

Square Kilometre Array

Level 4

Science

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This resource has been produced to support the delivery of the New Zealand Curriculum, with funding from the New Zealand Government, through the Ministry of Economic Development.

This resource has seven student science activities reinforcing aspects of the ‘big idea’ in astronomy: that everything we know about the universe is from “messages” in the electromagnetic radiation we receive from beyond planet Earth.

The activities include the use of colour and on-off codes to carry messages in visible light and making simple spectrometers from fragments of a CD. Infrared and radio remote control devices are used to investigate the idea that light we cannot see can carry ‘messages’, plus a simple introduction to interference.

The activities introduce the properties and behaviour of waves, beginning with mechanical waves.

As the behaviour of light and waves is usually studied at either Year 9 or 10, depending on a school's scheme of work, it would be expected that Year 9 and 10 activities could be used in either year.

The activities support the ‘Nature of Science’ and ‘Physical World’ sections of the Science curriculum as well as the ‘Planet Earth and Beyond’ section.

The Level 4 student activities

These activities introduce several ‘big ideas’.

1. Investigating the qualities of waves which may be easily described: energy, wavelength, amplitude, period, velocity, frequency. This activity is to photograph waves in a tank and use the photos or video to identify how waves may be described.
2. Investigating how frequency and amplitude are related to the energy carried by a wave.
3. The electromagnetic spectrum.
4. Inferring the inverse square law of radiation from a point source.
5. Investigating reflection of waves.
6. Investigating refraction of waves.
7. Investigating dispersion of light.

Each of the activities varies in the time required, from about 45 minutes if equipment is ready to use, with students in groups of 3–4, to two or three times that.

Starting with the familiar

The intention is to use everyday examples to show some of the concepts of electromagnetic radiation that astronomers utilise to gain information about the universe. The strength of the linkage between these common examples and astronomy will depend on the particular objectives you may have in this area. While the concepts are not difficult, their practical realisation in astronomy can be complex and beyond the level of understanding required at this level. These resources are part of a series for Years 7–13.

Prior knowledge and skills required

Little or no specific prior knowledge is assumed for each activity.

As your time is limited, few URLs are provided. Instead, the teacher guide for each activity attempts to provide the essential information.

Assessment

Assessment examples have not been included.

Radio telescopes

This resource is part of the **Square Kilometre Array (SKA) Project**, the largest international science project so far attempted. It would consist of an extensive array of radio telescopes providing a total collecting area of about one square kilometre, hence the project name. Australia has been short-listed as a location and it would also involve New Zealand to give a 5,500 km baseline—the longer the baseline the higher the resolution. The sensitivity and resolution of this array would enable it to see further into the universe, almost as far back in time as when it was formed.

From an educational perspective, the SKA project provides a context for several curriculum areas at different levels. It may also be where some of your students could work in the future.

For details of the whole SKA project see:

<http://www.skatelescope.org/>

For the Australian and NZ part of it:

<http://www.ska.gov.au/Pages/default.aspx>

For the NZ part of the project see:

<http://www.ska.ac.nz/news>

For an overview:

http://en.wikipedia.org/wiki/Square_Kilometre_Array

AV material (starter loops) and other resources available online for free download:

<http://www.ska.gov.au/media/audioandvisual/Pages/default.aspx>

Describing Waves

The 'big idea' in this activity is that waves have certain properties which may be used to describe them: wavelength, frequency, amplitude, period, and speed. Waves also transfer energy, but not the medium.

Physical waves in shallow water are investigated as some concepts of waves, especially their wavelength and amplitude, are more easily understood by beginning with waveforms that are familiar and easily seen.

Although simulation software could be used, or the topic approached by demonstration, the approach here is for students to directly investigate water waves and describe them by their waveform properties.

Rationale

Waves are a common phenomenon in our environment. Readily experienced examples include waves on the surface of water, sound waves, earthquake waves, plus radio waves, microwaves, light, etc., which are parts of the electromagnetic radiation spectrum.

To 'read' the "messages" from the universe in electromagnetic radiation, an understanding of the properties of waves is necessary. This exercise is brief. It begins with a common experience and utilises readily available equipment.

Equipment

1. Per group: a transparent or translucent shallow container at least 300 mm long. Its width is not critical. A piece of wood about 2–3 cm on its sides and its length a little less than the width of the container to use as a 'wave-maker'. Boiled, cooled water is best as air will no longer be in solution so bubbles are less likely to form on the sides of the container, obscuring the waves.
2. A digital camera capable of burst mode shooting (e.g. 5 frames per second) or video in Motion-JPEG format so it can be readily viewed frame-by-frame on a computer screen (avoid the AVCHD format).
3. Two rulers. A computer and printer.

References

For information on the physics of ocean waves, see:
<http://hyperphysics.phy-astr.gsu.edu/hbase/waves/watwav2.html>

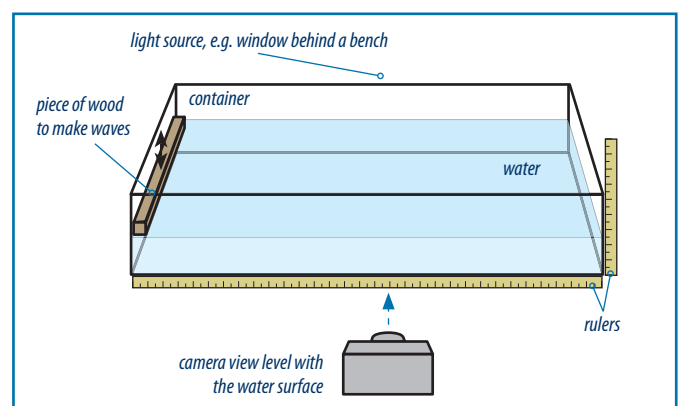
Outcomes

Students should be able to describe a waveform by its characteristics of: wavelength, amplitude, direction, period and speed. They should begin to develop understanding of a wave as a periodic disturbance in a medium, which transports energy but not the medium, and has a particular waveform.

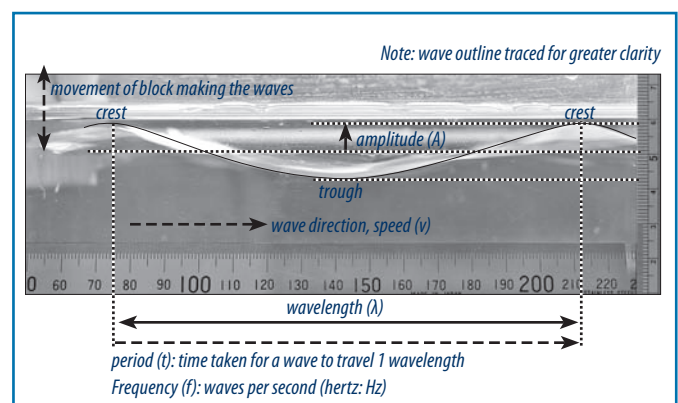
Background information

This activity is to introduce some of the terminology of waves, as students often have difficulty with the language of science.

