

SURFING

NSW PHYSICS

FOCUS AREA
2

Waves



• Brian Shadwick •

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Introduction To Depth Studies

The new physics syllabus contains much the same content as the previous syllabus. While it may be slightly different in terms of the grouping of content areas within the major topics, this author has used personal discretion in linking that content together to present it in a logical, cohesive way.

The major difference in the new syllabus is the inclusion of **mandatory depth studies** – at least one in each of years 11 and 12, each requiring at least **15 hours of independent or collaborative work**, depending on the school preferences and student needs. Student selection of topic, design of work, and presentation of findings, although initial consultation with teachers for guidance is allowed.

Types of depth studies

Practical investigations

- Design and conduct experiments
- Test a claim or hypothesis
- Test or evaluate a device

Secondary sourced investigations

- Literature reviews
- Documentaries or media reports
- Evidence based arguments
- Journal articles or essays (historical or theoretical)
- Environmental management plans
- Analysis of fiction or film for scientific relevance
- Visual presentations
- Investigating emerging technologies

Creative and design projects

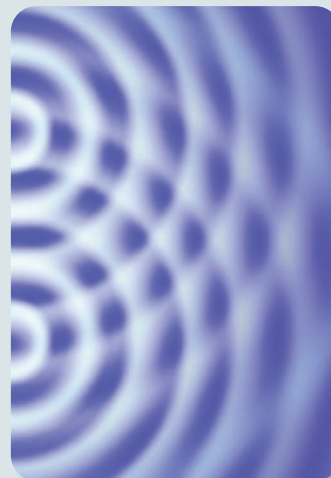
- Design and invent devices or models
- Create portfolios or working models

Field work

- Excursions or engagement with community experts
- Field based data collection and analysis

Data analysis

- Construction and interpretation of graphs and tables
- Analysis of data from various sources
- Longitudinal or resource management data analysis



Purpose of depth studies

Depth studies are designed to:

- Allow students to **explore content in greater detail**
- Develop **scientific thinking and inquiry skills**
- Encourage **creativity, collaboration, and communication**
- Provide opportunities for **authentic, student driven learning**

Assessment of depth studies

The NSW Department of Education requires a minimum 25% of the assessment mark awarded to each student to be derived from their depth study. Many schools in trial programs leading up to implementation of this course are allocating 30% to the depth study.

Depth study content integration

Each depth study must include:

- **Working scientifically skills**, specifically from **questioning and predicting**, and **communicating**
- **At least two other working scientifically skills outcomes** (e.g. planning investigations, conducting investigations, processing data, analysing data, and problem solving)
- **Further development of at least one knowledge and understanding outcome** (see outcomes in topic areas in the syllabus document)



Assessment of depth studies must:

-  Address questioning and predicting and communicating skills outcomes
-  Address a minimum of two additional working scientifically skills outcomes
-  Include assessment of at least one knowledge and understanding outcome

Mechanical Waves

Conduct a practical investigation to model the oscillation of particles in transverse waves and longitudinal waves.

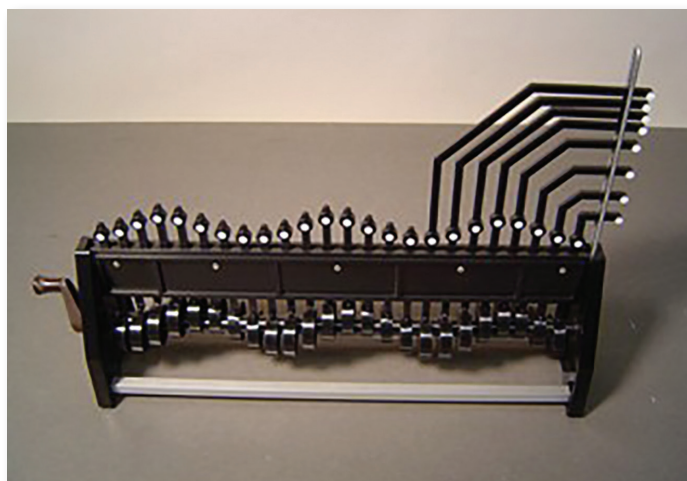
1 Role Of the Medium Carrying a Wave

We can observe mechanical waves in the laboratory using 'wave machines'.

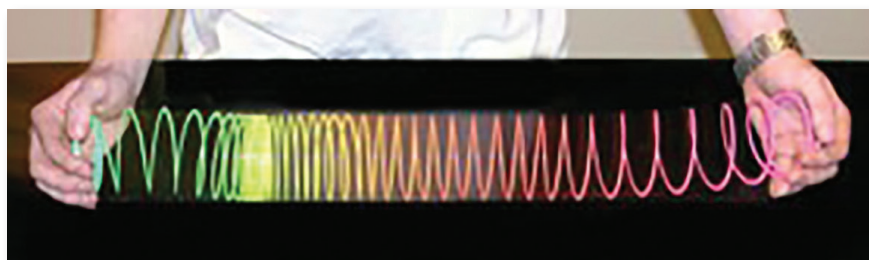
These machines also allow us to model the motion of the particles in the medium that carries the wave as well as the progression of the wave through the medium carrying it.

For example, when the handle on the wave machine (shown) is turned, the cam shaft at the bottom turns and the white balls at the top of the vertical risers and the horizontal arms move up and down and side to side (respectively) to simulate the particle movement in transverse and longitudinal waves.

On the particle level, these oscillations result in the transfer of energy from one particle to the next and transfer the energy through the medium.



Transverse and longitudinal waves can also be produced in a slinky spring and the movement of the individual coils in the slinky models the motion of the particles in a medium such as air for those waves.



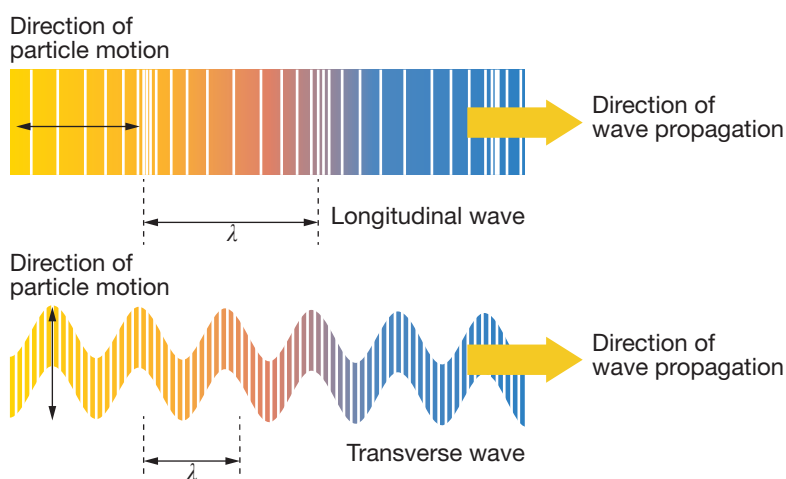
In these ways we can model the nature of the particle movement in the medium carrying either a transverse wave or a longitudinal wave.

Conclusions from modelling experiments

The diagrams show the conclusions we can draw from these modelling experiments.

Particle motion in a medium carrying a **longitudinal wave** is oscillation back and forth in the same plane as the direction of propagation of the energy.

Particle motion in a medium carrying a **transverse wave** is oscillation at 90° to the direction of propagation of the energy.



2 Transfer Of Energy By Mechanical Waves

QUESTIONS

For each photo identify the type of mechanical wave involved and the evidence or implied evidence it presents to show that energy is or has been carried by that wave.



Electromagnetic Waves

Identify light as an electromagnetic wave that does not require a medium for propagation and travels at c , the speed of light, in a vacuum and describe the production and transfer of energy of electromagnetic waves. Interpret diagrams of the electromagnetic spectrum to quantitatively demonstrate the relationship between frequency, wavelength and energy $E = hf$ and $c = f\lambda$ and describe practical applications for regions of the electromagnetic spectrum, linking properties to uses.

5 Electromagnetic Waves

The wave model of light was accepted by scientists for over 200 years because it was able to explain all the observed properties of light. The only weakness of the wave theory at the time was that light waves, like soundwaves, would need a medium for transmission.

The existence of the hypothetical substance *luminiferous aether* proposed by **Christiaan Huygens** in 1678 held up the development of the knowledge of the nature of light for many years.

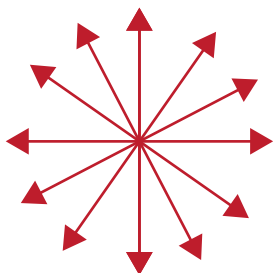
The electromagnetic theory

In 1845, **Michael Faraday** discovered that light was affected by magnetic fields. This was the first evidence that light was related to electromagnetism. In 1847 Faraday proposed that light was a high-frequency electromagnetic vibration, which could propagate even in the absence of a medium such as the aether.

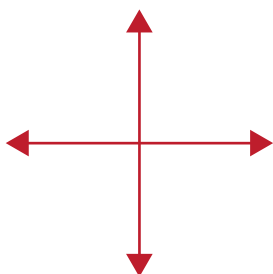


Michael Faraday (1791-1867).

A light wave is known to have pairs of fields oscillating at all angles.



For simplicity, we consider electromagnetic waves as fields oscillating only in the vertical and horizontal planes.



Faraday's work inspired **James Clerk Maxwell** to study electromagnetic radiation and light. Maxwell discovered, while working on mathematical equations to describe electrical phenomena, that self-propagating electromagnetic waves would travel through space at a constant speed, which happened to be equal to the previously measured speed of light. From this, Maxwell supported Faraday's idea, proposing, in 1873, that light was a form of electromagnetic radiation.

In 1887, **Heinrich Hertz** confirmed Maxwell's idea of additional electromagnetic waves experimentally by generating and detecting what we now know as radio waves and demonstrating that they had the same properties as light.

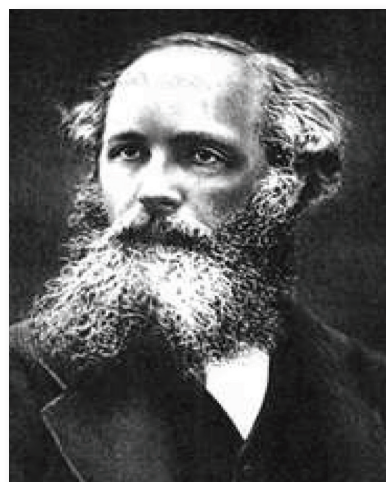
The electromagnetic model for light was the first one able to explain **polarisation**.

