17 Light

In this chapter you will learn:
- about reflection at a plane surface
- to use the law of reflection
- about objects with smooth surfaces (Science extra)
- about the speed of light (Science in context)
- about refraction of light at the boundary between air and glass or air and water
- about tricks of light (Science extra)
- that white light is made of many colours and that this can be shown through the dispersion of white light by using a prism
- about Newton's investigations with prisms (Science in context)
- about the rainbow (Science extra)
- how colours of light can be added, subtracted, absorbed and reflected.

Do you remember?

- Does light travel in straight or wavy lines?
- What is a ray diagram?
- A luminous object is something that gives out light. What is the luminous object which is providing light for you to read this book?
- Light can be reflected. What does this mean?
- How can you see an object that is not a light source?
- What happens to a ray of light when it is reflected from a mirror?
- Does a ray of light keep travelling in the same direction when it moves from air to water? Explain your answer.
- What do you understand by the term 'refraction'?

Light is a form of energy. In this chapter, we will look at how it is reflected and refracted, and investigate the colours of light.

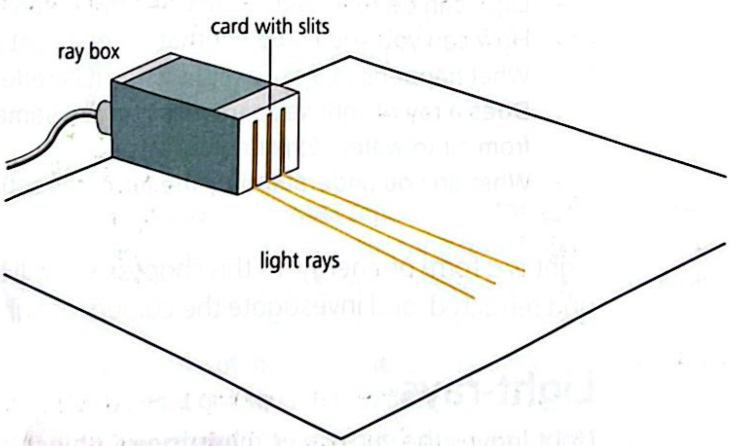
Light-rays

Light leaves the surface of a **luminous object** in all directions but, if some of the light is made to pass through a hole, it can be seen to travel in straight lines.

For example, when sunlight shines through a small gap in the clouds, it forms broad sunbeams with straight edges (see Figure 17.1). The path of the light can be seen because some of it is reflected off dust in the atmosphere. Similarly, sunlight shining through a gap in the curtains of a dark room produces a beam of light which can be seen when the light reflects off the dust in the air of the room.

▲ **Figure 17.1** Although the Sun radiates light in all directions, the sides of sunbeams seem almost parallel because the Sun is a very distant luminous object.

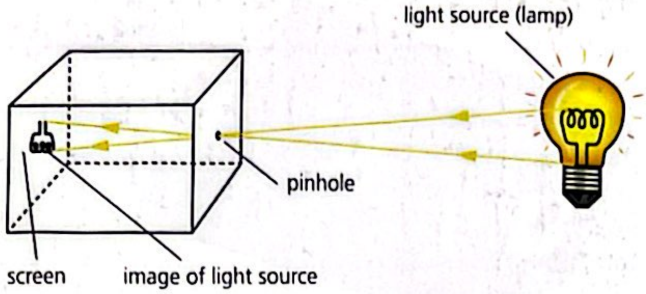
Smaller lines of light, called **rays**, can be made by shining a lamp through slits in a piece of card.



▲ **Figure 17.2** Making rays of light.

Light-rays can be further investigated by letting them pass though a circular hole and strike a screen behind the hole. The device used to investigate light-rays in this way is called the **pinhole camera**. The ray diagram in Figure 17.3 on the next page shows light-rays passing from a light source to the screen in the pinhole camera.

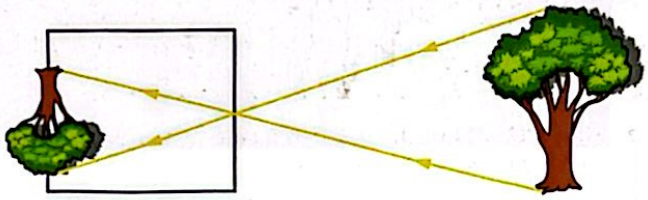
1 How is the image of the light source on the screen different from the real light source?



▲ **Figure 17.3**

Light-rays that are reflected from a **non-luminous object**, such as a tree, can also pass through the hole in a pinhole camera and form an image on the screen. The ray diagram in Figure 17.4 shows light-rays passing from a tree to the screen in the pinhole camera.

2 Where do you think the light-rays reflected from the tree originally came from?

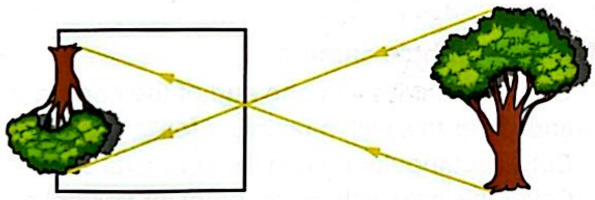


▲ **Figure 17.4**

If the pinhole camera is brought nearer to the tree, the light-rays from the tree travel as shown in Figure 17.5.

