Applied Physics for Engineers **(PHY121)**

Geometrical Optics

LECTURE # 18

Instructor
Muhammad Kaleem Ullah
Lecturer,
Department of Physics,
CUI, Lahore Campus.

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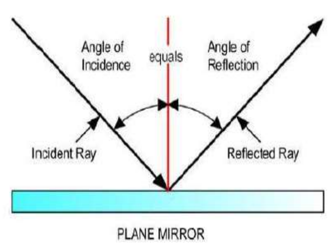
TERMS RELATED TO REFLECTION/REFRACTION OF LIGHT

- "Light is an electromagnetic ray that travels in a straight line"
- **Incident Ray:** The ray of light that falls on the reflecting surface
- **Reflected Ray:** The ray of light that is sent back by the reflecting surface
- **Normal:** The normal is a line at right angle to the reflecting surface to the point of incidence
- **Angle of Incidence:** It is the angle made by the incident ray and the normal
- **Angle of Reflection**: It is the angle made by the reflected ray and the normal



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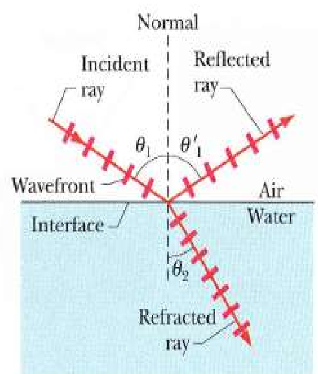
TERMS RELATED TO REFLECTION/REFRACTION OF LIGHT

- Reflection of Light:
  - When light falls on a surface and is reflected back into the same medium, we say reflection has taken place
- Refraction of Light:
  - When light travels from one medium to another it bends from its original path
  - This phenomenon is called refraction



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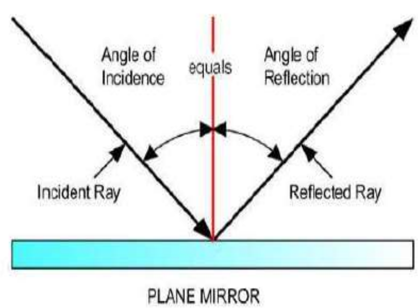
LAWS OF REFLECTION OF LIGHT

- **Laws of Reflection of light are:**
  - The angle of incidence is equal to the angle of reflection
  - The incident ray, the reflected ray and the normal to the mirror at the point of incidence all lie in the same plane
  - The incident ray and the reflected ray lie on either side of the normal



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REFRACTION OF LIGHT

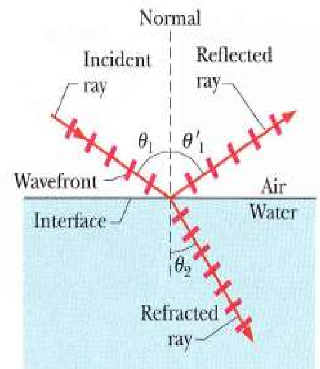
- The phenomenon of bending of light when it travels from one medium to another is called as 'refraction'

- Laws of refraction of light:

A refracted ray lies in the plane of incidence and has an angle of refraction θ_2 that is related to the angle of incidence θ_1 by

$$n_2 \sin \theta_2 = n_1 \sin \theta_1 \quad \text{(refraction).}$$

Here each of the symbols n_1 and n_2 is a dimensionless constant, called the **index of refraction,** that is associated with a medium involved in the refraction.



This is called Snell's law

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REFRACTIVE INDEX

- The refractive index of a medium gives an indication of light bending ability of that medium

$$n_{21} = \frac{\text{Speed of light in medium 1}}{\text{Speed of light in medium 2}} = \frac{v_1}{v_2}$$

$$n_{12} = \frac{\text{Speed of light in medium 2}}{\text{Speed of light in medium 1}} = \frac{v_2}{v_1}$$

$$n_m = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}} = \frac{c}{v}$$

- Where $\mathbf{n_{21}}$ is the refractive index of medium 2 with respect to medium 1

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Table (in next slide) gives the indexes of refraction of vacuum and some common substances. For vacuum, n is defined to be exactly 1; for air, n is very close to 1.0 (an approximation we shall often make). Nothing has an index of refraction below 1.