Polarisation is a property of waves that can oscillate with more than one orientation.

In the electromagnetic model for light, light is considered to have many pairs of electric and magnetic fields oscillating at right angles to each other.

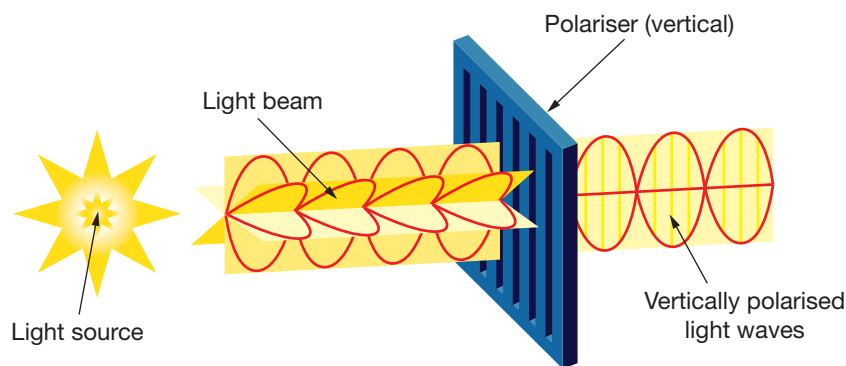
We would refer to a light wave like this as being **unpolarised**. When a light wave is passed through a **polariser**, all the sets of field pairs are cut from the beam except those in one plane. The light is now **polarised**.

Polarisation reduces the intensity of the light beam which is why it is useful in sunglasses.



James Clerk Maxwell (1831-1879).

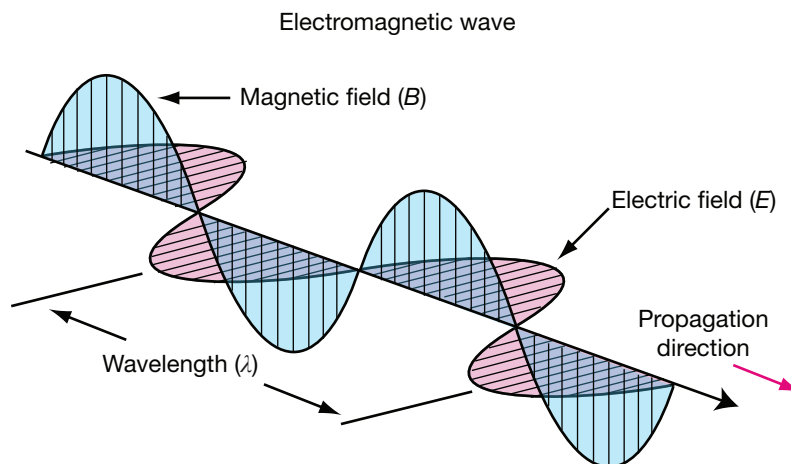
While Maxwell's theory and Hertz's work led directly to the development of modern radio, radar, television, electromagnetic imaging, and wireless communications, it was unable to explain spectral lines and the threshold frequency in the photoelectric effect which Hertz also observed, but did not study further.



Properties of electromagnetic waves

Electromagnetic transverse waves are different from transverse matter waves in that they have the following properties.

- Electromagnetic waves can travel through a vacuum.
- They all travel at the speed of light ($3 \times 10^8 \text{ m s}^{-1}$) in a vacuum – they slow down a little in other media.
- Electromagnetic waves are proposed to be **self-propagating alternating electric and magnetic fields**.
- Because the motion of the changing magnetic and electric fields are at right angles to the direction in which they carry energy, electromagnetic waves are also classified as transverse waves.
- Because electromagnetic waves are really hard to draw, we usually draw them as transverse matter waves. The flaw in doing this is that the energy carried by a transverse wave is indicated by the amplitude of the wave but this is not the case with electromagnetic waves.
- In electromagnetic waves, the energy is directly proportional to the frequency of the photons which constitute the radiation as given by Planck's quantum theory equation, $E = hf$, which you shall learn about later.
- The **wavelength** of an electromagnetic wave is the distance between the peaks of successive magnetic or electric field pulses.
- We usually refer to the **intensity** of an electromagnetic wave rather than to its amplitude. The intensity of an electromagnetic wave depends on the number of photons in the beam. Each photon will have energy dependent on its frequency.
- The **period** of an electromagnetic wave is the time for one wavelength to pass a given point.
- The **frequency** of an electromagnetic wave is the number of wavelengths that pass a point each second. Frequency is measured in hertz (Hz).

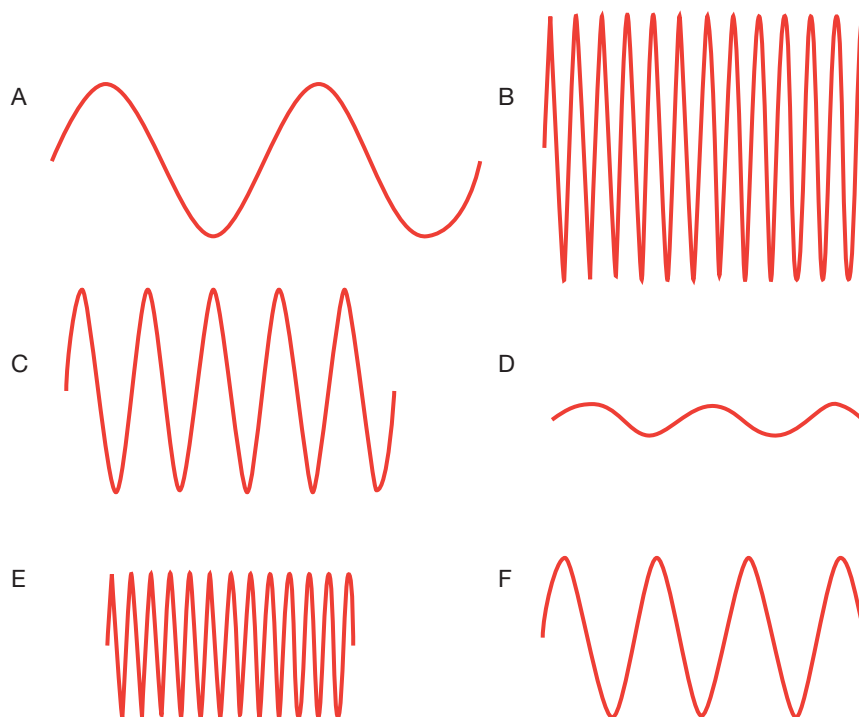


Transverse waves

Electromagnetic waves are often referred to as being transverse electromagnetic waves. This is because the shape of the growth and decay of the alternating electric and magnetic fields that produces them follows a sinusoidal pattern, and the oscillation of those fields are both at right angles to the direction of propagation of the energy.

However, they *are not* correctly drawn using the transverse waves that we usually use when we want to represent them on paper. These are used for simplicity and for ease of understanding, and the analysis of them gives the correct results.

5. The transverse waves A to E in the diagrams below represent longitudinal soundwaves.



Rank the sounds produced by each of the original longitudinal waves in order of:

- (a) Increasing pitch.
 - (b) Increasing frequency.
 - (c) Increasing volume.
 - (d) Increasing amplitude.
6. (a) A particle of dust is floating at rest 15 cm directly in front of a loudspeaker. The loudspeaker is initially not operating. The sound is then switched on and the speaker emits sound of frequency 30 Hz and with a speed of 330 m s^{-1} .



● Particle of dust

- Which one of the following statements best describes the motion of the dust particle?
- (A) It will oscillate vertically up and down at 30 Hz remaining (on average) 15 cm in front of the loudspeaker.
 - (B) It will oscillate horizontally backwards and forwards at 30 Hz remaining (on average) 15 cm in front of the loudspeaker.
 - (C) It travels away from the loudspeaker at 330 m s^{-1} while oscillating horizontally backwards and forwards at 30 Hz.
 - (D) It remains at rest.
- (b) The loudspeaker now emits a sound of frequency 256 Hz. Which choice best gives the wavelength of sound from the loudspeaker?
- (A) 0.78 m
 - (B) 1.29 m
 - (C) 17.0 m
 - (D) $8.4 \times 10^4 \text{ m}$

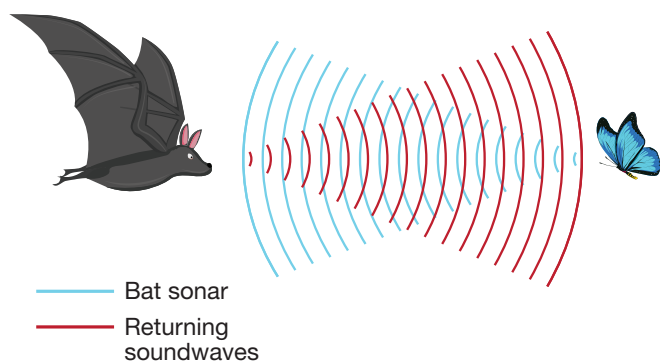
14 Applications Of Reflection Of Sound

We have briefly touched on several applications of reflection of light rays in the work already done. These include satellite dishes, reflecting telescopes, radio telescopes, solar barbecues, plane mirrors in bathrooms, convex mirrors on tight corners and the like.

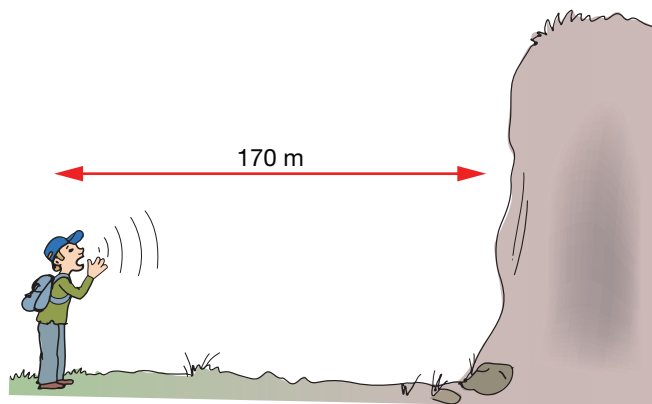
Longitudinal soundwaves also reflect as do compression waves in rocks (longitudinal pressure waves). A common phenomenon of the reflection of soundwaves is what we know as **echoes**. Echoes are interesting for tourists on lookouts opposite cliffs and mountains, are used by bats to navigate, porpoises to find fish shoals, scientific research and exploration vessels to map ocean depths or find rock formations which may contain oil or natural gas. Commonly used forms of echoes in medicine include **X-rays** and **ultrasounds**.



