

SNC2D-B



**Physics: Light and
Geometric Optics**

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Introduction

In both visible and invisible forms, light surrounds you. Your eyes, if you can see, use visible light to help you interact with your world, gaze upon sunsets, and recognize faces. Invisible forms of light are used to broadcast TV and radio signals, diagnose medical problems, and help predict the weather. Light of all kinds from the sun provides the energy to drive life on this planet. In fact, light is so much a part of our lives that we take it for granted. But what is light? What produces it and how has it been used to create beneficial technologies?

In this unit, you will learn what light is, how it is formed, and how it is used in modern technologies.

Overall Expectations

- demonstrate an understanding of the properties of light, especially with respect to reflection in both plane and curved mirrors, along with refraction in converging lenses
 - predict the formation of images by different types of mirrors (plane, curved) and converging lenses
 - evaluate the effectiveness of various optical devices (cameras, eyeglasses) and their benefit to society
- At the end of this unit there is a Practice Test. It will help you prepare for the Final Test. You will not be marked on the Practice Test, but you should try to answer all the questions.
- The Practice Test is on your course page on the ILC website, along with the Practice Test Suggested Answers so that you can mark it yourself. Instructions will be given at the end of Lesson 20.

SNC2D-B



See the Light: Properties and Sources

Suggested Timing for This Lesson (hours)	
Sources of Light	½
Activity 1: Triboluminescence	¼
What Is Light?	2
Activity 2: Sunset in a Glass	½
Key Questions	1

You may find this time grid helpful in planning when and how you will work through this lesson.

Planning Your Study

Do you realize that you obtain most of your information about the world around you by interpreting energy? If you are a sighted person crossing a busy road, you rely mainly on your eyes to let you know when it's safe. For the most part, people know what's happening around them because of the light that enters their eyes—and light is a form of energy.

When you were an infant, your brain learned to use light energy to obtain information about the world around you; now it's so natural you hardly ever think about it. But it's because of light that you can watch television, listen to the radio, read printed words, take and view photographs, and enjoy the colours of nature. If you think about it, the list of things we need light for is almost endless.

But what do you know about light? What are its properties? And how is it produced? This lesson will introduce you to the basic properties of visible light and the ways in which we've come to understand and use them. Later lessons will explore how light rays move around and how the basic properties of light have been used to create technologies that enrich your life.

Introduction

What You Will Learn

After completing this lesson, you will be able to

- explain the different ways visible light can be produced
- describe how the basic properties of light produce an image for your eyes
- describe the significance of shadows as they relate to light
- identify the visible and invisible parts of the electromagnetic spectrum
- demonstrate how the visible spectrum helps produce the colour of an object

Sources of Light

Humans have long been fascinated with light. It makes us feel safe on a dark night and gives us colours to enjoy. Over a million years ago, our evolutionary ancestors knew how to create light using fire. Thousands of years ago, ancient civilizations learned how to create mirrors to move light around. People have always wondered what light is and where it comes from, yet we knew almost nothing about the nature of light until the last 300 years. Even today we are still learning about its fundamental properties. However, we can now answer some basic questions, like where light comes from and what it's made of.

Anything that gives off its own light is referred to as **luminous**. The flame of a candle, the sun, a glowing light bulb, your TV or computer monitor when turned on—all are considered luminous and all are sources of light. Anything that does not produce its own light is **non-luminous**. The pages of this book are non-luminous; you can see them only because you're using a light source to cast light on this page. Look around you and see what luminous objects are allowing you to read this paragraph.

Luminous objects can produce light in a variety of different ways, all by converting some form of energy into light. The eight main types are described below. To see examples of light sources, go to your course page on the ILC website and click on "Types of Visible Light Sources" under Lesson 16.

Chemical

When ignited, a substance such as gasoline, wood, or wax will give off light as well as heat because of the chemical energy stored within it.

Heat

If heated to a very high temperature, a piece of metal starts to glow and gives off light. This process is referred to as **incandescence**. The light we see from the sun is largely produced by this process.

Electrical

Electricity can be used to produce light in many ways, such as in plasma and LCD TVs, lasers, neon signs, and LED lights. But you're probably most familiar with using electricity to power an old-style light bulb. In this case, an electric current passes through a very thin wire (the "filament") in the bulb, causing the metal to get hot and glow. We call these incandescent light bulbs because they use incandescence (see above) to generate light.



Fluorescence

Fluorescent substances give off a visible light when exposed to ultraviolet light (sometimes called "black light"). This process is referred to as **fluorescence**. Fluorescent lights produce visible light by first using electricity to produce ultraviolet light inside a tube. When these ultraviolet rays strike a fluorescent coating inside the tube, visible light is produced.

Phosphorescence

As soon as a fluorescent tube is switched off, it stops giving off light. However, some substances continue to give off light after the energy source is switched off. These substances are said to be phosphorescent, and the process is referred to as **phosphorescence**. Glow-in-the-dark Halloween toys and the painted luminous dials on some watches are made of phosphorescent material.

Chemiluminescence

Chemiluminescence is the process of changing chemical energy into light with little or no heat produced. Safety lightsticks, found in many car emergency roadside kits, produce light using chemiluminescence. In these lights, a sealed glass tube containing a chemical is placed inside a plastic rod that contains another chemical. When the plastic rod is bent, the glass tube inside breaks and the two chemicals react as they mix. A light is produced until the chemicals finish reacting.

Bioluminescence

Bioluminescence is similar to chemiluminescence, except it occurs in living things that produce light through a chemical reaction. Fireflies; glow-worms; and some types of fish, bacteria, and fungi display bioluminescence.

Triboluminescence

In **triboluminescence**, light is produced by scratching, rubbing, or crushing a substance. Some minerals such as fluorite will display this property, along with sugar and Wint-O-Green Life Savers™. Pulling some brands of adhesive tape from the roll may also produce this effect.

Activity 1: Triboluminescence



Purpose

Create triboluminescence using a Life Saver™ candy.

Materials

- a dark room
- a mirror
- Wint-O-Green Life Saver™ candy
- sugar cubes

Procedure

1. Find yourself a room, such as a closet or bathroom, that you can make completely dark. If light is leaking in under the bottom of the door, put a towel against it. You want the room so dark that you can barely see your hand in front of your face.
2. Wait in the room a few minutes so your eyes become accustomed to the dark.
3. Face the mirror so that you will be able to see your mouth.
4. Place a Wint-O-Green Life Saver™ candy between your teeth, keeping your mouth open, and bite down. Be quick—once the candy gets soggy, it will not produce any more light. You can also crush the candy with pliers to get the same effect.

Analysis

You should be able to see a flash of blue light coming from your mouth as you bite. If you haven't got a mirror, have someone else bite the candy while you watch. To some extent, triboluminescence also occurs when you strike two sugar cubes together, but it is harder to see this very faint light. In a dark room, try striking one sugar cube against the other as if you were trying to strike a match. A faint bluish-white flash of light will result.

Support Questions

Do not send your answers in for evaluation.

1.

If the space inside an incandescent light bulb were filled with air, the oxygen in the air would react with the glowing filament, which would quickly burn up. In order to make the bulbs last longer, this problem had to be solved. How was it solved? Use the Internet to help you with the answer.



Figure 16.1 Incandescent bulb
Source: iStockphoto.com

2.

Why are many people switching from incandescent bulbs to compact fluorescent bulbs (like the one shown on the next page)?

What is Light?

Visible light can be simply defined as a form of energy that can be detected by the human eye.

As you have seen, other forms of energy, such as electrical and chemical, can be changed into visible light. Light can also be changed back into other forms of energy. For example, the solar cell in calculators converts light energy into electrical energy to run the calculator. Since energy has the ability to produce motion, we can even use light to make things move. You may have seen a toy in a science store or on TV called a radiometer. It looks a bit like an old-style light bulb with little black and white squares mounted on some fine wires inside a glass bulb with all the air sucked out of it. When light shines on the squares, the light energy causes these squares to rotate.

This principle can be useful for more than toys. There are proposals to build spacecraft that could travel great distances using “solar sails” to capture sunlight and turn that energy into motion.

When light strikes a surface, it can be absorbed, transmitted, or reflected. A substance such as glass will transmit most of the light, whereas a mirror will reflect most of it. For us to see a non-luminous object, at least some of the light hitting it must be reflected from the object into our eyes. If the light is absorbed, it gets converted into other forms of energy, such as heat. That’s why a dark lawn chair gets hot sitting outside in summer.

There are Suggested Answers to Support Questions at the end of this unit.

Figure 16.2 Compact fluorescent bulb

Source: iStockphoto.com



Support Question

3. In order for us to see an object, the light from the object must enter our eyes. So how can an object be made invisible?

Why Do Shadows Form?

Light travels in a straight line until its path is interrupted or deflected by a change in the material it's travelling through (you'll learn more about that in Lesson 18). Scientists refer to this property of light as **linear propagation**. When it strikes an opaque object, light cannot pass through it; in consequence, a dark region forms behind the object. This dark region is referred to as a **shadow**.

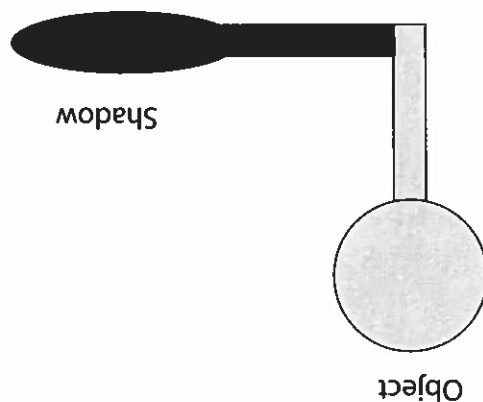
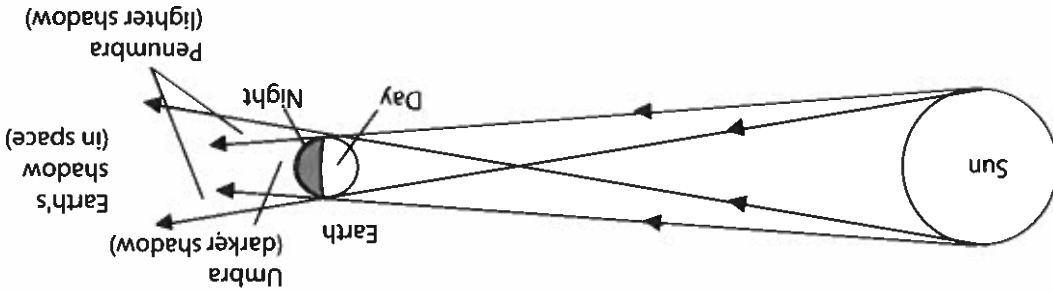


Figure 16.3 Shadow formed by an object in sunlight

The shadow is formed because light travels in straight lines and gets blocked by the object. You can't see around corners or through opaque objects because the light reaching your eyes only travels in straight lines. If the light is blocked, it can't reach your eyes and so you can't see it.

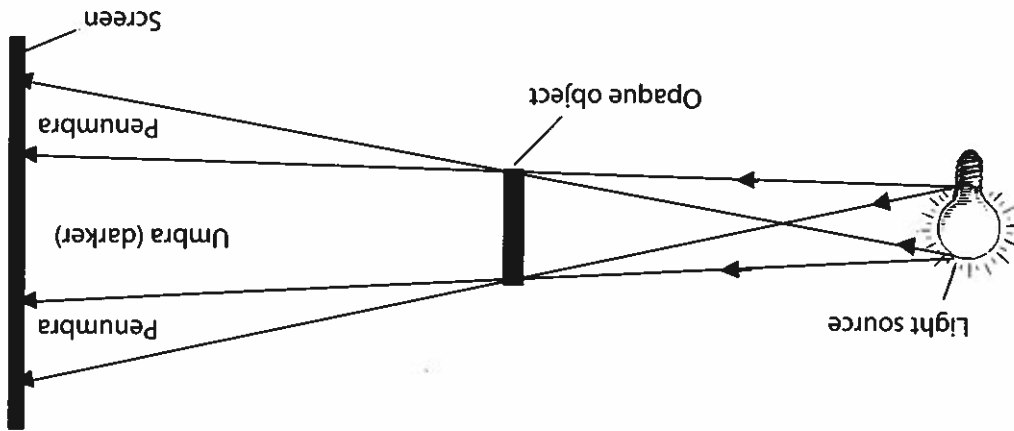
A shadow is also created when the moon blocks the sun's light. Because the moon is smaller than the earth, its shadow covers only part of the earth's surface. This is referred to as a solar eclipse since the sun becomes eclipsed or blocked out by the moon. As a result, the sky darkens on the part of the earth where the moon's shadow has fallen.

Figure 16.5 The earth's shadow creates day and night



One shadow in particular regulates almost all life on earth: that formed by the earth itself. At night you are in the earth's shadow since the side of the earth facing the sun is now blocking the sunlight, preventing it from reaching you.

Figure 16.4 Formation of a shadow



Shadows have two parts. The darkest part of the shadow, where very little light falls, is called the **umbra**. The lighter shadow around the edge of the umbra is called the **penumbra**. The formation of the umbra and penumbra largely depends on the size of the light source and its proximity to the object. Shadows that seem very sharply defined have a small penumbra, while those with a large, blurry, gray edge have a large penumbra.

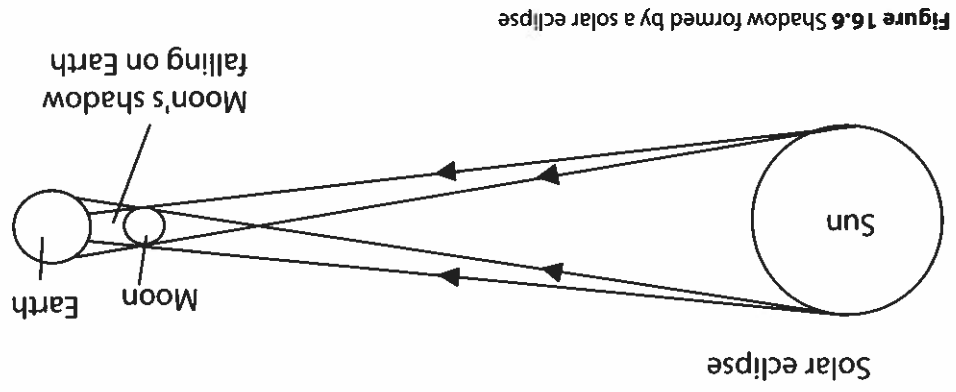


Figure 16.6 Shadow formed by a solar eclipse

Support Question

4. What does the creation of shadows tell us about how light travels?

Electromagnetic Spectrum

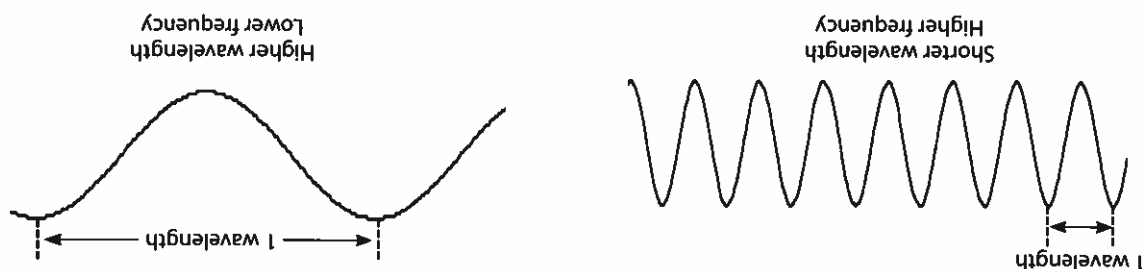
The light from the sun spreads out or radiates in all directions. Some of this light reaches the earth and is referred to as **radiation**. Since the space between the earth and the sun is not filled with any material, light energy must have the ability to travel through empty space. Energy that travels by radiation, such as light, is called radiant energy.

When a baseball pitcher throws a ball to a catcher, the pitcher transfers energy to the ball and the ball transfers that energy to the catcher. In this case, matter (the baseball) had to move from one place to another for the energy to be transferred. However, energy can also be transferred from one place to another without transferring matter. This form of energy transfer occurs through a wave. A wave is a disturbance that transfers energy without transferring any matter.

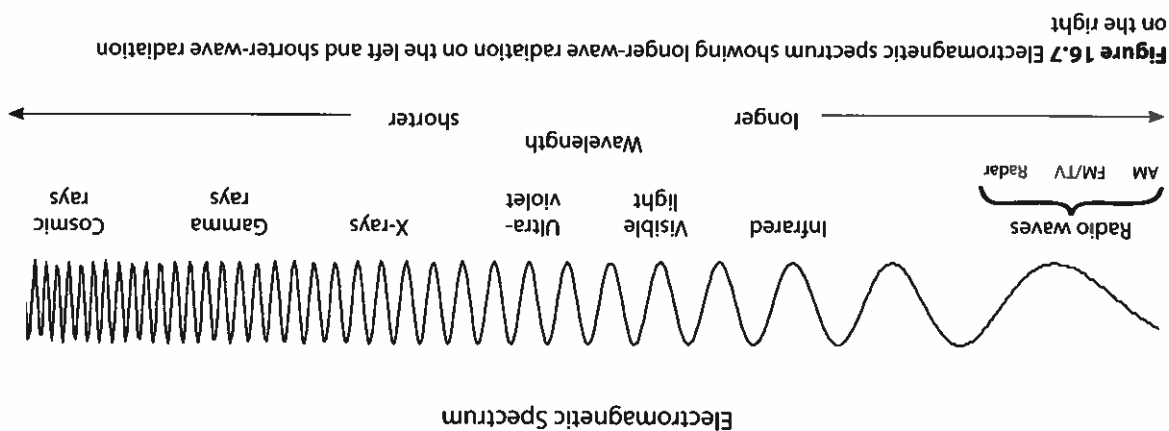
You probably made waves as a child playing with a skipping rope. When you flicked it up and down rapidly, you sent waves flowing down the rope. Waves can occur in all kinds of matter. We can see some waves, such as water waves or waves in a skipping rope; others, such as sound waves and radio waves, are invisible to us.

The wavelength affects the way light travels through objects; because of this, we can use light of different wavelengths for different applications. For example, Figure 16.7 shows that radio waves have a longer wavelength than visible light. They can thus travel through solid opaque objects like buildings and walls—letting you listen to the radio inside your house. Sometimes we also need to know the **frequency** of a wave. This can be measured by counting how many peaks occur in one second. In the electromagnetic wave family, radio waves have a low frequency (few peaks per second) and cosmic rays have a very high frequency (many thousands of peaks per second). You can see that frequency is directly related to wavelength (longer wavelength = lower frequency).

Figure 16.8 Measuring wavelengths



Scientists distinguish the different kinds of waves in the electromagnetic spectrum by the length of their waves or **wavelength**. A wavelength is measured by taking the distance between two peaks of a wave.



The light that we see is in the form of a wave. These light waves belong to a family of waves referred to as the **electromagnetic spectrum**. Visible light represents a small portion of all the electromagnetic waves. The figure below shows some of the other members of the electromagnetic family, such as radio waves, gamma rays, ultraviolet rays, and X-rays.

In the picture below, the dog has a higher frequency of steps than the man: the dog takes about four steps for every step the man takes over the same time period.

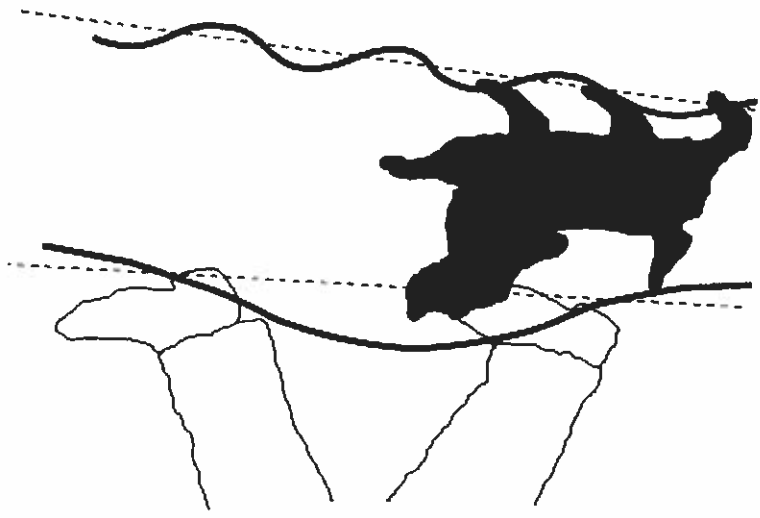


Figure 16.9 Relation between wavelength and frequency

Most of the time when people are talking about using electromagnetic waves, they mention frequency, for example when tuning in radio and TV stations or selecting communications channels for portable phones, cell phones, satellites, and so forth.

Support Question

5. Though only able to see a small portion of the electromagnetic spectrum, humans are still able to use other regions of the spectrum. After doing an Internet search, describe two ways we use the radar region of the electromagnetic spectrum.

The Colours of Visible Light

Though it looks white, sunlight is actually made up of different colours that combine together to produce white. We can see the different colours that make up white light when a rainbow forms after a storm: the sunlight's colours are separated by the water droplets in the air. The colours range from red through orange, yellow, green, blue, and violet. This pattern is called the solar spectrum. Go to your course page on the ILC website and click on "A Rainbow of Colours" under Lesson 16.

It isn't just sunlight that is composed of many colours—all white light is, even if produced by a flashlight. This feature of white light is what lets us see so many colours in our world.

The colour of an opaque object depends on which colours the object reflects and which it absorbs. A blank white page appears white because it *reflects* almost all the light. A crow appears black because it *absorbs* almost all the light. A carrot appears orange because it reflects the colour orange and absorbs the other colours. A leaf appears green because it reflects mostly green light and absorbs the other colours.

Looking at the objects around you, you see more than just the colours of the rainbow. For example, an object may reflect a small amount of the colour red and a larger amount of orange and yellow. When these colours are combined together, the result is a new colour. Because of the combination of various amounts of different colours, we see an almost infinite variety of colours.

Activity 2: Sunset in a Glass



Purpose

Investigate changes in colour.

Materials

- clear glass
- water
- milk ($\frac{1}{4}$ teaspoon)
- teaspoon
- bright flashlight (halogen is best, LED ones are not as good)

Procedure

1. Fill the glass nearly full of water.
2. Add about $\frac{1}{4}$ teaspoon of milk to the water and stir.
3. Shine the flashlight through the water by holding it at right angles to the side of the glass, as shown in the diagram below.
4. Look at the beam coming out the other side of the glass.
5. Keep adding a $\frac{1}{4}$ teaspoon at a time until the light coming out the other side becomes reddish.
6. Look at the colour of light in the surrounding milky water.

