7. HEAT, LIGHT AND SOUND

7.1 INTRODUCING HEAT, LIGHT AND SOUND

Heat, light and sound are rather strange things. We know they are there because we can sense them - we feel heat on our skin, we see light with our eyes, and we hear sound with our ears. We cannot touch any of them, or pick them up to examine them, however we can observe them, we can think about where they come from, and we can study what they do.

**Heat.** We need heat to keep warm, to cook our food and for other human activities. Where does heat come from? Our most important *source of heat* is the sun. Fire is a good source of heat too - remember the combustion equation in Module 6.8? Electric cookers, electric heaters and electric light bulbs all get hot - so do many machines such as the engine of a truck. Even our bodies make heat. You can feel the warmth of your own breath when you breathe out on a cold day. Any source of heat warms up nearby objects and these become secondary sources of heat. If we get close to a hot object, we can feel the heat coming from it. In many traditional cultures, stones are heated in a fire, then heat from the stones is used to cook food. We will learn about heat in the first part of this section.

**Light.** We need light in order to see! If it was always dark, we could not see what was going on in the world around us. As with heat, our most important *source of light* is the sun. At night we can sometimes see by moonlight and starlight, but not very well. We also use light that we make ourselves - such as firelight, candle light, oil lamps and, of course, electric light. Later in this section you will learn more about light; about shadows and images, and how they are formed, and why we see colours.

**Sound.** We need sound so that we can hear. Without sound we would not be able to talk to one another or enjoy music. We also rely on sound to warn us when something we cannot see is approaching us! Where does sound come from? Think about *sources of sound* - wind in the trees, waves on the beach, footsteps, machines and, of course, speech and music. All sources of sound involve movement - even in a radio you can feel the loudspeaker vibrating. You will learn more about sound and its relationship with movement at the end this section.

- 1. What is the name of the science that studies things that we cannot touch like heat, light and sound?
- 2. List some human activities that use heat.
- 3. Can you speak without moving anything?
- 4. Write a few sentences to try to explain to a blind or a deaf person what it is like to see or to hear.
7.2 HEAT - CONDUCTION AND INSULATION

Heat moves from one place to another in three different ways called conduction, convection and radiation. This section is about conduction.

When a metal spoon is used to stir a cup of very hot tea of coffee, the spoon quickly becomes very hot too. Heat from the hot water travels up the spoon by conduction. In the same way, if one end of a metal rod is placed in a fire, heat is conducted along the rod so that the whole rod soon becomes too hot to touch. Metals are good conductors of heat but most other materials are not. For example a plastic spoon conducts very little heat.

**Insulators** are substances that do not conduct heat well. Plastic, glass and wood are insulators and so are liquids and gases. A plastic spoon in a hot drink will not burn your fingers. Air is one of the best insulators. Fabrics such as wool trap a lot of air so they are very good insulators. Insulators can be used to keep heat in or to keep heat out!

**Activity to compare conduction in different materials.** Your teacher may be able to show you a practical activity like the one in this diagram.

When enough heat is conducted to the end of each rod, the vaseline melts and the match falls off. In the example above, copper is the best conductor so the match on the end of the copper rod falls off first. The iron is the second best conductor and the glass is the worst. Glass is an insulator (a bad conductor), so the match on the end of the glass rod may not fall off at all!

Using conductors and insulators. A cooking pan is a good example of how we use conductors and insulators. The pan is made of metal so the heat is conducted through it and cooks the food. The handle is made of an insulator such as wood or plastic so it does not get too hot to hold. Another example of insulation is wearing clothes to keep us warm in cold weather.

Iron is a good conductor. A house with an iron roof will heat up quickly when the sun shines. It will also cool down quickly at night or in cold weather. Traditional roofs are made from plant materials such as grasses or leaves. These materials are good insulators, mainly because they trap a lot of air. A traditional roof is better than an iron roof at keeping heat out - and also better at keeping heat in! Compared to a "modern" house, a traditional house tends to be cooler in hot weather and warmer in cold weather.

- 1. What kinds of materials are (i) good conductors of heat, (ii) good insulators of heat?
- 2. List additional examples (not given on the page above) of conduction and insulation in everyday life.
- 3. Try to explain why metals usually feel hotter than wood on a hot day, but colder than wood on a cold day!
7.3 HEAT - CONVECTION

Liquids are generally poor conductors of heat. Try the activity described in the box on the left. When you heat the water at the top of the test tube, it takes a long time for the heat to be conducted to the bottom. However, when you heat the water at the bottom, the top soon becomes too hot to hold. The reason is that hot water is lighter (has a lower density) than cold water. The hot water floats to the top! This process is called convection. Your teacher may show you the simple activity below to demonstrate convection. Study the picture carefully. As the hot water rises, it carries the purple colour of the crystals with it. Cooler water moves in to replace it. The cooler water in turn is heated and rises. The movement of hot water upwards and cooler water downwards is called a convection current and is shown by the arrows in the diagram below. Because of convection currents, all the water in the beaker soon becomes hot.

Your teacher may show you the simple activity below to demonstrate convection. Study the picture carefully. As the hot water rises, it carries the purple colour of the crystals with it. Cooler water moves in to replace it. The cooler water in turn is heated and rises. The movement of hot water upwards and cooler water downwards is called a convection current and is shown by the arrows in the diagram below. Because of convection currents, all the water in the beaker soon becomes hot.