Ultrasound of human baby.



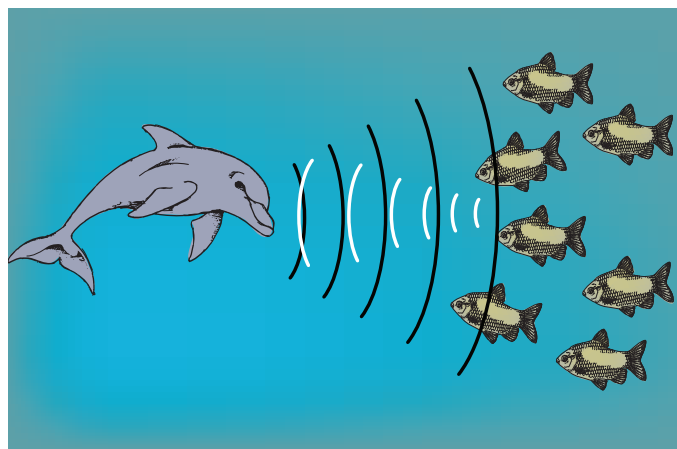
Bats navigate by echoes.



Tourists love echoes.



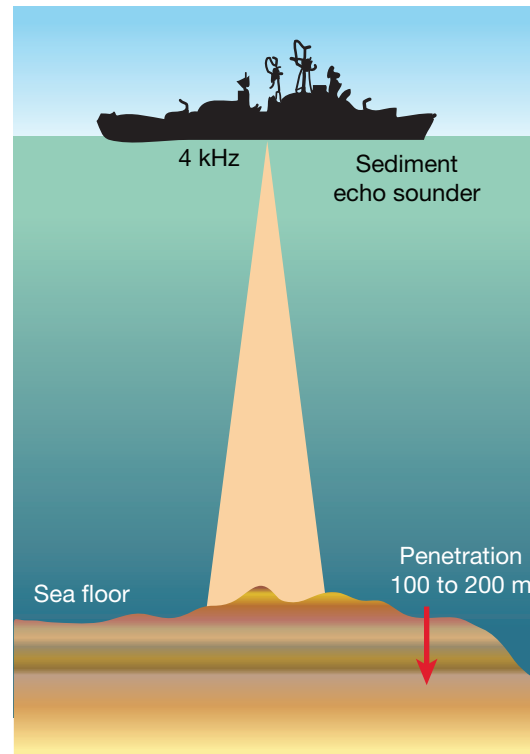
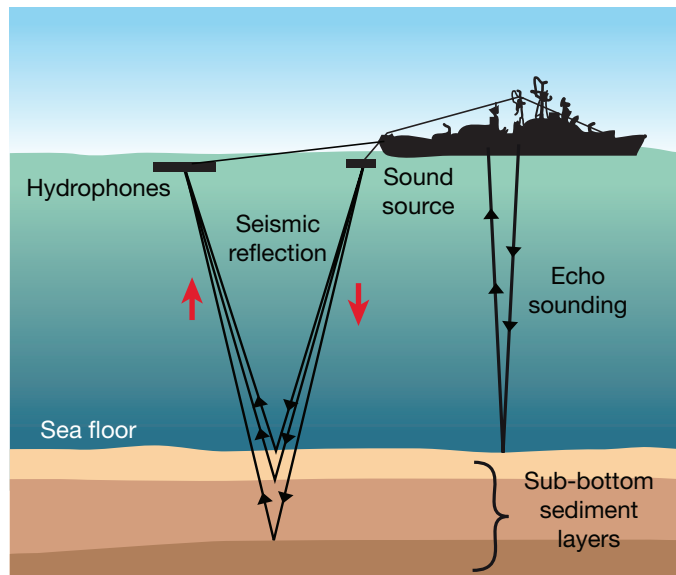
X-ray of human hand.



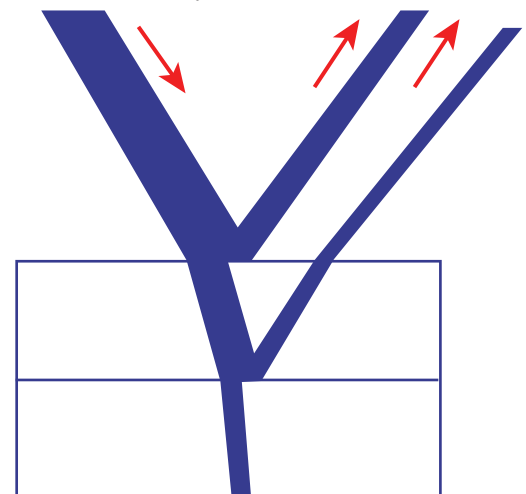
Porpoises find fish by echoes.

QUESTIONS

1. Consider the diagram of a tourist making an echo on the previous page. If sound travels at 330 m s^{-1} , how long is it before the guy shouting hears his echo?
2. The echo sounder from the ship shown in the picture to the right receives an echo 2.25 seconds after it sends the pulse out. If the speed of sound in the water is 1500 m s^{-1} , how deep is the water underneath the boat?



3. The ship shown in the picture above surveys the depth of the ocean floor by echo sounding. It also surveys the sediment making up the floor by seismic reflection. Given this information, and the facts that the speed of sound in the water is 1500 m s^{-1} and in the sediment is 6500 m s^{-1} answer the following.
 - (a) Explain the difference between echo sounding and seismic surveying.
 - (b) Explain why soundwaves travel faster in rock than they do in water and faster in water than they do in air.
 - (c) Explain why soundwaves do not pass through a vacuum.
 - (d) The water beneath the boat is 2.5 km deep. The seismic reflection from the deepest sediment layer arrives back at the boat 3.58 s after the sound pulse leaves the ship. How thick is the sediment layer?
 - (e) Use the diagram on the right to explain how seismic surveys work to determine the structure of sedimentary rock layers on the ocean floor.



The Inverse Square Law

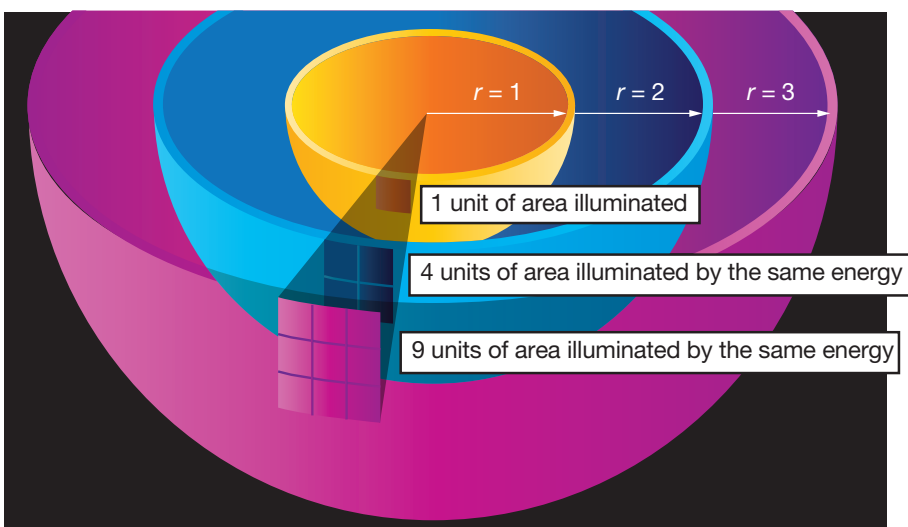
Investigate the inverse square law for the transfer of energy by electromagnetic radiation, sound, and gravitational field strength (and other quantities in physics) and solve problems involving the inverse square law using $I \propto \frac{1}{r^2}$ and $I_1 r_1^2 = I_2 r_2^2$ to compare the intensity of light at points r_1 and r_2 . Analyse experimental results to determine the relationship between light intensity and distance from a light source.

15 The Inverse Square Law 1

A problem with long distance communications is the **attenuation** of the transmitted signal – it **decreases in strength** as distance from the transmitter increases. You notice this as the radio station you are listening to on a long drive begins to lose reception as your distance from home increases. This problem can be remedied by transmitting at a very high power, or by amplifying the signal at the reception point. Amplification is essential if the transmission uses repeater stations or when the signal goes via a satellite.

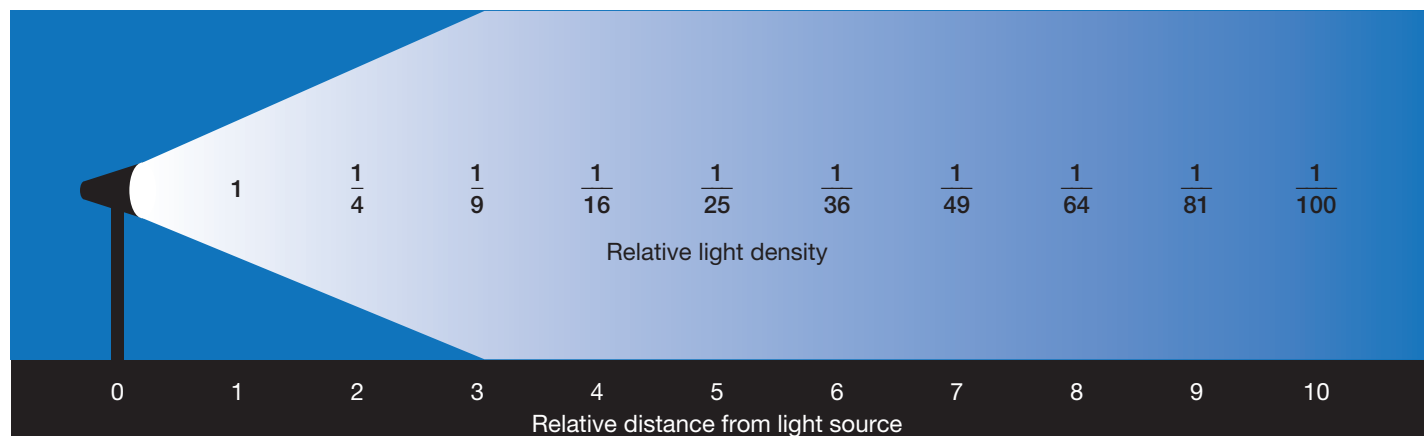
Both the diagrams on this page illustrate that a beam of energy spreading in all directions or just straight out will spread as the distance from the source increases. It is simple logic that the intensity of the radiation will decrease because it is covering larger and larger areas. A closer analysis of these situations with accurate measurements provides us with the relationship outlined below – **the inverse square law**.

