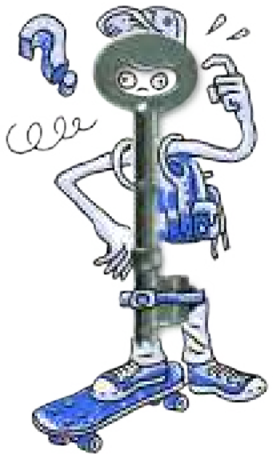
4 Visible light



KEY QUESTIONS:

- Where does light come from?
- How does light travel?
- How do we see?
- Why do leaves look green?
- How do mirrors work?
- Why do my legs look crooked underwater?

In this chapter we will learn about **visible light**. We call it visible light because we can see it with our own eyes. There are different forms of light which we cannot see with our naked eyes. Ultraviolet light is an example of a form of light which we cannot see with just our eyes. We will focus our attention on the visible light spectrum and investigate how we are able to see different colours and how light behaves.

NEW WORDS

- luminous
- radiation
- rectilinear
- propagation

4.1 Radiation of light

Where does light come from? Natural light comes from luminous objects such as the Sun and light bulbs. We say that these objects emit light.

The Sun is our main source of light on Earth.

A light bulb is a luminous object as it emits light.

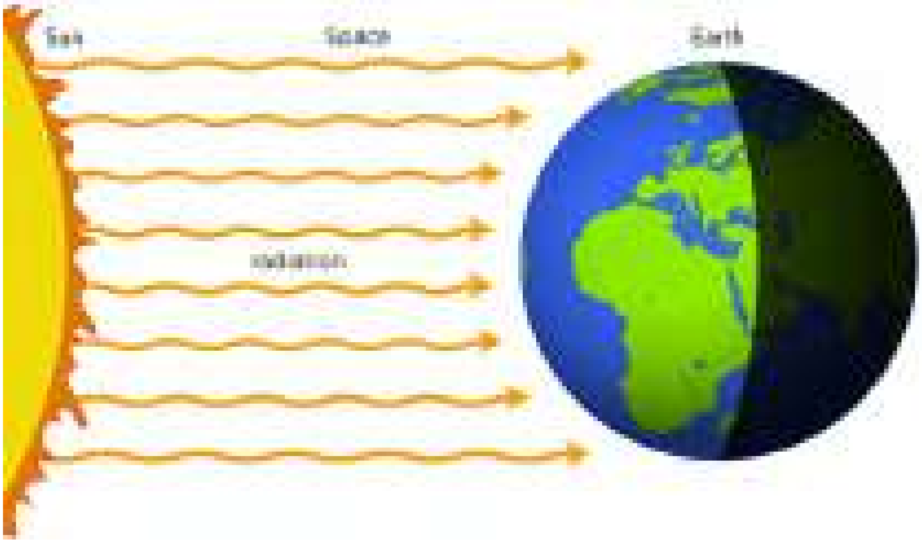
VISIT

The speed of light (video)

bit.ly/GAMgFW

This image from NASA shows the Earth's lights at night. You can see how much we rely on light nowadays.

Light travels through space at a speed of 300 000 kilometers per second. We say that energy is transferred by radiation. The energy of the light is transferred through space as **electromagnetic waves** in straight lines.

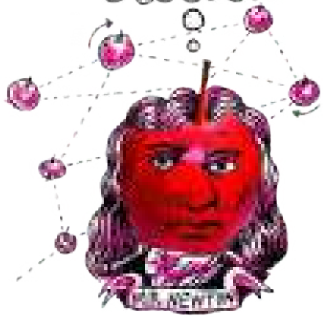


Light and heat are transferred to Earth through space from the Sun by radiation.

Let's look at how light travels. We will make a simple camera to investigate how light travels.

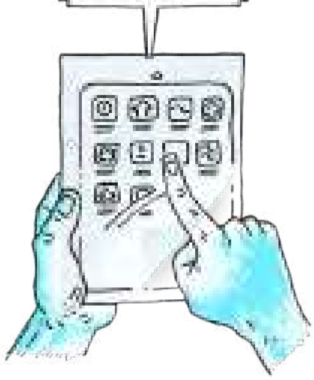
DID YOU KNOW?

If you could travel at the speed of light you could travel around the equator 7,5 times in 1 second!



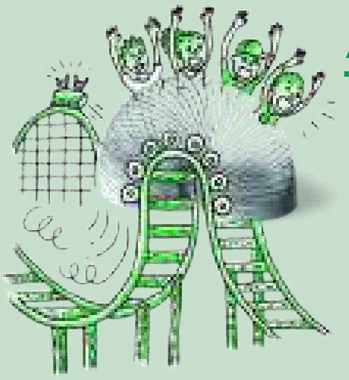
TAKE NOTE

The Moon is NOT a luminous object as it does not emit its own light light. It reflects the light from the Sun.



DID YOU KNOW?

It takes light 8 minutes to travel from the Sun to the Earth.



ACTIVITY: Make a pinhole camera

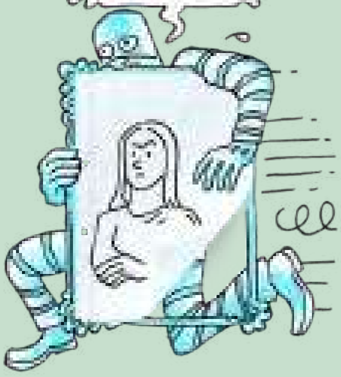
MATERIALS:

- Pringles chip can
- craft knife
- aluminium foil
- tape
- ruler
- drawing pin

INSTRUCTIONS:

TAKE NOTE

The Sun emits radiation in **all directions**, but in the diagram here, only the radiation which reaches Earth has been shown.



1. Measure 5 cm from the bottom of the can (opposite end to the plastic lid) and make a mark all around the can.

2. Cut through the can along the line so that you have cut the can into 2 pieces.

3. If you have a clear lid, put a piece of wax paper on top of the lid before sticking everything together.

4. Place the lid between the 2 pieces and stick it all together using tape.

5. Wrap the aluminium foil around the can to prevent any light from coming in from the sides.

6. Use a drawing pin to make a hole in the centre of the metal base of the can.
7. Go outside with your pinhole camera.
8. Point the metal end with the hole at an object which is in bright sunlight.
9. Cup your hands around the other end and look through the open end.

QUESTIONS:

1. What did you see when you looked through the open end of the tube?

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2. What happens when you move closer or further away from an object?

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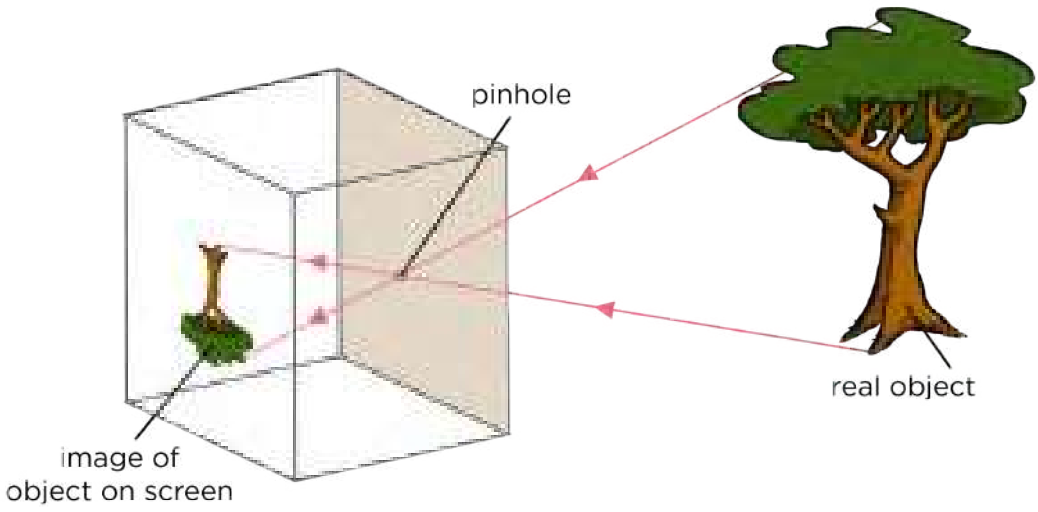
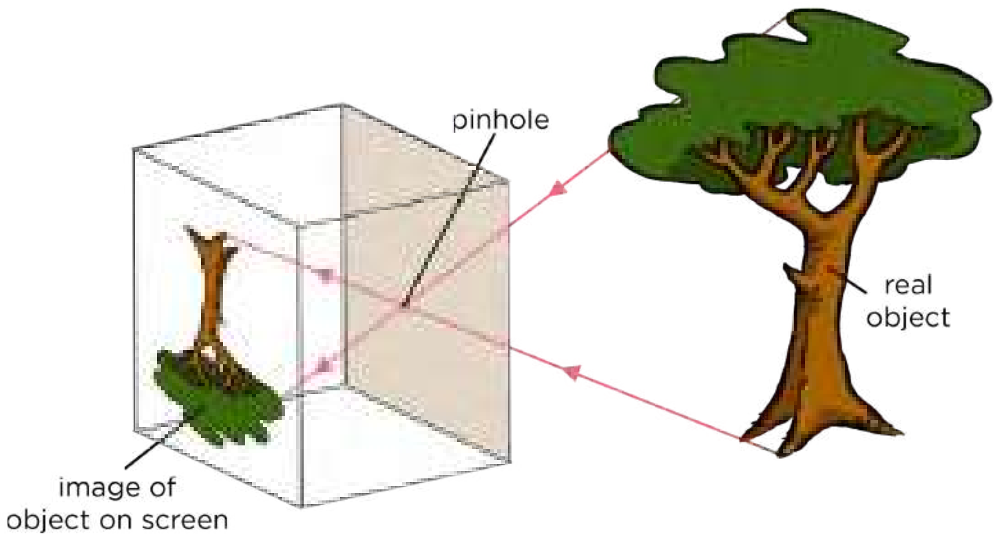
Did you see an upside down image? Why is it upside down?

We see objects because light reflects off them and enters our eyes. If the image is upside down it means that the light from the bottom of the object has arrived at the top of the screen and the light from the top of the object has reached the bottom of the screen, as shown in the following diagram.



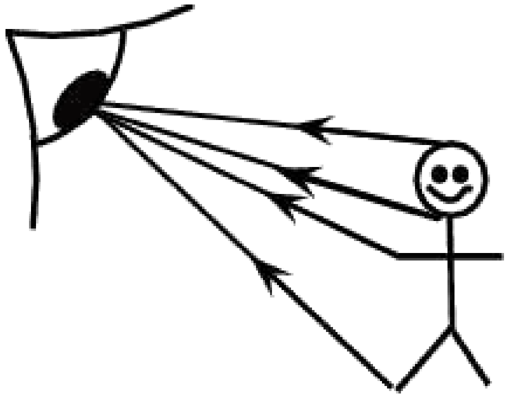
When you moved closer to the object, the image appeared bigger, as shown in the following diagram.



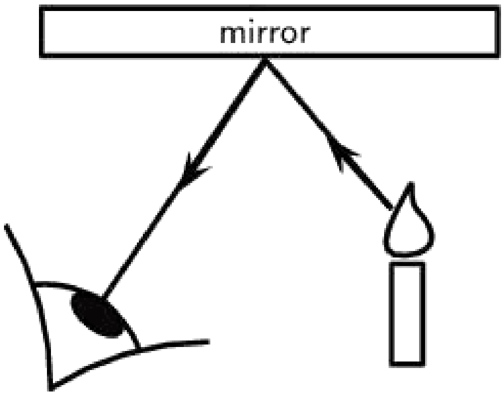
What does this mean? It means that light must be travelling in straight lines. This is called the **rectilinear propagation** of light.

Ray diagrams

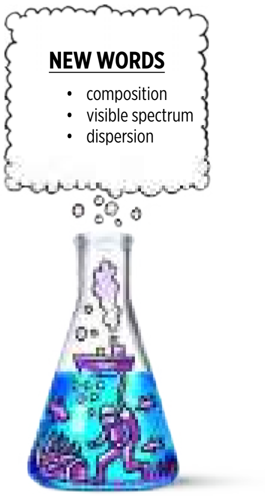
A ray diagram is a drawing that shows the path of light. Light rays are drawn using straight lines and arrowheads, because light travels in straight lines. The figure below shows some examples of ray diagrams.



A ray diagram showing how you see another person.



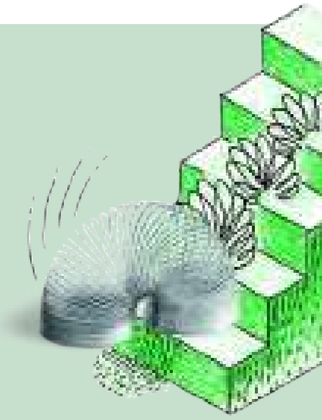
A ray diagram showing how you see a reflection in a mirror.



4.2 Spectrum of visible light

The visible light spectrum is the light that we are able to see with our naked eyes. Have you ever wondered why everything is colourful and not just black and white? Have you ever seen a rainbow and wondered where the colours have come from? The colours that we see everyday are part of the visible light spectrum. Let's investigate the visible light spectrum.

ACTIVITY: Splitting white light



MATERIALS:

- triangular perspex prism
- ray box and power source

INSTRUCTIONS:

1. Connect the ray box to the power source. If you do not have a ray box, your teacher will show you how to use a piece of cardboard with a slit cut into it.
2. Place the triangular prism on a white background.
3. Shine a beam of white light through the side of the prism.