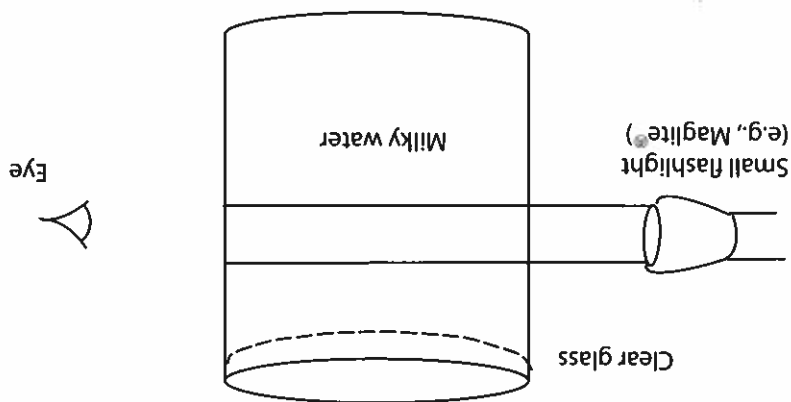


Figure 16.10 Experimental set-up

Support Questions

6. a) What colour did the surrounding milky water become?

b) Why do you think the yellow light from the flashlight became reddish?
(Hint: This is related to red sunsets. Do an Internet search to find out why sunsets are reddish.)

7. a) What makes a red apple appear red?

b) Why is the sky blue?

Conclusion

This lesson introduced you to the basic features of light. You learned about the different ways light can be created, and how shadows are formed. You also learned how light can travel as a wave, and how its frequency and wavelength are related in the electromagnetic spectrum. In the next lesson, you will explore the different ways light is reflected by mirrors and how we use that knowledge in high technology and everyday life.

Key Concepts

Luminous: a luminous object gives off light

Non-luminous: a non-luminous object does not give off light

Incandescence: the process by which light is given off when a material is heated

Fluorescence: the process by which light is given off when a substance is exposed to ultraviolet light

Phosphorescence: the process by which light continues to be given off after the energy source is switched off

Chemiluminescence: the process by which chemical energy is changed into light with little or no heat produced

Bioluminescence: a process similar to chemiluminescence, except it occurs in living things able to produce light through a chemical reaction

Triboluminescence: the process by which light is produced by scratching, rubbing, or crushing a substance

Visible light: light that we can detect with our eyes

Linear propagation: refers to the fact that light travels in a straight line until its path is interrupted or deflected

Shadow: the dark region produced when light strikes an opaque object

Umbra: the darkest part of a shadow where no light falls

Penumbra: the lighter part of a shadow formed around the edges where some light may fall

Radiation: light energy that radiates out (spreads out) from a source such as the sun

Wave: a disturbance that transfers energy without transferring any matter

Electromagnetic spectrum: the range of light wavelengths from the very small to very large, with visible light near the middle

Wavelength: the distance between peaks of a single light wave

Frequency: a measure of the number of light wavelengths per second

Key Questions

Save your answers to the Key Questions in your
Course Journal or e-Journal.

Total: 16 marks

- 65.** Explain why an incandescent light bulb is less energy-efficient than a fluorescent light bulb. (4 marks)
- 66.** Why can you see through a solid glass window, but not through an opaque object like a wall? (4 marks)
- 67.** What evidence do we have that light travels in a straight line? (4 marks)
- 68.** After doing an Internet search, identify and describe two ways we use the X-ray region of the electromagnetic spectrum. (4 marks)

Now go on to Lesson 17. Remember, you do not send your journal to the Independent Learning Centre until you have completed Unit 4 (Lessons 16 to 20).

Mirror, Mirror on the Wall:
Plane and Curved



SNC2D-B

Suggested Timing for This Lesson (hours)	
Laws of Reflection	1½
Images in a Plane Mirror/ Activity: Mirror Image	1½
Images in a Curved Mirror	1
Characteristics of Images	¾
Key Questions	1

You may find this time grid helpful in planning when and how you will work through this lesson.

Planning Your Study

You learned in Lesson 16 that light always travels in straight lines. To get around this, we can use mirrors to redirect light in different directions so that we can see behind us or around corners, enlarge a view, or help capture an image in a camera. You probably use mirrors every day—in a bathroom, in a car, while shaving or checking your hair. Plane (or flat) mirrors, the most common kind, are found throughout the house. They are also used in a wide range of important technologies such as cameras and telescopes, and dentists use them to see inside your mouth. Curved mirrors are also quite common. You may find them helpful in the bathroom for shaving or applying cosmetics because they enlarge the image of your face. Whatever their use, all mirrors work by reflecting light. Mirrors are so much a part of our life that we take them granted. But to get the most out of them in our latest technologies, we need to know how they work. In this lesson, you will learn the laws that describe the reflection of light. You will also learn about the characteristics of images in plane and curved mirrors and how we can predict where the images will appear.

Introduction

What You Will Learn

After completing this lesson, you will be able to

- describe and apply the laws of reflection
- use the terms associated with reflection and images
- show how images are formed in plane and curved mirrors
- locate a reflected image using light-ray diagrams

Laws of Reflection

If a ball is thrown straight at a wall, it will come back to you along the same path. However, if a ball is thrown at an angle to the wall, it doesn't bounce back along the same path, but rather bounces away at the same angle as it hit the wall. You can see this demonstrated in the diagram below.

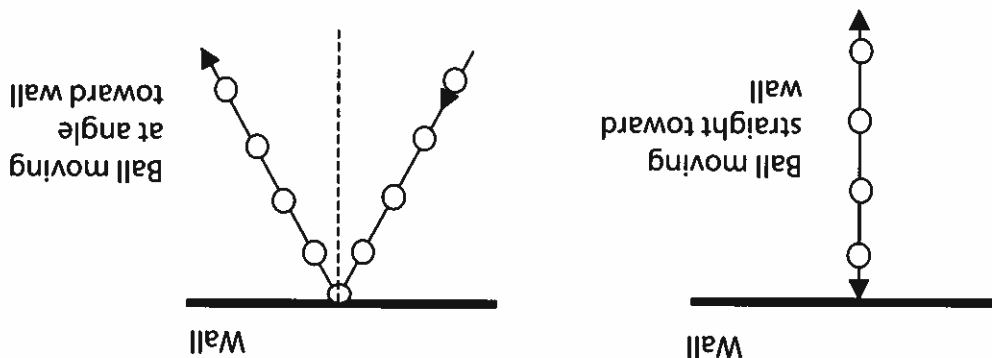
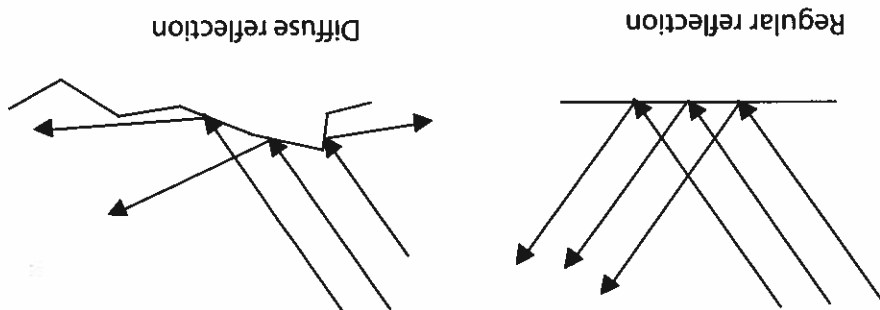


Figure 17.1 Angles of reflection

This is something you probably learned as a child playing schoolyard games with your friends. A lot of sports and games use this fact. For example, hockey players sometimes shoot the puck at the boards at deliberate angles so the puck will rebound just where it's needed for a teammate to get a great shot on goal. Light behaves in the same way when it is reflected from a smooth surface such as a **plane (flat) mirror**. The reflection of a beam of light from smooth surfaces like mirrors, shiny metal, or calm water is called **regular reflection**. The reflection of a beam of light from rough surfaces like a brick wall is called **diffuse reflection**; in this case, light is scattered or diffused. When you polish metal jewelry to make it glitter again, you are changing the reflection from diffuse to regular. The dust, grease, and fine scratches that build up on the metal create a rough surface that causes the light to bounce off in diffuse reflections that spread the light around. Polishing removes the dirt and smooths the rough surface. The light bounces off in regular reflections, concentrating the light so that it's brighter when it reaches our eye.

Figure 17.2 Regular reflection versus diffuse reflection



To understand and work with reflections, you need to know some terminology. The light ray that travels toward the surface is called the **incident ray**, and the light ray that is reflected off the surface is called the **reflected ray**. The point where the incident ray touches the surface is referred to as the **point of incidence**. A line drawn at right angles to the surface at the point of incidence is called the **normal line** (or just the **normal**). The angle between the normal and the incident ray is called the **angle of incidence**, and the angle between the normal and the reflected ray is called the **angle of reflection**. Figure 17.3 below will help you understand these definitions.

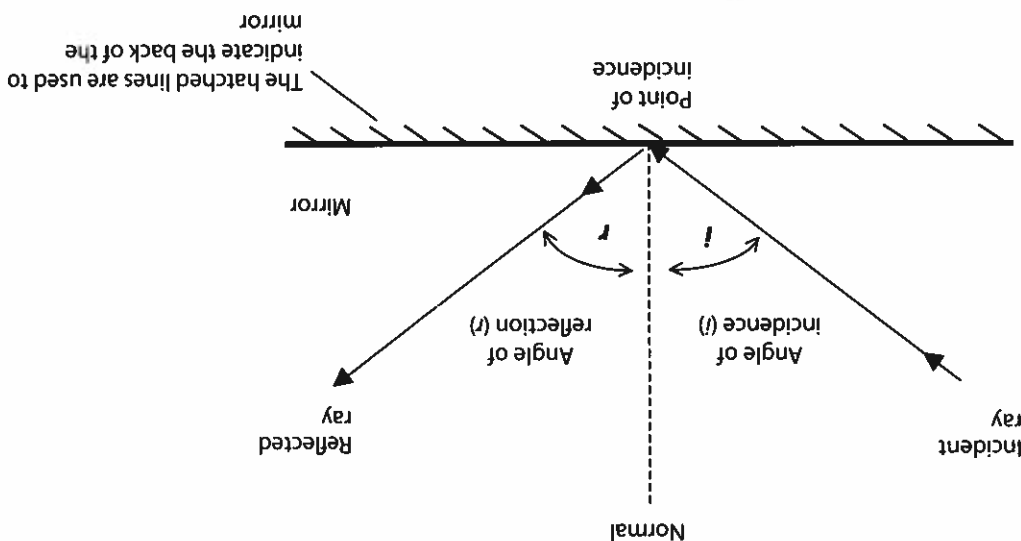


Figure 17.3 Features of reflections

Light falling on the surface of a mirror is reflected. If the light is shone at right angles to the mirror, the reflected ray bounces straight back—just like the ball did when thrown against the wall. If the angle between the incident ray and the normal line is 30° , then the angle between the reflected ray and the normal is also 30° . This is known as the **first law of reflection**: the angle of incidence is equal to the angle of reflection. The **second law of reflection** states that the incident

ray, the reflected ray, and the normal line all lie in the same plane (the same flat surface). That is why you can draw all three of these lines on a flat sheet of paper. These **laws of reflection** are not restricted to light. Pool (also known as billiards) is a popular game that makes use of the laws of reflection. The billiard balls all move across the same flat surface of the table top, so they are always in the same plane. As with light, when a ball bounces off the side cushion of the table, the angle of incidence will equal the angle of reflection. Good players know how to calculate these angles in their head in order to make amazingly accurate shots.

Support Question

Do not send your answers in for evaluation.

8. a) Draw a diagram showing an incident ray with a 60° angle of incidence striking a plane mirror. Draw the resulting reflected ray. In the diagram, label the following: *normal, point of incidence, angle of incidence, angle of reflection, incident ray, reflected ray.*

- b) What will happen to the reflected ray when the angle of incidence is 0° ?

There are Suggested Answers to Support Questions at the end of this unit.

Images in a Plane Mirror

When you are in a lighted room, light bounces off you in all directions. If you stand in front of a plane mirror, some of the light that is reflected off you strikes the mirror and is reflected back into your eyes. What you see in the mirror is your **image**. Your body (or any object) standing in front of the mirror is referred to as the **object**.

The image that you see in the mirror appears to be coming from behind the mirror. And the image seems to be the same distance behind the mirror as the object is in front of the mirror. The object and the image appear the same. However, if you hold a book in front of a mirror, you'll find it hard to read the words in the book's image. The images and the object may look the same, but they are not identical. The image in the mirror represents the object flipped sideways. This is called a **mirror image**: a likeness in which left and right are reversed.

Activity: Mirror Image



Purpose

Examine an image in a plane mirror.

Materials

- plane mirror (any size)
- piece of cardboard
- ruler

Procedure

1. On a piece of cardboard approximately the size of a business card, print the letter "d" (in lower case) near the top.
2. Place a ruler at right angles to the mirror so that the end of the ruler is touching the mirror.
3. Tape the cardboard to the ruler in front of the mirror so that the letter "d" is facing the mirror, approximately 10 centimetres from it. Figure 17.4 on the next page illustrates how your experiment should be set up.

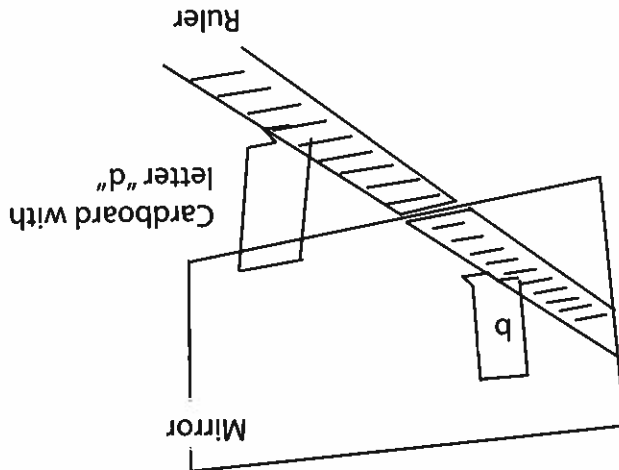
Support Question

This question is based on the above activity.

9. a) What letter does the image of the letter "d" look like?

- b) What does this tell us about the image in a plane mirror?

Figure 17.4 Experimental set-up showing card taped to ruler placed in front of mirror



4. Flip the card down and print the words "pop" and "civic" in the empty space below the "d." Predict what these words will look like in the mirror and then place the card back up to check to see if you were right.
5. Answer the Support Question below.

Locating Images in a Plane Mirror

By following the reflected rays that bounce off the mirror backwards, we can find the location of where the image appears to be, as shown in the following diagram.

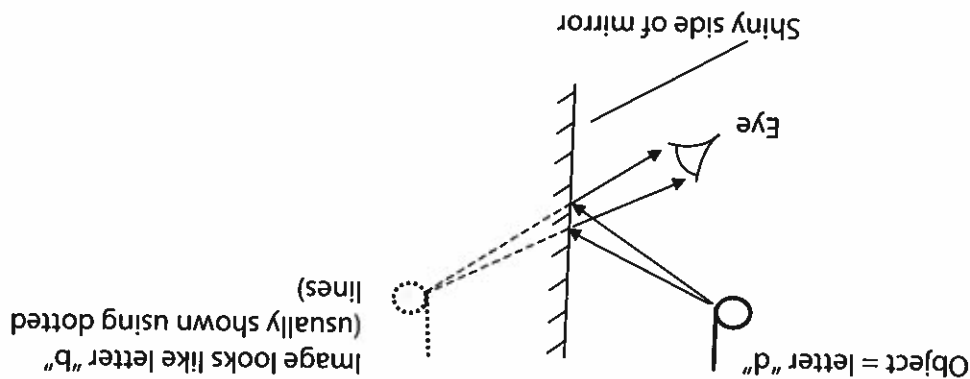


Figure 17.5 Locating image in a plane mirror

Note that the image appears to be behind the mirror, and the distance from the mirror to the object is the same as the distance from the mirror to the image. The image that you see in a mirror is different from that produced by a movie projector on a screen. The image on a movie theatre screen is made by actual light projected onto the screen. Light is actually present where the image appears to be. An image that can be projected onto a screen is called a **real image**.

Now suppose you place a lit candle in front of a plane mirror. The image of the flame will appear to be located behind the mirror. However, if you place a blank piece of paper (a screen) behind the mirror where the image appears to be, nothing can be seen on the blank paper. The image does not appear on the screen even though it seems to be located back there. This type of image is called a **virtual image**. Virtual images can be seen by the eye and photographed, but cannot be caught on a screen. A virtual image seen in a plane mirror appears to be where you see it, but it's not really there!

To find the location of the image in a plane mirror, you may find it easier to use normal lines instead of following the reflected rays backwards. (As you've seen, a normal line is any line drawn at right angles to the mirror.) Remember that the image will be the same distance behind the mirror as the object is in front of the mirror. To draw the image in the correct location, first draw a normal line from a point on the object to the mirror. Then measure the length of that normal line. Now extend that normal line the same distance behind the mirror and place a dot there. By drawing normal lines for several points from the object to the mirror, you can then locate the image. The diagrams on pages 9 and 10 show the three steps of this process.

Step 1

Select a key point on the object and draw a normal line from that point to the mirror. Then extend the normal line the same distance behind the mirror. In this example, the distance is 10 cm.

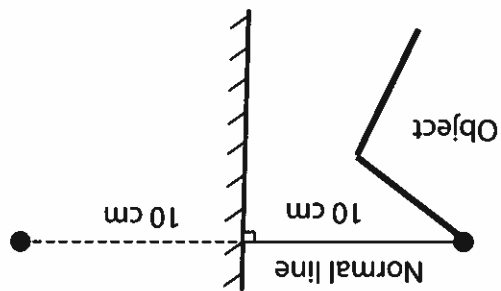


Figure 17.6 Step 1: Draw first normal line from object to locate first image point

Step 2

Select another key point on the object and draw a normal line from that point to the mirror. Then extend the normal line the same distance behind the mirror.

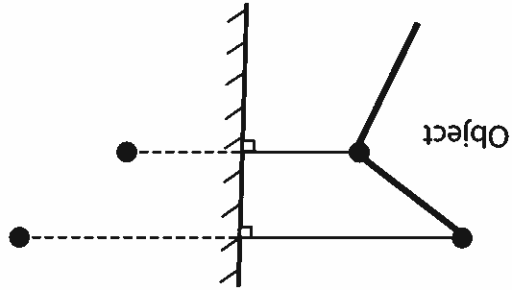


Figure 17.7 Step 2: Draw second normal line from object to locate second image point

Step 3

Select another key point on the object and draw a normal line from that point to the mirror. Then extend the normal line the same distance behind the mirror. When you have enough key points, join them together to form the image.

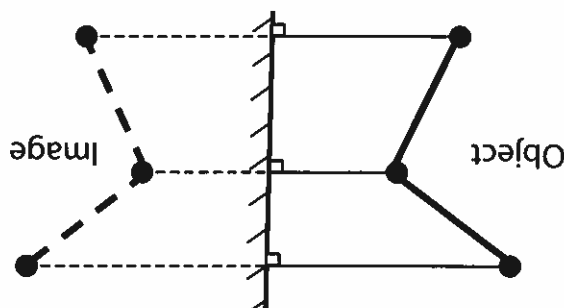


Figure 17.8 Step 3: Draw third normal line from object to locate third image point and then connect the dots to form the mirror image

Here are two more examples:

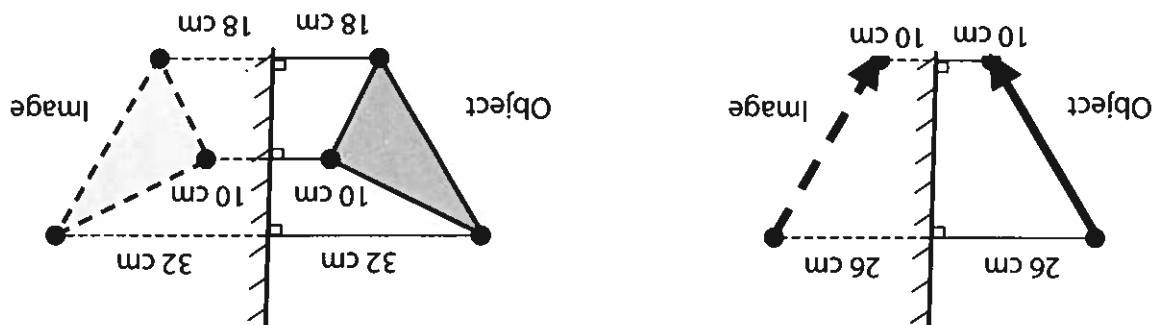


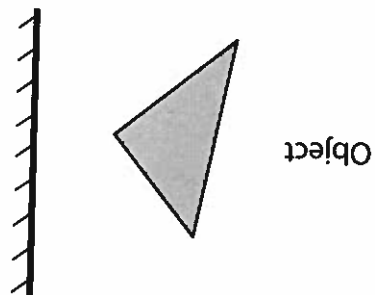
Figure 17.9 Examples of mirror images formed in a plane mirror

To find the image in each of these two examples, a line was drawn at right angles to the mirror from a point on the object. This line was extended the same distance behind the mirror to find where the corresponding image point should be. This was done for as many points as needed in order to draw the complete image.

Support Question

10. a) What do the words “MOM” and “RAT” look like in a plane mirror? Explain why this is the case.

- b) Locate and draw the image of the triangular object in the following diagram. Show all the lines you needed to draw in order to find the image.



- c) Explain why the image that you see in a plane mirror is considered a virtual image.

Images in a Curved Mirror

Curved mirrors have a lot of uses because of their ability to concentrate or scatter light rays. For example, curved mirrors are used in spotlights and in lighthouses to concentrate light rays into powerful beams that can be seen over long distances. The same technique is used in car headlights and flashlights to provide a bright beam from a small bulb.

The diagrams below show the two basic curved mirror shapes: converging and diverging.

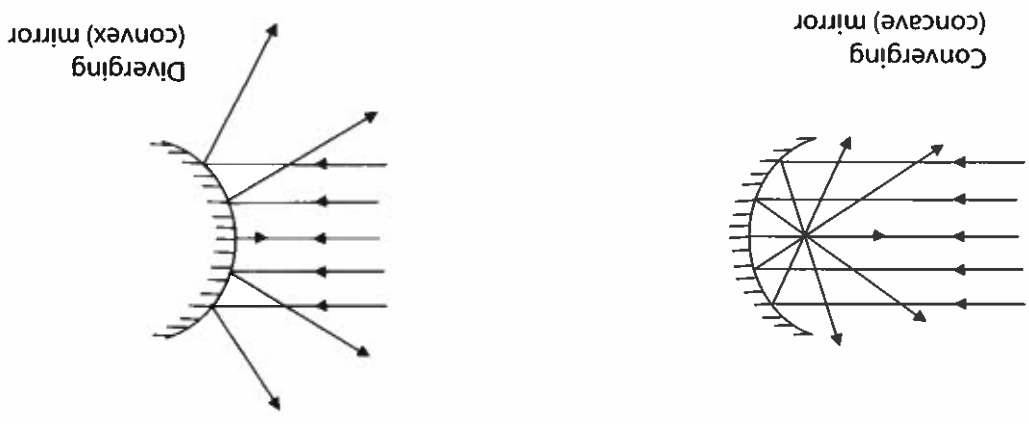


Figure 17.10 Pattern of light rays reflecting off a converging and a diverging mirror

Converging mirrors cause parallel light rays to come to a point. They are sometimes called **concave mirrors** because the reflecting surface is curved inward like the inside of a bowl. The word *concave* contains the word *cave*; if you think of looking into a cave, this may help you remember the shape.

