6.4 Thin Lens Formula

You have studied the use of ray diagrams to determine the position and characteristics of images formed by convex lens and concave lens. Other than ray diagrams, **thin lens formula** can be used to solve problems regarding lenses.

Thin lens formula gives the relationship between object distance, u, image distance, v and focal length, f for a lens as:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

(a) *Position of camera lens close to object produces a large image*

(b) *Position of camera lens far from object produces a small image*

Photograph 6.4 *Position of camera lens from object*

Photograph 6.4 shows the images for different object distances with a camera lens of the same focal length.

Experiment 6.3

Inference: Image distance is influenced by object distance

Hypothesis: When the object distance increases, the image distance decreases

Aim: (i) To study the relationship between object distance, u and image distance, v for a convex lens
(ii) To determine the focal length of a thin lens using lens formula

Variables:
(a) Manipulated variable: Object distance, u
(b) Responding variable: Image distance, v
(c) Constant variable: Focal length, f

Apparatus: Convex lens (f = 10.0 cm), lens holder, 6 V bulb, a wooden block, power supply, cardboard with a small triangular shaped hole, white screen and metre rule

Procedure:

1. Set up the apparatus as shown in Figure 6.36.

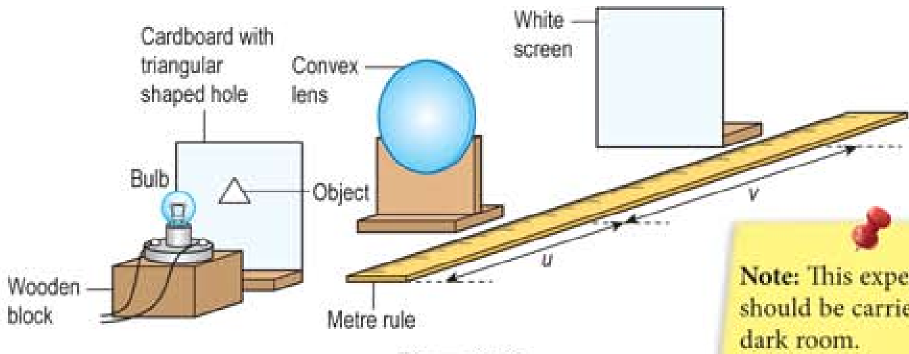


Figure 6.36

Note: This experiment should be carried out in a dark room.

2. Switch on the bulb and start the experiment with object distance, u = 15.0 cm. Adjust the position of the screen until a sharp image is formed.
3. Measure the image distance, v and record the reading in Table 6.9.
4. Repeat steps 2 and 3 with object distance, u = 20.0 cm, 25.0 cm, 30.0 cm and 35.0 cm. Record the readings in Table 6.9.

Video demonstration of non-parallax method

http://bt.sasbadi.com/p4260

Results:

Table 6.9

u / cm	v / cm	$\frac{1}{u}$ / cm^{-1}	$\frac{1}{v}$ / cm^{-1}
15.0			
20.0			
25.0			
30.0			
35.0			

Analysis of data:

1. Plot a graph of $\frac{1}{v}$ against $\frac{1}{u}$.
2. Determine the gradient of the graph, m.
3. Determine the intercepts for both axes.
4. Using lens formula and the graph plotted, determine the focal length of the lens in this experiment.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report for this experiment.

Discussion:

State a precaution to be taken to increase the accuracy of the results of this experiment.

Solving Problems Involving Thin Lens Formula

Table 6.10 Sign convention used in thin lens formula

	Positive (+)	Negative (–)
Focal length, f	Converging lens or convex lens	Diverging lens or concave lens
Image distance, v	• Real image • On the opposite side of the object	• Virtual image • On the same side as the object

Example 1

A thin convex lens has a focal length of 12 cm. Determine the characteristics and the position of the images formed and linear magnification when the object distance is:
(a) 18 cm
(b) 4 cm

Solution:

(a) $u = +18$ cm
$f = +12$ cm

Thin lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$
$$= \frac{1}{12} - \frac{1}{18}$$
$$v = +36 \text{ cm}$$

Linear magnification, $m = \frac{v}{u}$

$$= \frac{36}{18}$$
$$= 2$$

Image is real, inverted and magnified. Image is located 36 cm from the lens and on the opposite side of the object. Image is magnified 2 times.

(b) $u = +4$ cm
$f = +12$ cm

Thin lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$
$$= \frac{1}{12} - \frac{1}{4}$$
$$v = -6 \text{ cm}$$

Linear magnification, $m = \frac{v}{u}$

$$= \frac{6}{4}$$
$$= 1.5$$

Image is virtual, upright and magnified. Image is located 6 cm from the lens and on the same side as the object. Image is magnified 1.5 times.

Example 2

An object with a height of 9 cm is placed 60 cm from a concave lens with a focal length of 30 cm. Determine the position and size of the image formed. State the characteristics of the image formed.

Solution:

$u = +60$ cm
$f = -30$ cm

Thin lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$

$= \frac{1}{-30} - \frac{1}{60}$

$v = -20$ cm

Linear magnification, $m = \frac{h_i}{h_o} = \frac{v}{u}$

$\frac{h_i}{9} = \frac{20}{60}$

$h_i = 3$ cm

Image is virtual, upright and diminished. Image is 20 cm from the lens and is on the same side as the object. Image height is 3 cm.

Example 3

Figure 6.37 shows a straight wire placed along the principal axis of a thin convex lens with a focal length of 12 cm. X and Y are 24 cm and 18 cm respectively from the lens. A cricket takes 6 seconds to move from X to Y. What is the speed of the cricket's image?