QUESTIONS:

1. Draw a picture showing what you observe.

2. Write a description of what you observed.

3. Write down the order in which the colours appear.

4. If you repeat the experiment, does the order of the colours change?

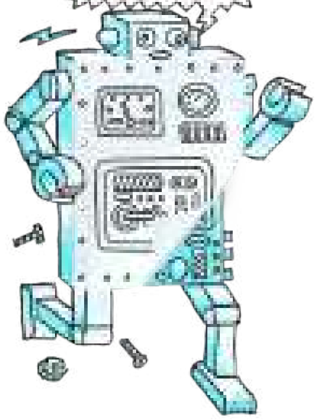
5. What do the different colours we see tell us about the composition of white light?

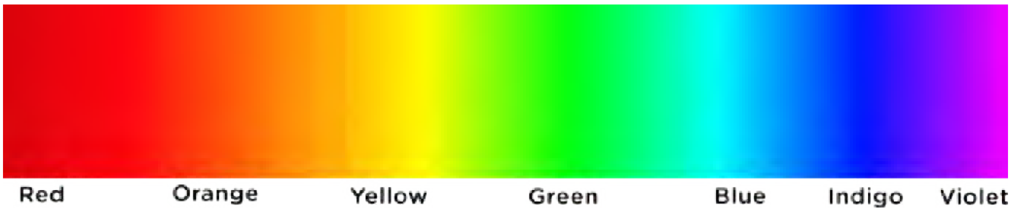
So, what have we learned so far? Light radiates from luminous objects and always travels in straight lines. The white light that we see is made up of the 7 different colours of the spectrum. When the 7 colours are travelling together we see them as white light.

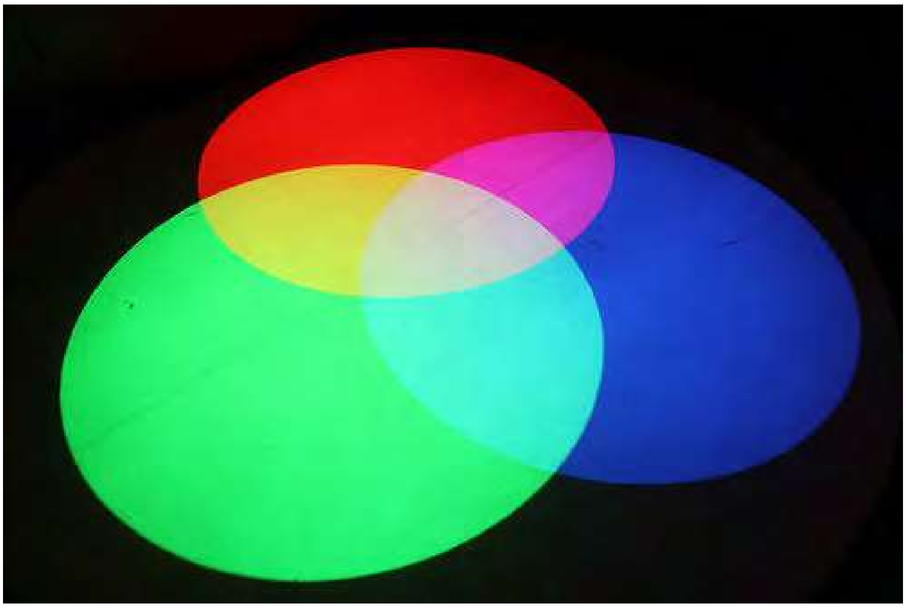
The 7 colours of the visible spectrum are **R**ed, **O**range, **Y**ellow, **G**reen, **B**lue, **I**ndigo and **V**iolet. Each colour has a different wavelength and frequency. Have a look at the following image which shows the spectrum of visible light.

TAKE NOTE

You can use the abbreviation ROYGBIV to remember the order of the colours.



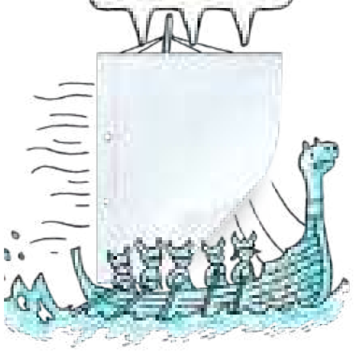




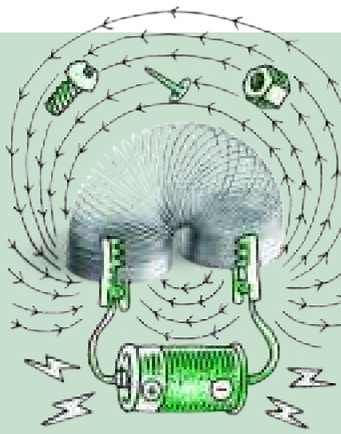
The colours combine to form white light.

TAKE NOTE

The primary colours of light are red, green and blue.



ACTIVITY: Colour spinning wheels



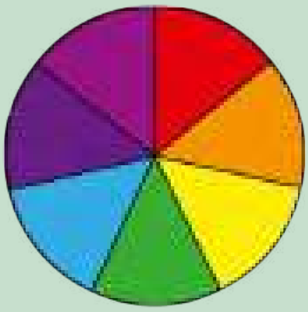
MATERIALS:

- white cardboard
- coloured pens or pencils (red, orange, yellow, green, blue, indigo, violet)
- string
- scissors
- round object

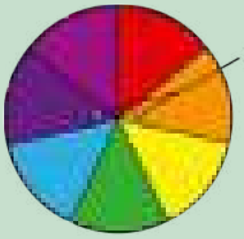
INSTRUCTIONS:

1. Draw a circle on the cardboard. You can trace around a round object such as a cup or saucer to do this. Cut out the circle.

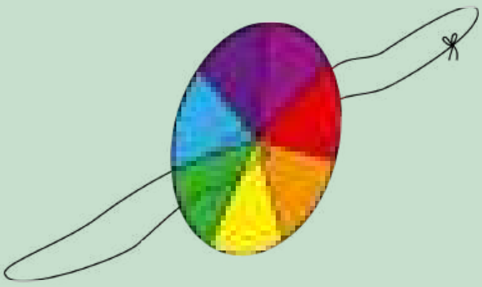
2. Now divide the circle into 7 equal segments. If you do not have indigo and violet colours, but just one purple pen or crayon, then you can divide the circle into 6 equal segments rather.
3. Shade in each segment a different colour, in the order red, orange, yellow, green, blue, indigo, violet (or just purple if you do not have indigo and violet).



4. Next, make two holes, one on either side of the centre as shown below.



5. Thread the string through the holes and tie it in a loop.



6. You are now ready to spin the wheel. Holding the ends of the loop in each hand, twirl the string over, like you would a skipping rope, so that the string twists. Once the string is tightly twisted, pull your hands apart, then bring them back together. Continue bringing your hands in and out and watch the circle spin.
7. What do you observe about the colour of the wheel as it spins faster?

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DID YOU KNOW?

An artist might tell you that the primary colours of paint are red, yellow and blue. This is different to the primary colours of light. This is because the pigments yellow, blue and red cannot be mixed from other pigments. In printing, the primary colours are magenta, yellow and cyan.

VISIT

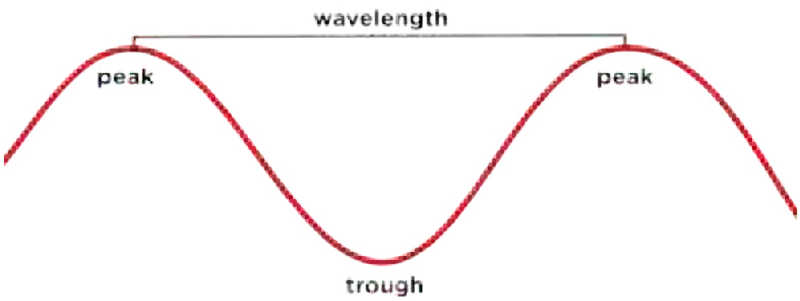
There is no pink light.
bit.ly/1b2gFXU

So far we have been talking about the **visible** light spectrum. As we mentioned in the beginning, this is the light that we can see. We also spoke about how light travels in **electromagnetic waves.** We can only see light with a certain range of **wavelengths**. What does this mean?

The size of a wave is measured in wavelengths. A wavelength is the distance between two corresponding points on two consecutive waves. Normally this is done by measuring from peak to peak or from trough to trough. Have a look at the following diagram which illustrates a wavelength.

DID YOU KNOW?

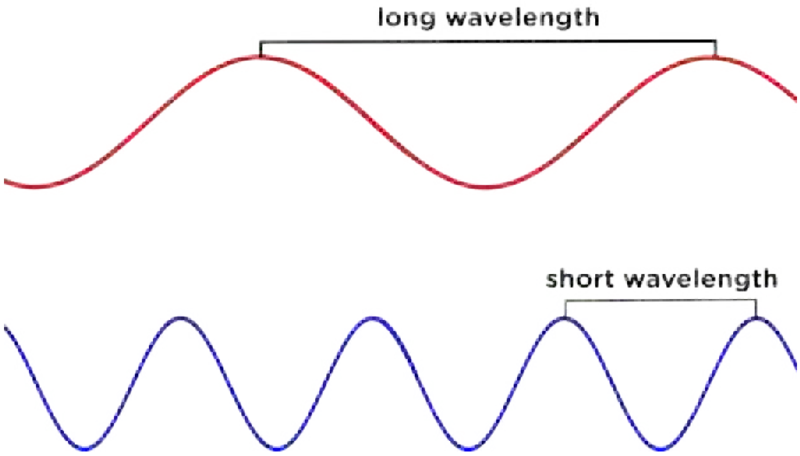
Wavelengths can be as small as one billionth of a meter, as with gamma rays. Wavelengths can even be as long as meters, for example in radio waves.



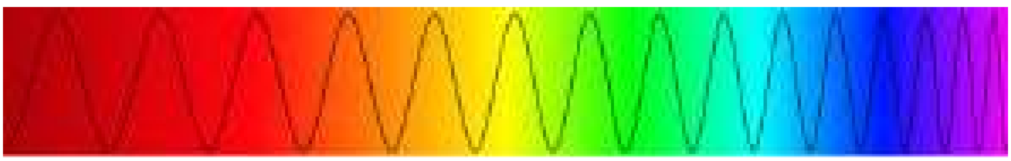
The wavelengths of the different colours of visible light are different lengths, as shown in the following diagram.

DID YOU KNOW?

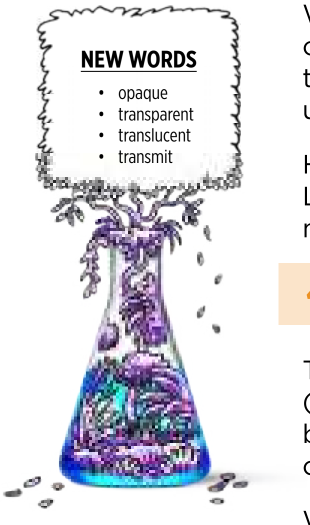
In police forensics, ultraviolet light can be used along with a special powder to detect finger and shoe prints that can help solve crimes.



We can also talk about the frequency of a wave. If a wave has a long wavelength, then it has a low frequency; if it has a short wavelength, then it has a high frequency.



Of visible light, orange and red light have the longest wavelengths (and lowest frequency) and violet, indigo and blue have the shorter wavelengths (and highest frequency).



When it comes to visible light, we only see wavelengths of 400 to 700 billionths of a meter. This is called the visible spectrum. But, light waves are just part of the wave spectrum. There is invisible light with shorter wavelengths, such as ultraviolet light, and there are longer wavelengths, such as infrared light.

Have you ever looked through a window and wondered why it is made of glass? Let's find out how light behaves when it strikes the surface of different types of materials in the next section.

4.3 Opaque and transparent substances

Three different things happen when light hits a surface, it can be **reflected** (bounce off), **absorbed** or **transmitted** (pass through). Glass reflects some light but most of the light is transmitted straight through. That's why we can see objects on the other side of a closed window.

We say that glass is **transparent**. Let's find out more about what this means. If a substance is not transparent, it is **opaque**.

ACTIVITY: Shadow Play

MATERIALS:

- cardboard
- clear plastic
- plastic shopping bag
- scissors
- light source (ray box or light bulb)

INSTRUCTIONS:

1. Cut out three shapes from your cardboard. All of the shapes should be similar but three different sizes: small, medium and large.
2. Switch on the light source.
3. Hold your first shape a short distance in front of the light source.
4. Look at the shadow that forms. Write down what you observe.

5. Hold your second shape the same distance in front of the light source.
6. Look at the shadow that forms. Write down what you observe.

7. Hold your third shape the same distance in front of the light source.
8. Look at the shadow that forms. Write down what you observe.

9. The shadow is formed on the side furthest from the light source. It is dark

in colour and larger than the first and second shadows.

10. Use your first cardboard shape as a template and cut the shape from the clear plastic and the plastic shopping bag.
11. Hold the clear plastic shape the same distance from the light source. Write down what you observe.

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12. Hold the plastic shopping bag shape the same distance from the light source. Write down what you observe.

QUESTIONS

1. When you held the cardboard up to the light, did it allow light to pass through it? How do you know this?

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2. Is the cardboard shape opaque or transparent?

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3. What did you notice about the shadows formed by the different size cardboard shapes?

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4. Draw a diagram to show how the shadow is formed behind the opaque shape. Use straight lines with arrowheads to represent the rays of light.

5. The distance between the shape and the light source was kept the same. What do you think would have happened to the shadow if the distance was increased?

6. Test your idea from question 5 by moving your cardboard shapes closer to and further away from the light source. What do you see? Were you correct in your prediction?

7. Is the clear plastic shape opaque or transparent?

8. Did the clear plastic cast a shadow?

9. Explain why the cardboard casts a shadow but the clear plastic does not.

10. Is the plastic shopping bag shape opaque or transparent?

11. Explain why the shopping bag casts a lighter shadow.

What have we learned? Shadows are formed because light travels in straight lines and cannot pass through opaque objects.