Diverging mirrors cause parallel light rays to spread apart. They are sometimes called **convex mirrors** because the reflecting surface is curved outward, like the outside of a bowl.

To better understand some of the terms used with curved mirrors, you may find it helpful to draw a diagram like the one below.

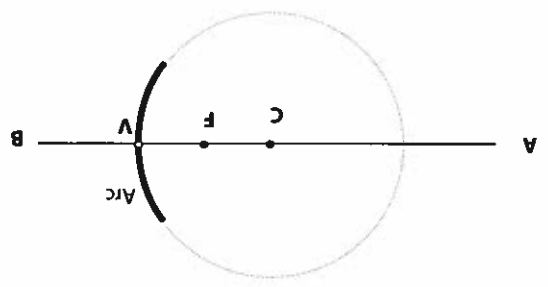


Figure 17.11 Illustrating the terminology used in curved mirrors

Start by drawing a line AB across the page. A point about halfway along the line is labelled C . A compass is placed at point C and an arc is drawn, such that half of the arc is above the line and half below.

The point where the line AB crosses at the centre of the arc is labelled V . A point halfway between the letter C and V is labelled F .

The arc is a small part of a circle. If a circle had been drawn instead of an arc, the letter C would be in the centre of the circle, and the distance from C to V would be the radius of the circle. Because point C is at the centre, it is referred to as the **centre of curvature**.

The arc represents a curved mirror. The letter V is at the centre of the mirror and is called the **vertex**. The straight line AB passing through both the centre of curvature (C) and the vertex (V) is referred to as the **principal axis**. The point halfway between the centre of curvature (C) and the vertex (V) is called the **principal focus (F)**.

If you are standing at point A and looking towards the mirror, it's a converging (concave) mirror, as shown below.

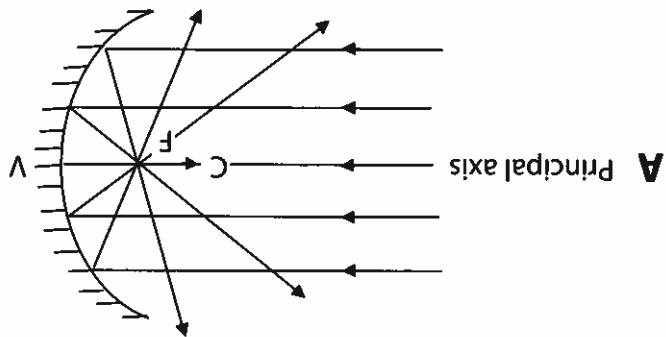


Figure 17.12 Components of a light-ray diagram for a converging mirror

In a converging (concave) mirror, if the incident rays are parallel to the principal axis, then all the reflected rays will pass through the principal focus (F). That's why this mirror is so good at concentrating light rays.

If you are standing at point *B* and looking towards the mirror, it's a diverging (convex) mirror, as shown below. Points *C* and *F* are still the same distance from *V*, but are now on the other side of the arc.

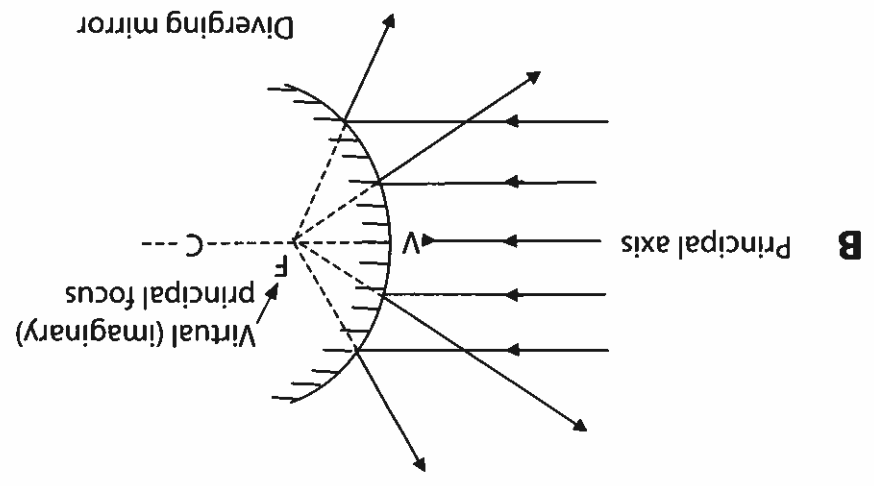


Figure 17.13 Components of a light-ray diagram for a diverging mirror

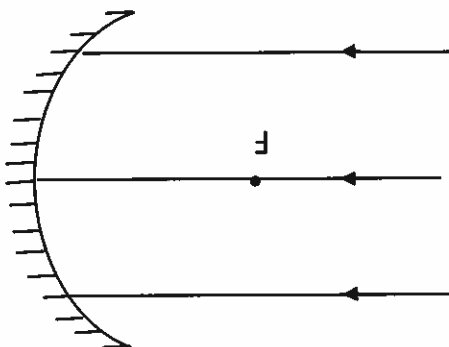
In a diverging (convex) mirror, if the incident rays are parallel to the principal axis, then the reflected rays will spread out. But if you extend the incident rays behind the mirror, the reflected rays will appear to be passing through the principal focus (*F*). Since the light rays are spread apart in diverging mirrors, *F* doesn't really exist. Considered an imaginary point, it is generally referred to as the virtual principal focus.

Locating Images in a Curved Mirror

By looking at a shiny metal bowl or a metal spoon from both sides, you can get an idea of the images that are formed by converging and diverging mirrors. They are quite different from those that you would see in a plane mirror. In converging mirrors, the image tends to be closed in, appearing shorter and fatter—and usually upside down. In diverging mirrors, the image gets spread out, appearing taller and thinner. For years, abstract painters like Picasso have played with curved mirrors to create distorted versions of reality that inspire their paintings and self-portraits.

We can learn a great deal about the images formed in converging and diverging mirrors by looking at three important light rays and how they are reflected from these mirrors. The pattern of reflection of each of these three light rays is captured in the following ray rules for converging and diverging mirrors. These rules will help you draw light-ray diagrams for each kind of mirror.

Converging (concave) mirror



11. Observe the diagram of a converging (concave) mirror below.
 - a) Complete the light-ray diagram and draw the reflected rays.
 - b) Label the vertex and principal axis.

Support Question

Ray Rules for Converging Mirrors

1. Any incident ray that is parallel to the principal axis will be reflected through the principal focus.
2. Any incident ray passing through the principal focus will be reflected parallel to the principal axis. (Think of it as the same as rule 1, but going in the opposite direction.)
3. Any incident ray passing through the centre of curvature is reflected back along the same path.

These rules for converging mirrors are shown in the diagram below, with each rule number circled.

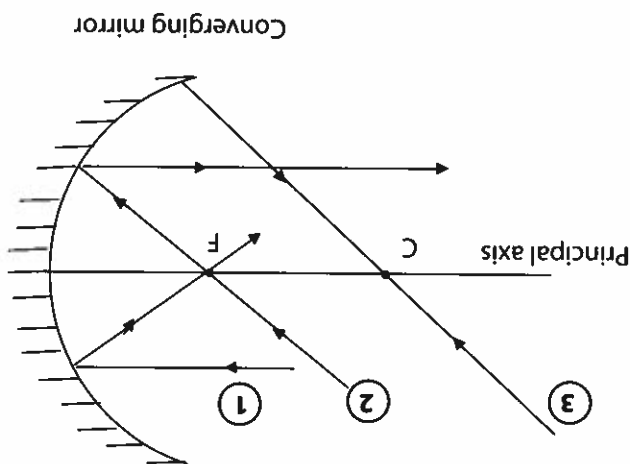


Figure 17.14 Ray rules for a converging mirror

Ray Rules for Diverging Mirrors

1. Any incident ray that is parallel to the principal axis is reflected as though it had gone through the virtual principal focus.
2. Any incident ray that appears to be passing through the virtual principal focus will be reflected parallel to the principal axis. (Think of this as the same as rule 1, but going in the opposite direction.)
3. Any incident ray which appears to be passing through the centre of curvature is reflected back along the same path.

- **Type:** refers to whether the image is *real* or *virtual*. A real image can be projected onto a screen, whereas a virtual image cannot. If you are using light-ray diagrams to locate an image, the image will be real if the light rays cross in front of the mirror. The images of converging mirrors produce real images unless the object is between the vertex and the principal focus.
 - **Size:** the size of the image compared to the object: is it *smaller*, *larger*, or the *same size*? In converging mirrors, the size will vary according to the location of the object.
- When examining images created by mirrors, you generally consider four **image characteristics**: type, size, orientation, and location.

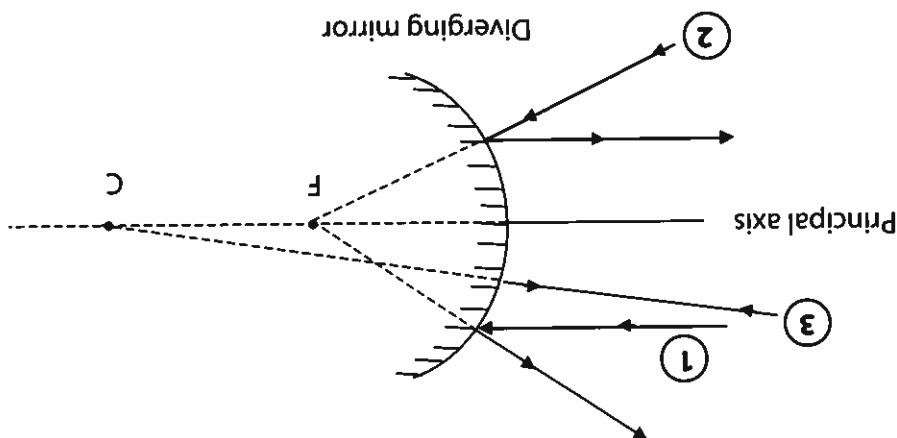
Characteristics of Images

You can explore the way light rays reflect in converging and diverging mirrors using an online tool. This activity is *optional*. It is not required to complete this lesson, but may help you to understand the concepts better.

If you want to experiment with light rays in different kinds of mirrors, go to your course page on the ILC website and click on "Reflections in Mirrors" under Lesson 17. You can explore the effects of different focal distances and different types of curved mirrors by dragging the mirrors and the object along an "optical bench."



Figure 17.15 Ray rules for a diverging mirror



These rules for diverging mirrors are shown in the diagram below, with each rule number circled.

- **Orientation:** if the image is pointing in the same direction as the object, then its orientation is *upright*. If the image is pointing in the opposite direction, then its orientation is *upside down*. Images from a converging mirror are upside down unless the object is closer than the principal focus, in which case the image becomes upright. Also, if the object is placed at the principal focus, all the reflected rays from the converging mirror are parallel to the principal axis and no image is produced.
 - **Location:** refers to whether the image can be seen *in front* of the mirror or *behind* it.
- For diverging mirrors, the image is always virtual, smaller than the object, upright, and located on the other side of the mirror.

Table 17.1 Summary of image characteristics in converging and diverging mirrors

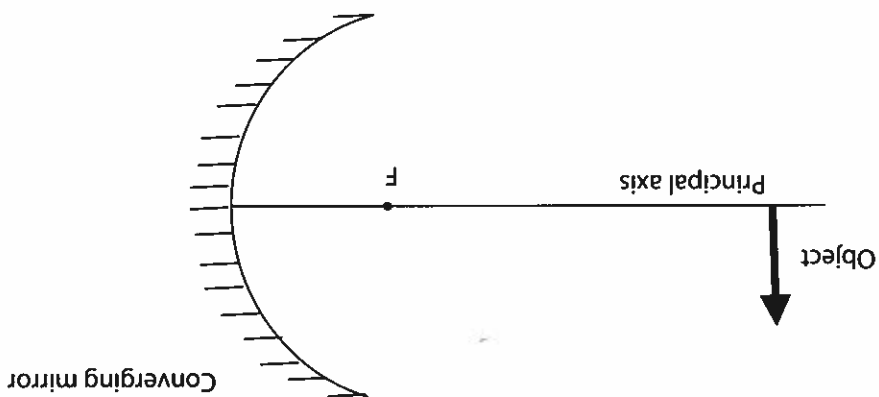
Summary of Image Characteristics					Position of Object
Location		Size	Orientation	Type	
Converging Mirror					
beyond C	in front	smaller	upside down	real	
at C	in front	same	upside down	real	
between C and F	in front	larger	upside down	real	
at F	no image				
between F and V	behind	larger	upright	virtual	
Diverging Mirror					
any position	behind	smaller	upright	virtual	

Support Questions

12.

Observe the diagram below.

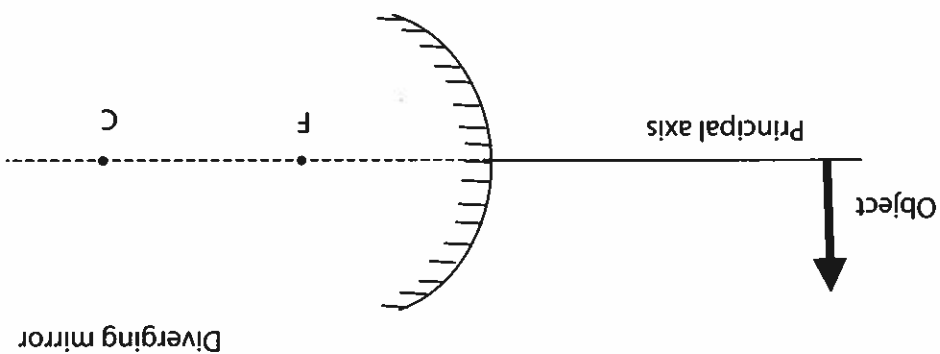
- Use light rays to locate and draw the image in the converging mirror.
- What are the values for the four characteristics of the image?



13.

Observe the diagram below.

- Use light rays to locate and draw the image in the diverging mirror.
- What are the values for the four characteristics of the image?



Conclusion

In this lesson, you continued your exploration of the nature of light by learning about what happens to light when it reflects off a material. You learned the laws of reflection in plane and curved mirrors, and practised locating images in all kinds of mirrors. Finally, you learned how to recognize the important characteristics of reflected images. The next lesson will show what happens to light when it passes through a material and is refracted.

Key Concepts

Plane mirror: a flat mirror

Regular reflection: the reflection of a beam of light from smooth surfaces like mirrors, shiny metal, or calm water

Diffuse reflection: the reflection of a beam of light from rough surfaces like a brick wall; causes light to be scattered or diffused

Incident ray: the light ray that travels toward the surface of a reflective material like a mirror

Reflected ray: the light ray that is reflected off the shiny surface of a reflective material like a mirror

Point of incidence: the point where the incident ray touches the surface

Normal line (or just “normal”): a line drawn at right angles to the surface at the point of incidence

Angle of incidence: the angle between the normal and the incident ray

Angle of reflection: the angle between the normal and the reflected ray

Laws of reflection: two laws that describe how a reflected light ray moves in relation to the incident ray

First law of reflection: the angle of incidence is equal to the angle of reflection

Second law of reflection: the incident ray, the reflected ray, and the normal line all lie in the same plane

Image: what you see in a mirror

Object: any object positioned in front of a mirror

Mirror image: a likeness in which left and right are reversed

Real image: an image that can be projected onto a screen

Virtual image: an image that cannot be projected onto a screen. Virtual images

can be seen by the eye and photographed.

Converging mirror: a mirror that curves inward (also called concave)

Diverging mirror: a mirror that curves outward (also called convex)

Centre of curvature (C): the centre of a circle. (In the case of an arc, imagine the arc made into a full circle.)

Vertex (V): the centre of a curved mirror

Principal axis: The straight line AB passing through both the centre of curvature (C) and the vertex (V)

Principal focus (F): the point halfway between the centre of curvature (C) and the vertex (V)

Ray rules for converging and diverging mirrors: these rules help you draw light-ray diagrams for each kind of mirror

Image characteristics: four characteristics that compare the image with the object—type, size, orientation, and location

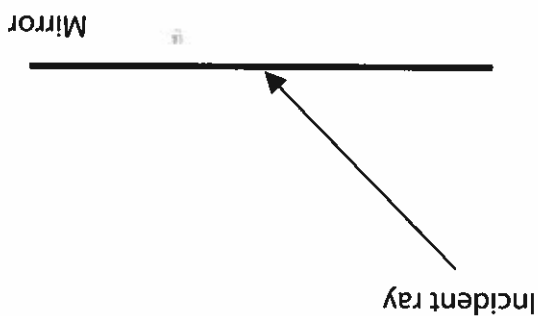
Key Questions

Save your answers to the Key Questions in your
Course Journal or e-Journal.

Total: 20 marks

69. Observe the diagram below.

- Draw the normal and reflected rays. (2 marks)
- Label the angle of incidence and angle of reflection. (2 marks)

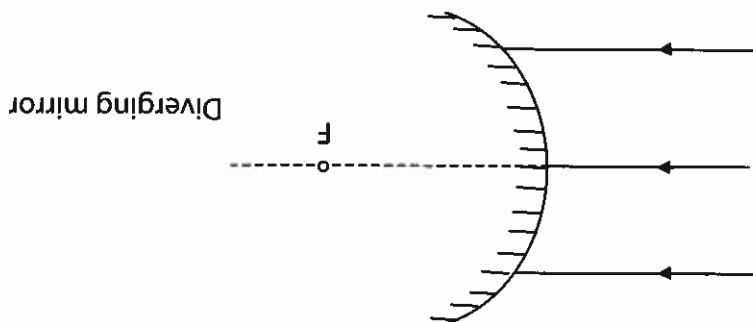


- What does the image of the word "WOW" look like in a plane mirror? (1 mark)

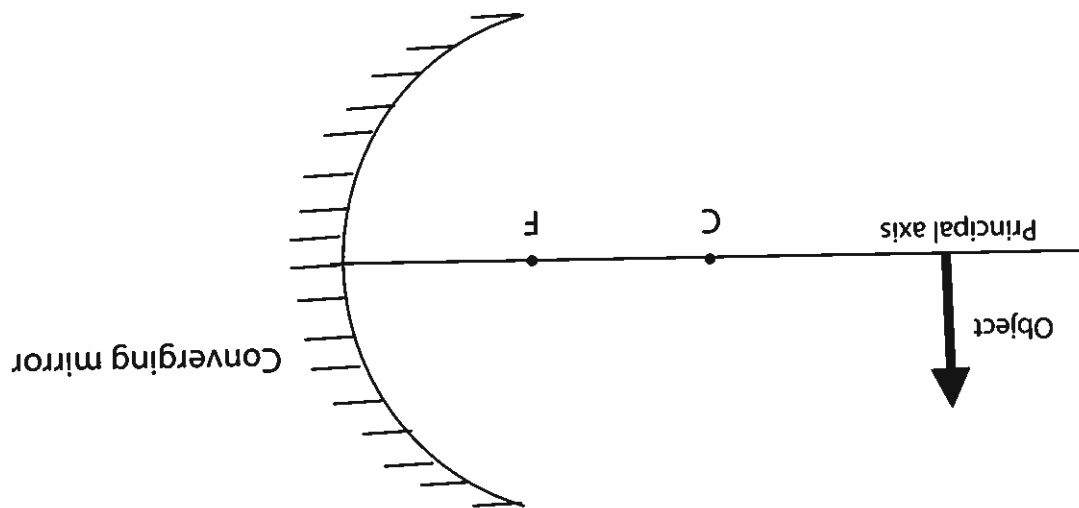
b) Explain why this is the case. (3 marks)

71. Observe the diagram below.

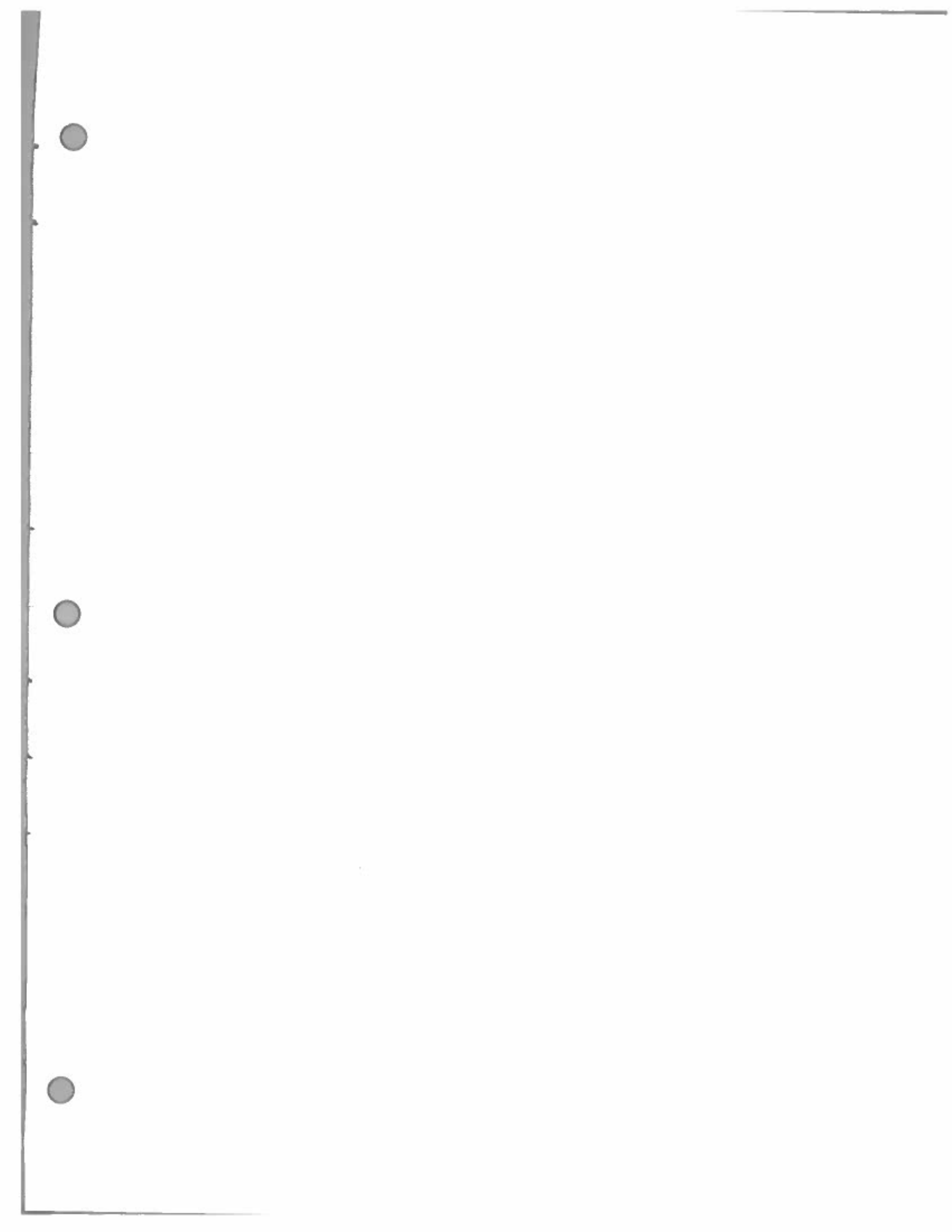
- Complete the light-ray diagram and draw the reflected rays. (3 marks)
- Label the vertex and the principal axis. (2 marks)



Now go on to Lesson 18. Remember, you do not send your journal to the Independent Learning Centre until you have completed Unit 4 (Lessons 16 to 20).



