15 Light

- Light rays
- Classifying non-luminous objects
- Shadows
- Reflecting light
- Passing light through transparent materials
- The prism
- The rainbow
- Colour

Light is a form of **energy**. It is a form of **electromagnetic radiation**. Objects that emit light are said to be **luminous** while those that do not emit light are said to be **non-luminous**. Non-luminous objects can only be seen if they are reflecting light from a luminous source. The Moon is a non-luminous body – the 'moonlight' it produces is reflected sunlight. Most luminous objects, such as the Sun, stars, fire and candle flames, release light together with a large amount of heat.

1 What is the luminous object which is providing light for you to read this book?

Figure 15.1 A bonfire is luminous: it radiates light and heat.

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 15.2). The path of the light can be seen because some of it is reflected from 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 from the dust in the air of the room.

Figure 15.2 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.

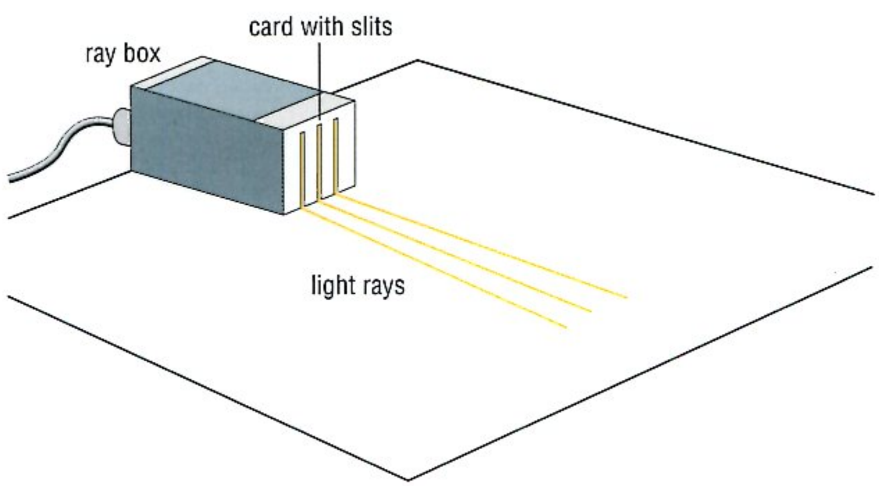


Figure 15.3 Making rays of light

What is light?

Empedocles (about 490–430 BCE) was a Greek philosopher who believed that we see things because our eyes send out rays which touch objects. Plato (427–347 BCE) built on this idea but believed that objects gave out rays which the eyes' rays intercepted. Democritus (about 470–380 BCE) believed that objects were made of atoms, some of which passed from the objects through the air to the eye and allowed us to see the objects.

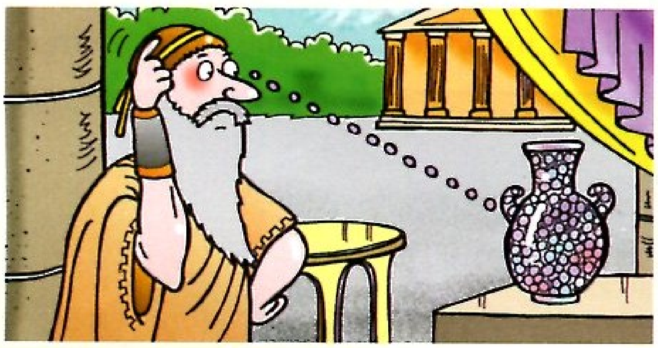


Figure A Democritus thought that sight involved moving atoms.

1. How do you think Empedocles came up with his idea through creative thinking?
2. Which part of Empedocles' idea did Plato use to develop his explanation?
3. What idea did Democritus produce through his creative thinking that built on the ideas of the other philosophers?
4. Which piece of scientific knowledge did Young use to explain his results?
5. Which piece of scientific knowledge do you think von Lenard used to come to his conclusion?

Figure B Did light travel like waves in a puddle?

Christian Huygens (1629–1695), a Dutch physicist, put forward a wave theory of light in which he claimed that light moved in a similar way to waves of water. He thought the waves were very small and for most experiments they did not affect the light rays which could be considered as travelling in straight lines.

In 1801 Thomas Young (1773–1829), an English physicist, performed an experiment in which he shone a light through narrow, close slits as shown in Figure C. The result could not be explained if light travelled as particles such as atoms but could be explained by the wave theory. Young believed that the regions where the light was brightest were where the crests of the light waves met together and the regions of darkness were where the troughs of the waves cancelled out the crests (see Figure D).

