FLEET Schools.

Light: reflection, refraction, diffraction

Contents

Introduction

We observe light all around us in the form of sunlight, from torches or fire, but what actually is light?

Light is not actually matter – it has no mass – so in effect it can't be seen. We can't hold it or smell it. We can only learn about it by how it interacts with or affects things around it.

This resource covers the basic physics of light and how it works, a bit of the history and philosophy of light and its applications and implications for society. There are links to critical thinking exercises and experiments that cover the concepts of absorption, reflection, refraction and diffraction to help students (and curious adults) think critically about the phenomenon of light, to potentially challenge their perceptions, and reflect on their understanding of light. The resources and activities are aligned to the years 4-9 curriculum, but there are links and suggestions to extend students' thinking in some activities. Some concepts and activities may be suitable for younger year levels.

FLEET researchers use light to help develop atomically thin materials and electronic circuits for the next generation of energy-efficient electronic technologies. Light is also crucial to control the function of these technologies. See FLEET research and the need for the next generation of electronics.

How long before the digital revolution enables a new generation of technologies?
It may be sooner than you think and the way we generate and consume electricity is one of the main drivers of the research that will replace the digital technologies and enable driverless cars, advanced artificial intelligence, robotics and advances in human health. It could enable computers the ability to monitor and track your every movement, conversation and your proximity to others. That computer could analyse and interpret the meaning of your conversation and actions and make decisions based on that data. What are acceptable uses of such technologies? Who should control such technology? Such questions and the motivation for FLEET's research should be part of the dialogue about the direction and application of scientific research and, alongside the hands-on experiments, are part of the critical thinking activities in this unit.

Lighting the way to a solution

FLEET works in the quantum world, which is where some of our deepest understanding yet of the universe may be. FLEET researchers want to understand how the atomically thin (2D) materials they are developing behave at the quantum level, and to manipulate and control their useful properties. The next task is to develop ways to fabricate these materials at a commercial scale. The use and manipulation of light is crucial to FLEET researchers to help test, understand and control the behaviour of 2D materials, and to develop novel materials of use to lowenergy electronics. You can find out more about FLEET's research and the importance of light at FLEET research and the need for the next generation of electronics.

Broader implications of understanding light.

Our understanding of light has led to the development of microscopes, microwave ovens, telescopes, X-rays, lasers, our optical fibre network that delivers all our data worldwide, sending and receiving signals worldwide via satellites (ie radio or microwaves), even development of an artificial eye. In fact, light can help describe most of the physical universe around us. As one of the most extensive carriers of information, we can study and learn about some of the smallest things such as atoms and bacteria, to the most distant and largest such as stars and galaxies. Understanding light has led us into the quantum world where some of the deepest-held secrets of the universe are being revealed. Now it is time to get our heads around what light actually is.

Learning outcomes

By the end of the unit, students will….

- Have a solid understanding of the nature of light
- Have knowledge about the nature of light as a wave and particle
- Be able to communicate ideas, explanations and processes about light using scientific representations
- Develop an awareness of the history and philosophy that led to our understanding of light and its application to modern digital technologies
- Be able to think critically about and the social implications of how we exploit light to develop modern digital technologies
- Have the ability to apply experience from each stage of the unit to predict or develop hypotheses in novel contexts
- Be able to use evidence to generate a discussion about what is happening.