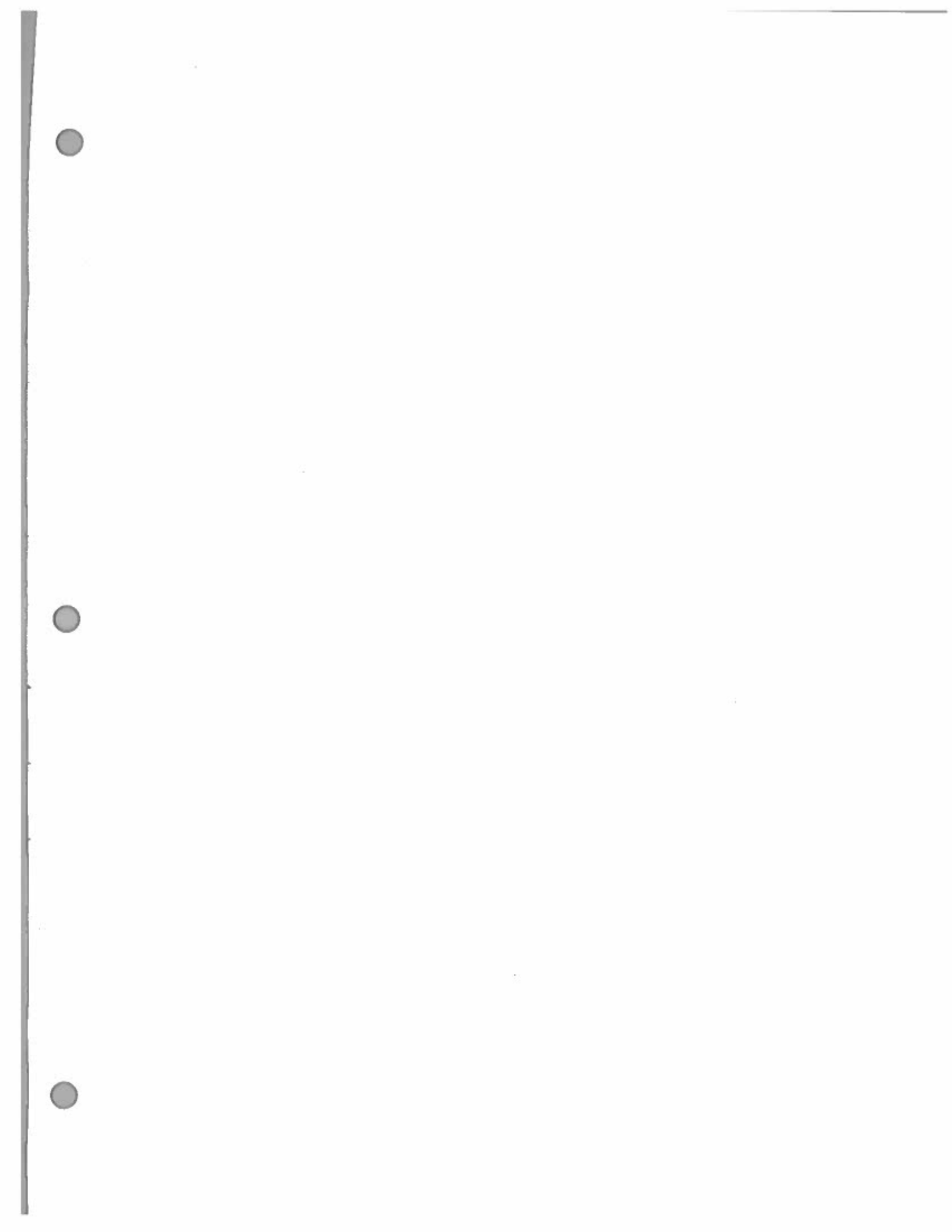
- 72.** Observe the diagram below.
- Use light rays to locate and draw the image. (5 marks)
 - Indicate the values for the four characteristics of the image. (2 marks)



SNC2D-B



**Refraction: Why Things Aren't Always
as They Appear**



Suggested Timing for This Lesson (hours)	
Refraction	1
Activity: Refraction—Broken Pencils	½
Index of Refraction	½
Angle of Refraction	½
Critical Angle	1
Activity: Total Internal Reflection	½
Key Questions	1

You may find this time grid helpful in planning when and how you will work through this lesson.

Planning Your Study

As long as light is travelling in the same material, such as air, it will travel in a straight line. But if light passes from one material to another, its speed and direction can both change. This change, called refraction, can significantly affect how we see things.

You experience refraction every day, but don't always notice it. Yet if you've ever tried to pick up an object that's underwater, you might have misjudged its position. Because of refraction, objects underwater are not where you think they are, even when you're looking right at them.

Mirages are also caused by refraction. During the summer, you've probably seen what look like water puddles appear in the middle of the road and then disappear as you drive closer to them. What causes them? And how are optic fibres, so vital to long distance telecommunications, able to transmit light even when they get bent and twisted as we run the cables around our cities?

These diverse examples all involve the refraction of light as it travels through different materials.

Introduction

What You Will Learn

After completing this lesson, you will be able to

- use terminology associated with the refraction of light
- calculate the relationship between index of refraction and speed of light
- determine how the angle of refraction varies with the angle of incidence
- predict in what direction light will travel as it moves between materials with different indices of refraction
- demonstrate how critical angle relates to total internal reflection

Refraction

You know that light travels incredibly fast. In fact, nothing in the universe can travel faster than the maximum speed of light. But did you know that the speed of light is not constant? It depends on the material light is travelling through. Light will travel through any transparent material. The material is often referred to as a **medium** (plural: **media**). Air and water are good media for the transmission of light.

Light travels at its maximum speed in a vacuum. The denser the material, the slower the light speed. Because water is denser than air, light travels through water more slowly than through air. This change in speed has an interesting effect on light's behaviour. In previous lessons, you've seen that light travels in straight lines in air and in water, but when light passes *between* air and water, its speed changes. This change in speed causes the light to bend at the point where the two media meet, as shown in the diagram below. Note that the light beam bends twice—once when it goes from air into the water, and again when it re-enters the air.

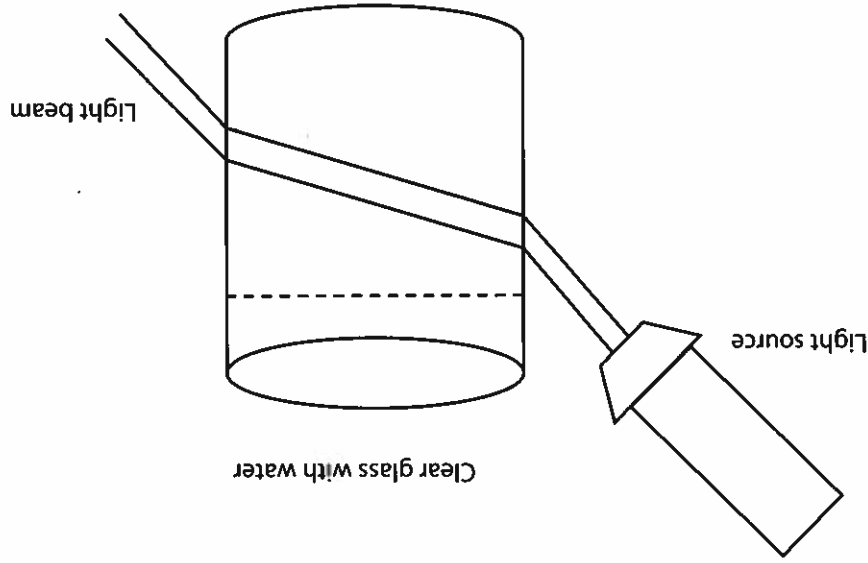


Figure 18.1 Refraction in a glass of water

This bending of light as it travels from one medium into another is called **refraction**. The medium in which light travels more slowly is said to be the more refractive medium. Since light travels more slowly in water than air, water is more refractive than air.

Example

You can see refraction take place by placing a penny inside an empty opaque mug and positioning your eyes so that the penny is just out of view.

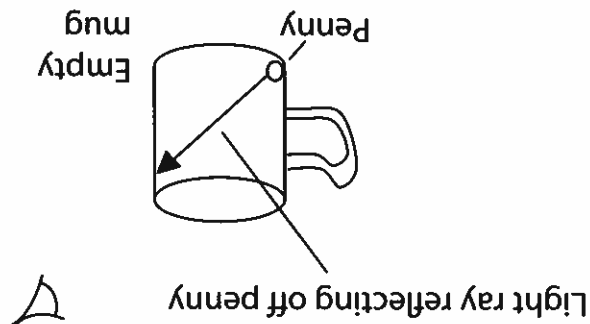


Figure 18.2 Penny just out of view in an empty cup

As the above diagram shows, you can't see the penny because the light rays coming off the penny hit the upper part of the mug and so are blocked from reaching your eye.

But an interesting thing happens when you add water to the mug. If you keep your head in the *same position* and slowly pour water into the mug so that the penny will not be disturbed and move around, you will suddenly see the penny come into view.

This happens because the water causes the light rays moving towards the upper lip of the mug to bend as they cross over into the air. Now the light ray from the penny can reach your eye, making the penny visible.

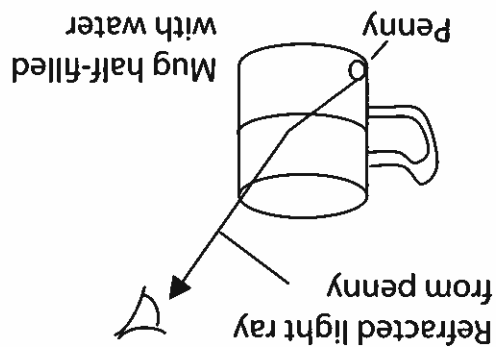


Figure 18.3 Penny comes into view as water is added

Activity: Refraction—Broken Pencils



Investigate refraction.

Purpose

Materials

- clear glass
- pencil
- water

Procedure

1. Place a pencil in an empty glass so that it rests against the glass at an angle (as shown in Figure 18.4 below).
2. Look at it from the side of the glass.

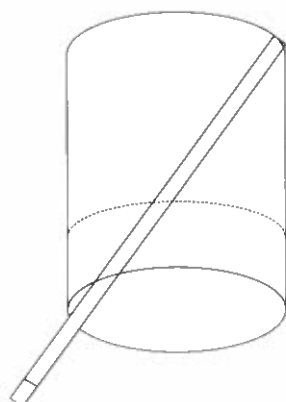


Figure 18.4 Pencil in an empty glass

3. Add water until the glass is about $\frac{3}{4}$ full (the position is marked with a dotted line in Figure 18.4).
4. Look at the pencil from the side of the glass.

Support Questions

Do not send your answers in for evaluation.

14. Make the following observations about your experimental results.
- a) Describe the appearance of the pencil before and after adding the water.

- b) Draw a simple diagram to illustrate what you see.

There are Suggested Answers to Support Questions at the end of this unit.

Index of Refraction

Light moves fastest when travelling through a vacuum, and more slowly through other materials. Because the speed of light is at its maximum in a vacuum, scientists compare the speed of light in a vacuum to that in other materials. The ratio of the speed of light in a vacuum to the speed of light in a material is called that medium's **index of refraction**. It is usually represented by the letter n . Since n is a ratio, it's simply a number and doesn't have any units associated with it. Mathematically this can be expressed in the following way:

$$n = \frac{\text{speed of light in a vacuum}}{\text{speed of light in the material}}$$

The index of refraction of glass is 1.52.

$$n = \frac{\text{speed of light in a vacuum}}{\text{speed of light in glass}} = \frac{300\,000 \text{ km/s}}{197\,000 \text{ km/s}} = 1.52$$

If the speed of light in glass is 197 000 km/s, what is glass's index of refraction? You already know that the speed of light in a vacuum is 300 000 km/s, so you use the index formula to calculate n , the index of refraction.

Example

You can experiment with refraction in various materials using an online tool. This activity is *optional*. It is not required in order to complete this lesson, but may help you understand the concepts better.

If you want to explore further how refraction works, go to your course page on the ILC website and click on "Exploring Refraction" under Lesson 18.



Material	Index of Refraction (n)
vacuum	1.00
air	1.00
water	1.33
plastic	1.51
ice	1.31
glass	1.52
diamond	2.42

Table 18.1 Indices of refraction for some materials

Some common indices of refraction are listed in the following table. The more light slows down as it travels from air into the substance, the higher the index of refraction. The higher the index, the more the light bends or is refracted.

The speed of light in a vacuum is 300 000 kilometres per second (or 3.00×10^8 km/s). Moving at this speed, you could travel 7.5 times around the world in one second. In air, light travels slightly more slowly, but still close to its maximum. However, as the medium becomes denser, light slows down. For example, in water, light travels at about 225 000 km/s; in glass it slows down even more to approximately 197 000 km/s.

Example

What is the speed of light in ice if its index of refraction is 1.31?

In this case, we already know the value of n , the index of refraction. So we use the formula to find the speed of light in ice:

$$n = \frac{\text{speed of light in a vacuum}}{\text{speed of light in ice}}$$

$$1.31 = \frac{300\,000 \text{ km/s}}{\text{speed of light in ice}}$$

(Now solve for the speed in ice.)

$$\text{speed of light in ice} = \frac{300\,000 \text{ km/s}}{1.31} = 229\,007 \text{ km/s}$$

The speed of light in ice is 229 007 km/s.

Support Question

16. a) Explain how the refracted ray is affected by a material with a different index of refraction.

- b) The speed of light in water is 225 000 km/s (or 2.25×10^6 km/s). Calculate the index of refraction of water.

- c) The index of refraction of plastic is 1.51. What is the speed of light in plastic?

Angle of Refraction

You measure the bending of light in much the same way as the reflection of light. For reflected light, you measure the angle of incidence and the angle of reflection by drawing a normal and measuring the angles between the light rays and the normal. For refraction, you draw a normal line at right angles to the surface, and measure the angle of incidence and the **angle of refraction**. The diagram below shows the refraction angle as a light ray travels from air into water.

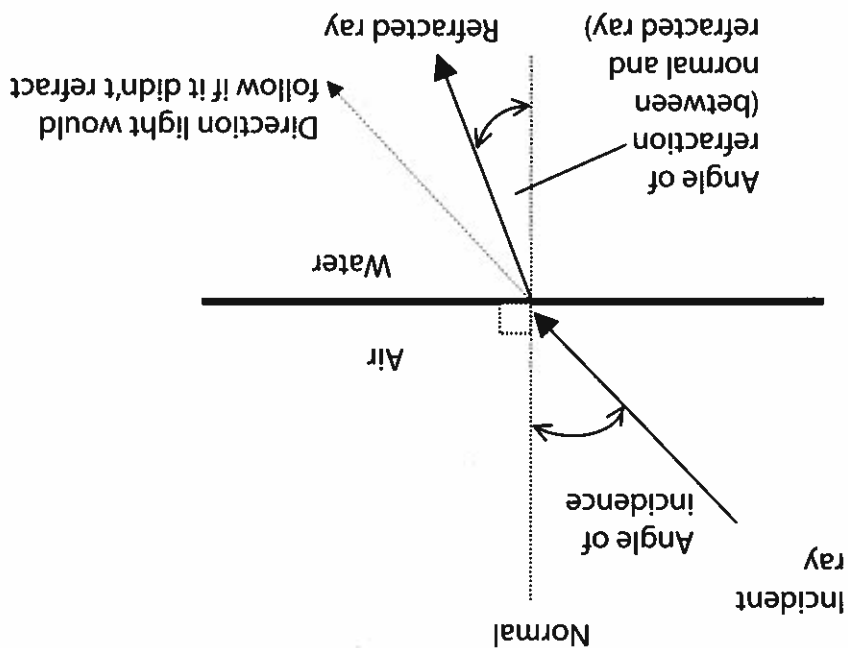


Figure 18.5 Angle of refraction in relation to angle of incidence when light enters a denser medium

Air has an index of refraction of 1.00, while water has an index of refraction of 1.33. When a light ray is going from air into water, it is travelling from a less refractive substance into a more refractive substance. When this happens the refracted ray is bent *towards* the normal, as seen in the diagram above. However, if the light enters the water at right angles to it—in other words, along the normal line—then the light ray will not bend. For refraction to occur, the angle of incidence must be greater than 0°.

Light bends *towards* the normal when it travels from air ($n = 1.00$) into water ($n = 1.33$). But when travelling from water into air, light is travelling from a medium with a higher index of refraction (water) towards a medium with a lower index of refraction (air). When this happens, the refracted ray is bent *away* from the normal, as shown in the following diagram. Note that the angle of refraction is now larger than the angle of incidence.

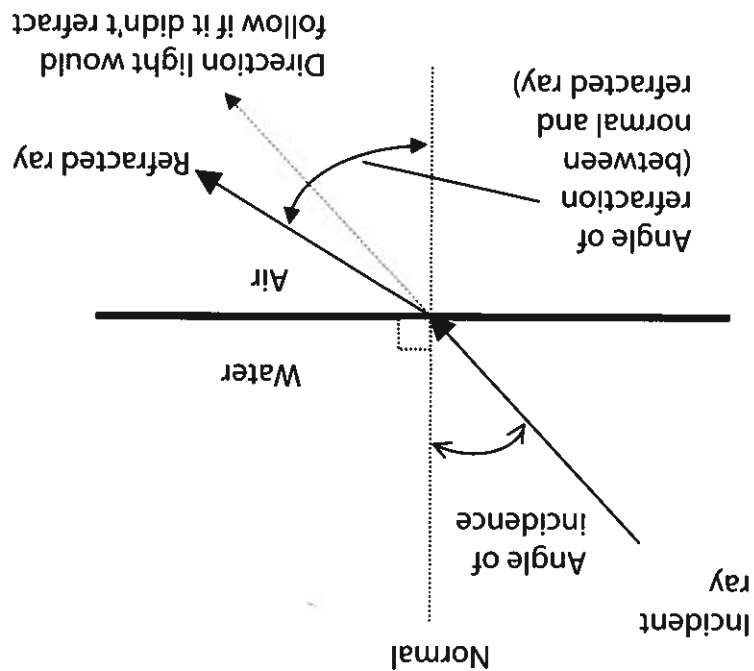


Figure 18.6 Angle of refraction in relation to angle of incidence when light enters a less dense medium

The angle of refraction is affected by the angle of incidence. If the angle of incidence is increased, the angle of refraction also increases. But if you double the angle of incidence, the angle of refraction does not double. In other words, increasing the angle of incidence increases the angle of refraction, but not by the same amount as the angle of incidence.

You can explore the effect that changing the angle of incidence has on the angle of refraction using an online tool. This activity is *optional*. It is not required for you to complete this lesson, but may help you understand the concepts better.

If you want to experiment with changing the angle of incidence, go back to the “Exploring Refraction” tool on your course page.



Support Questions

17. a) What happens to the refracted ray, in relation to the normal, as light travels from air into water?

- b) Explain what happens to the angle of refraction if the angle of incidence is increased.

18. Draw a diagram showing what happens to a light ray travelling from glass into air. Label it with the following: *glass, air, normal, angle of incidence, angle of refraction.*

Refraction and Colour

As you saw in Lesson 16, whether from the sun or a light bulb, white light is made up of the colours red, orange, yellow, green, blue, and violet. This collection of colours is sometimes referred to as the **solar spectrum**.

When white light passes through a prism, such as you find in jewellery and glass crystals, the light is refracted. However, each of the different colours that make up the white light is refracted a slightly different amount. Red is refracted the least and violet the most. As a result, the colours become separated when the white light passes through the prism, as shown in the diagram below. This separation of white light into its composite colours is referred to as **dispersion**. This is what gives rainbows their colour since the white light of the sun is broken up by the water droplets remaining in the air after a rain shower, which act like little prisms.

