Waves

Part 3 Light waves
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Lesson 11—Absorption of light

Light energy, light waves, light radiation and light rays all refer to the part of the electromagnetic spectrum that you can see with your eyes.

About half of the light energy that reaches the Earth’s surface is absorbed.

Activity: What happens to light energy from the Sun?

The percentage figures in the diagram above add up to more than 100%. Show your understanding by answering the following questions.

Write the quantities represented by these percentages under the figures:

1. Light radiation entering Earth’s atmosphere
   
   \[100\% = 50\% + 5\% + 20\% + 25\%\]

2. Light energy entering Earth’s atmosphere but then lost to space
   
   \[30\% = 25\% + 5\%\]
Over two-thirds of the Earth’s surface is covered with water. Most of the solar energy penetrates the water surface and is absorbed.

The small amount of ultraviolet radiation and the larger amount of visible light radiation that are absorbed are changed to heat energy.

In the oceans about:
- 55% of light energy is absorbed by 1 m depth
- 85% of light energy is absorbed by 10 m depth
- 99% of light energy is absorbed by 100 m depth.

Absorption of light energy by the hydrosphere

You have probably noticed that the colour of the sea depends on the depth of the water. Shallow water looks green because this colour is least absorbed and can be reflected back out of the water. For similar reasons deep water is blue. Note that blue is the least absorbed colour at 100 m depth.

Heat energy that is absorbed by the atmosphere, transferred to the atmosphere by the heated land and absorbed by the oceans is transferred around the Earth by an ocean ‘conveyor belt’.
The conversion of light energy to heat energy keeps the Earth’s surface at an average of 15°C. If there was no moving atmosphere or ocean ‘conveyor belt’ to trap and spread heat energy the average temperature of the Earth’s surface would be less than −15°C.

The heated oceans, land and atmosphere emit infra-red (IR) radiation. About 70% of the IR is lost to space. The remaining 30% is returned to the Earth by reflection from clouds and absorption and re-emission by ‘greenhouse’ gases in the atmosphere.
Activity: Explaining warm and cold nights

Have you noticed how warm cloudy nights can be? The water in the clouds absorbs IR from the Earth and re-emits the IR (heat) rays back to the Earth’s surface.

Write cause, effect or explanation after each of the following statements.

Cloudy nights are warm

Water in clouds absorbs IR from the Earth and re-emits the IR back to the Earth’s surface

IR from the Earth’s surface is absorbed by water in clouds

Check your answers.

How cold can a clear night become? On a clear night most of the IR escapes to space and the Earth’s surface cools rapidly.

Colour

The colour of a surface depends on which parts of visible light it absorbs and which part it reflects.

Visible light is made up of red, orange, yellow, green, blue and violet. These are the colours you see when sunlight is separated by rain drops to form a rainbow.

A red object appears red because it reflects red light and absorbs most of the other colours.

A white object reflects most of the light without absorbing any particular colour.

A black object reflects little light but absorbs all colours.
Investigating by using absorption of light

When light passes through a transparent triangular prism or small water droplets the light is split up into the visible spectrum of red, orange, yellow, green, blue and violet.

Activity: Splitting up light

What you need:

• triangular glass or plastic prism
• a water hose and water supply
• water atomiser or spray bottle filled with water
• corner of a rectangular glass aquarium

• coloured pencils or textas

What you do:

Observe light passing through the triangular prism/spray of water droplets from the hose or atomiser or spray bottle/corner of a rectangular glass aquarium.

Copy the colour pattern seen using coloured pencils or textas.
Results:

What you have drawn is called a continuous spectrum because it has no gaps.

An electric light globe also gives a continuous spectrum. When the tungsten metal filament is heated to a high temperature by electricity it gives a white light. What other type of electromagnetic radiation is emitted by the light globe?

You should also feel infra-red (heat) rays with your skin.

Activity: Observing spectra using a CD or DVD disc

Another way of splitting up light is to use the under surface of a CD or DVD. Hold the CD or DVD with its shiny surface uppermost, in front of you, towards a street light. Stand at a distance (about twice the height of the street light) away. Tilt the CD or DVD slightly until you get the clearest spectrum.