The mathematical relationship between the intensity of the energy falling on a given area and the distance of that area from the source of the energy is known as the inverse square law, summarised as follows.



$$I \propto \frac{1}{r^2} \text{ or } \frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$$

Where I = intensity of energy per unit area (units)
 r = distance from source (m)

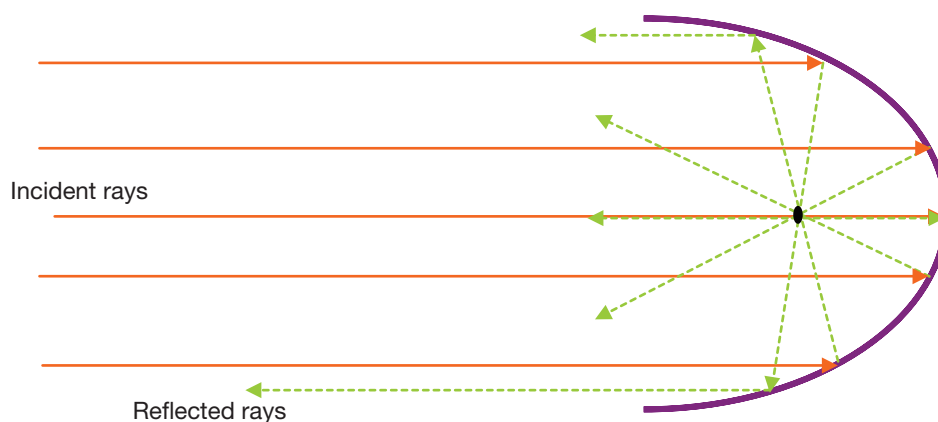


20 Reflection From Curved Surfaces

Surfaces which curve inwards (like a cave) are known as **concave** surfaces. Surfaces which curve outwards are called **convex** surfaces. The focus of a curved surface is the point on the **principal axis**, midway between the curve and its **centre of curvature**.



- When electromagnetic rays parallel to the principal axis hit a concave surface they reflect so that they pass through the **focus** of the curve.
- The ray travelling along the principal axis is reflected straight back (it hits the curved surface at 90°).
- Any reflected ray which then hits the surface will be reflected again to travel parallel to the principal axis. It is this property of concave surfaces that makes them useful in torches and car headlights.



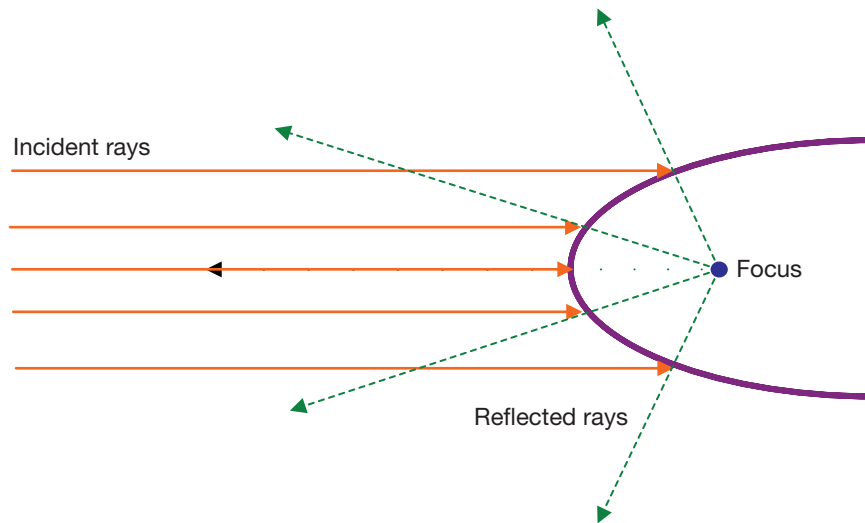
Satellite transmitter and receiving dishes use a concave reflecting system. The transmitter or receiver is at the focus of the concave dish.



A solar barbecue cooker uses a concave reflector to reflect the infra-red rays from the Sun to the food at the focus.

Convex surfaces are **converging** surfaces as they cause the parallel rays to reflect and move closer together until they pass through the focus. It is this property of a concave surface which we use in solar cookers (we place the meat on a skewer at the focus) and in collecting data from radio and microwave signals from space (the receiver is suspended at the focus of the collecting dish).

Convex surfaces reflect parallel rays so that their backwards extension passes through the focus of the curve. Convex surfaces are called **diverging** surfaces as they reflect the rays so that they travel further apart. This makes them useful in rear vision mirrors or driveway mirrors to give drivers and oncoming traffic a wider view of the area behind them or around a corner respectively.



A convex reflecting surface can be used to see around tight corners on roads, or narrow driveways in building complexes.



Convex reflecting surfaces can be used to increase the field of view of a traffic camera or a driver's rear view mirror.

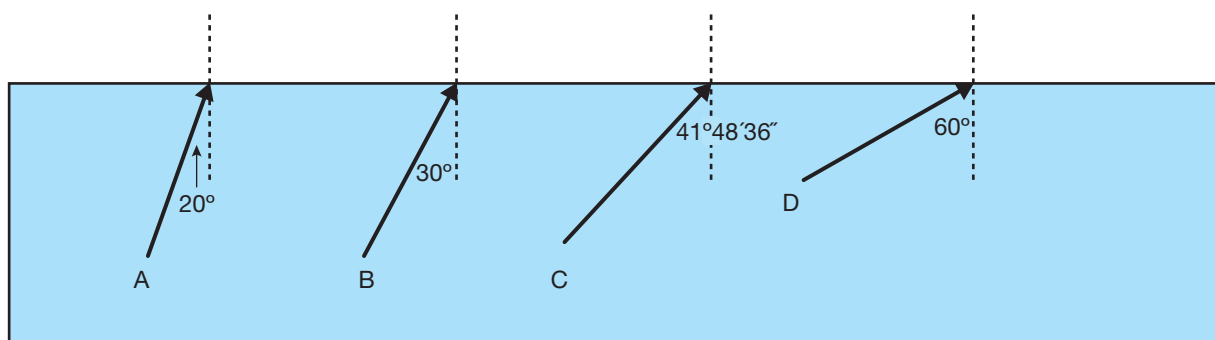


Examine the internal reflection of a light ray passing from a more dense medium to a less dense medium leading to the concept of total internal reflection, and solve total internal reflection and critical angle problems using $\sin \theta_c = \frac{n_2}{n_1}$.

24 Total Internal Reflection

QUESTIONS

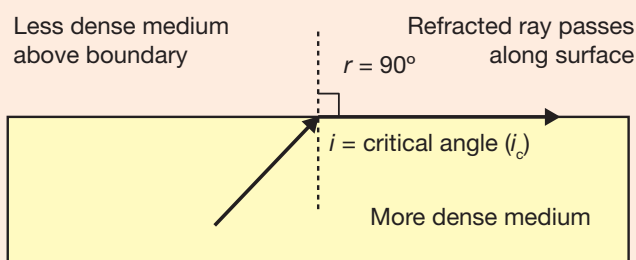
- The diagram represents a glass slab of refractive index 1.50. Several incident rays, from inside the glass, are shown. For each, calculate the angle of refraction to the nearest degree, and draw in the refracted ray. (Note: Use stated angle values not measured values.)



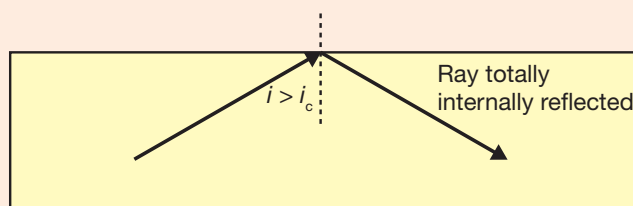
Notice when you do these calculations that you get a very interesting answer for the angle of refraction for C, and that you get 'error' for D – the incident ray at 60° to the glass/air boundary.

This is because for this piece of glass, the angle $41^\circ 48' 36''$ is a very special angle, called the *critical angle*.

The **critical angle** for any substance is the incident angle for which a ray of light incident on the boundary *from inside the substance* is refracted such that the angle of refraction is 90° , that is, the ray of light is refracted along the surface of the boundary.

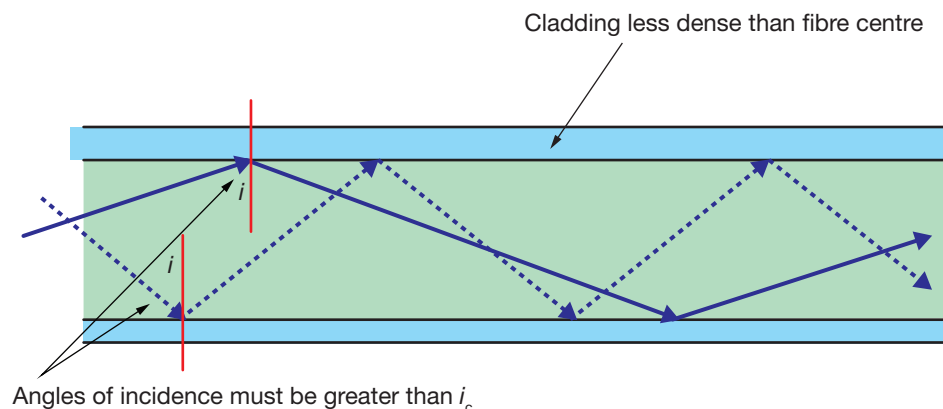


Note that if the angle of incidence is greater than the critical angle then **total internal reflection** occurs. There is no refraction as the ray is reflected back into the denser medium.



