Physics

Year 1

SECTION

4

MIRRORS, REFLECTION AND REFRACTION

ENERGY

Waves

INTRODUCTION

Welcome to this section where you shall use diagrammatic skills and mathematics to find the nature of images produced in plane mirrors. Make sure that you are careful with the construction of your diagrams, and that you seek the help of a teacher or peer if you aren't sure how to complete your sketch or use a protractor accurately!

You shall explore the phenomenon of the reflection of light in two different types of spherical mirrors, the convex mirror and the concave mirror. You will focus on ray diagrams and their formation of fascinating images. You will gain hands-on experience in understanding the properties of these mirrors, the important relationship between focal length and radius of curvature for spherical mirrors, and the formation of ray diagrams.

You will further explore light interactions with mirrors and different media, using the mirror formula, to predict image formation and the magnification formula to determine image size, whether they are enlarged, diminished, upright, or inverted. You will also delve into the laws of refraction, including Snell's Law, to understand light's direction and motion. By experimenting with angles and media, you will see light change direction and understand the science behind it.

At the end of this section, you should be able to;

- Deduce the laws of reflection.
- Describe the processes involved in image formation in plane mirrors and their characteristics.
- Determine the number of images formed by inclined mirrors.
- Explain the terminologies associated with spherical mirrors.
- Describe the processes involved in image formation in spherical mirrors and their characteristics using ray tracing.
- Determine the position and characteristics of images formed by spherical mirrors with mirror formula and magnification formula.

- Explain refraction and state the laws of refraction.

Key ideas:

- Reflection is the phenomenon of light rays bouncing back when they encounter a smooth, highly polished, or shiny surface. Very reflective surfaces are often called mirrors.
- When two mirrors are placed at an angle (θ) with respect to each other, multiple images can be formed due to the repeated reflection of light between the mirrors.
- Spherical mirrors are mirrors with surfaces that are part of a sphere. These mirrors can either be concave (inward-curved) or convex (outward-curved). They reflect light in specific ways due to their curved surfaces, making them useful in various applications. Their images can either be real (formed on a screen) or virtual (formed 'inside' and behind the mirror), upright or inverted, magnified or diminished.
- The **mirror formula** calculates the position of images formed by spherical mirrors by relating focal length, object distance, and image distance.
- The **magnification formula** determines the size and orientation of an image.
- The **laws of refraction** explain how light changes speed and direction between different media.

REFLECTION IN A PLANE MIRROR

Reflection is a phenomenon of the 'bouncing back' of a wave in the same medium. One example of this is when a light ray encounters a surface; some proportion of the light will be reflected, whilst some is absorbed. Highly polished or shiny surfaces (mirrors) are some of the most efficient reflectors of light, leaving only a small proportion absorbed.

Laws of Reflection

LAW 1: The incident ray, the reflected ray and the normal at the point of incidence all lie on the same plane.

LAW 2: The angle of incidence is equal to the angle of reflection (i = r)

The angle of incidence: The angle of incidence is the angle between an incident ray and the normal (a line perpendicular to the surface) of a surface at the point where the ray strikes the surface. It is measured in relation to the normal and is usually denoted by the symbol "i".

The angle of reflection: The angle of reflection is the angle between a reflected ray and the normal to a surface at the point where the incident ray strikes the surface. It is also measured in relation to the normal and is usually denoted by the symbol "r".

Activity 4.1: Verifying the Laws of Reflection

Investigate the relationship between the angle of incidence and the angle of reflection when light reflects off a plane mirror.

Materials needed:

- Plane mirror
- Protractor
- Paper and pencil
- Ray box or laser pointer

Procedure:

1. Set up a plane mirror on top of a piece of plain paper, so that the mirror's surface is at 90 degrees to the paper.
2. Draw a straight line along the surface of the mirror, leaving it in place.
3. Direct a narrow beam of light towards the surface of the mirror, such that it can be seen travelling on the surface of the paper.
4. Mark two crosses on the 'incident' (incoming) beam of light and two crosses on the 'reflected' beam of light.
5. Remove the mirror and connect the crosses, forming a complete picture of the path of the light (see image below).

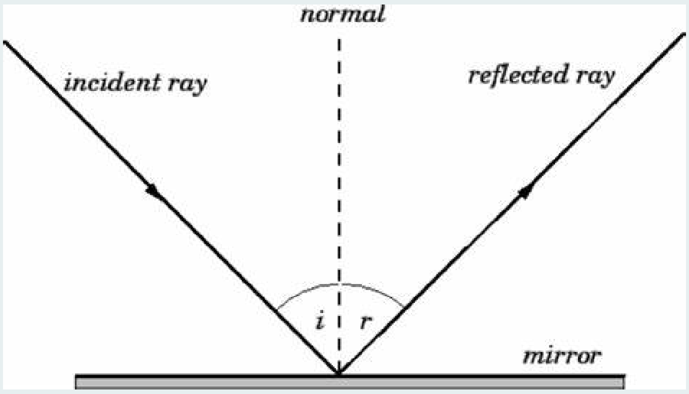


Fig. 4.1: Reflection of light on a plane mirror

6. Using a protractor, measure and record the angle of incidence (the angle between the incident ray and the normal, a line perpendicular to the mirror's surface at the point where the light meets it) and the angle of reflection (the angle between the reflected ray and the normal).
7. Repeat steps 3-5 with the beam of light directed towards the mirror at a range of angles.
8. Analyse your data and look for patterns in the relationship between the angle of incidence and the angle of reflection.

Note: In the absence of practical equipment, the PHeT simulation could be used; follow QR code below.

Activity 4.2 Calculating angles of incidence, reflection, and deviation using the laws of reflection.

Solve the questions below

1. Find the angle of reflection, r, when a light ray incident at a glancing angle ,30°
2. *What is the angle of deviation when angle of incidence of light is 30°?*

3. A light ray strikes a plane mirror making an angle of 25° with the mirror. Calculate the angle between the incident and reflected ray.

Formation of image in a plane mirror

An image is formed when two or more rays meet or appear to meet at a point. A ray diagram can be constructed by taking a beam of light from the image and reflecting it into the top of the eye, then by taking another beam and reflecting it into the bottom of the eye (being careful to obey the laws of reflection). The rays of light can then be extrapolated back to where they 'appear' to originate. See images below.

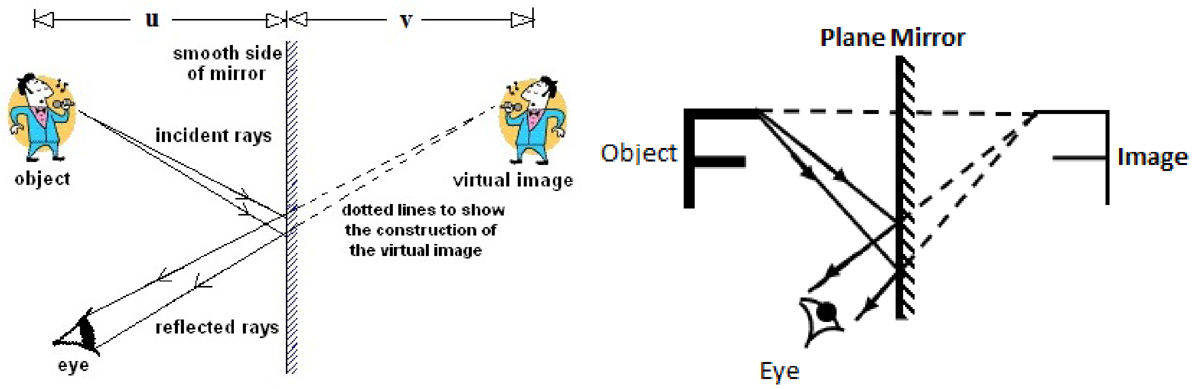


Fig. 4.2: Ray diagram for the formation of a mirror image

Activity 4.3 Identifying characteristics of images formed by a plane mirror

Select the correct description of an image formed in a plane mirror, using the images above for guidance.

- Laterally inverted (left becomes right and vice versa **or** not inverted.
- Inverted (upside down) **or** erect (upright)
- Real (actual light rays meet) **or** virtual (light rays appear to meet)
- The same size as the object **or** smaller than the object.
- Object-mirror distance is equal to image-mirror distance **or** image is further from mirror.

Note: see **Annex 4.2** for definitions of some of the above terms.

Activity 4.4 Images formed when two mirrors are inclined at 90^0

Materials needed:

- 2 plane mirrors
- Protractor
- Paper and pencil

Procedure:

1. Join a mixed-ability group of 3-4 learners.
2. Set the two mirrors at an initial angle of 30 degrees to one another, as measured using the protractor.
3. Observe the number of images you see in the mirrors and record your observations.
4. Repeat steps 3-4, adjusting the angle between the mirrors to 45 degrees and then 60 degrees.
5. Once the observations are complete, discuss the following questions within your groups:

a. How does the number of images change as the angle between the mirrors is increased?

b. Can you identify any patterns or relationships between the angle of inclination and the number of images?

c. Can you explain why the number of images changes as the angle is adjusted?

When two mirrors are placed at an angle (θ) with respect to each other, multiple images can be formed due to the repeated reflection of light between the mirrors. The number of images (N) formed is inversely proportional to the angle of inclination and can be calculated using the formula:

$$N = \left(\frac{360}{\theta}\right) - 1.$$

As the angle of inclination (θ) decreases, the number of images increases. This is because the light undergoes more reflections between the two mirrors, creating a larger number of virtual images. The principles governing the formation of images in inclined mirrors build upon the fundamental laws of reflection.

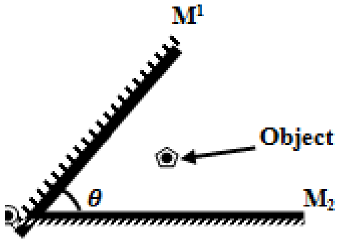


Fig. 4.3: Reflection of light between two mirrors at an angle θ

Activity 4.5 Calculating the number of images and angle of inclination between two mirrors

1. Find the number of images formed in two plane mirrors inclined at
   a. 60^o
   b. 30^o
   c. 90^o
2. Find the angle of inclination of the mirrors in the case that there are this many images:
   a. 5
   b. 11
   c. 23
3. A light ray strikes a vertical mirror at incident angle of 30^o which is inclined at 90^o with another horizontal mirror. Sketch this arrangement, and find
   a. the angle of reflection in the second mirror and
   b. the glancing angle in the second mirror.

TERMINOLOGIES ASSOCIATED WITH SPHERICAL MIRRORS

Concave mirror: It is an optical mirror, which is part of a sphere with reflecting inner surface.

Convex mirror: It is an optical mirror, which is part of a sphere with reflecting outer surface.

Activity 4.6 Labelling the key features of spherical mirrors.