With an ordinary light globe you should see a continuous spectrum.
If you look at strong street, building or sports oval lights that give out bright white light or yellow street lights you should notice some bright emission lines with the continuous spectrum. This is called an emission line spectrum.

Bright lines seen from a bright white light are due to mercury in the lamp. Bright yellow lines are due to sodium vapour in the light. Each chemical element emits a different pattern of lines. The elements in a star billions of kilometres away can be determined by the emission lines in its spectrum.

The Universe contains giant clouds of dust and gas. The chemical elements in these clouds can be determined using absorption spectrum. The light of a star passing through a cloud will have certain absorption lines. These absorption lines determine which elements are present and how much of each element. Some yellow street lights show absorption of the red near orange.

A yellow streetlight can show emission and absorption. These are bright coloured areas of emission and a dark band between red and yellow.
Go to the exercises section and complete Exercise 3.1: Explaining why plants are green.

What did you achieve?

Tick what you can do.

☐ describe absorption of light energy by the atmosphere, hydrosphere and Earth’s surface

☐ describe absorption and reflection of infra-red radiation

☐ relate the different colours of surfaces to absorption and reflection of different parts of the visible spectrum

☐ explain how absorption of light can be used to investigate the Universe
Lesson 12 – Reflection of light

When you play ball games you have probably noticed that the angle at which a ball hits a flat surface is the same as the angle at which the ball reflects. This is easily seen when a ball bounces off the side of a billiard table, the surface of a table tennis table or the walls of a squash court.

If the ball hits a flat surface at 90° to the surface then the ball is reflected back along the same path.

Similarly, when you make sounds near a flat vertical surface the sound waves bounce back to you as an echo.
Activity: Reflecting light

What you need:

• a source of a light beam such as a torch, laser pointer or beam of sunlight coming into a darkened room
• a flat reflecting surface such as a mirror, flat surface of a watch, a CD or DVD

What you can do:

1 Set up the light source so that you have a light beam that is easy to see from the side. Avoid eye damage; the beam must not enter your eye. If you use a beam of sunlight into a dark bedroom, shaking the bedclothes to stir up dust makes the light beam very visible!

2 Hold the reflecting surface so that the light beam hits the reflecting surface. Change the angle at which the light beam hits the surface (angle of incidence). Note what happens to the angle of reflection.

3 Compare the amount of movement of the reflected light beam with the amount of movement of the reflecting surface.

4 Can you suggest a way of making a movement that is too small to see, visible to the unaided eye? Scientists have been doing this for hundreds of years with a light beam and a reflecting surface.

Check your responses by going to the suggested answers section.
Visualising reflection

Light waves are mostly simply represented by rays—straight lines with arrowheads—that show the direction the light waves are travelling.

The incoming ray is called the incident ray. The outgoing ray is called the reflected ray. An imaginary line drawn at right angles to the surface is called the normal.

The angles of incidence and reflection are the angles between the incoming and outgoing rays and the normal. For a flat mirror surface these two angles are always equal. Because this always happens in reflection a scientific law has been established, the Law of reflection:

\[ \angle i^\circ = \angle r^\circ \]

A beam of light can be represented by parallel rays. When the parallel rays are reflected from a flat surface they will still be parallel:

A curved mirror surface can be imagined as made up of many small flat mirrors.
When a light ray hits a curved mirror you can predict where the light rays will be reflected to by replacing the curved mirror with a series of small flat mirrors:

![Curved mirror replaced by a series of small flat mirrors](image)

**Internal reflection**

When light is moving from a dense medium where it travels slowly (e.g. water) to a less dense medium where it travels more quickly (e.g. air) it can undergo internal reflection. Internal reflection occurs when the angle of incidence is large. (The angle of incidence at which the light does not move into the less dense medium is called the critical angle.)

![Internal reflection diagram](image)

Internal reflection is used in the optical fibres of telephone systems and cable TV connections. The optically dense core is said to have a high refractive index while the outer, less optically dense, layer is said to have a lower refractive index.
Originally optical fibres transmitted visible light. Today most optical fibres use infra-red light that is less affected by defects than visible light.