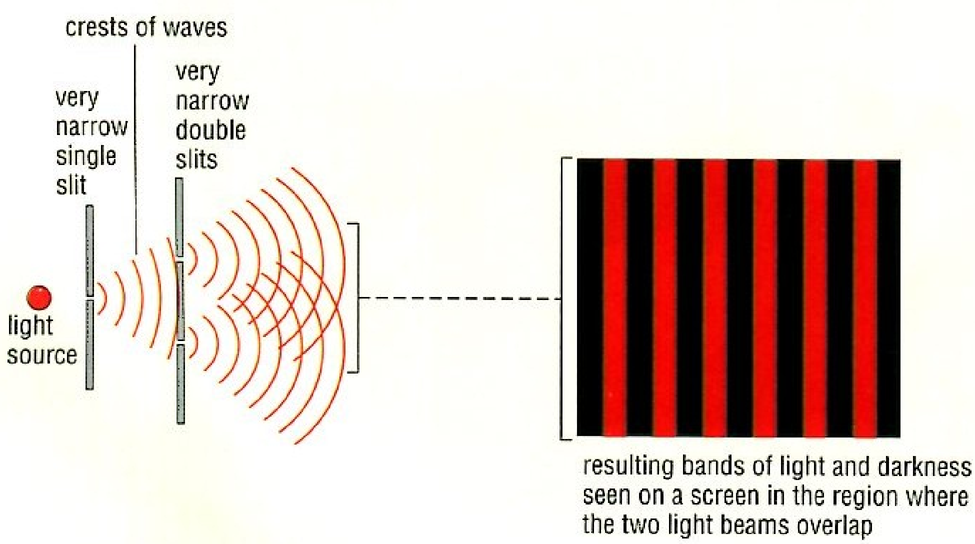


Figure C Young's experiment

Philip von Lenard (1862–1947), a Hungarian physicist, discovered that when light is shone onto certain metals, tiny electrically-charged particles called electrons are released from the metal surface. He found that a bright light released a greater number of electrons than a dim light. This suggested to him that light was made from 'particles of energy' which moved the electrons.

Further investigations into the nature of light reveal that it can be considered either to be waves or particles. The form that you consider it to be depends on the work that you are doing with light. For example, if the way light passes through transparent objects is being studied, the light can be considered to be formed of waves. But if the way in which light makes the solar cells on a calculator generate electricity is being studied, the light can be considered to be made of 'particles' of energy which scientists now call photons.

You may have trouble thinking that light can be considered in two different ways. It may help this problem if you think about how we consider people in different ways. The way you behave when with an older person, such as a parent, is different to the way you behave with people of your own age. Both older and younger people see you in different ways. Possibly none of them see the 'real' you!

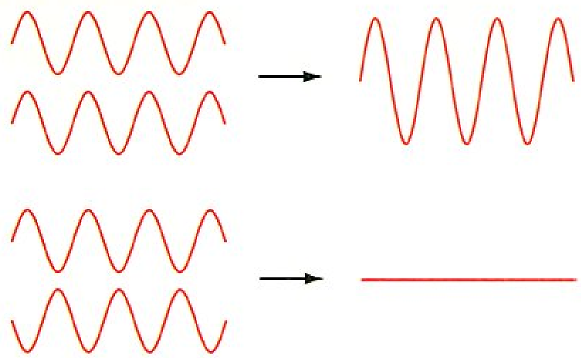


Figure D How the crests and troughs combine

Figure E These cars are powered by photons which strike the solar cells on their surface.

Classifying non-luminous objects

Non-luminous materials can be classified as **transparent**, **translucent** or **opaque** according to the way light behaves when it meets them. When light shines on a transparent material, such as glass in a window, it passes through it and so objects on the other side of it can be seen clearly.

When light shines on a translucent object, such as tracing paper, some of the light passes through but many light rays are scattered. Objects on the other side cannot be seen clearly unless they are very close to the translucent object.

When light shines on an opaque object none of the light passes through it.

Shadows

When a beam of light shines on an opaque object the light rays which reach the object are stopped while those rays which pass by the edges continue on their path. A region without light, called a **shadow**, forms behind the object. The shape of the shadow may not be identical to the shape of the object because the shadow's shape depends on the position of the light source and on where the shadow falls.

The size and intensity of the shadow depends on the size of the light source and the distance between the light source and the object. A small light source gives a sharp shadow that is equally dark all over. A larger light source gives a shadow with a dark central region and a lighter shadow surrounding it.

Shadows can be formed by the Moon and the Earth.

For discussion

How might the shadow of a brick appear if light travelled in a curve from the light source?

