Module 3
The Nature and Properties of Light

What this module is about

Most of the things that you know you have learned about through your eyes. You can only see if there is light. Light makes you see shapes and colors. Light also helps you identify objects both near and far. But what is light?

In this module you will learn about the nature and properties of light in the following lessons:

- **Lesson 1 – The Nature of Light**
- **Lesson 2 – Reflection and Mirrors**
- **Lesson 3 – Refraction and Lenses**
- **Lesson 4 – Colors, Interference and Polarization**

What you are expected to learn

After studying the lessons in this module, you are expected to:

1. state the different theories about the nature of light;
2. demonstrate reflection properties of light using mirrors;
3. describe the image formed by mirrors;
4. show the refraction properties of light using lenses;
5. give applications of total internal reflection;
6. describe the image formed by lenses;
7. enumerate the colors that make up white light;
8. explain what causes colors of object; and
9. cite applications of diffractions, interference and polarization of light.

How to learn from this module

Here is a simple guide for you in going about the module.

1. Read and follow the instructions very carefully.
2. Take the pretest (20-item multiple-choice test) to determine how much you know about the lessons in the module.
3. Check your answers against the correct answers provided at the last page of the module.
4. Be very honest in taking the test so you know how much knowledge you already have about the topic.
5. Perform all the activities, as these will help you have a better understanding of the topic.
6. Take the self-tests at the end of each lesson to determine how much you learned about the lesson.
7. Take the posttest (20-item multiple choice test) to assess how much you learned in this module.

Have fun in learning these lessons about light. Good luck!

What to do before (Pretest)

Multiple Choice: Write the letter of the best answer:

1. Which of the following is Sir Isaac Newton's theory that explains light as a particle?
   a. Corpuscular Theory   c. Quantum Theory
   b. Electromagnetic Wave Theory   d. Wave Theory

2. When light hits a smooth surface, it is
   a. bent around corners   c. reflected
   b. polarized   d. refracted

3. A ray of light is reflected from a plane mirror. The angle of incidence is 20^{o}. The angle between the incident and the reflected ray is
   a. 10^{o} c. 30^{o}
   b. 20^{o} d. 40^{o}

4. What kind of mirror is used in automobile and trucks to give the driver a wider area and smaller image of the traffic behind him/her?
   a. concave mirror
   b. convex mirror
   c. plane mirror
   d. none of these

5. The image in a plane mirror is always
   a. erect but reversed.
   b. erect but not reversed.
   c. inverted and reversed.
   d. inverted but not reversed.

6. When rays parallel to the principal axis of a concave mirror are reflected, they pass through
   a. any point on the axis..
   b. the principal focus.
   c. the center of curvature of the mirror.
   d. the point halfway between the focus and the mirror.

7. A stick partly submerged obliquely in water appears to be bent at a point where it enters the water surface. Which one of the following gives explanation for this observation?
   a. Dispersion of light on entering water
   b. Light does not travel in straight line in water.
   c. Diffraction of light by the surface of the water
   d. Refraction of light due to differences in speed of light in air

8. The principle involved in the formation of images on lenses is
   a. aberration.
   b. dispersion.
   c. reflection.
   d. refraction.

9. A diamond is a brilliant gem because
   a. it has low index of refraction.
   b. it has big critical angle.
   c. most of the light is refracted.
   d. most of the light is reflected internally.

10. When light travels from air to glass its speed
    a. increases .
    b. decreases.
    c. remains the same.
    d. increases then decreases.

11. The property of light responsible for the formation of colors is
    a. amplitude .
    b. quality.
    c. velocity.
    d. wavelength.

12. Which of the following statements is **NOT** true about the dispersion of sunlight by a prism?
    a. The color most bent is red.
    b. White light consists of waves of varying length.
    c. Different wavelengths travel with different speed.
    d. Different wavelengths correspond to different colors.

13. After a rainstorm, a rainbow may appear in the sky. Which statement explains this observation?
    a. Raindrops act as prisms separating sunlight into colors.
    b. The white clouds are actually prisms composed of different colors.
    c. The colors of the rainbow come from raindrops in the atmosphere.
    d. When the sunlight is reflected by the ground towards the clouds, it separates into different colors.

14. A piece of coal appears black when viewed in sunlight because it __________ all the light that falls on it.
    a. absorbs
    b. disperses
    c. reflects
    d. transmits

15. A red rose appears red because of its ability to
    a. absorb the red color and reflect all others.
    b. reflect the red color and absorb all others.
    c. transmit all colors except red.
    d. transmit the red color and reflect all others.

16. Diffraction of light means that
    a. light is a transverse wave.
    b. light is reflected from a film.
    c. light bends as it enters a different medium.
    d. light bends as it passes through a small opening.

17. The sun appears to be more reddish at sunset than at noon. Which of the following phenomena is responsible for this effect?
    a. dispersion
    b. interference
    c. reflection
    d. scattering

18. Which property of light produces bright and dark bands on a screen after light from a source passes through two very narrow slits that are near each other?
    a. dispersion
    b. interference
    c. polarization
    d. refraction

19. When sunlight falls on soap bubble, the band of colors seen is due to
    a. dispersion.
    b. interference.
    c. pigments of soap.
    d. refraction.

20. Polarization of light is an evidence that light
    a. is a transverse wave.
    b. is a longitudinal wave.
    c. has a particle property.
    d. wave can destructively interfere with each other.

Key to answers on page 30

Lesson 1 The Nature of Light

What is light? Is it matter or is it energy? Is it a particle or is it a wave? Do you know that for centuries, scientists disagreed about the nature of light? Sir Isaac Newton in his corpuscular theory of light thought that light is made up of particles that travels through space on a straight line. On the other hand, Christian Huygens, a Dutch physicist, thought that light is made up of waves similar to that of water waves. This is called the **wave theory of light**.

When scientist discovered the interference of light they thought they had proved that light consists of waves. They felt that particles did not act this way. Yet, at that time, scientists believed that waves must travel through a medium. They could not explain how waves of sunlight traveled to the earth through a vacuum or space. Later, it was found that an electromagnetic wave, such as light, could travel through a vacuum. Electromagnetic waves are disturbances caused by both electric and magnetic fields. According to James Clerk Maxwell, light is that small part of the electromagnetic spectrum which affects our vision. Light is propagated in space as electromagnetic waves. This is known as **electromagnetic wave theory of light**.

More recently, scientists found evidence to prove that light does consist of particles. In photoelectric effect, Einstein discovered that light shining on certain metals can make electron jumps out of the metal. Brighter light can make more electrons jump, but they jump out at the same speed. However, different colors of light make electrons jump out at different speeds. Scientists could explain these observations if light was made up of particles of energy called photons. Based on this, the **Quantum Theory** was proposed by Max Planck in 1900 and advanced by Albert Einstein in 1905. This theory assumes that light is radiated in discrete packets or bundles of energy called **photons**, which also exhibit wave characteristics. Based on the scientists' investigations of the different behaviors of light, it is now considered to have dual characteristics – those of a wave and those of a particle. These behaviors can only be observed under different conditions.

Know This

When does light behave as a particle? When does it behave as a wave? In general, if light interacts with light such as in interference, it manifests wave behavior. If light interacts with matter like in the photoelectric effect, the particle behavior is strongly manifested.

Light of higher frequencies shows more of a particle behavior while light of lower frequencies shows more of the wavelike behavior.

What you will do

Self-Test 1.1

Direction: Match the theories about the nature of light in column A with their corresponding proponents in column B.