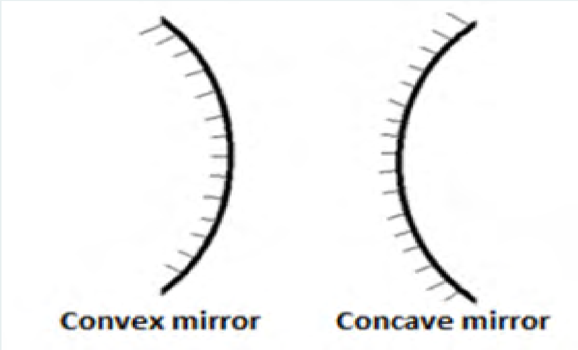


Fig 4.4: Diagram of convex mirror and concave mirror

The figure above shows the two types of spherical mirror. Note that the dashed lines indicate the non-reflective side. Re-draw these diagrams, labelling on and defining the following features (you should use the internet or other research resources to help you):

1. **Pole P**:
2. **Principal axis**
3. **Centre of Curvature C**.
4. **Radius of curvature**
5. **Principal focus F**
6. **Focal length of a mirror f**

(a) Concave mirror

(b) Convex mirror

Fig. 4.5: Images of concave and convex mirror

Watch the video linked here: https://youtu.be/oDNqfxRYQY0. In the case that you do not have access to the video, find details on its message in **Annex 4.4**

Concave mirror - From the video, it can be concluded that concave mirrors give both inverted and erect images, but the erect image is bigger than the size of the object.

Convex mirror - Also, in the case of the convex mirror, the image is always diminished and upright.

In mirrors, images that are inverted are called real images. These are images formed as a result of the actual intersection of rays. They can be formed on a screen. Images that are erect or upright are formed as a result of the apparent intersection of rays. That means the image can be formed inside the mirror and cannot be formed on a screen.

Activity 4.7 Exploring convex and concave mirrors with flexible reflective material

Materials needed:

- A piece of flexible reflective material (e.g., a shiny, bendable plastic or foil)
- A light source that emits narrow beams (e.g., a laser pointer or a flashlight with a narrow beam attachment)
- A ruler or measuring tape
- A flat surface to work on
- A stand or something to hold the reflective material in place

Note: in the absence of practical equipment the interactive PhET simulation could be used; follow QR code below.

Procedure:

1. Forming the mirrors:
    a. **Convex Mirror:** Hold the reflective material so that it bulges outward, like the back of a spoon.

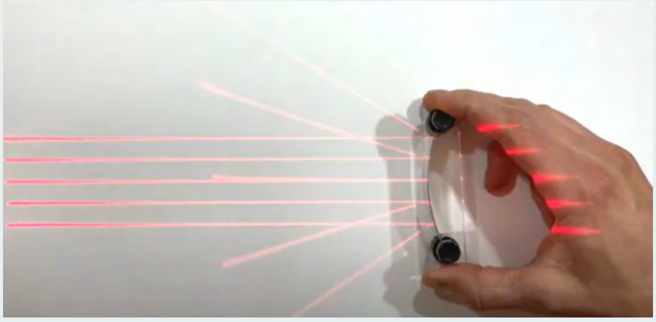


Fig. 4.6: Parallel rays of light reflected by convex mirror

b. **Concave Mirror:** Hold the reflective material so that it curves inward, like the inside of a bowl.

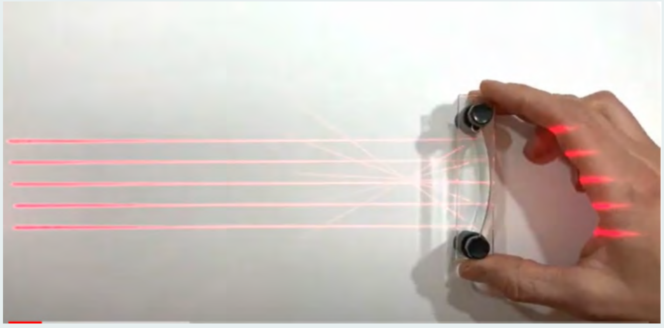


Fig. 4.7: Parallel rays of light reflected by concave mirror

2. Shining Light and Measuring Focal Length:

   a. When the 'mirror' is in the convex position, shine the narrow beam of light parallel to the principal axis of the mirror. Trace the path of the light on to the paper.
   b. Repeat for a range of distances between the light ray and the principal axis.
   c. Observe where the light rays appear to diverge from behind the mirror. Trace these rays backward to find the virtual focus point. Measure the distance from the mirror's surface to this virtual focus point to find the focal length.
   d. Repeat the procedure with the mirror in the concave position, but with an Equal radius of curvature to before (you can confirm this by ensuring that the ends of the mirror are the same direct distance apart). Observe where the light rays converge in front of the mirror. This point is the real focus. Measure the distance from the mirror's surface to this real focus point to find the focal length.

3. Comparing Focal Lengths:

a. Discuss and compare the focal lengths for both the convex and concave mirrors.

Relationship between Focal Length and Radius of Curvature:

a. The focal length (f) of a spherical mirror is related to the radius of curvature (R) by the equation

$$f = \frac{R}{2}$$

b. This means that the magnitude of the focal length is half the radius of curvature for both types of mirrors.

Comparison of Convex and Concave Mirrors:

a. Although the magnitude of the focal length is the same, the type of focal point differs. In a concave mirror, the focus is real and located in front of the mirror. In a convex mirror, the focus is virtual and appears behind the mirror.

b. Example:

i. If the radius of curvature (R) is 10 cm, then the focal length (f) for both mirrors will be 5 cm.

ii. For the concave mirror, $f = +5$ cm (real focus).

iii. For the convex mirror, $f = -5$ cm (virtual focus).

Activity 4.8 Quiz Game: Spherical mirrors terminologies

Game Setup:

1. **Participants:** Divide yourselves into teams of at most four or compete individually.

2. **Materials needed:**

- Quiz question cards (or a digital quiz platform)
- A scoreboard
- Buzzers or any system to determine who answers first (optional)

3. **Rules:**
    - Assign one person to be quiz master or take a turn each. Alternatively, your teacher may run this quiz.
    - Each correct answer earns a point.
    - The team or individual with the most points at the end wins.

Quiz Questions

1. What is the point on the surface of the mirror that lies on the principal axis?
2. What is the name of the imaginary line that passes through the pole and the centre of curvature of the mirror?
3. What is the point called where parallel rays of light either converge (for concave mirrors) or appear to diverge (for convex mirrors) after reflecting from the mirror?
4. What term describes the distance between the pole and the focus of a spherical mirror?
5. What is the term for the centre of the sphere from which a spherical mirror segment is taken?
6. What is the distance from the pole to the centre of curvature called?
7. True or False: For a concave mirror, the focal length is positive.
8. True or False: The focal length of a convex mirror is negative.
9. In which type of mirror does the image always appear virtual, smaller, and upright?
10. In which type of mirror can the image be real or virtual, magnified or reduced, and upright or inverted?
11. What is the term for the imaginary plane that is perpendicular to the principal axis and passes through the focal point?
12. Which mirror is used to converge light rays to a focal point?
13. Which mirror is used in vehicles to provide a wider field of view for the driver?
14. True or False: The image formed by a concave mirror can be projected onto a screen.
15. What happens to light rays that are parallel to the principal axis when they reflect off a convex mirror?

16. In a concave mirror, what is the nature of the image when the object is placed between the focal point and the mirror?
17. What kind of mirror is used in solar cookers to focus sunlight to a single point?
18. What is the term for the type of image that cannot be projected onto a screen and appears to be located inside the mirror?
19. Which mirror would you use to get a diminished image of a large area, like in a store or an intersection?
20. In what type of mirror does the reflected image appear to be the same size as the object and upright when the object is placed at the centre of curvature?

Characteristics of image formation in spherical mirrors using ray diagram

The position, nature, and size of the image formed depend on the object's location relative to the mirror. Concave mirrors can form real or virtual images depending on the object's position. Convex mirrors always produce virtual images that are upright, diminished and located behind the mirror.

In locating the image formed by a spherical mirror, three specific rays are commonly used. They help in understanding whether the image is real or virtual, upright or inverted, and magnified or diminished, depending on the mirror's type and object position relative to it:

1. **Paraxial Ray (Parallel Ray)**
2. **Principal Ray (Focal Ray)**
3. **Centre Ray (Through the Centre of Curvature)**

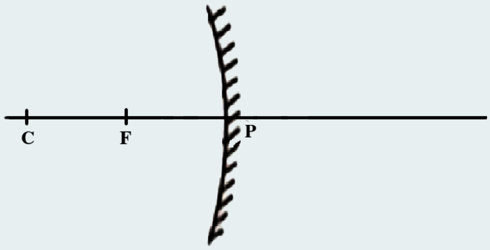
Activity 4.9 Drawing a ray diagram for a concave mirror

Scenario:

You have a concave mirror with a radius of curvature R=20 cm. An object is placed 15 cm away from the mirror along the principal axis.

Materials needed:

- Blank diagram with the principal axis, centre of curvature (C), focal point (F), pole (P), mirror, and object position marked.



Procedure:

1. **Identify Key Points on the Diagram:**
   a. **Principal Axis:** The horizontal line on which all key points are located.
   b. **Center of Curvature (C):** Marked at 20 cm from the pole (P).
   c. **Focal Point (F):** Located at R/2=10 cm from the pole (P).
   d. **Pole (P):** The point on the mirror's surface.

2. **Draw the Object:**
   a. Draw the object as a vertical arrow (O) at the given distance (15 cm) from the pole (P).

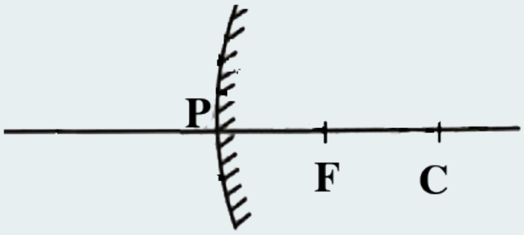
3. **Draw the Rays:**
   a. **Paraxial Ray (Parallel Ray):**
      i. Draw a ray parallel to the principal axis from the top of the object (O) towards the mirror.
      ii. After hitting the mirror, draw the reflected ray passing through the focal point (F).
   b. **Principal Ray (Focal Ray):**
      i. Draw a ray from the top of the object (O) through the focal point (F).
      ii. After hitting the mirror, draw the reflected ray parallel to the principal axis.

4. Using the diagram, describe the characteristics of the image formed. Choose the correct terms to describe the image:
   a. **Magnified** or **Diminished:** Is the image larger or smaller than the object?
   b. **Inverted** or **Upright:** Is the image upside down or right side up compared to the object?

   c. **Real** or **Virtual:** Can the image be projected onto a screen (real) or does it appear to be inside the mirror (virtual)?

5. Repeat the procedure and describe the image with object placed
   a. 5 cm and
   b. 25 cm from the concave mirror

6. Repeat the procedure using convex mirror with the same radius of curvature.



Deduce whether the position of an object in relation to a curved mirror affects the nature of the image produced, alongside instructions for how to draw the three rays. Construct the entire diagram, including drawing a mirror and a principal axis etc.

Activity 4.10 Virtual lab simulations for spherical Mirrors

Objective: To understand the principles of image formation by concave and convex mirrors using virtual lab simulations.