Transmission by internal reflection through an optical fibre

Activity: Observing internal reflection

What you need:
- a transparent plastic tumbler or glass
- a coin
- water in a container

What you do:
1. Place the coin in the bottom of the glass at one side.
2. Hold the glass about 10 cm above and about 30 cm from your eyes with the coin away from you.
3. Add water to the glass until you have a few centimetres depth.
   Can you see a reflection of the coin from the water surface? If not, remove some water, add some water or move the glass until you can see the internal reflection.
Everyday situations involving reflection

A light source placed in front of a concave mirror produces parallel light rays. This is used in headlight reflectors, torches, searchlights, etc.

A convex mirror gives observer a wide rear vision view. This is used in shop security mirrors, on roads at ‘blind’ corners, in rear vision mirrors.

Go to the exercises section and complete Exercise 3.2: Predicting reflection.

What did you achieve?

Tick what you can do.

☐ use simple equipment to demonstrate reflection and internal reflection of light

☐ apply the law of reflection to predict path of reflected rays

☐ identify everyday situations where reflection occurs.
Lesson 13 – Refraction of light

Refraction is bending. Light usually travels in straight lines but it can appear to bend when it travels:

• through a medium whose properties change
• from one medium to another.

Activity: Observing refraction of light

What you need:
• a transparent plastic tumbler or glass half filled with water
• a pencil or straight stick

What you do:
1. Place the pencil half in the water at an angle to the water surface.
2. Observe the pencil from the side of the glass.
3. Observe the pencil from above the top of the glass.
4. Record your results in words and simple diagrams.

Results:
1. What I observed from the side.
2. What I observed from above the top of the glass.

Conclusions:
Complete the following statements by choosing the best answers.

When observed from the side, the section of pencil underwater appeared (thicker/same size/thinner). The two pencil halves observed at the interface between air and water were (in line/partly in line/completely out of line).

When observed from above, the half of the pencil in water appeared (longer/same length/shorter) and (bent/straight).

The bending of light when it passes out of the (water/air) to my eyes caused the effect of a change in appearance of the pencil half in (water/air).

Check your conclusions by going to the suggested answers section.

The diagram below shows how the appearance of a stick in an aquarium of water is changed by refraction of light. The bending of the light rays when they pass out of the water makes the observer think that they came from a different location.

When spearing a fish an experienced hunter would throw the spear below where the fish appears to be swimming to hit the fish.

Be careful entering water. Refraction of light from objects at the bottom can make the apparent depth less than the real depth.
The scientific understanding of refraction is based on the following facts.

- Light travelling through a constant medium travels in a straight line.
- When light passes the interface from one medium into another medium with different density, the light path bends.
- Refraction of light occurs only at the interface. Once the light has crossed the interface between the two media, it continues to travel in a straight line. However, the direction of that line is different.

Activity: ‘Magic’ using refraction

What you need:
- glass of water
- ceramic bowl or cup
- coin

What you do:
1. Place the coin in the bottom of the bowl on the side closest to you.
2. Move your head so that you can just no longer see the coin.
3. Add water to the bowl without moving your head.
4. What did you observe as you poured more water into the bowl?
Results:

Is this what you saw happen?

Conclusion:

Use this diagram to explain in words what happened.

Check your conclusion by going to the suggested answers section.

The whole shape of your eye is designed to make use of refraction in order to see more clearly.
Refraction of light by the eye

As light travels from one eye layer to another it refracts. Notice in the diagram below the way light bends so that it is focused on the retina at the back of the eyeball. Muscles shown around the lens can change its shape to assist in focusing.

The cornea, aqueous humour, lens and vitreous humour are all refractive media found in the eye. As you age, the dimensions of the eye change and the light rays do not meet on the retina at the back of the eyeball. The lens in older people cannot focus as well as it once did. Many older people need to wear glasses or contact lenses to help focus light onto the retina.

A far-sighted eye has difficulty seeing a close object.
A convex lens refracts light rays together and corrects far-sightedness.

A convex lens converges the image.

A convex lens corrects far-sightedness by focusing the image onto the retina.