Column A Theory	**Column B Proponent**
1. Wave Theory	a. James Clerk Maxwell
2. Corpuscular Theory	b. Christian Huygens
3. Electromagnetic Theory	c. Max Planck
4. Quantum Theory	d. Sir Isaac Newton

Key to answers on page 30

Lesson 2 Reflection and Mirrors

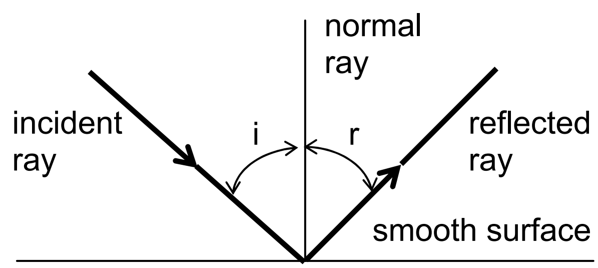
What can you see when you look at a mirror, or a polished metal or a still pool of water? You can see your image. Why? These objects are image reflecting objects.

Types of Image

There are two types of images formed by reflecting surfaces. They are real and virtual images. Real image is always inverted and is formed by actual rays of light. It can be projected on the screen. Virtual image is always erect and is formed by apparent rays of light. It cannot be projected on the screen.

Reflection of Light

When light hits a smooth surface like a mirror, light is reflected. Reflection is the turning back of light when it hits a barrier. The angle between the incident ray and the normal rays is called the **angle of incidence**. The angle between the reflected ray and the normal ray is the angle of reflection.



i = angle of incidence
r = angle of reflection

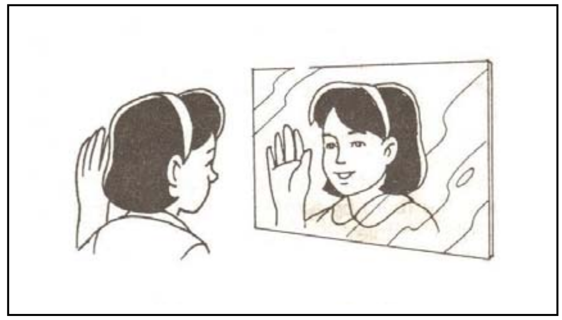
The laws of reflection state that:

1. the incident ray, the reflected ray, and the normal to the reflecting surface all lie in the same plane.
2. the angle of incidence is equal to the angle of reflection.

What you will do

Activity 2.1 Image in a Plane Mirror

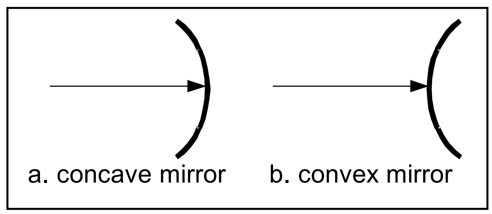
1. Stand in front of a plane mirror. Is your image exactly the same in size as you are? Where is it apparently found?
2. Raise your left hand. What hand does your image raise?
3. Is your image erect or inverted? Is it real or virtual?



The mirrors that we use as looking glasses are plane mirrors. The image formed by a plane mirror is always erect, virtual, laterally reversed, same size as the object and found to be apparently behind the mirror.

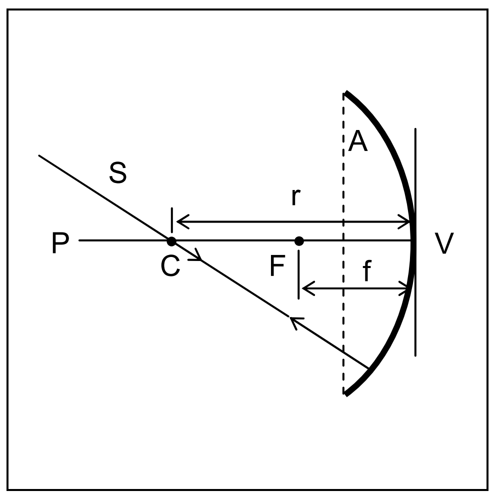
Spherical Mirrors

There are two kinds of spherical mirrors, the concave and convex mirrors. If the reflecting surface is curved inward, it is a concave mirror. If the reflecting surface is curved outward it is a convex mirror.



There are mirrors terminology which you should know. They are the following:

1. **Vertex** (V) is the middle portion of the mirror.
2. **Center of curvature** (C) is the center of the sphere of which the curved mirror is a part.
3. **Radius of curvature** (r) is the distance of the center of curvature from the vertex.
4. **Principal axis** (P) is the line drawn passing through the vertex and the center of curvature.
5. **Secondary axis** (S) is a line drawn through the center of curvature to any part in the mirror.
6. **Aperture** (A) is the opening of the mirror.
7. **Focus** (F) is the point where the reflected rays meet.
8. **Focal length** (f) is the distance between the focus and the vertex.



Remember This

For spherical mirrors with small opening, the focal length is one-half the radius of curvature.

What you will do

Activity 2.2 Image in spherical mirrors

1. Get a spoon. This can serve as your mirror.
2. Look at the concave surface of the spoon. Place the mirror very near your face. Describe your image.
3. Bring the spoon an arm length distance away from you. Describe your image.
4. Look now at the convex surface of the spoon. Observe your image as you bring the spoon farther from you. Describe your image.

You observed that the position and size of the image changes when the distance of a concave mirror from the observer varies. For a convex mirror, you observed only one kind of image which is smaller, erect and virtual.

Ray Method of Image Formation

How can we construct, locate and describe the image formed by spherical mirrors?

To construct the image formed by spherical mirrors by the ray method draw at least two of the following rays from point A on the object (See Figure 2.1):

- Ray 1 is an incident ray parallel to the principal axis and is reflected through the principal focus.
- Ray 2 is a ray traveling along a secondary axis and passes through the center of curvature which is reflected back along itself.
- Ray 3 is a ray that passes through the focus and is reflected parallel to the principal axis.

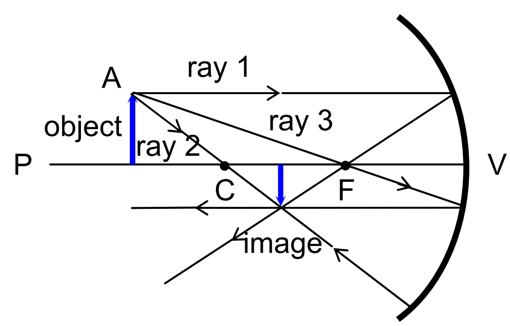
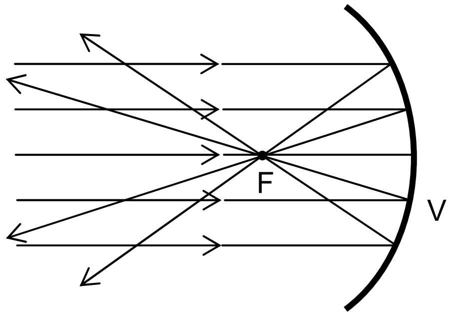


Fig. 2.1
Ray method of locating images

Figure 2.2 summarizes the kind of image formed in a concave mirror at different position of the object. Study how the image is constructed using the ray method. Note the kind of image formed.

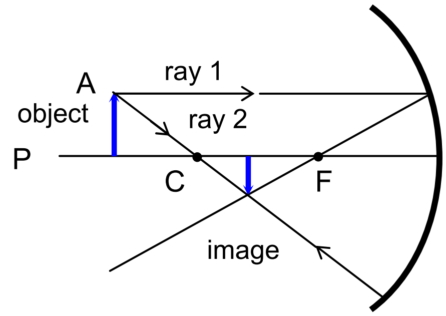
Fig. 2.2 Image in a Concave Mirror

a. Object is at infinite distance



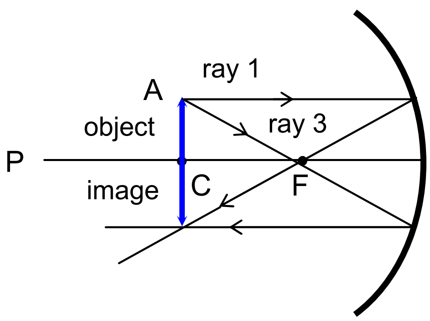
The image is a point at the principal focus.