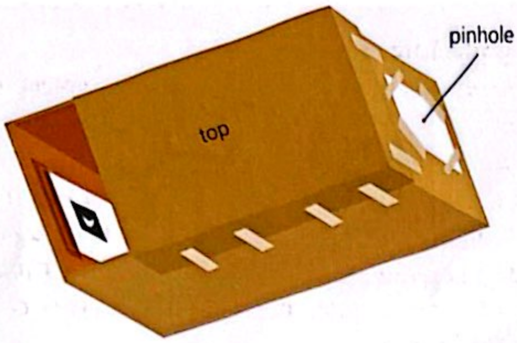
3 How does bringing the camera closer to the tree affect the image of the tree seen on the screen?

4 Draw a ray diagram of the pinhole camera further away from the tree than in Figure 17.5.



▲ **Figure 17.5**

Scientists sometimes make equipment to test the information they have read. Test the information you have just read by making a pinhole camera like the one shown in Figure 17.6 on the next page, and then undertaking the suggested investigations.



▲ **Figure 17.6** The parts of a pinhole camera.

Can you make and test a pinhole camera?

Work safely

You must never point the camera towards the Sun as it can permanently damage your eyes.

Take great care while using the needle.

You will need:

a cardboard box, aluminium foil, greaseproof or tracing paper, glue or sticky tape, a desk lamp or carbon filament lamp, a needle and a towel (optional).

Making a pinhole camera

1. Cut a circular hole in one end of the cardboard box, 15 mm in diameter, and cover this with aluminium foil (glued or taped to the box).
2. Cut a rectangular hole in the opposite side of the box, 50 mm × 80 mm. Cover this hole with greaseproof (or tracing) paper and glue it to the box.
3. Carefully use the needle to make a small hole in the centre of the foil.

Checking the performance of the pinhole camera

1. Set up a brightly lit object, such as a lamp.
2. Point the pinhole camera at the bright object, with the hole and foil pointing towards the object.
3. Look at the greaseproof paper screen for an image of the object.
4. If you cannot see an image, put the towel over the end of the box and hold it up with your hand to make it as dark as possible around the screen. The image should be visible now.

CHALLENGE YOURSELF

Create a PowerPoint presentation about making and using your pinhole camera. Compare it with other presentations and decide which provides the information most clearly.

Testing the information

1. Point your camera at the lamp and observe the image.
2. Point your camera at the tree and observe the image.
3. Move nearer to the tree and observe again.
4. Move further away from the tree and observe again, then move closer and further away and observe again each time.
5. Your observations should confirm the information you have read. If they do not, suggest improvements to your camera and technique that you could make.

CHALLENGE YOURSELF

When scientists make a piece of equipment, they may think of other investigations they could make with it. Here are two you might like to try.

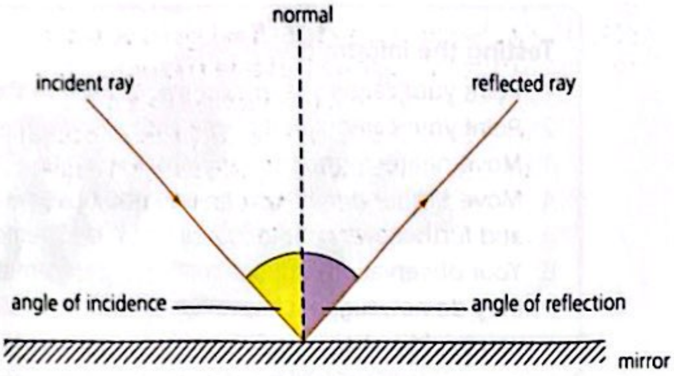
1. How does the size of the hole affect the image on the screen of the pinhole camera? Note that you may have to replace the foil at the front of your camera before you try the next investigation.
2. Do many small holes make many images on the screen?

Reflection of light

A few terms are used in the study of light which make it easier for scientists to describe their investigations and ideas. In the study of **reflections**, the following terms are used:

- **Incident ray** – a light-ray that strikes a surface.
- **Reflected ray** – a light-ray that is reflected from a surface.
- **Normal** – a line that is at right angles (that is at 90°) to the surface that the incident ray strikes.
- **Angle of incidence** – the angle between the incident ray and the normal.
- **Angle of reflection** – the angle between the reflected ray and the normal.
- **Plane mirror** – a mirror with a flat surface.
- **Image** – the appearance of an object in a smooth, shiny surface. It is produced by light from the object being reflected by the surface.