Materials needed:

- Computer or tablet with internet access
- Access to a virtual lab simulation tool (e.g., PhET Interactive Simulations, available at PhET or Sunflower)

Procedure:

1. **Setup:**
   a. Go to the PhET Interactive Simulations website.

b. Search for the "Geometric Optics" simulation or a similar tool that allows manipulation of mirrors and lenses.

2. Exploring Concave Mirrors:

a. Launch the simulation and select a concave mirror.

b. Place an object (such as an arrow) in front of the concave mirror.

c. Adjust the position of the object to various distances (e.g. beyond the centre of curvature (C), at C, between C and F, and between F and the mirror).

d. Observe the changes in the image formed: note the position, size, orientation (upright or inverted), and type (real or virtual) of the image.

e. Record the observations for each position of the object in a table as in the table below:

3. Exploring Convex Mirrors:

a. Select a convex mirror in the simulation.

b. Place an object in front of the convex mirror.

c. Move the object to different positions and observe how the image characteristics change.

d. Note the position, size, orientation, and type of image formed for each object position.

e. Record the observations in a table.

Table 4.1: Table to record observations made throughout Activity 4.10

Mirror Type	Object Position	Image Position	Image Size	Image Orientation	Image Type
Concave	Beyond C	Between F and C	Diminished	Inverted	Real
Concave	At C				
Concave	Between C and F				
Concave	Between F and Mirror				

CHARACTERISTICS OF IMAGE FORMATION IN SPHERICAL MIRRORS USING MIRROR FORMULA AND MAGNIFICATION FORMULA

Mirrors are fundamental optical devices used to reflect light and form images. In this lesson, you will explore how to determine the characteristics of images formed by concave and convex mirrors using the mirror formula and magnification formula. By conducting hands-on experiments and engaging in critical thinking, you will develop a deeper understanding of optical principles.

The mirror formula relates to the object distance (u), the image distance (v) and the focal length (f) of a mirror. It is expressed as,

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

The magnification formula relates the height of the image ($h\ i$) to the height of the object ($h\ o$). It is given by,

$$m = \frac{h_i}{h_o} = \frac{v}{u}$$

Sign convention for spherical mirrors

Understanding and correctly applying the sign convention in spherical mirrors is essential for accurate and consistent results in optical calculations and for understanding the nature and characteristics of images formed by these mirrors. It avoids confusion and errors, ensuring clarity and precision in both academic and practical applications. The information below shows the signs of the various quantities in the spherical mirrors.

a. For object distance (**u**) and image distance (**v**):

i. Distances measured from the same side of the mirror as the reflective surface are negative.

ii. Distances measured from the opposite side of the mirror are positive.

b. For focal length (f):

i. For a concave mirror, f is negative.

ii. For a convex mirror, f is positive.

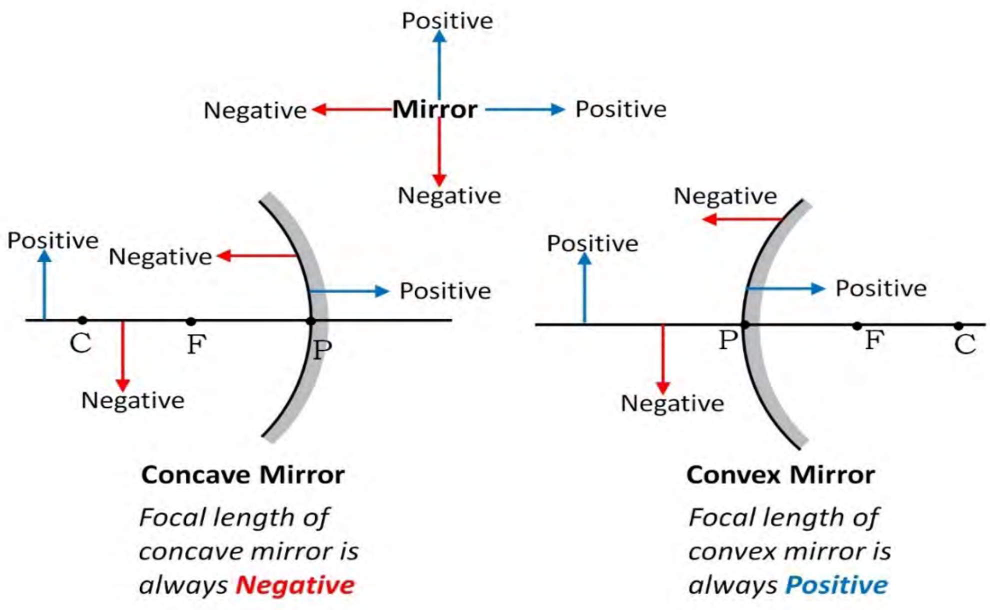


Fig 4.8: Sign convention for spherical mirror

[Sign convention for Spherical Mirrors - Class 10 - Teachoo]

Activity 4.11 Investigating magnification

Objective: Explore how the height of the image relates to the height of the object using the magnification formula.

Materials needed:

- Concave mirror
- Convex mirror
- Small object with a known height (e.g., an optical pin, a ruler or a printed scale)
- Paper and pen

Procedure:

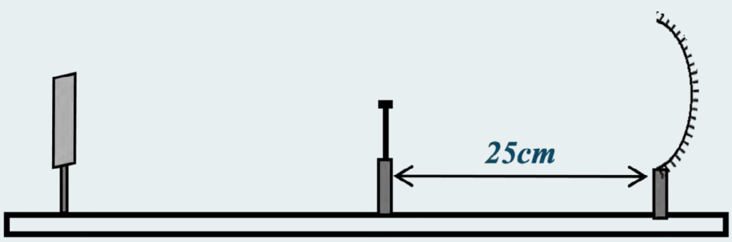


Fig 4.9: schematic of the experimental setup

1. Place the concave mirror on a flat surface.
2. Position the object at a known distance (u) from the mirror.
3. Measure and record the height of the object (ho).
4. Observe and measure the height of the image (hi) formed by the mirror.
5. Use the magnification formula $m = \frac{h_i}{h_o} = \frac{-v}{u}$ to calculate the magnification of the image.
6. Repeat the process with the convex mirror.
7. Compare the calculated magnification values with your observations.
8. Discuss how the magnification changes with different object distances (u).

Questions (see Annex 4.5 for solutions):

- How does the magnification (M) of the image change as the object distance (u) changes for concave and convex mirrors?
- What do your results tell you about the size and orientation of images formed by concave versus convex mirrors?

Activity 4.12 Exploring the Mirror Formula

Objective: Determine the characteristics of images formed by concave and convex mirrors using the mirror formula.

Materials needed:

- Concave mirror
- Convex mirror
- Meter ruler
- Small object (e.g., a toy or a candle)
- Paper and pen

Procedure:

1. Place the concave mirror on a flat surface.
2. Position the small object at various distances (u) from the mirror.
3. Measure and record the object distance (u) and the corresponding image distance (v) for each position.

4. Use the meter ruler to ensure accurate measurements.
5. Use the mirror formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ to calculate the focal length (f) of the concave mirror.
6. Repeat the process with the convex mirror.
7. Compare the calculated focal lengths with the known focal lengths (if provided).
8. Reflect on any discrepancies and consider possible sources of error.

Questions (see Annex 4.5 for solutions):

- How does the image distance (v) change as the object distance (u) changes for concave and convex mirrors?
- What do your results tell you about the nature of images formed by concave versus convex mirrors?

Activity 4.13 Calculating image properties using mirror and magnification Formulas

A concave mirror with an object beyond centre of curvature

1. An object is placed 30 cm in front of a concave mirror with a focal length of 10 cm. Determine the position and nature of the image formed.

The object between focal Point and concave mirror

2. An object is placed 15 cm in front of a concave mirror with a focal length of 10 cm. Determine the position and nature of the image formed.

Object at the focal point of a concave mirror

3. An object is placed at the focal point of a concave mirror with a focal length of 10 cm. Determine the position and characteristics of the image formed.

Object in front of a convex mirror

4. An object is placed 20 cm in front of a convex mirror with a focal length of -10 cm. Determine the position and characteristics of the image formed. Sketch the ray diagram for this scenario, showing the position and nature of the image formed by the convex mirror.

Activity 4.14 Critical thinking and real-world applications

Objective: Develop a deeper understanding of optical principles by applying them to real-world scenarios.

Materials needed:

- Internet access for research (optional)
- Paper and pen

Procedure:

1. Research real-world applications of concave and convex mirrors (e.g., telescopes, car rearview mirrors, make-up mirrors).
2. Write a summary of one application, explaining how the mirror formula and magnification formula are used.
3. Design a simple optical device using concave and/or convex mirrors (e.g., a basic periscope or a magnifying mirror).
4. Draw a diagram of your device, labelling the important parts and explaining how it works using the mirror formula and magnification formula.
5. Create a presentation or a report summarizing your research and your designed optical device.
6. Include explanations of how the mirror formula and magnification formula apply to your examples.

Questions:

i. How are concave and convex mirrors used in everyday life?

ii. How does understanding the mirror formula and magnification formula help in designing optical devices?

Activity 4.15 Verifying the mirror formula experimentally

Experimental exploration – if equipment is available (otherwise, you can replicate this using the PhET simulation linked previously)

Materials needed:

- Concave and convex mirror
- Optical bench
- Mounted object (e.g., a pin or small object)
- Screen
- Metre ruler or measuring tape

Procedure:

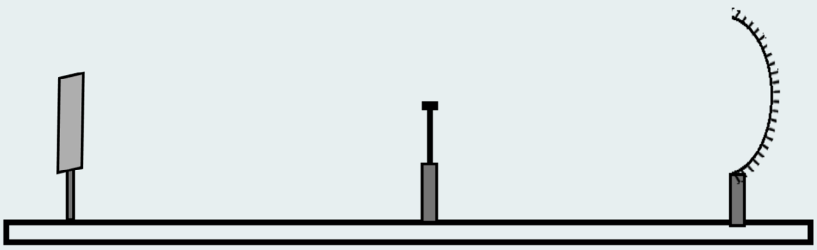


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Fig 4.10: schematic of the experimental setup

1. Mount the concave mirror on the optical bench.
2. Place the object at a fixed distance (e.g., 30 cm) from the mirror
3. Move the screen along the optical bench to find the position where a sharp image is formed.
4. Measure and record the distance between the mirror and the screen (v).
5. Measure and record the distance between the object and the mirror (u).
6. Repeat steps 2 and 3 for different object distances (e.g., 25 cm, 20 cm, 15 cm).
7. Use the recorded values of **u** and **v** to calculate $\frac{1}{u}$, $\frac{1}{v}$ and $\frac{1}{f}$ (using the mirror formula)
8. Compare the calculated focal length with the known focal length of the mirror to confirm the validity of the equation.
9. Plot a graph of $\frac{1}{v}$ (***x axis***) against $\frac{1}{u}$ (***y axis***)**.** Add a line of best fit. Both the x and y intercepts of the graph should give the value of $\frac{1}{f}$**.**

10. Repeat the experiment using a convex mirror.

Data Table:

Table 4.2: Table to record observations made throughout Activity 4.15

Object distance(u)	Image distance (v)	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$
30				
25				
20				
15				

Analysis:

- Why is it important to ensure the object and screen are precisely aligned on the optical bench?
- What is the significance of the negative focal length for convex mirrors in the mirror formula?