b. Object is located beyond the center of curvature



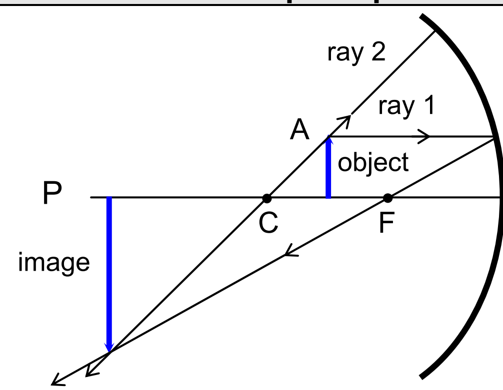
The image is smaller, inverted, real and located between the center of curvature and the focus.

c. Object is at the center of curvature



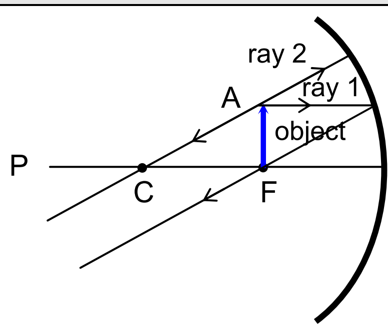
The image is of the same size, inverted, real and located at the center of curvature.

d. Object is between the center of curvature & the principal focus



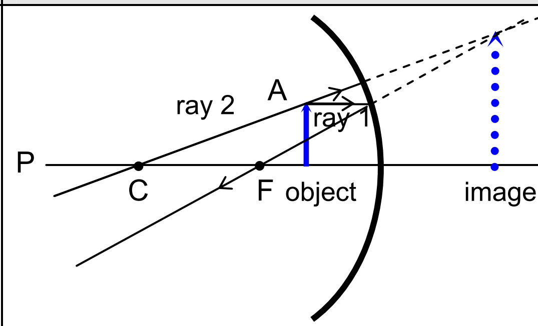
The image is larger, inverted, real and located beyond the center of curvature.

e. Object at principal focus



The image is at infinity – no image is observed.

f. Object is between principal focus and the mirror



The image is larger, erect, virtual and located behind the mirror.

Image in a convex mirror

In a convex mirror, the image is always smaller than the object, erect and located behind the mirror. As the object is brought closer to the mirror, the size of the image increases, but it can never become as large as the object itself.

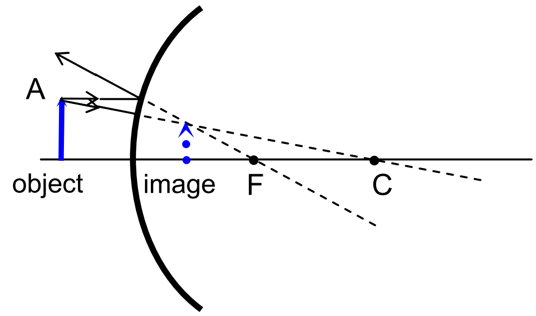


Fig. 2.3 Image in a convex mirror

Where are mirrors used?

Concave mirrors are used in amusement parks to form fantastic images. The convex side view mirror used by automobile and trucks gives a wide field of view and vision. Can you name other uses of mirrors?

The Mirror Equation:

Mathematically, the object distance (d_o), image distance (d_i) and the focal length (f) of the mirror can be found using the mirror formula:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

The size of the object (S_o) and size of image (S_i) are determined using the size formula:

$$\frac{S_i}{S_o} = \frac{d_i}{d_o}$$

The mirror formula is applicable for both concave and convex mirror. The following conventions are helpful in using the equation for solving problems.

Mirror	f	d_o	d_i
concave			
real image	+	+	+
virtual image	+	+	-
convex (virtual image)	-	+	-

What you will do
Self-Test 2.1

Direction: Identify the term herein defined, described or referred to in the following:

_____________ 1. The kind of image that is formed by actual ray of light and can be projected on the screen
_____________ 2. The angle between the incident ray and the normal ray
_____________ 3. The kind of mirror that will always produce a smaller, virtual and erect image
_____________ 4. The distance between the focus and the vertex of a mirror
_____________ 5. The kind of mirror that will produce an image of the same size as the object, erect and virtual
_____________ 6. Position of the object in front of a concave mirror that will produce an image that is smaller, inverted and real
_____________ 7. Position of the object where no image is formed
_____________ 8. The middle portion of the mirror
_____________ 9. Spherical mirror used in automobile that gives wider view of area
_____________ 10. Kind of mirror that will give a virtual, erect and larger image

Key to answers on page 30

Lesson 3. Refraction and Lenses

How does light travel? What happens to the ray of light when it passes through different media, say air to water?

What you will do

Activity 3.1 Refraction of light

1. Get a glass half-filled with water.
2. Place a pencil in this glass of water
3. Look at the pencil at the top of the glass. What happens to the pencil?
4. Look from the side of the glass. Do you notice any difference?
5. Remove the pencil out of the water. Is there a difference between the way it looks in water and the way it looks in air?

The pencil appears bent when it is partly submerged in water. This shows that a light ray bends as it passes from air to water. The change in direction or the bending of light when it passes from one medium to another of different optical density is called **refraction**. Refraction also makes the water appear shallower. Because of refraction, a fish appears higher in the water when viewed from the bank than it actually is. A teaspoon placed in a glass of water appears to be bent or broken at the surface of the water. A coin placed in the bottom of a teacup, out of the line of vision of an observer, will become visible when the cup is filled with water

Refraction and the Speed of Light

When light travels from air to water, its speed decreases. A medium is optically dense if it slows down the speed of light. Water is optically denser than air.

When light travels from an optically less dense to denser medium at an angle, say from air to glass, light bends toward the normal (Figure 3.1a). When light travels from a denser to a less dense medium at an angle, say from glass to air, the light bends away from the normal (Figure 3.1b). The angle formed between the incident ray and the normal is called the **angle of incidence**, i, and the angle between the refracted and the normal is called the **angle of refraction**, r.

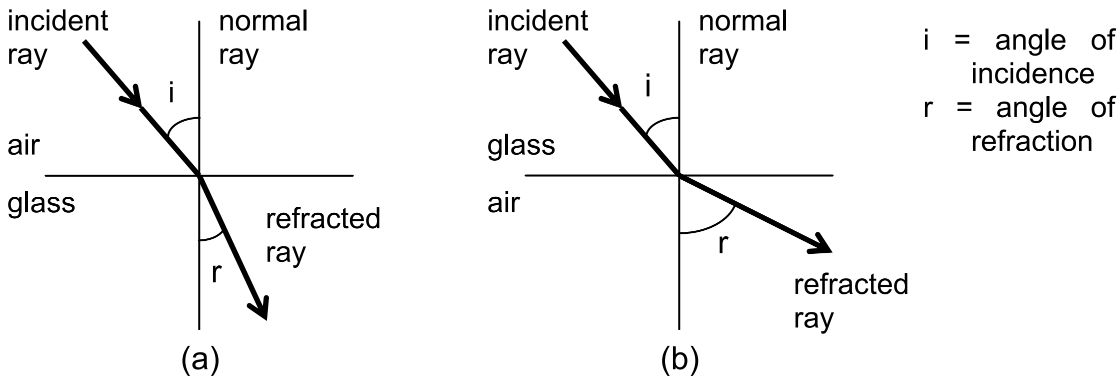


Fig. 3.1
(a) Refraction of light as it passes from air to glass
(b) Refraction of light as it passes from glass to air

Where does light travel fastest? The speed of light is different in almost transparent material. In a vacuum the speed of light is about 3.0 x 10^8 m/s, and in water the speed is 1.88 x 10^8 m/s. The ratio of the speed of light in a vacuum to its speed in another substance is called the **absolute index of refraction**, n, for that substance.

Remember This

$$\text{Index of refraction} = \frac{\text{Speed of light, c}}{\text{Speed of light in a given substance, v}}$$

$$n = \frac{c}{v}$$

So, if you know the index of refraction of a substance you can determine the speed of light in that substance.

Also, the higher the index of refraction, the slower the speed of light in the substance. This means that the higher the optical density of a substance, the higher is its index of refraction.