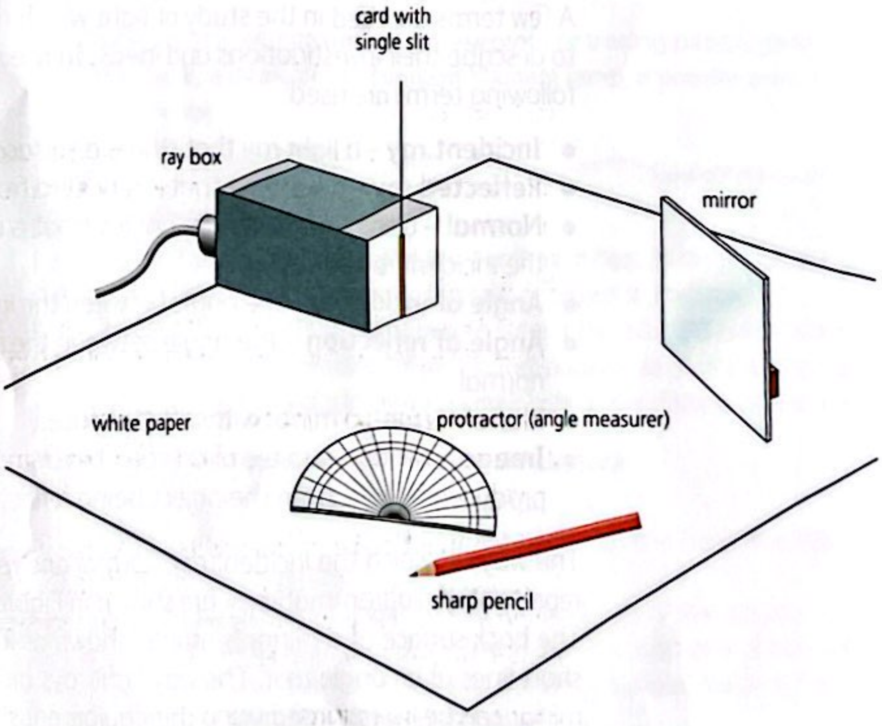
The ways in which the incident ray, normal and reflected ray are represented diagrammatically are shown in Figure 17.7 on the next page. The back surface of a mirror is usually shown as it is here, as a line with short lines at an angle to it. The way light-rays are reflected from a plane mirror can be investigated using the equipment shown in Figure 17.8 on the next page.



▲ **Figure 17.7** The reflection of light from a plane mirror.

The law of reflection

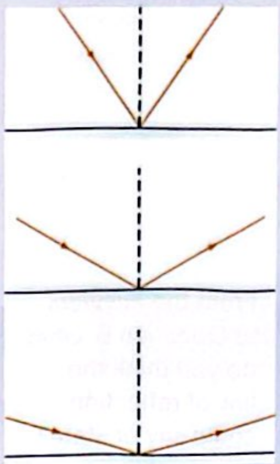
When scientists make a large number of experiments and observations on a particular topic, they may find that there is a trend or a pattern. If they do find a trend, they make a statement about the relationship, which is called a **law**. The angle between the incident ray and the normal is the same as the angle between the reflected ray and the normal. See if you can find a trend or pattern that leads to a law of reflection, by trying the following enquiry, which uses the equipment shown in Figure 17.8.



▲ **Figure 17.8** Equipment to investigate reflection from a plane mirror.

Scientists use patterns to guide them in order to create laws of science. In order to establish a law, they have to collect many examples.

5 Figure 17.9 shows three drawings made of the paths of incident and reflected rays in an experiment using the equipment shown in Figure 17.8. Use a protractor (angle measurer) to measure the angles of incidence and angles of reflection. What do these drawings tell you about the process of reflection?



▲ Figure 17.9

Can you confirm the law of reflection?

You will need:

a ray box, a mirror, a protractor (angle measurer) and a piece of white paper.

Hypothesis

The law of reflection states that the angle between the incident ray and the normal is the same as the angle between the reflected ray and the normal.

Prediction

If the law is correct then when any ray of light is shone onto a mirror its angle of incidence and angle of reflection will be the same.

Plan, investigation and recording data

If a law of reflection can be established, the data from many experiments must be collected.

Plan an investigation to collect data that might support a law of reflection. In your plan, set out what you will do with the equipment you have been given and the table you will set up in which to record your results. If your teacher approves your plan, try it.

Examining the results

Compare the angles of reflection at different angles of incidence and look for a pattern in the data.

6 From the answers to Question 5, what do you think the law of reflection could say or state?

How can you tell if there are one or more anomalous results? If you find any in your data, identify them by marking them with an A.

Compare your data with the information you gathered in your answer to question 5.

Conclusion

From your evaluation, state the law of reflection you think you have discovered.

Is your conclusion limited in some way? Explain your answer.

What improvements could be made? Explain the changes that you suggest.