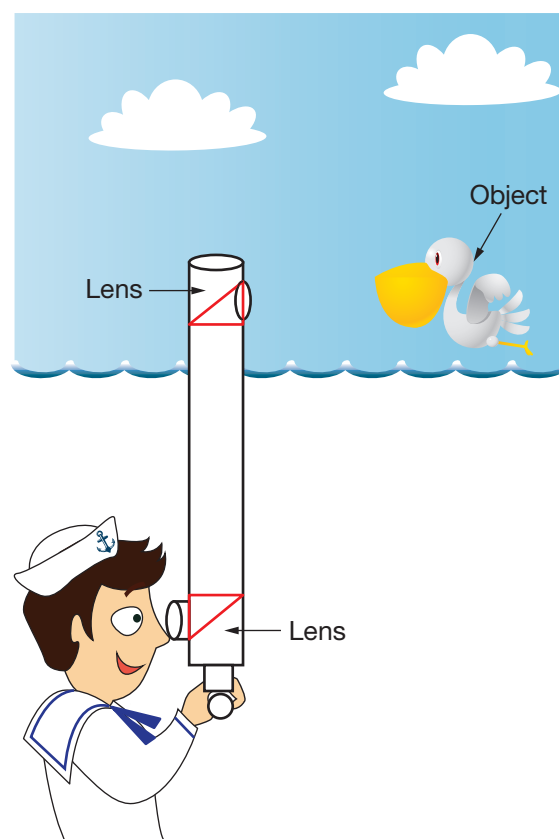
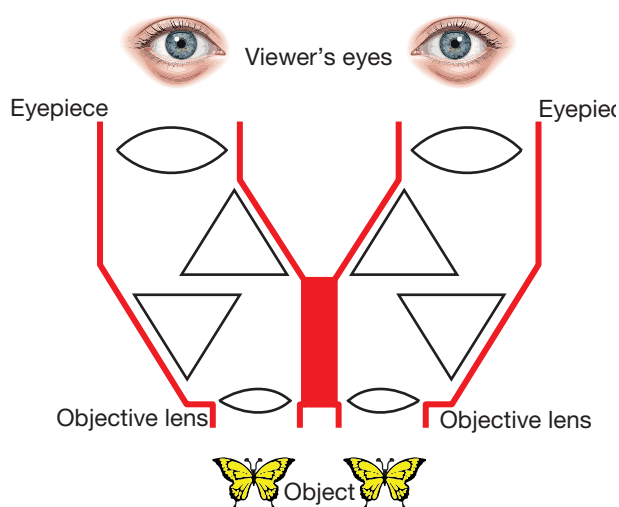
Note also that total internal reflection *only occurs* with light rays reflecting *inside a denser medium*.

Optical fibres use the principle of total internal reflection. Light, carrying digital data, travels through the fibre reflecting off its internal walls thousands of times each second. While the angles of incidence of these reflections are greater than the critical angle (i_c) of the material which makes up the fibre, minimal information will be lost by refraction. Optical fibres are also usually covered by a cladding which prevents data loss by refraction.



MORE QUESTIONS

2. Explain the principle of total internal reflection and the conditions under which it occurs.
3. Explain why the angles of incidence of the light waves inside the optical fibre must be greater than the critical angle of the fibre.
4.
 - (a) What is a cladding?
 - (b) What is the function of cladding?
 - (c) Explain why the cladding needs to be less dense than the material making up the fibre.
 - (d) Suppose the cladding was more dense than the material making up the fibre. What difference would this make to the transmission of the data through the fibre?
5. Assess the role of total internal reflection in optical fibre communications.
6. The diagram shows a simple periscope which uses two triangular lenses.
 - (a) Draw in the rays of light from the object to the viewer and show how this is an application of total internal reflection.
 - (b) What is essential in the shape of the lenses used in this periscope?
7. The diagram below shows a pair of binoculars. Draw in the rays of light travelling from the object, through the objective lens and through the binoculars to the viewer's eyes at the eyepiece. Show how this instrument uses total internal reflection.

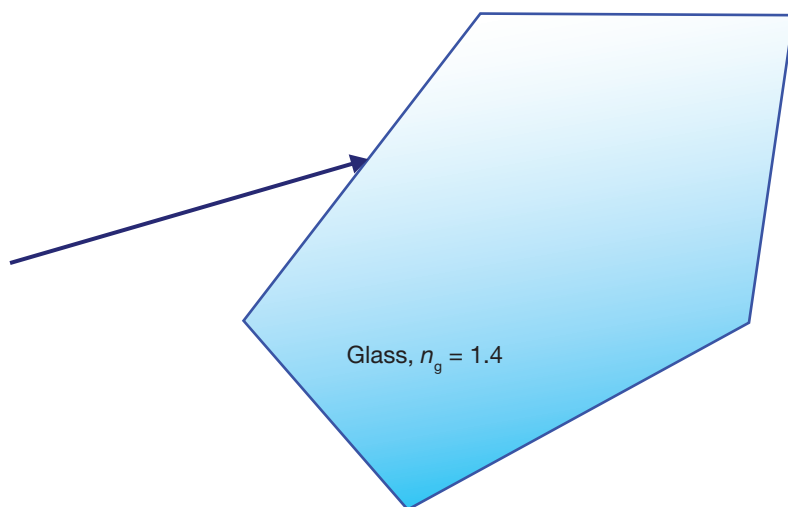


27 Some More Refraction Problems

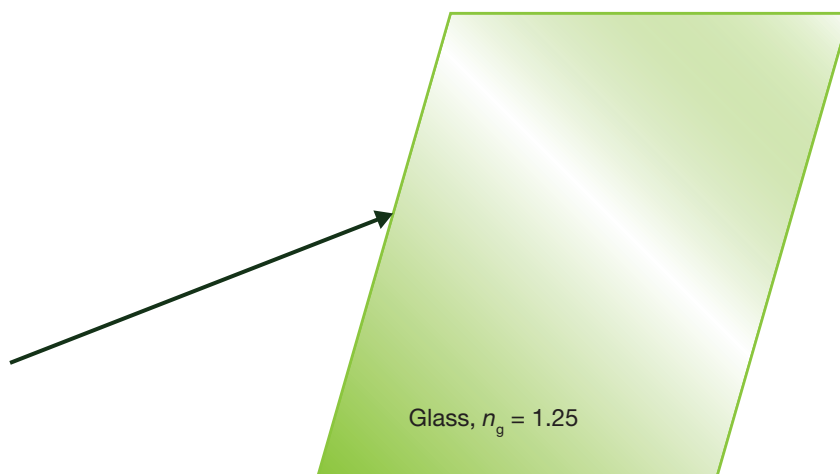
QUESTIONS

1. The diagrams show rays of light entering slabs of glass from air and being refracted. For each diagram make calculations so you can draw in the path of the ray of light through the slab and back out into the air. Label all appropriate angles with their values.

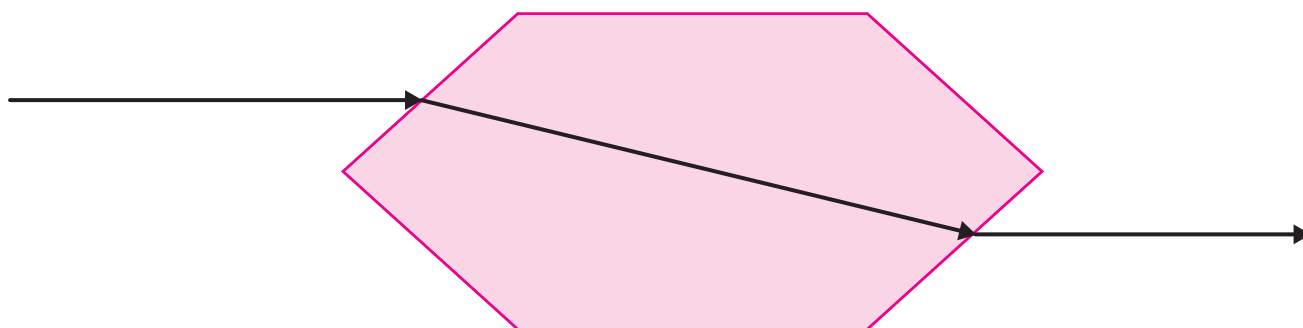
(a)



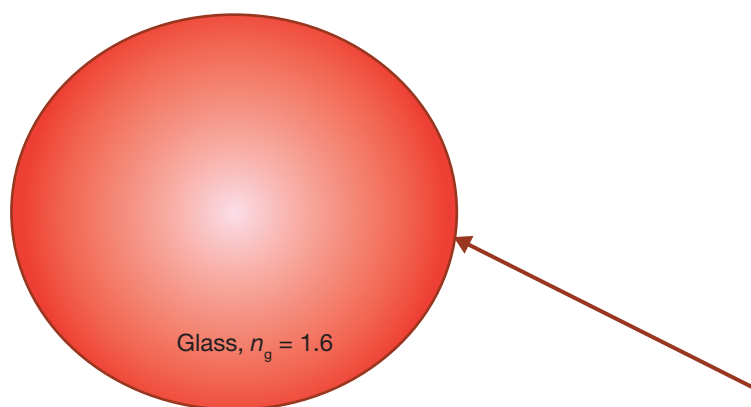
(b)