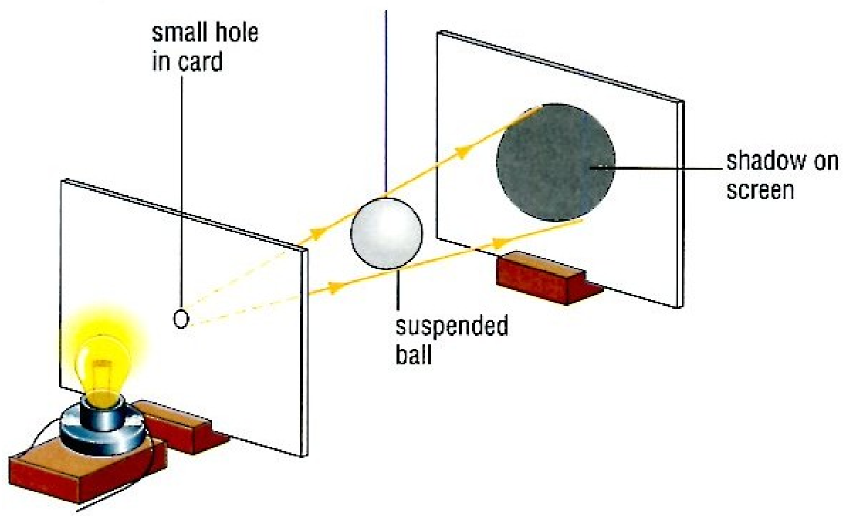


Figure 15.4 The formation of a shadow by a small light source

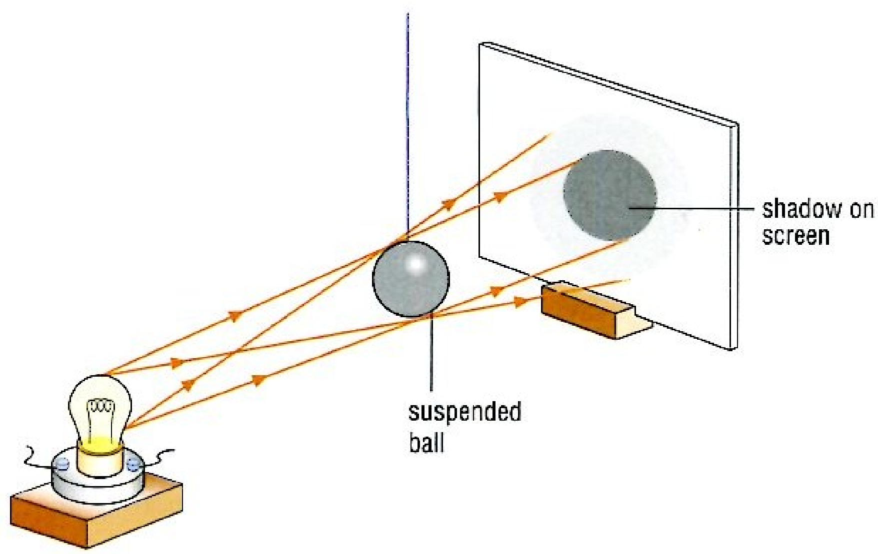


Figure 15.5 The formation of a shadow by a large light source

If the light source is close to the object it makes a bigger shadow than if it is further away.

Reflecting light

Your bedroom is probably full of objects but if you wake in the middle of the night you cannot see them clearly because they are not luminous. You can only see them by reflected light and, unless your room is partially lit by street lights or other lights, the objects will not be clearly seen until sunrise. The way light is reflected from a surface depends on whether the surface is smooth or rough.

Studying reflections

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 perpendicular (that is at 90°) to the surface where 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 15.6. The back surface of a mirror is usually shown as here, as a line with short lines at an angle to it.

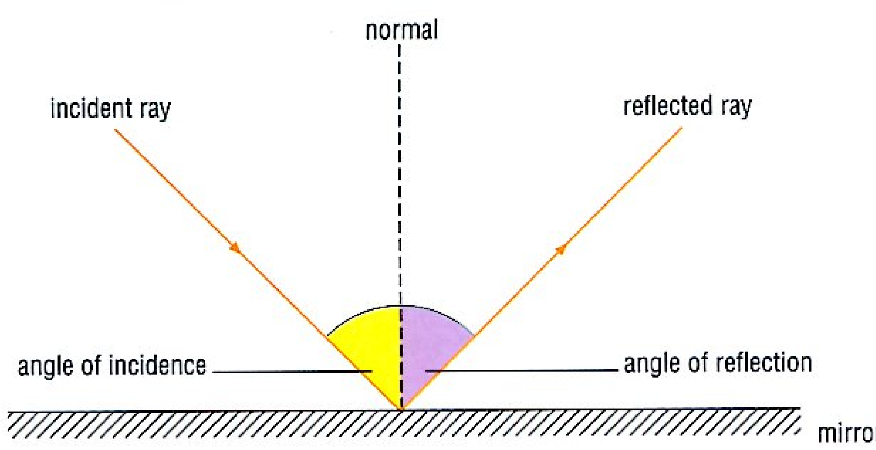


Figure 15.6 The reflection of light from a plane mirror

2 Figure 15.8 shows three drawings made of the paths of incident and reflected rays in an experiment using the apparatus in Figure 15.7. Use a protractor to measure the angles of incidence and angles of reflection. What do these drawings tell you about the process of reflection?

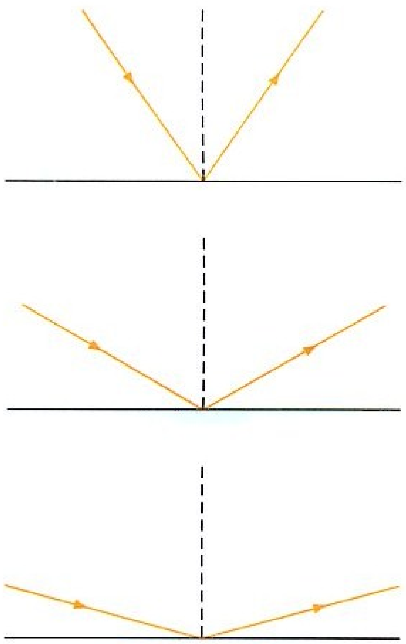


Figure 15.8

The way light rays are reflected from a plane mirror can be investigated using the apparatus shown in Figure 15.7.