This setup is suggested. Placing the container on a bench with a window behind will provide the necessary backlighting to show the wave. A ruler along the front and a short vertical ruler allows direct measurement of the wave. The camera is best on a tripod to provide consistency of viewpoint. The piece of wood can be pushed up and down in the water to make waves. It would be useful to discuss the design of this investigation with your students.



A digital camera is a useful tool. In burst mode it will capture several frames a second. Print one frame and directly measure the wavelength and amplitude, as shown below, and note the wave direction. If the video frame rate is known the wave speed and period could be estimated.



This activity is primarily to introduce the terminology of waves. It is not necessary at this stage to discuss types of waves (transverse, longitudinal, surface). Reflections from the end of the container and subsequent wave interference can be a problem, so suggest that only the initial waves be photographed each time.

Extension

Investigate two questions: Where does the energy for ocean waves come from? Why do ocean waves nearly always arrive parallel to a shore?

Describing Waves

We use the word 'waves' to refer to several things. For example: waves in our hair, someone waves to us, waves on the beach, earthquake waves, microwaves, radio waves, light waves, and so on. What they have in common is they have an up-and-down or back-and-forth motion or shape. We can see the shape of ocean waves, but not the shape of light or radio waves.

This activity investigates the properties of water waves and the words we use to describe them.

Waves in water (or air, or any other material) are called physical or mechanical waves. Another type of waves, electromagnetic, can travel through a vacuum, e.g. radio and light waves.

Because waves in water move quickly the easiest way to study them is to use a digital camera.

Gathering the data

1. Fill a transparent container with water until it is about 3–4 cm deep. With a felt marker pen make a horizontal line about 2 cm long on the side of the container at the resting level of the water surface.
2. Place the container so it has a light source behind it and the camera on a tripod in front. Have a ruler along the base and a vertical ruler at one end. When photographing transparent materials the best results are obtained when they are back-lit.
3. Use a small piece of wood or something similar as a 'wave-maker' to push up and down in the water to make waves. Practice making waves. You don't want them too big. Aim to make several small waves quickly. Push up and down on your 'wave-maker' 2–3 times quickly but in small movements. Do the waves seem to 'bounce back' (reflect) from the far side of the container? If they do, the reflected waves will interfere with the shape of the waves you make.
4. Have the camera level with the surface of the water. Set it for burst mode and begin shooting as someone begins making waves. You need photographs of the shape of a wave between one crest and another crest (i.e. clearly shows at least two crests of waves). Make sure that the rulers are included in the photograph. Let the water settle to a flat surface before trying again.
5. If your camera can shoot movies, set it on Motion-JPEG format (not AVCHD nor MPEG) and take a video clip of the waves.
6. Try to make more and then fewer waves in the same time and photograph and video them.

Interpreting the data

1. If you have taken photographs in burst mode, either look at them on a computer or choose and print photographs showing at least two wave crests (the highest points of waves).

If you filmed the waves in Motion-JPEG, load the file into a computer and look at it frame-by-frame (pause the movie, use the right arrow key to advance a frame at a time).

2. Using the ruler along the bottom of the photograph, or as shown in frames on the movie, measure the distance between two wave crests. This distance is called the **wavelength**. Record this in the summary table below.
3. Look at the water resting level line. How far above this was the wave crest? How far below? The distance that a wave crest has moved above (or below) the resting level is called its **amplitude**. Record it below.
4. A wave also has direction, speed, frequency and period. Find the number of frames per second of your video (usually either 24 or 30), then:
 - a) Count how many frames it takes for a wave to **move one wavelength** and calculate the **time** it took. This is the **period** of the wave; record it below. Using the wavelength and period calculate the **speed** of the wave in metres per second (m s^{-1}). Record it below.
 - b) From your movie, count the number of complete waves (e.g. crest to crest) per second. This is the **frequency**, measured in hertz (Hz: repetitions per second). Record it below. The period also = $1/\text{frequency}$; compare it to your answer above.

Summary

wavelength (cm)		speed (m s^{-1})	
amplitude (cm)		frequency (Hz)	
period (s)			

A wave is a disturbance that moves energy from one place to another, but does not move the medium. The water went up and down but didn't move along with the wave. This may not be obvious in a small container, as currents in the water caused by the 'wave-maker' move the water around.

Question: How do you know that the waves you made were transferring energy? In your answer say where the energy came from and how you could show that there was energy in the wave at the far end of the container.

Energy and Waves

Waves are generally defined as disturbances which are periodic in space and time. Waves transport energy, but not the medium, have characteristic waveforms, and travel at particular speeds which are affected by the medium.

From everyday experiences we know that physical waves (also called mechanical waves) and electromagnetic waves are two important ways that energy is transferred. We may have felt the impact of an ocean wave when swimming, and we have felt the warmth of sunlight.

The previous activity reinforced ideas of describing waves by their wavelength, frequency, amplitude, period and speed, attributes applicable to all waves. It also emphasised the concept of waves transferring energy but not the medium.

Rationale

The energy transferred by waves is related to the amplitude and frequency of the wave. When 'reading' the 'messages' from stars in their radiation, the frequency and amplitude are utilised.

This activity uses physical transverse waves to experience the relationship of frequency and amplitude to energy carried by waves.

Equipment

Per group of 3–4:

1. A piece of 6 mm bungee cord about 2 m long with the ends knotted to provide a grip.
2. An old oven rack (made of parallel wires).

References

- Download the *Window to the Universe* teacher resource (5.7 MB):
- http://www.ska.edu.au/educators/assets/window_to_the_universe.pdf (See pages 2–5)

Outcomes

Students should be able to explain (1) the relationship between frequency and amplitude in the transfer of energy by waves, and (2) how polarisation of transverse waves occurs.

As with Activity One, this is aimed at helping students construct and develop further their own understanding of the characteristics of waves, and the terminology used to describe them.

Background information

Activity One focussed on the familiar example of water waves. These are surface waves, one of the three types of physical or mechanical waves. The other types are transverse and longitudinal waves. Particles in a surface waves have a circular motion, the result of transverse and longitudinal waves mixed together.

This activity uses a piece of bungee cord to experience aspects of transverse waves. Unfortunately, waves are not a simple topic! Multiple waves in a piece of cord held at each end become standing waves, a complication better ignored for the purposes of this activity.

The bungee cord stretches to allow an increase in length to accommodate the waveforms.

One characteristic of a wave is that its speed is affected by the properties of the medium through which it is travelling. For a particular length of cord the tension and its density affect the wave speed. It is not necessary to discuss this aspect of waves in a cord.

The intention of this activity is for your students to experience (a) how the amount of effort to shake the cord affects the amplitude; (b) whether more effort is required to increase the frequency; and (c) how a transverse wave may be polarised.

In this activity, effort is regarded as equivalent to energy and the comparison of the amounts of energy is merely subjective. The intention is for students to realise from experience that energy is related to wavelength and amplitude.

A bungee cord has been used in preference to a slinky spring as it allows transverse waves in different planes. This provides an opportunity to experience how a transverse wave may be polarised.