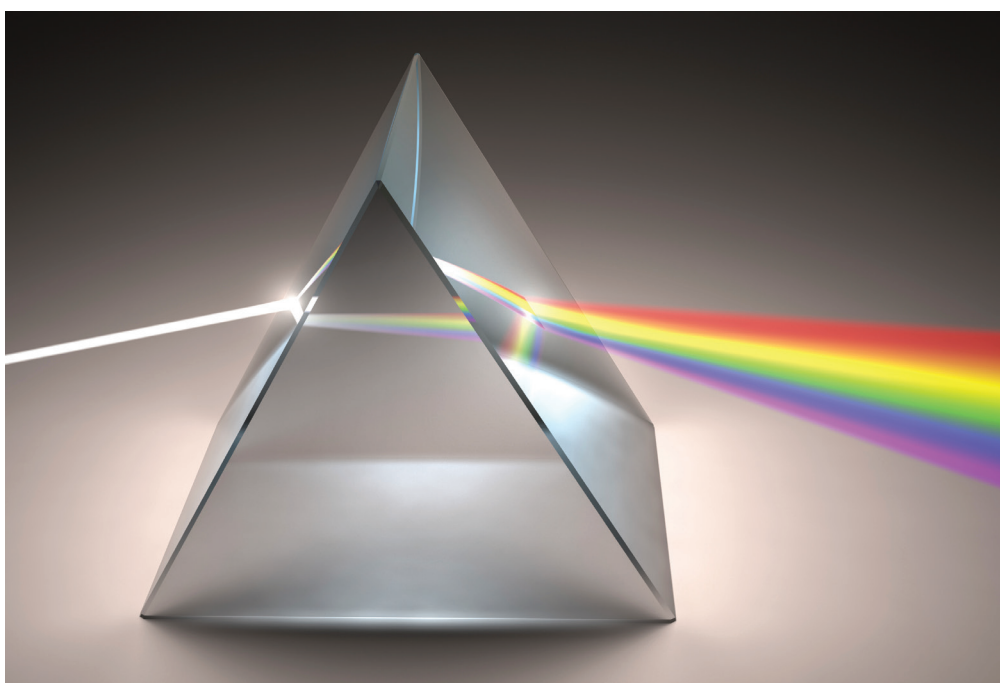
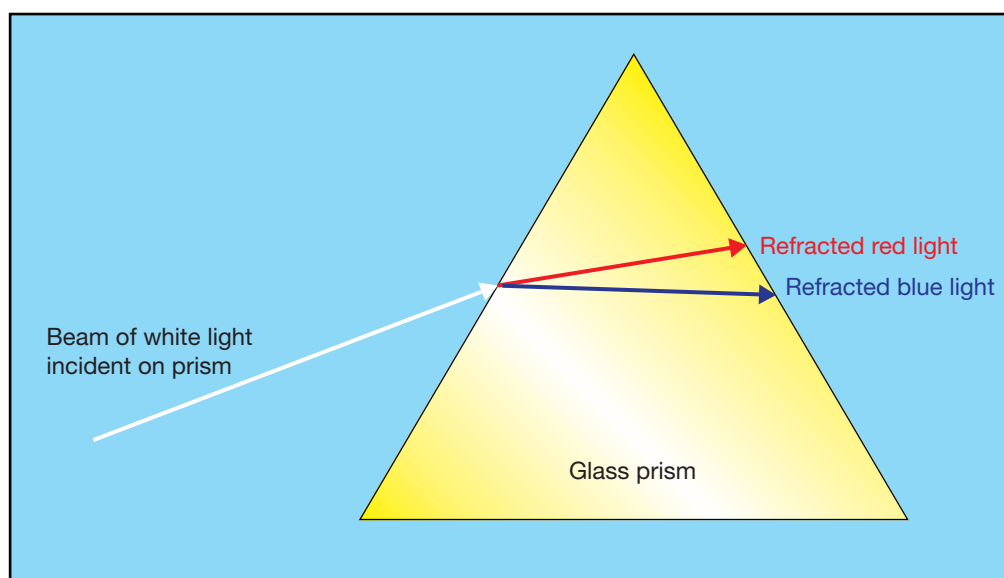
(c)



(d)



2. Make appropriate additions to the diagram below so that you can calculate:
- (a) The refractive index for red light entering the glass prism from the air.
 - (b) The refractive index for blue light entering the glass prism from the air.
 - (c) Account for the difference.



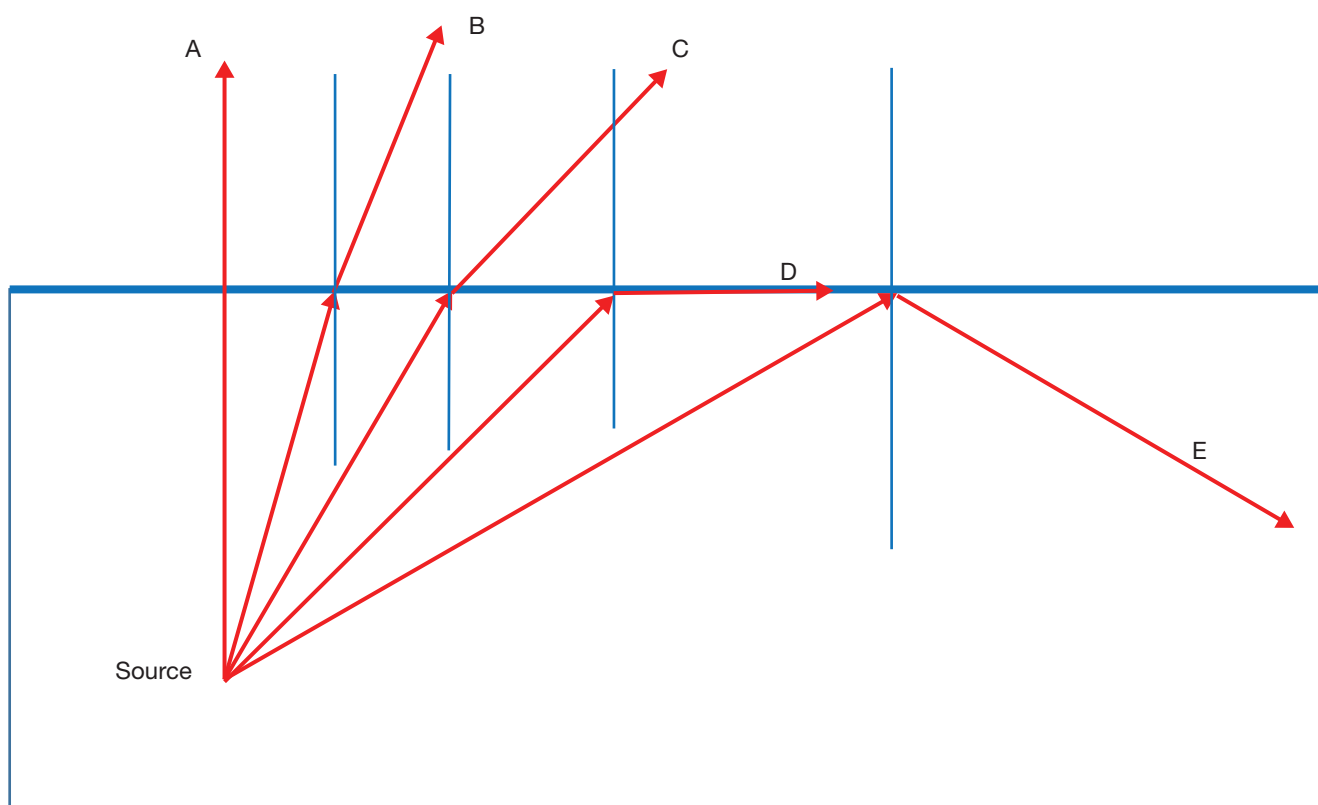
28 Analysing a Total Internal Reflection Experiment

QUESTIONS

1. The diagram represents an experiment done where beams of light were shone from an underwater source towards the surface of the water to determine the refractive index of the water/air boundary and its critical angle. Several incident rays, from inside the water, are shown.

For rays A, B, C and D:

- Label and measure the angle of incidence to the nearest degree. Put your results in the table below.
- Label and measure the angle of refraction to the nearest degree. Put your results in the table below as well.
- For E measure and label the angles of incidence and reflection.
- Where appropriate, calculate the refractive index for the boundary.



Beam	Angle of incidence	Angle of refraction/reflection	$\frac{\sin i}{\sin r}$	Refractive index of boundary
A				
B				
C				
D				
E				

- Comment on the angles of incidence and refraction for D.
- Comment on the reflection rather than the refraction of ray E.
- Determine the refractive index for the boundary.
- What would be the refractive index of the boundary for the beam travelling from the air into the water?
- Determine the critical angle for the boundary.
- Write a conclusion for the experiment.

How Do Spectacles Work?

Conduct a scientific investigation to discuss how spectacles assist people with vision impairment.

29 How Do Spectacles Work – Investigation

- For the rest of this topic **you have to produce the work** – after all, it is a scientific investigation!
- If this really interests you, discuss the possibility of it becoming a depth study topic for you with your teacher.
- Note that no answers have been provided for this topic just in case it is set as an assessment or you choose it as a depth study.

Some hints

- To understand how spectacles (glasses) work, you need to understand how convex and concave lenses work, and research how these scientific ideas relate to spectacles. This work is covered in the next two chapters.
- You will then need to summarise why spectacles are needed. Research the three most common eye problems that lead to people wearing glasses, *and*, why these happen:
 - Myopia: short-sightedness
 - Hyperopia (hypermetropia): long-sightedness
 - Astigmatism: uneven focusing
- Then discuss, perhaps with appropriate diagrams, how spectacles can be used to correct these problems.
- And then, after organising all your thoughts, design, and write up your investigation report.



30 Forming Images With Convex Lenses

Properties of images

Images are:

- **Real** if they occur on the *opposite side* of the lens as the object. (R)
- **Virtual** if they occur on the *same side* of the lens to the object. (V)
- **Upright** if they are the same way up as the object. (U)
- **Inverted** if they are upside down. (I)
- **Diminished** if they are smaller than the object. (D)
- **Magnified** if they are larger than the object. (M)
- **Same size** if they are the same size as the object. (S)

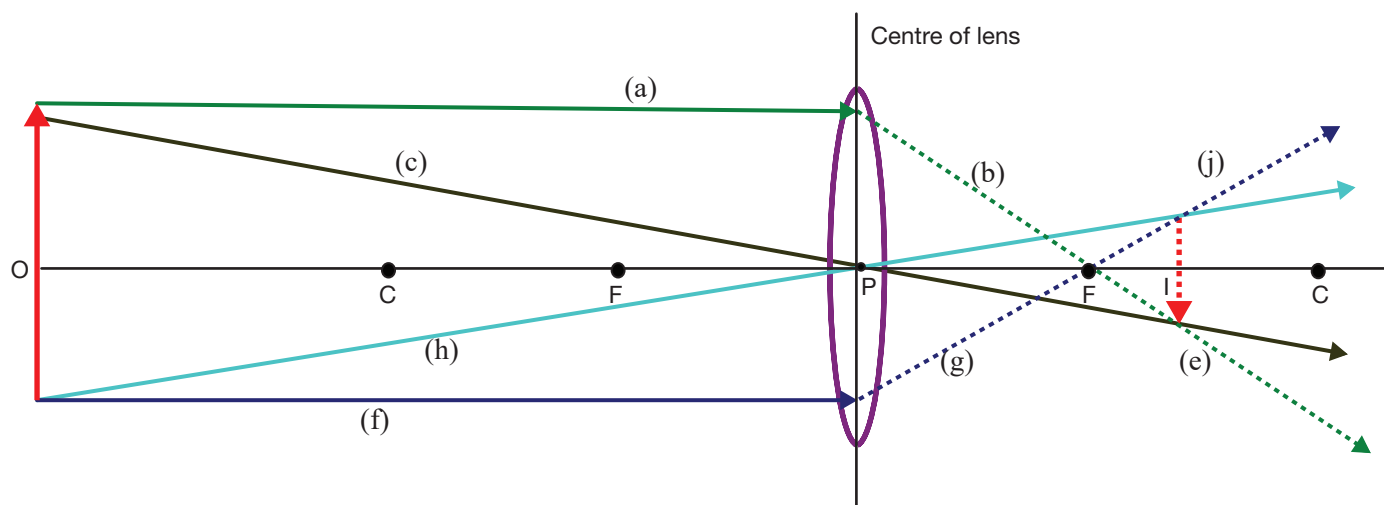
Finding the position of an image

For an object significantly beyond the centre of curvature (at infinity).