Activity 4.16 Verifying the magnification formula experimentally

Using the same experimental set up as in **Activity 4.14**, follow this alternative procedure to verify the magnification formula:

Procedure:

1. Mount the concave mirror on the optical bench.
2. Place the object at a fixed distance (e.g., 20 cm) from the mirror.
3. Move the screen along the optical bench to find the position where a sharp image is formed.
4. Measure and record the distance between the mirror and the screen (v).
5. Measure the height of the object (ho).
6. Measure the height of the image (hi) formed on the screen.
7. Repeat steps 2 and 3 for different object distances (e.g., 25 cm, 15 cm).

Data Table:

Table 4.3: Table to record observations made throughout Activity 4.16

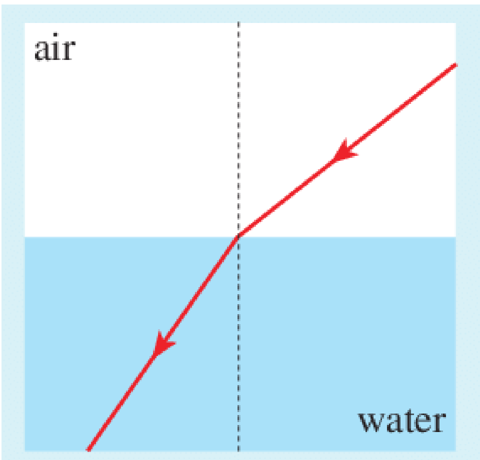
Object Distance (u)	Image Distance (v)	Object Height (h_o)	Image Height (h_i)	Magnification $m = \frac{h_i}{h_o}$	Magnification $m = -\frac{v}{u}$
-20 cm					
-25 cm					
-15 cm					

Analysis:

- Compare the calculated magnification values from $m = \frac{h_i}{h_o}$ and $m = -\frac{v}{u}$ to check for consistency.
- Why does the image height vary when you change the object distance?

LAWS OF REFRACTION

Refraction is a phenomenon where there is a change in the direction and velocity of light when the light travelling in a transparent medium enters another transparent medium of different optical densities.



Light Bending as it passes from Air to Water

Fig 4.11: Refraction of light at the air-water interface

The laws governing the phenomenon of refraction are:

1. The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane.

2. Snell's law: The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for a given pair of media.

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

$$n_1 \sin i = n_2 \sin r$$

Activity 4.17 Investigate refraction at home or in the lab

Materials needed:

- A transparent glass or cup
- Water
- A pencil or straw

Procedure:

1. Fill the glass with water.
2. Place the pencil or straw in the glass.
3. Look at the pencil or straw from the side of the glass.

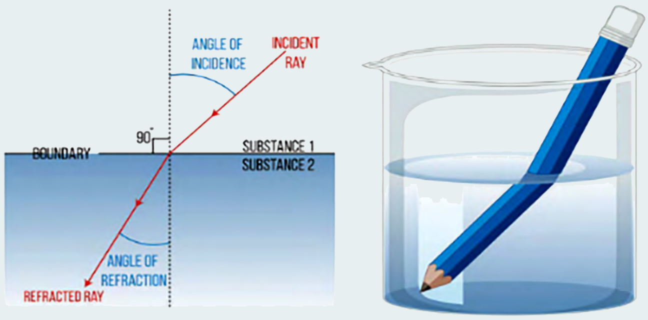


Fig 4.12: Apparent bending of a pencil due to refraction in water

Observation:

Why did the pencil or straw appear bent? Relate your observation to the concepts and laws of refraction you have learned and share with a friend.

Activity 4.18 Research and answer the questions below about refraction in everyday life.

1. What happens to the appearance of a pencil when it is placed in a glass of water?
2. Why does this happen?
3. How do lenses in glasses and cameras help correct vision and capture clear images?
4. How is a rainbow formed in the sky?
5. Why do objects underwater appear closer to the surface than they are?
6. What causes the appearance of a mirage in deserts or on hot roads?

Activity 4.19 - Investigating refraction using water and oil Interface

Objective: understand how waves refract when travelling between two different mediums other than air, specifically water and oil.

Materials needed:

- A clear rectangular container
- Water
- Vegetable oil
- Laser pointer
- Protractor
- Ruler
- Graph paper
- Safety goggles

Procedure:

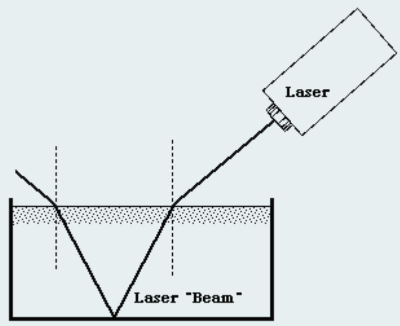


Fig 4.13: Laser beam refraction

1. Join a group of 2-4 people.
2. Fill the clear container halfway with water.
3. Carefully add a layer of vegetable oil on top of the water. The oil will float on the water, creating a clear interface between the two mediums.
4. Shine the laser pointer at an angle through the oil-water interface. Observe the path of the laser beam as it travels from the oil into the water.
5. Using the protractor, measure the angle of incidence (the angle at which the laser beam enters the oil-water interface).
6. Measure the angle of refraction (the angle at which the laser beam bends as it enters the water).
7. Record your measurements of the angle of incidence and the angle of refraction in a table. Repeat the experiment for different angles of incidence.

Analysis:

Using Snell's Law, calculate the ratio of the refractive indices of the oil and water.

Discussion:

Compare your experimental results with the theoretical values of refractive indices for water and oil.

Activity 4.20 Investigating Snell's law

Objective: to measure the incident and refracted angles of light as it passes through a glass block and to observe how these angles change with varying incident angles.

Materials needed:

- Laser pointer
- Glass block
- Protractor
- Ruler
- Sheet of paper
- Pencil

Procedure:

1. Place a piece of paper on a table.
2. Position the glass block in the centre of the paper.
3. Draw a straight line along one edge of the glass block to mark its position. Label this line as the boundary between air and glass.
4. Using the protractor, draw a line perpendicular (90 degrees) to the boundary line at the point where the laser light will enter the glass block. This line is called the normal line.
5. Secure the laser pointer in place so it shines a beam of light at the boundary line. Ensure the laser pointer is stable and will not move during the experiment.
6. Trace the path of the light onto the paper.
7. Mark the point where the light exits the glass block on the paper.
8. Draw a line connecting the point where the light enters the glass block to the point where it exits. This is the refracted ray.
9. Use the protractor to measure the angle between the laser beam (incident ray) and the normal line. Record this angle as the incident angle (i).
10. Use the protractor to measure the angle between the refracted ray and the normal line on the exit side of the glass block. Record this angle as the refracted angle (r).
11. Change the angle at which the laser beam hits the glass block by rotating the laser pointer.
12. Repeat steps 1 to 3 for different incident angles (e.g., 10 degrees, 20 degrees, 30 degrees, etc.).
13. Record the incident and refracted angles for each trial.

Data Collection:

Table 4.4: Table to record observations made throughout Activity 4.20

Trial	Incident Angle (i)	Refracted Angle (r)	sin (i)	sin (r)
1				
2				
3				
4				
5				

Analysis:

- Create a graph with sin(i) on the y-axis and sin(r) on the x-axis.
- Find the slope of the graph to give a value for $\frac{n_2}{n_1}$.
- $n_1 = 1$ for air, therefore, find n_2 (the refractive index of the glass).

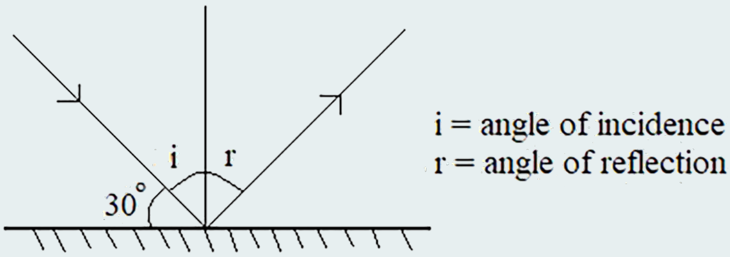
Conclusion:

- Summarise your findings on how the incident angle affects the refracted angle.
- Discuss any patterns observed in your data.

Annex 4.1 – Solutions to some activities

Activity 4.2

1.



$[glancing\ angle] + [angle\ of\ incidence] = 90^o$

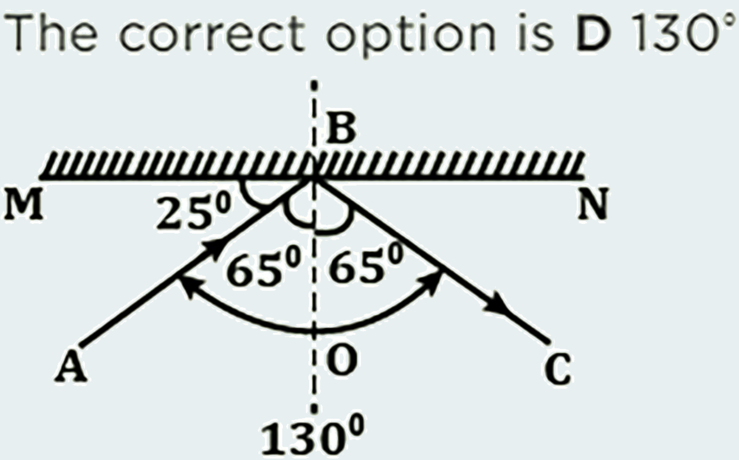
$30^o + i = 90^o$

$i = 90^o - 30^o = 60^o$

$r = i, r = 60^o$

2. *The angle of deviation is 180° - 60° = 120°*

3.



Ans; 130°

Activity 4.3

Laterally inverted (left becomes right and right becomes left) and vice versa.

Erect

Virtual (cannot be formed on the screen)

Image is of the same size as object, $h_1 = h_o$

Image distance is equal to object distance, v= u

Activity 4.5

1.

a) $n = \left(\frac{360}{\theta}\right) - 1 \rightarrow n = \left(\frac{360}{60}\right) - 1 \rightarrow n = 6 - 1 = 5$ images

b) $n = \left(\frac{360}{\theta}\right) - 1 \rightarrow n = \left(\frac{360}{30}\right) - 1 \rightarrow n = 12 - 1 = 11$ images

c) $n = \left(\frac{360}{\theta}\right) - 1 \rightarrow n = \left(\frac{360}{90}\right) - 1 \rightarrow n = 4 - 1 = 3$ images

2.