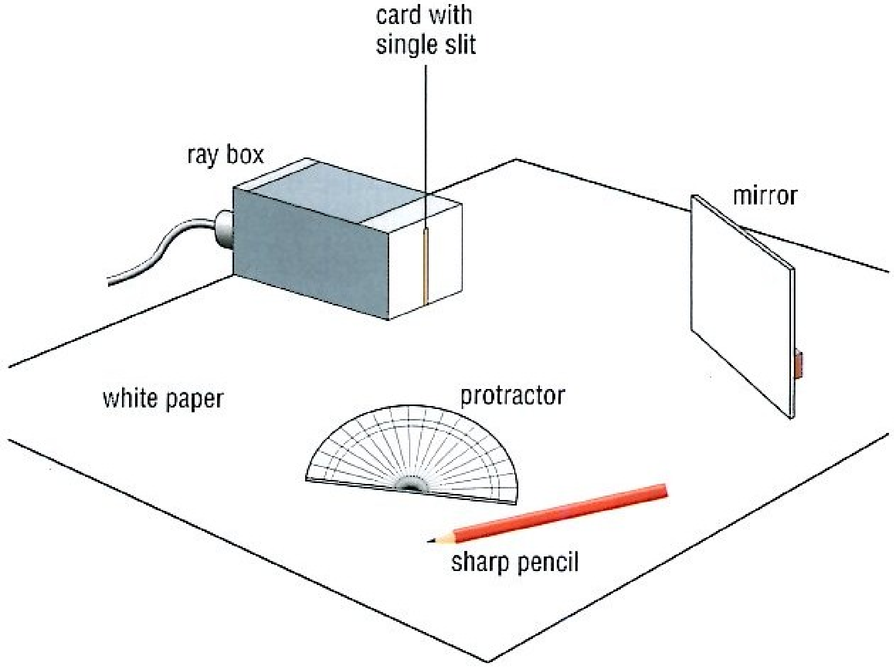


Figure 15.7 Apparatus to investigate reflection from a plane mirror

Objects with smooth surfaces

Glass, still water and polished metal have very smooth surfaces. Light rays striking their flat surfaces are reflected as shown in Figure 15.9. The angle of reflection is equal to the angle of incidence. When the reflected light reaches your eyes you see an image (see Figure 15.10).

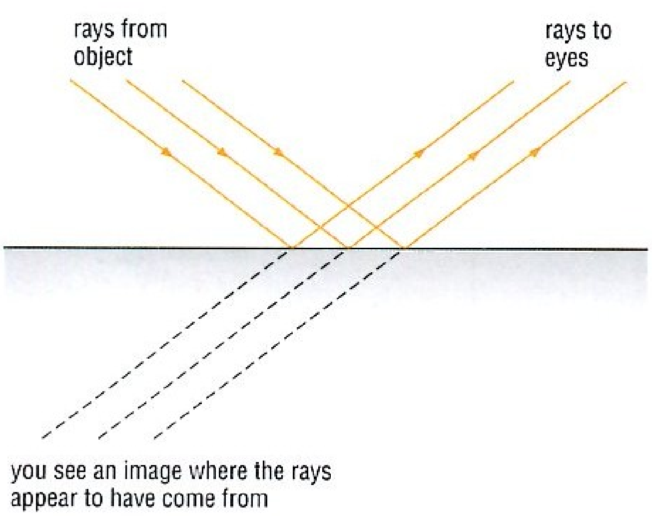


Figure 15.9 Regular reflection from a smooth surface

Figure 15.10 Light reflected from the smooth surface of a lake can produce an image in the water.

Two types of images

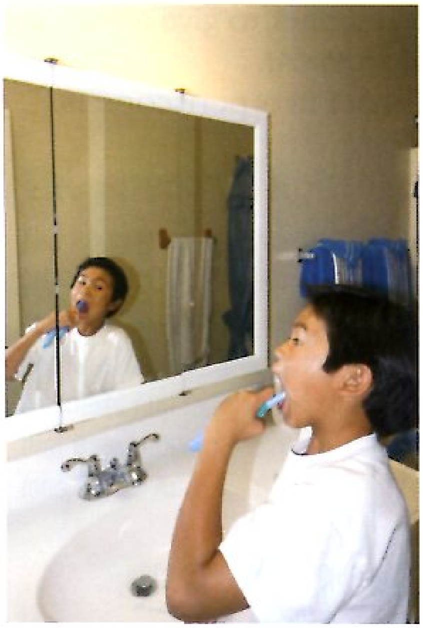


Figure 15.11 Your image in a mirror is the wrong way round.

There are two types of images that can be formed with light. They are real images, such as those produced on a cinema screen by biconvex lenses, and virtual images, which cannot be projected onto a surface but only appear to exist, such as those in a plane mirror or other smooth, shiny surface.

The virtual image of yourself that you see when you look in a plane mirror is the same way up as you are, is the same size as you are, and is at the same distance from the mirror's surface as you are but behind the mirror instead of in front of it.

The main difference between you and your virtual image is that the virtual image is the 'wrong way round' – for example, your left shoulder appears to be the right shoulder of your virtual image.

Figure 15.12 Some of the people in this scene are using periscopes to help them see over the crowd.

3 Copy Figure 15.13 and draw in the path of a ray of light travelling from the golfer to the eye.

4 Why is a periscope useful on a submarine?

The periscope

Two plane mirrors may be used together to give a person at the back of a crowd a view of an event.

The arrangement of the mirrors in a periscope is shown in Figure 15.13.

