with increased distance from the centre of the screen. As the width of the slit is reduced the diffraction effect is increased. This means that the bands are spread further apart as the width of the slit decreases.

##### Risk assessment for investigation four

|  |  |  |
| --- | --- | --- |
| Identify hazard | Evaluate risk | Control measure used |
| Laser pointer | Laser light can cause serious eye damage | Keep laser at waist height to prevent stray light entering eyes  Post a warning sign on each entrance to laboratory |
|  |  |  |
|  |  |  |

**Method**

**Note:** As an alternative to this investigation watch the video [Laser diffraction and interference](https://www.youtube.com/watch?v=9D8cPrEAGyc) (duration 2:25) taking notes and sketching the different diffraction patterns produced.

* Attach a red laser pointer (less than 1 mW) to a retort stand to hold the laser steady.
* Use narrow slit, your school may have these or you can make one. Sticky tape two pencils together with one of the pencils having a few extra layers of sticky tape placed over one end. This should make a very narrow gap through which the laser light can be passed.
* A dark room.
* A screen to make observations, this could be a sheet of graph paper stuck on the wall.
* Sticky tape to keep the laser switched on.
* Measure the width of the central fringe.
* Next change the width of the slit and observe how this changes the diffraction pattern

**Results**

Draw and describe your diffraction pattern. You can also take a photograph. You may find a different camera app than that which is installed by default on your smartphone will give better results especially one which allows a longer exposure. A DSLR camera on manual settings is an excellent alternative.

If you need reassurance that you are observing a diffraction pattern, then search the internet for images of single slit diffraction and compare them your observations.

##### Investigation five: Young’s double slit experiment

Young carried out his experiment in the early 1800s. Young’s experimental findings played a major role in the general acceptance of the wave theory model of light.

**Aim**

To show the interference of light passing through two narrow slits

**Background knowledge**

The waves that interfere with each other can be considered as both constructively and destructively. Constructive interference lines produce bright bands and are also known as anti-nodal lines. Whilst destructive interference produces dark bands and are also known as nodal lines. When the light passing through the narrow slits strikes a screen, a distinctive diffraction pattern of light and dark bands is observed. The position of the bright bands on the screen can be determined using the following equation.

For further details on Young’s double slit experiment and on applying the above equation, OpenStax College and sample problems with answers can be found on the [Physics Classroom](https://www.physicsclassroom.com/class/light/Lesson-3/Young-s-Experiment).

##### Risk assessment for investigation five

|  |  |  |
| --- | --- | --- |
| Identify hazard | Evaluate risk | Control measure used |
| Laser pointer | Laser light can cause serious eye damage | Keep laser at waist height to prevent stray light entering eyes |
|  |  |  |
|  |  |  |

**Method**

* attach a red laser pointer (less than 1mW) to a retort stand to hold the laser steady.
* place a double slit in front of lasers path. Your school may have these, or you can make you own. Instructions are available at [How To Make Your Own Double Slit Experiment.](https://www.youtube.com/watch?v=kKdaRJ3vAmA)
* attach a screen to the wall you will be directing the laser light. Graph paper or a piece of white paper will be suitable. Apply sticky tape to keep the laser switched on
* mark and measure the width of the central fringe.
* change the width of the slit and observe how this changes the diffraction pattern.

**Note:** The room may need to be very dark in order to clearly observe the interference pattern.

**Results**

Construct a table of your results, along with a diagram showing how your equipment was setup.

|  |
| --- |

## Resources

* [VISUAL PHYSICS ONLINE](http://www.physics.usyd.edu.au/teach_res/hsp/sp/spHome.htm)  Ian Cooper, School of Physics, University of Sydney

This website offers a comprehensive range of pdf’s that are tailored to support the Stage 6 Physics course in NSW. Each resource includes clear explanations, activities and makes good use of diagrams to support understanding. Most resources also included differentiated levels of explanation that can be tailored to suit the needs of your students.