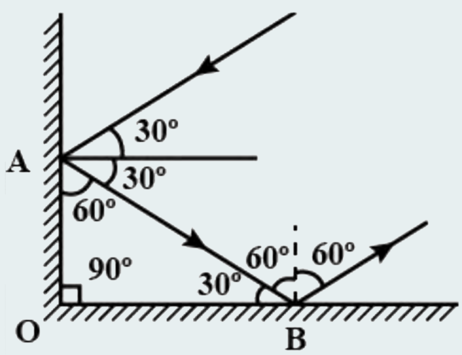
a) $\theta = \left(\frac{360}{n+1}\right), \theta = \left(\frac{360}{5+1}\right) = \left(\frac{360}{6}\right) = 60^o$

b) $\theta = \left(\frac{360}{n+1}\right) = \theta = \left(\frac{360}{11+1}\right) = \left(\frac{360}{12}\right) = 30^o$

c) $\theta = \left(\frac{360}{n+1}\right) = \theta = \left(\frac{360}{23+1}\right) = \left(\frac{360}{24}\right) = 15^o$

3.

Illustration



From the diagram above

a. 60^o

b. 30^o

Annex 4.2 – Further Information on Reflection in a Plane Mirror

Laws of reflection

Relationship between the angle of incidence, reflection and glancing angle:

Consider the diagram below

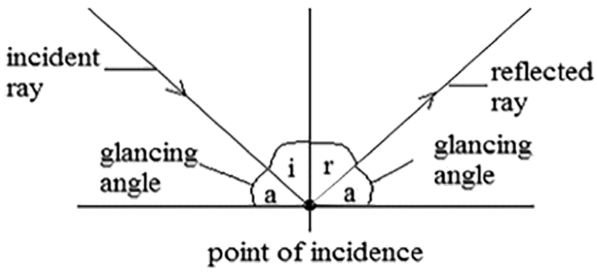


Fig 4.14: Reflection showing angle of incidence and glancing angle
glancing angle + angle of incidence = 90 °

Lateral inversion is a phenomenon where a lateral side or part of a body or an object becomes the opposite side.

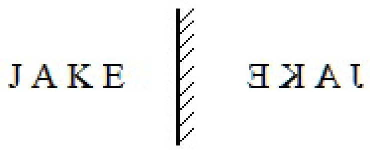


Fig. 4.15: Image showing lateral inversion

Real and virtual images

Images are formed either at the point where rays of light meet intersect or at the point where they appear to originate. An image formed can be two kinds. These are **real image and virtual image.**

A real image is formed by the *actual* intersection of two or more rays from an object (real light rays). Real images are formed on a screen. e.g. the image in a pinhole camera.

A virtual image is formed by the *apparent* intersection of two or more rays from an object. A virtual image is formed from two divergent rays of light that never meet but are 'tracked back' to the point that they appear to have originated from. In simple terms, a plane mirror creates an image of an object you cannot touch. All mirrors create virtual images in this manner, but plane mirrors reflect light differently than concave or convex mirrors do.

Virtual images are not formed on a screen such as image formed on a plane mirror. Virtual images or rays are represented by dotted lines or rays.

Images formed when two mirrors are inclined at 90^0

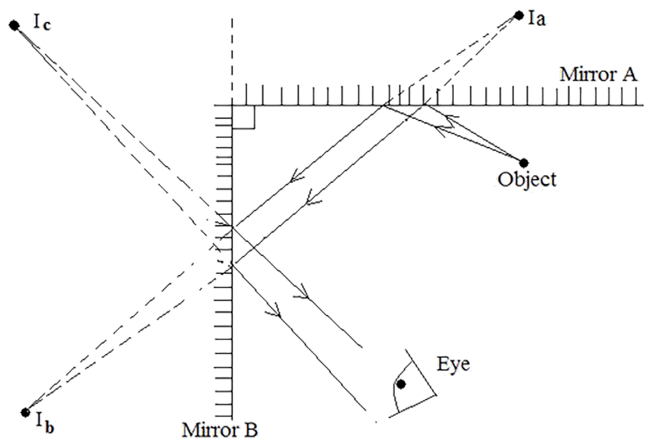


Fig 4.16: Ray diagram of images formed when two mirrors are inclined at 90^0

Whenever two mirrors are inclined at an angle 90^o to each other and an object is placed in front of them, it revealed by observation that three images are formed on the mirrors by multiple reflection the images I_a and I_b are formed by simple reflection. The additional image I_c is produced as a result of reflection of two main images that is reflection of image 'I_a' in mirror ('I_b') and reflection image (I_b) in mirror (A) it is the super imposition of two images.

The relationship between the angle of inclination and the number of images is:

$$n = \left(\frac{360}{\theta}\right) - 1, \rightarrow \theta = \left(\frac{360}{n + 1}\right)$$

NOTE 1

Consider two mirrors inclined at an angle of 180º.

M1 M2

The number of images formed is given as:

$N = \frac{360}{180} - 1 = 1$ image

It takes a single mirror to form one image of an object. This means that, this arrangement of the two mirrors, inclined 180º acts as a single mirror

NOTE 2

Consider the mirrors inclined at an angle 0º in which case the two mirrors are parallel to each other.

The number of images formed is given as

$N = \left(\frac{360}{0}\right) - 1 = \infty$ images

(this means multiple or uncountable images)

Annex 4.3 – Solutions to some activities

Activity 4.6

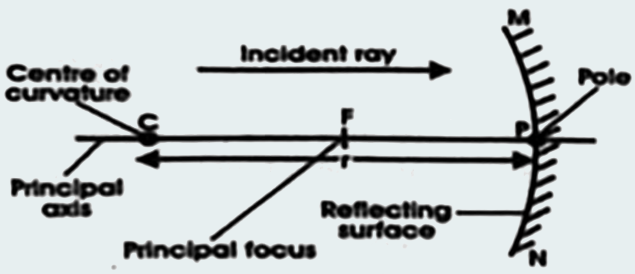


Fig. 4.17: Diagram illustrating a concave mirror with accompanying terminologies

1. **Pole P**: It is the central point of a concave or convex mirror through which the principal axis passes.
2. **Principal axis** is an imaginary line joining the centre of curvature through the principal focus to the pole.

3. **Centre of Curvature C** is the centre of a sphere of which the mirror is part.
4. **Radius of curvature** is the distance from this centre of curvature to the pole of the mirror.
5. **Principal focus F** is a point on the principal axis, where all rays parallel and close to the principal axis either converge or appear to diverge after reflection from the curved mirror.
6. **Focal length of a mirror f** is the distance between the pole of the mirror and the principal focus.

Activity 4.7

Conclusion: For mirrors with the same radius of curvature (R), the magnitude of the focal length (f) should be the same, but the nature of the focal point is different:

- For a concave mirror, the focal length is positive (real focus).
- For a convex mirror, the focal length is negative (virtual focus).

Activity 4.8

Quiz Answers:

1. Pole (P)
2. Principal Axis
3. Focus (F)
4. Focal Length (f)
5. Center of Curvature (C)
6. Radius of Curvature (R)
7. True
8. True
9. Convex Mirror
10. Concave Mirror
11. Focal Plane
12. Concave Mirror

13. Convex Mirror

14. True (when the image is real)

15. They diverge as if they are coming from the virtual focus behind the mirror.

16. The image is virtual, magnified, and upright.

17. Concave Mirror

18. Virtual Image

19. Convex Mirror

20. Concave Mirror

Activity 4.9

5 a.

- **Magnified:** The image appears larger than the object.
- **Upright:** The image is right side up compared to the object.
- **Virtual:** The image appears to be inside the mirror and cannot be projected onto a screen.

5b

- **Diminished:** The image appears smaller than the object.
- **Inverted:** The image is upside down compared to the object.
- **Real:** The image can be projected onto a screen.

Annex 4.4 – Further Information on Spherical Mirrors

Welcome to this section. In the case where the video mentioned previously cannot be watched at the place where you are currently, join the dialogue below. I would like you to follow the picture of a man watching himself in a spherical mirror and read the conversation between Laila, Kotey and their teacher to understand what is going on.

Scenario 1 – Concave (stood far away)

Scenario 2- Concave mirror (stood closer)

Fig. 4.12: Image of a man watching himself in a spherical mirror (Courtesy of Manocha Academy)

Teacher: Today, we are going to watch a man standing at a distance in front of a spherical mirror. What do you see and what can you say about his image?

Laila: He is turned upside down.

Teacher: Good, we say his image is inverted. Can you say anything about him again?

Kotey: Yes, his image size is smaller than himself.

Teacher: Fantastic. You are right. We say his image is diminished. Now, watch the second scenario as he moves closer to the mirror. What do you now observe?

Kotey: Well, I think his image size now looks bigger than himself.

Teacher: Good! We say his image is magnified or enlarged. Is that all?

Laila: No Sir. His image this time is not inverted. He is standing straight.

Teacher: Awesome! We say his image is upright or erect.

Scenario 3- Convex mirror

Fig. 4.13: Image of a man watching himself in a convex mirror

Now let us consider scenario 3 as he moves to stand in front of the next spherical mirror B.

Teacher: What do you observe?

Kotey: The man is standing upright

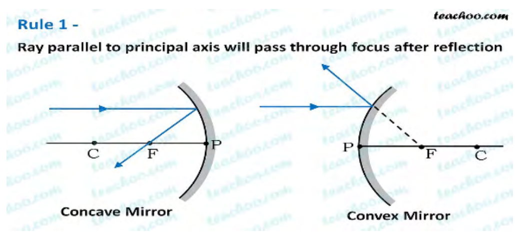
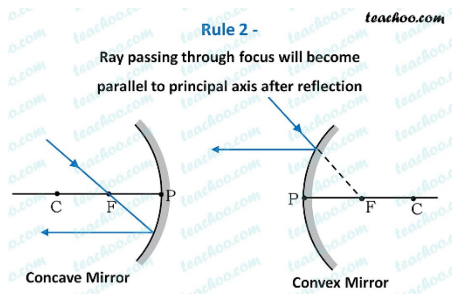
Teacher: Precisely.

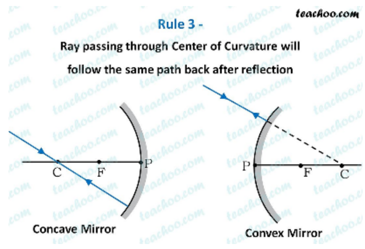
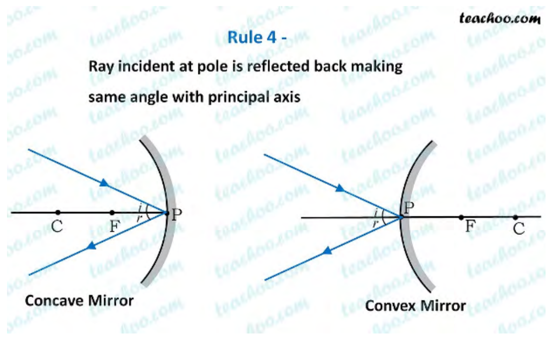
Laila: Yes! He is also diminished in size.