Substances which transmit most of the light and only absorb or reflect a little bit are called **transparent**. Can you list some everyday objects which are transparent?

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Substances which completely reflect or absorb light without transmitting any are called **opaque**. Can you list some everyday objects which are opaque?

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Some substances, such as the plastic shopping bag, allow some light to pass through, but not all of it. This substance is **translucent**, or **semi-transparent.**

Shadows can be useful. Sundials have been used since ancient times as a time-keeping device, like a watch or a clock. As the position of the Sun changes in the sky, the shadow cast by the style moves across the surface of the sundial. The surface is marked with numbers, allowing the shadow to indicate time of day.

We can use transparent objects to make filters. If we want red light we use a red glass bulb or a red plastic film placed in front of the light. Only red light is able to transmit through the red glass or plastic. The other colours are absorbed by the filter.

These are different colour filters for a camera. The red filter will only allow red light through and so the photograph will have a red effect applied to it. The other colours of light are absorbed by the filter.

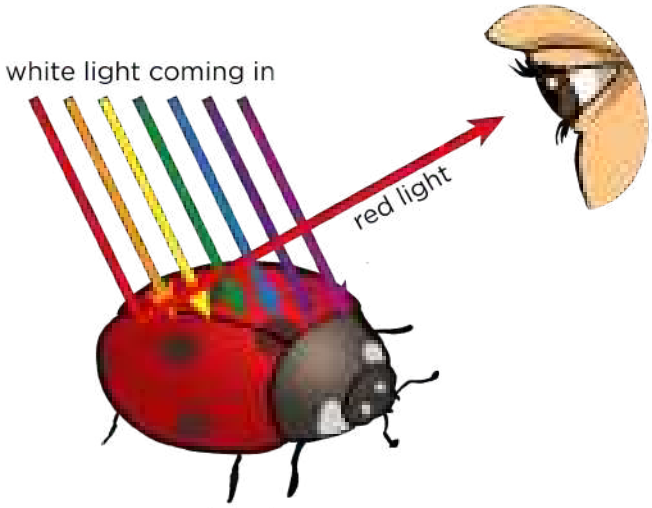
Now that we have seen some examples of transparent and opaque substances, let's take a closer look at what it means to absorb or reflect light.

4.4 Absorption of light

Look at this picture of a ladybird. Why is it red and black? And why is the leaf so green? How do we see the different colours? It all has to do with what happens when light hits a surface. When light hits a surface, some of the light is absorbed and the rest is reflected. It is the reflected light that reaches our eyes and allows us to see the object.

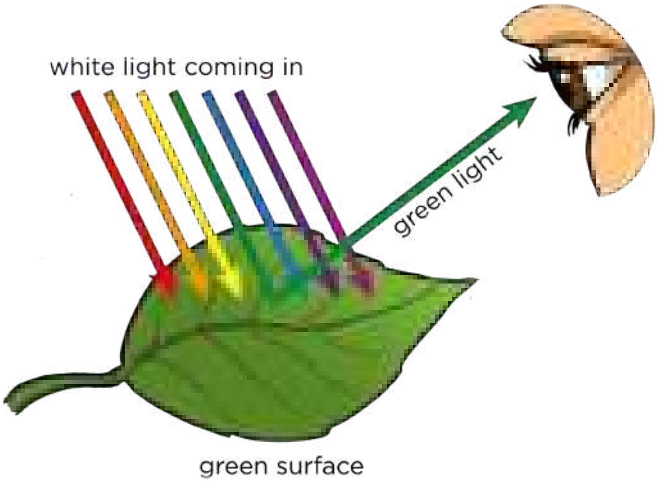
A ladybird.

Previously, we learned that white light is a mixture of different colours. When white light from the Sun hits the red shell of the ladybird all of the colours are absorbed, except red. Red light is reflected back to our eyes and so we see a red ladybird.

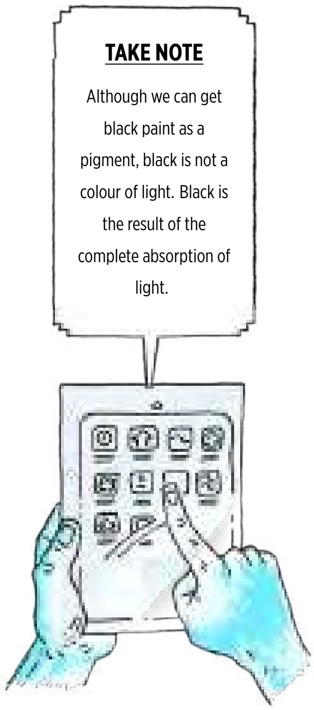


We see the red shell of the ladybird as red light is reflected and the other colours are absorbed.

The green leaf absorbs all the colours except green which it reflects back into our eyes.



We see a green leaf as green light is reflected and the other colours are absorbed by the leaf's surface.



What about the black spots of the ladybird? Is black a colour? The black spots on the ladybird absorb **all** the colours and no light is reflected. That is why they appear black.

Do you remember learning about heat as energy transfer in Gr 7? We looked at the absorption of heat. We saw that black, matt objects absorbed all of the light energy, while white objects reflected all of it. Black, matt (not shiny) objects absorb all of the colours of light and reflect none and so appear black to our eyes.

What about a white object? Why do you think white objects look white? Have a look at the following diagram for a clue.

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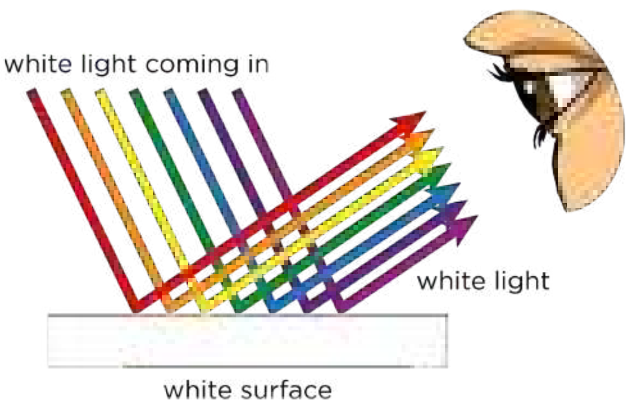

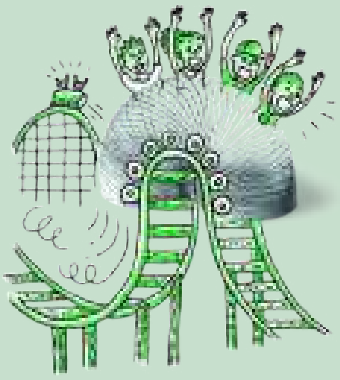

ACTIVITY: Why do objects look red under red light?

MATERIALS:

- piece of red plastic to act as a filter
- light source (light bulb or torch)
- white object

INSTRUCTIONS:

1. Place a white object on the desk.
2. Switch on your light source and place the red plastic in front of the light.
3. Shine the light (with the red plastic in front) onto the piece of white paper.

QUESTIONS:

1. What colour was the page under normal light?

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2. Why does the page appear white in normal light?

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3. What did you see when the red plastic filter shone on the white page?

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4. Explain why the paper changed colour.

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Let's now look more at what we mean by reflection of light.

4.5 Reflection of light

NEW WORDS

- reflect
- incident ray
- reflected ray
- normal line
- angle of incidence
- angle of reflection
- perpendicular

When light hits a surface it is often reflected off the surface. This photograph shows how light is reflected off a still lake, creating a mirror image of the tree. The still, flat surface of the lake has acted as a mirror.

A tree reflection.

Have some fun with these photos of reflections in water. One photograph is the right way up and the other one is upside down! Which one is which?

Reflections on the Negro River in the Amazon.

Reflections in the Arno River in Italy.

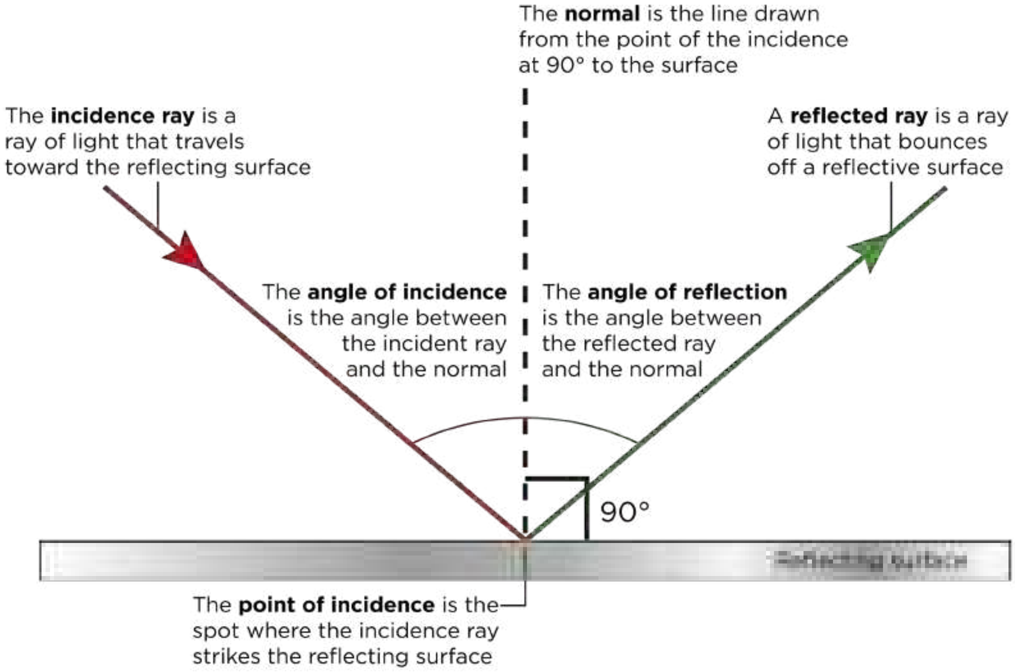
Most surfaces reflect light. When light strikes a reflective surface, it can change direction. Let's look at how this happens.

When light reflects off a surface the ray which hits the surface, it is called the **incident ray**. The ray of light which is reflected from the surface is called the **reflected ray.** When we draw diagrams of reflection we also draw in an imaginary line to help us measure different angles. This line is called the **normal**. The normal line is always drawn perpendicular to the surface.

Between the normal line and the incident and reflected rays, there are two angles. These are:

- **angle of incidence** - the angle between the incident ray and normal line
- **angle of reflection** - the angle between the reflected ray and normal line

The following diagram explains these concepts.



Let's investigate the relationship between the angle of incidence and the angle of reflection.

INVESTIGATION: Is there a relationship between the angles of incidence and reflections?

AIM: To investigate the reflection of light from a surface.

INVESTIGATIVE QUESTION:

Look at the diagram above and try to formulate an investigative question for this investigation.

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HYPOTHESIS: The angle of incidence is equal to the angle of reflection

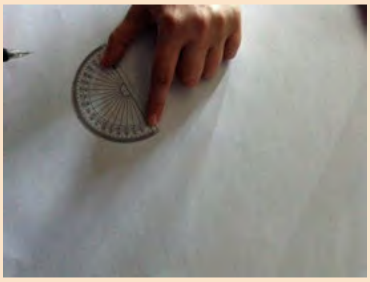
MATERIALS AND APPARATUS:

- mirror
- white paper
- pencil
- protractor
- ruler
- ray box

METHOD:

1. Put a white piece of paper on the desk.
2. Use your ruler to draw a straight line near the top of the white paper.

3. Use your protractor to make a right angle in the middle of your pencil line. This is the **normal** line.

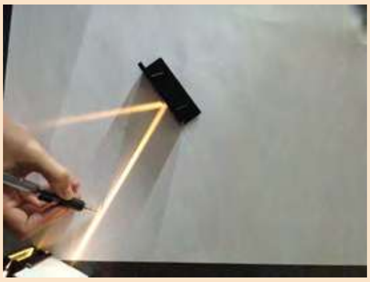


Marking a right angle with a protractor.

4. Place your mirror upright along the first line.
5. Shine a light from the ray box along the paper so that it "hits" the mirror where your normal line and your mirror meet.

A mirror is placed on the line and a ray shone to strike the mirror at the normal line.

6. Use a pencil to mark the incident light ray.



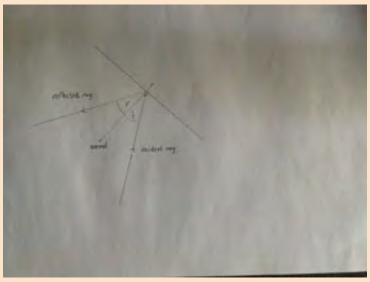
Marking the incident light ray.

7. Use a pencil to mark the reflected light ray.

Marking the reflected ray.

8. Remove the mirror and switch off the ray box.
9. Use a ruler and pencil to draw a line from the points you have marked on each ray to the normal line.

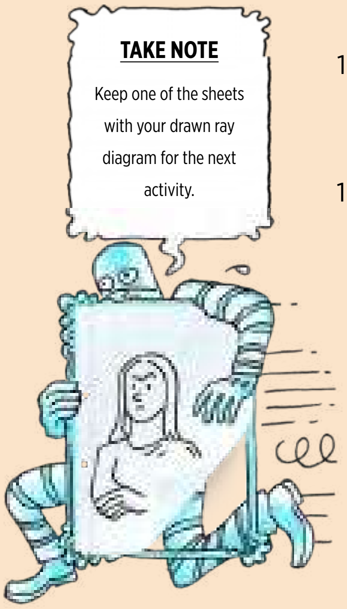
10. Mark the angle of incidence (i) and angle of reflection (r).



Your ray diagram should look similar to this.

11. Turn the ray box on again to confirm that your pencil lines follow the rays.

The ray diagram overlaps the actual rays.