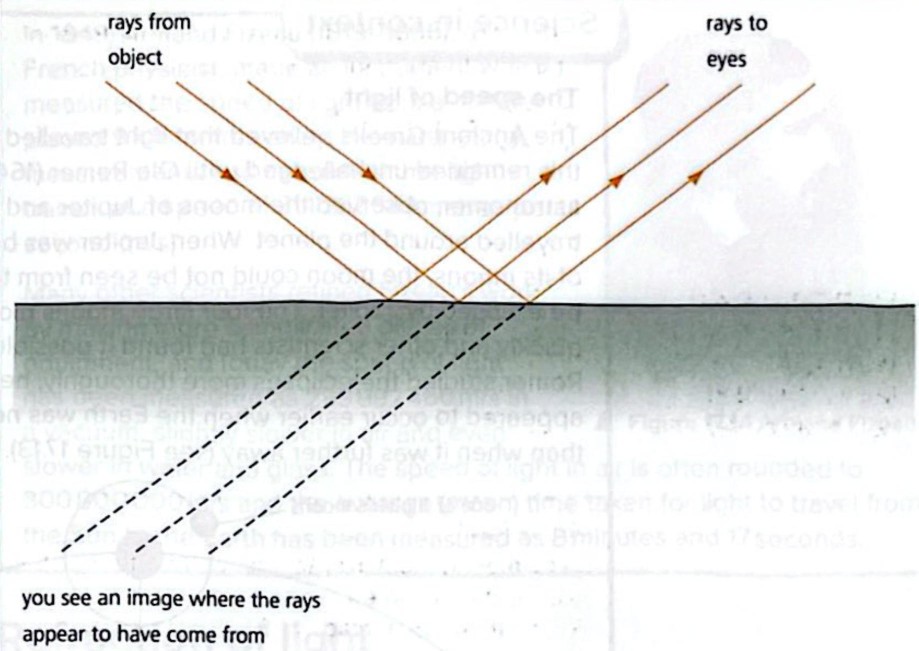
LET'S TALK

If you moved the mirror to a different angle on the paper and investigated the relationship between the angle of incidence and the angle of reflection, what do you think you would find? Would it support a law of reflection? Explain your answer. If you as a group think another investigation is required to answer the question, plan it and, if your teacher approves, try it. What do you find?

Science extra: Objects with smooth and rough surfaces

Glass, still water and polished metal have very smooth surfaces. Light-rays striking their flat surfaces are reflected, as shown in Figure 17.10. Their angle of reflection is equal to their angle of incidence. When the reflected light reaches your eyes, you see an image (see Figure 17.11).

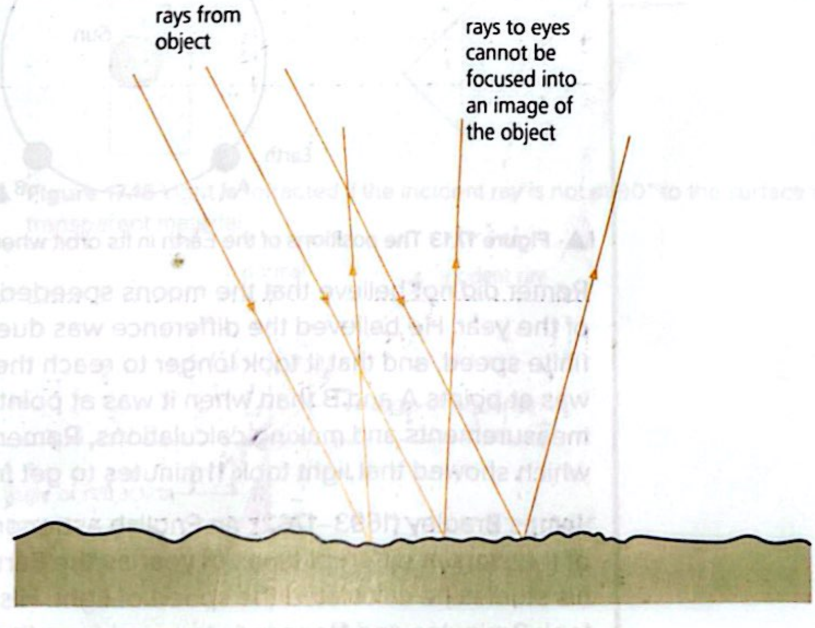
▲ **Figure 17.10** Light reflected from the smooth surface of a lake can produce an image in the water.



▲ **Figure 17.11** Regular reflection from a smooth surface.

Most objects have rough surfaces. They may be very rough, like the surface of a woollen jumper, or they may be only slightly rough, like the surface of paper. When light-rays strike any of these surfaces, the rays are scattered in different directions (see Figure 17.12).

You see a jumper, or this page of your book, by the light scattered from its surface. You do not see your face in a piece of paper, because the reflection of light is irregular, so it does not form an image.

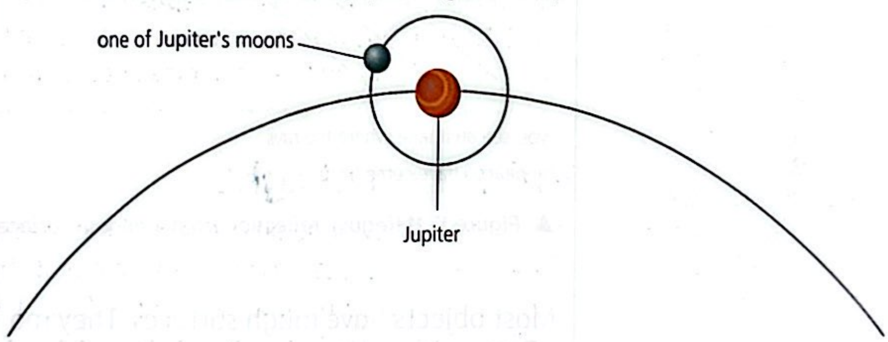


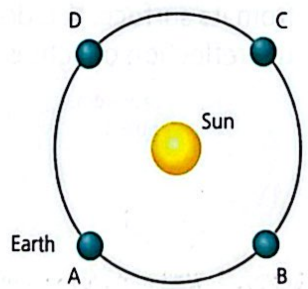
▲ **Figure 17.12** Light-rays are scattered by a rough surface.