A short-sighted person has too much refraction occurring in the eye.

A short-sighted eye viewing a distant object focuses in front of the retina.

A concave lens refracts light rays apart and corrects short-sightedness.
A concave lens corrects short-sightedness. Note that the lens is still curved outwards at the front but has a much deeper curvature at the back.

**Refraction of white light by a prism**

All wavelengths in this diagram are shown in nanometres (billionths of a metre).

Different amounts of refraction by the short and long wavelengths in white light produces the visible light spectrum.

Which colour is refracted the most? Red or violet light?

---

Violet.

Which wavelengths are refracted the most? Long or short wavelengths?

---

Short wavelengths.
Natural phenomena caused by refraction

1. Refraction followed by reflection of light inside raindrops produces a rainbow. To see a rainbow you need to stand with your back to sunlight and be looking at raindrops in the distant sky. The different colours of sunlight are refracted by different amounts and then reflected back inside each raindrop.

2. As the Sun sets it looks like a squashed sphere. The squashing appearance is due to refraction of light from the Sun.

3. The coldest time in the morning is usually just after the Sun has risen. Although you can see refracted light from the rising Sun the refracted infra-red (heat) rays don’t reach you until after the light.

4. The water-like layer that you can see on a hot bitumen road surface is due to refraction of light from the sky.

5. Mirages in desert regions are produced by refraction of light.

Go to the exercises section and complete Exercise 3.3: Using refraction with a magnifying lens.

What did you achieve?
Tick what you can do.

☐ use simple equipment to demonstrate refraction of light

☐ explain formation of a visible light spectrum using refraction

☐ identify everyday situations where refraction occurs.
Lesson 14 – Using a light raybox

A light raybox is a piece of equipment used to demonstrate the properties of light in a school laboratory.

Find more information about using a light raybox through diagrams, photos and videos by visiting the following website.

<http://www.cli.nsw.edu.au/Kto12>

Select Science, then Stage 5 and follow the links to resources for this unit, Waves.

Use the information in Part 3 Light waves of Waves on the website for this lesson.

If you do not have access to a computer, contact your teacher.

Step 1 Start by clicking on Using a light raybox

The photograph at the website under the heading Home shows the following:

- mirror surfaces for demonstrating reflection (plane [flat] mirror, slightly curved mirror, deeply curved mirror)
- transparent plastic blocks for demonstrating refraction (concave lens, thin convex lens, thick convex lens, rectangular block, equilateral triangular prism, isosceles triangular prism, hemispherical prism).

Many of these shape names you probably already know from your study of mathematics.

Concave and convex are two terms that are often mixed up. A concave surface goes in at the middle like the entrance to a cave. A convex surface is the opposite, it comes out at the middle.
Activity: Labelling equipment

Place the appropriate number on each item in the diagram below to label the equipment:

1. concave lens  
2. deeply curved mirror  
3. equilateral triangular prism  
4. hemispherical prism  
5. isosceles triangular prism  
6. plane mirror  
7. rectangular block  
8. slightly curved mirror  
9. thick convex lens  
10. thin convex lens

Check your labelling by going to the suggested answers section.

Step 2  Click the Raybox button on the left-hand menu.

The transformer changes 240 V electricity to 2–12 volts.

240 V electricity is too dangerous to use with the equipment as 240 V is sufficient ‘electrical pressure’ to push electricity through your skin and electrocute you. 12 V is not a high enough ‘electrical pressure’ to push electricity through your skin.
This transformer has a section that can supply DC or AC. AC is more economical.

The lamp inside the raybox can use 2–12 V depending on how bright you want the light.

Step 3 Go to Connecting the equipment.

Watch the video and read the information.

If you have access to equipment use the triple beam slide and move the adjust knob so that the light rays are parallel.

Step 4 Click the Mirrors button on the left-hand menu.

Note that the mirror is set up so that the middle light ray hits the middle of the curved mirror. This light ray is reflected back along its incoming path.

Step 5 Click the Refraction button on the left-hand menu.

Note that the outgoing light ray is parallel to the incoming light ray for the rectangular block.

Step 6 Click the Lenses button on the left-hand menu.