Teacher: Good! Your observations are right.

Rules in drawing Ray diagrams

Table 4.5: rules in drawing ray diagrams

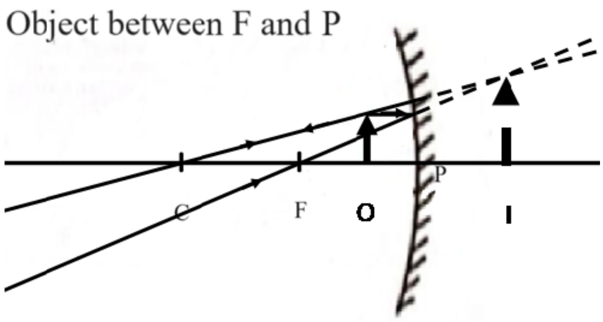
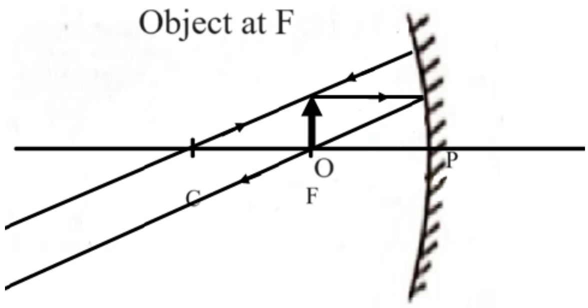
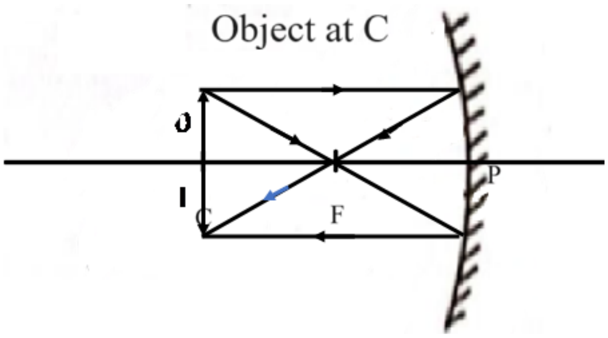
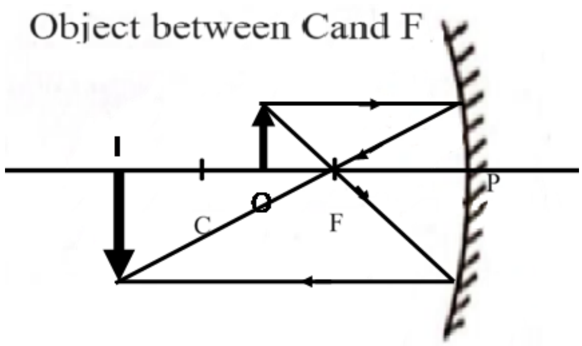
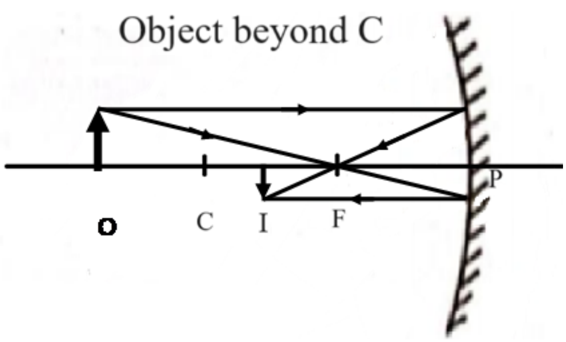
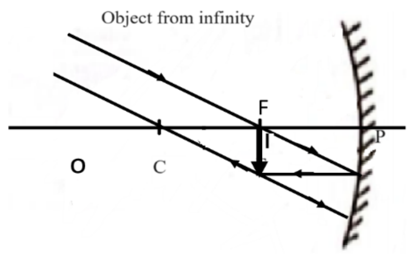
<table>
<tr><th>Rule</th><th>Representation</th></tr>
<tr><td>Paraxial ray - Ray parallel to principal axis will pass through the focus after reflection or appear to come from focus, F.</td><td>
</td></tr>
<tr><td>Principle ray - Ray passing through the focus will become parallel to the principal axis after reflection or a ray is in line with the focus after striking the mirror will move parallel to the principal axis.</td><td>
</td></tr>
</table>

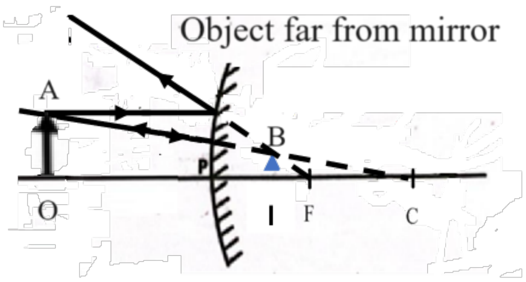
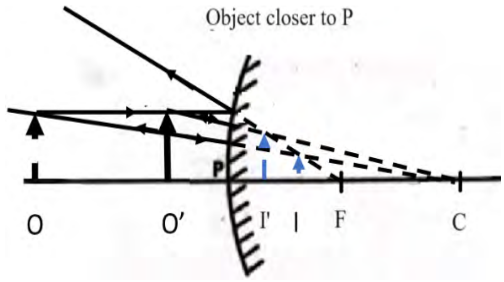
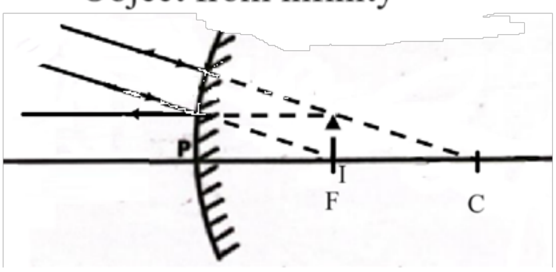
Rule	Representation
Centre ray – A ray of light that passes through the centre of curvature or in line with it after striking the mirror, is reflected back along the same path.	
Ray 4 - A ray of light that strikes the pole of the mirror at an angle of incidence is reflected back at the same angle that the angle of incidence equals the angle of reflection. *NOTE: achieving equal angles is difficult in practice.*	

https://www.teachoo.com/10824/3118/Rules-for-drawing-Ray-Diagram-in-Mirrors/category/Concepts/

Formation of ray diagrams

Table 4.6: Table containing ray diagrams for concave and convex mirrors

Ray diagrams of concave mirror	
1 	2  Image forming at infinity
3 	4 
5 	6 Scenario A  If you draw 2 on a light plane paper and you turn the back of the paper, you will get this diagram.

Ray diagrams in convex mirrors	
1 	2  Object moves from O to O' and image moves from I to I' closer to mirror.
3 Scenario A  Two rays from infinity are parallel: one in line with C and the other in line with F	

Uses of spherical mirrors

Convex

Some examples of where spherical mirrors are used include for convex mirrors; Car side mirrors, Security mirrors in stores, near ATM machines and Industrial and Workplace Safety

Concave

Makeup mirrors, Telescopes (concave), Shaving mirrors, Reflectors in flashlights, Solar cookers, Dentist's mirrors, Streetlight reflectors and Magnifying glasses.

Annex 4.5 – Solutions to some activities

Activity 4.11

- For a concave mirror, the magnification (M) can be greater than 1 (image is larger) or less than 1 (image is smaller) and can be positive (upright) or negative (inverted) depending on the object's distance (u).
- For a convex mirror, the magnification (M) is always less than 1 (the image is smaller) and positive (upright).
- As the object distance (u) changes, the magnification (M) changes inversely. For closer objects, the image appears larger in a concave mirror and smaller in a convex mirror.

Activity 4.12

- For a concave mirror, as the object distance (u) decreases (object moves closer to the mirror), the image distance (v) increases (image moves farther from the mirror) and can become real and inverted if within the focal length.
- For a convex mirror, the image distance (v) is always negative (virtual image) and located behind the mirror, getting closer to the mirror as the object distance (u) decreases.
- Any discrepancies could be due to measurement errors, improper alignment, or imperfections in the mirrors.

Activity 4.13

1. Given:

- u = −30 cm
- f = 10 cm

Using the mirror formula:

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

$$\frac{1}{10} = \frac{1}{30} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{10} + \frac{1}{30}$$

$\frac{1}{v} = \frac{3+1}{30}$

$\frac{1}{v} = \frac{4}{30}$

$\frac{1}{v} = \frac{2}{15}$

$v = \frac{15}{2}$

$v = 7.5$ cm

Determine the Magnification

$\mathrm{m} = -\frac{\mathrm{v}}{\mathrm{m}}$

$\mathrm{m} = -\frac{7.5}{-30}$

$\mathrm{m} = \frac{7.5}{30}$

$\mathrm{m} = 0.25$

Characteristics:

- **Nature**: Real (since v is positive)
- **Orientation**: Inverted (since m is negative)
- **Size**: Diminished (since | m | < 1)

2. Given:

- $\mathrm{u} = -15$ cm
- $\mathrm{f} = 10$ cm

Using the mirror formula:

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

$\frac{1}{\mathrm{v}} = \frac{1}{10} - \frac{1}{15}$

$\frac{1}{\mathrm{v}} = \frac{1}{10} + \frac{1}{15}$

$\frac{1}{\mathrm{v}} = \frac{3}{30} + \frac{2}{30}$

$\frac{1}{\mathrm{v}} = \frac{5}{30}$

$\mathrm{v} = 6$ cm

Determine the Magnification

$m = -\frac{\mathrm{v}}{\mathrm{u}}$

$m = -\frac{6}{-15}$

$m = \frac{6}{15}$

$m = 0.4$

Characteristics:

- **Nature**: Virtual (since v is positive)
- **Orientation**: Upright (since m is positive)
- **Size**: Diminished (since | m | < 1)

3. v = ∞

4. v = -6.66cm

Annex 4.6 - Further Information on Image Formation

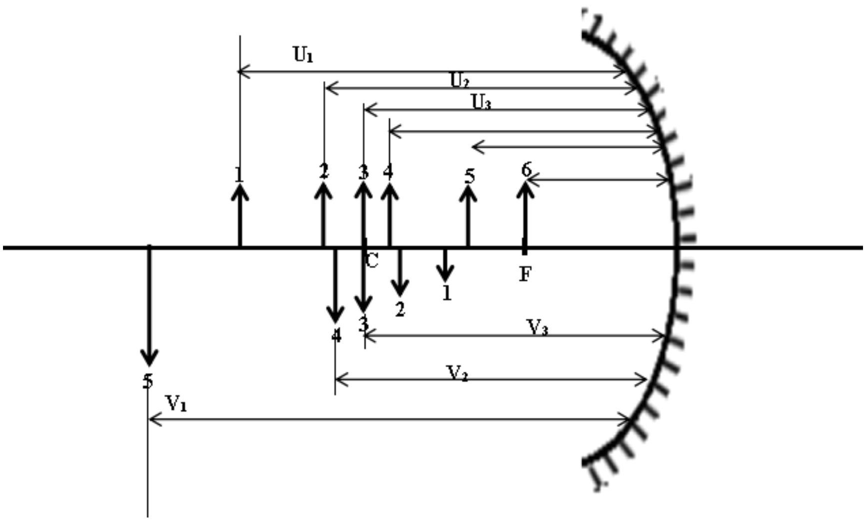
Spherical mirrors

Graph plotting in spherical mirrors

Graph plotting is a powerful tool that helps us visualise relationships between different variables. Let us dive in and explore how different distances relate in the context of mirrors