Note: F = focus of the lens C = centre of curvature of the lens

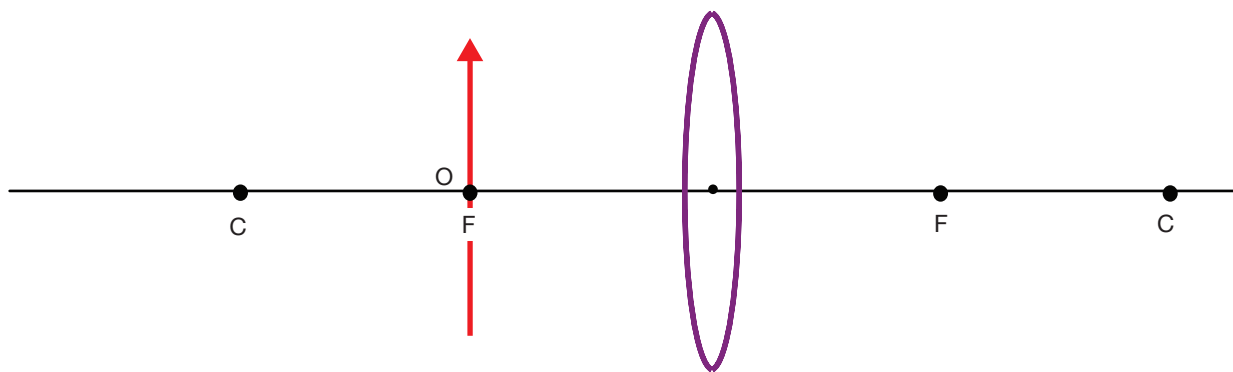
P = centre of the lens CF = FP

O = object I = image

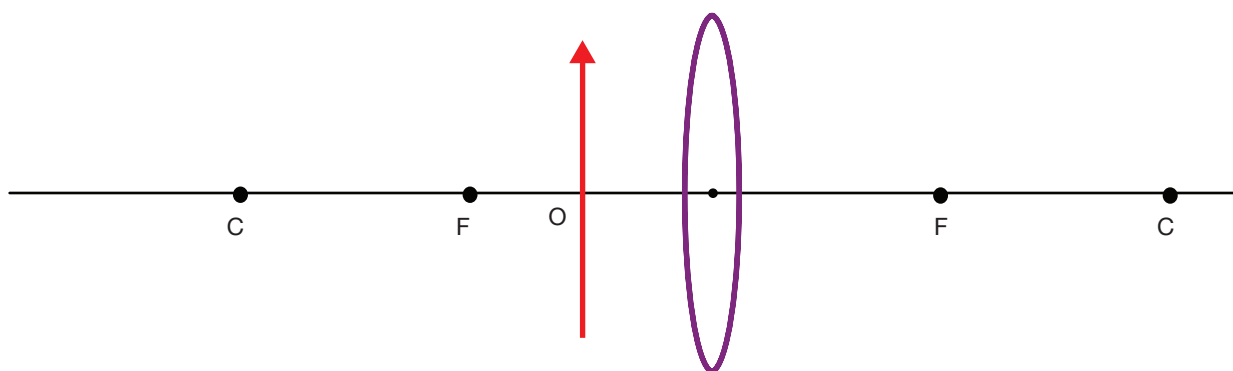


- Draw a light ray from the top of the object, parallel to the principal axis, to the centre line of the lens (green ray).
- Refract it to pass through the focus on the opposite side of the lens (dotted green ray).
- Draw a second ray from the top of the object to pass through the centre of the lens (dark green ray).
- This ray will pass through the lens without changing path.
- The point where these two rays meet is the position of the head of the image.
- Draw a light ray from the bottom of the object, parallel to the principal axis, to the centre line of the lens (blue ray).
- Refract it to pass through the focus on the opposite side of the lens (dotted blue ray).
- Draw a second ray from the bottom of the object to pass through the centre of the lens (light blue ray).
- This ray passes through the lens without changing path.
- The point where these two rays meet is the position of the foot of the image.
- Draw in the image and describe it – **Image is virtual, diminished and upright.**

4. Object at F. Image is:



5. Object between F and the lens. Image is:



31 Forming Images With Concave Lenses

Properties of images

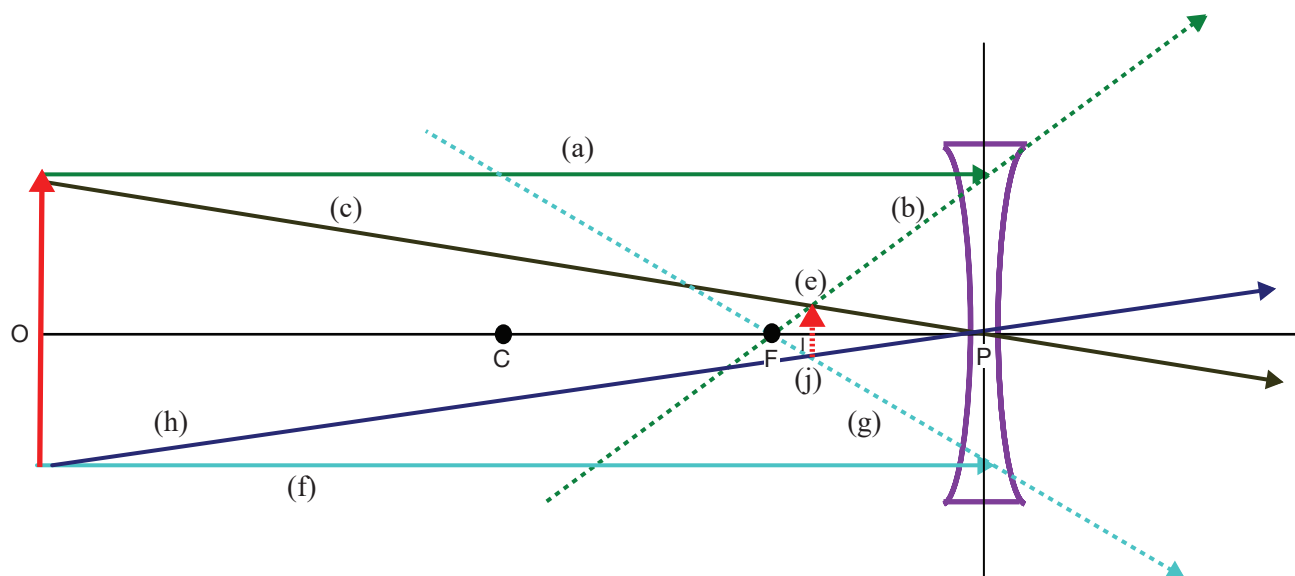
Images are:

- **Real** if they occur on the **opposite side** of the lens as the object. (R)
- **Virtual** if they occur on the **same side** of the lens to the object. (V)
- **Upright** if they are the same way up as the object. (U)
- **Inverted** if they are upside down. (I)
- **Diminished** if they are smaller than the object. (D)
- **Magnified** if they are larger than the object. (M)
- **Same size** if they are the same size as the object. (S)

Finding the position of an image

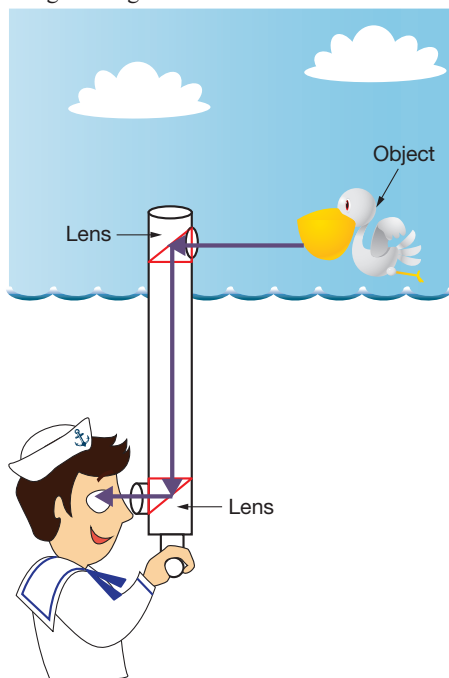
For an object significantly beyond the centre of curvature (at infinity).

Note: F = focus of the lens C = centre of curvature of the lens
P = centre of the lens CF = FP
O = object I = image

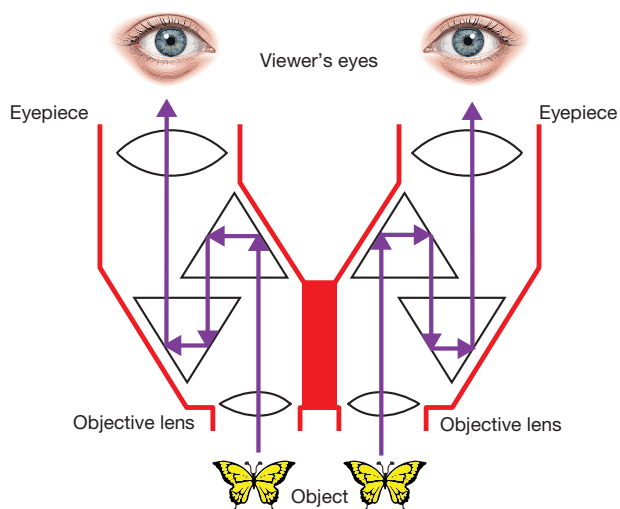


- Draw a light ray from the top of the object, parallel to the principal axis, to the centre line of the lens (green ray).
- Refract it to pass through the focus on the same side of the lens as the object (dotted green ray).
- Draw a second ray from the top of the object to pass through the centre of the lens (dark green ray).
- This ray will pass through the lens without changing path.
- The point where these two rays meet is the position of the head of the image.
- Draw a light ray from the bottom of the object, parallel to the principal axis, to the centre line of the lens (blue ray).
- Refract it to pass through the focus on the same side of the lens as the object (dotted blue ray).
- Draw a second ray from the top of the object to pass through the centre of the lens (dark blue ray).
- This ray passes through the lens without changing path.
- The point where these two rays meet is the position of the foot of the image.
- Draw in the image and describe it – **Image is real, diminished and upright.**

4. (a) Cladding is an insulating cover over an optical fibre, hot water pipe, cold water feed pipes etc.
 (b) The function of cladding is to prevent or minimise energy loss in to the surroundings.
 (c) For an optical fibre, so that total internal reflection from its internal boundary with the fibre is possible.
 (d) A more dense cladding may reflect more data back into the fibre if the angle of incidence is less than the critical angle, but it will still allow refraction of data to the outside of the fibre at any angle.
5. Without total internal reflection, the efficiency of data transmission by optical fibre would be much less reliable, and may be impossible due to excess data corruption by cross talk (interference due to signals moving from fibre to fibre), or loss of energy through leakage from the fibre.
- 6.