Science in context

The speed of light

The Ancient Greeks believed that light travelled at infinite speed, and this remained unchallenged until Ole Rømer (1644–1710), a Danish astronomer, observed the moons of Jupiter and studied how they travelled around the planet. When Jupiter was between the Earth and one of its moons, the moon could not be seen from the Earth and was said to be eclipsed by Jupiter. The four large moons move around Jupiter quite quickly and other scientists had found it possible to time them. When Rømer studied the eclipses more thoroughly, he discovered that they appeared to occur earlier when the Earth was nearer Jupiter in its orbit than when it was further away (see Figure 17.13).





▲ **Figure 17.13** The positions of the Earth in its orbit when Rømer made his observations.

Rømer did not believe that the moons speeded up at different times of the year. He believed the difference was due to light having a finite speed, and that it took longer to reach the Earth when the Earth was at points A and B than when it was at points C and D. By taking measurements and making calculations, Rømer deduced a **speed of light** which showed that light took 11 minutes to get from the Sun to the Earth.

James Bradley (1693–1762), an English astronomer, studied the position of the stars at different times of year as the Earth moved in its orbit. From his studies he calculated the speed of light. His results showed that light took 8 minutes and 11 seconds to travel from the Sun to the Earth.

7 What evidence about the speed of light had Rømer to work with when making his studies?

8 What two pieces of evidence about Jupiter's moons did Rømer use to plan his investigation?

9 What did Rømer's measurements show?

10 What creative thought did Rømer have to explain his measurements?

11 How accurate was Bradley's calculation of the time it takes light to reach the Earth from the Sun? Explain your answer.

12 How accurate was Fizeau's value for the speed of light compared to the current-day value? Explain your answer.

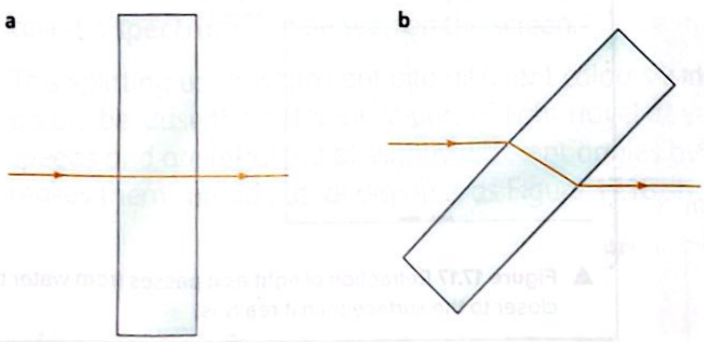
In 1849, Armand Fizeau (1819–1896), a French physicist, made an instrument which measured the speed of light from a candle placed 9 kilometres away. He made many measurements and calculated that light travels at a speed of 314 262 944 metres per second (m/s).

▲ **Figure 17.14** Armand Fizeau.

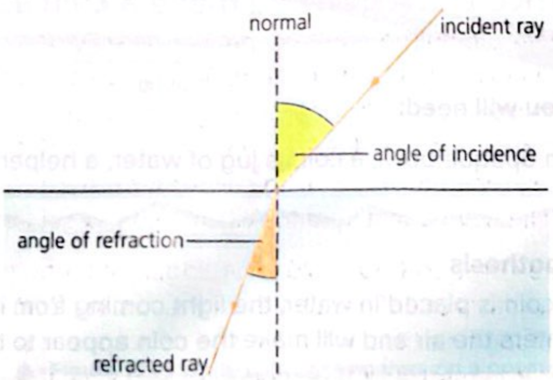
Many other scientists refined Fizeau's work by making more complicated pieces of equipment, and today the speed of light has been measured as 299 992 460 m/s in a vacuum, slightly slower in air and even slower in water and glass. The speed of light in air is often rounded to 300 000 000 m/s and the average (mean) time taken for light to travel from the Sun to the Earth has been measured as 8 minutes and 17 seconds.

Refraction of light

If a ray of light is shone on the side of a glass block, as shown in Figure 17.15a, the ray passes straight through but, if the block is tilted, the ray of light follows the path shown in Figure 17.15b. This 'bending' of the light-ray is called **refraction**. The angle that the refracted ray makes with the normal is called the angle of refraction (see Figure 17.16).



▲ **Figure 17.15** Light is refracted if the incident ray is not at 90° to the surface of the transparent material.



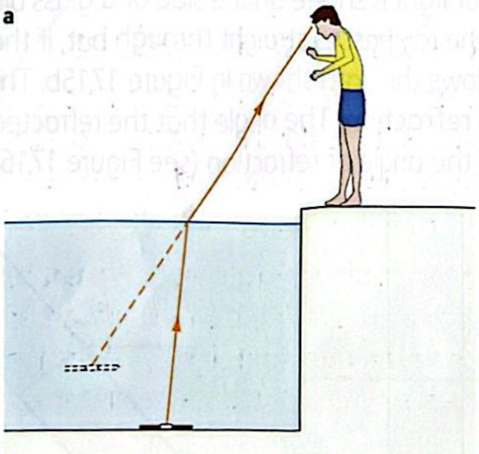
▲ **Figure 17.16** The angle of incidence and the angle of refraction.

The refraction of light as it passes from one transparent substance or 'medium' to another is due to the change in the speed of the light. Light travels at different speeds in different media. For example, it travels at almost 300 million m/s in air but only 200 million m/s in glass. If the light slows down when it moves from one medium to the other, the ray bends towards the normal. If the light speeds up as it passes from one medium to the next, the ray bends away from the normal.