* [PHYSCLIPS Light](https://www.animations.physics.unsw.edu.au/light/nature-of-light/index.html)

This site has a range of animations and recorded practical demonstrations to support concepts covered in module 7. This includes a detailed demonstration of a modern method for measuring the speed of light using a laser, a beam splitter and a CRO.

* [compadre.org/physlets](https://www.compadre.org/physlets/)

This collection of interactive illustrations, explorations and problems for introductory physics contains interactive activities based on a wide range of physics topics. The ‘Before you start’ section contains explanations of how they can be used to support learning, with a focus on developing deep learning through experimentation along with critical thinking and problem-solving skills. Each activity contains detailed notes to guide learning and exploration.

* A sample set of interactives relevant to this module include:
  + [Single slit diffraction](https://www.compadre.org/Physlets/optics/illustration38_1.cfm) (illustration)
  + [Modelling diffraction from a slit](https://www.compadre.org/Physlets/optics/ex38_1.cfm) (exploration)
  + [Wavelength of light through a single slit](https://www.compadre.org/Physlets/optics/prob38_4.cfm) (problem)

**The Perimeter Institute**

Each of the resources provided by the Perimeter Institute includes a video, lesson notes, classroom worksheets and assessments with worked responses. They can be downloaded for free from the [Perimeter Institute website](https://resources.perimeterinstitute.ca/collections/astrophysics-cosmology/products/the-expanding-universe?variant=17163100102) after registering for a free account. They have an extensive collection of resources available to support learning and teaching of concepts relevant to the Stage 6 Physics course. Specific examples relevant to this module are listed below.

* [Fields](https://resources.perimeterinstitute.ca/collections/lesson-compilations/products/fields?variant=29797321965646) The resource contains a set of five activities. Activity 3: Maxwell’s equations, explores the significance of each equation and scaffolds student understanding through questioning, diagrams and hands-on activities.
* [The expanding Universe Activity](https://resources.perimeterinstitute.ca/collections/astrophysics-cosmology/products/the-expanding-universe?variant=17163100102) 2: The signature of the stars contains data driven activities for students to explore the information contained in the light from stars. Students will be guided through the analysis and display of spectral plots and develop an understanding of the evidence for an expanding Universe provided by the spectra of distant galaxies and Type 1a supernovas.
* [Contemporary Physics Activity](https://resources.perimeterinstitute.ca/collections/featured/products/contemporary-physics?variant=29797467160654) 4: How does motion affect time, guides students to investigate time using the models of Newton and Einstein using printed templates, drawing pins and string.
* [The challenge of quantum reality](https://resources.perimeterinstitute.ca/collections/quantum/products/the-challenge-of-quantum-reality?variant=17148646726)  Activity 1: Video summary. Watching the video provided in this package and completing the question included in activity 1 will introduce students to the core principles of the wave-particle duality relevant to Module 7. It would be suitable as a segue between the wave and quantum model topics. The other activities in this lesson compilation could be set as extension work for more advanced students.
* [Year 12 Physics problem set](https://schoolsequella.det.nsw.edu.au/file/082e857c-f945-4d72-ad9f-9f6dd1ea7abc/1/Physics%20Year%2012%20modules%20Problem%20Set.docx) – NSW Department of Education

This document contains questions to probe students’ understanding of various concepts in the Year 12 course of the Stage 6 Physics syllabus. The questions have been designed by NSW Physics teachers who attended the ‘Teaching the Year 12 modules in Stage 6 Science’ workshops in 2019, as well as the science curriculum support officers at the Learning and Teaching Directorate. The problem set may be used as classroom activities or in assessments to evaluate student understanding. Teachers are free to adapt or modify the questions in this problem set to suit the learning needs of their students.

J. S. Aslanides and C. M. Savage. (9 May 2013). [Relativity concept inventory: Development, analysis, and results.](https://arxiv.org/pdf/1302.7094.pdf) Phys. Rev. ST Phys. Educ. Res. 9, 010118. DOI:https://doi.org/10.1103/PhysRevSTPER.9.010118