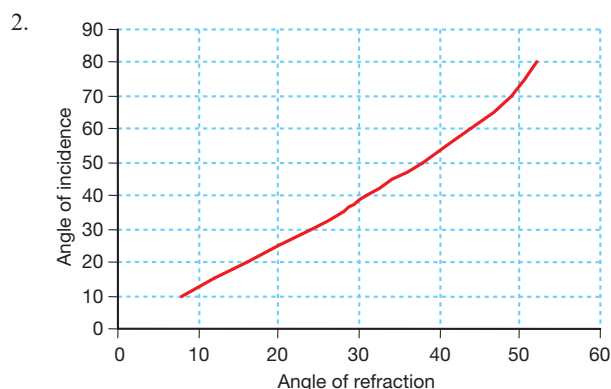
- (a) The beam of light reflects totally internally from the hypotenuse side of the triangular lenses.
 - (b) Using lenses like these, they must be right angled with the hypotenuse at 45° to reflect the beams in the correct directions.
7. The beams of light reflect totally internally through the pyramidal lenses to travel from the object to the viewer's eyes.



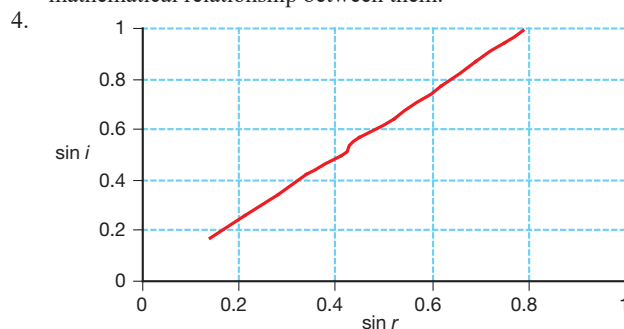
25 Analysing a Refraction Experiment

1. (Note: Calculations done to 2 decimal places only.)

Sin i	Sin r	Ratio $\frac{\sin i}{\sin r}$
0.17	0.14	1.21
0.26	0.21	1.24
0.34	0.28	1.21
0.42	0.34	1.24
0.50	0.41	1.22
0.57	0.45	1.27
0.64	0.52	1.23
0.77	0.62	1.26
0.87	0.69	1.26
0.94	0.75	1.25
0.99	0.79	1.25
Average ratio		1.24



3. Can only say that as angle i increases, angle r increases. Because we don't know the equation of the curve, we cannot give a defined mathematical relationship between them.



5. Done by hand, and drawing in a line of best fit, you should get a straight line here, so, yes, we can determine the relationship:

$$\frac{\sin i}{\sin r} = \text{constant}$$

6. Refractive index = $\frac{\sin i}{\sin r} = \text{gradient} = 1.25$

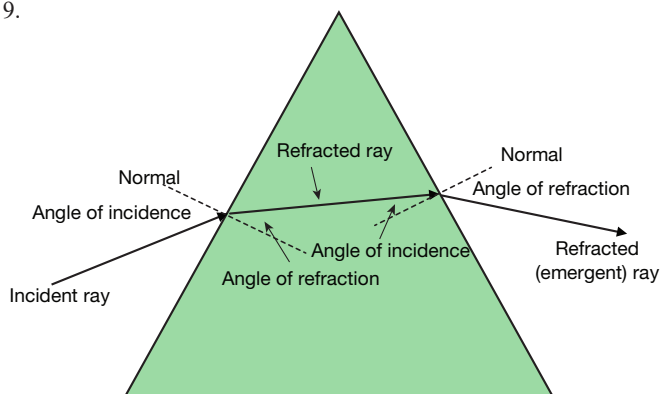
$$1.25 = \frac{\sin 45^\circ}{\sin r}; \sin r = 0.5657; r = 34^\circ 36'$$

$$\frac{1.25 - \sin i}{\sin 45^\circ}; \sin i = 0.8839; i = 61^\circ 42'$$

9. It is usually accepted that a gradient from line of best fit data is more reliable than averaged data. While one could argue that a line of best fit actually represents the 'average trend' in the data, graphed data allows you to notice 'outliers' (obviously incorrect data readings) and ignore them, and it also reduces the possibility of incorporating 'systematic' errors. A systematic error is one which occurs in every data reading. When graphed, the data may be situated slightly differently in the quadrant, but the systematic errors usually don't affect gradients – they do however, affect mathematical averages.

26 Analysing Another Refraction Experiment

- 51°
- $1.4 = \frac{\sin 51^\circ}{\sin r}$; $\sin r = 5551$; $r = 34^\circ$
- $n = \frac{1.40}{1} = 1.40$
- See diagram.
- $180 = 60 + 56 + a$; $a = 64$; $i = 90 - 64 = 26^\circ$
- $\frac{1}{1.4} = \frac{\sin 26^\circ}{\sin r}$; $\sin r = 6137$; $r = 38^\circ$
- $n = 1.14 = 0.71$
- Reciprocal relationship.
-



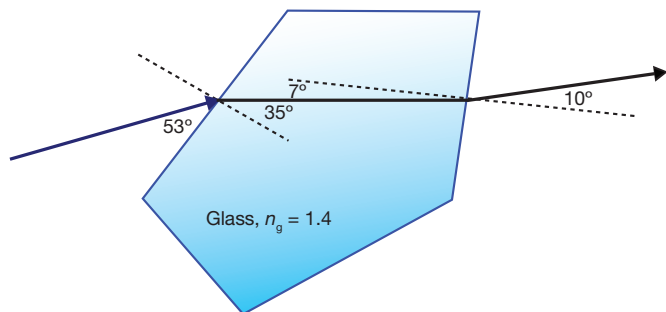
Note: Angles not to scale

- Repeat for several different incident angles, calculating values for refractive index and use average value, take several measures of each angle and use average.

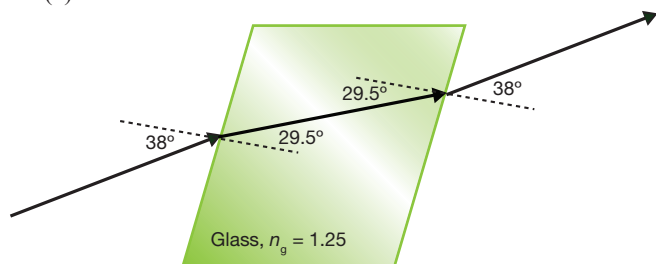
27 Some More Refraction Problems

(Note: Angles not to scale in these answers.)

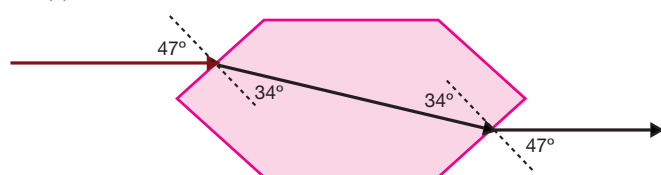
- (a)



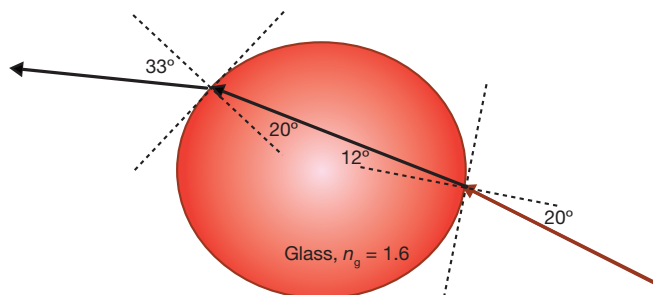
- (b)



- (c)



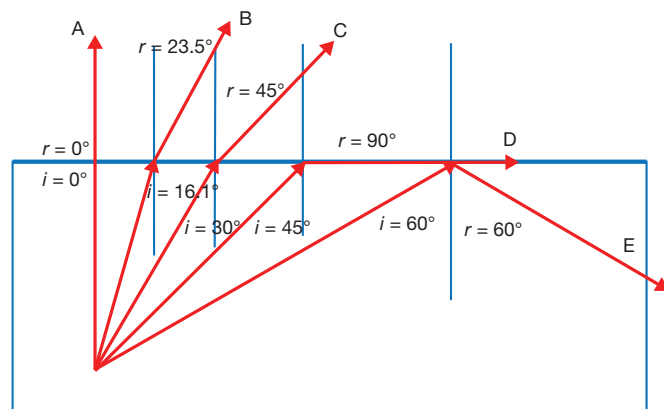
- (d)



- $\frac{\sin 53^\circ}{\sin 40^\circ} = 1.25$
 - $\frac{\sin 53^\circ}{\sin 28^\circ} = 1.68$
 - Refractive index depends on wavelength of the ray of light (remember that frequency stays constant in refraction). The shorter the wavelength of the radiation, the larger the refraction (remember 'blue bends best').

28 Analysing a Total Internal Reflection Experiment

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Beam	Angle of incidence	Angle of refraction/reflection	$\frac{\sin i}{\sin r}$	Refractive index of boundary
A	0	0	-	-
B	16.1	23.5	0.70	0.70
C	30	45	0.71	0.71
D	45	90	0.71	0.71
E	60	60	0.71	-

- Angle of incidence for D, as indicated by the angle of refraction being 90°, is the critical angle.
- Beam E reflects rather than refracting because the angle of incidence is greater than the critical angle.
- Refractive index of the boundary is 0.71.
- $\frac{1}{0.71} = 1.41$
- Critical angle, from results $i_c = 45^\circ$
Checking, critical angle, from $\sin i_c = n_a = 0.71$ leading to $i_c = 45^\circ$
- The refractive index of the boundary was found to be 0.71, and the critical angle to be 45°.