Object Distance (u) vs. Image Distance (v)

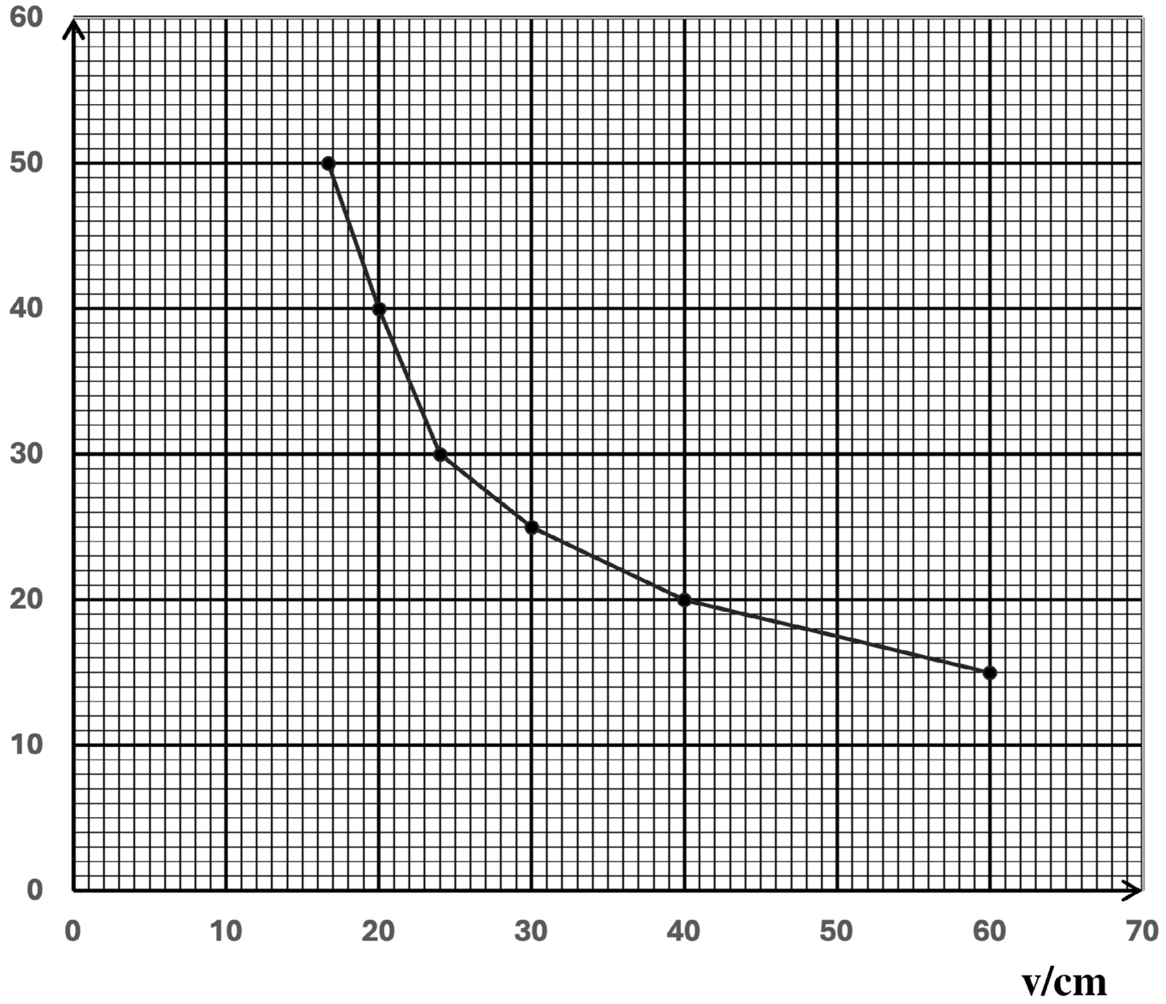
The diagram below shows how the distance between an object and a concave mirror (**u**) affects the distance of the resulting image (**v**) from the mirror. Each point represents a different position of the object. As the object moves closer to the mirror, notice how the image distance changes



Here is a sample table of data showing the relationship between object distance and image distance. The graph of object distance (u) versus image distance (v) is shown below.

Object Distance (u/cm)	Image Distance (v/cm)
50	16.67
40	20
30	24
25	30
20	40
15	60

Here is the graph of the object distance (**u**) on the x-axis and the image distance (v) on the y-axis for a concave mirror.



Whilst the graph is an interesting shape, it is challenging to use it to discover the value of the focal length of the mirror. Plotting an alternative graph of $\frac{1}{v}$ against $\frac{1}{u}$ is more useful; see the results of **Activity 4.15**.

Annex 4.7 – Solutions to some activities

Activity 4.18

1. **Bending of a pencil in Water:** When you place a pencil in a glass of water, it appears bent at the surface of the water
2. **It happens** due to refraction.
3. **Lenses in Glasses and Cameras:** Lenses bend light to focus it, which helps correct vision and capture clear images.
4. **Rainbow Formation:** Sunlight refracts as it enters and exits raindrops, splitting into different colours and creating a rainbow.
5. **Apparent Depth:** Objects underwater appear closer to the surface than they actually are because light rays bend when they move from water to air.
6. **Mirage:** In deserts or hot roads, light bends due to temperature variations in the air, creating the illusion of water.

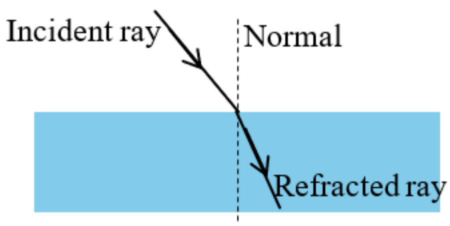
Annex 4.8 – Further Information on the laws of refraction

1. *The First Law of Refraction:*

   The incident ray, the refracted ray, and the normal to the interface of two media at the point of incidence all lie in the same plane.

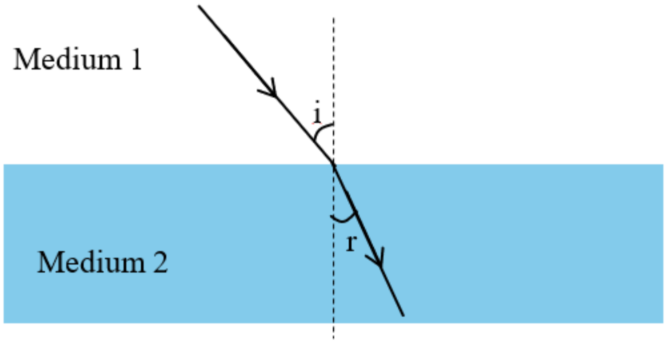
   Explanation:

   This means that if you draw a line perpendicular (normal) to the surface where the light is entering the new medium, the incoming ray (incident ray) and the outgoing ray (refracted ray) will both lie on the same flat surface.



2. *The Second Law of Refraction (Snell's Law):*

   The ratio of the sine of the angle of incidence (sin i) to the sine of the angle of refraction (sin r) is a constant for two given media, which is equal to the refractive index (n) of the second medium relative to the first medium.



Mathematically, this can be expressed as:

$$\frac{sin i}{sin r} = n$$

$$n_1 sin i = n_2 sin r$$

where:

- n_1 is the refractive index of the first medium,
- n_2 is the refractive index of the second medium,
- i is the angle of incidence,
- r is the angle of refraction.

Explanation:

Snell's Law quantifies how much light will bend when entering a different medium. The refractive index is a measure of how much the speed of light is reduced inside the medium. For example, the refractive index of water is about 1.33, which means light travels 1.33 times slower in water than in a vacuum.

REVIEW QUESTIONS

Review Questions 4.1

1. A light ray strikes a plane mirror at an angle of 30° to the normal to the mirror surface. What is the angle of reflection?
2. A light ray strikes a plane mirror at an angle of 45° to the normal to the mirror surface. What is the angle between the incident ray and the reflected ray (the angle of deviation)?
3. A light ray strikes a plane mirror at an angle of 60° with the normal to the mirror surface. What is the angle of reflection, and what is the angle between the incident ray and the reflected ray?
4. What is the relationship between the angle of inclination between two mirrors and the number of images formed?
5. Explain the process of formation of multiple images in a system of two inclined mirrors.
6. How can the knowledge of image formation in inclined mirrors be applied in real-world scenarios?

Review Questions 4.2

1. How would the image characteristics change if an object moves from beyond the centre of curvature (C) to the focal point (F) of a concave mirror?
2. Describe the differences between the real images formed by concave mirrors when the object is placed at different positions: beyond C, at C, and between C and F.
3. Explain how a concave mirror can be used to concentrate sunlight to a single point and what practical applications this has.
4. Compare the image formation of a concave mirror when used as a makeup mirror versus when used in a reflecting telescope.
5. Design an investigation to explore how the curvature of a concave mirror affects the focal length, and the characteristics of the images formed.

6. How would you demonstrate to your classmates the principle of image inversion in concave mirrors using everyday materials?
7. Propose a real-world scenario where the understanding of concave mirrors can solve a practical problem and explain your solution.
8. How does the image formed by a convex mirror differ from that formed by a concave mirror when the object is placed at the same distance from the mirrors?
9. Explain why convex mirrors are commonly used as side mirrors on vehicles.
10. Describe how a convex mirror can be used for security purposes in a store.
11. Compare the effectiveness of convex mirrors versus flat mirrors in providing a clear view of surroundings in public transportation systems.
12. Design an experiment to compare the field of view provided by a convex mirror to that of a flat mirror. What would you measure and what outcomes would you expect?

Review Questions 4.3

1. What is a spherical mirror?
2. Provide two examples of everyday objects that use spherical mirrors.
3. Define the terms
   a) Principal axis
   b) Pole
   c) Principal focus in the context of spherical mirrors.
4. Describe three rays that could be used in locating the image formed in a concave mirror and state how they are reflected by the mirror.
5. With the aid of a diagram, show how an image may be produced by a convex mirror.
6. With the aid of a diagram, show how a virtual image may be produced by a concave mirror.
7. How are the laws of reflection seen in the rules applied to the formation of images in spherical mirrors?

Review Questions 4.4

1. Compare and contrast reflection and refraction of light.
2. Evaluate the impact of varying refractive indices on the behaviour of light.
3. Discuss the environmental impact of refraction-based technologies.
4. Predict the path of light through a prism and explain why white light separates into colours.
5. Explain the concept of magnification in the context of mirrors. How is it calculated using the mirror formula?
6. A concave mirror has a focal length of 20 cm. If an object is placed 40 cm from the mirror, calculate the position of the image using the mirror formula.
7. Discuss the relationship between object distance, image distance, and focal length in concave mirrors. Provide an example calculation using the mirror formula to illustrate your explanation.