Victorian Curriculum Links Years 5-6

Scientific understandings, discoveries and inventions are used to inform personal and community decisions and to solve problems that directly affect people's lives	● Considering how electricity and electrical appliances have changed the way some people live ● Considering how guidelines help to ensure the safe use of electrical devices
Energy from a variety of sources can be used to generate electricity; electric circuits enable this energy to be transferred to another place and then to be transformed into another form of energy	● Recognising the need for a complete circuit to allow the flow of electricity ● Exploring circuit features, for example, wires and switches, and electrical devices, for example, light globes, LEDs and motors ● Investigating different electrical conductors and insulators ● Investigating how moving air and water can turn turbines to generate electricity ● Investigating how solar panels can generate electricity
With guidance, pose questions to clarify practical problems or inform a scientific investigation, and predict what the findings of an investigation might be based on previous experiences or general rules	● Exploring a range of questions that can be asked about a problem or phenomena and, with guidance, identifying those questions that could be investigated by students ● Refining questions to enable scientific investigation ● Applying experience from previous investigations to predict the outcomes of investigations in new contexts
With guidance, plan appropriate investigation types to answer questions or solve problems and use equipment, technologies and materials safely, identifying potential risks	● Following a given procedure to design an experimental or field investigation ● Experiencing a range of ways of investigating questions, including experimental testing, creating models, internet research, field observations, simulations and trial and error methods ● Discussing the advantages and disadvantages of certain types of investigation for answering certain types of questions ● Discussing possible hazards involved in conducting investigations, and how these risks can be reduced
Construct and use a range of representations, including tables and graphs, to record, represent and describe observations, patterns or relationships in data	● Using familiar units such as grams, seconds and metres and developing the use of standard multipliers such as kilometres and millimetres ● Using digital technologies to record data as digital images or in spreadsheets and to present data in tables and simple graphs ● Using digital technologies to construct representations, including dynamic representations
Compare data with predictions and use as evidence in developing explanations	● Discussing the difference between data and evidence ● Referring to evidence when explaining the outcomes of an investigation ● Sharing ideas as to whether observations match predictions, and discussing possible reasons for predictions being incorrect

Suggest improvements to the methods used to investigate a question or solve a problem	• Working collaboratively to identify where testing was not fair and suggesting how fairness could be improved • Identifying improvements to investigation methods, and discussing how these improvements would affect the quality of the data obtained
Communicate ideas and processes using evidence to develop explanations of events and phenomena and to identify simple cause-and-effect relationships	• Discussing how models represent scientific ideas and constructing physical models to demonstrate an aspect of scientific understanding • Using a variety of communication modes, for example, reports, explanations, arguments, debates and procedural accounts, to communicate science ideas • Using labelled diagrams, including cross-sectional representations, to communicate ideas and processes

Victorian Curriculum Links Years 7-8

Scientific knowledge and understanding of the world changes as new evidence becomes available; science knowledge can develop through collaboration and connecting ideas across the disciplines and practice of science	
Science and technology contribute to finding solutions to a range of contemporary issues; these solutions may impact on other areas of society and involve ethical considerations	● Investigating the development of vehicles over time, including the application of science and technology to the designs of solar-powered or electric vehicles
Energy appears in different forms including movement (kinetic energy), heat, light, chemical energy and potential energy; devices can change energy from one form to another	● Using flow diagrams to illustrate changes between different forms of energy
Identify questions, problems and claims that can be investigated scientifically and make predictions based on scientific knowledge	● Considering whether an investigation using available resources is possible when identifying questions or problems to investigate ● Using information and knowledge from their own investigations and secondary sources to predict the expected results from an investigation ● Recognising that the solution of some questions and problems may require consideration of social, cultural, economic or moral factors in addition to results from scientific investigation
Collaboratively and individually plan and conduct a range of investigation types, including fieldwork and experiments, ensuring safety and ethical guidelines are followed	● Identifying whether the use of their own observations and experiments or the use of other research materials is appropriate for their investigation ● Using simulations and identifying their strengths and limitations ● Developing strategies and techniques for effective research using secondary sources, including use of the internet
In fair tests, measure and control variables, and select equipment to collect data with accuracy appropriate to the task	● Taking into consideration all aspects of fair testing, available equipment, safe investigation and ethical considerations identifying and explaining the differences between controlled, dependent and independent variables when planning investigations ● Using specialised equipment to increase the accuracy of measurement within an investigation
Construct and use a range of representations including graphs, keys and models to record and summarise data from students' own investigations and secondary sources, and to represent and analyse patterns and relationships	● Understanding different types of diagrammatic, graphical and physical representations and considering their strengths and limitations ● Comparing and contrasting data from a number of sources in order to create a summary of collected data ● Using diagrammatic representations to convey abstract ideas and to simplify complex situations
	● Identifying data that provides evidence to support or refute the hypothesis being tested