Liquids and gases are called fluids because they can flow. Convection occurs whenever a fluid is heated. The hot fluid rises to the top and is replaced by cooler fluid.

Examples of convection. Think about what happens when we boil water in a pan. First heat is conducted through the metal pan and heats the water at the bottom. The hot water rises by convection and is replaced by cooler water from higher in the pan. This cooler water is now heated by conduction through the pan and the whole process continues until all the water boils!

A good example of convection is the smoke rising from a fire. Air that has been heated by the fire rises by convection and carries the smoke with it. Another example is the water cycle. Look back at Module 3.3. Hot air over the sea rises by convection carrying water vapour with it. High in the atmosphere the water vapour condenses into clouds and later falls as rain. Convection in the air also affects our weather in other ways. Two examples are sea breezes and land breezes, which are illustrated below.

On a hot sunny day, the land is hotter than the sea. Hot air over the land rises by convection. Cooler air from the sea rushes in to replace it. This causes a sea breeze that blows in from the sea.

At night, the land cools much quicker than the sea. Now the air over the sea is warmer. It rises by convection and cool air from the land rushes in to replace it. This causes a land breeze that blows out from the land.

1. What is convection? Explain convection currents.
2. Explain 3 ways convection affects weather.
7.4 HEAT - RADIATION

When we stand in the sun we can feel its heat on our skin. How does the sun's heat reach us? There is no metal to conduct it and no fluid to carry it by convection. In fact the heat travels straight through space, and through the atmosphere, in the form of heat rays. We say that the sun's heat reaches us by radiation.

Fires radiate heat. So do all hot objects such as stones and buildings that have been heated by the sun. When you sit near a fire, you are warmed by heat rays. But what happens if someone sits between you and the fire? The heat is cut off because heat rays travel in straight lines only. Heat rays cannot bend around objects that get in the way.

Emission, absorption and reflection of heat. Some kinds of surface emit (give out) heat better than others. Look at the illustration on the left below. A metal plate is heated in a fire or by several Bunsen burners. One side of the metal plate is light-coloured and shiny, the other side is black and unpolished. Bring your hands (which are sensitive to heat) close to the sides of the plate. You will find the dull black surface emits more heat than the light-coloured shiny surface.

Some kinds of surface absorb heat better than others. The illustration on the right shows how to compare the heat absorbed by a dull black surface and a light-coloured, shiny surface. Two metal plates are placed at the same distance from anything that radiates heat equally in all directions. The plates are exactly the same except that one has a dull black surface and the other has a light-coloured shiny surface. A pin is stuck onto the back of each plate with a little candle wax. When the metal plates absorb the radiant heat, the wax melts and the pins fall off. The pin on the dull black metal plate falls off first because dark, unpolished surfaces absorb heat better than light-coloured shiny ones. Another way of saying the same thing is that light-coloured, shiny surfaces tend to reflect heat while dark, dull surfaces absorb it.

Examples and applications. Radiation is used in heaters like the electric fire shown on the right. A coil of red hot wire produces heat, and a curved screen of shiny metal reflects the heat so that most of it radiates in front of the heater. A radiant heater warms people or objects which absorb the rays in front of it, but it does not heat the air in the room!

The diagrams on the left show what happens when heat from the sun falls on a brick that is made of red earth and the same brick when it is painted white. White bricks reflect about 60% of the heat and absorb only 40%. However, red earth bricks reflect only about 15% of the heat and absorb the remaining 85%. A house built with red earth walls will be hotter than one that is painted white. In the same way a dirty, dark coloured car will get hotter in the sun than a polished, light coloured car.

- 1. Name three different ways in which heat moves. Describe and explain how it moves in each case.
- 2. To make a light bulb into a heater, paint it what colour?
- 3. Explain why (i) you do not feel the heat if someone stands between you and a fire, (ii) an electric fire has a shiny metal screen behind the red hot element, (iii) people in hot climates often paint their houses white?
The most obvious effect of heat is that it makes things hot! The hotness of something is called its temperature. Heating anything increases its temperature. Another effect of heating may be a change of state. If a solid is heated it may melt, or a liquid may boil. Look back to Module 3.2 to revise changes of state. In this section we will look at a different effect of heat. Anything that is heated expands (gets bigger) - and when it is cooled it contracts (gets smaller). Expansion and contraction that are caused by heating and cooling are called thermal expansion and contraction.

### Thermal expansion of gases

For gases, even a small rise in temperature causes obvious expansion. For solids, however, even a large rise in temperature causes only a very tiny expansion. Liquids expand more than solids but less than gases.

### An air thermometer

This simple thermometer is a crude version of one that was invented by a famous Italian scientist named Galileo in about 1590. When the temperature of the room rises, the water in the tube goes down. When the temperature falls, the water level goes up again.

### Some effects of thermal expansion and contraction

Although solids expand only a little, the forces involved are very strong so the effects may be serious! Bridges, roadways and railway lines built of steel and concrete have small gaps to allow for expansion on hot days! Without precautions such as these, the steel would bend and the concrete would crack. When electric or telephone wires are hung from poles in hot weather, the workers must allow the wires to sag between the poles. If the wires are tight they will break when they contract in cold weather.