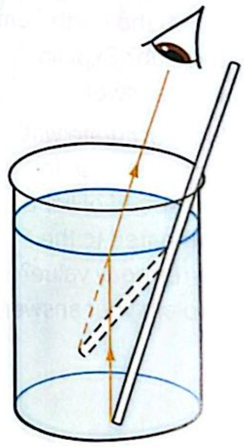
Science extra: Tricks of light

Light speeds up as it leaves the water's surface and enters the air. A light-ray appears to have come from a different direction than that of the path it actually travelled (see Figure 17.17). The refraction of the light-rays makes the bottom of a swimming pool seem closer to the water's surface than it really is. It also makes streams and rivers seem shallower than they really are, and this fact must be considered by anyone thinking of wading across a seemingly shallow stretch of water. The refracted light from a straw in a glass of water makes the straw appear to be bent.

a



b



▲ **Figure 17.17** Refraction of light as it passes from water to air makes an object appear closer to the surface than it really is.

13 How is the reflection of a light-ray from a plane mirror (see pages 193–5) different from the refraction of a light-ray as it enters a piece of glass?

Science extra: Can you make a coin appear?

You will need:

an opaque bowl, a coin, a jug of water, a helper and a camera.

Hypothesis

If a coin is placed in water, the light coming from it will be refracted when it enters the air and will make the coin appear to be in a different place.

LET'S TALK

Identify the light source you are using for seeing things around you. Choose an object in the room. Describe the changes that take place in the light from when it leaves the source until it reaches your eyes, from the object. Is it refracted through glass? Is it partially reflected from any surface? Which colours have been absorbed by the object?

Prediction

Use your knowledge and understanding of refraction to predict how your view of the coin may change.

Investigation and recording data

1 Put the bowl on a table and set up a coin in its centre.
2 Step back from the bowl until the coin disappears under the rim of the bowl.
3 Start filming and focus on the rim of the bowl and the inside of the bowl where the water will be placed.
4 Ask a helper to slowly and carefully fill up the bowl with water.
5 Keep filming and look for the coin to appear. If and when it does, stop filming.

Examining the results

Play back the film and let others see it.

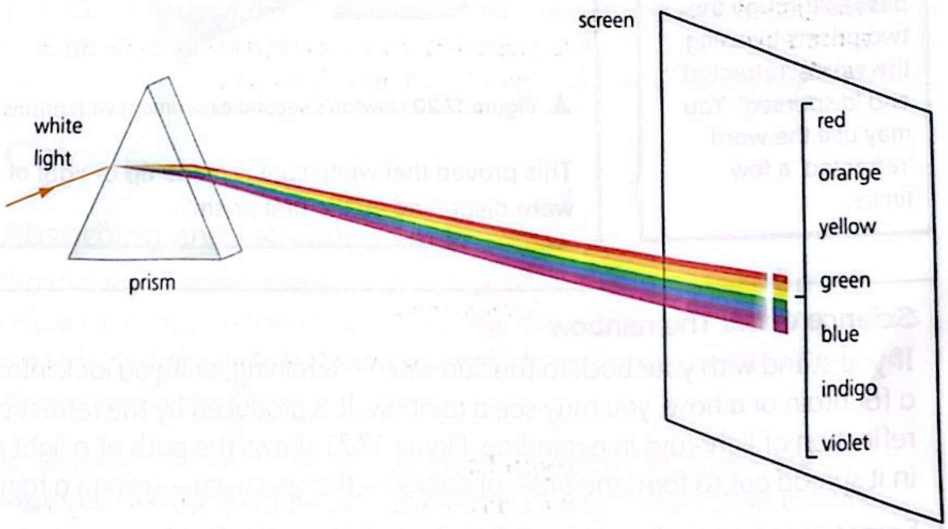
Conclusion

Use your knowledge of refraction to explain your observations and your film.

White light and the prism

A triangular **prism** is a glass or plastic block with a triangular cross-section. When a ray of sunlight is shone through a prism at certain angles of incidence, and its path is stopped by a white screen, a range of colours, called a **spectrum**, can be seen on the screen.

This splitting up of white light into different colours is called **dispersion**. It occurs because the different colours of light travel at very slightly different speeds and are refracted at slightly different angles by the prism. This makes them spread out, or disperse, as Figure 17.18 shows.



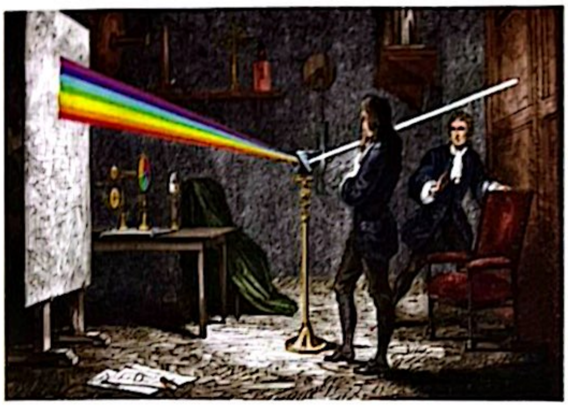
▲ **Figure 17.18** White light passing through a prism is split up into its constituent colours, forming a spectrum.