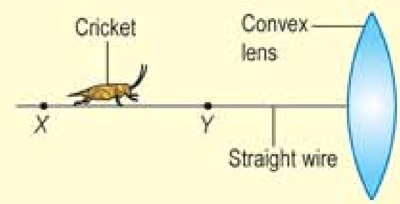


Figure 6.37

Solution:

$u_1 = +18$ cm $\quad u_2 = +24$ cm $\quad f = +12$ cm

Thin lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{v_1} = \frac{1}{f} - \frac{1}{u_1}$

$= \frac{1}{12} - \frac{1}{18}$

$v_1 = +36$ cm

$\frac{1}{v_2} = \frac{1}{f} - \frac{1}{u_2}$

$= \frac{1}{12} - \frac{1}{24}$

$v_2 = +24$ cm

Speed of the cricket's image $= \frac{36 - 24}{6}$

$= 2 \text{ cm s}^{-1}$

Formative Practice 6.4

1. A concave lens with a focal length of 25 cm forms a virtual image of an ant at a distance of 20 cm from the optical centre of the lens.
   (a) What is the original position of the ant?
   (b) Draw a ray diagram to show the formation of a virtual image of the ant.
2. A small bulb is at a distance of 1.6 m from the screen and a thin convex lens with a focal length of 30 cm is placed between the bulb and the screen. Determine two positions of the convex lens that can produce a sharp image on the screen.

6.5 Optical Instruments

Use of Lenses in Optical Instruments

Lenses in optical instruments have many benefits in our daily lives.

Activity 6.11

Aim: To study the use of lenses in optical instruments

Instructions:

1. Work in groups.
2. Gather information from reading resources or websites on the use of lenses in optical instruments, such as magnifying glass, compound microscope and telescope in the following aspects:
   (a) Use of lenses in the optical instrument
   (b) Function of the lenses used
3. Present your findings.

Use of lenses in optical instruments

http://bt.sasbadi.com/p4263

Activity 6.12

ISS ICS

Aim: To justify the usage of lenses in optical instruments

Apparatus: Magnifying glass, compound microscope and telescope

Instructions:

1. Place the magnifying glass, compound microscope and telescope on separate tables.
2. Divide the class into three groups. Each group is given 20 minutes to observe objects through the optical instruments and study the structure of the optical instruments.
3. Record the findings.

Discussion:

1. State the characteristics of the images formed by the lenses used in magnifying glass, compound microscope and telescope.
2. Justify the usage of lenses in magnifying glass, compound microscope and telescope.

(a) Magnifying glass

(b) Microscope

(c) Telescope

Photograph 6.5

6.5.1

Figure 6.38 shows the uses of lenses in optical instruments such as magnifying glass, compound microscope and telescope.

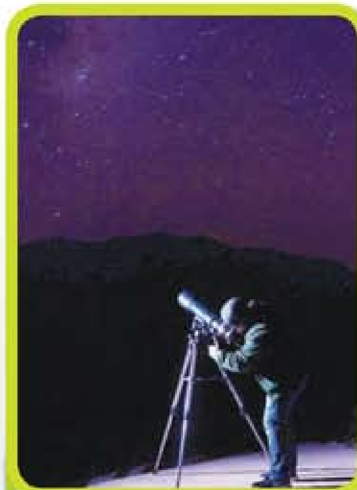
- I am a gemologist. I use a magnifying glass to identify and evaluate gemstones.

- I am an ophthalmologist. I use a magnifying glass to examine eyes.

- I am a microbiologist. I use a microscope to examine various microorganisms.

- I am a geologist. I use a microscope to study and identify specimens of rocks and minerals.

Figure 6.38 Uses of lenses in optical instruments



- I am an astronomer. I use a telescope to study celestial objects.

Video on the discovery of image of black hole using *Event Horizon Telescope*

http://bt.sasbadi.com/p4264

INTEGRATION OF HISTORY

In 1609, Galileo Galilei (1564–1642) invented the telescope to observe the four Moons which orbited Jupiter. This success triggered a revolution in astronomical studies.

INTEGRATION OF HISTORY

In the mid-17th century, Antonie van Leeuwenhoek (1632–1723) successfully invented the single-lensed microscope that can make linear magnifications of 300 times. He succeeded in observing and drawing microorganisms.

Designing and Building Compound Microscopes and Telescopes Using Convex Lenses

Activity 6.13

ISS ICS

Aim: To design and build a compound microscope and a telescope using convex lenses

Instructions:

1. Work in groups.
2. Gather information on compound microscope and telescope from reading resources or websites based on the following:
   (a) Type of lens used and its function
   (b) Criteria for choosing objective lens and eyepiece lens of a compound microscope which can produce the largest image
   (c) Criteria for choosing objective lens and eyepiece lens of a telescope which can produce the clearest and brightest image
   (d) Draw ray diagrams to show the formation of images in compound microscope and telescope
3. Discuss the information and complete the K-W-L Chart as a guide to design and build your compound microscope and telescope. You can download and print the form from the website given.
4. Sketch the design of your compound microscope and telescope.
5. Build your compound microscope and telescope based on your sketch.
6. Comment on the effectiveness of the design and improve on the design produced.
7. Present your group's design, and the compound microscope and telescope built.

Video on the working principle of microscope

http://bt.sasbadi.com/p4265a

Video on the working principle of telescope

http://bt.sasbadi.com/p4265b

Download K-W-L Chart

http://bt.sasbadi.com/p4265c

Compound Microscope

- Made up of two convex lenses with short focal lengths. Objective lens has focal length, f_o and eyepiece lens has focal length, f_e. Focal length f_o is less than focal length f_e.
- Distance between objective lens and eyepiece lens > $f_o + f_e$.
- Object distance is between f_o and $2f_o$. Objective lens forms the first image, I_1 which is real, inverted and magnified. I_1 lies between F_e and the optical centre of the eyepiece lens and becomes the object for the eyepiece lens.
- Eyepiece lens functions as a magnifying glass. Eyepiece lens forms the final image, I_2 which is **virtual**, **magnified** and **inverted** compared to object O (Figure 6.39).
- Normally, eyepiece lens is adjusted so that the final image, I_2 is at the near point of the observer's eye to achieve the clearest vision.

Info File

Normal adjustment of a compound microscope can be done by adjusting the eyepiece lens so that the final image is formed at the near point of the eye, which is 25 cm away.