Use scientific knowledge and findings from investigations to identify relationships, evaluate claims and draw conclusions	● Drawing conclusions based on a range of evidence including from primary and secondary sources
Reflect on the method used to investigate a question or solve a problem, including evaluating the quality of the data collected, and identify improvements to the method	● Identifying and considering indicators of the quality of the data when analysing results ● Discussing investigation methods with others to share ideas about the quality of the inquiry processes used ● Suggesting improvements to investigation methods that would improve the accuracy of the data recorded
Communicate ideas, findings and solutions to problems including identifying impacts and limitations of conclusions and using appropriate scientific language and representations	● Using digital technologies to access information, to communicate and collaborate with others on and off site and to present science ideas ● Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience

Victorian Curriculum Links Years 9 - 10

Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries	
Electric circuits can be designed for diverse purposes using different components; the operation of circuits can be explained by the concepts of voltage and current	● Investigating parallel and series circuits and measuring voltage drops across and currents through various components ● Investigating the properties of components such as LEDs, and temperature and light sensors ● Comparing circuit design to household wiring ● Exploring the use of sensors in robotics and control devices
The interaction of magnets can be explained by a field model; magnets are used in the generation of electricity and the operation of motors	● Investigating the movement of a magnet and a wire to produce electricity ● Investigating the effect of a magnet on a current from a battery to produce movement
Energy flow in Earth's atmosphere can be explained by the processes of heat transfer	● Recognising that the Law of Conservation of Energy explains that total energy is maintained in energy transfers and transformations ● Recognising that in energy transfers and transformations, a number of steps can occur and the system is not 100% efficient so that usable energy is reduced
Formulate questions or hypotheses that can be investigated scientifically, including identification of independent, dependent and controlled variables	● Formulating questions that can be investigated within the scope of the classroom or field with available resources ● Developing ideas from students' own or others' investigations and experiences to investigate further ● Revising and refining research questions to target specific information and data collection or finding a solution to the specific problem identified
Independently plan, select and use appropriate investigation types, including fieldwork and laboratory experimentation, to collect reliable data, assess risk and address ethical issues associated with these investigation types	● Explaining the choice of variables to be controlled, changed and measured in an investigation ● Deciding how much data are needed to obtain reliable measurements ● Using modelling and simulations, including using digital technologies, to investigate situations and events ● Using the internet to facilitate collaboration in joint projects and discussions
Select and use appropriate equipment and technologies to systematically collect and record accurate and reliable data, and use repeat trials to improve accuracy, precision and reliability	● Applying specific skills in the use of scientific instruments ● Selecting and using probes and data loggers to record information ● Identifying how human error can influence the reliability of data

Construct and use a range of representations, including graphs, keys, models and formulas, to record and summarise data from students' own investigations and secondary sources, to represent qualitative and quantitative patterns or relationships, and distinguish between discrete and continuous data	● Using spreadsheets to present data in tables and graphical forms and to carry out mathematical analyses of data ● Designing and constructing appropriate graphs to represent data and to look for trends and patterns
Analyse patterns and trends in data, including describing relationships between variables, identifying inconsistencies in data and sources of uncertainty, and drawing conclusions that are consistent with evidence	● Exploring relationships between variables using spreadsheets, databases, tables, charts, graphs and statistics ● Describing data properties (for example mean, median, range, outliers, large gaps visible on a graph) and their significance for a particular investigation sample, acknowledging uncertainties
Use knowledge of scientific concepts to evaluate investigation conclusions, including assessing the approaches used to solve problems, critically analysing the validity of information obtained from primary and secondary sources, suggesting possible alternative explanations and describing specific ways to improve the quality of data	● Discussing what is meant by 'validity' and how we can evaluate the validity of information in secondary sources ● Judging the validity of science-related media reports and how these reports might be interpreted by the public ● Using primary or secondary scientific evidence to support or refute a conclusion or claim ● Suggesting more than one possible explanation of the data presented
Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations	● Using secondary sources as well as students' own findings to help explain a scientific concept ● Using a range of representations, including mathematical and symbolic forms, to communicate science ideas ● Presenting results and ideas using formal experimental reports, oral presentations, multimodal presentations, poster presentations and contributing to group discussions

Understanding light

As we noted, light is not matter and has no mass. How do students perceive the concept of light? Do students consider light to just exist? Do they have a concept that light 'travels' and that it travels at a certain speed and in a straight line? How does light travel? How do we see? This section will explore the nature of light, but to get students' initial perceptions of light and to think critically about its nature, do Activity 1, *What is light? Exploring student perceptions of light.*

Light is a packet of energy, though that is a bit simplistic because everything is a packet of energy when broken down to its simplest or smallest elementary particle. The simplest form of light is a photon, which is an electromagnetic wave that as it moves – oscillates – it produces an electrical and magnetic field. One field does not exist without the other and together, it makes up the electromagnetic spectrum.