Extensions

- Stringed musical instruments are useful to demonstrate the relationship between the frequency of string vibrations (or standing waves in this situation) and the pitch of the sound. Similarly, the relationship between amplitude and perceived volume of sound.
- Discuss the relationship between frequency and wavelength. It is difficult to measure the wavelength and frequency in this activity, but it is obvious that for the frequency to increase then the wavelength becomes shorter. Students will have noticed that at a higher frequency there are more waves in the same length of cord, so the wavelength will have decreased. Note: $\text{speed} = \text{wavelength} \times \text{frequency}$.
- Polarised sunglasses could be used to investigate polarisation. Keen photographers amongst your students could describe the effect of a polarising filter.
- Polarisation of radio transmissions.

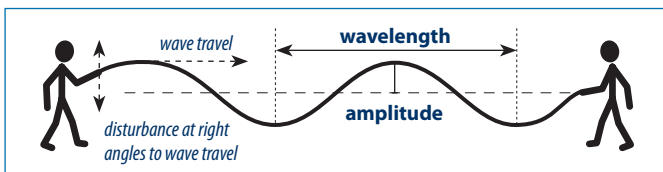
Energy And Waves

Waves transport energy. You may have felt the push of a wave at the beach as some of its energy was transferred to you. You will have felt the warmth of sunlight as energy in the light waves was transferred to your body.

Waves can be described by their wavelength, frequency, amplitude, period and speed. This activity explores the relationship between the energy a wave carries and its wavelength and amplitude.

This activity explores waves in a thin bungee cord. When two people hold the cord fairly tightly between them and one of them shakes one end of the cord up-and-down, waves travel along the cord. The person at the other end feels the shaking of the wave as energy is transferred to them.

To experience the relationship between the wavelength and amplitude of a wave and the energy it transfers, follow the steps below. For each investigation shake the cord for only a few seconds. If the cord is shaken too long, standing waves are produced where the waves stay in the same place. The aim is to investigate travelling waves.



- 1. Changing the amplitude:** One person shakes the cord gently about 3–4 times, like this:



Repeat it a little harder but try to keep the rate of shaking (the frequency) at the same number of shakes per second, not faster or slower, like this:



Does it take more or less effort to increase the amplitude at the same frequency?

What did the person at the other end feel was changing as the amplitude was changing?

Now have the other person shake the cord so they can experience the amount of effort they would have to make.

- 2. Changing the frequency:** Shake the cord gently as before, but this time try to make 5–8 shakes in the same time. The aim is to increase the frequency (which means a shorter wavelength), but keep the amplitude small, like this:



Did it take more or less effort to shake it faster than shaking it slowly? Did the person at the other end feel more or less energy being transmitted as the frequency was increased?

Now, increase the amplitude, but try to keep the frequency the same as before, like this:



Did it take even more effort to increase the amplitude? What did the person at the other end feel?

- 3. Changing the plane of the waves:** Briefly shake the cord (3–5 shakes) in different planes, side-to-side, up-and-down, diagonally, etc. Was energy still transmitted along the cord regardless of the angle of shaking?

- 4. Investigating polarisation:** A wave disturbance at right angles to the direction of travel of the disturbance is called a transverse wave. Transverse means across something.

However, as you found above, the wave can be at any angle from sideways to up-and-down.

If you were to thread the cord through a narrow slit and then create a travelling wave, as before, would you expect a wave at right angles to the slit to be blocked?

Thread your cord through an old oven rack and create waves in different planes. Be careful to make only 3–4 waves each time, so you have travelling transverse waves, not a standing wave.



If you had separate cords through each slit, with waves in different planes, which waves would continue through the slits?

Transverse waves oscillating in one plane are polarised. Light normally oscillates in all planes at once, but light is polarised travelling through the atmosphere and when it is reflected. Polarised sunglasses act like the oven tray above, passing only light oscillating in one plane, so they block some reflected light and darken parts of a bright sky.

The Electromagnetic Spectrum

What we know about the universe is from decoding the 'messages' in the electromagnetic radiation (EMR) we receive. Obvious questions are what produces the radiation and what actually is the radiation.

Stars are the most common sources of the radiation. Energy for most of the radiation is produced when atoms of hydrogen in a star fuse to give a helium atom, with some of the mass being converted to energy. The energy is emitted as EMR over a wide range of wavelengths: gamma rays, X-rays, ultraviolet light, visible light, infrared, microwaves, and radio waves.

The wavelength of the radiation is proportional to the temperature of what is producing it: the higher the temperature the shorter the wavelength (and the higher the frequency) of radiation produced. In addition, every element and molecule has a characteristic emission spectrum when heated, so elements and molecules in the universe can be identified by their emission 'fingerprints'.

Rationale

From previous activities students will be familiar with the concept of waves, wavelength, frequency and amplitude, and that more energy is carried by waves with shorter wavelengths and/or greater amplitude.

To further appreciate and understand how we gain knowledge of the universe, an understanding of the nature of the EMR spectrum is required.

Equipment

Begin this activity with familiar parts of the electromagnetic spectrum: e.g. visible light, radio, infrared, ultraviolet, x-rays.

1. A broadcast radio receiver or other tunable device using radio frequencies (walkie-talkie, TV, etc.).
2. Devices using other areas of the EM spectrum, such as infrared remotes, or the results of their use, such as photographic film from x-rays. Before digital imaging of x-rays, people were sent their x-ray film to keep, so someone may loan their x-ray film. X-rays provide a good example of how energy, and penetration, increases with EMR frequency. An example of ultraviolet use is a water steriliser, either as a fixed installation in a water supply, or as a portable device such as a Steripen®.
3. Internet access, as most of the activity involves students working in groups to find out about the bands of electromagnetic radiation. The 'jigsaw' technique is recommended; see: <http://www.jigsaw.org/overview.htm>

References

Reference summary diagrams and table of the electromagnetic spectrum which may be freely used:

- http://en.wikipedia.org/wiki/Electromagnetic_spectrum
- The 'Window to the Universe' SKA teacher resource (5.7MB); See pages 7–11: http://www.ska.edu.au/educators/assets/window_to_the_universe.pdf

- Also, in this series, Years 7 & 8 activities 4, 5, 6.
- X-rays in every-day use and in astronomy: <http://science.hq.nasa.gov/kids/imagers/ems/xrays.html>

Outcomes

1. Knowledge that visible light, infrared, ultraviolet, x-rays, radio, television, microwaves, radar, etc., are all fundamentally similar, differing only in their wavelength, frequency and energy.
2. Further knowledge of the interrelationship between the qualities (wavelength, frequency and energy) we use to describe electromagnetic radiation, and perhaps able to apply the relationship equation: speed of light (c) = frequency (f) × wavelength (λ).
3. Able to describe how we produce and utilise different bands of the electromagnetic spectrum, the benefits and risks of the applications, and how each of these occur in nature.

Background information

For convenience, the different areas of the EMR spectrum are referred to as 'bands' to reinforce the idea that the spectrum is continuous.

Today we utilise all of the electromagnetic spectrum and the names of different spectral bands are in common use. Students may think they are not related. The activity will focus on the applications and characteristics of the different bands of the EMR spectrum.

As energy increases so does the penetration into materials.