12. Use a protractor and measure the angle of incidence and the angle of reflection and record your results in the table.
13. Repeat this method 3 more times, each time using a different angle of incidence.

A different angle of incidence.

RESULTS:

Fill your results into the following table.

Repeat	Angle of Incidence	Angle of Reflection
1		
2		
3		
4		

ANALYSIS:

1. Has your investigation provided everything you need to answer your investigative question?

---

2. How could you improve this investigation to get more accurate results?

CONCLUSION:

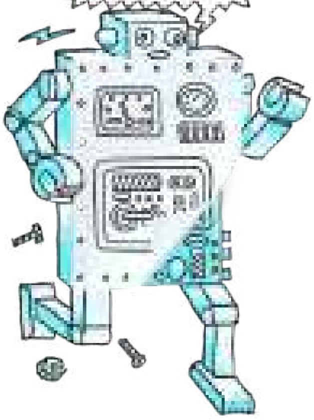
What can you conclude based on your results?

Whenever light is reflected from a surface, the angle of incidence to equal to the angle of reflection. On a smooth surface all the light rays are reflected in the same way and so the image is clear and focused.

A mirror is an example of a smooth surface. The image you see is focused and clear. As you can see in the photograph, the scientists and engineers are clear and focused in the mirror image.

TAKE NOTE

In reflection, not only is the angle of incidence equal to the angle of reflection, but the incident ray and reflection ray are also in the same **plane**.



A mirror segment from one of NASA's telescopes provides a clear and focused reflection.

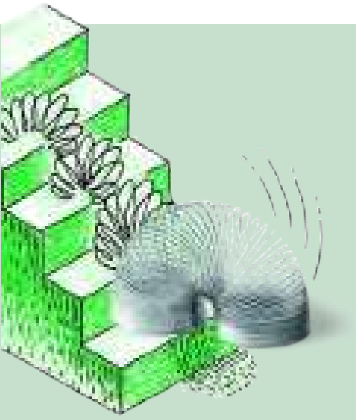
VISIT

What colour is a mirror? (video)

bit.ly/GABdNZ

What happens when we do not have a smooth surface? Have a look at the photo.

Why is the reflection of the grass and reeds not clear, but rather blurred?



ACTIVITY: Light reflection off aluminium foil

MATERIALS:

- aluminium foil
- white paper
- ray box

INSTRUCTIONS:

1. If possible, use the white sheets of paper from the last investigation where you drew your ray diagrams.
2. Similar to what you did in the last investigation, set up a ray box and direct the ray along the line of incidence which you drew.
3. Crumple a piece of aluminium foil and place this in the spot instead of the mirror.
4. Observe the reflected ray.

QUESTIONS:

1. Describe the reflected ray off the aluminium foil and how this compares to the reflected ray off the mirror.

____

____

2. Why do you think you observed these differences?

____

____

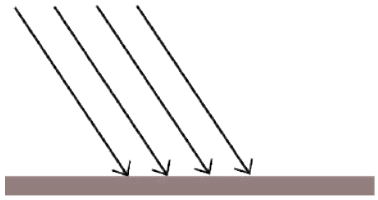
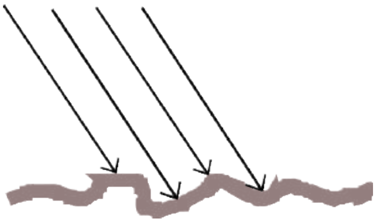
VISIT

Watch a video about the creative way that scientists have tried to answer the question: "What is light?"

bit.ly/GAMvAL

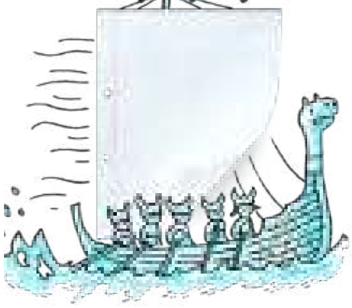
Can you now see why reflections off rippled water are not clear, but rather blurred? This is because the light rays have not reflected parallel to each other as they do from a smooth surface, but have scattered in different directions.

The following table shows the difference between a smooth surface and a rough surface. Straight parallel rays are approaching the surface. You need to draw in the reflected rays to show specular (clear) reflection from a smooth surface and diffuse (unclear) reflection from a rough surface.

Specular diffusion from a smooth surface	**Diffuse reflection from a rough surface.**
	

TAKE NOTE

'Diffuse' can mean unclear as well as spread out. In this example, the reflection is unclear because the rays are spread out or diffuse.



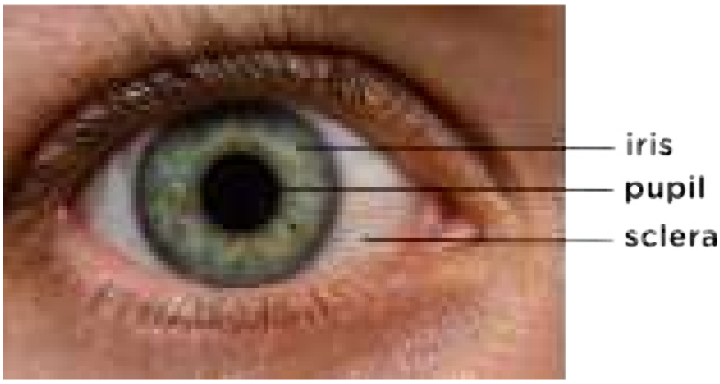
Visible light is the range of frequencies of light that are visible to the human eye, and is responsible for the sense of sight. Are you curious to find out how we actually see light? Let's discover more in the next section.

4.6 How do we see light?

NEW WORDS

- retina
- stimulate

How is it that we are able to see light? Light that is absorbed by objects does not enter the eye. Only reflected light or direct light from luminous objects can enter the eye and be interpreted. Have a look at the following image which shows the outer structure of the eye.



VISIT

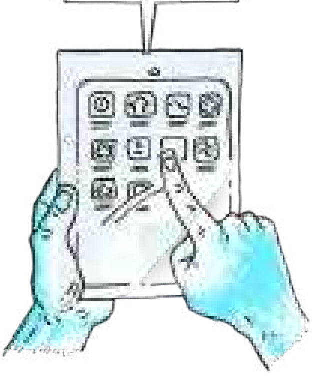
2012 Nobel Prize: How do we see light?

bit.ly/1a4zs2D

We can see the iris, the pupil and the sclera. The sclera is a the tough white, outer part of the eye, which acts as protection. The iris is the coloured part of the eye which differs from person to person. It is circular and surrounds the pupil. Light enters the eye through the pupil.

TAKE NOTE

The fovea is the part of the eye located in the centre of the retina where the clearest image is formed.

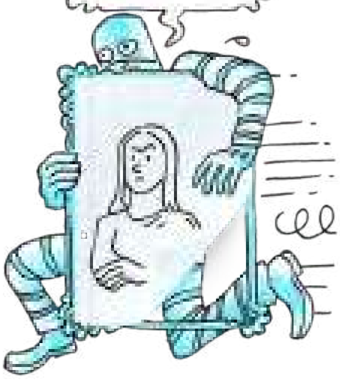


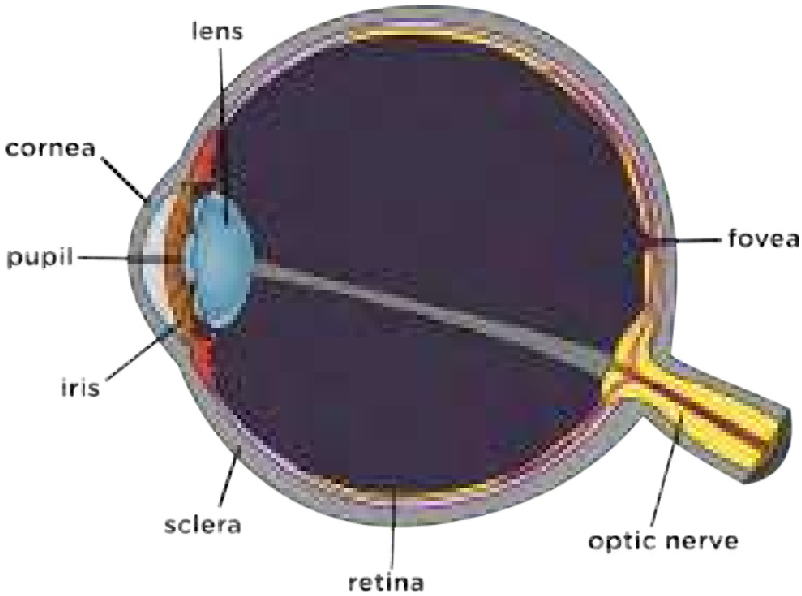
The size of your pupil changes in different light conditions. In bright light, the pupil contracts (gets smaller) to let less light through (as on the left), and in low light your pupil dilates (gets bigger) to let more light through (as on the right).

Let's take a look at the internal structure of the human eye. The following diagram shows a cross section through the eye. The eye is actually a large ball, and only a small part is visible on the outside. Covering the iris is a tough, transparent layer called the cornea. Behind the iris is the lens. Both the cornea and the lens help you to focus the light entering your eyes, as we will learn about in the next section.

TAKE NOTE

The cell is the basic structural and functional unit of all living things. We will be learning more about the cell next year in Gr 9 Life and Living.





A diagram of the eye.

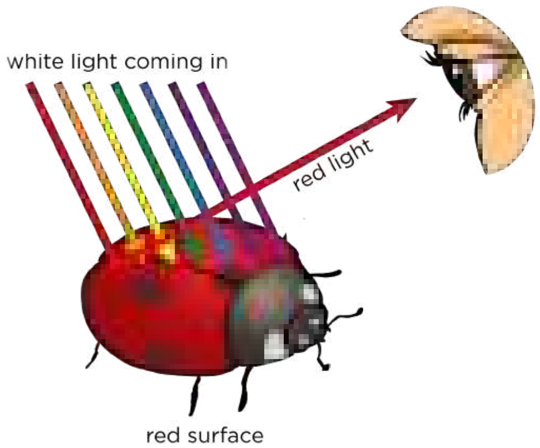
VISIT

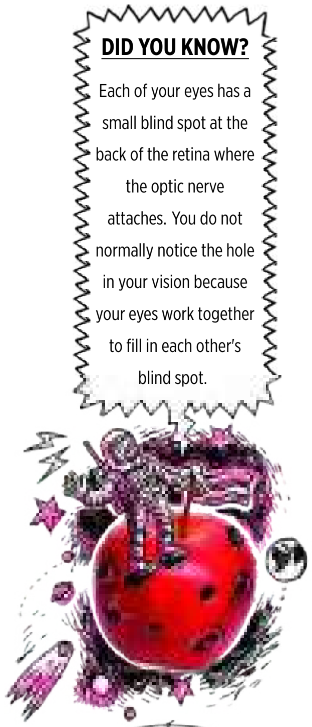
Find your blind spot with this optical illusion.

bit.ly/19jumEr

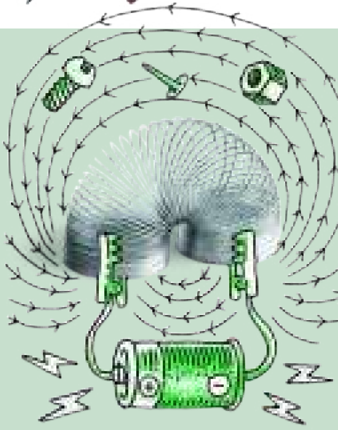
The light travels through the eye and hits the retina at the back of the eyeball. The retina is a layer of tissue lining the back of the eyeball, as indicated in the diagram, it is the yellow layer. The retina consists of cells which are sensitive to light. Light enters the eye and forms an image on the back of the eyeball. The way in which light hits the back of the eye, is similar to what happens in a pinhole camera. The receptor cells convert the light energy into electrical nerve impulses. These impulses travel out of the eye through the optic nerve and to the brain where they are interpreted as sight.

So how do we see colour? Do you remember when we spoke about why the ladybird appears red and black? Look at the following diagram again.





The white light hits the ladybird's surface. The white light has all the colours of light, but when it hits the red surface, only the red light is reflected. The other colours are absorbed by the red surface. This means that when we look at the red parts of the ladybird, we only get red light reflected into our eyes. Therefore, when this reflected light hits our retina and the electrical impulse is sent to our brains, we see the red colour.



ACTIVITY: Seeing colours

MATERIALS:

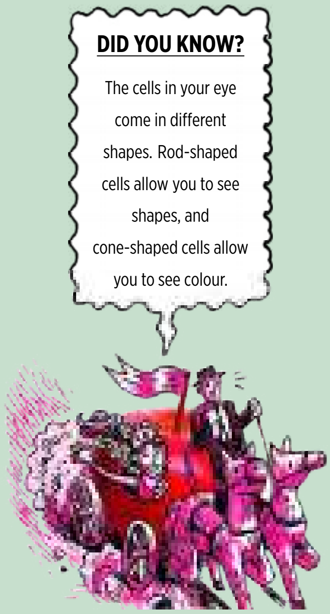
- coloured pens or pencils

INSTRUCTIONS:

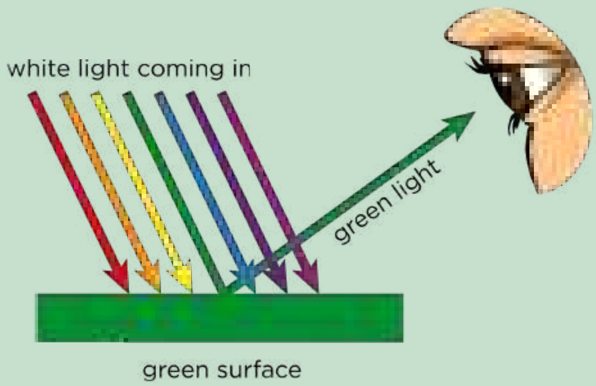
1. Answer the following questions about how we see objects.
2. Draw a ray diagram to accompany your written answer.
3. An example has been done for you.