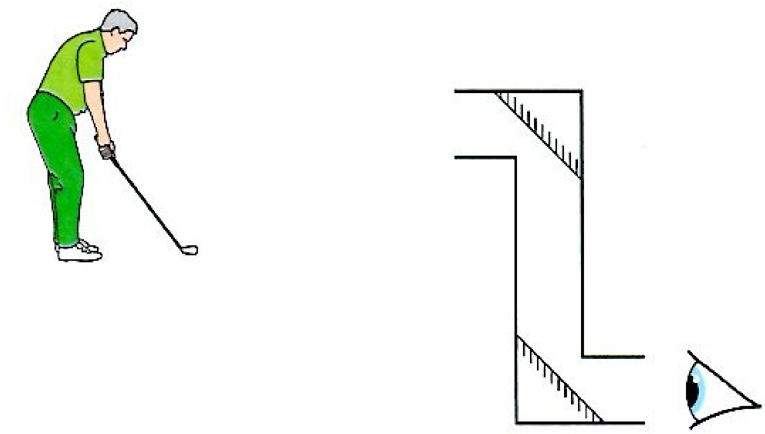


Figure 15.13 A simple periscope

Objects with rough surfaces

Most objects have rough surfaces. They may be very rough like the surface of a woollen pullover 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 15.14).

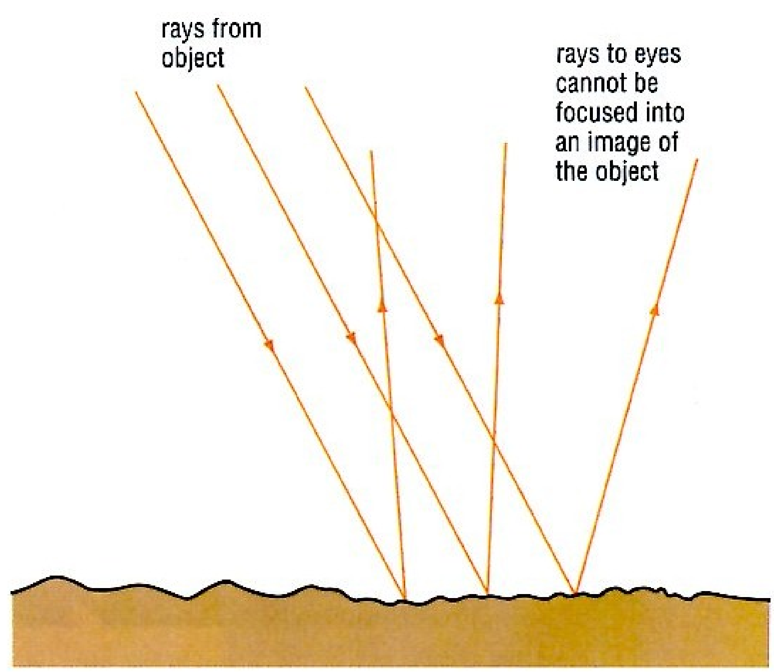
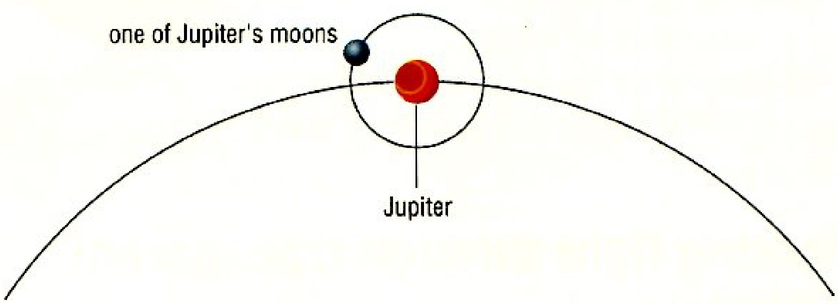


Figure 15.14 Light rays are scattered by a rough surface

You see a pullover or this page 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 does not form an image.

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 A).



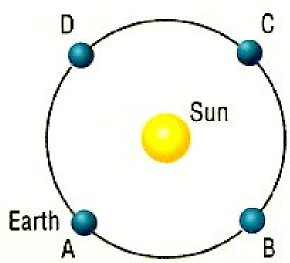


Figure F The positions of the Earth in its orbit when Rømer made his observations

Rømer did not believe that the moons speeded up at different times of 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 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 11 seconds to travel from the Sun to the Earth.

In 1849 Armand Fizeau (1819–1876), 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.

Many other scientists refined Fizeau's work by making more complicated pieces of apparatus and today the speed of light has been measured as 299 992 460 metres per second 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 metres per second and the average time taken for light to travel from the Sun to the Earth has been measured as 8 minutes and 17 seconds.

Figure G Armand Fizeau

6 What evidence about the speed of light had Rømer to work with when making his studies?
7 What two pieces of evidence about Jupiter's moons did Rømer use to plan his investigation?
8 What did Rømer's measurements show?
9 What creative thought did Rømer have to explain his measurements?
10 How accurate was Bradley's calculation of the time it takes light to reach the Earth from the Sun? Explain your answer.
11 How accurate was Fizeau's value for the speed of light compared to the current-day value? Explain your answer.

Passing light through transparent materials

If a ray of light is shone on the side of a glass block as shown in Figure 15.15a the ray passes straight through but, if the block is tilted, the ray of light follows the path shown in Figure 15.15b.