1. **Gamma rays** have the highest penetration and are also damaging to living tissue, hence their application in medicine to target cancer cells, and to sterilise medical equipment and food (which is said to be irradiated).
2. **X-rays** are used for non-destructive imaging of interior features of items in a wide range of areas, such as medicine, dentistry, industrial, airline security, crystallography.
3. **Ultraviolet light** could include UVA ('black light', used for illuminating fluorescent dyes), UVB, which is required for Vitamin D production in the skin, but causes sunburn and other skin damage at excessive exposures, and UVC, used in germicidal applications. UV light is used to cure (set) a range of materials, e.g. adhesives, dental fillings, inks. Fluorescent lamps produce UV light, which then fluoresces the coating on the inside of the lamps to produce visible light. Fluorescent inks are used for security purposes, a common example being bank notes which can easily be shown under UV. Fluorescent whiteners are used in soap powders so that the blue light they produce makes whites look whiter. It would be useful to have a safe source of UV to show fluorescence. The cheapest and safest source for classroom use is a UV LED, such as the ZD-0260 from Jaycar. Connect it to

The Electromagnetic Spectrum

- This activity aims to extend your knowledge about waves to the electromagnetic radiation spectrum.
- Electromagnetic waves do not require a medium for transmission and can travel through a vacuum.
- In a vacuum all electromagnetic waves travel at a constant speed: the 'speed of light', $3 \times 10^8 \text{ m s}^{-1}$ (300,000,000 metres per second).
- Electromagnetic waves may be identified by their wavelength or frequency. Shorter wavelength (higher frequency) waves have higher energy.
- The relationship between the speed (c), wavelength (λ) and frequency (f) is: $c = f \times \lambda$.
- When we look at the sky we can see stars as twinkling points of light, but they also radiate waves in other parts of the electromagnetic spectrum. To 'see' them we use different sensors.

Spectrum spread

The electromagnetic spectrum covers a very wide range of wavelengths. Although it is continuous, for convenience the spectrum is divided into bands by wavelength and by their properties and applications.

For example, visible light is one band, having wavelengths from about 390 to 750 nm ($390 \text{ to } 750 \times 10^{-9} \text{ m}$). This is defined by being the only part of the electromagnetic spectrum that we can see.

Stars emit radiation in all bands of the electromagnetic spectrum because they are so hot. As atoms become hotter they emit radiation at shorter wavelengths. We can not make devices with temperatures as high as those in stars so we have devised other ways of producing short-wavelength radiation.

Find out about ...

Working in groups for each band of the spectrum of electromagnetic radiation, find out:

1. The range of wavelengths in the band.
2. The range of frequencies in the band.
3. The most common emitter of naturally produced radiation in the band (for some bands, stars are not the only natural emitters).
4. Whether the Earth's atmosphere blocks waves in that band from penetrating to the surface.
5. The devices or materials we use to produce radiation in the band.
6. How we use radiation in the band, its benefits and risks.

The radiation bands are, in order of increasing wavelength (and decreasing frequency and energy):

- Gamma rays
- X-rays
- Ultra-violet waves
- Visible light waves

- Infrared waves
- Microwaves
- Radio waves

Record the information for the radiation band your group is responsible for:

Radiation band:
1. Wavelengths:
2. Frequencies:
3. Natural sources:
4. Radiation blocked by atmosphere? Yes/No:
5. Human-made sources:
6. Uses, benefits, risks:

Collate information from other groups and record it in the summary table on the following page.

Student Activity Three

	1 Wave-lengths	2 Frequen-cies	3 Natural sources	4 Blocked Y/N	5 Human-made sources	6 Uses, benefits, risks
Gamma rays						
X-rays						
Ultra-violet						
Visible light						
Infrared						
Microwaves						
Radio						

Inverse Square Law of Radiation from a Point Source

Stars appear as tiny points of light. The concept of waves from a point source quickly diminishing in intensity with increasing distance is important in both everyday experience and in astronomy. Telescopes need to be large to gather the faint signals from distant objects in the universe.

The inverse square law applies to anything radiating uniformly in all directions from a point source.

Rationale

The concept of waves or any other influence rapidly diminishing in intensity as they spread into a greater volume from a point source applies to electromagnetic radiation, gravitational forces, electric fields, sound, and even earthquakes.

The 'big idea' is that wave intensity from a point source diminishes in a predictable and geometric way.

It can be easily investigated in the laboratory and also shown mathematically.

Equipment

Per group of 3–4:

1. A small light bulb with a filament that emits light in all directions—the ideal is a Mini-Maglite® torch with the head unscrewed to reveal the lamp which has a filament about 1 mm long, but an 'ordinary' torch bulb would work if it is turned slightly so the filament is mostly 'end-on' to the hole. If a Mini-Maglite® is available you will also need Blu-Tack® or Plasticine® to hold it upright.
2. A piece of black card with a hole 1 cm square cut in it (or card, trimming knife, board, and a metal ruler for students to cut their own).
3. Pages of graph paper with a 1 cm grid; a PDF may be downloaded here: <http://incompetech.com/graphpaper/plain/>
4. A ruler.

References

This website describes the investigation using a Mini-Maglite® torch: http://www.exploratorium.edu/snacks/inverse_square_law/index.html

Outcomes

Students will be able to explain why waves from a point source decrease in intensity by the inverse of the square of the distance, i.e. decreases by $1/\text{distance}^2$.

Background information

Waves or any other influence radiating from a point source cover an increasingly greater area as they spread out, so the intensity per unit area will decrease. A point source is effectively at the centre of a sphere. As the area of a sphere increases with the square of the radius, the intensity of the wave or influence will decrease per unit area inversely with the square of the radius (the surface area of a sphere = $4\pi r^2$).

The card with the 1 cm square hole is placed close to the bulb and remains in that position. Its distance from the bulb filament is regarded as $r = 1$ (i.e. it is the radius of the illuminated sphere). To easily cut an accurate 1 cm square hole, place a piece of 1 cm grid graph paper over the card and cut through both layers. Folding the black card and the graph paper so they stand upright, as shown, makes it easier to carry out the activity.

The piece of graph paper could be first placed against this card to show at this sample point that only a 1 cm square is illuminated (it's best to look at the graph paper from the side opposite the bulb), or it could be taken for granted. This initial distance is obviously $r = 1$. Students need to note this distance as each successive distance of the graph paper location is a multiple of this distance.

The graph paper is then moved to twice this distance ($r = 2$) and the squares now illuminated are counted. This is then repeated for three, four and five times the distance.

The major source of error in this series of measurements is the size of the torch bulb. A Mini-Maglite® may be difficult to obtain. The standard torch bulb used for electrical circuit work is sufficient, but best if the bulb is turned so the filament is nearly end-on to the piece of card to make the filament as small as possible. Another small lamp is the mini-lamp series from Jaycar: SL-2680 to SL-2684 covering 1.5–9V.

An LED is not a point source, as it will probably have a lens moulded into its case. Any focussed beam does not conform to the inverse square law.

Extensions

- If you have a sound meter the decrease in the intensity of a constant sound could be measured with increasing distance to see if there is a similar relationship. The sound meter collector would represent the constant unit area.
- Calculate the area of lenses or mirrors of astronomical telescopes, or radio telescope dishes of various diameters.

Inverse Square Law of Radiation from a Point Source

Stars appear as tiny points of light. As many of these are much bigger, brighter and hotter than our sun, why do they appear so dim? We can investigate this question using a point source of light.