The part of the electromagnetic spectrum that enables us to see and produce the colours of the rainbow sits in a narrow part of the spectrum we call visible light.

If you consider only the electrical part of the electro-magnetic wave, waves on water that we can observe are a reasonable analogy. As with a water wave, the electrical wave has a peak and trough (up and down, or top and bottom), and they have a forward motion, but it is the energy that propagates forwards rather than anything physical. Remember that light is massless and the key point here about a photon (light) is about its energy, not the space or size of the elementary particle because a photon does not actually occupy space in the same way you think of a classical object such as a bacterium, rock or planet.

Other properties of a photon include the following:
--They have no charge (unlike electrons and protons)
--Their speed in a vacuum is 299,792,458 metres per second (or about 300 million metres per second)

The wavelength determines the type of light. See Figures 1 and 2 below.

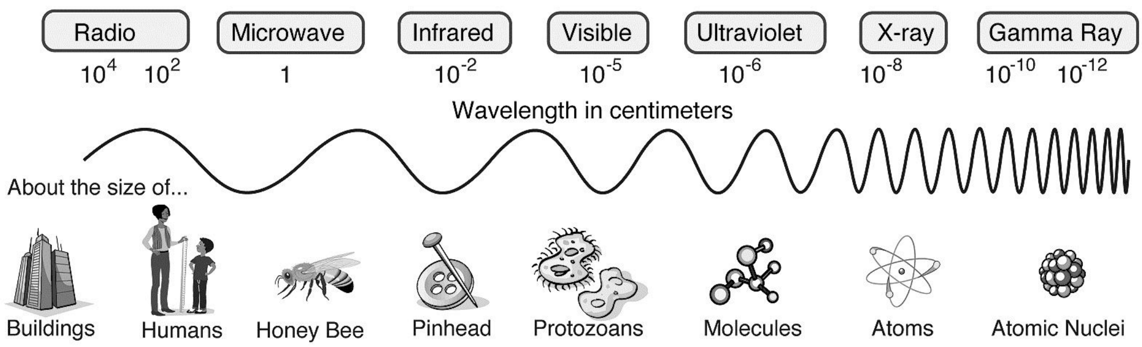

Figure 1. The distance between light waves (their wavelengths) determines the type of light it is. The distance will range from kilometres to lengths about the width of an atom, but they all travel at the same speed, the speed of light. (Image: [National Geographic Education Blog]())