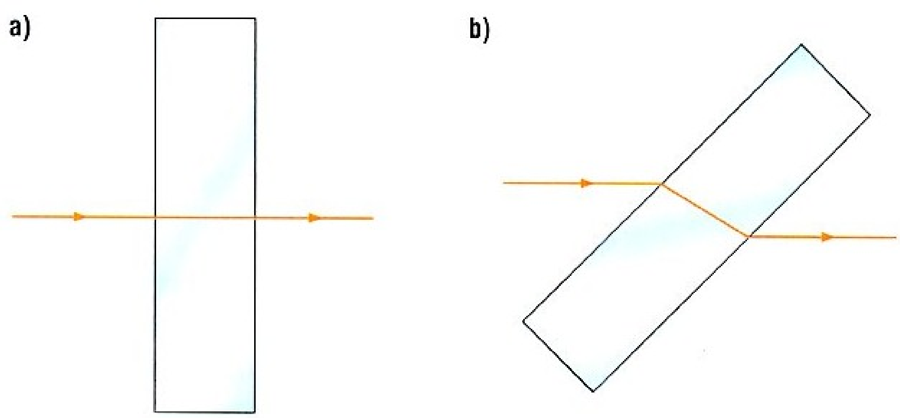


Figure 15.15 Light is refracted if the incident ray is not at 90° to the surface of the transparent material.

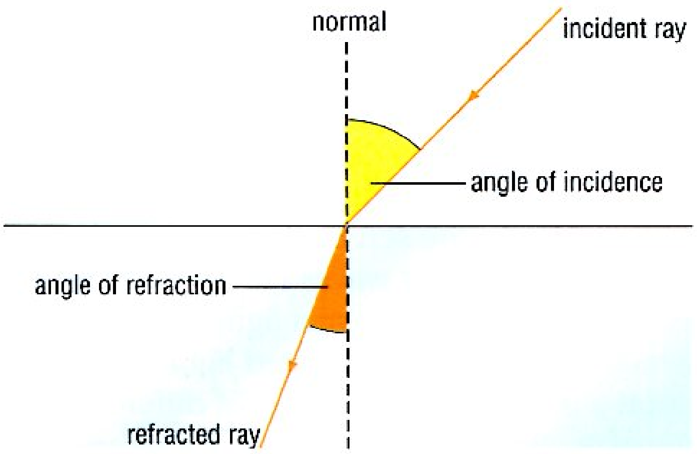


Figure 15.16 The angle of incidence and the angle of refraction

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 15.16).

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 metres per second in air but only 200 million metres per second 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.

5 How is the reflection of a light ray from a plane mirror (see page 179) different from the refraction of a light ray as it enters a piece of glass?

Light speeds up as it leaves a water 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 15.17). The refraction of the light rays makes the bottom of a swimming pool seem closer to the water 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.

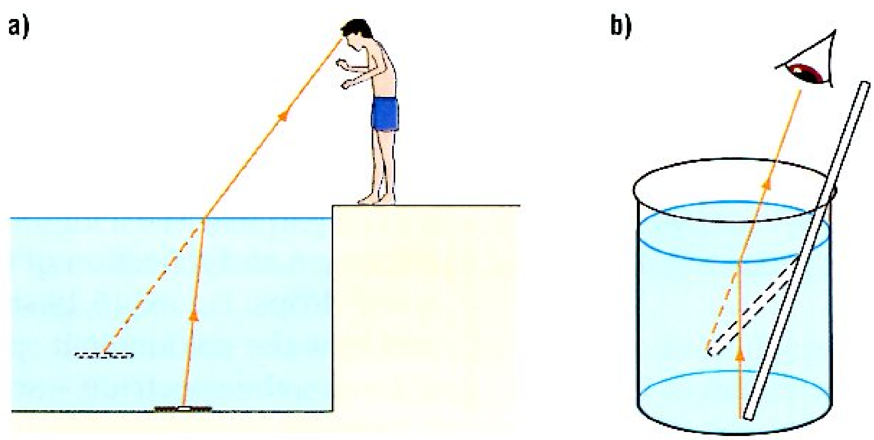


Figure 15.17 Refraction of light as it passes from water to air makes an object appear closer to the surface than it really is.

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.

Light behaves as if it travels as waves (see page 176). The 'white' light from the Sun contains light of different wavelengths which give different coloured light. When they pass through a prism the light waves of different wavelengths travel at slightly different speeds and are spread out, by a process called **dispersion**, to form the colours of the spectrum. The light waves with the shortest wavelengths are slowed down and refracted the most.

6 Look at Figure 15.18. Which colour of light has the shortest wavelength? Explain your answer.

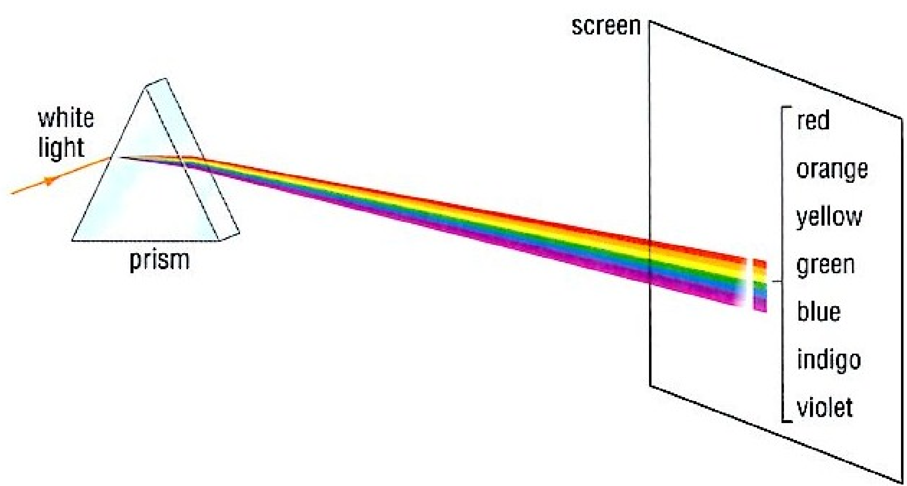


Figure 15.18 White light passing through a prism is split up into its constituent colours, forming a spectrum.