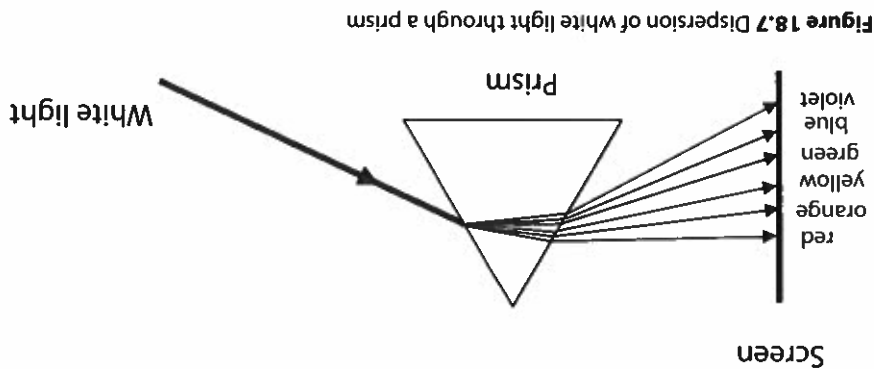


Figure 18.7 Dispersion of white light through a prism

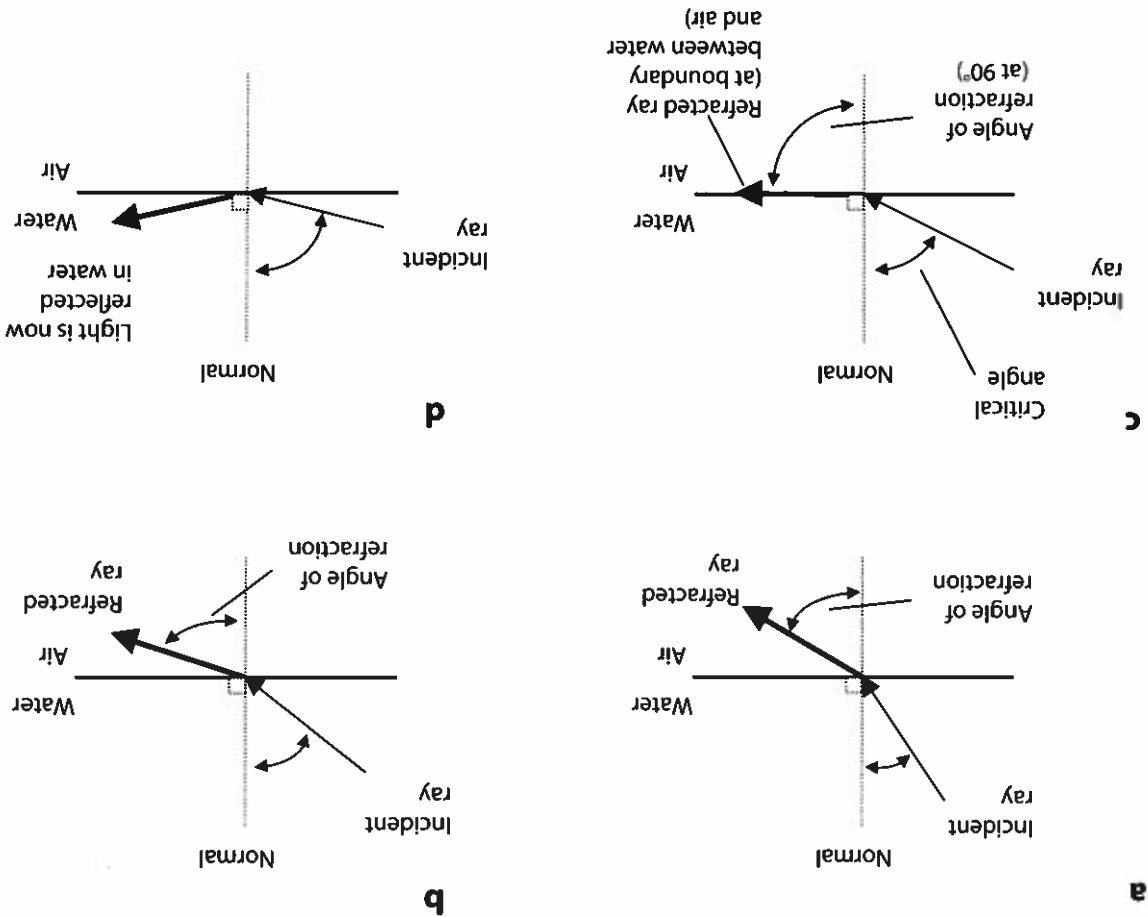
Critical Angle

As you saw, when light travels from a more refractive material (water) to a less refractive one (air), the angle of refraction is larger than the angle of incidence. As the angle of incidence increases, the angle of refraction gets closer and closer to 90° , as indicated in the four parts (a to d) of Figure 18.8 on the next page.

When the angle of incidence increases to the point where the angle of refraction is 90° (as shown in Figure 18.8 c), this angle of incidence is referred to as the **critical angle**. At the critical angle, the refracted ray travels along the boundary between the two materials. Beyond the critical value, the light now is reflected back into the original material (as shown in Figure 18.8 d). Each material has its own value of critical angle.

Materials with a larger index of refraction have a smaller critical angle. This means that a larger portion of light is reflected inside the material. For example, diamonds have a large index of refraction ($n = 2.42$) and a small critical angle of 25° . As a result of the small critical angle, diamonds tend to sparkle from the internal reflections. That's why they sparkle more than glass crystals and why we value them more.

Figure 18.8 a-d Angle of refraction in relation to angle of incidence



Support Questions

19. Explain what is meant by the critical angle.

20. How does a material's critical angle vary with the index of refraction?

Total Internal Reflection

If the angle of incidence is increased more than the critical angle, then the light is no longer refracted; instead it is totally reflected back internally into the more refractive material, as demonstrated in Figure 18.8 d on page 13. This phenomenon, called **total internal reflection**, can only occur when light travels from a medium with a higher refractive index to one with a lower refractive index. For example, it occurs when light passes from water to air, but not from air to water.

For light travelling from water into air, the critical angle is approximately 49° . That means that if the angle of incidence is less than 49° , refraction will occur, but if the angle of incidence is greater than 49° , then total internal reflection will occur in the water.

Besides jewelry, another use of the principle of internal reflection can be found in cars with automatic windshield wiper systems. These systems turn on the wipers when it starts to rain. An infrared light is continually beamed at a 45° angle into the windshield from the interior. If the glass is wet on the outside, less light goes back to the sensor, which triggers the wipers to turn on.

Total internal reflection is also the principle behind optical fibres used in high-speed communications. As shown in the diagram on page 15, light undergoes multiple internal reflections as it travels through a curved fibre; this allows it to follow bends in the fibre cable without getting absorbed. Optical fibres can therefore transport light signals around the globe without having to be perfectly



Activity: Total Internal Reflection

Purpose

Investigate total internal reflection.

Materials

- clear water glass
- all-purpose flour
- water
- small flashlight (for example, a Maglite®)

Procedure

1. Add a pinch of all-purpose flour to a clear glass of water and stir. This will suspend some particles of flour in the water so that the light beam can be seen. If the beam still cannot be seen, add a bit more flour until the beam is visible.
2. Use a small flashlight to shine the light beam into the cloudy water.
3. Shine the light at different angles, as shown in Figure 18.10, until total internal reflection occurs.

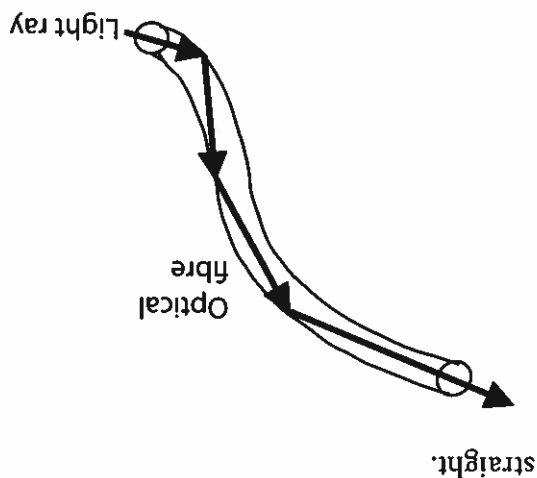


Figure 18.9 Internal reflection allows light to travel down a curved optical fibre

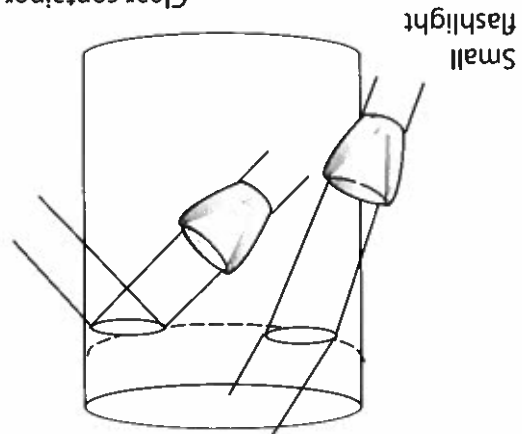


Figure 18.10 Experimental set-up showing the effect of aiming the flashlight at different angles

Support Questions

These questions are based on the preceding activity.

21. What happens to the light beams as the angle of the flashlight is changed?

22. Explain why you think this occurred.

Conclusion

Light bends when it moves between materials of different densities. The amount it bends depends on the material's refractive index. The denser the material, the more slowly light moves through it and the higher its refractive index. The angle of refraction also depends on the angle of incidence. At a certain angle for each material, called the critical angle, the incident light ray reflects inside the material rather than being refracted. We use this property to create beneficial technologies, like optical fibres that can transmit light rays along curved pathways. The simple process of refraction has surprising consequences for human well-being. In the next lesson, you will see how we have learned to use refraction to create new technologies and ways of seeing the universe and ourselves through the use of lenses.

Key Concepts

Medium: the material that light travels through (plural: **media**)

Refraction: the bending of light as it passes from one material to another

Index of refraction: a number (without units) that tells you how much light will bend as it enters a material. Represented by n .

Angle of refraction: the angle of a refracted light ray from the normal

Solar spectrum: the collection of colours that make up white light

Dispersion: the separation of white light into its composite colours

Critical angle: the angle of incidence at which a light ray will no longer refract in a material, but will begin to reflect back into the material

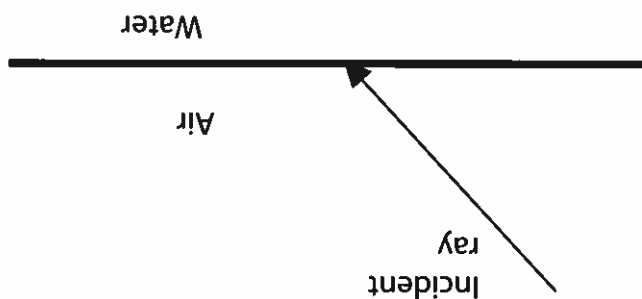
Total internal reflection: occurs when light no longer refracts off a material, but instead reflects back into the material

Key Questions

Save your answers to the Key Questions in your
Course Journal or e-Journal.

Total: 16 marks

- 73.** What happens to the speed of light as it passes from water to air? Which is the more refractive material? (2 marks)
- 74.** The index of refraction of diamond is 2.42. What is the speed of light in diamond? (5 marks)
- 75.** In which direction does the refracted ray bend in relation to the normal when light is going from air into a material with a higher index of refraction? (2 marks)
- 76.** Complete the diagram below by labelling the following: *normal*, *angle of incidence*, *angle of refraction*, *refracted ray*. (4 marks)



- 77.** Explain what happens when light travels from water into air and the angle of incidence is greater than the critical angle. (3 marks)

Now go on to Lesson 19. Remember, you do not send your journal to the Independent Learning Centre until you have completed Unit 4 (Lessons 16 to 20).

SNC2D-B



**Let's Get Focused: Forming Images
with Lenses**



- After completing this lesson, you will be able to
- recognize the different types of lenses
- use the terminology associated with lenses
- show how images are formed by lenses
- identify the main characteristics of images
- locate an image using light-ray diagrams

What You Will Learn

Suggested Timing for This Lesson (hours)	
What Is a Lens?	$\frac{3}{4}$
Light Rays and Lenses	1
Images and Lenses	$1\frac{1}{4}$
Magnification	$\frac{1}{2}$
Key Questions	1

You may find this time grid helpful in planning when and how you will work through this lesson.

Planning Your Study

The previous lesson introduced you to refraction. By far the most common and important application of refraction is in lenses. Lenses are used in eyeglasses, cameras, projectors, telescopes, and a wide variety of other devices. Even your own eye contains a lens. So everything you see comes through a lens, whether you are aware of it or not—and often several lenses. In fact, if you wear glasses and look through a camera, you are looking at the world through at least three lenses. Lenses have allowed us to see into the far reaches of the universe and the tiniest structures in living cells. Without lenses there would be no eyeglasses, photography, video, movies, or TV—and medicine would still be in the dark ages. Lenses are so much a part of our lives and technology that it's important to know how they work and what effect they have on the images that we see.

Introduction

What Is a Lens?

A **lens** is a piece of transparent material with at least one curved side. Light rays can pass through this material, but it alters their direction and quality.

Artificial lenses are usually circular in shape and made of glass or plastic. As you learned in Lesson 18, when passing from air into a denser medium like glass, light rays change direction because of refraction. As light rays strike a glass lens at different points along its curved surface, the amount the rays refract can vary, depending on the shape of the lens. Differently shaped lenses can produce images that are different from the original object in size, shape, or orientation.

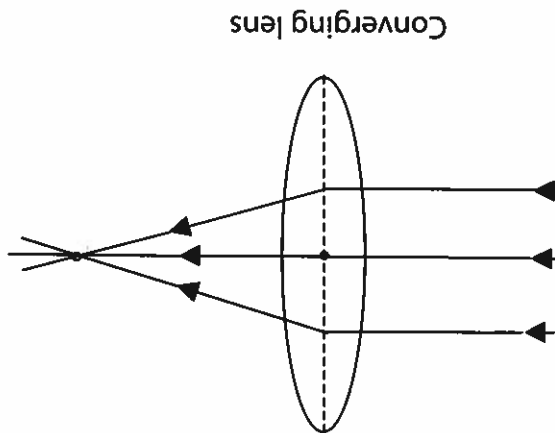
Knowledge of lenses has brought enormous benefit to many people. It was critical to the invention of prescription eyeglasses, contact lenses, and even laser eye surgery. The invention of eyeglass lenses has revolutionized modern life by allowing millions of people to read, sew, do close-up manufacturing work, and drive. This has opened up a world of social and business opportunities that otherwise would have been unavailable to them.

Lenses have also extended our knowledge of the infinitely large reaches of space and the immensely small world of living cells. For example, the earliest telescopes built about 400 years ago opened our eyes to the composition of the solar system. In 1610, Galileo (1564–1642) used a telescope he had built himself to see that our moon was not smooth and that Jupiter had moons. Now we even have lenses in space to increase our ability to see farther. Space telescopes, like the Hubble Space Telescope, travel in orbit about 600 kilometres above the earth's surface, using many lenses to see objects at the edge of the universe.

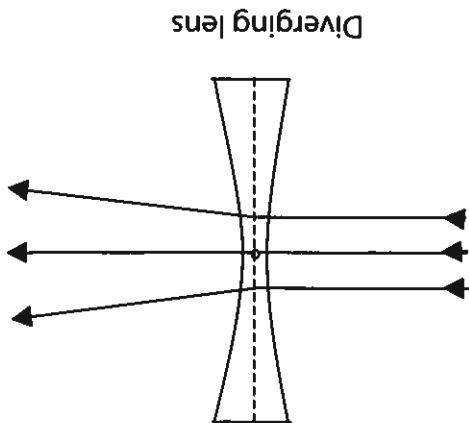
In the world of the very small, microscopes use lenses to magnify tiny objects. This has revealed the existence of microbes, creating the field of cell biology that has brought us amazing medical breakthroughs. You will learn more about the uses of lenses and optical devices in the next lesson.

Types of Lenses

There are two main types of lenses, diverging and converging. **Converging lenses** (sometimes called convex) bring the light rays together, and **diverging lenses** (sometimes called concave) spread the light rays apart. Both are illustrated in the diagrams on the next page.



Converging lens



Diverging lens

Figure 19.1 Light rays passing through a converging and a diverging lens

Light rays striking the edge of the lens are bent the most, because the angles of incidence are greater where the surface of the lens is curved more. The least bending of the light rays occurs in the middle of the lens. At the very middle of the lens, the light ray does not get bent at all, but passes straight through. As you can see from the diagram above, the shape of a converging lens causes parallel light rays to come together so that they cross at a point beyond the lens. In contrast, a diverging lens spreads apart the parallel light rays. Because they are moving between media of different densities, the light rays are refracted when they enter the lens and then again when they leave it. You know this from the last lesson. However, in order to simplify things, diagrams generally show light rays as changing their direction only once from the centre of the lens, as illustrated in Figure 19.2 below. The final angle of the light ray is correct in both images, but the second image is easier to draw, especially when you are drawing multiple light rays passing through the same lens.

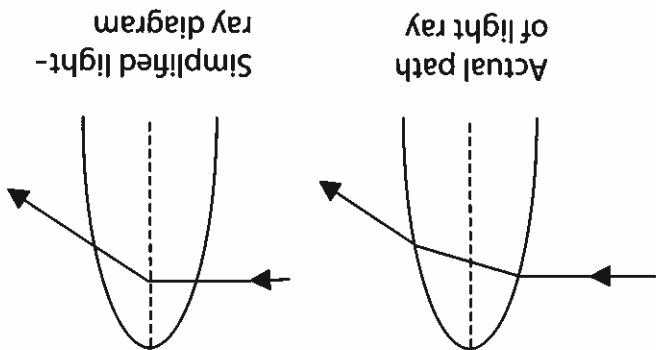


Figure 19.2 Actual path of a light ray through a converging lens and the simplified version

As seen in Figure 19.3 below, lenses come in a variety of shapes in order to refract light for different applications. However, you only have to remember one rule to determine if a lens will converge or diverge light. If the lens is thicker in the middle, it converges the light rays, and if the lens is thinner in the middle, it diverges the light rays.

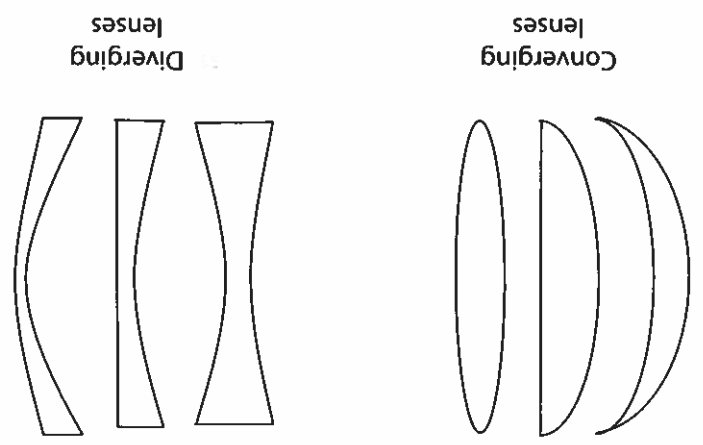


Figure 19.3 Examples of converging and diverging lenses

Support Question

Do not send your answers in for evaluation.

23. a) Draw a diagram of a converging lens. Show at least three light rays, parallel to the principal axis, entering and leaving the lens.

- b) Explain what causes light rays to change direction when passing through a lens.

There are Suggested Answers to Support Questions at the end of this unit.

In a converging lens, the point on the principal axis where the refracted light rays converge (or cross) is called the **principal focus (F)**. The distance from the optical centre to the principal focus is referred to as the **focal length**. On the other side of the lens (the same side as the incident rays), there is a point referred to as the **secondary principal focus**. It is also located on the principal axis, one focal length away from the optical centre. You can think of it as the exact opposite of the principal focus.

Figure 19.4 Main features of light rays passing through a converging lens

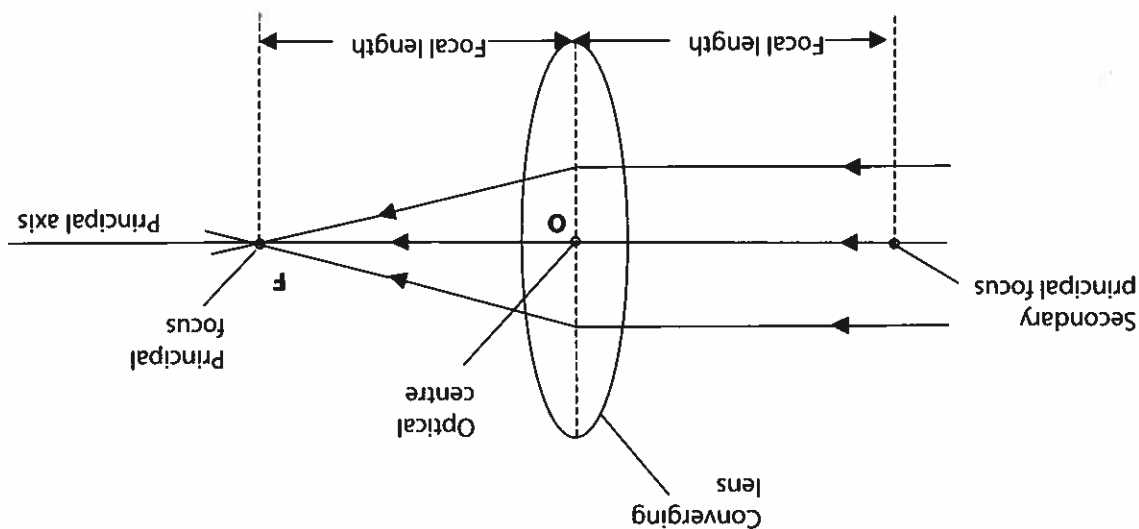


Figure 19.4 below depicts a converging lens with three light rays passing through it. Note that the middle light ray lies along the principal axis and so passes straight through the lens.

Converging Lens

The terminology you learned in Lesson 17 for analyzing reflections in mirrors is very similar to that used for lenses. There are a few additional terms to learn. For example, the centre of the lens is called the **optical centre (O)**, and a line drawn through the optical centre at a right angle to the lens is called the **principal axis**. You can see these features in Figures 19.4 and 19.5. There are a few differences in terminology between converging and diverging lenses that relate to the different ways they refract light. It's easiest to learn these new terms by looking at diagrams of each.

Light Rays and Lenses

Diverging Lens

Figure 19.5 below depicts a diverging lens with three light rays passing through it. Note that the middle light ray here also lies along the principal axis and so passes straight through the lens without bending.

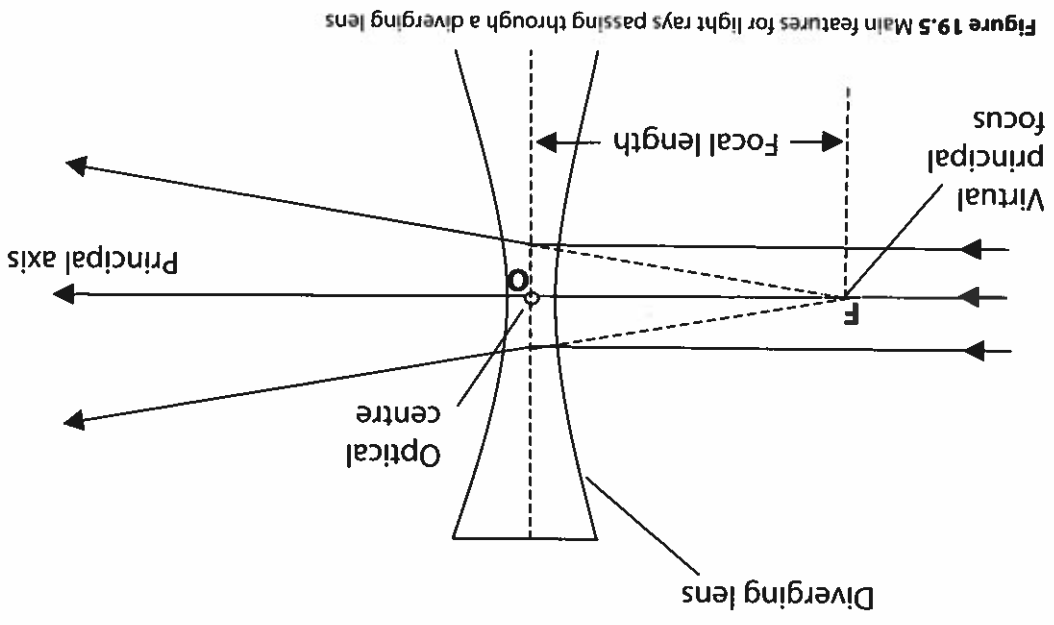


Figure 19.5 Main features for light rays passing through a diverging lens

In a diverging lens, the features are a bit different. Since the refracted light rays are spread apart in a diverging lens, there is no real focus point, only a virtual principal focus. The **virtual principal focus** is found by following the refracted light rays back until they cross. The virtual principal focus will appear to be a point on the same side of the lens as the incoming light rays.

To keep things simple, you will only focus on converging lenses for the rest of this lesson as you explore how images are formed in lenses.