1. Try to explain how Galileo's air thermometer works. Why is this not a very good thermometer?

2. Why are there gaps between the ends of the bridge and the road?

3. Why do telephone wires sag in hot weather?
Thermometers. A thermometer is an instrument that measures the temperature or hotness of anything. As you learned in Module 1.6, the SI unit of temperature is degrees Celsius (°C). The freezing point of water and the melting point of ice are both 0°C, and the boiling point of water is 100°C. The normal temperature of a healthy human being is 37°C. The most familiar kind of thermometer is made from a thin glass tube called a capillary tube. The tube ends in a small bulb that is filled with a silvery liquid called mercury. When the bulb is warmed the mercury expands up the capillary tube and the temperature can be read on a scale.

In a laboratory thermometer, the mercury moves freely up and down the capillary tube, so the temperature must always be read with the bulb of the thermometer in the place where the temperature is to be measured.

In a clinical thermometer, there is kink in the capillary tube. This prevents the mercury contracting back into the bulb. This means that a clinical thermometer can be removed from the patient's mouth before it is read. After use, the mercury must be ‘shaken down’ before the clinical thermometer can be used again.

Mercury-in-glass thermometers are not the only kind! Other coloured liquids, including red ink, may be used in place of mercury for some purposes. However many industrial thermometers do not depend on the expansion of liquids - some use the expansion of solids and some do not depend on expansion at all.

Thermostats. A thermostat switches something off or on at a particular temperature. Domestic appliances such as irons, water heaters and refrigerators have thermostats in them. When the iron or the water is hot enough, or the fridge is cold enough, the thermostat switches off the electricity. This avoids the danger of the iron or the water becoming too hot, or the fridge becoming too cold. When the iron or the water cools down a bit (or the fridge starts to warm up) the thermostat switches the electricity back on so the appliance re-starts. A thermostat is always busy switching an appliance off and on again!

One common kind of thermostat uses a bimetallic strip. The strip is a made from two different metals (usually copper and iron) which are welded on top of one another. When the strip is heated, the copper expands more than the iron so the strip bends and operates a switch.

In the USA, temperatures are still sometimes measured in the old Fahrenheit scale (°F). On this scale water boils at 212 °F and freezes at 32 °F. The normal temperature of a human body is 98.4 °F. To convert between the two scales, we can use the following formulae:

C = (F – 32) x 5/9  \quad F = (C x 9/5) + 32

Where C in the temperature in Celsius and F is the temperature in Fahrenheit.

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Where C in the temperature in Celsius and F is the temperature in Fahrenheit.

1. (i) What does a thermometer measure? (ii) Who uses a clinical thermometer? (iii) What is the normal temperature?

2. Convert (i) 0 °C, 30 °C and 80 °C into °F. (ii) Convert 50 °F, 68 °F and 212 °F into °C. (iii) In your area, what might the temperature be on (a) a hot day, (b) a cold day?

3. (i) What is a thermostat? (ii) Which way does a bimetallic strip of copper and iron bend when it is heated? Explain why.
7.7 LIGHT - LIGHT AND SHADOWS

Light is a form of radiation. It travels outwards from the sun, or any other source of light, at the incredible speed of 300,000 kilometres per second. When light meets a solid object, most of it bounces off in all directions. We say the light is scattered. We see an object when the light scattered from the object enters our eyes. In Module 7.12 we will learn more about our eyes and how they work.

Hold a book at arm’s length in front of you. The book cuts off the view of objects behind it. Light scattered from the objects does not bend around the sides of the book. Light travels in straight lines only.

Find a light coloured wall that the sun is shining onto. If the sun is not shining, use an electric light bulb as your source of light. Hold a book between the light source and the wall. You will see a dark shadow of the book on the wall. Shadows are formed because light travels in straight lines. If you hold your book close to the wall, the shadow is about the same size as the book. But if you move the book away from the wall, the shadow gets bigger. If you study the diagram and think about it, you can see why.

You can have fun with shadows! Try shining a torch at the wall in a darkened room. Hold your hands between the torch and the wall and experiment to see if you can make shadows that look like animals or people’s faces. A sundial uses shadows cast by the sun to tell the time. To make your own sundial, fix a stick upright in the ground and mark the line of the shadow every hour. Two additional activities, which depend on light travelling in straight lines, are described below.

**Activity to show that light travels in a straight line.** Fold three cards so they will stand on a table. Make small holes (2 mm diameter) at exactly the same height in each card and loop a long piece of thread through them. Place the two end cards about 30 cm apart. Look through the two holes at a light source. Now move the middle card from side to side until you can see the light through all three holes. When the thread is stretched tight it shows that all three holes are in a straight line.

**Make a pin hole camera.** The sketches show how to make a "pin hole camera" and how it works. An image appears on the paper screen.

- 1. (i) What does it mean when we say light is scattered? (ii) How does scattering help us to see things? (iii) Why is it sometimes difficult to see a very clean sheet of glass? (iv) What is translucent glass and what is it used for?
- 2. The Earth is about 162,000,000 km from the sun. How long does it take sunlight to reach the Earth?
- 3. When you make the pin hole camera you will find that the picture on the screen is upside down! Explain why.