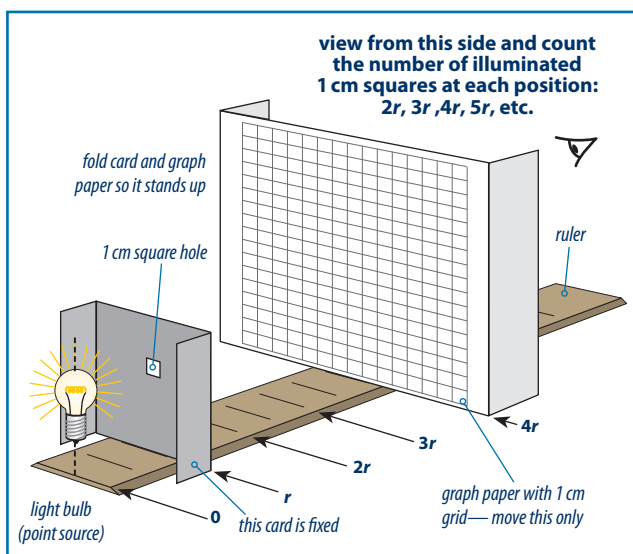
Equipment

You will need:

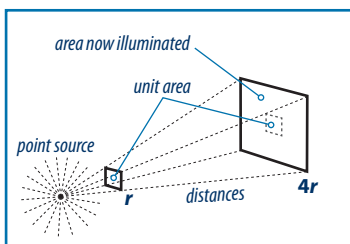
1. a small light bulb with a filament that emits light in all directions (the lamp should be really small so it is a point source of light).
2. a piece of black card with a hole 1 cm square cut in it.
3. a page of graph paper with a 1 cm grid.
4. a ruler.

What to do

1. Set up the light bulb, black card with its 1 cm square hole and ruler as shown below. The light bulb must be on the end of the ruler (the centre of the filament is the zero point). It is not important where the card is, but 2–3 cm from the bulb would be a good start.



2. Note the exact distance: this becomes the first measurement location (r), where light from the point source covers one square centimetre in area. The light will continue to spread out. The graph paper grid will be used to measure how far it spreads out at multiples of the distance of the 1 cm square hole from the point source. The 1 cm square hole represents the initial unit area with a certain light intensity. As light spreads, the intensity per unit area will decrease. This activity is a way of measuring the ratio of the decrease of intensity in relation to increasing distance from the source.



3. Place the graph paper at distance $2r$ from the light bulb. Count the number of squares being illuminated. It is easiest to count the squares from the 'back' side of the paper.

Record the results in the following table.

Distance	Area illuminated (cm^2)	Unit area intensity as a fraction
r	1	$\frac{1}{1}$
$2r$		
$3r$		
$4r$		
$5r$		

4. Repeat for distances $3r$, $4r$, and $5r$.
5. Light from a point source travels outwards in all directions, and is in the shape of a sphere. What is the formula for the area of a sphere?
6. Using this formula, calculate the area for quantity $r = 1$ and $r = 2$ (i.e. the sphere radius was doubled).
7. Do your measurements follow the same pattern? Explain how the intensity of light on a unit area from a point source varies with increasing distance, and what "inverse square law" means:

$r = 1$: _____

$r = 2$: _____

8. What would be the fraction of the intensity of light on the 1 cm^2 unit area if the distance of your graph paper was increased to $100r$?

9. Stars are a very long way away. Imagine if you increased the distance of your graph paper to ten million times ($10^7 r$)—what would be the fraction of the light intensity now? Imagine the challenge of detecting light intensity from distant stars!

Reflection of Waves

Reflection is a characteristic of waves. In everyday life we see illuminated objects by the light they reflect. Large terrestrial-based astronomical telescopes, optical and radio, utilise reflection from a parabolic mirror.

Rationale

Reflection of waves is an important phenomenon, both in everyday life and in astronomy. As the concepts are readily understandable, this activity also explores image formation by concave mirrors and the difference between spherical and parabolic mirrors in the quality of image formation.

The 'big idea' is that reflection is when a wave is thrown back by a surface and that reflection from a smooth surface follows a 'law' (i.e. is predictable). The 'surface' is a boundary between media.

Equipment

Per group of 3–4:

1. A ray track light box with inserts to produce single and multiple light rays or, if not available, a supply of pins.
2. A flat mirror and a strip of curved (circular) mirror suitable for use with a ray track.
3. Protractor.
4. Two round concave (spherical) mirrors of different focal lengths for comparison.

For demonstration: A ripple tank would be useful if you wish to demonstrate that water waves also show reflection.

An umbrella is useful to demonstrate the reflection of sound waves, more convincing if the sound source (e.g. a small radio) is at the focus of the umbrella and pointing into it, so that 'focussed' and point-source sounds can be compared. Listening at the focus for distant or faint sounds is not easy as the head and shoulders block too much of the umbrella area; better if a microphone is used instead.

References

<http://www.physicsclassroom.com/class/refln/>

[http://en.wikipedia.org/wiki/Reflection_\(physics\)](http://en.wikipedia.org/wiki/Reflection_(physics))

http://en.wikipedia.org/wiki/Curved_mirror

http://en.wikipedia.org/wiki/Reflecting_telescope

Outcomes

Students would be able to distinguish between specular and diffuse reflection; state the law of reflection; describe how an image is formed by a concave mirror; discuss why a spherical mirror is not suitable for astronomical telescopes and why a parabolic mirror would be a better choice.

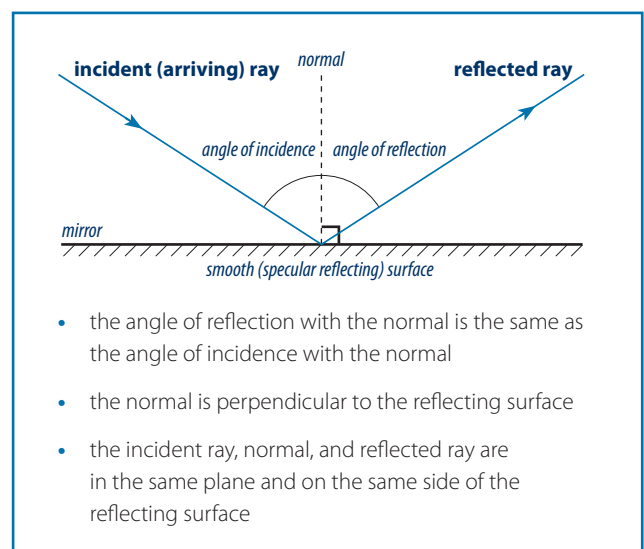
Background information

Reflection may be specular, where the wave is reflected at the angle it met the surface, or diffuse, where reflection occurs at random angles. These terms are not necessary at this level, but students would be aware that reflecting objects can either produce images (specular reflections) or appear brighter from reflecting light in all directions (diffuse reflection). It is the differences in absorption and reflection that give objects their distinctive visual qualities. Specular reflection requires a very smooth surface, otherwise the reflection becomes diffuse.

All waves may be reflected: sound waves, sea waves, seismic waves, light, radio, etc., would all be reflected in the same way.