14 What happens to white light when it passes through a prism?

Science in context

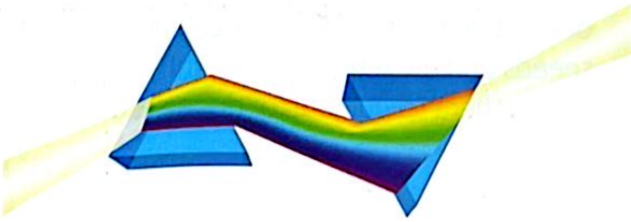
Newton's investigations with prisms

Isaac Newton (1642–1727) was an English scientist who made many scientific investigations. His investigation of light began when he bought a prism at a fair. He put it in a dark room and shone sunlight onto it from a hole in a window shutter. The light entered the prism and dispersed to form a spectrum of colours on a screen, as Figure 17.19 shows.



▲ **Figure 17.19** Newton dispersing light with a glass prism.

Newton thought that it was possible that the prism could have produced the colours just by the light shining through it. To check this idea, he got a second prism and set it up behind the first, but the opposite way round. When the rays of the separate colours of light passed through the second prism, they formed a beam of white light, as Figure 17.20 shows.



▲ **Figure 17.20** Newton's second experiment with prisms.

This proved that white light is made up of light of different colours that were dispersed by the first prism.

CHALLENGE YOURSELF

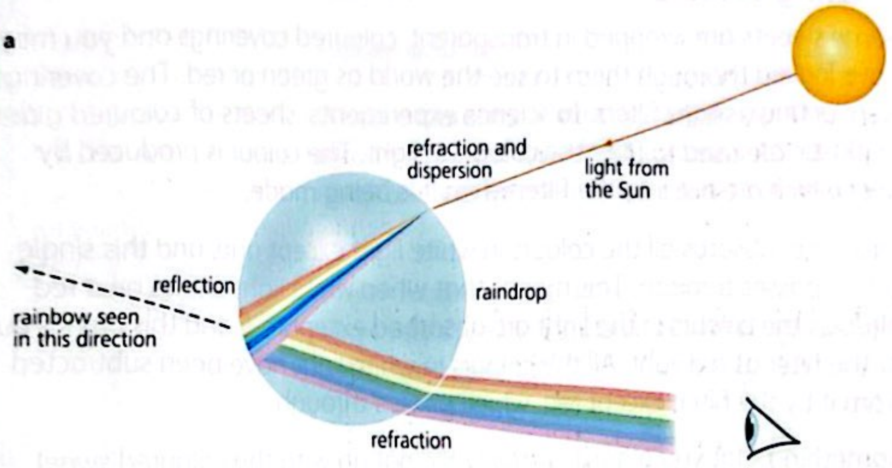
Explain how the light passed through the two prisms by using the words 'refracted' and 'dispersed'. You may use the word 'refracted' a few times.

Science extra: The rainbow

If you stand with your back to the Sun when it is raining, or if you look into a spray of water from a fountain or a hose, you may see a rainbow. It is produced by the refraction, dispersion and reflection of light-rays in a raindrop. Figure 17.21 shows the path of a light-ray and how the colours in it spread out to form the order of colours – the spectrum – seen in a rainbow.

Sometimes a second, weaker rainbow is seen above the first because two reflections occur in each droplet. In the second rainbow, the order of colours is reversed.

a



b

▲ **Figure 17.21a** The formation of a rainbow; **b** a double rainbow in the sky.

Science extra: Modelling a raindrop in a rainbow

You will need:

a transparent glass full of water, a source of white light (for example, a flashlight), a piece of white card and a dark room.

Process

1. Set up the glass of water on the card in a darkened room and shine the flashlight on it.
2. Move the flashlight around until you see a spectrum form on the card. You may have to look hard to see it.
3. Comment on your model by identifying the analogy, and assess how good you were at modelling a raindrop.

Colour

15 Name some everyday objects which:

a reflect all the colours in sunlight

b absorb all the colours in sunlight.

Absorbing and reflecting colours

When a ray of sunlight strikes the surface of an object, all the different colours in it may be reflected, or they may all be absorbed. If all the colours are reflected, the object appears white; if all the colours are absorbed, the object appears black.

Most objects, however, absorb some colours and reflect others. For example, healthy grass reflects mainly green and absorbs other colours.

16 What happens to white light when it is shone on a
a blue filter
b green filter?

Filtering colours

Some sweets are wrapped in transparent, coloured coverings and you may have looked thorough them to see the world as green or red. The coverings were acting as light filters. In science experiments, sheets of coloured glass or plastic are used to filter the colours in light. The colour is produced by dyes which are put into the filter when it is being made.

Each filter absorbs all the colours in white light except one, and this single colour passes through. This means that when white light shines on a red filter, all the colours in the light are absorbed except red, and this passes out of the filter as red light. All the colours in white light have been subtracted from it by the filter, except red, which passes through.

Something that you almost certainly did not do with the coloured sweet wrappers was to shine a light through them. The following investigation allows you to shine lights through coloured filters and see what happens when the different colours meet and mix.

What happens when red, blue and green light mix?

You will need:

three colour filters (red, blue and green), three flashlights and a piece of white card.

Plan, investigation and recording data

Construct a plan by answering these questions.