Ray Rules for Converging Lenses

A great deal can be learned about the images that are formed in converging lenses by looking at three important light rays and how they are refracted as they pass through the lens.

The following three **ray rules for converging lenses** will help you draw light-ray diagrams for converging lenses.

1. A light ray that is parallel to the principal axis is refracted through the principal focus.
2. A ray that goes through the optical centre goes straight through without bending.
3. A ray that passes through the secondary principal focus is refracted parallel to the principal axis. (This is the reverse of rule number 1.)

These ray rules are demonstrated in the diagram of a converging lens below.

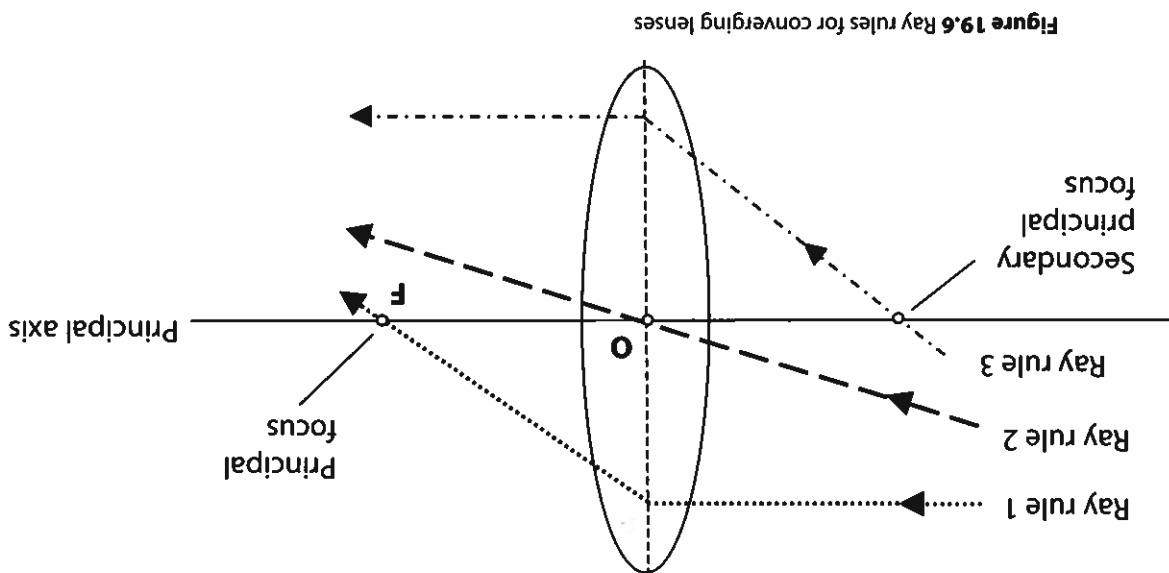
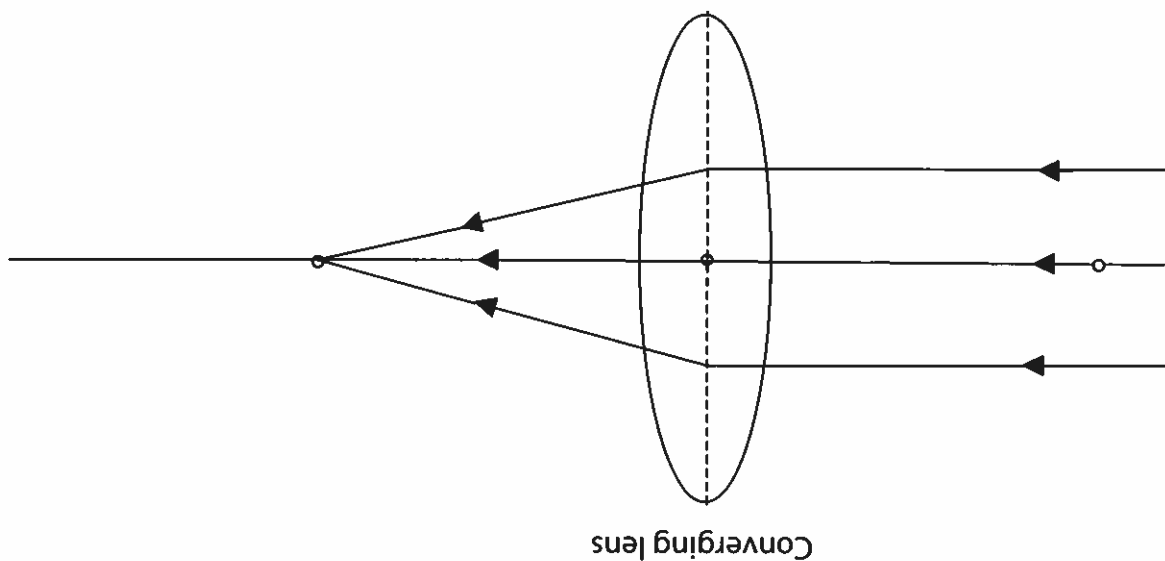


Figure 19.6 Ray rules for converging lenses

Support Questions

- 24.** On the diagram below of light rays passing through a converging lens, label the following: *optical centre, principal axis, principal focus, secondary principal focus, focal length.*



- 25.** Explain what happens at the principal focus of a converging lens.

Images and Lenses

Lenses have been used for over 3000 years, but not until the 17th century did the science of lenses really begin. In the early 1600s, lens makers began experimenting with the use of more than one lens. In 1608, Dutch lens makers produced the first known telescope by placing two converging lenses one in front of the other. This design was soon modified by other people, like Galileo in Italy, and used to make new discoveries in astronomy.

Converging lenses were first used to magnify distant images. They were commonly built into devices to allow people to see objects far away, either in telescopes or in early forms of eyeglasses. However, they can also be used to

magnify very small objects, such as tiny organisms and cells. About the same time that the first telescopes were being made, microscopes were being developed by the same inventors.

As does the telescope, the compound microscope uses two converging lenses to magnify objects. In the telescope and microscope, the lens closest to the object being viewed is called the objective lens. In the telescope, the objective lens has a long focal length to view large objects at great distances, whereas the microscope has an objective lens with a short focal length to view small objects at very small distances.

The invention of the telescope and microscope opened up new worlds of scientific discovery, revolutionizing chemistry, physics, earth science, and biology.

How Images Are Formed in Lenses

By knowing the path of the light rays, we can predict where the image will be formed by a converging lens. Just as in mirrors, the image formed by a lens has certain characteristics.

The three ray rules described on page 7 let us determine how an image will look when an object is seen through a converging lens. The following diagrams show the steps to creating an image from an object using the ray rules for a converging lens. Follow the steps to find where the image is formed and how it is positioned. Of course, to actually see the image, you have to place a blank piece of paper (screen) approximately where the image will occur.

Step 1 is to draw the ray following ray rule #1. The object in this case is an arrow pointed upwards.

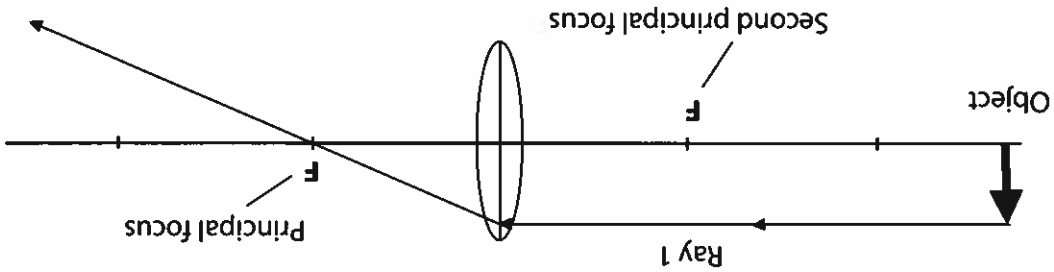


Figure 19.7 Step 1: Ray rule #1 added for a converging lens locates the principal focus

Step 2 is to add the ray following ray rule #2.

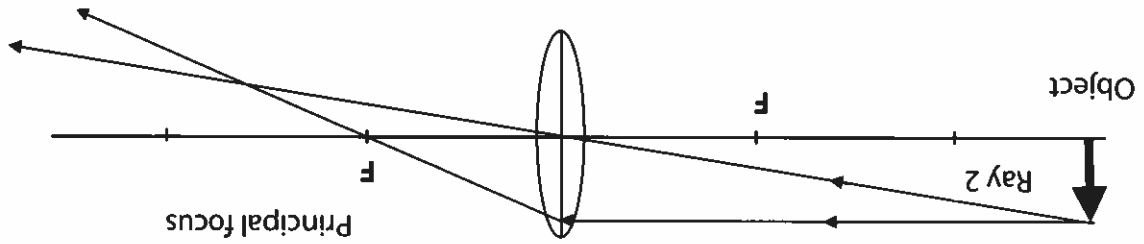


Figure 19.8 Step 2: Ray rule #2 added for a converging lens locates the position of the image

Step 3 is to add the ray following ray rule #3. Ray 3 should cross at the same location as rays 1 and 2. It is used as a test to confirm that you positioned rays 1 and 2 correctly. Draw an image of the top of the object where rays 1, 2, and 3 cross. The image is usually shown using dotted lines to distinguish it from the object. Note that the image is upside down.

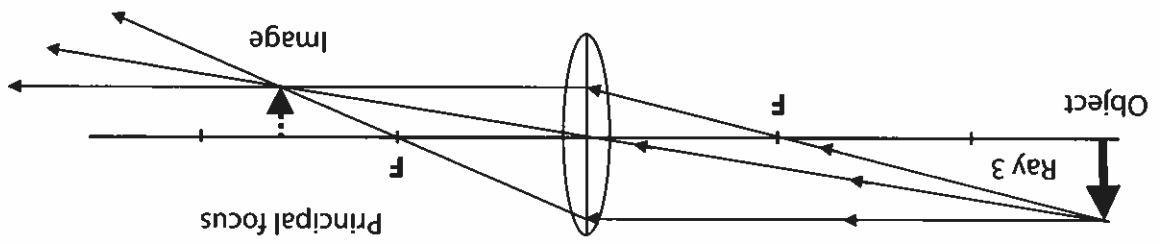


Figure 19.9 Step 3: Ray rule #3 added for a converging lens confirms the location of the image

By changing the location of the lens in relation to the object, you can change the size and orientation of the image. You can try this at home using a candle, a magnifying glass (converging lens), and a white paper screen set up like the diagram below. The candle, magnifying glass (converging lens), and screen can all be positioned along a ruler to help keep track of where they are. Try moving the lens closer to the object—what happens to the image?

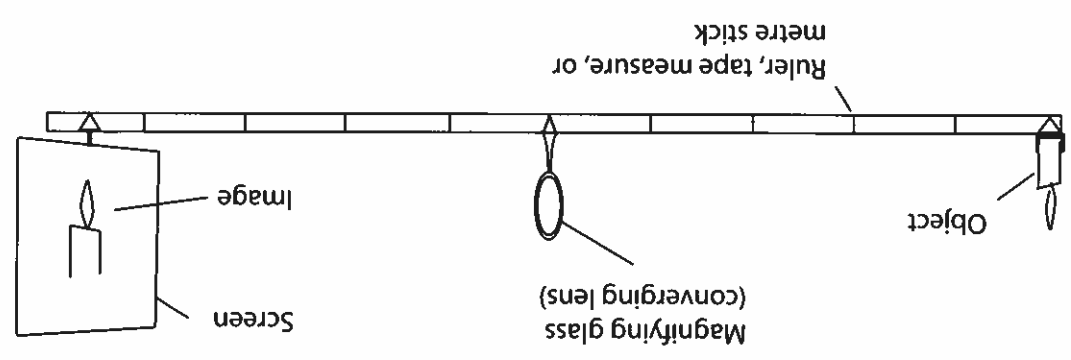


Figure 19.10 Experimental set-up showing position of object, lens, and screen to capture the image



You can also conduct experiments like this using an online tool. This activity is *optional*. It is not required to complete this lesson, but you may find it helps you understand the concepts better.

If you want to explore the behaviour of lenses further, go to your course page on the ILC website and click on “Images in Lenses” under Lesson 19.



Characteristics of Images in Lenses

When examining images created by lenses, you need to consider the following **image characteristics**: type, size, orientation, and location. You are familiar with these characteristics from your study of mirror reflections in Lesson 17.

- **Type:** refers to whether the image is *real* or *virtual*. A real image can be projected onto a screen, whereas a virtual image cannot. Generally, a converging lens produces a real image unless the object is between the optical centre and the secondary principal focus, in which case it produces a virtual image.

- **Size:** the size of the image compared to the object: is it *smaller*, *larger*, or the *same size*? In converging lenses, the size will vary according to the location of the object.

- **Orientation:** if the image is pointing in the same direction as the object, then its orientation is *upright*. If the image is pointing in the opposite direction, then its orientation is *upside down*. Images from a converging lens are upside down unless the object is closer than the secondary principal focus, in which case the image is upright. Also, if the object is placed at the secondary principal focus, all the refracted rays from the converging lens are parallel to each other and no image is produced.

- **Location:** refers to where the image can be seen: either on the same side of the lens as the object or on the other side of the lens, opposite the object.

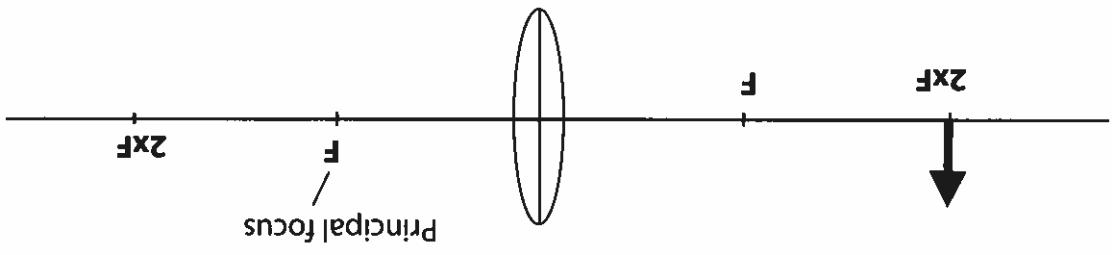
The characteristics of images in converging lenses are summarized in the following table.

Table 19.1 Characteristics of images in converging lenses

Position of Object		Image Characteristics of Converging Lenses		
		Location	Size	Orientation
far away	opposite side from object	smaller	upside down	real
	opposite side from object	same	upside down	real
	opposite side from object	larger	upside down	real
between one and two focal lengths from lens	opposite side from object	larger	upside down	real
at secondary principal focus	no image			
between secondary principal focus and optical centre	same side as object	larger	upright	virtual

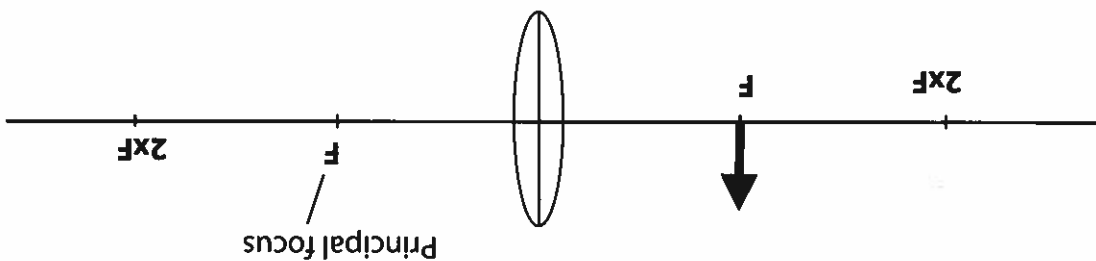
Support Questions

26. a) Draw a light-ray diagram for the object shown in the diagram below. The object is at a distance of two focal lengths away from a converging lens.



- b) Describe the characteristics of the image: location, orientation, size, and type.

- 27. a)** Using the diagram below, draw a light-ray diagram for an object at a distance of one focal length from the converging lens (at the secondary principal focus).



- b)** What does the light-ray diagram tell you about the formation of an image?

Magnification

In the light-ray diagram in Figure 19.11, the object is located in between one and two focal lengths from the converging lens. The size of the image is larger than the object. But how much larger?

Magnification is the size of the image in relation to the object. It can be calculated by dividing the height of the image by the height of the object. Mathematically this can be expressed as

$$\text{magnification} = \frac{\text{height of the image}}{\text{height of the object}}$$

If the magnification number is greater than 1, the image is larger than the object. If the magnification number is less than 1, the image is smaller than the object. Magnification is a relative measure. This means that it doesn't matter what units are used to measure the object and the image, as long as the same units are used for both. In diagrams, the height is usually measured in millimetres or centimetres.

The telescope used by Galileo in 1610 had a magnification of only around 30 times. This was soon improved on by the astronomer Johannes Kepler (1571–1630), who developed a telescope with magnifying powers of almost 1000 times.

Figure 19.11 below shows how a converging lens magnifies the image of the arrow on the left side of the figure. The image produced appears on the right side. The image is drawn with dashed lines to distinguish it from the object. Note that in this case the image is bigger than the object and appears further beyond from the focal point than the object.

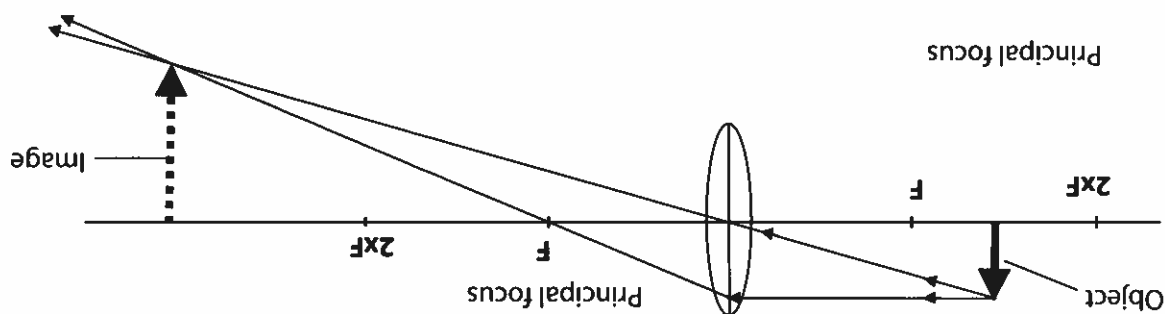


Figure 19.11 How an object gets magnified in a converging lens

Given a diagram like the one above, it is easy to calculate the magnification.

Example

If an object is 45 centimetres high and the image is 105 centimetres high, what is the magnification?

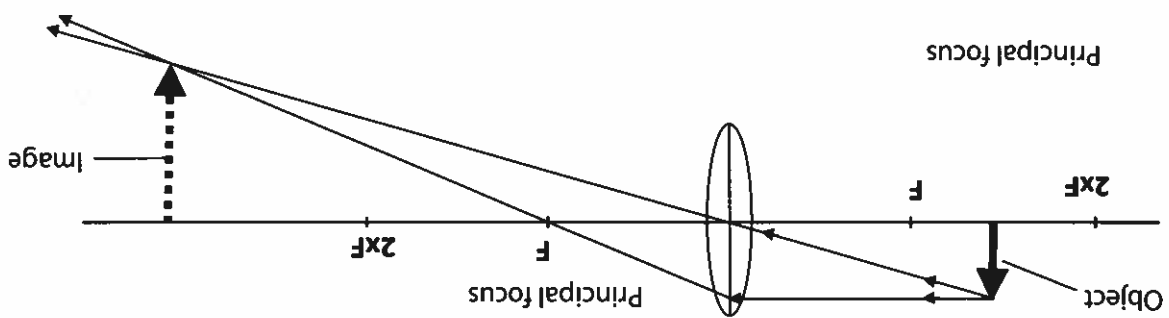
$$\text{magnification} = \frac{\text{height of the image}}{\text{height of the object}}$$

$$\text{magnification} = \frac{105 \text{ cm}}{45 \text{ cm}} = 2.3$$

The image is approximately 2.3 times larger than the object.

Support Question

28. a) What is the magnification of the image in the following diagram? You can measure the heights directly off this page using a ruler.



- b) Indicate the characteristics of the above image.

Conclusion

In this lesson, you learned how the principles of refraction are used in converging lenses to create images that are bigger or smaller than the original object. The lesson first introduced you to the principles of refraction in both converging and diverging lenses. Next you explored how images are created in converging lenses, using ray rules to find the image and summarizing the characteristics of images. You also learned how to calculate magnifications.

So far in this unit you have learned about the basic properties of light, its transmission, and its interaction with materials. You have also seen how light can be reflected and refracted, and how we use those properties to manipulate images. In the final lesson of this unit, you will explore how all these properties of light are used to create technologies essential to our lives.

Key Concepts

Lens: piece of transparent material with at least one curved side

Converging lens: brings the light rays together. Sometimes called a convex lens.

Diverging lens: spreads the light rays apart. Sometimes called a concave lens.

Optical centre: the centre of the lens

Principal axis: a line drawn through the optical centre at a right angle to the lens

Principal focus: the point on the principal axis of a converging lens where the refracted light rays converge (or cross)

Focal length: the distance from the optical centre to the principal focus

Secondary principal focus: located on the principal axis, one focal length away from the optical centre. It is on the opposite side of the principal focus.

Virtual principal focus: only occurs with a diverging lens. It is found by following the refracted light rays back until they cross, and will appear to be a point on the same side of the lens as the incoming light rays.

Ray rules for converging lenses: three rules that help you draw the image based on the position of the object in relation to the lens. Each rule describes the behaviour of one light ray as it gets refracted passing through the lens.

Image characteristics: four characteristics that compare the image with the object—type, size, orientation, and location

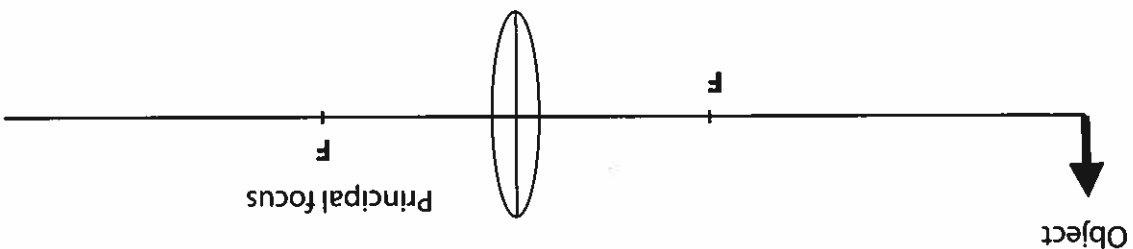
Magnification: the size of the image in relation to the object. It is a relative measure. Both the image and object must be measured in the same units.