Look at the picture of a sunflower.

A black and yellow sunflower.



We can draw a ray diagram to show why we see the green leaves as green, as shown below. The green surface of the leaves absorb all the colours of white light except green light which is reflected into our eyes.



Now explain why the petals appear yellow and the centre appears black. Use the concepts of absorption and reflection in your explanation. Draw diagrams to support your answer.

Heath has bought himself a blue car. Explain why we see the car as blue by using the absorption and reflection of light. Draw a diagram to support your answer.

Heath's blue car.

VISIT

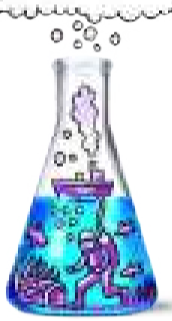
A simulation on colour vision.

bit.ly/18TbpEA

We have looked at opaque and transparent substances, absorption of light, reflection of light and how we see light. We are now going to go back to transparent substances and see how light can interact with these materials.

NEW WORDS

- refraction
- medium
- optical density

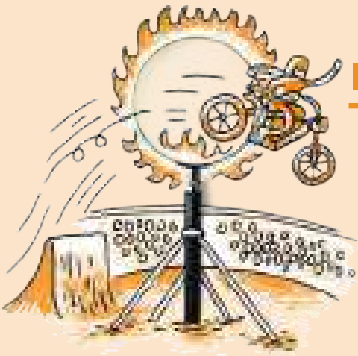


4.7 Refraction of light

Do you remember the last time you drank a cold drink with a straw? Did you notice that the straw did not look straight anymore once it was in the water or cool drink?

Why does the pencil in this glass of water look bent?

Let's investigate this by examining what happens to light when it passes through a glass block.

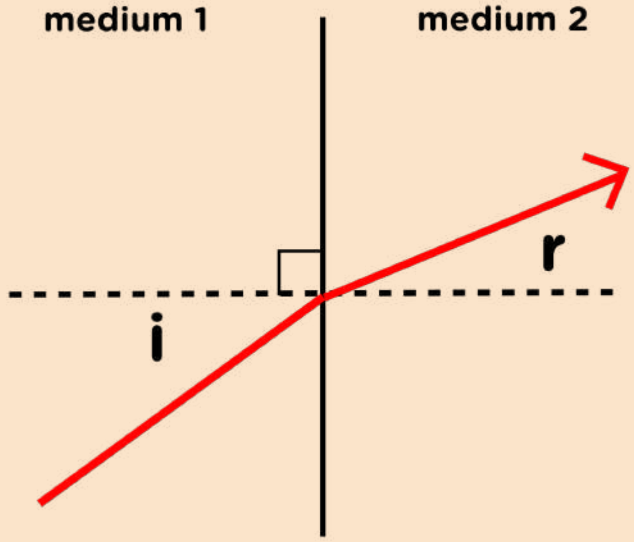


INVESTIGATION: What happens to light when it passes through a glass block

We are going to investigate what happens to a ray of light when it passes from air and into a glass block and then from the glass block back into air. We are going to use a glass block with parallel sides.

Before we start the investigation, we need to think about how we are going to determine if light changes direction or not. Do you remember in the investigation on reflection where we measured the angle of incidence and the angle of reflection? What did we find in this investigation?

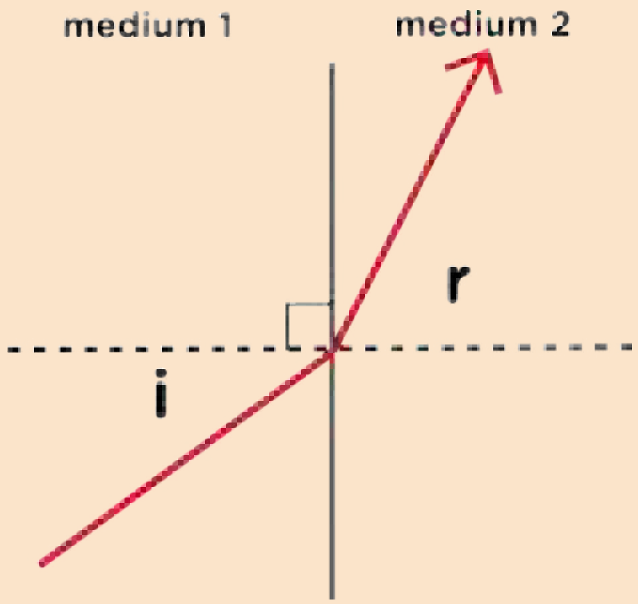
When light passes through a transparent substance, we can also measure the angles. Look at the following diagram. The angle of incidence (i) is measured between the incident light ray and the normal line. As the light passes through the transparent substance, the angle of refraction (r) is the angle between the refracted light ray and the normal.



A light ray passing from one medium to another.

In the diagram above, you can see that the angle of refraction is smaller than the angle of incidence. Therefore, the refracted light ray changed direction when it entered the transparent medium. We can also say something about which direction it bent towards. Did the light ray bend towards or away from the normal line?

The next diagram shows another outcome.



A light ray passing from one medium to another.

In the diagram above, does the refracted ray change direction when it enters the transparent medium? Give a reason for your answer.

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____

In which direction did the refracted ray change?

____

We are now ready to start our investigation.

AIM: To determine whether light changes direction when it passes through a parallel-sided glass block.

HYPOTHESIS: Write a hypothesis for this investigation.

____

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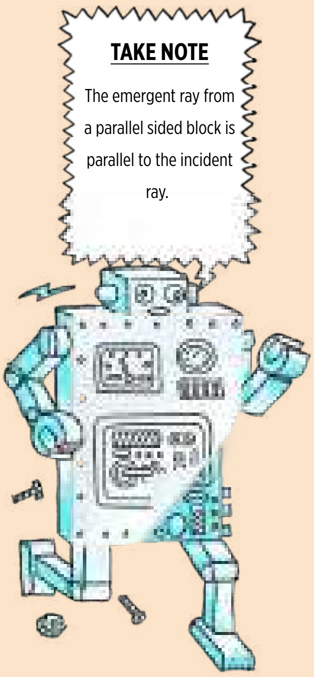
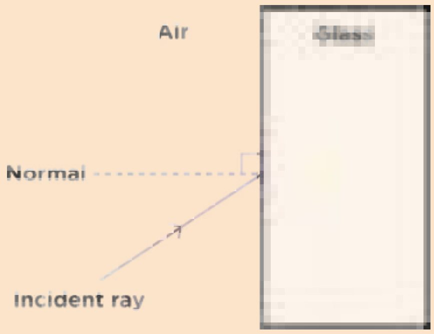


MATERIALS AND APPARATUS:

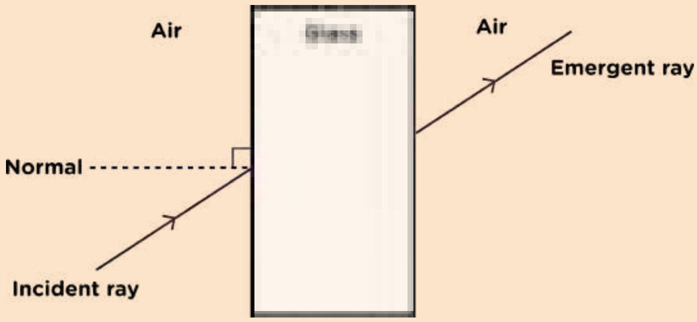
- glass block
- ray box, laser pointer or other light source
- protractor

METHOD:

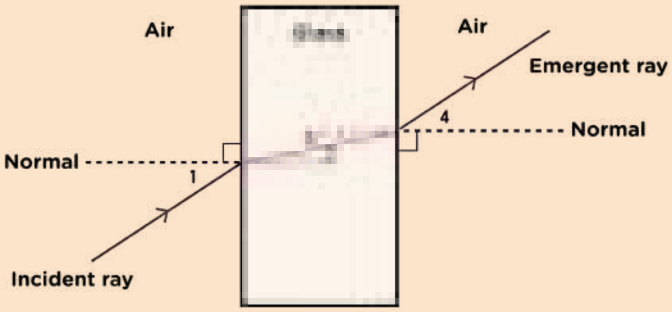
1. Put the glass block in the centre of a piece of white paper and trace around it.
2. Shine a ray of light into the glass block. The ray should be at an angle to the surface of the block.



3. Trace the light ray with pencil and mark the point at which it enters the glass block.
4. The light ray emerges on the other side of the glass block. Mark the point at which it emerges with a pencil and trace the emergent ray.



5. Remove the glass block. Your diagram should look similar to the one above.
6. Draw a line joining the incident ray and emergent ray. You have traced the refracted ray through the glass block.
7. Draw the normal lines where the incident ray meets the block and where the emergent ray leaves the block.



8. Measure the angles labelled 1, 2, 3 and 4 as shown on the diagram with a protractor.
9. Fill in the measurements in the table.
10. Repeat the steps above three times using different angles of incidence (angle 1).

RESULTS AND OBSERVATIONS:

Fill your results into the following table.

Experimental repeat	Angle 1	Angle 2	Angle 3	Angle 4
1				
2				
3				
4				

1. Which pairs of angles are equal in the measurements you have taken?

2. Which of the angles you measured are the angles of incidence and which are the angles of refraction? Write this down below and mark them on the diagram above.

3. What do you notice about the angle of incidence and angle of refraction for each of your sets of measurements?

4. Did the light entering the glass block bend towards or away from the normal line?

5. Make the angle of incidence zero (make the light ray enter the block perpendicular to the surface). What is the angle of refraction?

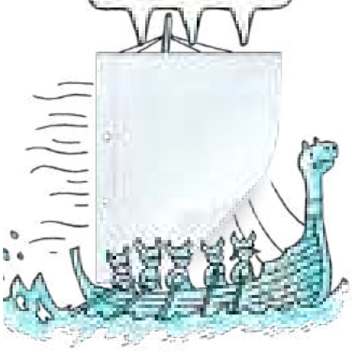
CONCLUSION:

What can you conclude from your results?

The angle of incidence is not equal to the angle of refraction because the light has changed direction as it enters the glass. Therefore, when light travels from one medium to another, it bends, or changes direction. This is called **refraction**.

TAKE NOTE

Remember that although we learn about Natural Sciences in 4 strands throughout the year, there are many connections and links between the strands.



VISIT

The speed of light in glass.

bit.ly/1fcfJVZ

When light enters a different medium at right angles then it does not change direction.

So why does the light refract? Light behaves as a wave does and waves travel at different speeds in different media. For example, light travels faster in air than it does in water. When light enters a different medium, it changes speed, and if it entered at an angle other than 90°, then it also changes direction. The more dense the medium, the slower the light moves.

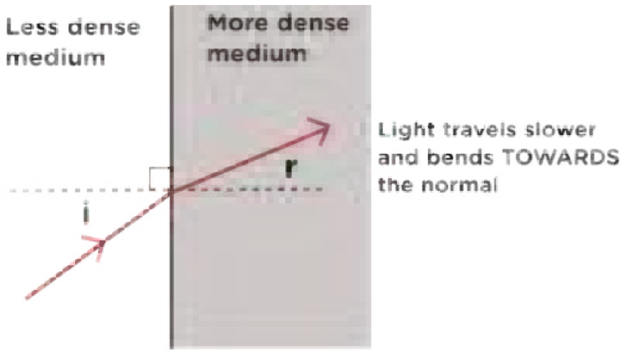
Do you remember learning about density last term in Matter and Materials? Write down your own definition for density in the space below.

____

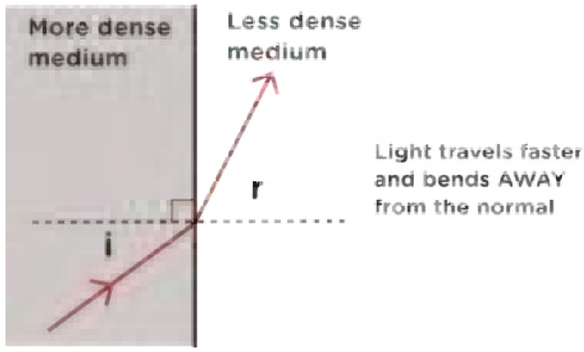
____

____

If light moves from a less dense medium, like air, into a denser medium, like glass, then the light slows down. The light will bend towards the normal line.



If light moves from a more dense medium to a less dense medium then the light speeds up and moves away from the normal.



When light refracts and changes direction as it passes through different mediums, it can distort what we see. Think back to the pencil or straw in a glass of water at the start of the section. We can now explain why a drinking straw or pencil in a glass of water looks bent. The light bends when it moves from one medium to another. Light moves from the air to glass to water, and therefore changes direction.

If you have stood in a pool of water before and looked down, have you noticed how short your legs appear to be? Let's have a look at this a bit more in the next activity.

ACTIVITY: Magic coin trick

MATERIALS:

- coin
- prestik
- opaque bowl or cup
- water

INSTRUCTIONS:

1. Work in pairs for this activity.
2. Put a small amount of prestik onto the bottom of the bowl.
3. Stick the coin to the bottom of the bowl.
4. Take small steps back from the desk/table until you cannot see the coin over the lip of the bowl.
5. Ask your partner to slowly pour water into the bowl and observe.