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**Transparent, opaque or translucent?** Transparent materials such as air, water, glass and some plastics do not scatter much light. Most of the light passes straight through them. However, most materials are opaque. Light cannot pass through them so it is scattered. A few materials are translucent - some light passes through them, but not enough to allow us to see clearly what is on the other side. Some kinds of thin paper are translucent and a translucent kind of glass is often used in the windows of toilets - it lets plenty of light get in, but no one can see through it!
7.8 LIGHT - REFLECTION AND MIRRORS

When a beam of light hits a very smooth surface, such as polished metal or a mirror, it is not scattered in all directions, instead it is reflected in one particular direction.

Careful measurements show that the angles of the incident and reflected rays are always the same. This observation has been summarised as a scientific law. The law of the reflection of light at a plane (flat) surface states that the angle of incidence is equal to the angle of reflection. Study the ray diagram below and make sure you can identify these angles. The normal is a line at right angles to the mirror.

The image in a plane mirror. When you look in a mirror you see an image of yourself. The image looks exactly like you, but when you try to shake hands, your image holds out the wrong hand! Hold up some writing and try to read it in a mirror. It is not easy because the writing in the image reads from right to left! The image in a plane mirror is laterally inverted - that means that left and right are the wrong way round.

Ray diagrams can help us to understand how images are formed. The ray diagram on the right shows three rays being reflected in a plane mirror. Imagine the three rays starting off from the end of your nose! Ray X hits the mirror at right angles and bounces straight back at you. Rays Y and Z hit the mirror at different angles and bounce off as shown. The image of your nose must be on the path of all these reflected rays. As you can see, the rays never meet but they all appear to come from the same point behind the mirror, where the dotted lines meet. That is the point where you see the image of your nose. The interesting thing is that the image is not really there at all! No light passes through the image so, unlike a real image, it can not be caught on a screen. It is called a virtual image.

- 1. What is (i) an incident ray, (ii) a normal? (iii) If the angle of incidence is 50°, what is the angle of reflection?
- 2. Why does the ray labelled X bounce straight back?
- 3. Four characteristics of an image of any object are: (i) its position, (ii) its size, (iii) its orientation (which way round it is) and (iv) whether it is real or virtual. Describe these characteristics for the image in a pin hole camera and the image in a plane mirror.

Check the law of reflection yourself. To get a narrow beam of light, cover the end of a torch leaving a thin vertical slit. Work in a fairly dark room. Fix a small mirror so it stands upright on a sheet of paper. Shine your torch at the mirror so that you can see the path of the beam on the paper. Use a pencil to draw the line of the mirror and of the incident and reflected rays. Later you can draw in the normal and measure the angles of incidence and reflection.
7.9 LIGHT - REFRACTION

Light normally reaches us through the air, however it can also travel through transparent materials such as water, glass and some plastics. When a ray of light passes from one transparent substance to another it bends as shown in the ray diagram below. This bending is called refraction.

When light passes from air to a denser substance, it is refracted towards the normal. When it passes from a denser substance back into air, it is refracted away from the normal. However, if the light is travelling along the normal it is not refracted at all.

Refraction leads to a number of interesting effects. If you look at a pencil in a glass of water, the pencil appears to be bent! Try it for yourself and see. Study the ray diagram below to find out why. Imagine two rays of light, X and Y, leaving the tip of the pencil and being refracted when they leave the surface of the water. An eye looking down these rays will see the tip of the pencil at Z. That is where the rays seem to come from; where the dotted lines meet. What you are seeing is not the real tip of the pencil, but a virtual image of it! Because of refraction water always looks a bit shallower than it really is. And if you are trying to spear a fish you must aim a bit deeper and a bit nearer yourself than the image of the fish that you can see!

Perhaps the most important use of refraction is in lenses. Lenses are used in many interesting devices. You will learn more about lenses in Module 7.11.

- 1. What are (i) reflection and (ii) refraction?
- 2. Which way does light bend when it travels (i) from water to air? (ii) from air to glass?
- 3. In the diagram above what the fisherman actually sees is only an image of the fish. Is this a real or a virtual image?
- 4. List 5 devices that use lenses.
Dispersion. When a beam of sunlight passes through the corner of a glass prism it is refracted twice. The first time as it enters the prism and the second time as it leaves. It is also dispersed (split up) into a band of colours called the spectrum. You can see the same effect by shining a torch through the corner of a prism in a darkened room.

A rainbow is a natural spectrum, so the colours of the spectrum are the same as the colours of a rainbow - red, orange, yellow, green, blue, indigo and violet.

Ordinary light (called "white" light) contains all the colours of the spectrum. During refraction in a prism, different colours are bent by different amounts (violet the most and red the least) so the light becomes split up. The lower diagram shows how another prism can be used to combine the colours forming white light again.

Mixing light. In physics, red, green and blue are called the primary colours. Red, blue and green light can combine to form all other colours. Colours made from two primary colours are called secondary colours. The secondary colours are yellow (red + green), magenta (red + blue) and cyan (green + blue). Combining all three primary colours (or all three secondary colours) gives white light. The different ways in which coloured lights combine are shown in the colour triangle on the right.

Colours in everyday life. The colour of an object depends on the light that it scatters. When white light hits any surface, some colours are absorbed and the rest are scattered. We only see the colours that are not absorbed. The skin of a ripe banana absorbs blue light, so we see the red and green light that is scattered. Red light and green light make yellow so that is the colour we see.