Key Questions

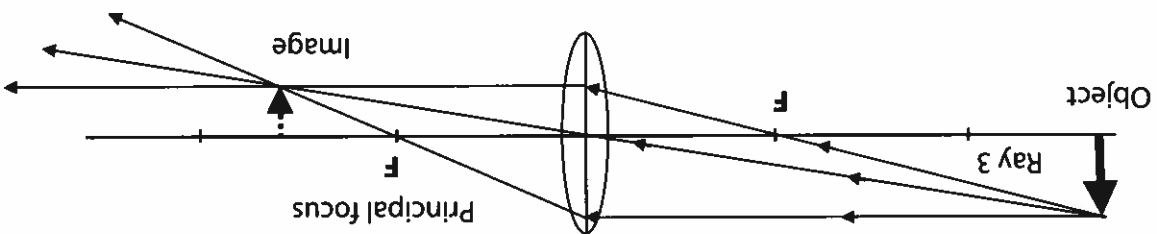
Save your answers to the Key Questions in your Course Journal or e-Journal.

Total: 16 marks

78. Why is a converging lens able to focus light rays? (3 marks)
79. What happens to a light ray that passes through the optical centre of a converging lens? (2 marks)
80. Draw a light-ray diagram for the object shown in the following diagram and calculate the magnification of the image produced. (7 marks: 4 marks for the drawing, 3 marks for the magnification)



81. Indicate the four characteristics of the image in the following diagram. (4 marks)



Now go on to Lesson 20. Remember, you do not send your journal to the Independent Learning Centre until you have completed Unit 4 (Lessons 16 to 20).



Optical Devices



SNC2D-B

Suggested Timing for This Lesson (hours)	
Mirrors	¾
Lenses	1
Correcting Vision	¾
Activity: Blind Spot	½
Natural Refraction Phenomena	½
Key Questions	1

You may find this time grid helpful in planning when and how you will work through this lesson.

Planning Your Study

In this final lesson of the unit and the course, you will learn how knowledge of the properties of light has been applied to create new technologies and explain natural events.

You will explore how the patterns of reflection and refraction are being used to create devices and technologies, like cameras and satellite receivers, which have forever changed the way people communicate. Imagine the world without lenses. What would you do without eyeglasses or flashlights? Without movies or photos? In this lesson, you will study some examples of refraction and reflection found in natural phenomena, as well as the optical devices that are so much a part of your life.

Once you have completed this lesson and studied for the Final Test, you may take a Practice Test. It will help you prepare for the Final Test.

The Practice Test is on your course page on the ILC website. When you have completed it, you can use the Practice Test Suggested Answers on your course page to check your work. Follow the instructions at the end of this lesson.

Introduction

What You Will Learn

After completing this lesson, you will be able to

- recognize when to use different kinds of lenses and mirrors and evaluate their effectiveness for the chosen task
- describe the social benefits of optical technologies
- describe how lenses in eyeglasses correct nearsightedness and farsightedness
- explain natural phenomena caused by refraction, such as mirages and the twinkling of stars

Uses of Optical Devices

Everything we know about the physics of light started with curiosity. Thousands of years ago, people began playing with shiny materials to see their reflections. Some even peered through small rock crystals that acted as primitive lenses. Progress in understanding light's properties was slow until the scientific revolution began in the early 1600s. Since then, knowledge of optics has expanded greatly, creating new technologies and new ways of living.

So far in this unit you have learned what light is, how it travels, and how it reflects and refracts. In this final lesson, you will focus on how people use these features of light to make important optical devices. You will start by looking at the different uses of mirrors. Next you will examine how a camera works and how it is similar in design to the human eye. You will learn how vision problems are being solved using lenses and lasers. Finally you will learn how to explain many common natural events, like mirages and rainbows, using concepts of refraction.

Mirrors

Reflection is a very useful property of light—try shaving or applying makeup without a mirror, and you'll quickly understand this. People have used mirrors for thousands of years. Most ancient mirrors were made of polished metals, like tin or silver. Modern mirrors are generally still based on a metal, usually a thin layer of steel and chrome, with a glass covering.

In ancient Rome, mirrors were considered so valuable that only the rich had them; most people never got a chance to see their own face. But now mirrors are so cheap that everyone can have one. Mirrors are found everywhere, from the simplest technologies to the most complex.

Diverging Mirrors

Diverging, or convex, mirrors are probably most familiar to you as cosmetic or shaving mirrors. They produce an enlarged image if the object is placed closer than the principal focus. They are also commonly used in stores and security areas because they let you see a large area and the image is always upright. The following diagram shows how a convex mirror is able to capture a larger viewing area than a flat plane mirror.

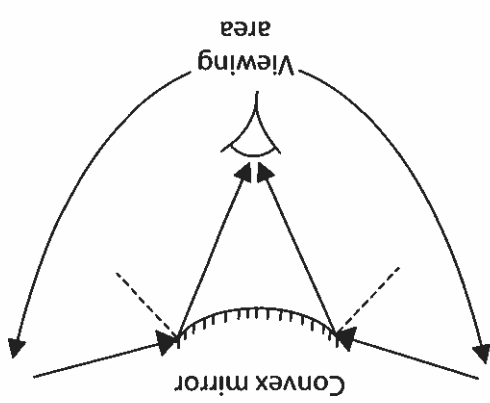
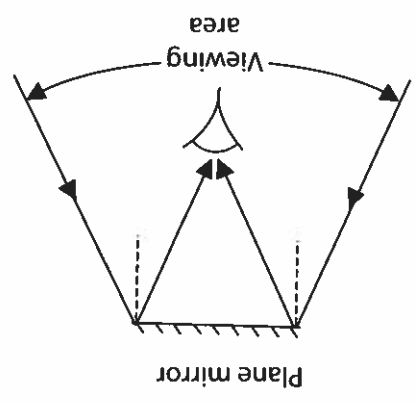


Figure 20.1 Comparing the size of viewing areas in plane and convex mirrors

Diverging mirrors are also used as side view mirrors on cars and trucks since they allow the driver to see several lanes at once. However, the image in diverging mirrors is smaller than in the plane mirrors. As a result, cars seen in the mirror are closer than they appear.

Support Question

Do not send your answers in for evaluation.

29. Explain why diverging (convex) mirrors are used for surveillance.

There are Suggested Answers to Support Questions at the end of this unit.

Converging Mirrors

As you learned previously, when light rays parallel to the principal axis are reflected from a converging (concave) mirror, they pass through the principal focus (F). This is shown below.

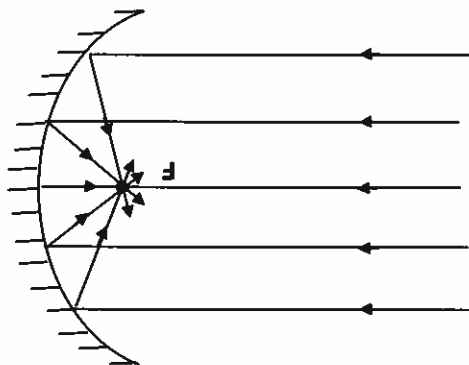


Figure 20.2 Light rays reflecting in a converging (concave) mirror

The principal focus becomes the point where all the energy from the light rays can be concentrated. We use this fact to generate power, cook food, watch satellite TV, and telecommunicate around the globe. Details on how these technologies use reflection are described below.

Power Generation: Thermal Solar

In very sunny parts of the world, like the southwestern USA, new solar-energy power plants are being built that use converging mirrors to concentrate the sun's energy. Concave mirrors focus the sunlight onto a narrow tube containing flowing oil. After travelling past many dozens of mirrors, the oil reaches 700°C, hot enough to boil water. This generates steam that drives an electric generator. The end result is electrical power that emits no greenhouse gases. The waste steam is allowed to cool down back to water and gets re-used. After boiling the water, the cooled oil can be circulated back out to the mirrors to be heated up again, so there is no waste there either.

Called *thermal solar*, this way of generating clean electricity is becoming more widespread. This is one example of an innovative uses of mirrors helping to solve a serious environmental problem like climate change.

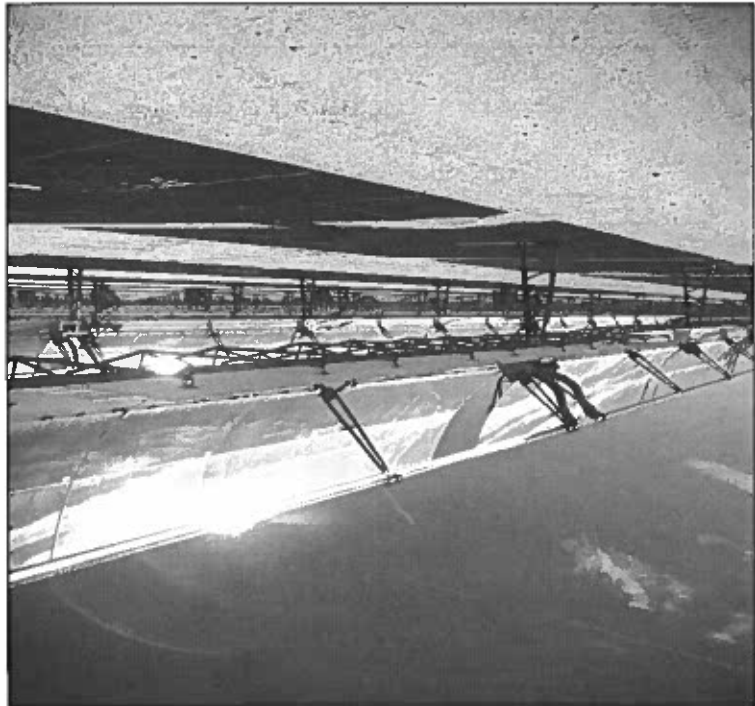


Figure 20.3 Curved mirrors in the California desert. The mirrors heat a reusable oil used to create steam, which in turn powers turbines to create clean electricity.

Source: iStockphoto.com

Solar Cookers

Solar cookers also use a converging mirror. On a sunny day, the sun's rays are focused in the area of the principal focus and anything placed in that area will get very hot. Food is placed at the principal focus in order to be cooked. This requires no polluting fuel or expensive firewood, making this technology especially useful in some developing countries.

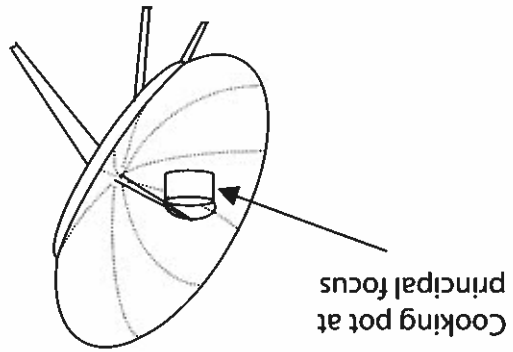


Figure 20.4 Solar cooker uses a converging mirror to concentrate the sun's energy on a cooking pot

The ancient Greek philosopher and scientist Archimedes (c. 287 BC–c. 212 BC) took this idea even further. It is said that he created a large converging mirror to concentrate the sun's rays and set fire to invading ships before they were able to land their army.

Satellite Receivers

Generally made of aluminum, satellite receivers (or dishes) are shaped like converging mirrors. They are often used to receive a signal from a satellite in orbit. The satellite signal is an electromagnetic wave; though invisible to our eyes, it can be focused in the same way as visible light. In satellite receivers, the actual equipment that receives the signal (called the feed horn) is placed at the principal focus of the receiving dish in order to obtain maximum signal strength.

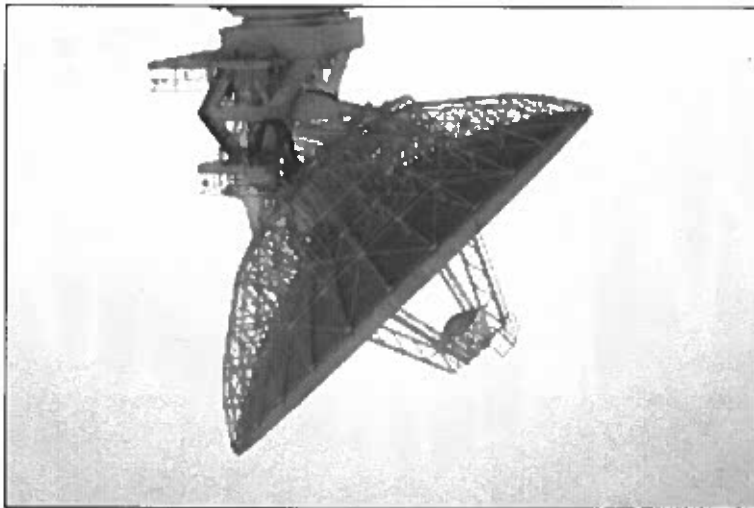


Figure 20.5 Satellite dish receiver

Source: iStockphoto.com

Telescopes

Converging mirrors have been used for hundreds of years in **reflecting telescopes**. The larger the mirror, the more light can be collected. Some of these mirrors are now over five metres in diameter, allowing us to see light from very faint stars.

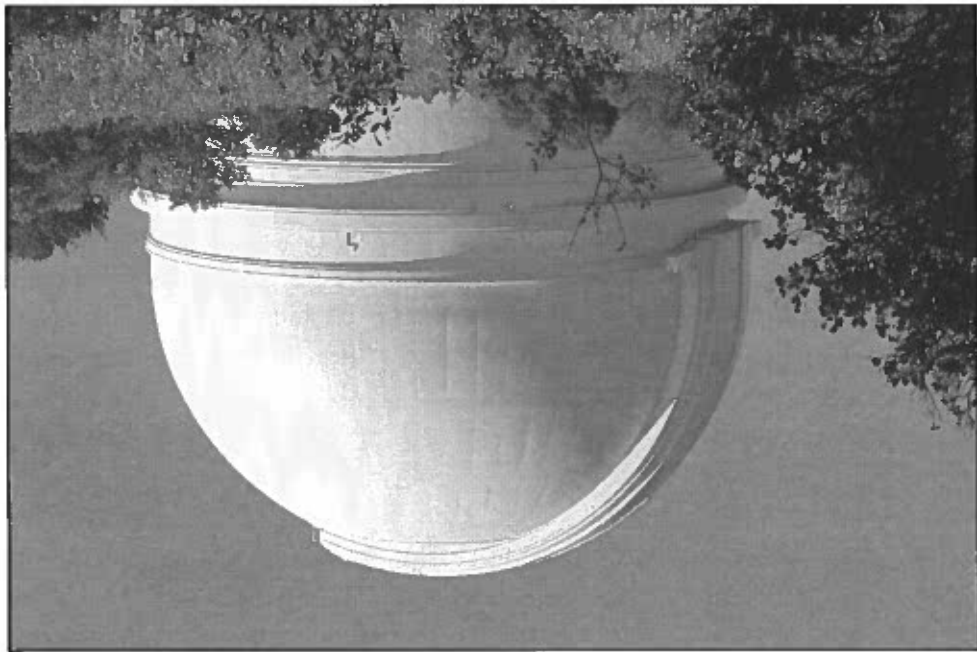


Figure 20.6 Mount Palomar Observatory in southern California. This observatory contains a five-metre diameter mirror reflector telescope.

Source: iStockphoto.com

The following diagram indicates how the reflecting telescope works.

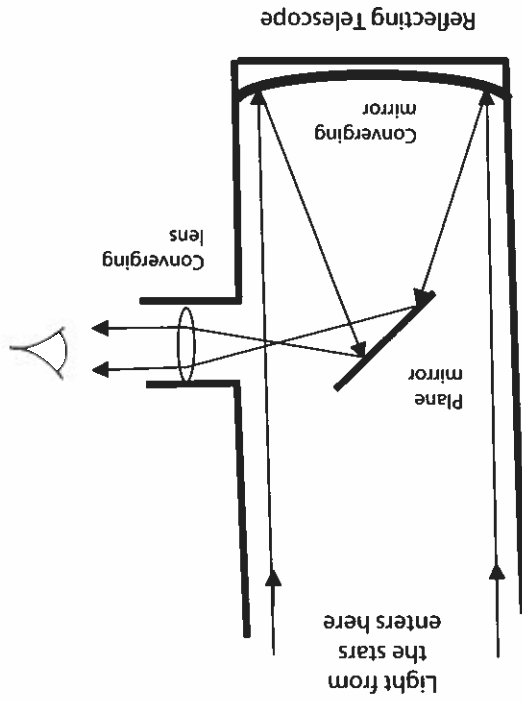


Figure 20.7 How a reflecting telescope focuses the light rays coming from stars

Faint light rays from distant stars enter the telescope and are reflected off the converging mirror at the back of the telescope. The light rays are concentrated and reflected off a plane mirror placed at the principal focus point. These rays are then focused using a converging lens to make them easier to see. The large size of the converging mirror means it can collect many faint light rays and concentrate them so that their light becomes easier to detect. Using mirror telescopes, astronomers can detect distant stars and galaxies at the edge of the universe.

Transmitting Light

This process can also be reversed, as shown below. If a light source, such as a glowing light filament, is placed at the principal focus of a converging mirror, then the light rays coming off the filament will be reflected off the mirror and come out parallel to the principal axis. This creates a focused beam of light.

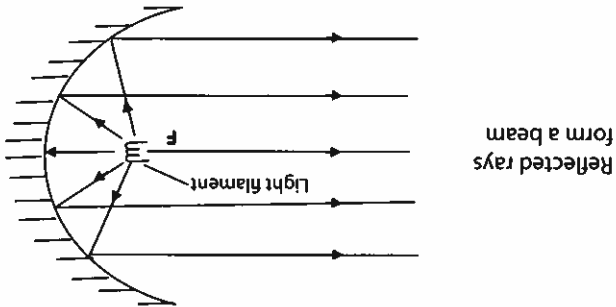


Figure 20.8 Using a converging mirror to make a bright light

This effect is used in devices such as search lights, flashlights, and car headlights. The glowing filament is placed at the principal focus of a converging mirror in order to produce a focused light beam. This creates a much brighter light than you would get if the rays were just allowed to scatter off the filament in all directions. Using this method, even a small bulb can give off a very bright light.

Telecommunication transmitting towers use dishes in the shape of a converging mirror to send out their signals. A transmitter is placed at the principal focus of the dish. When the transmitter gives off electromagnetic waves, they are focused and sent out as a beam of invisible light that is directed towards a satellite in space.

Support Question

30. With the aid of a light-ray diagram, explain how solar cookers work.

Lenses

As you learned in the last lesson, lenses are responsible for giving us many new technologies and ways of knowing the universe. You will examine three particularly important uses of lenses in our society: cameras, the human eye, and vision correction.

Camera

A **camera** is simply a light-proof box with an opening at one end and a converging lens to focus the image on a recording surface at the back of the camera. The modern camera was invented about 150 years ago, but the principle of using a sealed box with a small opening to focus an image for capture goes back about 1000 years. All cameras work on the same basic plan, shown in Figure 20.9.

Light enters through the front lens, then passes through a second lens that focuses the light onto a light-sensitive surface where the image can be captured. For most of their history, cameras used light-sensitive film to capture the image, but now most cameras use a light-sensitive integrated circuit called a charge coupled device (CCD) that records the intensity of light falling on tiny squares called pixels. The amount of light allowed in is controlled by the diaphragm, which determines the size of the hole that light passes through. Once inside, the light is refracted by a second lens. By moving the second lens closer or further away from the front lens, you can focus different parts of the image onto the light-sensitive surface. The technology of new cameras is very sophisticated. Most have features that allow them to focus on objects automatically, control light levels, and prevent vibrations from affecting the image. The invention of the camera made it possible for anyone to capture an image of an object. Before the camera, people relied on artists to create portraits of people, paint landscape images, and draw descriptive maps of areas. The invention of the camera gave everyone this ability, and changed the way news and public events were recorded. Can you imagine a magazine or television newscast without photographs? Cameras, and eventually movie and video cameras, allowed us to see things that our eyes could not easily detect. Cameras can change our perception of time. Events that happen very fast can be frozen in time. A lightning strike, the flap of a bird's wings, or the finish order in a close race can be captured and studied at leisure. Events that take a long time to occur can now be speeded up using time-lapse photography, making the whole process easier to understand. You've probably seen sped-up videos of flowers opening and closing, or of hurricanes spiralling towards a city.

Simple Digital Camera

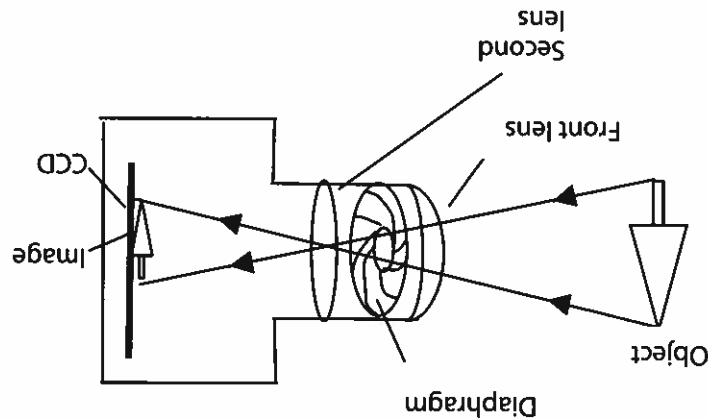


Figure 20.9 How a camera captures an image

The Human Eye

The human eye is an example of a piece of biological technology shaped by natural evolution. Your eyes work very much like a camera, as demonstrated in the diagram below.

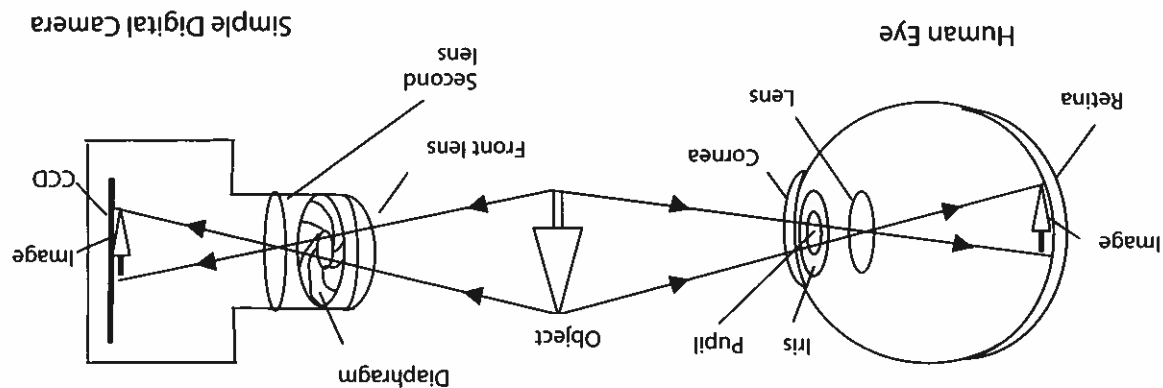


Figure 20.10 Human eyes and cameras capture images in similar ways

Light rays enter through the cornea on the surface of the eye. Because of the curvature of the cornea and its refractive index of approximately 1.4, refraction takes place at the front surface of the cornea. When the light reaches the converging lens inside the eye, the light rays are refracted again by the lens in order to focus the image directly on the retina located at the back of the eye. The retina is like the CCD on a digital camera. It is able to sense how much light is hitting individual cells and send that information to your brain. The brain interprets that information to create the image you perceive.