VISIT

Watch a video that shows and explains the coin activity.

bit.ly/15NmXXO

QUESTIONS:

1. What happened when your partner poured the water into the bowl?

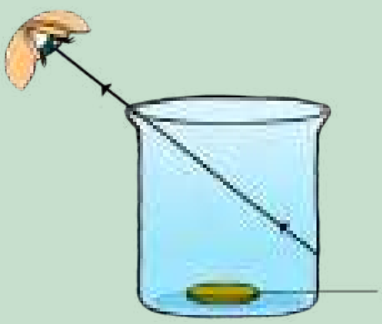
___

___

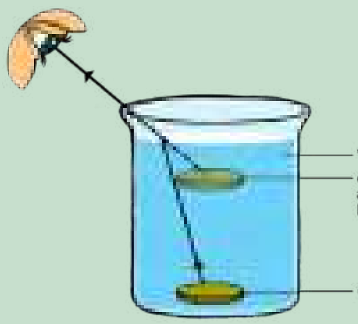
2. Where does the coin appear to be?

___

3. Explain why the coin can be seen when the water is added, but not before. The diagrams below will help you explain what is happening in words.



Empty container.



Container with water.

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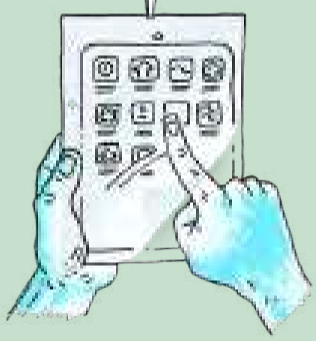
TAKE NOTE

The diagrams used here show the container as transparent so that you can see the coin inside, whereas you will actually be using an opaque container.



Refraction can be used to explain why images appear to be distorted when we view them through transparent mediums. For example, if you are looking at your legs or hands through some water, they will appear closer than they actually are as the light is refracted. Look at the photograph of the glass with water in it in front of diagonal lines. Can you see how the lines are distorted when the light travels through the water and glass compared to when it does not?

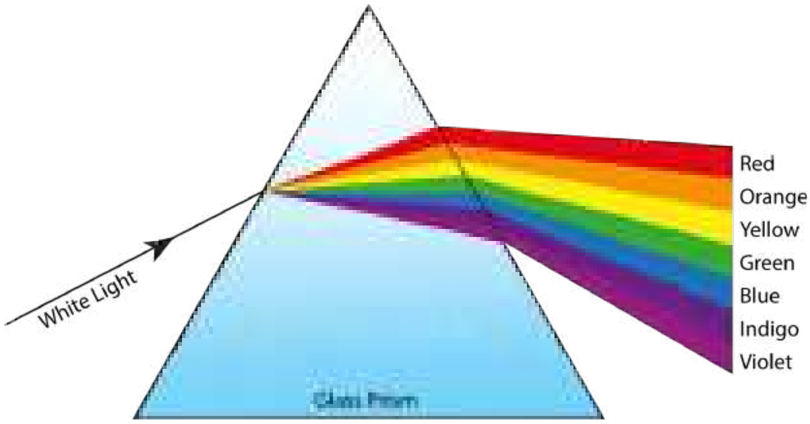
Light refraction through glass and water.

Can you remember how we split white light into the separate colours of the visible spectrum in the beginning of this chapter? What did we use to do this in the activity?

We can do this because the different colours of light bend by different amounts when the light enters a different medium. Different colours of light will slow down to different speeds, causing them to bend by different amounts.

Refraction through a triangular prism.

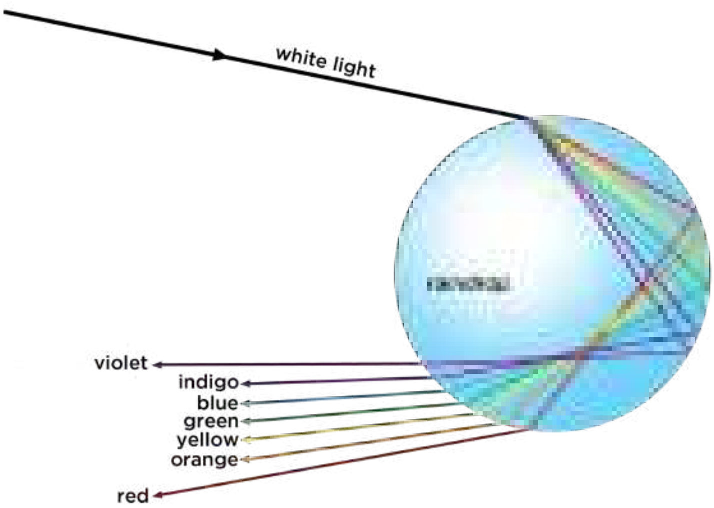
When the white light entered the prism it refracted. The different colours of light travel at different speeds in the prism so they refracted at different angles and split up. Red light refracts the least and the violet light refracts the most as you can see in the following diagram.



Prisms are not the only objects that can split white light into separate colours. In fact, a rainbow is a good example of white light splitting up.

A rainbow.

Light from the Sun enters the raindrops and refracts. The light is then reflected off the back of the raindrop. When the light passes out of the raindrop it is refracted again and the colours split up even more as shown in the diagram.

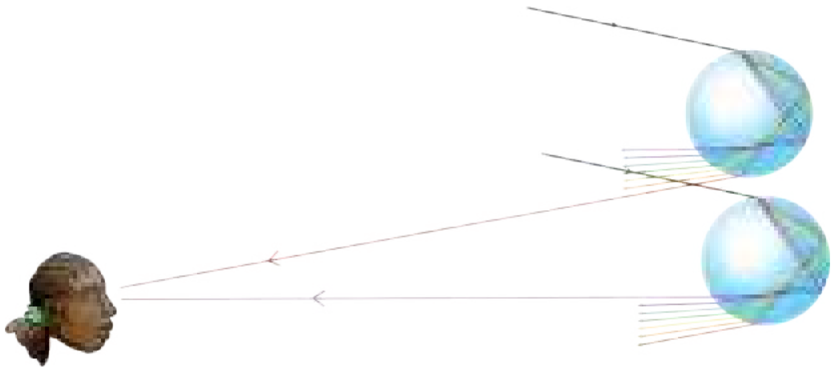


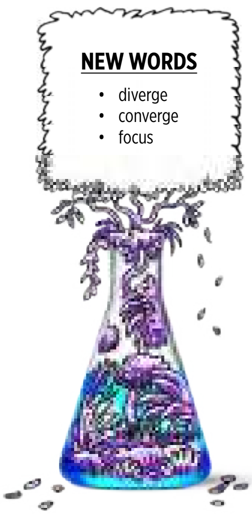
A raindrop refracts and reflects light, dispersing white light into the colours of the visible spectrum.

What colour is at the top of a rainbow and which colour is at the bottom?

Does this match the order which we see in the diagram showing how light is refracted and reflected in a raindrop?

How does this happen? When we see a rainbow, we see a combination of millions of raindrops. Although each raindrop refracts and reflects all 7 colours, we only see only colour of light reflected from each particular raindrop. This depends on the angle of the raindrop from our position. Therefore, the raindrops higher up in the sky reflect red light to us and the rain drops lower down reflect violet light to us. This is shown in the following diagram.





We see rainbows with red at the top and violet at the bottom due to the combination of millions of raindrops. We only see one colour reflected from a particular raindrop, depending on its position in the sky.

We are now going to look at an application of the refraction of light.

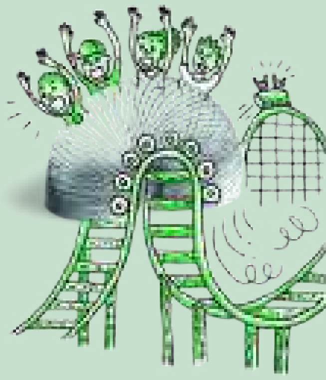
Lenses

Do you remember when we spoke about how we see light and the structure of the eye, we mentioned that there is a lens just behind the iris? Another place where you may have seen lenses before are in reading glasses which some people wear to correct their vision. Or, have you seen how a magnifying glass makes things appear bigger. What are lenses and how do they work?

A magnifying glass makes things look bigger.

A lens is a transparent object which focuses or refracts light. When light is spread out, we say it has **diverged**. Some lenses will diverge light while others will **converge** light, bringing the light rays together. When light rays are all brought to the same point, we say they have been **focused**. Let's have a look at this more closely.

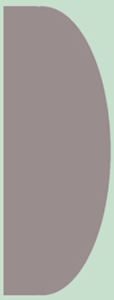
ACTIVITY: Diverging and converging light with lenses



MATERIALS:

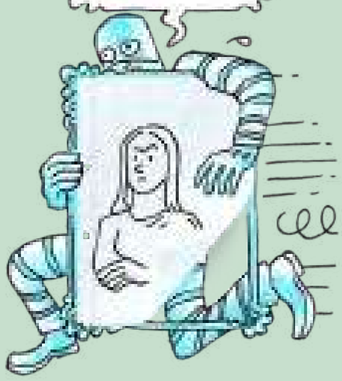
- ray box or light source
- concave lens
- convex lens
- piece of paper
- pencil

Before we start, it is important that you know the difference between a convex and a concave lens.

Convex lens	Concave lens
	
A convex lens has one side which curves or bulges **outwards.** A convex lens **converges** light.	A concave lens has one side which curves or is hollowed **inwards.** A concave lens **diverges** light.

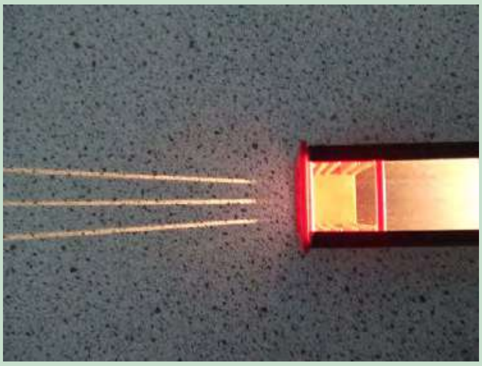
TAKE NOTE

A lens can have two sides which are concave and it is then called a biconcave lens or two sides which are convex and it is then called a biconvex lens.



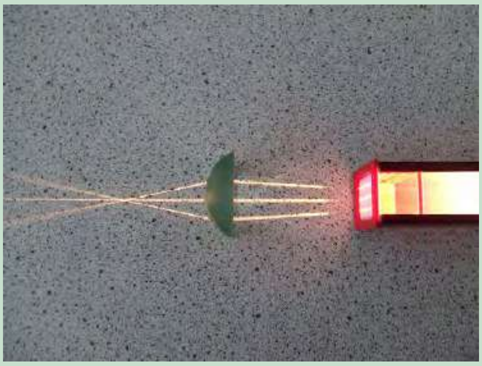
INSTRUCTIONS:

1. Place a ray box or light source on one side of a piece of paper and turn it on. Observe the light rays. You might see something as shown in the photograph here.



Three rays coming out of a ray box.

2. Turn the ray box off.
3. Place the convex lens (with the rounded surface) on the piece of paper where the light rays will pass through it. Trace around it.
4. Turn on the ray box or light source and observe what happens to the rays when they pass through the lens.



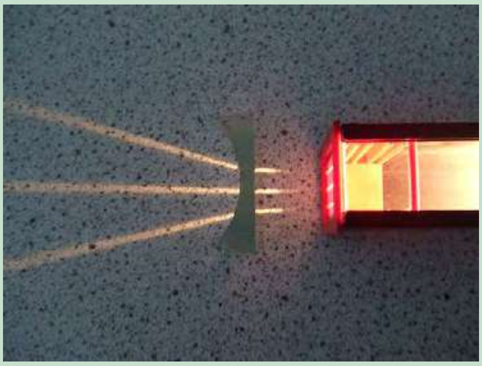
Light rays passing through a convex lens.

5. Trace the path of the light rays on your piece of paper.
6. Describe what has happened to the light rays.

---

7. Mark the point where the light rays cross. This is called the **focal point** of a convex lens.
8. Turn off the ray box or light source and place a new piece of paper in front of it.
9. Now place the concave lens in the path of the light rays and trace around the lens.
10. Turn on the light source and observe what happens to the rays.

11. Trace the path of the rays on the piece of paper.



A concave lens in front of the rays of light.

12. Describe what has happened to the light rays.

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13. Turn off the light rays and extend the rays you have drawn until they meet at a point in front of the lens. This is the **focal point** of a concave lens.
14. If you still have your pin hole cameras, place a convex and concave lens in front of the camera and observe the image that forms.

Viewing a light source through a pinhole camera with different lenses.

15. Is the image larger or smaller when you observe through a concave lens?

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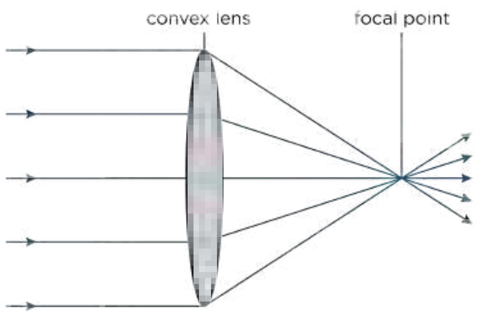
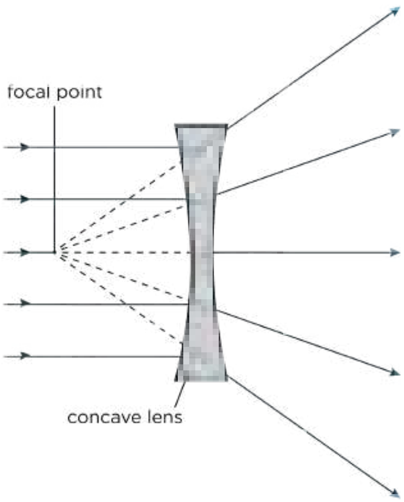
16. Is the image larger or smaller when you observe through a convex lens?