Compare refraction by thick and thin convex lenses.

Step 7 Click the Spectrum button on the left-hand menu.

The demonstration shows how violet light is refracted more than red light.

Go to the exercises section and complete Exercise 3.4: Using a light raybox to study reflection and refraction.
What did you achieve?

Tick what you can do.

☐ describe how to connect a transformer and raybox

☐ describe how to adjust a raybox to produce parallel light rays

☐ describe how to demonstrate reflection using a raybox

☐ describe how to demonstrate refraction using a raybox
Lesson 15 – Using light waves to study the Universe

Telescopes

Telescopes make distant objects visible by using reflection and refraction of light waves.

The first telescopes in the 1600s used lenses to refract light and produce large images. Dutch spectacle makers found that two lenses arranged one after the other could be positioned so a distant object appeared larger. The Italian scientist Galileo heard of this and built his telescope in 1609.

Galileo was the first human to see parts of the Solar System invisible to the unaided eye. He could see moons moving around the planet Jupiter. He provided evidence that everything did not move around the Earth.

Unfortunately, refraction in refracting telescopes like Galileo’s produced rings of colour around the image of the object being viewed. Refracting telescopes using lenses were replaced by reflecting telescopes using mirrors. Reflection from mirrors does not produce rings of colour. Colour was caused by lens refraction not mirror reflection.

In the late 1700s lenses were built of two different kinds of glass which cancelled out the ability of each other to form coloured rings. These lenses are called achromatic meaning without colour.

Refracting telescopes became popular again and the largest ever, with a 100 cm diameter lens, was built in 1897.

In the 1900s large telescopes built to explore the Universe were mostly reflecting telescopes. It was too difficult to build large lenses and large mirrors are lighter.

In the 2000s light signals from an array of large mirrors can be joined together using computers to get very clear images.
Telescopes used by people today mostly have this structure:

The Hubble space telescope

The Hubble space telescope (HST) was launched in 1990 to orbit the Earth 600 km above its surface.

After launching the primary mirror was found to be slightly out of shape and unable to focus on faint objects. This was corrected by a service crew flown to the low orbit HST by the space shuttle. By being above the Earth’s atmosphere the HST obtains extremely high quality images which are sent to Earth by radio waves.
Activity: Hubble space telescope (HST)

1. Why does the HST need solar panels that absorb light waves?
   ____________________________________________________________
   ____________________________________________________________

2. The HST has two mirrors. What are they called?
   ____________________________________________________________
   ____________________________________________________________

3. What is the main advantage of operating a telescope above the Earth’s atmosphere?
   ____________________________________________________________
   ____________________________________________________________

Check your answers by going to the suggested answers section.

The HST can be used to study the Sun as well as distant stars.

The different spectra help in understanding how the Sun works.
Spectroscopes

A spectroscope is a device for studying spectra of light. Light from a stellar object such as a star can be refracted by a prism to produce a spectrum. The spectral lines provide qualitative data (which chemical elements) and quantitative data (how much of each chemical element).

Spectra can be used to study the chemical elements emitting spectral lines from hot gas or the chemical elements in cold gas absorbing spectral lines.

Go to the exercises section and complete Exercise 3.5: Interaction of science and technology.
What did you achieve?

Tick what you can do.

☐ describe a historical case where development in science can lead to a new technological device

☐ describe a historical case where a technological device has transformed science
Suggested answers – Part 3

Check your responses against these suggested answers.

Activity: What happens to light energy from the sun?

1 Light radiation entering Earth’s atmosphere

\[
100\% = 50\% + 5\% + 20\% + 25\%
\]

\[
\text{light} = \text{absorbed by Earth’s surface} + \text{reflected by Earth’s surface} + \text{absorbed by atmosphere} + \text{reflection from atmosphere}
\]

2 Light energy entering Earth’s atmosphere but then lost to space

\[
30\% = 25\% + 5\%
\]

\[
\text{light} = \text{reflection lost from atmosphere to space} + \text{reflected by Earth’s surface}
\]

Activity: Explaining warm and cold nights

Cloudy nights are warm

Water in clouds absorbs IR from the Earth and re-emits the IR back to the Earth’s surface

IR from the Earth’s surface is absorbed by water in clouds

Activity: Reflecting light

2 Angle of reflection equals angle of incidence.

3 A very small movement of the reflecting surface produces a large movement of the reflected light beam.

4 Attach a very small reflecting surface to any equipment that could undergo movement too small to see. A long light beam reflecting from this surface will be seen to move if the equipment moves.
Activity: Observing refraction of light

When observed from the side, the section of pencil underwater appeared thicker. The two pencil halves observed at the interface between air and water were partly in line.