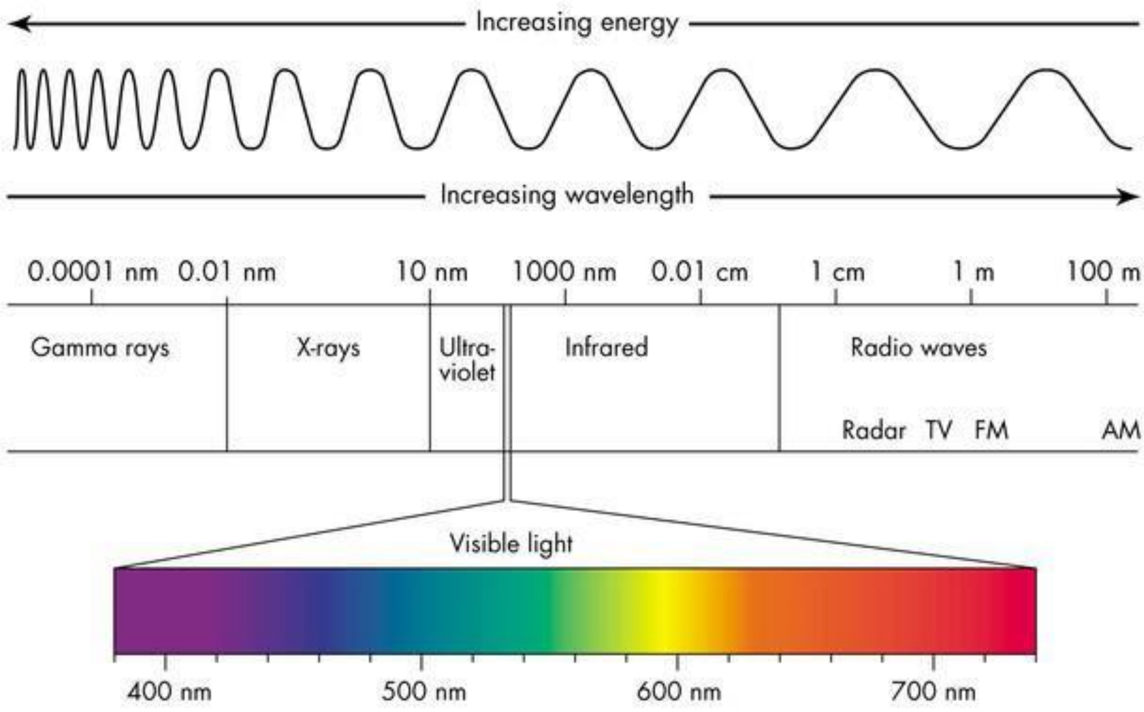

Figure 2. The energy of the wavelength increases with its frequency (number of oscillations per unit of time). Note the tiny proportion of the spectrum that makes up the visible spectrum. (Image: Cyberphysics)

Beyond the visible

Either side of visible light on the electromagnetic spectrum are a range of other forms of light. Sitting just outside the visible spectrum with a slightly longer wavelength is infrared light – or what we perceive as heat. On the other side of the spectrum from visible light with shorter wavelengths is UV light, which is what causes sunburn. The shorter the wavelength of light (and higher the frequency) the greater its energy. Regardless, the different forms of light are all the same thing, electromagnetic radiation, just with a different wavelength and energy.

Students can use a chocolate bar and microwave to see evidence of light as a wave and calculate the speed of light. See Activity 2, *Chocolate light: Observing light as a wave.* Younger students can simply observe how the chocolate melts in blobs that are a at specific distance apart and observe the light acting as a wave. Older or more advanced students can measure the wavelength and determine the speed of light.

Random fact 1. If you are lucky enough to be, for example, a manta shrimp or bee you can see or perceive your world in the UV through to the infrared wavelengths. The Australian Academy of Science has produced an excellent article and video on the visual systems of the mantis shrimp and similar animals and how our understanding of these systems has helped humans improve cancer detection and satellite imagery.

Random fact 2. Humans generate heat and we emit that in the form of infrared light. We can't see it because it is outside the invisible spectrum. But it is how night vision goggles work. They detect the infrared radiation (heat) from objects, which is why when we use night vision goggles we can see any object that gives off heat at night.

Thermal imaging to help see things at night, those that give off heat (infrared light) anyway. Courtesy NASA/JPL-Caltech, Linda Hermans-Killam

More information

See RiAus and their Explainer on the different forms of light in the EM spectrum, and here in their Short history of light.

For another neat explanation of electromagnetic radiation see Bernie Hobbs in action (Catalyst episode. Begins at the 23:30 mark in show)

The key concepts that students need to grasp to understand light and its interaction with our physical environment are reflection, absorption refraction and diffraction. These are explained next.

Reflection, absorption, refraction, diffraction – the basics

What is reflection

We can see objects because light reflects off that object and into our eyes. But we didn't always understand it this way.

Pythagoras (about 500 years BCE), best known for the theorem of the right-angled triangle, proposed that vision resulted from light rays emerging from a person's eye and striking an object. Epicurus argued the opposite: Objects produce light rays, which then travel to the eye. Other Greek philosophers -- most notably Euclid and Ptolemy -- used ray diagrams quite successfully to show how light bounces off a smooth surface or changes direction as it passes from one transparent medium to another.

Epicurus was honing in on the correct idea, but it took until the 9th and 10th centuries before we started to get close to what really happens. Abu Ali Mohammed Ibn Al Hasn Ibn Al Haytham (Ibn al-Haytham), who lived in present-day Iraq between A.D. 965 and 1039, identified the optical components of the human eye and correctly described vision as a process involving light rays bouncing from an object to a person's eye. A key difference with Ibn al Haytham's conclusion was that he determined it by performing an actual scientific experiment where he shone two lanterns through two pin holes at different heights into a dark room. In the wall of the dark room he saw two light spots. When he removed one lantern, the light spot that corresponded to that lantern disappeared. This finding enabled him to conclude that rather than light emanating from the eye, it is reflected off objects in a straight line.