Rainbows. Sir Isaac Newton (1643 - 1727) was the first scientist to explain how rainbows are formed. Light is refracted as it enters a raindrop, reflected at the back of the drop, and finally refracted again as it leaves the drop. Red light is refracted least and violet most. The diagram shows how two drops at different heights refract red and violet to a particular observer. Other raindrops, between these two, refract all the other colours to the same observer.

Mixing paints. For an artist, the three primary colours are red, blue and yellow. All other colours can be obtained by mixing these three. Green can be obtained by mixing blue and yellow paints. How can we explain that? Well - paints are the colour of the light which they scatter. Yellow paint absorbs blue light, and scatters green and red light. Blue paint always contains a little green. It absorbs red light, but scatters some green light as well as blue light. The only light scattered by a mixture of both paints is green - all other colours are absorbed.

1. What is meant by (i) the dispersion of white light, (ii) the spectrum of white light, (iii) a primary colour?

2. A theatre has red and green spotlights. (i) What colour will you see where these two lights overlap on the stage? (ii) What colour will a yellow object appear to be when illuminated by the red spotlight? (iii) What colour will a blue object appear to be when illuminated by both spotlights?
7.11 LIGHT - LENSES

Lenses made of glass or plastic use refraction to bend light in special ways. There are two main kinds of lens. A convex lens is thicker in the middle and thinner at the edges - it makes a parallel beam of light converge and focuses the light to a point. A concave lens is thinner in the middle and thicker at the edges - it makes a parallel beam of light diverge (spread out).

The point where a convex lens focuses light is called its *principal focus*. The distance from the lens to the principal focus is called the *focal length*. For a concave lens, the principal focus is the point from which the refracted rays *appear* to come. A straight line passing through the principal focus and the centre of the lens is called the *principal axis* of the lens.

**Describing images.** Four pieces of information are normally used to describe the image of an object formed by a lens: (i) the position of the image relative to the object and the lens. (ii) the size of the image relative to the object (magnified, diminished or the same size). (iii) the orientation of the image (upright, inverted or laterally inverted). (iv) whether the image is real (light passes through the image so it can be shown on a screen), or virtual (no light passes through the image so it cannot be shown on a screen).

**Measuring the focal length of a convex lens.** Hold up a convex lens and a sheet of paper so that light from a bright window passes through the lens before reaching the paper. Move the lens towards and away from the paper until you see, on the paper, a clear image of the view outside. Ask a friend to measure the distance between the lens and the paper when the image is clearest. This is the focal length of the lens.

**Convex lenses.** In Module 1.3 you learnt how to use a convex lens to magnify a small object. The ray diagram below shows how a magnifying glass works. The object observed is closer to the lens than the principal focus. The image is further behind the lens than the object, and it is magnified, upright and virtual.

**Hints for drawing ray diagrams.** Draw an arrow (the object) upright on the principal axis. Draw two rays from the top of the object. This ray should be parallel to the principal axis. This ray is refracted so that it goes through the principal focus (for a concave lens, it appears to come from the principal focus). The second ray goes through the exact centre of the lens. This ray is not refracted. The top of a real image is found at the point where the two rays meet. If the two rays do not meet, the top of a virtual image is found at the point that the two rays appear to come from.

**Safety note:** Lenses bend heat rays as well as light rays. If a convex lens is used to focus the sun's rays onto a piece of paper, it focuses the heat as well as the light. After a short time the paper will catch fire. This may be fun, but it can also be dangerous! Always be careful if you use a convex lens when the sun is shining.

*The image in a hand lens is magnified, upright and virtual*
When you measured the focal length of a convex lens, you projected a real image on a screen. This happens when a convex lens is used in a projector or a camera. Look at the ray diagrams below. The object must be further from the lens than the principal focus. The image is always on the opposite side of the lens from the object, and it is always inverted and real. The size of the image depends on the position of the object. When the object is between one and two times the focal length away from the lens, the image is magnified. In a film projector, the film is only a little more than the focal length away from the lens and a very large image is projected onto the screen. To make the image right way up, the film must be upside down!

Convex lens projecting an image that is magnified, inverted and real (for example, in a film projector)

When the object is more than two focal lengths away from the lens, the image is diminished. This happens in a camera. The diminished image falls on the film or digital screen inside the camera.

Convex lens projecting an image that is diminished, inverted and real (for example, in a camera)

Microscopes and telescopes use combinations of convex lenses to enable us to see very small or very distant objects more clearly.

**Concave lenses.** Study the ray diagram. A concave lens always forms images that are on the same side of the lens as the object. The image is always diminished, upright and virtual.

Concave lenses always produce an image that is diminished, upright and virtual

Concave lenses are used in optical instruments including some telescopes. Both concave and convex lenses are used in spectacles.

- 2. Explain what you understand by each of the following: (i) a convex lens, (ii) the focal length of a concave lens, (iii) the principal axis of a lens, (iv) a projector, (v) an image that is real, magnified and inverted.

- 3. What kind of lenses are used in (i) cameras, (ii) projectors, (iii) microscopes, (iv) telescopes, (v) spectacles?