Reflection has a 'law' and specific characteristics:

- The 'Law of reflection' is often stated as "the angle of incidence equals the angle of reflection". However this needs qualifying as the angles are measured with respect to the normal, not to the reflecting surface, as shown in the diagram:



- The incident and reflected waves are in the same plane with the normal.
- Any wave, sound, light, radio, seismic, sea, etc., will be reflected in the same way.
- No surface is a perfect reflector, the reflectivity of a surface depends on the material used for the surface, the type of wave, and its angle with the surface. Reflectivity is the ratio of reflected power to incident power. For example, a black umbrella will reflect sound and act as a concave sound mirror, but will absorb most light. X-rays are high-energy waves and will penetrate many surfaces, so reflection occurs only with some metal surfaces with the x-rays at a low (grazing) angle. Water is highly reflective at low angles but has low reflectivity (and high transparency) at higher angles.

An image in a plane mirror is two-dimensional, the same distance behind the mirror as the object is in front, is the same size as the object, appears laterally reversed (left-to-right), and is virtual. A virtual image is created when light rays diverge and can not be projected on to a screen. In a plane mirror the light rays exist only in front of the mirror, the image appears behind it as we see something as being in the path of the light reaching our eyes.

A real image is formed from converging light rays and can be projected on to a screen, which may be film, a digital camera sensor, or the retina of our eye.

Objects in the universe appear extremely tiny because of their distance, and the radiation from them is very faint. Consequently, large collecting devices are required to gather as much of the radiation as possible and to provide the highest resolution. Reflecting light telescopes can be made much larger with mirrors than with lenses. Radio telescopes can only use reflectors as it is not possible to make radio lenses. Each image must be focussed very precisely, but the slightest imperfection in the reflecting surface would distort such a tiny object. Making large reflectors accurately for light or radio telescopes is very difficult, as changes in temperature, even changes in position as it tracks celestial objects, can distort the surface slightly.

If circular mirrors for a ray track apparatus are available they are useful to show that the light rays are not focussed to a common point (spherical aberration). The round spherical mirrors commonly available in science departments will project what looks like a reasonably clear image, but the object is so large that aberrations are not readily obvious.

While parabolic mirrors can focus light to a common point (the focus) and provide much clearer images, they are not without their aberrations. Subjects imaged in the outer part of the mirror will show an aberration known as coma, where the image is smeared. The same problems occur whether light or radio waves are focussed. To overcome this, the waves may be reflected off a secondary mirror with a hyperbolic surface.

The magnification of an optical telescope is the focal length of the objective (lens or mirror) divided by the focal length of the eyepiece being used, e.g. a mirror with a focal length of 1000 mm with a 20 mm eyepiece gives a magnification of $\frac{1000}{20} = 50$.

Extensions

- Investigate convex mirrors. These have not been included in this activity, although they are part of the science curriculum.
- Why convex mirrors are used in cars as rear-vision mirrors and their advantages and disadvantages.
- How retro-reflectors (corner cubes) work, and common examples.
- Why the image does not rotate if you turn a mirror, but if you have two mirrors at right angles, the image will not be laterally reversed and the image will rotate when the mirrors are rotated.

If a ray track apparatus is not available, use pins:

1. Rule a horizontal line across a blank page about halfway down.
2. Place a plane mirror with its reflecting surface on the horizontal line.
3. Place a pin about 6–8 cm in front of the middle of the mirror. This will be the object pin. Identify it with 'O' next to it.
4. Look in the mirror to one side of this pin so you can see its image (the reflected light rays are reaching your eyes). Place two pins along your line of sight so they are in line with the image. Place a third pin in line with the object pin but on the object's path. Number all the pins as #1.
5. Repeat for different views from the other side and at different angles. Number the series of pins used for each view as above. You may wish to remove the first pins so they do not confuse the view, but either circle their pinholes in the paper or mark them with an 'x' so you can find their location later.
6. Remove the pins and mirror and with a ruler draw lines connecting the same numbered pins and the object pin.
7. Draw a line at right angles to the mirror from where each pair of lines meet the mirror. This is the 'normal' line.
8. Measure and record the angles that each pair of incident and reflected lines make with the normal.
9. Extend the viewing lines behind the mirror (which is where you saw the image). Do all the lines meet in the same place? Was this the location of the image of the object pin?

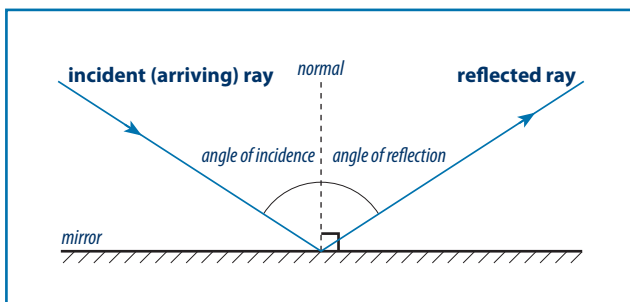
Reflection of Waves

All waves are reflected from surfaces in the same way. We see the world around us by reflected light. Some objects are shiny and we can see images of ourselves or parts of the world in them. Other objects are bright, but we can not see an image. Safety clothing and reflectors on vehicles are examples of objects designed to reflect as much light as possible, but do not form images.

What to do

Your teacher will show you how to use the equipment provided.

- Starting with a plane mirror placed so its reflecting surface is along a line marked on a blank page, mark the path of the light reflecting from the mirror and the path of the light reaching the mirror. Include arrows showing the light direction.
- Use a protractor or set square to draw a line at right angles from the mirror line from where your light ray lines touched the mirror reflecting surface. This line is called the normal.



- Repeat for different angles of light. You may wish to either number your different light ray lines, or draw them in different colours.
- Measure the angle of incidence and the angle of reflection for each complete light pathway. Record the results here:

Ray	Angle of incidence	Angle of reflection
1		
2		
3		
4		

- Within the limits of the accuracy of your measurements, what do your measurements indicate about the relationship of these angles?

Now use a circular concave mirror. This will be a plane mirror bent into part of a circle. It could be regarded as a strip cut from a sphere.

- Place the mirror on a piece of paper and trace the shape of the reflecting surface.
- If possible, shine multiple parallel rays of light at the mirror. See if you can find where most of the reflected light rays intersect as closely as possible at one point (the focus). Mark the path of each of the rays of light on your paper.
- Draw the normal line for each reflected ray. Hint: find the diameter of the circle of this mirror and draw radial lines from its centre of curvature. Measure the angles of incidence and reflection for each ray and record them here:

Ray	Angle of incidence	Angle of reflection
1		
2		
3		
4		

Do these measurements show a similar pattern to those of the plane mirror? Describe it.

- Look up the 'Law of reflection'. Write it here:

5. You may be provided with two round spherical concave mirrors. 'Spherical' means that the surface is part of a sphere. One may have more curvature than the other.

If you look at them from a short distance you will see a magnified view of yourself. This is a virtual image: it can not be projected on to a screen and actually appears to be behind the mirror.

If you aim the mirror at a bright but distant scene, such as the classroom windows, you will be able to reflect this image onto a piece of paper held in front of the mirror (but obviously not blocking its 'view' of the scene). Moving the mirror back and forwards from the paper will focus the image more sharply.