ANSWERS TO REVIEW QUESTIONS

Review Questions 4.1

1. The angle of reflection is 30°.
2. The angle between the incident ray and the reflected ray is 90°.
3. The angle of reflection is 60°.

   The angle between the incident ray and the reflected ray is 120°.
4. $n = \frac{360}{\theta} - 1$
5. When two mirrors are placed at an angle (θ) with respect to each other, multiple images are formed due to the repeated reflection of light between the two mirrors. As the angle of inclination (θ) is decreased, the number of images increases. This is because the light undergoes more reflections between the two mirrors, creating a larger number of virtual images.
6. The understanding of image formation in inclined mirrors has numerous applications in the real world, such as:
   - Design of optical instruments: The principles of image formation in inclined mirrors are used in the design of various optical instruments, such as periscopes, kaleidoscopes, and some types of telescopes.
   - Understanding mirror-based systems: The knowledge of image formation in inclined mirrors can be used to analyse and understand the behaviour of mirror-based systems, such as those used in security surveillance, vehicle rear-view mirrors, and some types of display technologies.
   - Educational and demonstration purposes: The phenomenon of multiple images in inclined mirrors is often used in educational settings to demonstrate the principles of reflection and the formation of virtual images.

Review Questions 4.2

1. As the object moves from beyond the centre of curvature (C) towards the focal point (F), the image will move from between C and F to further away from C. The image will grow larger (magnified) and remain inverted.

When the object reaches the focal point, no image is formed because the reflected rays are parallel.

2. **Beyond C:** The image is real, inverted, diminished, and located between F and C.

   At C: The image is real, inverted, the same size as the object, and located at C.

   Between C and F: The image is real, inverted, magnified, and located beyond C.

3. A concave mirror can be used to concentrate sunlight because it reflects parallel rays of light to converge at its focal point. This concentrated light can generate high temperatures, making concave mirrors useful in applications such as solar furnaces and solar cookers.

4. **Makeup Mirror:** The object is placed very close to the mirror, between F and P. The image formed is virtual, upright, and magnified, allowing for detailed viewing.

   Reflecting Telescope: Distant objects are the focus, and light rays entering the telescope are nearly parallel. The concave mirror forms a real, inverted, and often diminished image that is magnified by the eyepiece for detailed observation of celestial bodies.

5.
   - Obtain concave mirrors with different radii of curvature.
   - Set up a light source, mirrors, and a screen for capturing images.
   - Measure and record the focal lengths of each mirror.
   - Place an object at various distances (beyond C, at C, between C and F) for each mirror.
   - Record and analyse the images formed in terms of size, orientation, and type.
   - Compare the results to determine the relationship between curvature, focal length, and image characteristics.

6.
   - Use a spoon as a concave mirror.
   - Show the curved, inner surface of the spoon as the reflecting surface.

- Place an object (e.g., a small toy) in front of the spoon beyond its centre of curvature.
- Ask classmates to observe the image on the concave surface.
- Explain how the image is inverted and diminished.
- Move the object closer to the spoon and discuss changes in image characteristics.

7.

- **Example Scenario:** Improving energy efficiency in solar cookers.
- **Solution:** Use a large concave mirror to concentrate sunlight onto the cooking pot. The concave mirror focuses sunlight to a single point, increasing temperature and reducing cooking time. Proper alignment and angle adjustment can maximise energy absorption, making solar cooking more efficient.

8. The image formed by a convex mirror is always virtual, upright, and diminished regardless of the object's distance. In contrast, a concave mirror can form real, inverted, magnified or diminished images depending on the object's position relative to the focal point and centre of curvature.

9. Convex mirrors provide a wider field of view compared to flat or concave mirrors. This allows drivers to see more area beside and behind the vehicle, reducing blind spots and enhancing safety. The virtual, diminished images help drivers judge distances more effectively.

10. Convex mirrors are placed at strategic locations (e.g., corners, ceilings) in stores to provide a panoramic view of the area. This wide-angle view allows security personnel to monitor more space and detect any suspicious activity or theft. The upright, diminished images help cover larger areas efficiently.

11. Convex mirrors are more effective than flat mirrors in public transportation systems (e.g., buses, and trains) because they offer a broader field of view. This helps drivers and conductors monitor passenger areas and entrances more efficiently. Flat mirrors provide a limited view and may not cover blind spots as effectively.

12.

- **Experiment Design:** Place a flat mirror and a convex mirror at the same location. Mark several objects at varying angles and distances from the mirrors. Measure the angles at which each object becomes visible in the mirrors.

- **Measurements:** Field of view angles for each mirror type, distance at which objects are visible.
- **Expected Outcomes:** The convex mirror will provide a wider field of view, showing objects at greater angles and distances compared to the flat mirror.

Review Questions 4.3

1. A spherical mirror is a mirror that has a curved reflective surface, forming part of the surface of a sphere. There are two types: concave (curved inward) and convex (curved outward).
2. **Examples of Everyday Objects Using Spherical Mirrors**
   - Car side mirrors (convex)
   - Makeup mirrors (concave)
   - Telescopes (concave)
3. **Definitions**

a. **Principal Axis:** The principal axis is the straight line that passes through the centre of curvature and the pole of the mirror. It acts as a reference line for constructing ray diagrams.

b. **Pole (P):** The pole is the central point on the surface of the spherical mirror. It is the midpoint of the mirror and is where the principal axis meets the mirror.

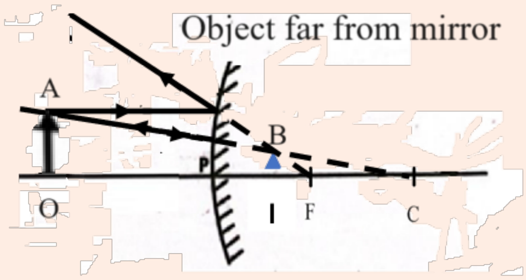
c. **Principal Focus (F):** The principal focus is the point on the principal axis where light rays parallel to the principal axis converge (concave mirror) or appear to diverge (convex mirror) after reflecting off the mirror.

4.
   - **Parallel Ray**: A ray parallel to the principal axis is reflected through the focal point.
   - **Focal Ray**: A ray passing through the focal point is reflected parallel to the principal axis.
   - **Centre of Curvature Ray**: A ray passing through the centre of curvature is reflected back along the same path.

5. Diagram Showing Image Formation by a Convex Mirror

Here's a simplified diagram illustrating how an image is formed by a convex mirror:

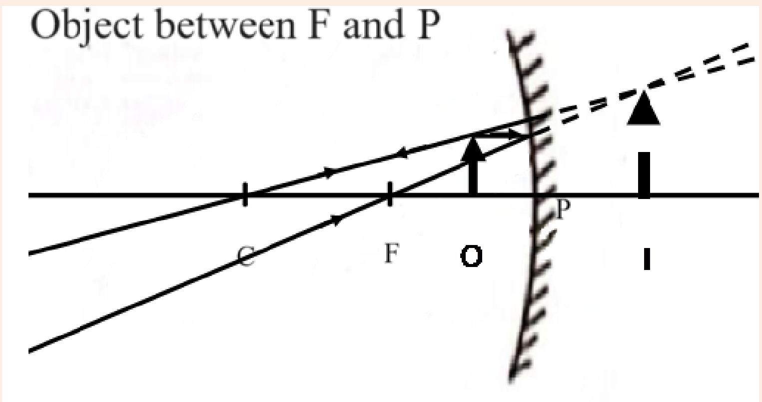
- Draw a ray parallel to the principal axis; it appears to diverge from the focal point behind the mirror.
- Draw a ray aiming towards the focal point behind the mirror; it is reflected parallel to the principal axis.
- Draw a ray directed towards the centre of curvature; it is reflected back along the same path.



6. Diagram Showing a Virtual Image in a Concave Mirror

Here's a simplified diagram illustrating how a virtual image is formed by a concave mirror when the object is placed between the focal point and the mirror:

- Draw a ray parallel to the principal axis; it is reflected through the focal point.
- Draw a ray towards the focal point; it is reflected parallel to the principal axis.
- Draw a ray directed towards the centre of curvature; it is reflected back along the same path.



7. Laws of Reflection in Spherical Mirrors

The laws of reflection state that the angle of incidence equals the angle of reflection. In spherical mirrors, these laws apply as follows:

- **Incident Ray and Reflected Ray**: Both rays make equal angles with the normal to the surface at the point of incidence.
- **Normal Line**: In spherical mirrors, the normal line at any point is a line drawn to the centre of curvature.
- **Image Formation Rules**: The rules for image formation (parallel ray through the focal point, focal ray parallel to the axis) directly follow from the law of reflection, ensuring that the angles of incidence and reflection are equal.

Review Questions 4.4

1. **Reflection:** Light bounces off a surface without entering it, obeying the law of reflection (angle of incidence equals angle of reflection).

   Refraction: Light bends as it enters a new medium, following Snell's Law and changing speed and direction.

2. Higher refractive indices indicate slower light speeds in a medium, affecting how light bends and interacts at boundaries between different materials. This understanding is crucial in designing lenses, prisms, and optical instruments.

3. Refraction-based technologies, like lenses in solar panels, help optimize energy collection. Understanding refraction aids in developing more efficient technologies that harness solar energy, reducing reliance on fossil fuels.

4. White light enters a prism and refracts at different angles depending on its wavelength (colour). This dispersion occurs because each colour of light bends differently due to its unique wavelength, resulting in the separation of colours seen as a spectrum.

5. **Explanation:** Magnification **m** is given by $\frac{h_i}{h_o} = -\frac{v}{u}$, where $\mathbf{h_i}$ is the image height, $\mathbf{h_o}$ is the object height, v is the image distance, and u is the object distance.

6. A concave mirror has a focal length of 20 cm. If an object is placed 40 cm from the mirror, calculate the position of the image using the mirror formula.

   Given: f = −20 cm (for concave mirror),

   u = −40 cm.

   v = −13.33cm

7. **Explanation:** In concave mirrors, when the object is placed beyond twice the focal length, the image is real and inverted. When the object is placed between the focal length and the mirror, the image is virtual and upright.

EXTENDED READING

- **Inclined Mirrors**:

  Chapter 34: "Reflection and Refraction" in Serway, R. A., & Jewett, J. W. (2018). Physics for Scientists and Engineers with Modern Physics (10th ed.). Cengage Learning.

  Chapter 34: "Geometric Optics" in Young, H. D., & Freedman, R. A. (2016). University Physics with Modern Physics (14th ed.). Pearson.

  Halliday, D., Resnick, R., & Walker, J. (2013). Fundamentals of Physics (10th ed.). Wiley. Images

- **Formation of Images in Plane Mirrors**:

  Chapter 34: "Images" in Halliday, D., Resnick, R., & Walker, J. (2013). Fundamentals of Physics (10th ed.). Wiley.

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