- 4. How can you test if a lens is concave or convex?
7.12 LIGHT - THE HUMAN EYE

We see when light enters our eyes. Each eye is contained in a sphere, about 3 cm in diameter, called an eyeball. Our eyeballs can be rotated by eye muscles so that we can point them in different directions. The lower diagram shows a simplified section through an eyeball.

Light enters the eye through a transparent skin called the cornea. The eyelid and eyelashes protect the cornea by keeping out dirt. Any dirt that gets past the eyelid is washed away by a watery liquid from the tear ducts. This liquid is called tears. Tears are mostly water but also contain a little salt and a mild antiseptic.

After passing through the cornea, light is focussed by the convex lens to form a real image on the retina at the back of the eyeball. The ciliary muscles can stretch the lens, increasing its focal length so that we can focus distant as well as nearby objects. Light reaches the lens through the pupil in the centre of the iris, which is the coloured ring of the eye. The pupil appears black because no light is scattered from it - all the light goes in! The iris controls the size of the pupil. When the light is dim, the iris draws back and the pupil becomes larger to let in as much light as possible. When the light is bright, the pupil becomes small so that too much light does not get in to damage the retina.

The lens forms an image on the retina. The image is diminished, inverted and real. The retina is made of cells that are sensitive to light. These cells detect the image and send messages to the brain through the optic nerve. Finally, the brain cleverly interprets what we see, so that it appears the proper size and the right way up (not diminished and inverted like the image on the retina).

Long and short sight. Most people who need glasses are either long sighted or short sighted. Long sighted people can not clearly focus objects that are too close to them. The lenses in their eyes are a bit weak. Glasses with convex lenses help them focus nearby objects. Short sighted people can not clearly focus objects that are too far away. The lenses in their eyes are a bit too thick. Glasses with concave lenses help them to focus distant objects.

**Binocular vision** means seeing with TWO eyes. This has two main advantages. (i) Two eyes give a wider field of vision than one. Some animals with eyes at the sides of the head can see all round, including behind, a full 360°! (ii) Animals with eyes at the front of the head, including humans and birds of prey, have a smaller field of vision, about 200°. The advantage is that they can see things straight in front of them from two points of view. This helps them to judge the distance, shape and position of objects very accurately.
7.13 SOUND - SOUND AS VIBRATION

Sit quietly and see how many different sounds you can hear. Think about what makes each sound. The main sources of sound are the weather, animals, human beings and machines. Sounds travel outwards from their sources in all directions and we hear them when they reach our ears.

Sound is NOT another kind of radiation like heat and light. We feel heat and light from the sun, but we never hear the sun! Sound does not travel through empty space. Unlike heat and light, sound does NOT travel only in straight lines. Sound goes around corners so we often hear someone coming before we can see them.

In fact sound is simply vibrations - a rapidly repeated shaking, back-and-forth or up-and-down. Look at the examples illustrated and think about what is vibrating. When we ring a bell or hit an empty gas cylinder, the metal vibrates. If you put the back of your hand against it, you can feel the vibrations. When a guitar is played, the strings vibrate and when you blow a whistle or a flute, the air inside vibrates. When we listen to a radio or a sound system, a loudspeaker produces the vibrations - if it is a big one, you can easily feel the vibrations. The vibrations we call sound are very fast. The lowest sounds we can hear (deeper than a big man's voice) have a frequency of at least 20 vibrations every second. The highest sounds we can hear (like a very high whistle) have a frequency of about 20,000 vibrations per second. You will learn more about the frequency of sounds at the end of this section. The vibrating object shakes the air next to it and the vibrations spread out through the air like ripples spreading across a pond after a stone is dropped in.

Speaking. When we speak, air from our lungs is forced through our voice box, which is also called the larynx. The illustration on the right shows where to find your voice box. Put your hand on your voice box and hum the lowest note you can. You should be able to feel the vibrations. In your voice box, the air from your lungs passes rapidly over two tightly stretched membranes called the vocal chords. The moving air makes the vocal chords vibrate. We control the exact sounds that come out by using muscles attached to the vocal chords and also by moving such things as our tongue, our teeth and our lips. It is very complicated so it is no surprise that babies take quite a long time to learn to speak clearly.

- 1. Explain how sounds travel from a vibrating source to our ears.
- 2. What are the highest and lowest frequencies of sound vibrations that can be heard by the human ear?
- 3. What vibrates when we speak?
7.14 SOUND – THE SPEED OF SOUND

Sound vibrations spread outwards from their source like ripples on a pond after a stone has been dropped in - but much faster! The vibrations travel through the air at a speed of approximately 330 m/s. The exact speed varies slightly with the wind and with the temperature of the air.

Sound vibrations travel through the air in all directions, easily passing round most obstructions. However, when a sound meets a cliff or a high wall head on, it is reflected back towards its source. When we hear a sound reflected back to us, we call it an echo. If you stand between 100 and 200 metres from a high wall and clap two blocks of wood together you will hear a clear echo. You can use this echo to measure the speed of sound.

Measuring the speed of sound. You need a stop watch, two blocks of wood to clap together, and a high wall to give an echo. You will need to measure your exact distance at right angles from the wall in metres. The distance should be between 100 and 200 m.