The way light reflects off a surface is predictable and follows the law of reflection. Essentially, if light hits a mirror at one angle it will be reflected from the mirror at the same angle. See Figure 1.

Or in more mathematical terms the angle of incidence (i) is equal to the angle of reflection (r). This is easily demonstrated with a laser light, a mirror and a protractor to measure angles. See Figure 1. where I is the incident (incoming) ray; R is the reflected ray; N is the normal line, which is an imaginary line that is perpendicular to the surface the light reflects off (a mirror in this case). The angle of incidence (i) is the angle between the incident ray and normal; the angle of reflection (r) is the angle between the reflected ray and normal.

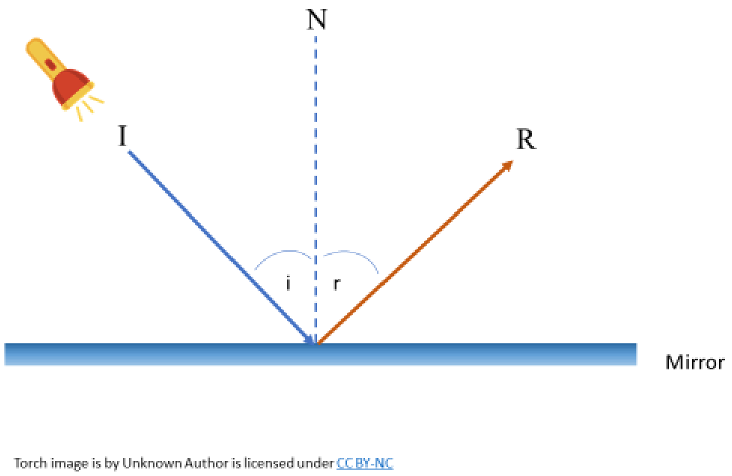

Figure 1 Reflection of light off a mirror, with incident (I) and reflected (R) rays; and the angles of incidence (i) and reflection (r). i=r

To explore the nature of reflection and how it enables us to see, get students to do Activity 3, *Light Box.*

Pepper's Ghost is another intriguing and visually appealing example of reflection. Students can examine the physics of reflection and how it is used to create haunted houses and theatrical effects to create virtual and ghostly images that appear to float in the air. See Activity 4, *Reflection of Pepper's Ghost*. A video of what the Pepper's Ghost illusion looks like using your mobile phone as the projector can be seen here.

Absorption

When an object absorbs light it transforms a proportion of that light into heat energy. Depending on the material, the light may also get transformed and re-emitted as a form of bioluminescence or phosphorescence. See the following story on glow-in-the-dark wombats, platypuses and other animals.

For visible light, coloured objects will reflect the colour we see, but absorb all the other colours in the visible spectrum.

What is refraction

While light travels in a straight line, when it passes from one medium into another, for example from air to water, it will change speed and change direction. This is called refraction. The speed of light will appear to change. The apparent change in speed is dependent on the medium it travels through. The constant (the c in $E = mc^2$) is the speed of light in a vacuum.

Technically the speed of light does not change, because as it passes through the medium it interacts with the atoms in that different media, changing direction with each interaction, which affects the time it takes to pass through the particular media. See Figure 2.

To introduce students to the concept of refraction and perform a magic trick, check Activity 5*, Appearing coin.*

Make your own magnifying glass. The concept of refraction is employed to make magnifying glasses, microscopes, telescopes, cameras and corrective lenses for our glasses to help us see. You can make you own magnifying glass using a droplet of water. A water droplet has a spherical shape above the surface it is resting on that will act as a lens. This creative site has an easy make-at-home version of the water droplet magnifying glass.