- a) Measure the distance from the mirror to the paper. This will give an approximate focal length of the mirror. Repeat for the second mirror.
- b) Is the image the right way up or upside-down?
- c) Does one mirror's image show less of the view than the other? Which one – the longer or shorter focal length mirror?

Mirror	Approx. focal length	Image Description
1		
2		

6. A plane mirror will not project an image on to a piece of paper in the same way. Try it! The concave mirror formed an image on the paper at its focus: where light rays from each parts of the object came to a focus.
7. While not obvious with small spherical mirrors, the parallel light rays do come to the same precise point at the focus. For this you need a mirror in the shape of a parabola.

Find out what a parabolic shape looks like and draw one here:

8. Light rays from very distant objects, such as stars, are parallel. What is the advantage of having light (or radio waves) from distant objects being brought to a very precise focus by a parabolic reflector?

9. Parabolic reflectors have many everyday applications for light and for radio/TV waves. List two common examples of parabolic reflectors used for light and at least one for radio/TV.

Refraction of Waves

Refraction is often observed along with reflection. We are familiar with sunlight reflecting off water, yet some sunlight also penetrates below the surface. Both reflection and refraction are surface phenomenon, the surface being the boundary or interface between two different things. Reflected waves do not penetrate a surface but are thrown away from it. Refracted waves penetrate a surface but may change direction at that surface depending on the angle with the surface.

Rationale

Refraction is an important concept in making sense of some everyday experiences. In relation to astronomy reflector telescopes use lenses to magnify the image from the mirror. The twinkling of stars is caused by refraction as starlight passes through layers of differing density in the atmosphere. Even radio waves are refracted in the atmosphere.

The 'big idea' is that light penetrating a boundary between two differing media at a non-perpendicular angle will be bent because it changes speed.

Students should notice in the activity that not all of a light ray is refracted, some light is always reflected off the boundary.

Equipment

Per group of 3–4:

1. A ray track light box with inserts to produce single and multiple (3-ray) light rays.
2. A glass or acrylic rectangular block, convex and concave lens shapes suitable for use with the ray track.
3. A shallow container, water, and a straw.

References

<http://en.wikipedia.org/wiki/Refraction>

Outcomes

Students should recognise that refraction occurs at the boundary between two optically different media; be able to correctly indicate the direction that light rays will be bent at the boundary; be able to explain such common phenomena as the apparent bending of a stick in water, or why water appears shallower than it actually is.

Background information

Refraction is the change in direction of a wave due to a change in its speed. For example, as a light wave enters a transparent medium of higher density it slows down; conversely when it leaves a higher density medium into a lower density medium the wave speeds up. The change of speed causes the wave to bend. It also causes a change in wavelength, but there is no change in frequency as the speed has also changed.

As with reflection, the angle of refraction is measured with respect to the normal. The direction of the bending is most easily remembered by:

As a light ray goes into a more optically dense material it bends towards the normal, as it leaves to a less optically dense material it bends away: i.e. *in and towards, out and away*.

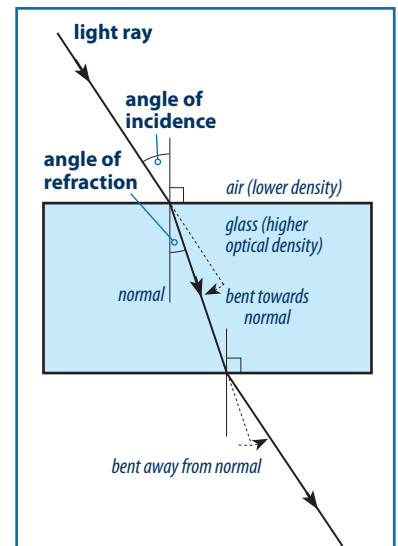
A ray perpendicular to a surface passes through without being bent.

The refractive index of a substance is the ratio of the speed of light in vacuum to its speed in that substance. It is usually expressed for one wavelength as the speed of light in materials differs by wavelength (causing dispersion). Physical density is not always an indication of optical density, although generally more physically dense optically transparent materials have a higher refractive index.

Neither Snell's law of refraction, nor diffraction, are included at this level. Total internal reflection is mentioned but not expanded in this activity as the emphasis is on what happens to light rays when they penetrate a boundary between two materials of different optical density.

Extensions

- Image formation in the eye. Note that most image formation in the eye is from the cornea, the lens is mainly a focussing element of what is effectively a two-lens system.
- Corrective lenses for short- or long-sightedness.
- Why sound travels clearly across the surface of a river or small lake in the evening. (<http://paws.kettering.edu/~drussell/Demos/refract/refract.html>)
- Why lenses are 'multi-coated' (an often-stated attribute of filters for photographic lenses, as today it is taken for granted that the lenses themselves are coated to reduce reflections).
- How a refractive index is used to identify a particular substance, or its concentration, or purity.



Refraction of Waves

Refraction is the bending of light as it goes through a surface between two different materials. This activity aims to help you (1) predict the way light would bend as it goes through different materials, (2) understand how lenses bend light, and (3) to explain some commonly observed phenomena.

What to do

Your teacher will show you how to use the equipment provided.

RECTANGULAR BLOCK

1. Place the rectangular glass or acrylic block on a piece of paper and trace its outline. Aim a ray of light at an angle to one side of the block and draw the path of the ray as it enters and leaves the block. You may also be able to also see the path of the light ray through the block. Mark the ray direction with an arrow.

2. Remove the block and complete the light path through the block. Where did the light ray bend?

3. Where the light ray entered and left the block draw a normal, a line at right angles to the surface of the block. Where the light ray entered the block, did it bend towards or away from the normal?

4. Where the light ray left the block, did it bend towards or away from the normal?

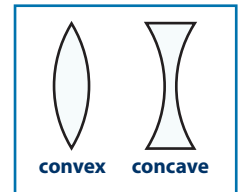
5. Try it at several angles. Did the ray bend in the same way with respect to the normal at different angles? What happened when the ray was at right angles or was at a very shallow angle?

6. What happened inside the block if the light ray met the inside surface (at one end for example) at a shallow angle? Was it reflected or refracted?

7. Construct a rule about the bending of a light ray when it enters a more optically dense material and when it leaves it for a less optically dense material.

LENSES

You will have two lens shapes, a concave lens and a convex lens (think of the concave lens going 'in' like a cave).



1. Trace the outline of the lenses on paper. Aim three parallel rays at the lenses in turn and draw the paths of the rays.

What happens to a light ray through the centre of each lens?