1. Clap the wooden blocks together and listen for the echo. Clap steadily and try keeping time with the echoes. When you get a steady rhythm, use the stop watch to time 50 claps. Record the time (T seconds).

2. Measure and record the distance to the wall (D metres).

3. Now to work out the speed of sound! The time between two claps is T/50 s. In that short time, the sound has travelled to the wall and back, a distance of 2D m. We know that speed = distance/time, so

\[
\text{Speed of sound} = \frac{2D}{T/50} \text{ m/s} = \frac{100D}{T} \text{ m/s}
\]

In a storm, we see the lightning before we hear the thunder. Light (travelling at 300,000,000 m/s) takes almost no time to reach us, but sound (at only 330 m/s) lags far behind! If you count the seconds between the flash and the thunder you can work out how far away the lightening is - 330 m for every second.

Sound requires a medium to travel through. Something must vibrate to pass on the sound. But the medium does not have to be air. In fact, sound travels faster through water than it does through air. It travels even faster through solids!

1. List three things that affect the speed of sound.

2. Look up the sound barrier and explain it to your class.

<table>
<thead>
<tr>
<th>Speed to compare</th>
<th>Human</th>
<th>10 m/s</th>
<th>36 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race horse</td>
<td>20 m/s</td>
<td>72 km/h</td>
<td></td>
</tr>
<tr>
<td>Racing car</td>
<td>50 m/s</td>
<td>180 km/h</td>
<td></td>
</tr>
<tr>
<td>Jumbo jet</td>
<td>260 m/s</td>
<td>950 km/h</td>
<td></td>
</tr>
<tr>
<td>Sound</td>
<td>330 m/s</td>
<td>1190 km/h</td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>300,000,000 m/s</td>
<td>1.08 x 10^9 km/h</td>
<td></td>
</tr>
</tbody>
</table>
We hear something when sound vibrations in the air reach our ears. To understand how the ear works study the diagram, which shows a section through an ear. The ear flap (pinna) funnels sound vibrations down the ear hole to the ear drum. The ear drum is a tight membrane that transmits the vibrations to three tiny bones (the ossicles) called the hammer (malleus), the anvil (incus) and the stirrup (stapes). The ossicles magnify the vibrations and transmit them to another membrane called the oval window. The oval window transmits the magnified vibrations to a liquid that surrounds a coiled organ called the cochlea. The cochlea is lined with fine hairs that detect the vibrations and pass information to the auditory nerve. Finally the auditory nerve passes the information to the brain, which interprets it as the sounds we hear.

The ear flap and the ear hole are often referred to as the outer ear. The ear drum, the ossicles and the oval window make up the middle ear, and the cochlea is situated in the inner ear.

The middle ear is filled with air and is connected to the back of the throat by a tube called the Eustacian tube. This tube is closed except when you yawn or swallow. Normally, the air in the middle ear is at the same pressure as the air outside - the pressure is the same on both sides of the ear drum. When you go up or come down in a plane, or dive under the sea, the external pressure changes rapidly, but the pressure inside the middle ear may remain the same. If this happens you feel pain because of the unbalanced pressure on your ear drum. You may hear a 'pop' as the Eustacian tube opens to equalise the pressure. Many air lines give out sweets when their planes are climbing or descending. This encourages passengers to swallow, which opens their Eustacian tubes. If the pressure is not equalised, the ear drum may burst which is very painful and may lead to deafness.

Binaural hearing. Just as two eyes help us to judge the position of things we see, two ears help us to judge the position of things we hear. You can have fun checking this with a partner. The subject must cover his or her eyes with a blindfold. The experimenter can then make the same clear sound in different positions. The subject tries to point to the source of the sound. Some interesting and amusing effects can be obtained using funnels and rubber tubes as illustrated. When the funnels are crossed over the subject is misled about where the sounds are coming from! The funnels and tubes can be used to listen to very quiet sounds too. Try using one to listen to your own or your friend's heart beating.

- 1. List, in order, all the parts of the ear that pass on sound vibrations.
- 2. What often causes pain in the ears of deep-sea divers?

The semi-circular canals. In addition to the cochlea, the inner ear contains the semi-circular canals. These have nothing to do with hearing. They consist of three semi-circular tubes, one in a horizontal plane and two in vertical planes at right angles to each other. They contribute to your sense of balance, especially when you are moving. The canals contain a liquid with solid granules floating in it. When you move, the granules brush against fibres, which send information to your brain. This helps you to be aware of the position of your body and to maintain your sense of balance. People with a disease of the inner ear feel 'dizzy' and may be unable to stand or walk without falling!
7.16 SOUND - PITCH AND VOLUME

Sounds differ in many ways. In this module we look at two ways of describing a sound - *pitch* (how *high* or *low* it is) and *volume* (how *loud* it is).

**Pitch.** The word *pitch* refers to the highness or lowness of a sound. A referee's whistle makes a high pitched sound, and a lion growling makes a low pitched sound! In Section 7.13 you learnt that the pitch of a sound depends on the *frequency* of the vibrations. The frequency is the number of *complete* vibrations (back-and-forth) every second and it is measured in *hertz* (Hz) - the higher the frequency, the higher the pitch of the sound.

A very low rumbling, like a lion's roar or the engine of a big truck, has a frequency of about 20 Hz. A very high shrill sound, like the referee's whistle or a child screaming, has a frequency of 10,000 Hz or more.