Magnification of compound microscope

http://bt.sasbadi.com/p4266

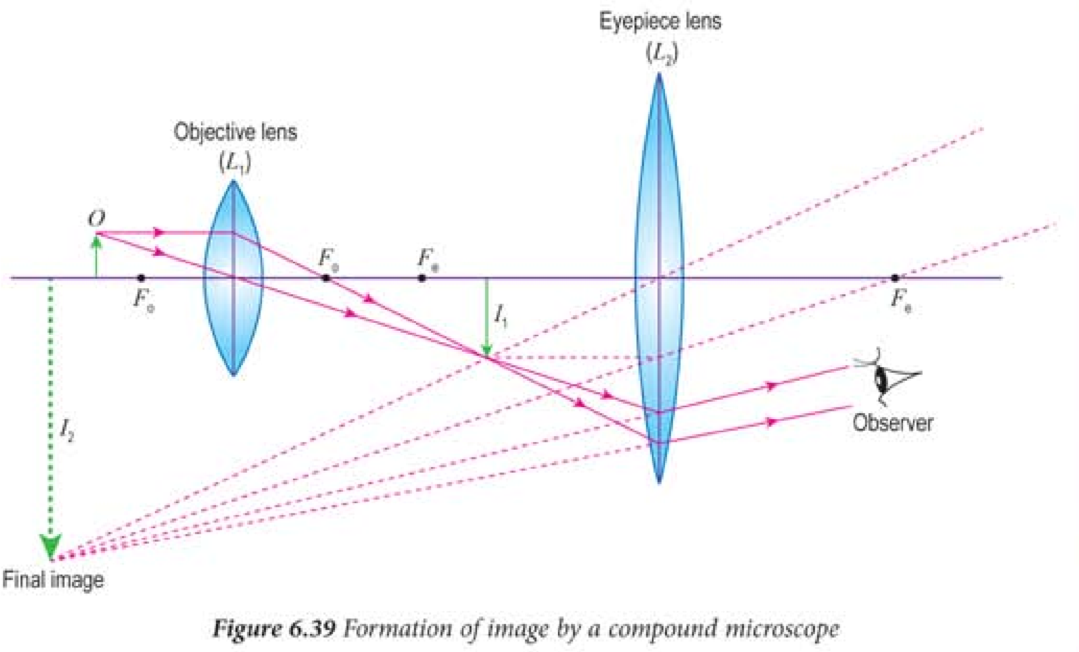


Figure 6.39 *Formation of image by a compound microscope*

Telescope

- Made up of two convex lenses. Objective lens has a long focal length, f_o and eyepiece lens has a short focal length, f_e. Distance between objective lens and eyepiece lens is $f_o + f_e$.
- Parallel rays from a distant object can be focused at the focal plane of the objective lens to form the first image, I_1 which is real, inverted and diminished. The first image, I_1 acts as the object for the eyepiece lens. Eyepiece lens forms the final image, I_2 which is **virtual**, **magnified** and **inverted** compared to the object (Figure 6.40).
- Normally, image I_2 is located at infinity. This is known as **normal adjustment**.

Info File

Normal adjustment of telescope can be done by adjusting the distance between the objective lens and the eyepiece lens, $L = f_o + f_e$. This enables the final image to be formed at infinity for a comfortable vision.

Magnification of telescope at normal adjustment, M is

$M = \frac{f_o}{f_e}$.

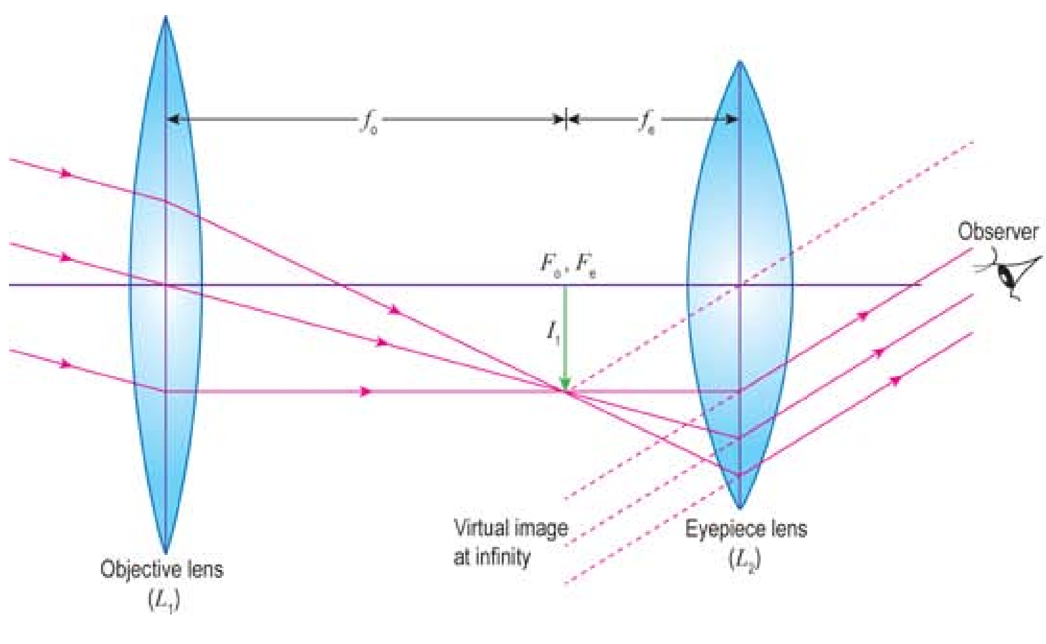


***Figure 6.40** Formation of image by a telescope*

Applications of Small Lenses in Optical Instrument Technology

The advancement of technology in optical instruments has successfully produced small lenses. These lenses are widely used in smartphone cameras and closed circuit television (CCTV).

Activity 6.14

ISS ICS

Aim: To discuss the application of small lenses in optical instruments

Instructions:

1. Work in groups.
2. Gather information on the application of small lenses in smartphone cameras and CCTV based on the following aspects:
   (a) Use of small lenses in optical instruments
   (b) Function of the small lenses

Small lenses in smartphones

http://bt.sasbadi.com/p4268

Photograph 6.6 *Lenses in a smartphone camera*

Photograph 6.7 *Small size CCTV*

3. Present your findings in graphic form.

Normally, smartphones and CCTV have cameras of high resolution to capture pictures and record videos clearly. As such, lens is the most important component in smartphone cameras and CCTV. Thin smartphones and small size CCTV have small size convex lens. This lens can form an image that is **real**, **diminished** and **inverted** at the sensor. Minimum distance between the sensor and the centre of the lens has to be the same as the focal length of the camera lens as shown in Figure 6.41. As the focal length of the camera lens cannot be of zero value, the overall thickness of a smartphone and CCTV is limited to the focal length of the camera lens.