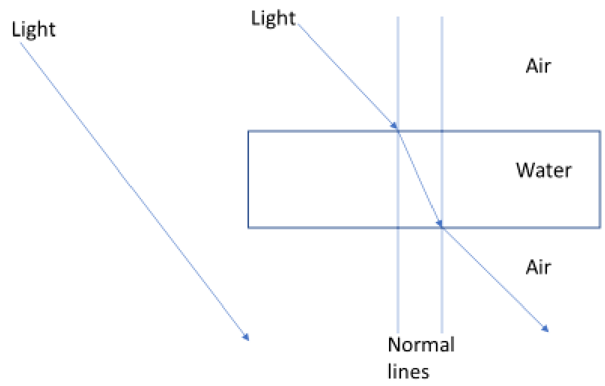

Figure 2. As light passes from one medium to another it will change direction (refracts) and slow down, or more accurately take a longer route from its point of entry to the point of exit and therefore appear to have slowed down. In this case because water is denser than air it refracts toward the normal line. As it exits the water into the air it will refract away from the normal line.

Snell's Law

Willebrord Snellius (1580–1626) is credited with working out the laws of refraction (Snell's Law), although many philosophers and scientists as far back as Ptolemy had worked out that the amount light changed direction was determined by the medium it passed through, but they had not worked out the math to explain it.

Again, it was Ibn al-Haytham that did much of the groundwork on refraction. He explained how a lens could magnify objects and that this was caused by the light changing direction (refracting) as it entered the glass. Before Ibn al-Haytham, however, another Islamic scientist, Ibn Sahl, discovered how lenses 'bend' and focus light and it was this work that Willebrord Snellius based his laws on. What Snell's Law demonstrates is that light will change direction though a media at a specific ratio relative to the angle it hits that media. Snell's law will determine the direction of light rays through a media that will refract light and is the simple equation, $n_1\sin(\theta_1) = n_2\sin(\theta_2)$, where n_1 and n_2 are the angle of incidence and angle of refraction.

We have used this understanding of how much light will refract in any given substance, to invent microscopes, telescopes and magnifying glasses. We have learned how the eye works and can now design lenses to correct vision. We have even begun development of a bionic eye. And we understand why we get rainbows, one of nature's most impressive sights. See Activity 6, *How to find a rainbow*, to give students a deeper understanding of refraction and some practical experience at using Snell's Law. As a bonus, you learn how to build a rainbow finder and find rainbows.

As with the law of reflection, to measure refraction, all angles are measured from an imaginary line (the normal) drawn at 90° to the surface of the two media.

The amount light will slow down and the degree it will change direction as it enters the different medium is determined by the refractive index of the medium it enters. Essentially the denser the medium, the greater the refractive index. For instance, glass is denser than water, and water is denser than air.

If light enters any medium that has a *higher* refractive index, (such as from air into glass) it slows down and changes direction *towards* the normal line. If light enters into a substance with a *lower* refractive index (such as from water into air) it changes direction *away* from the normal line.

Light does not bend, technically. you may see references to light bending when it refracts. This refers to light changing direction. Light does not actually bend like a hose or length of wire might. Light travels in a straight line.

For a deeper exploration of refraction, see Fermilab's in-depth video here and here.

What is diffraction (years 8-9)

Diffraction is light as a wave changing direction as it passes through a gap or around objects. Light waves appear to bend because of how the peaks and troughs of waves interact with each other once they go through a gap or around an object. When a wave goes around an object, however, it will split into two waves to pass around the object. As the two waves interact on the other side of the object they form what is known as a resultant wave. In the interaction of these two waves, where the peak of a wave overlaps with another peak they add themselves together to make a bigger wave (increase in amplitude). Where a peak meets a trough they will cancel each other out and you get a smaller or flatter wave (or decrease in amplitude). This results in the classic interference pattern that is indicative that light has a wave-like nature. The interference pattern will have bright blobs of light, which are where the peaks have overlapped. The dark blobs are where the peak and trough have cancelled each other out. This is also the pattern you would see if a wave passed through two gaps rather than one and is what is replicated in the classic double slit experiment. The waves passing through each gap would bend and then interfere with each other producing a similar interference pattern. The Exploratorium also has a home science version to demonstrate this.

For a neat in-depth demonstration and explanation of how light behaves when it goes around an object see this clip.

But why does the wave bend in the first place? This is where it gets a bit technical, but for any year 9-10 students who want to extend their thinking check Parth G's video out on diffraction – handy stuff.