1 How will you make beams of coloured light using the filters and flashlights?
2 When you are shining the light beams on the white card, how will you make your test fair?
3 You should begin by shining two beams onto the card at once.
4 If you find that a new colour has formed, describe it. The following words may be helpful: pink, light blue, yellow.
5 What happens when you shine all three beams onto the white card? You may need someone to hold a flashlight for you when you do this.
6 How will you record your observations in step 5?

Examining the results

Look at the colours produced when the three colours of light are shone together onto the white card.

Conclusion

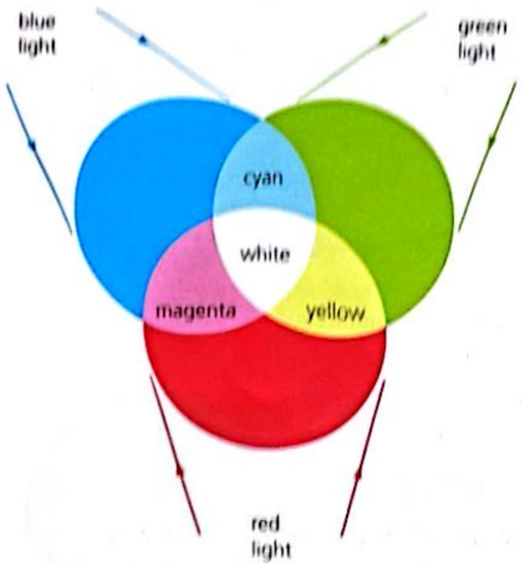
Draw conclusions from your observations.

Addition and subtraction of coloured light

Colour addition

When different coloured lights are combined, it is found that all the colours can be made from different combinations of just three colours. They are red, green and blue and they are called the primary colours of light.

When beams of the three primary colours are shone onto a white screen so that they overlap, they produce three **secondary colours** of light and white light (see Figure 17.22).



▲ **Figure 17.22** Overlapping beams of the primary colours form the secondary colours.

When light is brought together like this, the wavelengths of red, blue and green light come together to produce the colours you see in Figure 17.22, and when all three colours are added together, white light is produced. This combining of the three colours of light is called colour **addition** and the mixing of light is called **additive colour mixing**.

17 The colours on a television or computer screen are made by three different colours of substances called **phosphors**. They glow to release their colour of light.

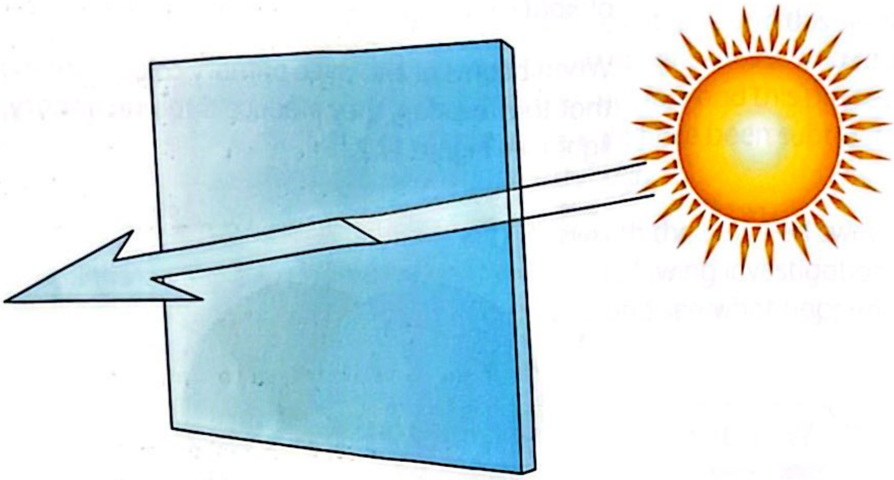
What do you think the colours of the phosphors are? Explain your answer.

18 Look at Figure 17.22. Which primary colours overlap to produce:

a yellow
b magenta
c cyan
d white light?

Colour subtraction

When white light passes through a blue filter, all the colours in the white light are absorbed, except blue light, which passes through the filter. All the colours in white light have been **subtracted** from the light, leaving the filter. This results in blue light passing through the filter and making the filter appear blue as Figure 17.23 shows.



▲ **Figure 17.23** Colour subtraction.

▲ **Figure 17.23** Glasses with blue-tinted lenses reduce the amount of blue light that enters your eyes, which can help to reduce eye strain.

Summary

- ✔ We can use the incident ray, normal and reflected ray to show the reflection of light on a plane surface.
- ✔ The law of reflection states that the angle of incidence and angle of reflection are the same.
- ✔ Science in context: The speed of light is rounded to 300 000 000 m/s.
- ✔ Light refracts at the boundary between air and glass or air and water.
- ✔ White light is made of many colours and this can be shown through the dispersion of white light by using a prism.
- ✔ Isaac Newton's investigations with prisms confirmed that white light was made up of light of different colours.
- ✔ Colours of light can be added, subtracted, absorbed and reflected.

End of chapter questions

1. What happens when a ray of light is reflected from a smooth flat surface?
2. What does the law of reflection say?
3. If a light-ray has an angle of incidence of 35°, what is its angle of reflection?
4. How do you measure an angle of incidence?
5. How does the path of a light-ray change when it moves from one transparent material to another?
6. What is the refraction of light and where does it occur?
7. Why is the speed of light important when light is refracted by a prism?
8. Explain what happens when white light is shone on a green filter.
9. What happens when a beam of red light is mixed with a beam of blue light?