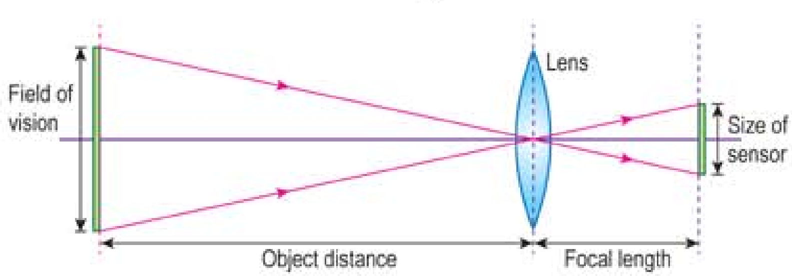


Figure 6.41 *Formation of image by small lens in smartphone camera and CCTV*

Activity 6.15

Logical Reasoning ISS ICS

Aim: To discuss the limitation to the thickness of a smartphone due to the thickness of camera lens

Instructions:

1. Work in groups.
2. Discuss the limitation to the thickness of a smartphone due to the thickness of camera lens.
3. You can obtain information through reading resources or websites.
4. Present your findings.

Formative Practice 6.5

A pupil is supplied with an eyepiece lens which has focal length, $f_e = 7$ cm and four pieces of objective lenses *A*, *B*, *C* and *D* as shown in Table 6.11.

Table 6.11

Lens	Focal length of objective lens, f_o / cm	Magnification of telescope, *M*	Diameter of objective lens / cm
A	14		5.0
B	14		10.0
C	70		5.0
D	70		10.0

1. Complete Table 6.11.
2. State two lenses which can produce the largest image.
3. State two lenses which can produce the brightest image.
4. Based on your answers in **2** and **3**, state the most suitable lens to be used as the objective lens of a telescope. Explain your answer.

6.5.3

6.6 Image Formation by Spherical Mirrors

Spherical mirrors are part of a sphere that has been cut as shown in Figure 6.42. If the inner surface of the part that has been cut reflects light, the mirror is a **concave mirror**. If the outer surface of the part that has been cut reflects light, the mirror is a **convex mirror**.

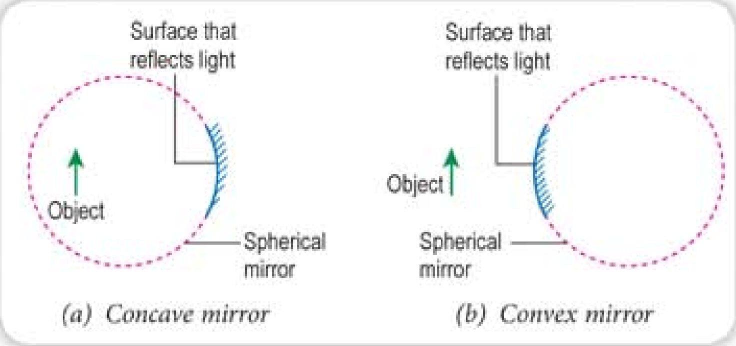


Figure 6.42 *Spherical mirror*

Photograph 6.8 *Images formed by surface of spoon*

Look at Photograph 6.8. Concave surface and convex surface of a steel spoon act as concave mirror and convex mirror respectively. Can you state the characteristics of the images formed by concave surface and convex surface of the spoon?

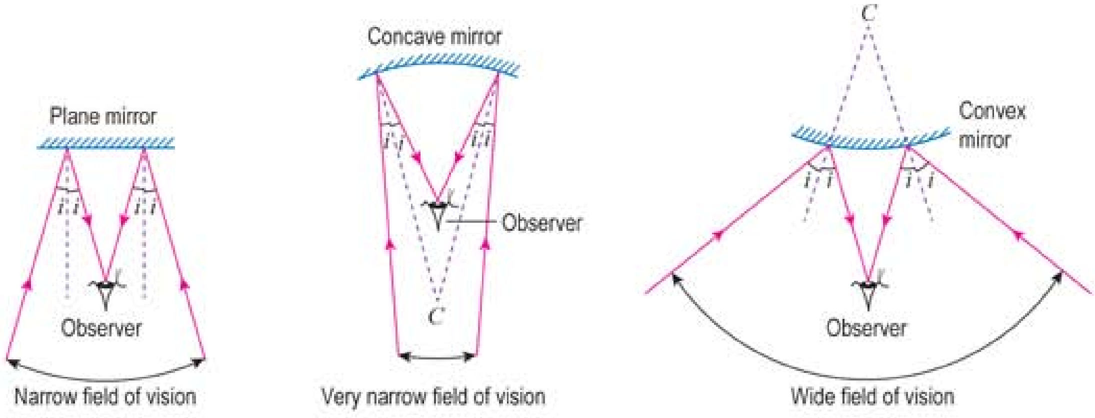


Figure 6.43 *Fields of vision in front of plane mirror, concave mirror and convex mirror*

Figure 6.43 shows the fields of vision of an observer in front of a plane mirror, concave mirror and convex mirror of the same size.

Formation of image by spherical mirrors

http://bt.sasbadi.com/p4270

Activity 6.16

ICS

Aim: To gather information on optical terms related to spherical mirrors

Instructions:

1. Work in groups.
2. Gather information from various reading resources and websites regarding the following terms:
   - principal axis
   - object distance, u
   - focal length, f
   - radius of curvature of mirror, r
   - focal point, F
   - image distance, v
   - centre of curvature, C
3. Present your findings.

Figure 6.44 shows the optical terms as used in spherical mirror ray diagrams. Table 6.12 explains these optical terms.