Table 3.1 shows the index of refraction of some substances.

Table 3.1 Index of Refraction

Substance	Index of Refraction, n
Air	1.0003
Glass, crown	1.52
Glass, float	1.63
Water	1.33
Diamond	2.42

Do you know what is the importance of the index of refraction? The index of refraction of a pure, transparent substance is a constant quantity which is a definite physical property of a substance. Hence, the identity of a substance can be determined by measuring its index of refraction. The very high index of refraction of diamond provides a positive test for its identification.

Laws of Refraction

The facts about refraction of light maybe summarized in three laws of refraction.

1. The incident ray, the refracted ray, and the normal to the surface at the point of incidence are all in the same plane.
2. The index of refraction for a particular substance is always a constant.
3. When a ray of light passes at an angle from a medium of lesser to one of greater optical density, it is bent toward the normal. Conversely, a ray of light passing at an angle from an optically denser medium to a lesser medium is bent away from the normal ray.

Total Internal Reflection

You already learned that as a ray of light passes from a medium of higher optical density (water) into one of a lower optical density (air) it is bent away from the normal. As the angle of incidence continues to increase, a value is finally reached at which the angle of refraction equals 90^o and the refracted ray does not enter the air at all but takes the path along the water surface. The angle of incidence in the denser medium resulting in angle of refraction of 90^o is called the **critical angle** i_c. (Figure 3.2) If the angle of incidence exceeds the critical angle total internal reflection occurs.

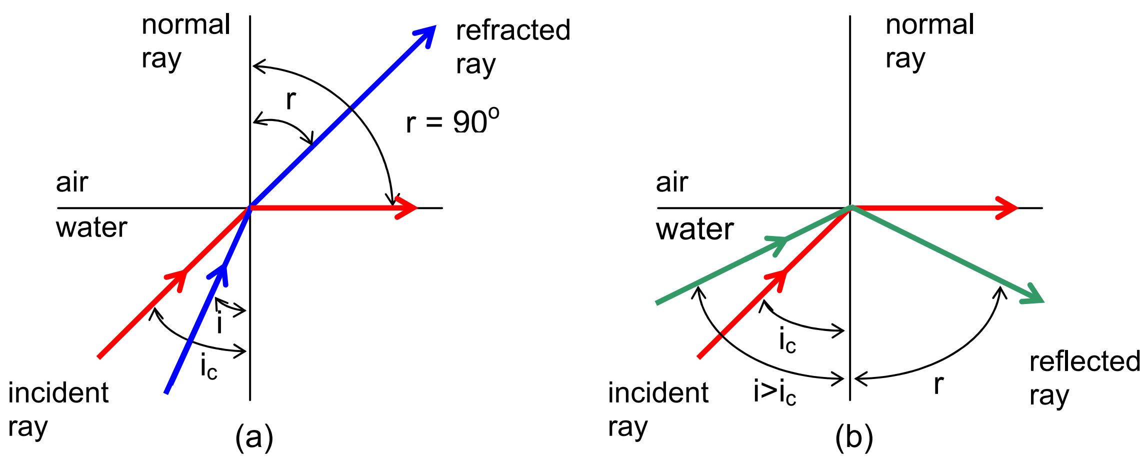


Fig. 3.2

(a) The critical angle is the angle of incidence in the denser medium which results in a 90^o angle of refraction.

(b) Total internal reflection occurs when the angle of incidence exceeds the critical angle.

Remember This

If the angle of incidence of a ray of light passing from water into air is increased beyond the critical angle, no part of the incident ray enters the air. It is totally reflected from the water surface. Total internal reflection occurs when the angle of incidence exceeds the critical angle.

Do you know why diamond is a very brilliant gem? It is because its index of refraction is high and its critical angle is very small. Very little of the light that enters a cut diamond passes through it. Most of the light is reflected internally.

Fiber optics makes it possible to use light instead of electricity to transmit messages by total internal reflection.

Optical fibers are also used in the field of medicine. An endoscope is an instrument used to explore the inside of the human body using the principle of total internal reflection.

Lenses

What are lenses made of? Lenses are made of transparent substance like glass or plastic which can bend light rays. Lenses are of two kinds:

a. Converging lens (convex) which is thicker at the middle than at the edge
b. Diverging lens (concave) which is thicker at the edge than at the middle

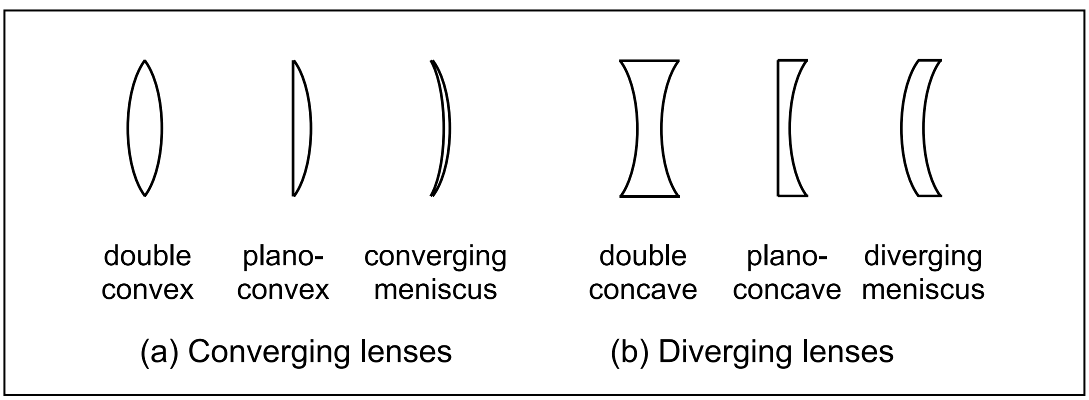


Fig. 3.3 Lens shapes

How do lenses refract rays of light?

When light rays parallel to the principal axis pass through a converging lens, the rays are refracted toward the thicker part of the lens, and they all converge at a point called the real focus. However, parallel rays of light are spread out by a diverging lens and appear to meet at a virtual focus.

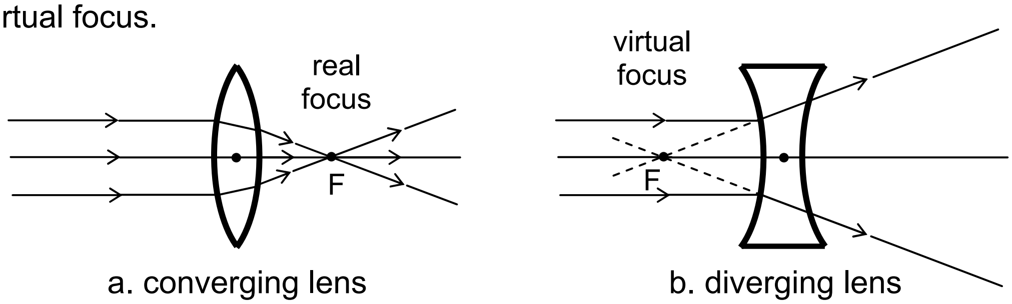


Fig. 3.4 Lenses refract parallel rays so they meet at the principal focus

Lens Terminology

What are the different terms related to lenses? **Spherical lenses** usually have two centers of curvature which are the centers of the intersecting spheres which form the lens surfaces. The centers are shown in Figure 3.5 as points C and C'.

In lenses, the focus is not midway between the lens and the center of curvature as we found to be in spherical mirrors. Its position on the principal axis depends on the index of refraction of the lens. With a double convex lens of crown glass the principal focus almost coincide with the centers of curvature, thus the radius of curvature and the focal length are almost equal.