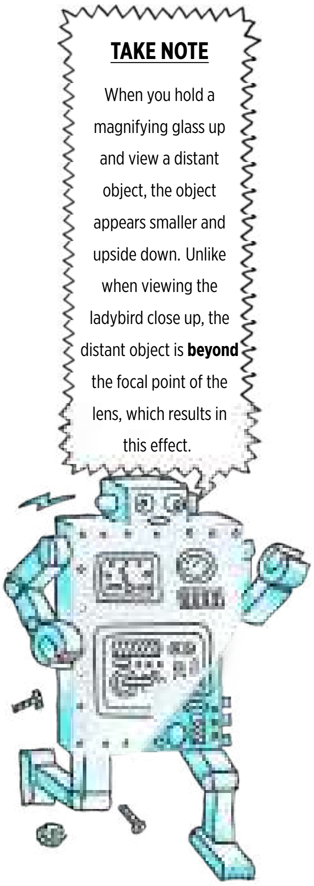
We have now seen how lenses can disperse or focus light. Have a look at the following diagrams which show how a biconvex lens converges light and a biconcave lens diverges light.

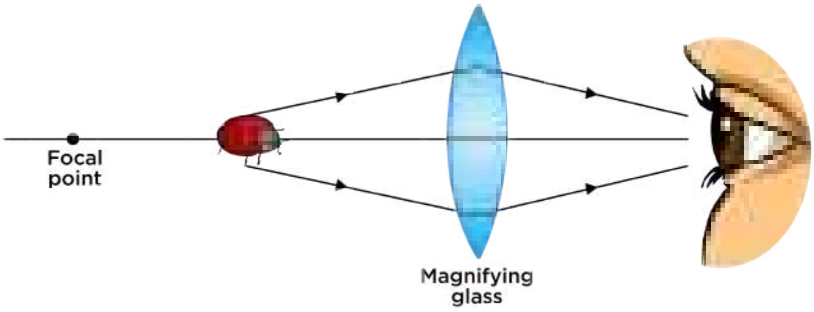
Converging lens	Diverging lens
	
A converging lens refracts the light entering it and bends the light rays to a **focal point** on the other side of the lens.	A diverging lens refracts the light entering it and bends the light rays away from each other. The light rays can be traced back to a **focal point** in front of the lens.

What do we use lenses for? Think of a magnifying glass. If you hold a magnifying glass over a picture or words then it enlarges the image. Is a magnifying glass an example of a diverging or converging lens?

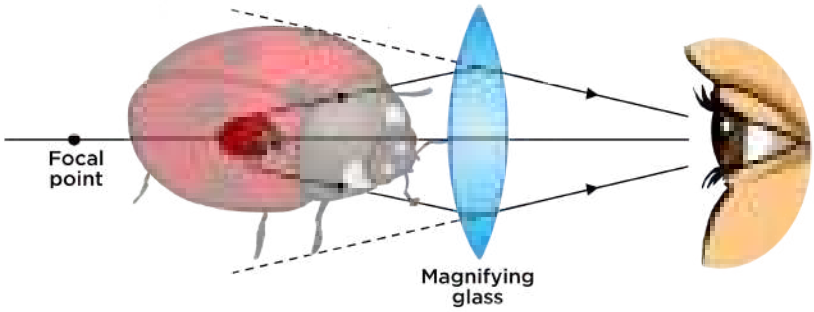
Let's think about how this works. Imagine you are looking at the ladybird from the beginning of the chapter through a magnifying glass. The ladybird looks bigger than what it actually is. When the object you are viewing is **closer** to the lens than the focal point, you see a virtual image of the ladybird that is **larger** than the object.

Have a look at the first diagram below. Can you see that the ladybird is between the focal point and the lens? The rays reflected from the ladybird are refracted by the magnifying glass and enter the person's eye.





In the next diagram you can see how your eyes see a virtual image of the ladybird which is bigger than the object. The more curved the convex lens is in a magnifying glass, the greater its ability to magnify objects.

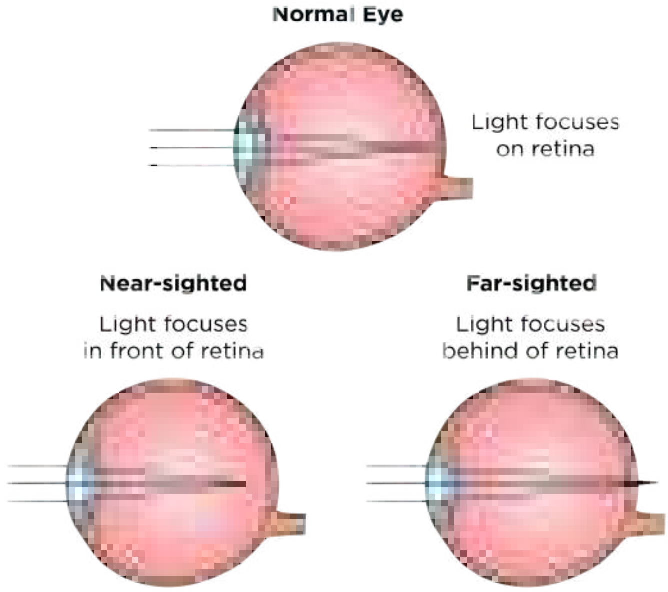


Do you remember what the human eye looks like? We have lenses in our eyes to allow us to see. The light enters the eye and passes through the lens. The lens focuses the light onto the back of our retina so that a clear image is formed. What type of lens do we have in our eyes? Give a reason for your answer.

____

____

In order for a clear image to form, the lens in our eye needs to focus the light rays coming into our eyes so that the focal point falls on the retina. This depends on the shape of the lens in our eyes. Sometimes, people have lenses in their eyes that cannot focus properly. Have a look at the following diagram which shows a normal eye and then an eye which focuses before the retina (near-sighted) and behind the retina (far-sighted).



Optical glasses, or spectacles, are used to correct near or far-sightedness.

If you are near-sighted you need a diverging lens. Would this be a biconcave or biconvex lens?

If you are far-sighted you need a converging lens. Would this be a biconcave or biconvex lens?

An optometrist holds a lens in front of a patient's eye to correct her vision.

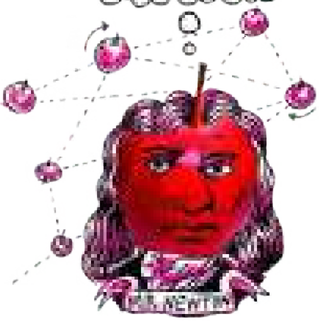
The following image shows how lenses can be used to correct far and near-sightedness.

DID YOU KNOW?

A contact lens is designed to rest on the cornea of the eye and correct vision. Leonardo da Vinci was the first to come up with the idea in the 16th century to help prevent eye infection.

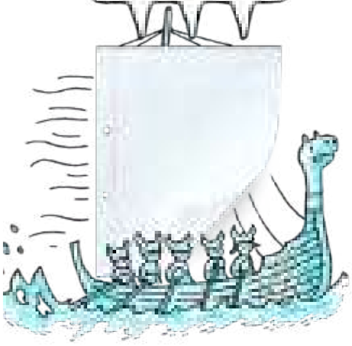
DID YOU KNOW?

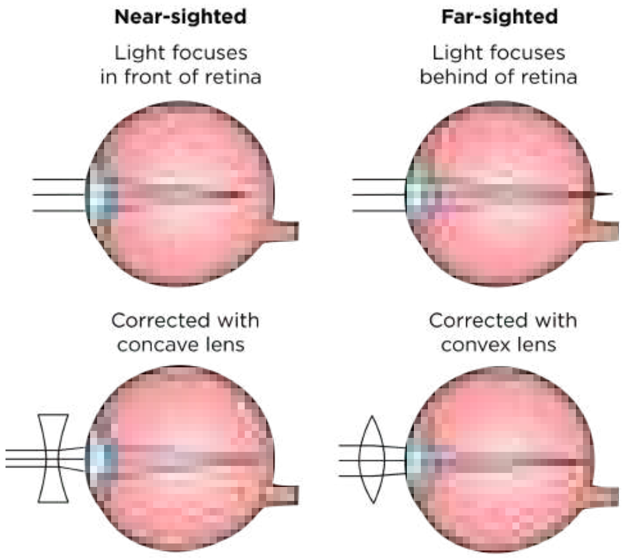
A **microscope** makes a tiny, nearby object look much bigger. A **telescope** makes a large, distant object look much closer and brighter. In both, light from the object passes through two or more lenses to form an image. The lens shapes and distances between them determine how the image is produced.

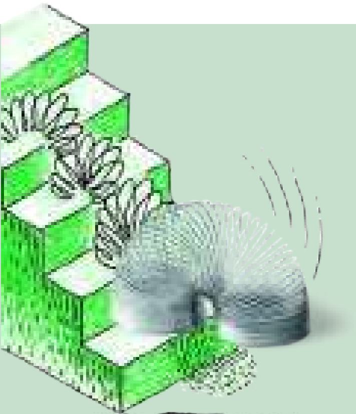


TAKE NOTE

Next term in Planet Earth and Beyond we will look at how lenses are used in optical telescopes to view objects in space.







ACTIVITY: Research careers in optics

There are many different careers in the field of geometric optics.

INSTRUCTIONS:

1. Work in groups of 3.
2. Interview someone in the field of geometric optics and find out how they chose their career and what and where they studied.
3. Write a paragraph explaining the career and the study options available in order to qualify for that career.
4. Here are some examples of careers in geometric optics.
   a) Optometry
   b) Ophthalmology
   c) Optoelectronics
   d) Illumination engineering

VISIT

An interview conducted with an optometrist.

bit.ly/19WxYYa

Remember to discover more online by visiting http://www.curious.org.za and by typing the links in the Visit margin boxes into your internet browser to watch any videos, play with simulations or read an interesting article.

Type the bit.ly link for the video or site that you want to visit into the address bar of your browser on your computer, tablet or mobile phone.

VISIT

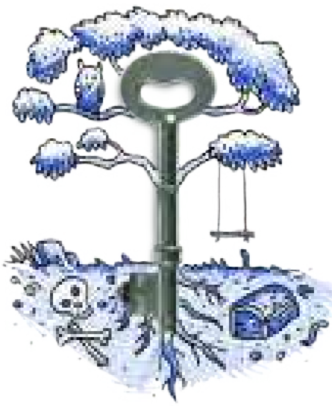
Want to take part in some real science research? Check out these citizen science projects to get involved easily.

bit.ly/15KjnmD

SUMMARY:

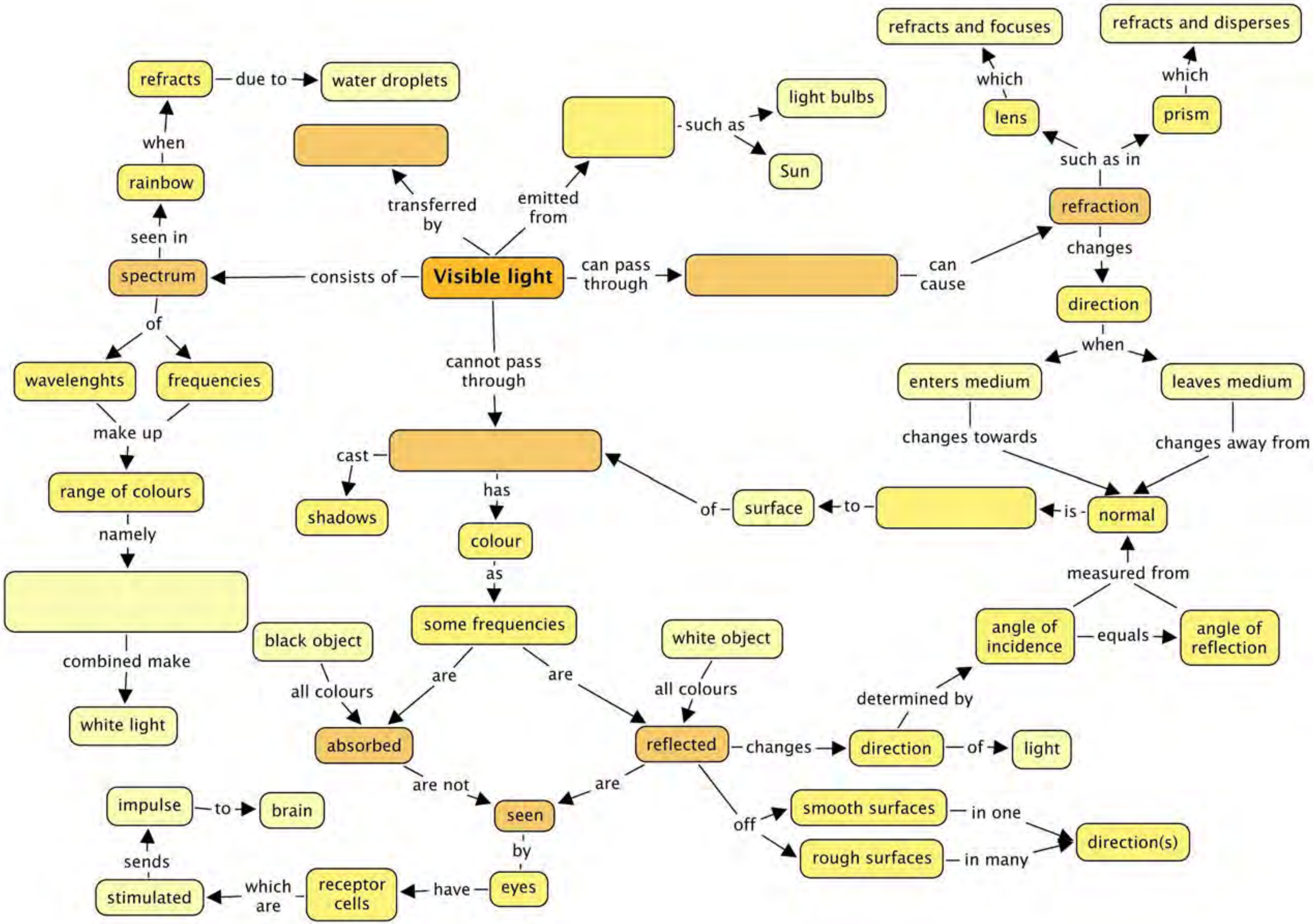
Key Concepts

- Light travels in straight lines.
- White light consists of all the colours of the visible spectrum.
- The colour spectrum can be seen when white light is dispersed by a prism or a raindrop (rainbow).
- Light cannot pass through opaque objects.
- Light can pass through transparent objects.
- Light is absorbed by some materials.
- A material appears to be a certain colour because it reflects that part of the colour spectrum. Other wavelengths of light are absorbed.
- In reflection, the angle of incidence is equal to the angle of reflection.
- On a smooth surface, parallel rays of light are all reflected at the same angle.
- On rough surfaces, the light is scattered and the image produced is not clear.
- The human eye has specialised cells in the retina which convert light into electrical nerve impulses. The nerve impulses are transmitted to the brain via the optic nerve, where they are interpreted.
- Light travels at different speeds in different media.
- When light enters a different medium at an angle, the light is refracted.
- If the light slows down, the light bends towards the normal line.
- If the light speeds up, the light bends away from the normal line.
- Converging lenses refract and focus light.
- Diverging lenses and triangular prisms refract and disperse light.
- Lenses have many applications, for example, in glasses to correct vision, microscopes, telescopes and magnifying glasses.