**Changing pitch.** Line up several glass bottles, all the same kind, and fill each to a different level with water. Tap each bottle with a pencil or spoon and listen to the sounds. Try to make a musical scale and play a tune! Try to find, or make, a 'bird whistle' and 'pan pipes' like the ones illustrated. Listen carefully to how the notes change when you play them.

You will find that the more water there is in the bottle, the higher the pitch of the sound you get when you tap it. When you push in the plunger on the bird whistle, the pitch of the note gets higher. With pan pipes, shorter tubes give higher notes. In these examples, the sound comes from the vibration of the column of air in the bottles or the whistle. The rule is, the shorter the column of air, the higher the pitch of the sound.

Try to find a guitar or similar instrument. Gently pluck each string. See it vibrate and listen to the sound. What happens to the sound if you tighten or loosen a string? What happens if you make the vibrating part of the string shorter by putting your finger on one of the frets? The rule for a vibrating string is the same as the rule for a vibrating column of air - the shorter the string, the higher the pitch. There are two more rules for vibrating strings: the *tighter* the string the higher the pitch, and the *thinner* the string the higher the pitch. So the *highest* notes come from strings that are short, thin and tight.

**Volume (or loudness).** The volume (or loudness) of a sound depends on the amplitude (or size) of the vibrations - the bigger the back-and-forth vibrations, the louder the sound. When you hit a drum or a bell gently, the amplitude of the vibration is small and the sound is soft. When you hit it hard the amplitude of the vibration is large and the sound is loud.

- 1. Give examples of (i) high, (ii) low and (iii) medium pitched sounds.
- 2. Who/what could hear whistles with pitches of (i) 15,000 (ii) 30,000 Hz?
- 3. How do you play, on a guitar, notes that are (i) high, (ii) low, (iii) loud?

**Units of frequency.**
The unit of frequency is *hertz* - symbol Hz. A frequency of 1 Hz means one complete vibration (back and forth) every second.

**Limits of hearing.** The *lowest* frequency that most people can hear as a continuous sound is about 20 Hz. The highest frequency varies a lot for different people but is usually between 10,000 and 20,000 Hz. Young people can usually hear higher sounds than older people and many animals can hear much higher frequencies that humans. For example, high-pitched whistles can be made for calling dogs. When you blow the whistle you can hear nothing, but your dog can hear it and come to you! Bats make very high pitched squeaks that most people can not hear. They use echoes from their squeaks to help them to find their way in the dark!

**Units of loudness.** The loudness of a sound is measured in *decibels*, symbol dB. The quietest sound we can hear is 0 dB. An increase of 10 dB corresponds to a doubling of the volume. An ordinary conversation between two people has a volume of about 50 dB and the horn of a car, if you are standing next to it, has a volume of about 100 dB. You will find more about decibels in the next module.
Almost everyone enjoys music but no one likes noise very much. So what is the difference? Well, music is usually played on musical instruments, and musical instruments are tuned so that they only play notes of a definite pitch or frequency. In most modern music, the notes are arranged in scales of 8 notes called octaves. You may know the scale doh, re, mi, fa, soh, la, ti, doh, which is often used in singing. When several musical instruments are played together, they must all be in tune. In the same way, singers must sing notes of the correct pitch, or they sound out of tune! In music, the sequence of notes, and the rhythm, is usually planned in advance and follows familiar rules. Noise is quite different - there are no fixed notes and sounds of many different frequencies are mixed up together. Noise has no set patterns. It usually happens without being planned at all.

Musical instruments are often classified as strings, wind and percussion. String instruments are played by making the strings vibrate. This is done by pushing and pulling a bow across the strings (as in the violin and cello), or by plucking the strings (as in the guitar). Each string is tuned by tension (tightness), and different notes are played by pressing fingers onto the string to change the length that vibrates. Wind instruments, such as the flute, trumpet and pan pipes, are played by blowing into them and making the air inside vibrate. Different notes are played mainly by changing the length of the column of vibrating air. Percussion instruments are played by hitting something; in drums, a stretched skin; in xylophones, strips of metal or bamboo. The piano is a percussion instrument in which 'keys' are pressed to make small 'hammers' hit long strings! In percussion instruments, the object that is hit vibrates. These instruments are tuned in advance by choosing the correct size and tension for the vibrating objects.

Noise as pollution. Noise can be a form of pollution. Noise pollution occurs when people can not obtain the quiet they need to concentrate on a difficult task, or to sleep. It also occurs when pleasant or important sounds are difficult to hear because of unwanted noise. Study the decibel chart opposite. Remember, an increase of 10 dB means that loudness doubles. Very loud noise, above about 120 dB, causes pain and is dangerous to health. Even moderate noise can damage our ears if we are exposed to it for a long time. Because of this, workers who use noisy machines protect their ears with thick ear pads.

1. What vibrates in a (i) violin, (ii) xylophone, (iii) pan pipes, (iv) piano, (v) trumpet?
2. (i) How many notes are there in an octave? What is the frequency of the C two octaves above middle C (ii) on the scientific standard, (iii) on the musical standard?
3. (i) How does the volume of sound in a quiet library compare with the volume of sound in a normal conversation? (ii) Is holding a conversation in a library 'noise pollution'?