1. Optical center, O – the center of the lens
2. Principal axis, P – line joining the centers of curvature and passes through the optical center
3. Secondary ray, S – ray passing through the optical center but not parallel to the principal axis
4. Focal length, f – the distance between the focus and the optical center

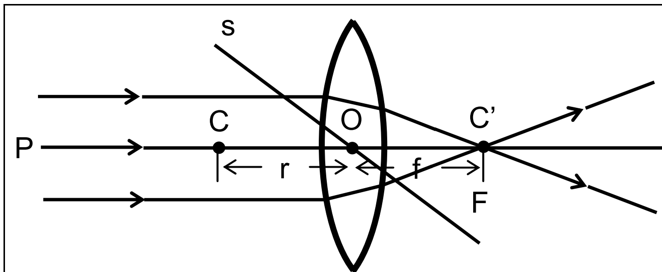


Figure 3.5

Ray Method of Image Formation in Lenses

How can we locate the image of an object formed by a lens? Lenses form images by refraction. To locate the image, use the following rays coming from point A on the object: (see Figure 3.6)

- Ray 1 is an incident ray parallel to the principal axis and is refracted through the focus.
- Ray 2 is an incident ray along the secondary axis which is not appreciably refracted as it passes through the optical center (O) of the lens.

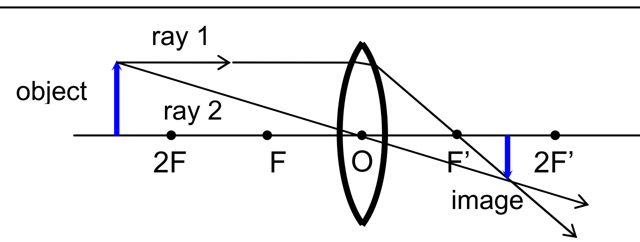


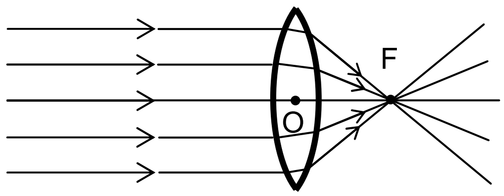
Figure 3.6

Image Formation in a Convex Lens

Using the ray method let us construct, locate and describe the images formed by a thin converging lens at different positions of the object from the lens. Study Figure 3.7.

Fig. 3.7 Image at Different Positions of the Object from the Lens

a. Object is at infinite distance



The image is a point at the principal focus.

b. Object is beyond twice the focal length (2F)

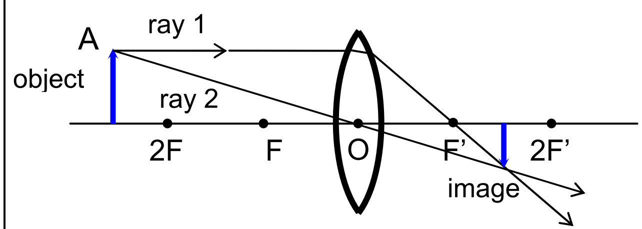


Image is real, inverted, diminished and located between F' and 2F'.

c. Object is at twice the focal length (2F)

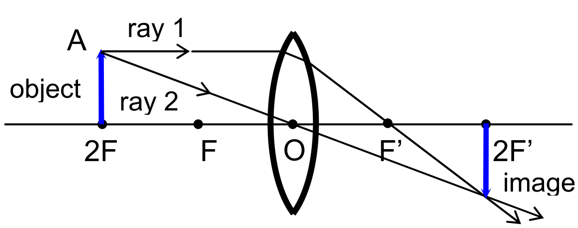


Image is real, inverted, of the same size and located at 2F'.

d. Object is between 2F and F

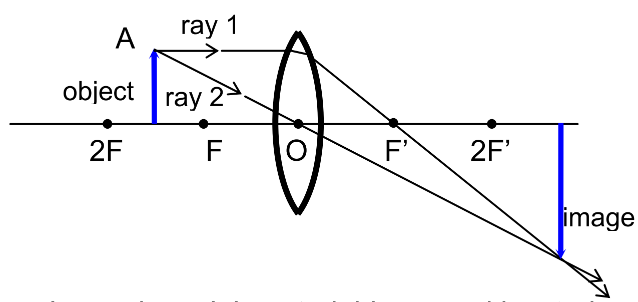
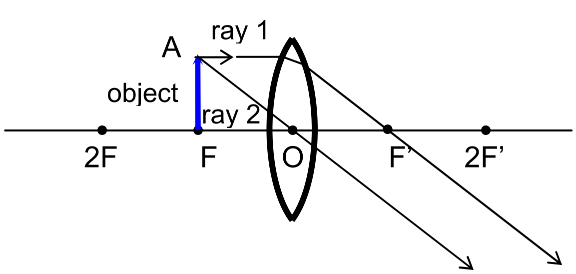


Image is real, inverted, bigger and located beyond 2F'.

e. Object is at the focus (F)



Refracted rays are parallel. No image is formed.

f. Object is between the focus and the optical center

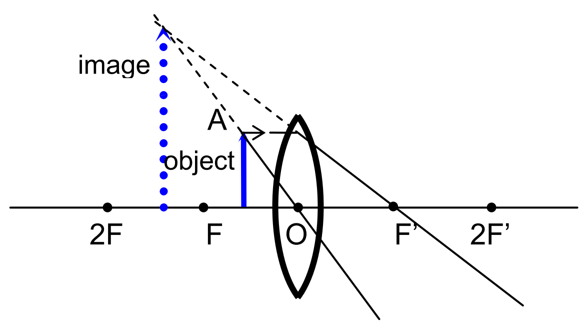


Image is virtual, erect, bigger and located between 2F and F.

Image Formation in a Concave Lens

What kind of image is formed by a concave lens? The ray method shown in Figure 3.8 shows the image formed by a concave lens. It is always erect, virtual and smaller in size.

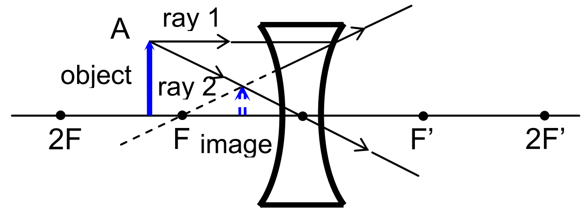


Figure 3.8 Image in a concave lens

The Lens Formula

The equation used to determine the object distance d_o, image distance d_i and the focal length f for spherical mirrors also applies for lenses. Hence, the lens formula is the same as the mirror formula.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

The size rule for mirrors also applies for lenses.

$$\frac{s_i}{s_o} = \frac{d_i}{d_o}$$

For numerical computations, the following sign conventions are followed:

Lens	f	d_o	d_i
convex (converging)			
real image	+	+	+
virtual image	+	+	-
concave (diverging)			
virtual image	-	+	-

The focal length is positive for a converging lens and negative for a diverging lens. Object distance is positive for both converging lens and diverging lens. Image distance is positive for real images and negative for virtual images.

Study This

Sample problem: An object 8 cm tall is placed 30 cm from a converging lens. A real image is formed 15 cm from the lens.

a) What is the focal length of the lens?
b) What is the size of the image? Describe the image.

Given: s_o = 8 cm
d_o = 30 cm
d_i = 15 cm

Find: a. f
b. s_i

Solutions:

a)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{f} = \frac{1}{30\ \text{cm}} + \frac{1}{15\ \text{cm}}$$

$$\frac{1}{f} = \frac{1+2}{30\ \text{cm}}$$

$$\frac{1}{f} = \frac{3}{30\ \text{cm}}$$

$$3f = 30\ \text{cm}$$

$$f = \frac{30\ \text{cm}}{3}$$

$$f = 10\ \text{cm}$$

b)

$$\frac{S_i}{S_o} = \frac{d_i}{d_o}$$

$$S_i = \frac{S_o\, d_i}{d_o}$$

$$S_i = \frac{8\ \text{cm} \times 15\ \text{cm}}{30\ \text{cm}}$$

$$S_i = 4\ \text{cm}$$

Image is smaller than the object

What you will do

Self-Test 3.1

Direction: Completion Type. Write the word or expression which best completes the meaning of the following statements.