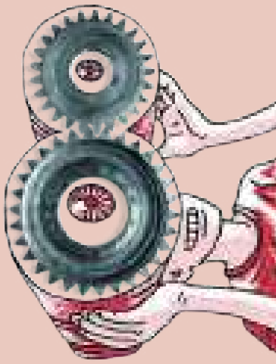
Concept Map

The concept map on the next page shows how all the concepts relating to visible light link together. Complete the map to reinforce what you have learned in this chapter.



Visible light
consists of
spectrum
seen in
rainbow
when
refracts
due to
water droplets
of
wavelenghts
frequencies
make up
range of colours
namely
combined make
white light
transferred by
emitted from
such as
light bulbs
Sun
can pass through
can cause
refraction
such as in
lens
which
refracts and focuses
prism
which
refracts and disperses
changes
direction
when
enters medium
leaves medium
changes towards
changes away from
normal
is
to
surface
of
cannot pass through
cast
shadows
has
colour
as
some frequencies
are
are
black object
all colours
absorbed
white object
all colours
reflected
changes
direction
of
light
determined by
angle of incidence
equals
angle of reflection
measured from
off
smooth surfaces
in one
rough surfaces
in many
direction(s)
are not
are
seen
by
eyes
have
receptor cells
which are
stimulated
sends
impulse
to
brain

REVISION:



1. Match the correct definitions to the terms in the following table. Write the letter of the definition next to the correct number below. [12 marks]

Term	Definition
1. Radiation	A. Light cannot pass through.
2. Visible light	B. The angle of incidence equals the angle of reflection when a ray is reflected off a smooth surface.
3. Opaque	C. One of the ways in which energy is transferred, specifically through a vacuum
4. Transparent	D. When light enters a transparent medium it can change direction.
5. Absorption	E. Curved inwards.
6. Reflection	F. The spectrum of light which we are able to see.
7. Retina	G. Bulging outwards.
8. Refraction	H. A transparent object able to refract and focus light.

Term	Definition
9. Diverging	I. Light can pass through.
10. Lens	J. When light rays are spread out from a point.
11. Concave	K. A layer of tissue at the back of the eye which is sensitive to light.
12. Convex	L. When the surface of a substance absorbs certain colours of light.

Answers:

1:

2:

3:

4:

5:

6:

7:

8:

9:

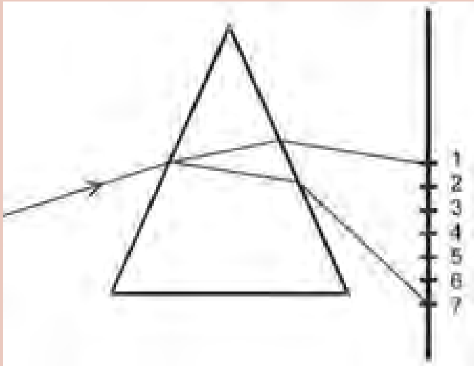
10:

11:

12:

2. A beam of white light is shone through a glass prism. It splits up into seven colours which are shone on a screen. A learner took a photograph which is shown below and drew a ray diagram to show the prism. The colours are marked 1 to 7 in the diagram.

A photograph of the prism.



A diagram drawn by the learner.

a) What does this tell us about white light? [1 mark]

b) Why does the light do this when it passes through the prism? [3 marks]

c) What colour is at label 1 and what colour is at label 7? Explain your answer. [3 marks]

d) What label corresponds to the colour of grass? [1 mark]

e) Can you see there are two other lighter, white rays emerging from the prism? What do you think this is the result of? [2 marks]

3. Why does an opaque object cast a shadow? [2 marks]

4. Look at the following photograph of water in a pond and answer the questions.

Water in a pond.

a) How are we able to see the image of the wooden poles sticking up on the edge of the pond? [2 marks]

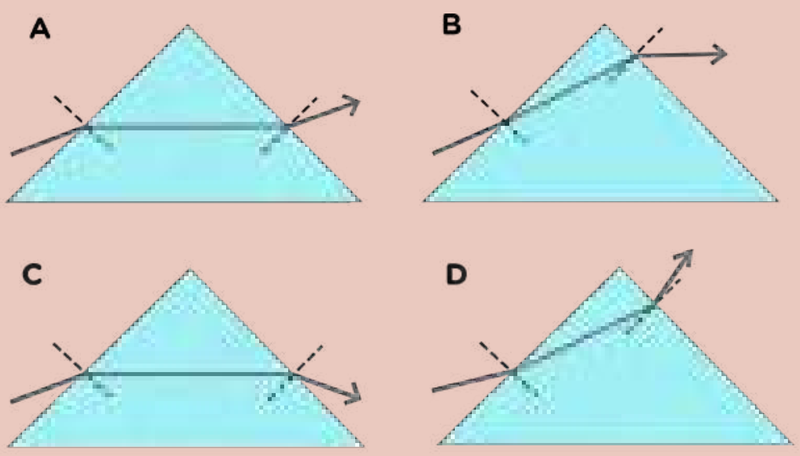
b) Why is the image not clear, but blurred? [2 marks]

5. Two learners are discussing the colours of light. They decide that white and black are not really colours of light. If they are not colours, then how can we see them? [5 marks]

6. Explain how we are able to see the different colours on the South African flag. [6 marks]

7. Draw a ray diagram in the space provided to show how we see the green part of the flag. [5 marks]

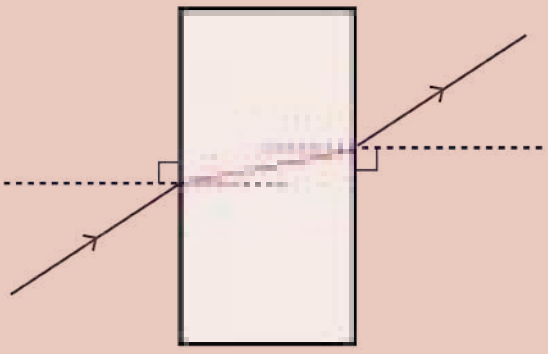
8. Which diagram shown below correctly shows the path of a ray of light through a triangular piece of glass? [2 marks]



9. Complete the following sentence and write it out in full on the lines provided: When light travels from a less dense into a more dense transparent medium, it refracts and bends __________ the normal line. When light travels from more dense to a less dense medium, it refracts and bends __________ from the normal line. [2 marks]

10. Draw a diagram to show what is meant by 'when the refracted ray bends towards the normal'. Mark the angle of incidence and angle of refraction. Indicate which medium is denser [4 marks]

11. Study the following diagram and answer the questions that follow.



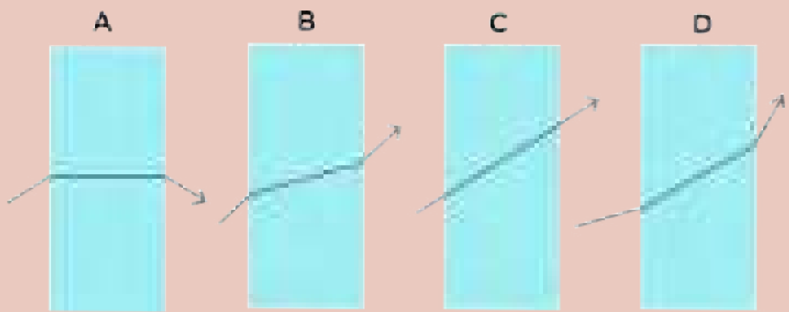
a) This diagram is a drawing that a learner made during an investigation into the refraction of light. What does the red line represent in this diagram? [1 mark]

b) What do the blue lines represent? Label this on the diagram. [1 mark]
c) The light passes from the air and into a block of another medium. Is this medium more or less dense than air? Give a reason for your answer. [2 marks]

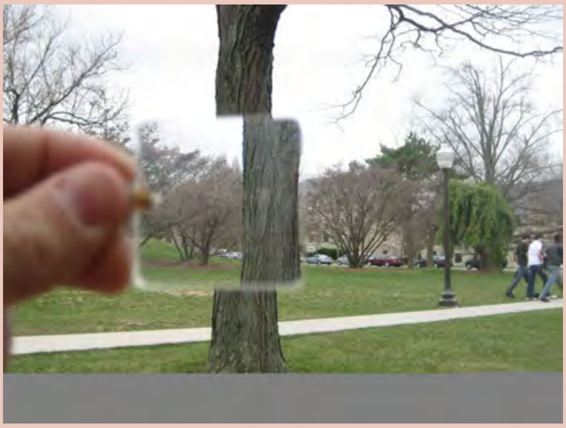
d) What type of medium could the block be made from? [1 mark]

e) Label the incident ray and the emergent ray on the diagram. [2 marks]
f) Label the angles of incidence (i) and angles of refraction (r) on the diagram. [2 marks]

12. Which diagram shown below shows the path of a light beam passing through a rectangular glass prism correctly? [2 marks]



13. Why does it look like the tree trunk in the photograph is skew? [2 marks]



14. What shape does a lens have to have in order to focus the light? [1 mark]

15. Draw a ray diagram to show how a converging lens focuses light to a point. [4 marks]

16. Which eyesight defect can be fixed by using a converging lens? Explain what this defect is and why it can be corrected. [4 mark]

Total [74 marks]

GLOSSARY

ammeter:	device that measures the strength of an electric current
ampere:	the standard unit for measuring electric current
angle of incidence:	the angle between the incident ray and the normal line
angle of reflection:	the angle between the reflected ray and the normal line
attract:	to pull something closer
cell:	a source of energy for an electric circuit
component:	a part of a larger system
composition:	the parts of a mixture
conductor:	a substance which easily transmits electricity, heat, sound or light
converge:	light rays that come together and focus on a point
delocalised:	not limited to a particular place, free to move
discharge:	the sudden flow of charged particles between two electrically charged objects
dispersion:	spreading of something over an area
diverge:	light rays that spread apart as they move further and further away from a point
earth:	(or ground) to connect with a conductor to the ground, or the earth
earthing:	a way to prevent electrical charge from building up on an object, or to neutralise an electric charge, by allowing the excess charge to flow into the Earth
electric circuit:	a complete path through which electrons can move
electric current:	the movement of charge in an electric circuit
electrodes:	a conductor which allows electricity to enter a substance
electrolysis:	the use of electricity to separate chemicals in a solution
electromagnet:	a device which becomes a magnet when electric current passes through it
electroplating:	covering an object with a thin layer of metal using electrolysis
electrostatic charge:	the electric charge resulting from static electricity caused by an excess or deficiency of electrons on the surface of an object
flammable:	something is easily set on fire
focus:	bring together to the same point
friction:	the resistance that results when two surfaces are rubbed or moved against each other
fuse:	a safety device designed to melt and break the circuit if an electric current reaches too high a level

ignite:	to light something
incident ray:	the ray of light which hits a surface
luminous:	bright or shining
medium:	substance through which waves (such as light) can travel
neutral:	when the number of positive charges (from the protons) is equal to the number of negative charges (from the electrons); the (positive and negative) charges balance each other so that the object is neither positively nor negatively charged
normal line:	this is an imaginary line which is drawn at 90° to the surface
opaque:	something that you cannot see through; no light passes through the object
optical density:	a measure of how well a medium allows light to travel through it
optics:	the scientific study of sight and the behaviour of light
parallel circuit:	a circuit that provides more than one pathway for the current to pass through it
perpendicular:	at right angles
propagation:	spreading into new areas
qualitative:	describing something in terms of its properties or characteristics rather than by a number or measurement
radiation:	the emission of energy as electromagnetic waves
rectilinear:	straight lines
reflect:	throw back without absorbing
reflected ray:	the ray of light which leaves a surface
refraction:	the change in direction of a wave passing from one medium to another caused by its change in speed
repel:	to push something away
resistance:	the opposition to the movement of charge in a conductor
resistor:	a component in an electrical circuit which slows the movement of charge
retina:	a layer at the back of the eyeball which is made up of light sensitive cells
series:	components connected in series provide only one pathway for electrical current; they are connected one after another
static electricity:	the build-up of a stationary electric charge (either positive or negative) on the surface of an object
stimulate:	to cause activity
switch:	a control component in an electrical circuit which opens or closes the circuit
translucent:	semi-transparent; some light is able to pass through but not enough for details to be seen clearly
transmit:	to cause light to pass through space or medium

transparent:	something that you can see through; light passes through the object
variable:	something that can vary or change
visible spectrum:	the portion of the wave spectrum that is visible to the human eye