The eye controls how much light reaches the inner lens using the iris, which controls the size of pupil. This is similar to a camera's diaphragm. As the size of the pupil changes, the amount of light passing through the lens can be controlled. You can see your pupil move by standing in front of a mirror in a dimly lit room and then suddenly turning on a bright light. Your pupils will rapidly close to reduce the amount of light entering the eye.

Note that in both the camera and eye, the image is presented upside down relative to the object.

Support Questions

- 31.** When light rays pass from air (which has an index of refraction of 1.0) through the cornea (which has an index of refraction of 1.4), the light is refracted. Water has an index of refraction of 1.3, which is much closer to the index of refraction of the cornea. In terms of refraction, what do you think happens to the light rays that are entering your eyes when you open your eyes underwater? How would goggles help?

- 32.** The image formed on the retina is upside down. What allows us to see the things that we are looking at upright instead of upside down? If necessary, find the answer on the Internet.

Correcting Vision

The lens in your eye can change shape through small muscles in the eye. By changing shape, the lens is able to focus the image on the retina at the back of the eye. To focus on objects far away, the lens needs to become flatter; to focus on objects that are close, the lens has to become thicker and more rounded.

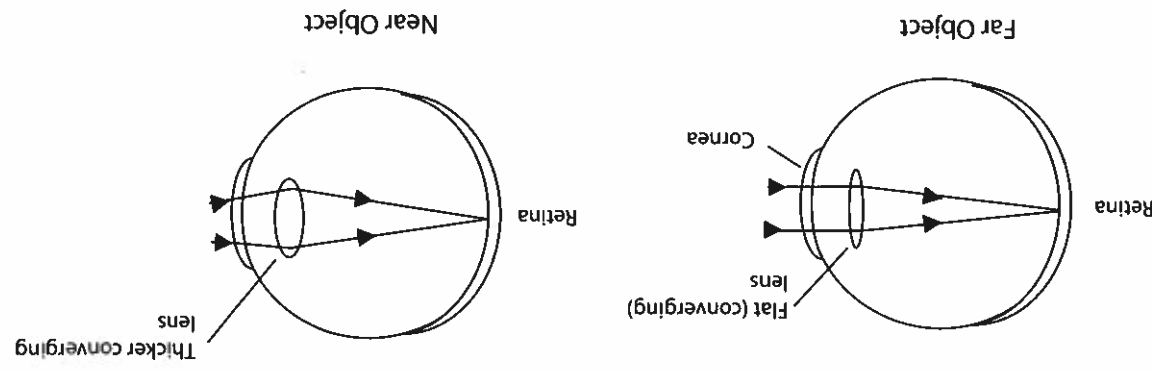


Figure 20.11 How the eye adjusts the thickness of the lens to focus on far and near objects

Note: The light is also refracted a bit as it passes through the cornea, but for simplicity's sake that has been left out of this and subsequent diagrams of the eye. The lens can only change shape if the muscles around it pull it in the correct way. With age, these muscles weaken, so most people will experience difficulty seeing things far away or very close up at some point in their lives.

People with **nearsightedness (myopia)** can see objects that are near, but have trouble focussing on distant objects due to the shape of the eye or the lens. With myopia, the image is focused in front of the retina rather than on the retina, and as a result the image on the retina is blurred. Nearsightedness is corrected with eyeglasses (or contact lenses) that diverge the light rays before they enter the eye so that the image will now reach the retina, as demonstrated below.

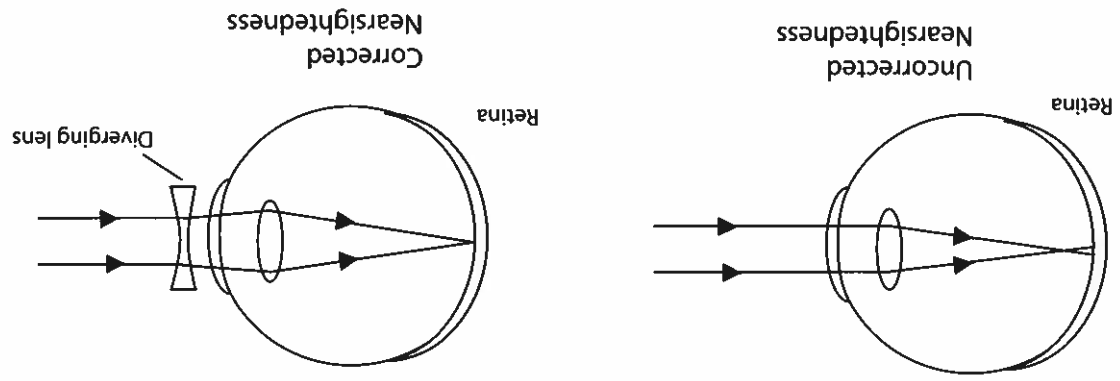


Figure 20.12 Correcting nearsightedness

Those who have **farsightedness (hyperopia)** are able to see distant objects, but have difficulty focussing on objects close up. In this case, the image is formed behind the retina. This can be corrected with a converging lens that causes the light rays to bend more and focus the light rays on the retina, as demonstrated in Figure 20.13 on the next page.

Activity: Blind Spot



Purpose

Investigate your blind spot in the retina.

Materials

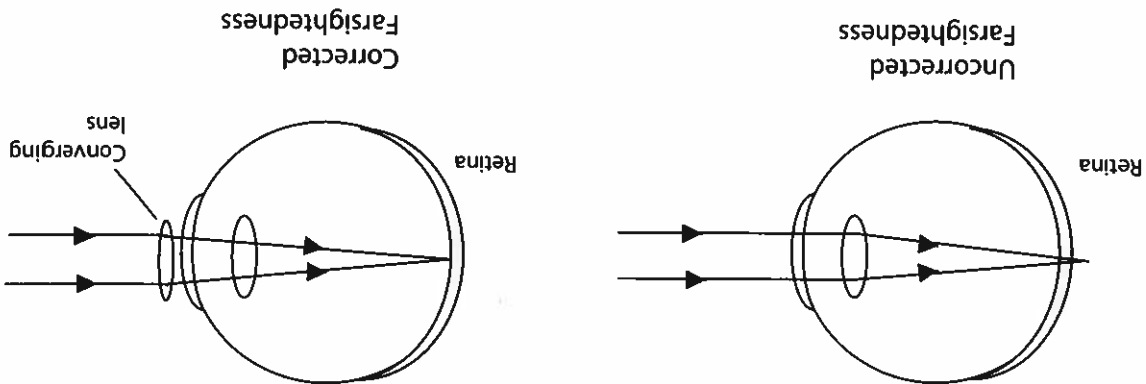
- a sheet of white paper with three small images printed on it, spaced apart like the ones shown in Figure 20.14

Another recent technique to correct vision uses laser surgery to tighten the muscles that control the shape of the lens. Depending upon which muscles the doctor targets with the laser, the lens can be reshaped to make it flatter or rounder. This can permanently improve vision and eliminate the need to wear eyeglasses or contact lenses. This procedure does not work for everyone, but for many people, laser surgery is an effective way to cure severe vision problems.

The eye is connected to the brain by the **optic nerve**. This nerve transmits information about the image formed on the retina to the brain. Even though the image formed on the retina is upside down, you see things upright because your brain interprets the information and turns the image upright. You taught your brain to do that when you were a very young infant by grabbing objects so that your hands could tell your brain the object's correct orientation.

Though very good at most things, your eye is not perfect. For example, the part of the retina where the optic nerve enters the eye is not sensitive to light. That area of the retina is known as the **blind spot**. To find your blind spot, do the following activity.

Figure 20.13 Correcting farsightedness



You can draw your own or download and print off a prepared sheet with these images. To download the prepared sheet, go to your course page on the ILC website and click on "Blind Spot Test Images" under Lesson 20.



Figure 20.14 Images used to test your blind spot

Procedure

1. Close your right eye tightly, or cover it with your right hand.
2. Hold the paper with the images of the circle, square, and X at arm's length away.
3. Stare at the X with your left eye.
4. Move the paper slowly towards you while you keep staring at the X.

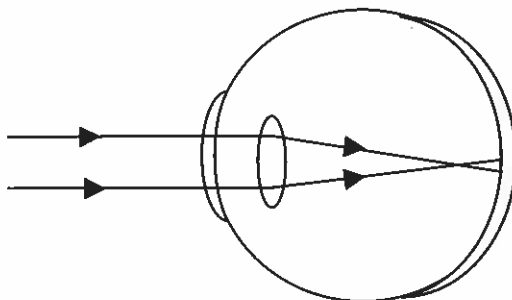
Support Questions

Questions 33 and 34 are based on the blind-spot activity.

33. What happens to the circle and the square as you slowly bring the paper closer to your face?

34. Why is an image not detected in the area of the blind spot?

35. Refer to the diagram of an eye below. Explain the problem associated with the image that is formed and how it can be corrected. Draw a diagram to illustrate your answer.



Natural Refraction Phenomena

There are many ways that light can be refracted. Many natural phenomena occur because of refraction in the air or water. For example, you enjoy beautiful sunsets and sunrises because of delays caused by refraction, and you may have been fooled by mirages appearing on hot roads in summer.

Sunsets

The light from the sun travels through the vacuum of outer space to reach the earth. Even though the index of refraction in air (1.0003) is only very slightly larger than the index of refraction in a vacuum (1.0000), it is enough to bend the light as it travels from outer space and enters our atmosphere. As shown below, when you see the sun setting, the light is coming from the sun situated below the horizon, for the sun has actually already set. However, the sun appears to be above the horizon because the light from the sun is bent as it travels through our atmosphere; as a result, you are still able to see it. This extends the time you can watch the sun setting, making the sunset more dramatic and enjoyable.

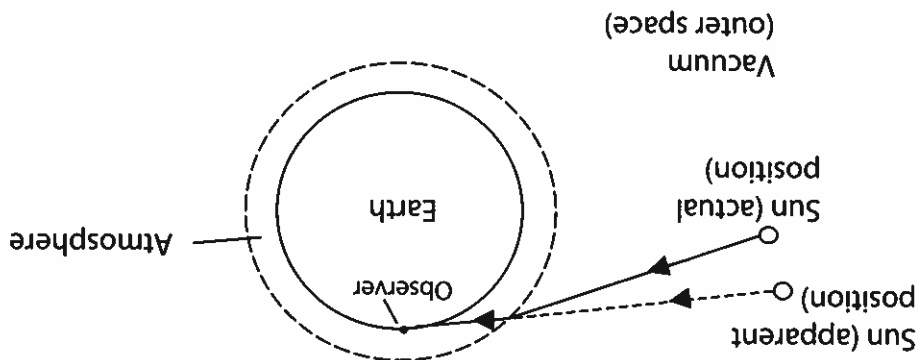


Figure 20.15 Refraction of sunlight in earth's atmosphere

This also happens when the sun is rising. Due to refraction, you are able to see the sun rise before it is actually above the horizon.

Refraction is also responsible for the oval shape of the sun when it is setting. The sun loses its round shape near the horizon since the light from the bottom part of the sun is refracted more than the light from the top part. The light from the bottom part is refracted more since it must travel through more of the earth's atmosphere before reaching your eyes. This makes the bottom of the sun look flatter, resulting in the oval shape of the setting sun. Watch for this next time you watch a sunset.

Heat Shimmers, Twinkling Stars, and Mirages

Heat Shimmers

Another natural phenomenon involving refraction occurs when air is heated. Warm air has a slightly different index of refraction than cold air. When light passes through warm air, such as above a hot paved road or a barbecue, the light is refracted (see Figure 20.16). The light from objects seen through the warm air is refracted unevenly due to air movements; as a result the objects appear to shimmer.

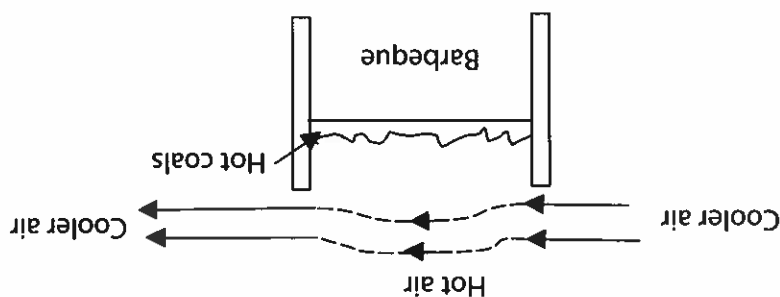


Figure 20.16 Refraction of light in heated air

You have probably also noticed this on hot roads in summer. Cars coming towards you seem to appear out of a shimmering haze.

The **heat shimmer** effect has caused problems for photographers for years. However, new computer technologies are giving camera makers and programmers of photo-editing software new ways to remove the shimmer effect from images. This also has important applications in defence and satellite mapping, which require distortion-free images.

Twinkling Stars

Have you ever wondered why stars seem to twinkle in the night? It's not because the stars themselves are twinkling—they shine with a steady glow. So why don't they just appear as round dots of light in the sky?

The earth's atmosphere contains layers of air masses at different temperatures, each having a slightly different index of refraction. These air masses are continually moving. When light from stars enters the atmosphere, it is refracted by different amounts in the different moving air masses. This makes the stars appear to twinkle.

Most large telescopes, like the Mount Palomar Observatory shown on page 8, are located on top of mountains where the air temperature is more constant and there is less atmospheric interference. This reduces distortions caused by atmospheric refraction. But to really escape atmospheric distortion, you have to go outside the earth's atmosphere. That's why the images from the space telescopes, like Hubble and Kepler, are so spectacular and clear: they do not suffer from any atmospheric distortions.

Mirages

Black asphalt and sand absorb a lot of heat from the sun on hot summer days, and this warms the air above them. As a result, the air near the ground has a different index of refraction than the cooler air higher up. As the light nears the ground, it is increasingly refracted by the different layers of warm air, each with a lower index of refraction.

Eventually, the light from the sky is totally internally reflected upwards (as demonstrated in the diagram below). What your eye sees is an image of the sky on the pavement or sand resembling a puddle of water. This illusion, called a **mirage**, has fooled desert travellers for centuries into thinking they were near an oasis of water.

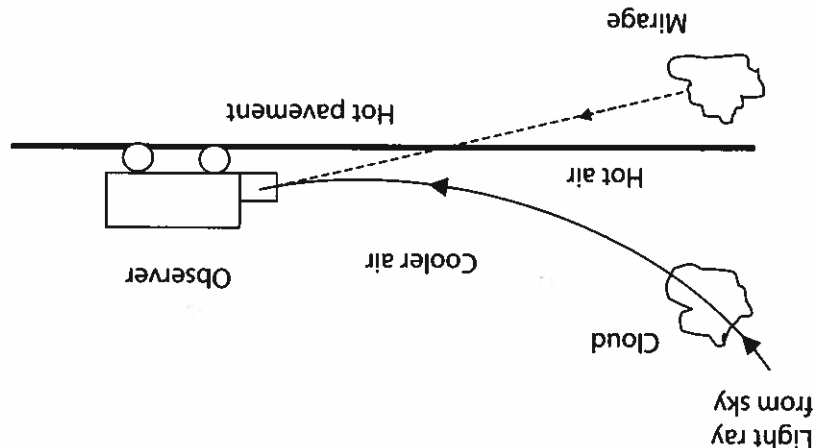


Figure 20.17 How a mirage forms on a hot road

Not confined to hot land surfaces, mirages can also be seen on big lakes or oceans on sunny days when the water is warmer than the air above it. The refraction due to heat causes distant objects, like coastlines or ships, to appear on the horizon when they are not normally visible because they are actually below the horizon. Before people understood this, there were many reports of ghost ships and mysterious islands that appeared and disappeared off the map.

As you learned in Lesson 17, the refraction of light in water can make things appear to be in a different place than they really are. For example, as shown below, a stick placed in the water will appear closer to the surface than it really is.

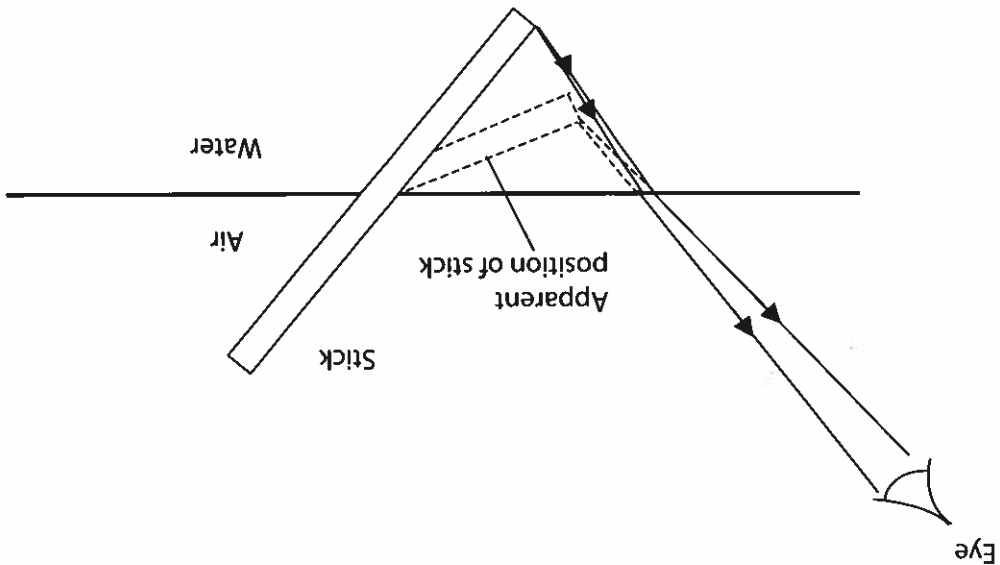


Figure 20.18 Refraction causes a stick underwater to appear closer than it is

In this case, the light rays reflected from the part of the stick in the water are travelling from a more refractive material (water) into a less refractive one (air) before reaching your eyes. The light rays are bent as they enter the air. The brain, assuming that light travels in a straight line, tells us the submerged part of the stick is closer to the surface than it actually is. For the same reason, the legs of a person standing in a pool will appear shorter than when viewed from the air.

Support Questions

- Please answer these questions on your own paper.
36. Explain how refraction can cause a rock in the water to appear closer than it really is. Include a diagram with your explanation.
 37. Draw a diagram to illustrate how refraction delays our sunset.
 38. Use the Internet to find out how rainbows are created.

Conclusion

The scientific approach can be used to examine all kinds of natural phenomena, including light. People have always been fascinated by light—what it is and how it travels. By asking questions about the nature and behaviour of light in a scientific way, humans have discovered many things about it. This has led to amazing new technologies that are so much a part of your everyday life that it's hard to imagine life without them.

How would your life be without photographs and videos? Without mirrors and eyeglasses? Without satellite communications, radio, and cell phones? If there were no knowledge of optics, you wouldn't have TV, and doctors wouldn't know about cells or X-rays. And who knows what other optical technologies are waiting to be discovered?

Everything we know about optics today comes from people being curious. They asked a question no one thought to ask before. They look at things a bit differently. They tried out different ways of doing things—in short, they asked questions and experimented with possible answers. That is what science is all about. When children do it, it's called play. Many adult scientists claim their best discoveries happen when they feel free to play with ideas and experiment.

Key Concepts

Reflecting telescope: a type of telescope that uses a concave mirror to gather light rays and concentrate them so that they can be seen better. The bigger the mirror, the fainter the light it allows us to see.

Camera: a device for capturing light images. Light enters through the adjustable diaphragm and passes through a converging lens before being captured on a photo-sensitive material at the back of the camera.

Eye: a biological device for capturing and focussing light rays. Works much like a camera. The iris controls the amount of light that enters, the lens focuses the light rays, and the retina captures the image.

Nearsightedness (myopia): people suffering from this condition can see objects that are near, but have trouble focussing on distant objects due to the shape of the eye or the lens. The image is focused in front of the retina rather than on the retina.

Farsightedness (hyperopia): people suffering from this condition can see distant objects, but have difficulty focussing on objects close up. The image is formed behind the retina.

Optic nerve: the nerve that connects the eye to the brain

Blind spot: the spot on your retina where the optic nerve connects. This area lacks light-sensitive cells, so any image that falls on this part of the retina will not be seen.

Heat shimmer: the wavy effect seen in the air over hot materials, like fires or black asphalt roads in the hot sun. It is caused by differences in the refractive index of the different air layers based on their temperature.

Mirage: an optical illusion whereby water or an object appears in a place where it isn't. A mirage is caused by the internal reflection of light within relatively warm layers of air trapped near the surface.

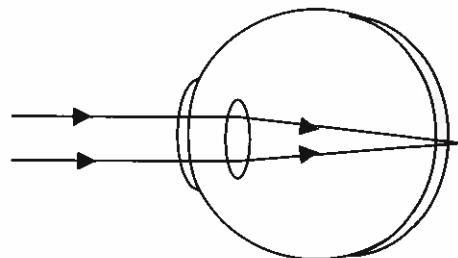
Key Questions

Save your answers to the Key Questions in your
Course Journal or e-Journal.

Total: 18 marks

- 82.** Explain how converging (concave) mirrors are used to make search lights extremely bright. (3 marks)

- 83.** Describe a part of the eye, besides the lens, that causes light to bend. (2 marks)
- 84.** Using the following diagram of an eye, explain the problem associated with the image formed and how it can be corrected. Draw a new diagram to illustrate your answer. (6 marks)



- 85.** Draw a diagram to illustrate how refraction can cause an object in the water to appear closer than it really is. Be sure to include the light rays and explain what is going on. (7 marks: 3 marks for the diagram and 4 marks for the explanation)

Congratulations! You have completed all the lessons in the course. Now do the Evaluation work in your Course Journal or e-Journal for Unit 4. Follow any other instructions you have received about sending in your journal, and then send it to ILC. A teacher will mark your work and ILC will send it back to you as soon as possible.

Prepare for the Final Test as you wait for your journal to be returned. ILC will get in touch with you about writing the test. To prepare for it, review the course material and do the Practice Test.

Practice Test

To help prepare you for the Final Test, there is a Practice Test on your course page on the ILC website.

The Practice Test is organized in the same way as the Final Test, so you will know what to expect. The front page is like the one you will see when you write the Final Test. Read over the instructions so that you are familiar with them, and so that there are no surprises at the time of the real test.

You will have two hours to do the Final Test. Time yourself when you do this Practice Test to see if you can complete the work in two hours. At the beginning of each section, you are told how long that section should take you to complete.

To access the Practice Test, go to your course page on the ILC website, and click on “Practice Test.” Print the test and complete it.

When you have completed the Practice Test, check the suggested answers to see how well you have done. Go to your course page on the ILC website and click on “Practice Test Suggested Answers.”

If you had trouble with any of the questions on the Practice Test, go back to that section of the course and review the material and Support Questions carefully.

If you have trouble completing the test in two hours, it may be because you are not familiar with some of the ideas you need to know. Plan to review the course material fully before the Final Test.

Do not send the Practice Test in to ILC for marking. It is for your own use, as practice for the real thing!