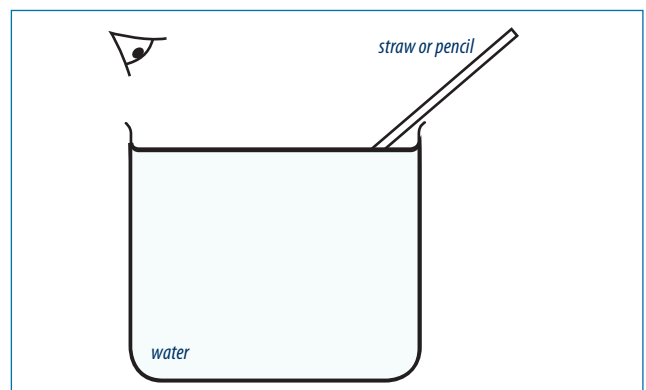
2. Which lens caused light rays to converge? (converge means to come from different directions to reach the same point)

Which lens caused the light rays to diverge? (diverge means to spread apart)

3. Draw a normal line for one of the rays on each lens. How did the light ray bend the same way with respect to the normal for the ray as it went into the lens and as it left the lens? Explain.

REFRACTION IN WATER

1. Fill a beaker with water and put a straw in it. Looking from above the straw appears to bend. Try it at different angles. Complete the drawing below to show the direction of the apparent bend and the light rays reflected from the straw to your eyes. Remember, light from the straw will be refracted.



2. Water in a river or pool looks shallower than it really is. This can cause people to enter water which is deeper than they thought and get into trouble. Explain, with reference to your drawing above, why this happens.

Dispersion of Light

When a light beam enters or leaves a medium of different optical density, different wavelengths of light in the beam are refracted differently. This spreads or disperses the different wavelengths, resulting in a colour spectrum from white light.

Rationale

This topic is an extension of refraction, where light is bent when it enters or leaves a medium of different optical density. The bending is different for different wavelengths. This is a problem in optical instruments, such as cameras and telescopes, as it causes images to have colour fringes and reduces the resolution. This is called chromatic aberration.

Although it is a problem for optical lens makers to solve, it is a useful phenomenon for astronomers to utilise with a spectroscope attached to a telescope to examine the spectrum of stars.

Equipment

Per group of 2–3: A glass or acrylic prism. A source of bright white light or a beam of sunlight (provided by a slit in a black card).

References

[http://en.wikipedia.org/wiki/Dispersion_\(optics\)](http://en.wikipedia.org/wiki/Dispersion_(optics))

<http://www.itp.uni-hannover.de/~zawischa/ITP/refraction.html>

<http://en.wikipedia.org/wiki/Rainbow>

Outcomes

Students will be able to recognise and explain phenomena associated with dispersion. For example: coloured bands of light projected on a wall from sunlight shining through the edge of glass; purple fringing on objects in a photograph; rainbows.

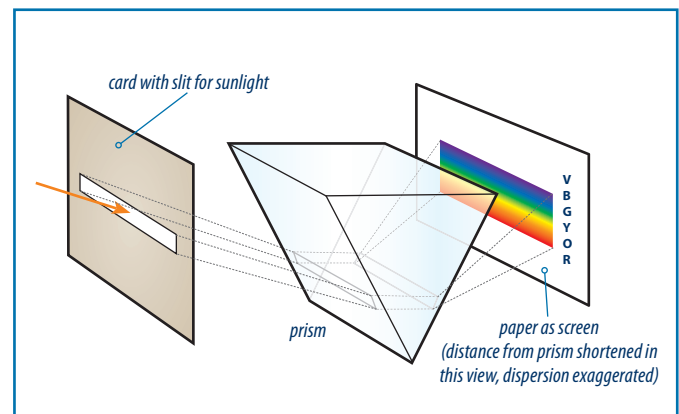
Background information

When a mixture of wavelengths of visible light enters a more optically dense medium, shorter wavelengths are slowed more than longer wavelengths. With sunlight, this results in a spread of wavelengths which we see as the white light spectrum. The blue end of the spectrum is bent more than the red end.

Dispersion is not usually seen when using a rectangular block for refraction investigations as any dispersion from the first surface is recombined at the second. However, if the beam is wide and the room quite dark a blue edge may be seen on the outgoing light beam as the blue part has travelled a little further and separated more.

When setting up the prism it is essential to have some distance between it and the screen the colours will be projected on to. To show dispersion effectively the greater the distance the greater the separation.

If sunlight is used (and it gives the brightest spectrum) then the prism needs to be mounted upside down because of the angle of the sunlight, unless a mirror is provided to reflect a beam upwards at an angle suitable for a prism the 'normal' way up.



You may decide to name seven colours of the spectrum (ROYGBIV) or omit indigo as some colour scientists do not recognise it. Indigo, if recognised, is a very narrow wavelength band.

Extensions

- How rainbows form, why you see them only when the sun is behind you, why they are seen most clearly in the morning or afternoon when the sun is at a lower angle, why 42° is a significant angle.
- Why a blue sky and a red or orange sunset or sunrise are not caused by dispersion (both phenomena are caused by scattering). Note: If the colour of a sunset was caused by dispersion then the light as the sun sets would turn from red to blue.
- Extend chromatic aberration in cameras: in addition to where to look for it in a photograph (purple fringes on the edges of dark objects against a bright background near the edges of the photograph) consider how it is minimised in lens design.

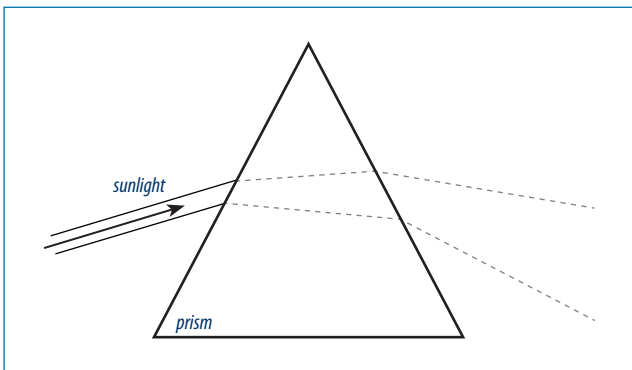
Dispersion of Light

Dispersion is when refracted light is separated into its colours. We see it in nature in a rainbow. Dispersion is utilised by astronomers to gain information about stars.

What to do

You will be provided with a prism. This will disperse (spread) a beam of sunlight or white light into its colours or spectrum.

1. You will need a black card with a slit in it about 3 mm wide, with a length about half the width of the prism.
2. Hold a piece of white paper about half a metre away from the prism on which to project the spectrum. It is easiest to hold the prism with one of its corners downwards. It will need two people at least to hold the prism, the slit and the screen.
3. Move the slit, prism and screen until you have a spectrum projected. The further you project it the wider the spectrum of colours.
4. Label the colours on this sketch (your prism will have been held upside-down to this one):



5. Which colour was bent the most?

6. Which colour was bent the least?

7. When light enters a more optically dense medium it is slowed down. The more it is slowed the more it bends. Which colour was slowed the most in the prism?

8. Convex lenses are similar to prisms in the way the surfaces curve. A simple lens will cause colours to appear around the edges of objects in the image. This unwanted colour is called *chromatic aberration*. It is corrected in camera and telescope lenses by combining lenses of different glasses. Find out about 'purple fringing' in photographs and where to look for it. Summarise the information.

9. A rainbow is a common natural phenomenon. The colours are caused by dispersion of light in raindrops, although the light is also reflected back towards you inside the raindrops.

- a) To see a rainbow, where would the sun need to be?

- b) What is the angle of illumination by the sun for a rainbow to form?

So, when would you be most likely to see a rainbow: midday, or morning or afternoon?