The rainbow

If you stand with your back to the Sun when it is raining or you look into a spray of water from a fountain or a hose you may see a rainbow. It is produced by the refraction and reflection of the Sun's light through the water drops. Figure 15.19 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.

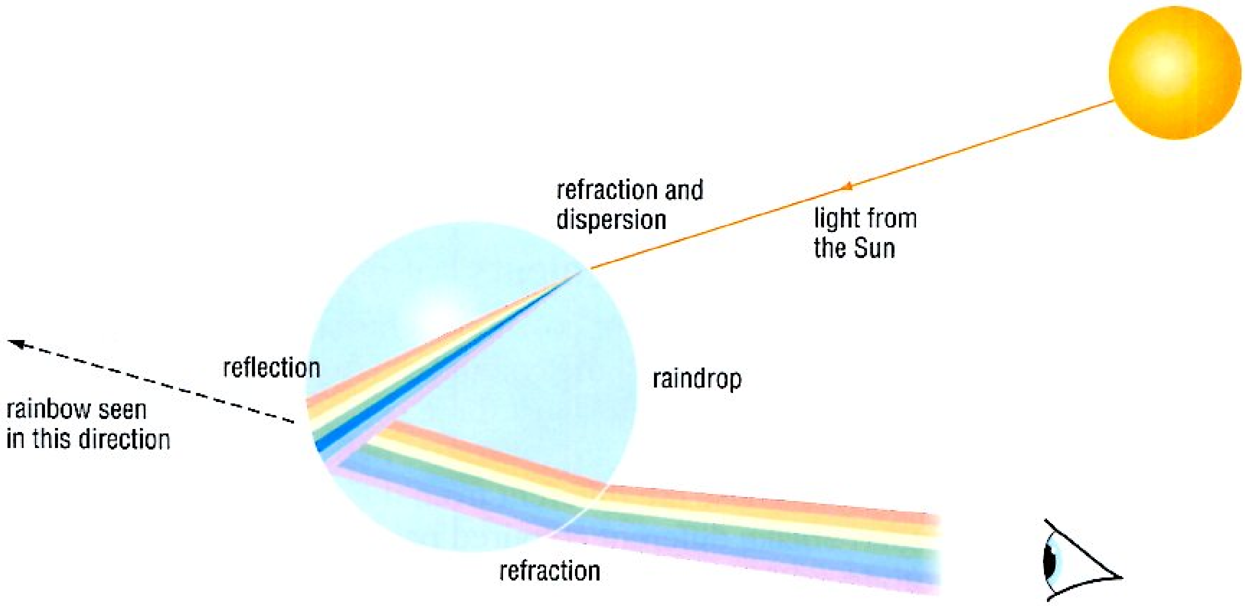


Figure 15.19 The formation of a rainbow

Colour

Absorbing and reflecting colours

7 Name some everyday objects which:
- **a)** reflect all the colours in sunlight
- **b)** absorb all the colours in sunlight.

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.

Filtering colours

Sheets of coloured plastic or glass can filter the colours in light. They absorb some of the colours and allow other colours to pass through, producing different coloured light. For example, a blue filter allows only blue light to pass through and a red filter allows only red light to pass through.

One of the most spectacular uses of colour filters is in the theatre where the stage is bathed in different coloured lights to give different effects. Blue light is used for night scenes or to generate scary feelings or excitement while red and yellow can make dance routines seem even more lively.

Colour filters are also used in photography to produce images for art exhibitions and advertising campaigns.

Figure 15.20 Green coloured filters in use at a rock concert

8 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.

9 Which primary colours overlap to produce:
  a) yellow
  b) magenta
  c) cyan
  d) white light?

> **For discussion**
>
> **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?**

In science colour filters are used for making parts of a view under investigation easier to see. For example a red filter used in a microscope absorbs the green light coming from chloroplasts and makes them appear dark. Telescopes can be fitted with filters which absorb the light produced by street lamps making objects in space more visible.

Combining colours

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 are called the **primary colours** of light.

These are different from the primary colours needed to make different coloured paint (see below).

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 15.22).

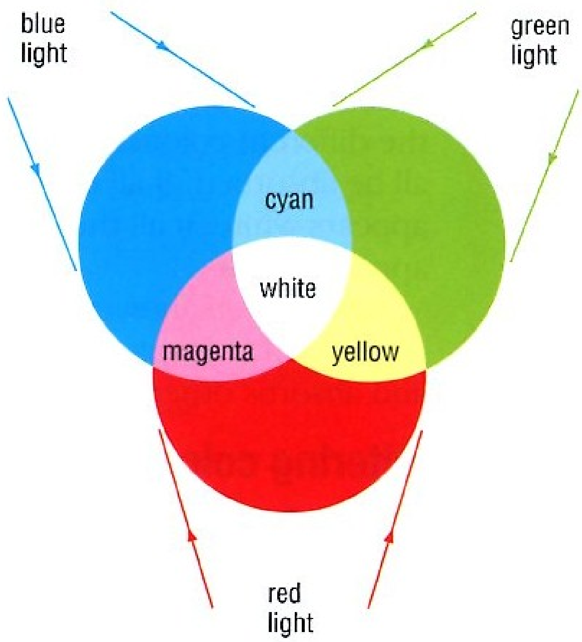


Figure 15.21 Overlapping beams of the primary colours form the secondary colours.