1. __________ is the bending of light as it passes at an angle from one medium into another of different optical density.
2. The angle between the refracted ray and the normal drawn to the point of refraction is called __________.
3. __________ is the ratio of the speed of light in a vacuum to its speed in a given substance.
4. The index of refraction for any two media is always equal to a __________.
5. When a ray of light passes at an angle from a medium of lesser to one of greater optical density, it bends __________ from the normal.
6. The limiting angle of incidence in the denser medium resulting in angle of refraction of 90^o is known as __________.
7. The distance between the principal focus and the optical center of the lens is __________.
8. __________ is the kind of lens that will always form a virtual, erect and smaller image.
9. The principle involved in the formation of image on lenses is __________.
10. An enlarged, erect and real image is formed by a __________ lens.

Key to answers on page 30

Lesson 4 Color, Interference and Polarization of Light

Have you ever wondered why the sky appears blue during noontime and reddish at sunset? Why do we see rainbow colors in soap bubbles or in thin films with oil? How are rainbows formed? What is color?

What you will do

Activity 4.1 Dispersion

Hold a prism or a bottle half-filled with water against sunlight or any light source like a flashlight.

Answer these:

1. What do you observe?
2. Enumerate the colors you observe.

Key to answers on page 31

Colors of Light

When light leaves the prism and strikes a white screen, it separates into spectral colors. **Dispersion** is the separation of white light by a prism into bands of colors – red, orange, yellow, green, blue and violet. The spectrum is due to the difference in the velocities and wavelength of the spectral colors. Violet is bent most and is slowed down more than the red light.

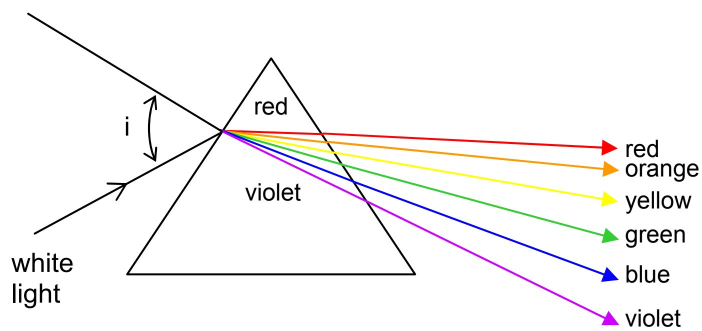


Fig. 4.1 Dispersion of light by a prism

Dispersion of light shows that light is a mixture of different spectral colors.

Know This

Have you seen a rainbow? When can you see a rainbow?

A rainbow is a spectacular display of colors. We usually observe a rainbow after a rainshower. The raindrops act as prism separating sunlight into bands of colors. A rainbow is produced by reflection, refraction and dispersion of light when sunlight strikes drops of falling water which act as prisms.

The difference between one color and another is due to difference in wavelengths or frequencies. Each color of light has its own wavelength and frequency. Violet has a higher frequency but shorter wavelength. Red has a lower frequency but longer wavelength (see Figure 4.2).

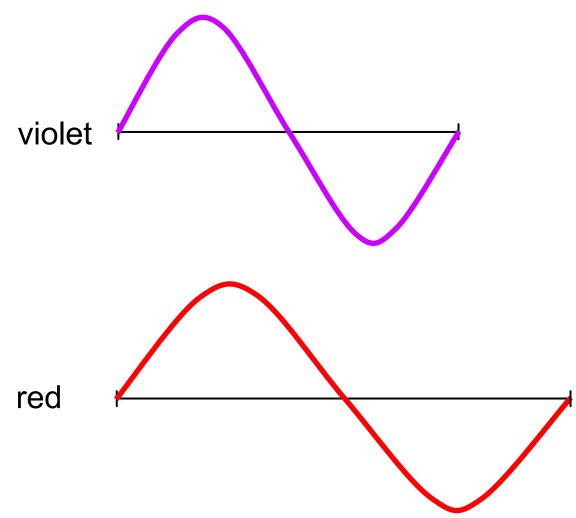


Fig. 4.2
Comparison of wavelengths of red and violet light

Colors of Object

Why do objects show colors? Objects show colors because they reflect one or more of the colors present in the white light. The color of an object depends on the wavelength of light that it reflects.

A camia flower appears white because it reflects all the colors of light it receives. A piece of coal appears black because it absorbs all the colors that fall on it. Under ordinary daylight a blue bird appears blue because it absorbs all other colors and reflects only blue. Why does a red rose appear red? The rose appears red because it reflects mainly red color and absorbs all other colors.

Think of This

Suppose the light falling on an object you are looking at is not white. What do you think will happen? For example, a blue book under a red light will appear black because it absorbs the red light and no color is reflected in our eyes. Similarly, when a green light falls on a red book, the book will also appear black because it absorbs the green light. No color is reflected to our eye. How will a green book appear under a blue light?

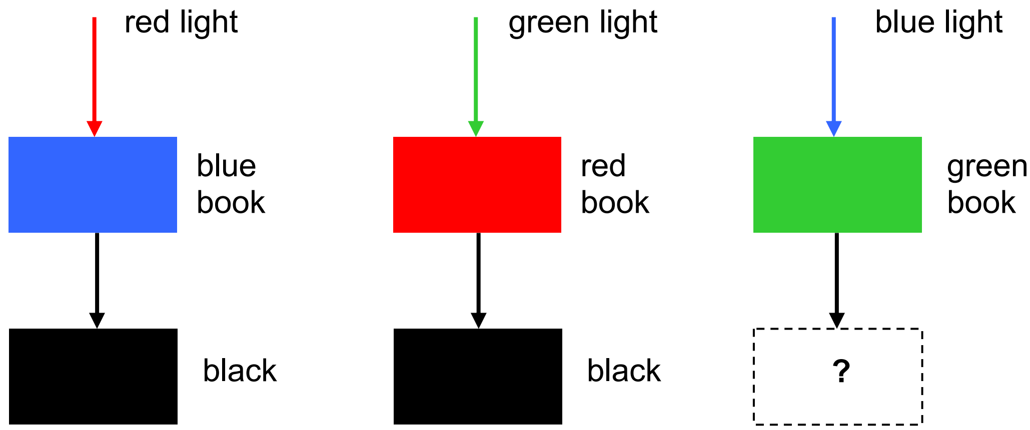


Fig. 4.3
Colored light falling on colored objects

What you will do

Activity 4.2 Diffraction of Light

1. Look at the light through a slit between your fingers. What do you observe? Do you see vertical white and dark bands? What causes the bands?
2. Repeat step 1 but make the slit narrower. What happens when the slit becomes narrower?

> **Know This**
>
> As you look at the light through one slit between your fingers you observe thin vertical white and dark bands. This is because of the bending or spreading out of light after passing through the opening. The bending of light as it passes through an obstruction such as a small slit is called **diffraction**.
>
> As the slit becomes narrow, diffraction patterns become more prominent.

Scattering of Light

Do you know why the sky is blue during noontime? Why is the sky red at sunset?

When sunlight shines down on the atmosphere, the dust particles or molecules in the atmosphere scatter the light in all direction. The amount of scattering of light depends on the wavelength of the light. During noontime, most of the blue light of shorter wavelength in sunlight is scattered and reflected to earth, so the sky looks blue. At sunset, the light travels longer distances with more air and dust in the atmosphere. Thus, most of the blue light is absorbed before it reaches you. Therefore, red light which has a longer wavelength is the most predominant color left when the light from the sun reaches the eye. Hence, the sunset appears red.

What you will do

Activity 4.3

Get a basin with soap suds. Blow on the soap suds. What can you observe in the soap bubbles?

Interference of light

Have you noticed the beautiful spectrum of colors reflected from a soap bubble? These colors are produced by the interference of light wave. This is often called **iridescenes** and is observed in the transparent film.