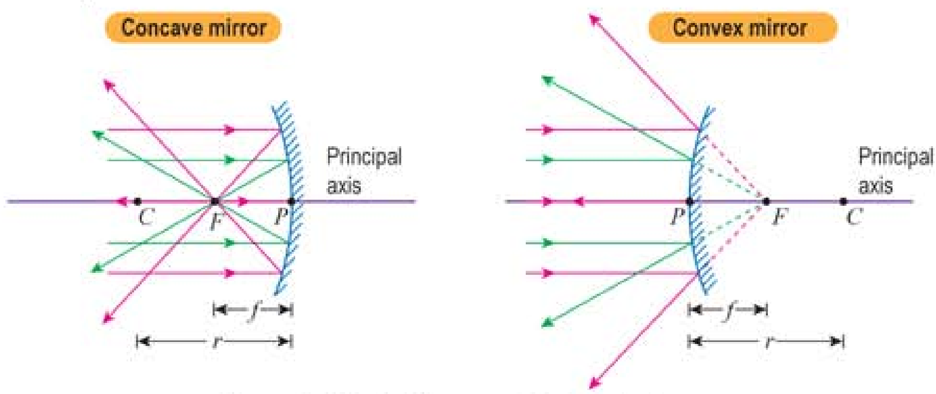


Figure 6.44 *Ray diagrams of spherical mirrors*

Table 6.12 *Explanation of optical terms related to spherical mirrors*

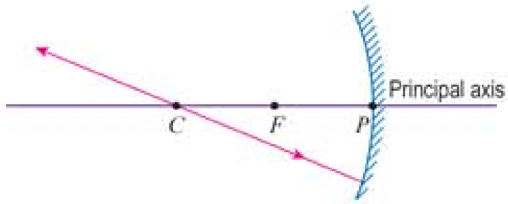
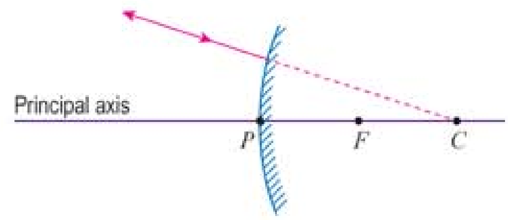
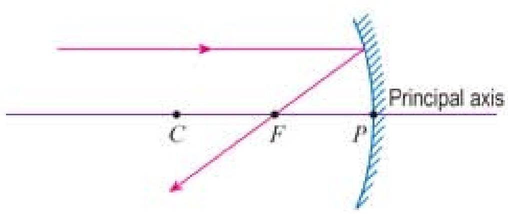
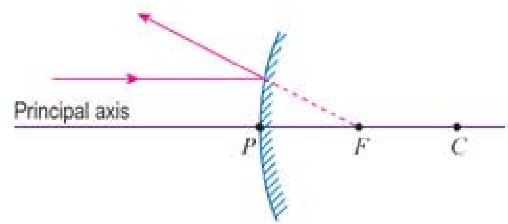
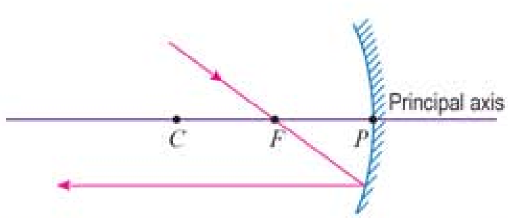
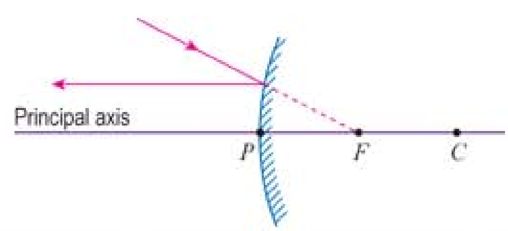
Optical Term	Explanation
Principal axis	Straight line passing through the centre of curvature, C and pole of the spherical mirror, P
Centre of curvature, C	Centre of sphere which produces a concave or convex mirror
Radius of curvature of mirror, r	Distance between the pole of spherical mirror, P and the centre of curvature, C
Focal point, F	A point on the principal axis of the spherical mirror, • for concave mirror, light rays which are parallel to the principal axis will converge at this point • for convex mirror, light rays which are parallel to the principal axis appear to diverge from this point
Object distance, u	Distance between object and the pole of spherical mirror, P
Image distance, v	Distance between image and the pole of spherical mirror, P
Focal length, f	Distance between focal point, F and the pole of spherical mirror, P

6.6.1

Guide to Drawing Spherical Mirror Ray Diagrams

Look at the guide in Table 6.13 to draw ray diagrams of spherical mirrors.

Table 6.13 *Guide on drawing ray diagrams of spherical mirrors*

Concave mirror	Convex mirror
1. Light ray passing through *C* is reflected back to its original path. 	**1.** Light ray travelling towards *C* is reflected back to its original path 
2. Light ray parallel to principal axis is reflected to the focal point, *F*. 	**2.** Light ray parallel to principal axis is reflected as if it originates from the focal point, *F*. 
3. Light ray passing through *F* is reflected parallel to the principal axis. 	**3.** Light ray travelling towards *F* is reflected parallel to the principal axis. 

SMART INFO

Radius of curvature of mirror, r is two times the focal length of the spherical mirror, f, that is $r = 2f$.

Activity 6.17

ICS

Aim: To draw ray diagrams to show the image position and determine the characteristics of images formed by a concave mirror and a convex mirror

Instructions:

1. Work in groups.
2. Visit the websites given and carry out the simulation in the websites.
3. Based on the simulation, complete Table 6.14 and Table 6.15. You can download and print the tables from the websites given.
4. Draw ray diagrams to show the image position and state the characteristics of images formed by concave mirror and convex mirror.