When observed from above, the half of the pencil in water appeared shorter and bent.

The bending of light when it passes out of water to my eyes caused the effect of a change in appearance of the pencil half in water.

Activity: ‘Magic’ using refraction

When water was added, light rays from the coin were caused to bend travelling from the water into the air. The bending made the light rays entering the eye appear to come from the furthest side of the bowl. The previously hidden coin can now be seen.

Activity: Labelling equipment

Activity: Hubble space telescope (HST)

1 Solar panels change light energy to electrical energy for the equipment.
2 Primary mirror and secondary mirror.
3 Electromagnetic radiation that is normally absorbed by the atmosphere can be observed.
Exercise 3.1  Explaining why plants are green

Photosynthesis involves chlorophyll absorbing light energy and the plant changing this energy to chemical energy stored in sugar.

Use the diagram below to explain why plants are green.

---
Exercise 3.2: Predicting reflection

Predict the paths of reflected light from this curved mirror surface by:
• replacing curved parts by drawing small flat mirrors
• applying the Law of reflection.

A pencil, rubber eraser and ruler will be useful.
Exercise 3.3 Using refraction with a magnifying lens

This activity requires access to a magnifying lens. This could be a hand lens (double folding magnifier in the basic kit for distance education students) or a magnifying glass or a convex lens.

You are going to work out the best way to use the magnifying lens to examine your fingerprints.

1 What are the best lighting conditions for seeing with the magnifier? Light from above your fingerprint? from the side? bright light beam or light that is spread out?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

2 Does it matter how far above your fingerprint that the magnifying lens is held? If it does, what is the best distance from fingerprint to lens?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

3 Using the best lighting conditions and the best distance from fingerprint to lens, does it matter where your eye is? If it does, what is the best distance from lens to eye?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Exercise 3.4  Using a light raybox to study reflection and refraction

Complete the missing words in the following statements:

1  A ________ changes the voltage of an electricity supply.

2  It is more economical to use _____ than DC electricity.

3  The adjust knob on a raybox is moved so that light rays coming out of the raybox are ____________.

4  If using a triple beam from a raybox the ___________ beam should hit the middle of the mirror or lens. If this is done the light ray is ____________ back along its incoming path.

5  When light is refracted by a rectangular block, the outgoing light ray is ____________ to the incoming light ray.

6  A convex lens brings light _______ together.

7  A concave lens spreads ________ rays further apart.

8  The more curved a lens is, the greater the __________ of light.

9  The more curved a mirror is, the greater the __________ of light.

10  The colour that is most refracted by a triangular prism is ________.
Exercise 3.5  Interaction of science and technology

What is the difference between science and technology?

Science deals with the natural world and tries to understand how it works. Technology deals with the made world and tries to use science to develop new devices.

1  In 1665 Isaac Newton found that a ray of white sunlight coming into a darkened room could be split up by a prism into different colours.

What technological device followed from this scientific development?

______________________________________________________________________________________

2  In the 1700s spectacle makers found that achromatic lenses could be made from two different glasses.

How did this technological device transform science’s ability to make observations with telescopes (and microscopes)?

______________________________________________________________________________________

______________________________________________________________________________________

3  In the 1800s chemists using spectrosopes found that each chemical element studied in the laboratory had a different set of spectral lines.

In 1868 a new spectral line for an unknown element was discovered in light from the Sun. This new element was called helium and was not discovered on Earth until 1898.

Discuss whether this an example of:

• a technological device following from a scientific development

OR

• a technological device transforming science.

______________________________________________________________________________________

______________________________________________________________________________________

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