When light strikes the outer surface of a transparent material like a soap bubble, part of the light is reflected and part of the light enters the inside surface. At the inside surface, some of the light is reflected again. The two reflected beams returning toward your eye may have a path difference that is determined by the thickness of the film. If the light waves are in phase, they interfere constructively and produce a bright fringe. If they are out of phase, they interfere destructively and produce a dark band. If white light is incident on the thin film, light of different wavelengths (colors) constructively interfere in different regions, giving rise to the rainbow-colored appearance of the film.

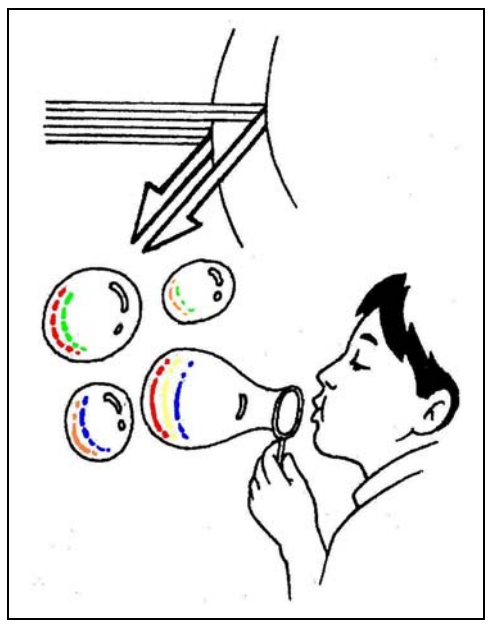


Fig. 4.4 Interference of light in soap bubbles

Thomas Young (1801) was the first to demonstrate interference of light using two slits. Waves from a monochromatic light source are made to pass through two narrow slits, S_1 and S_2 (Figure 4.5).

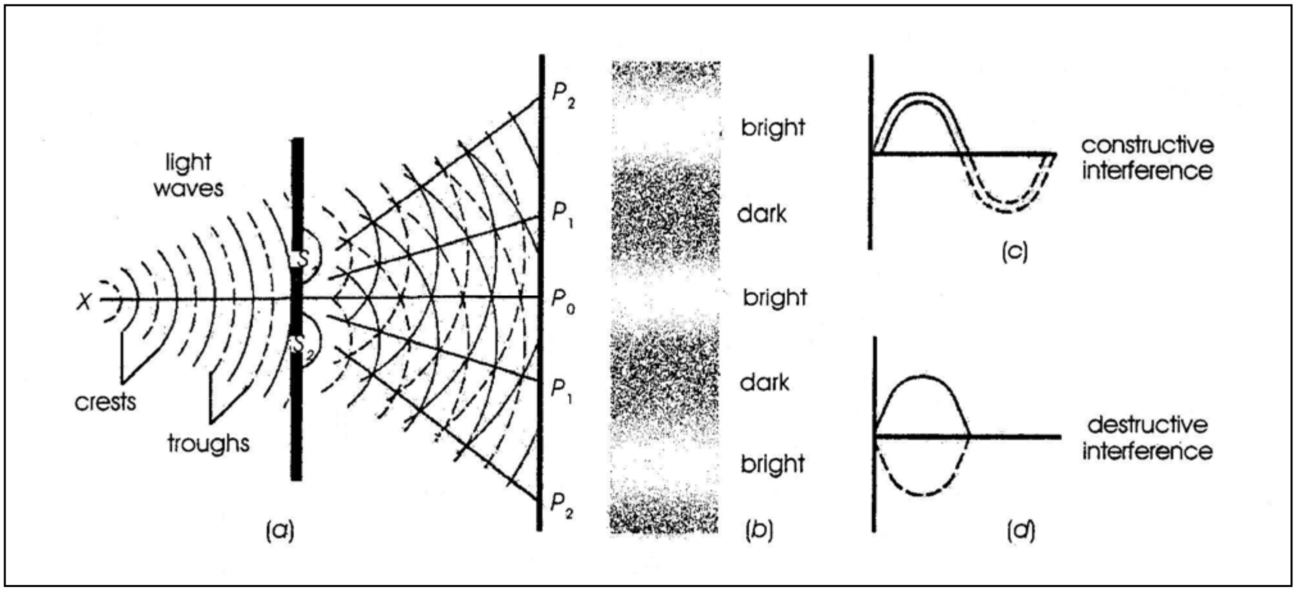


Fig. 4.5
Interference of light using two slits

According to Huygen's principle, these slits are sources of secondary waves. One slit spreads out the light and produces its own wave. The other slit also diffracts the light, producing another wave. These waves produced in S_1 and S_2 are of the same wavelength and in phase with the initial light source. When the light waves from S_1 and S_2 meet at point P_0 in phase, wave crests meet wave crests and troughs meet troughs, constructive interference occurs, producing a bright area.

Light waves from two slits may be completely out of phase when they meet at a point P_1, that is, a crest meets a trough. In such a case, destructive interference occurs, producing a dark area.

Polarization

Think of This

What is polarized light? Imagine a wave produced from a rope tied to a post (Figure 4.6). The rope is inserted through the vertical slits of two sheets of cardboard and waves are produced by moving the free end up and down. Waves pass through the slits when the slits in both cardboards are vertical. The waves are said to be plane polarized. All vibrations are in one plane, the vertical plane. When the slits in one cardboard are placed horizontally, they do not allow waves to pass through.

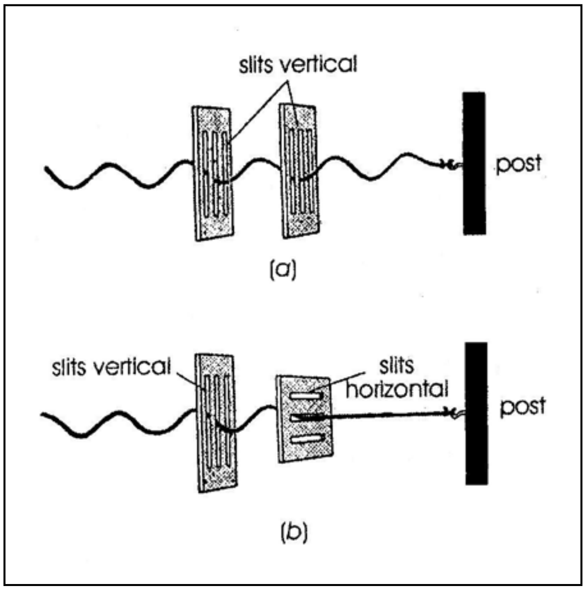


Fig. 4.6
A mechanical analogy of polarization

Ordinary light vibrates in all directions. It is unpolarized. When this light is allowed to pass through a filter called Polaroid, the light vibrates only in one plane (Figure 4.7). It comes out as polarized light.

What happens when light is allowed to pass through two Polaroid sheets? Light is transmitted when the axes of the Polaroid sheets are parallel. Light, however, is not transmitted when the axes of the polaroid sheets are perpendicular (Figure 4.8). What does this show about light? Light is a transverse wave.

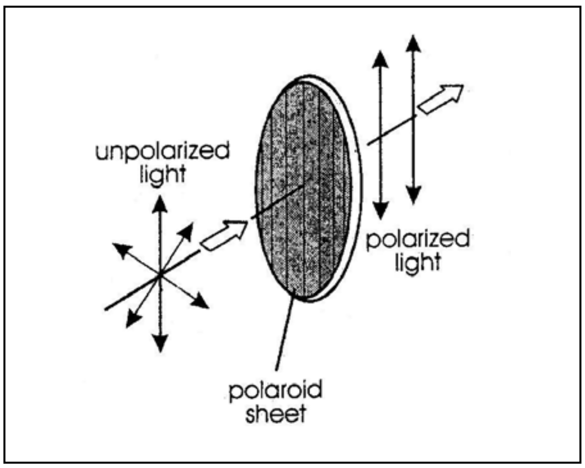


Fig. 4.7
Polarized light from a polaroid sheet

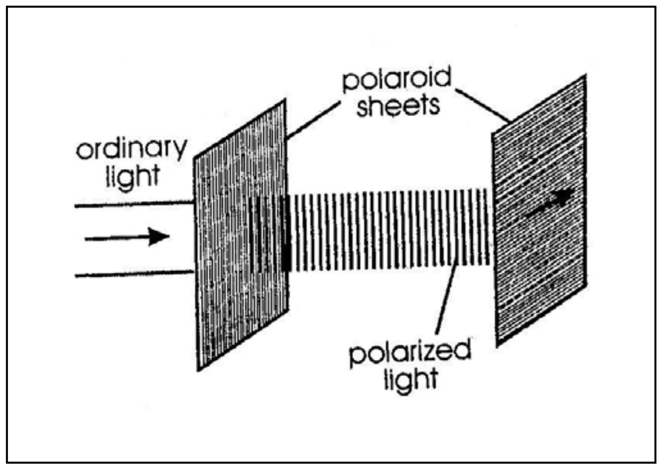


Fig. 4.8
Light is not transmitted when axes of the polaroid sheets are perpendicular

One application of polarization is the reduction of glare using polaroid sunglasses. Bright light reflected from a road or water surface is scattered in all directions. The polaroid sunglasses absorb the horizontal vibrations of the light, and hence reduce the glare.