Simulation of images for concave mirror and convex mirror

http://bt.sasbadi.com/p4273a

Download Table 6.14 and Table 6.15

http://bt.sasbadi.com/p4273b

Table 6.14 *Position and characteristics of images by a concave mirror*

Object position	Ray diagram	Image position	Characteristics of image
Object at infinity			
Object beyond C ($u > 2f$)			
Object at C ($u = 2f$)			
Object between F and C ($f < u < 2f$)			
Object at F ($u = f$)			
Object between F and P ($u < f$)			

Table 6.15 *Position and characteristics of images by a convex mirror*

Object position	Ray diagram	Image position	Characteristics of image
Object beyond F ($u > f$)			
Object between F and P ($u < f$)			

6.6.1

Table 6.16 Position and characteristics of images by a concave mirror

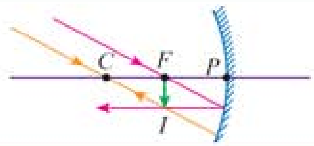
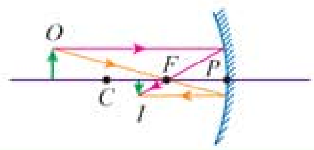
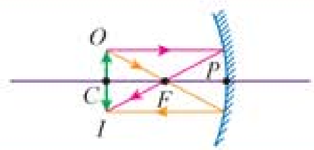
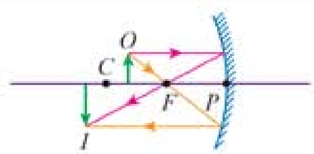
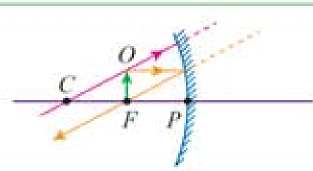
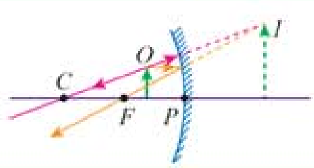
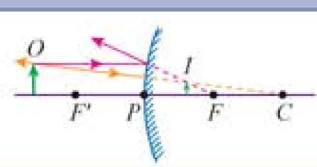
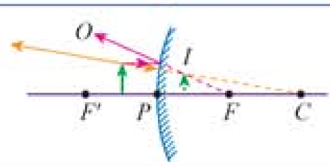
Object position	Ray diagram	Image position	Characteristics of image
Object at infinity		• Image distance: $v = f$ • In front of mirror	• Real • Inverted • Diminished
Object beyond C ($u > 2f$)		• Image distance: $f < v < 2f$ • In front of mirror	• Real • Inverted • Diminished
Object at C ($u = 2f$)		• Image distance: $v = 2f$ • In front of mirror	• Real • Inverted • Same size as object
Object between F and C ($f < u < 2f$)		• Image distance: $v > 2f$ • In front of mirror	• Real • Inverted • Magnified
Object at F ($u = f$)		• Image at infinity • Behind mirror	• Virtual • Upright • Magnified
Object between F and P ($u < f$)		• Image distance: $v > u$ • Behind mirror	• Virtual • Upright • Magnified

Table 6.17 Position and characteristics of images by a convex mirror

Object position	Ray diagram	Image position	Characteristics of image
Object beyond F ($u > f$)		• Image distance: $v < f$ • Behind mirror	• Virtual • Upright • Diminished
Object between F and P ($u < f$)		• Image distance: $v < f$ • Behind mirror	• Virtual • Upright • Diminished

Applications of Concave Mirror and Convex Mirror in Daily Life

Photograph 6.9 shows a blind spot mirror. This mirror is a convex mirror. What is the use of this mirror?

Photograph 6.9
Blind spot mirror

Activity 6.18 ISS ICS

Aim: To gather information to justify the use of concave mirror and convex mirror in daily life

Instructions:

1. Work in groups.
2. You can gather information from reading resources in the library or the websites regarding:
   (a) the use of concave mirror and convex mirror in daily life.
   (b) the importance of the mirrors.
3. Present your findings in a mind map.

Applications of Concave Mirrors in Daily Life

Cosmetic mirror
A concave mirror is used as a cosmetic mirror to produce a magnified image for applying make up.

Dental mirror
A dental mirror forms an upright and magnified image to examine the teeth.

Reflector in car headlight
A parabolic concave mirror is used as a reflector in car headlights to maintain light intensity even at a distance.

Figure 6.45 *Applications of concave mirrors in daily life*

Applications of Convex Mirrors in Daily Life

Blind spot mirror
A convex mirror is placed at sharp corners to widen the field of vision of the driver.

Security mirror in buildings
Convex mirrors are used in buildings or shopping centres for surveillance purposes.

Vehicle rear mirror
Vehicle rear mirrors provide a wide field of vision to enable the driver to see vehicles coming from behind.

Figure 6.46 *Applications of convex mirrors in daily life*

Formative Practice 6.6

1. Figure 6.47 shows a pupil looking in the direction of a plane mirror and a convex mirror of the same size.
   (a) Complete the path of light for both types of mirrors.
   (b) Which type of mirror can produce a wider field of vision?

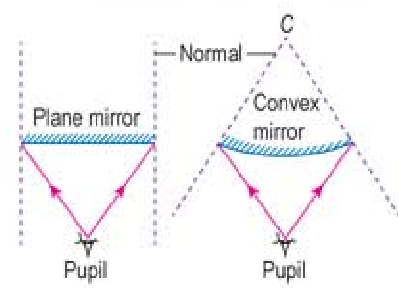


Figure 6.47

2. Adelia holds a shiny steel spoon with its back (convex surface) facing her eyes at a distance of approximately 30 cm. She sees an upright image of herself. However, when the spoon is changed so that the front (concave surface) of the spoon is facing her eyes, an inverted image is observed.
   (a) Explain this situation.
   (b) Why is an upright image not seen on the front surface of the spoon at that distance?