Colours and paint

Paint contains tiny particles called the pigment. The pigment absorbs some of the colours in sunlight and reflects others to give the paint its colour. Three colours of paint can be used to make almost all the other colours of paint. These colours are yellow, magenta and cyan. They are mixed together in different proportions to produce a wide range of colours. For example, when

Figure 15.22 The colours in this painting are due to the mixing of the pigments in the paints which absorb and reflect different amounts of colour in the white light shining on them.

yellow and magenta are mixed together reds are produced, when magenta and cyan are mixed blues are produced and when cyan and yellow are mixed greens are produced. Mixing all three produces black.

Three different colours of paint, ink or dye can be used to make almost all the other colours. These three colours are yellow, magenta and cyan. They are mixed together in different proportions to produce a wide range of colours, like those in the photographs in this book. Tiny dots of the three colours form the printed picture.

Detecting light

On page 176 we found that Empedocles thought we sent out rays to see and that Democritus thought that our eyes were bombarded by atoms from the objects we looked at. Today we know these ideas are wrong and some of the contents of this chapter can be brought together to show how our eyes let us see. Figure 15.23 shows the parts of the eye that are involved with light rays that shine towards us.

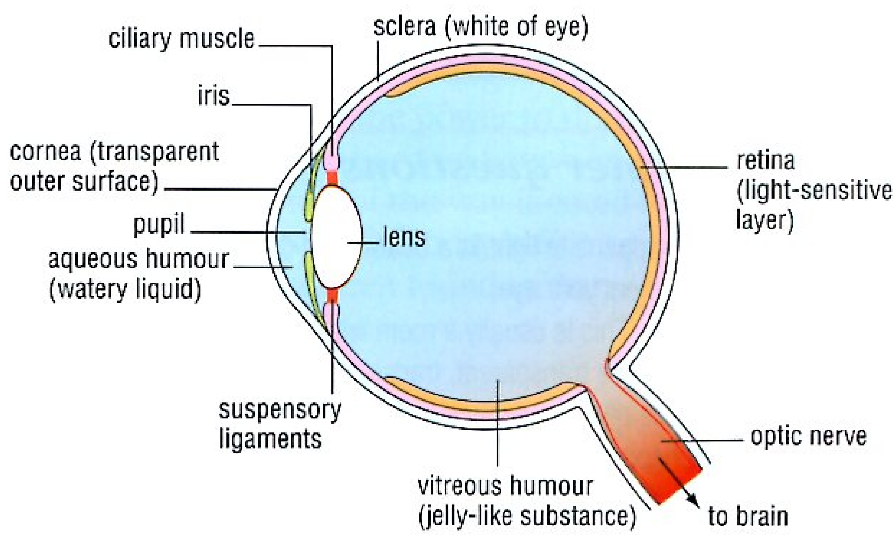


Figure 15.23 The structure of the right eye

Light rays strike the cornea and are refracted so that many of them change path as they move through the transparent aqueous humour and pass through the gap called the pupil. Once through this 'black hole' of the eye they are refracted again by the lens and travel on through the transparent vitreous humour to the retina where they form a picture on the light-sensitive cells. If the light is dim, as at dawn or dusk and at night, it causes rod-shaped cells in the layer to fire off messages along the optic nerve and we see a picture in black and grey. If there is more light, such as in the daytime, cone-shaped cells sensitive to red, green or violet light fire off messages to the brain and the brain merges the messages to produce the coloured picture we see.

10 Name three processes described in this chapter that are used when we see an object.

◆ SUMMARY ◆

- Light is a form of energy that is released from luminous objects (*see page 174*).
- Materials can be classified as opaque, translucent or transparent (*see page 177*).
- A shadow forms when light rays are stopped by an opaque object (*see page 178*).
- We see non-luminous objects by the light they reflect (*see page 179*).
- Light rays are reflected from a smooth surface at the same angle as that at which they strike it (*see page 179*).
- A real image can be formed on a screen but a virtual image cannot (*see page 181*).
- When light rays strike the surface of a transparent material at an angle to the perpendicular they are refracted (*see page 184*).
- A prism can split sunlight into different colours of light (*see page 186*).
- The colour of an object that we see depends on the colours of light that it absorbs and reflects (*see page 187*).

End of chapter questions

1 Describe what happens to light in a beam from the time it reaches the Earth from the Sun and shines upon a leaf to when it enters your eye.

2 Imagine a kitchen. This is usually a room with many types of surface. There are also objects with many colours and some are transparent, translucent or opaque. Describe what happens to the sunlight as it strikes the different types of surface. Here are two examples to help you begin your answer. Think of four more and describe what happens to light when it strikes them too.

- The white surface of a fridge
- The black surface of an oven hob