What you will do

Self-Test 4.1

Directions: Identify the term defined, described or referred to in the following.

_____________ 1. The process of separating light into a band of colors
_____________ 2. The bending or spreading out of light through small openings or around corners
_____________ 3. Light in which vibrations occur in a single plane perpendicular to the ray
_____________ 4. The property of light waves which is dependent on the frequency or wavelength of radiation that reaches the eye
_____________ 5. The superposition of 2 beams of light resulting in a loss of energy in one area and a reinforcement of energy in others
_____________ 6. The band of colors when sunlight is dispersed by a prism
_____________ 7. The color which is refracted most when sunlight is separated by a prism

Key to answers on page 31

Let's Summarize

1. The laws of reflection state that:
   a. The incident ray, reflected ray, and the normal to the reflecting surface all lie in the same plane.
   b. The angle of incidence is equal to the angle of reflection.

2. Images in mirrors are formed by reflection.

3. The size of an object and the size of its image are related to their distance from the mirror and are related to the focal length of the mirror. This relationship is given by the equations

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad \text{and} \quad \frac{S_i}{S_o} = \frac{d_i}{d_o}$$

4. *Refraction* is the bending of light rays as they pass at an angle from one medium to another with a different optical density.

5. The *index of refraction* for a particular medium is a constant that is independent of the angle of incidence.

6. The limiting angle of incidence in the denser medium, resulting in an angle of refraction of 90^o is known as the *critical angle*.

7. *Total internal reflection* occurs when the angle of incidence exceeds the critical angle.

8. *Converging lens* is a lens that is thicker in the middle than at the edges and refracts parallel rays passing through it to a focus.

9. *Diverging lens* is a lens that is thinner in the middle than at the edges, causing parallel rays passing through it to diverge as if from a point.

10. Lenses form images by refraction.

11. *Dispersion* is the process of separating white light into a band of colors.

12. *Diffraction* is the bending of light as it passes through a small opening.

13. The color of light is dependent on the frequency or wavelength of the radiation that reaches the eye.

14. The color of an opaque object depends on the kind of light it reflects to the eye. It also depends on the color of light incident on it.

15. Interference of light occurs when two beams of light superimposed with one another.

16. Polarization of light depends on the transverse nature of light waves – that is, light vibrates only in one plane.

Posttest

Multiple Choice. Choose the letter of the best answer.

1. The theory that explains light as a particle.
   a. corpuscular theory
   b. electromagnetic wave theory
   c. quantum theory
   d. wave theory

2. When we see a tree, the light that reaches our eyes
   a. has been reflected by the tree.
   b. has been refracted by the tree.
   c. has been separated into a spectrum by the tree.
   d. has undergone interference in passing through the tree.

3. Enlarged image can be formed by
    a. concave mirrors only
    b. convex mirrors only
    c. either concave or convex mirror
    d. neither concave nor convex mirror

4. The image formed by a convex mirror is always
    a. real
    b. inverted
    c. bigger than the object
    d. smaller than the object

5. If you are looking obliquely on a fish under water, in what direction should you aim your arrow to hit it?
    a. above the fish
    b. below the fish
    c. directly to the fish
    d. either below or above the fish

6. The term refraction refers to
    a. the bending of light rays when they strike a mirror.
    b. the bending of light rays when they enter a different medium.
    c. the fact that white light is made up of many colors.
    d. the fact that light travels in straight line in uniform medium.

7. As the angle of incidence increases, the index of refraction of a medium
    a. increases
    b. decreases
    c. remains unchanged
    d. none of the above

8. If you look down on a pool of still water, you see your face clearly. Which one of the following gives the best explanation for this observation?
    a. Dispersion of light on entering water
    b. Reflection of light by the surface of the water
    c. Refraction of light by the surface of the water
    d. Light is reflected from the surface of the water in different directions.

9. A diamond is a brilliant gem because
    a. it has low index of refraction.
    b. it has big critical angle.
    c. most of the light is refracted.
    d. most of the light is reflected internally.

10. A ray of light is reflected from a plane mirror. The angle of incidence is 20^o. The angle between the incident and the reflected ray is
    a. 10^o
    b. 20^o
    c. 30^o
    d. 40^o

11. When you stand 3 m in front of a full length mirror, your image is
    a. real and 1 m behind the mirror
    b. real and 3 m behind the mirror
    c. virtual and 2 m behind the mirror
    d. virtual and 3 m behind the mirror

12. The bottom of a clear and deep lake appears to be shallow because of ____________
    a. diffraction
    b. polarization
    c. reflection
    d. refraction

13. When sunlight strikes raindrops, it passes through them and produces
    a. halo   c. rainbow
    b. heat   d. shadow

14. Side mirrors of motor vehicles allow the driver to see wider areas. What best describes the images compared to the real object in this kind of mirror?
    a. bigger   c. the same
    b. smaller   d. inverted

15. What do you call the separation of light into its component colors?
    a. dispersion   c. reflection
    b. polarization   d. refraction

16. Where does light travel fastest?
    a. air   c. vacuum
    b. glass   d. water

17. What do you call the bending of light around the corners of objects?
    a. diffraction   c. reflection
    b. dispersion   d. refraction

18. A beam of light traveling in air enters a glass medium. What changes does it undergo?
    a. change in speed only   c. change in wavelength only
    b. change in frequency only   d. change in both speed and wavelength

19. Which is the color of visible light with the longest wavelength?
    a. blue   c. violet
    b. red   d. yellow

20. Which of the following is a good description of a polarized light?
    a. It is an ordinary light.
    b. It is a transverse wave.
    c. It is a longitudinal wave.
    d. It is a wave that vibrates in all directions.

Key to answers on page 31

Key to Answers

Pretest

1. a	6. b	11. d	16. a
2. c	7. d	12. a	17. d
3. d	8. d	13. a	18. b
4. b	9. d	14. a	19. b
5. a	10. b	15. a	20. a

Lesson 1

Self-Test 1.1

1. b
2. d
3. a
4. c

Lesson 2

Self-Test 2.1

1. real image
2. angle of incidence
3. convex mirror
4. focal length
5. plane mirror
6. beyond the center of curvature
7. at the focus
8. vertex
9. convex mirror
10. concave mirror

Lesson 3

Self-Test 3.1

1. refraction
2. angle of reflection
3. index of refraction
4. constant
5. towards
6. critical angle
7. focal length
8. concave lens
9. refraction
10. convex lens

Lesson 4

Activity 4.1

1. spectral colors
2. red, orange, yellow, green, blue, violet

Self-Test 4.1

1. dispersion
2. diffraction
3. polarized light
4. color
5. interference
6. spectral colors
7. violet

Posttest

1. a	6. b	11. d	16. c
2. a	7. c	12. d	17. a
3. a	8. b	13. c	18. d
4. d	9. d	14. b	19. b
5. b	10. d	15. a	20. b

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