Conceptual Framework

Light and Optics

- **Refraction of Light**
  - Snell's Law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$
  - Refractive index, n
    - $n = \dfrac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \dfrac{c}{v}$
    - $n = \dfrac{\sin i}{\sin r}$
    - $n = \dfrac{\text{real depth}}{\text{apparent depth}} = \dfrac{H}{h}$
- **Total Internal Reflection**
  - Critical angle, c
    - $n = \dfrac{1}{\sin c}$
      - Applications
        - Natural phenomena
          - Rainbow
          - Mirage
        - Daily life
          - Optical fibre
          - Prism periscope
          - Cat's eye reflector
- **Formation of Image**
  - Lens
    - Convex lens
    - Concave lens
    - Thin lens formula: $\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$
      - Optical instruments
        - Magnifying glass
        - Compound microscope
        - Telescope
        - Small lens in smartphone cameras and closed circuit television (CCTV)
  - Spherical mirror
    - Concave mirror
    - Convex mirror
    - Applications in daily life
      - Concave mirror
        - Reflector in car headlights
        - Dental mirror
        - Cosmetic mirror
      - Convex mirror
        - Blind spot mirror
        - Security mirror in buildings
        - Rear view mirror of vehicles

Interactive QUIZ

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SELF-REFLECTION

1. New things I learnt in this chapter on light and optics are ______________.

2. The most interesting thing I learnt in the chapter on light and optics is ______________.

3. Things I still do not fully understand or comprehend are ______________.

4. My performance in this chapter,

   Poor | 1 | 2 | 3 | 4 | 5 | Excellent

5. I need to ______________ to improve my performance in this chapter.

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Performance Evaluation

1. Diamond is a precious stone that always appears shiny. Critical angle of diamond in air is 24°.
   (a) (i) What is the meaning of critical angle?
       (ii) Determine the value of refractive index of diamond.
   (b) Figure 1 shows three diamonds of different shapes. A ray enters each diamond as shown in Figure 1. Complete the path of light rays until the ray emerges again into air in Figure 1.

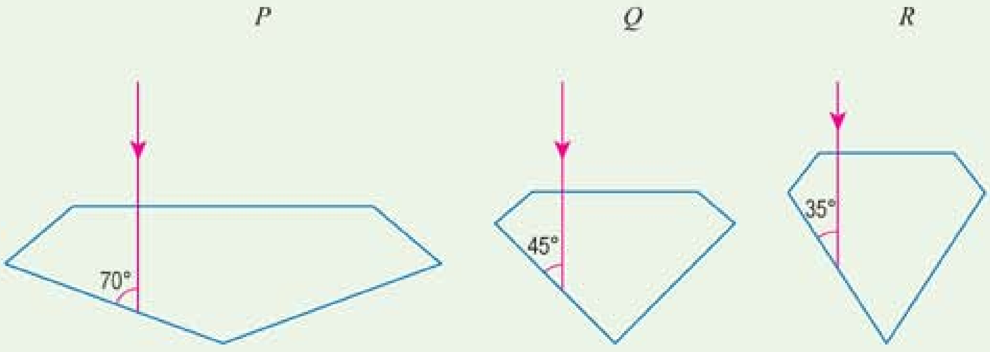

Figure 1

   (c) State the physics concepts involved in this phenomenon.

2. Figure 2 shows a glass block with a refractive index of 1.50 placed between the eyes of the observer, *E* and the object *P*. If the thickness of the glass is 30.0 cm, what is the distance between object *P* and its image?

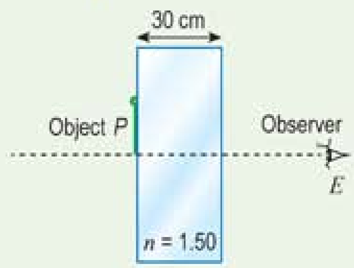

Figure 2

3. Figure 3 shows a light ray travelling from air to water and then entering a glass block. The refractive index of water is 1.33.
   (a) Determine angle *x*.
   (b) If speed of light in air is 3.0×10^8 m s^{-1}, what is the speed of light in water?
   (c) Between water and glass, which medium has a higher optical density? Explain your answer based on Figure 3.

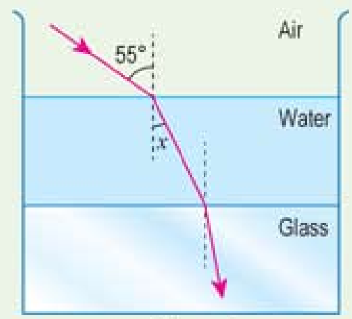

Figure 3

4. Mariam carried out an experiment with a semi-circular glass block and a ray box. Figure 4 shows the path of light ray entering the glass block at point *R* and travelling towards the centre of the semi-circular glass block, point *S*.

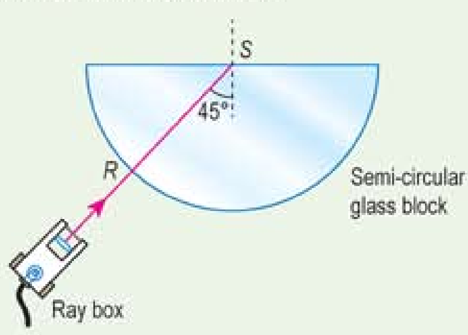

Figure 4

   (a) Why does the light ray not change direction at point *R*?
   (b) If the refractive index of the glass block is 1.52, determine the critical angle in this medium.
   (c) Draw the path of light ray after point *S* and mark the value of the angle of the light ray with the normal at point *S*.

5. When light from a star travels into the Earth's atmosphere, its direction of travel will change. This situation is shown in Figure 5. The change of direction is represented by the angle $\Delta\theta = i - r$.

   (a) Speed of light in air is 299 910 km s^{-1} and speed of light in vacuum is 3.00×10^8 m s^{-1}.
      (i) Calculate the refractive index of air.
      (ii) Explain the value of refractive index obtained.
   (b) Value of $\Delta\theta$ on a hot night is different from that on a cold night. State a logical reason for the difference.
   (c) Rajiv returns from school in a school van on a hot and bright day. Rajiv can see a puddle of water on the surface of the road ahead. When the van reaches the location of the puddle of water, Rajiv discovers that the puddle of water does not actually exist. Explain this phenomenon.

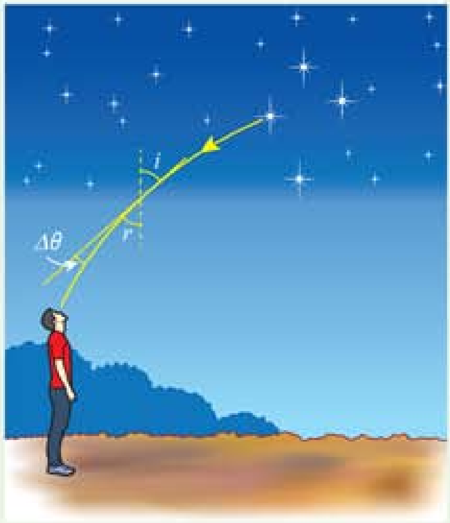

Figure 5

6. Figure 6 shows an object and its virtual image formed by a convex lens.

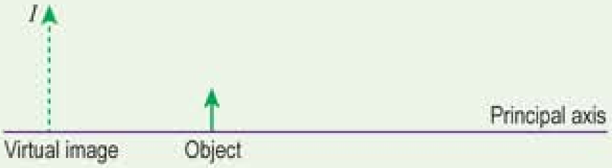

Figure 6

   (a) One of the characteristics of image *I* in Figure 6 is that it is virtual. State the other characteristics of image *I*.
   (b) Complete the ray diagram in Figure 6 and determine the position of the lens and focal point of the lens. Mark the position of the focal point of the lens with, *F*.
   (c) If the object is slowly moved away from the lens, state two changes that might happen to the image without drawing a ray diagram.

7. A sailor in the navy is looking at the situation on the surface of the sea through a submarine periscope. He found that the Sun is setting. The captain of the submarine told the sailor that the Sun had in fact already set.

   (a) Is the statement of the captain of the submarine true? Explain your answer.
   (b) Explain the formation of image in a prism periscope for object with obstruction in front with the help of suitable ray diagrams.

8. A lighted candle is placed in front of a concave mirror with a focal length of 2.4 cm. A white screen is moved behind the candle to catch a sharp image as shown in Figure 7.

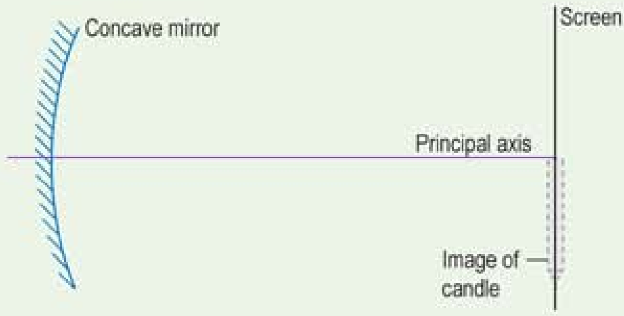

Figure 7

(a) On Figure 7,
    (i) mark the focal point of the mirror with *F* and centre of curvature with *C*.
    (ii) draw a complete ray diagram to determine the position of the object.
(b) How can the magnification of the image be increased?

9. (a) Explain the way to construct a compound microscope using two lenses. In your answer, state the type of lens that you chose, estimate the focal length of the lenses and characteristics of the image formed by each lens.
(b) Why is an astronomical telescope not suitable to be used to see distant objects on the surface of the Earth?
(c) How can you modify a compound microscope to become an astronomical telescope?

10. Table 1 shows the speed of light in vacuum and two materials for making optical fibre.

Table 1

Medium	Speed of light / m s^{-1}
Vacuum	3.00×10^8
Material I	2.01×10^8
Material II	1.96×10^8

(a) Identify suitable mediums to be used as core and cladding of optical fibre. Explain your answer.
(b) Determine the critical angle of the optical fibre.
(c) Why must the surface of optical fibre be very smooth?

Enrichment Corner

11. Amin carries out an experiment to investigate the relationship between real depth, H and apparent depth, h for an object in a liquid. The apparatus set up is shown in Figure 8. Pin A is placed at the base of a tall beaker. Liquid is poured into the beaker until pin A is at a depth of 5.0 cm. The real depth, H for pin A is the distance of the pin from the surface of the liquid.

Another pin, pin B is adjusted until the image of pin B in the plane mirror is in line with the image of pin A when observed from above as shown in Figure 9.

Apparent depth, h for pin A is the same as the distance between the image of pin B and the surface of the liquid. Distance x, can be determined by measuring the distance between pin B and the plane mirror. The distance from the surface of the liquid to the plane mirror, z is also measured.

This procedure is repeated for real depth of liquid, H = 10.0 cm, 15.0 cm, 20.0 cm, 25.0 cm and 30.0 cm. All readings are recorded in Table 2.

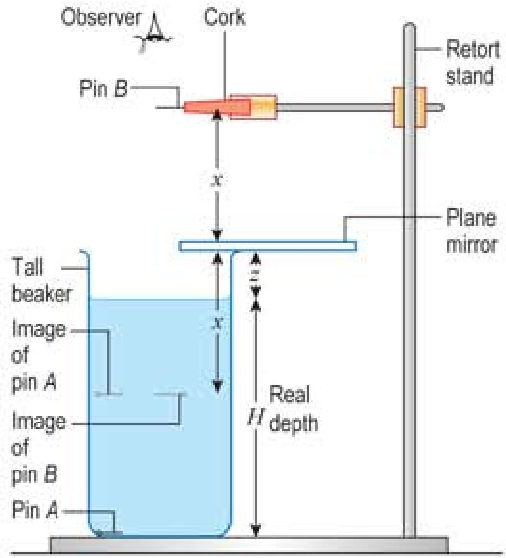

Figure 8

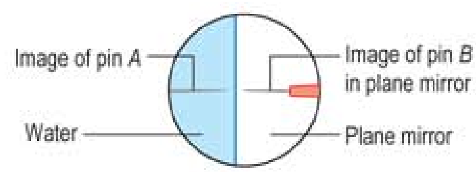

Figure 9

Table 2

H / cm	x / cm	z / cm	h / cm
5.0	30.8	27.0	
10.0	29.5	22.0	
15.0	28.3	17.0	
20.0	27.0	12.0	
25.0	25.8	7.0	
30.0	24.6	2.0	

(a) Based on the results of this experiment, determine the relationship between h and H and then deduce the value of the refractive index of the liquid.

(b) Draw suitable ray diagrams regarding the formation of images that can be seen by Amin.

(c) Discuss the importance of plane mirror and non-parallax method in this experiment.