Rearranging above equation as

$$\sin \theta_2 = \frac{n_1}{n_2} \sin \theta_1$$

to compare the angle of refraction θ_2 with the angle of incidence θ_1. We can

then see that the relative value of θ_2 depends on the relative values of n_2 and n_1.

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REFRACTIVE INDEX

Material medium	Refractive index	Material medium	Refractive index
Air	1.0003	Crown glass	1.52
Ice	1.31	Canada Balsam	1.53
Water	1.33	Rock salt	1.54
Alcohol	1.36	Carbon disulphide	1.63
Kerosene	1.44	Dense flint glass	1.65
Fused Quartz	1.46	Ruby	1.71
Turpentine Oil	1.47	Sapphire	1.77
Benzene	1.50	Diamond	2.42

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In fact, we can have three basic results:

1. If n_2 is equal to n_1, then θ_2 is equal to θ_1 and refraction does not bend the light beam, which continues in the *undeflected direction,* as in Fig. 33-17*a*.
2. If n_2 is greater than n_1, then θ_2 is less than θ_1. In this case, refraction bends the light beam away from the undeflected direction and toward the normal, as in Fig. 33-17*b*.
3. If n_2 is less than n_1, then θ_2 is greater than θ_1. In this case, refraction bends the light beam away from the undeflected direction and away from the normal, as in Fig. 33-17*c*.

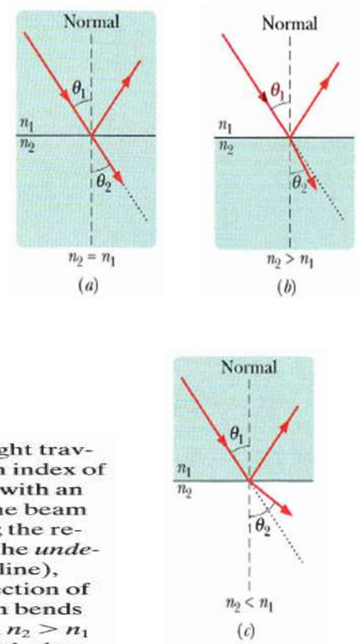

FIG. 33-17 Refraction of light traveling from a medium with an index of refraction n_1 into a medium with an index of refraction n_2. (*a*) The beam does not bend when $n_2 = n_1$; the refracted light then travels in the *undeflected direction* (the dotted line), which is the same as the direction of the incident beam. The beam bends (*b*) toward the normal when $n_2 > n_1$ and (*c*) away from the normal when $n_2 < n_1$.

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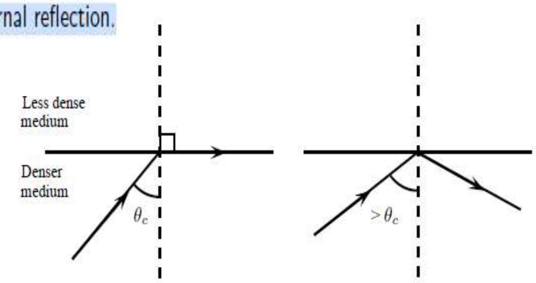
Definition: Critical Angle
The critical angle is the angle of incidence where the angle of reflection is 90°. The light must shine from a dense to a less dense medium.

Definition: Total Internal Reflection
Total internal reflection takes place when light is reflected back into the medium because the angle of incidence is greater than the critical angle.

If the angle of incidence is bigger than this critical angle, the refracted ray will not emerge from the medium, but will be reflected back into the medium. This is called total internal reflection.

Total internal reflection takes place when

- light shines from an optically denser medium to an optically less dense medium
- the angle of incidence is greater than the critical angle.



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Calculating the Critical Angle

Snell's Law states:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where n_1 is the refractive index of material 1, n_2 is the refractive index of material 2, θ_1 is the angle of incidence and θ_2 is the angle of refraction. For total internal reflection we know that the angle of incidence is the critical angle. So,

$$\theta_1 = \theta_c.$$

However, we also know that the angle of refraction at the critical angle is 90°. So we have:

$$\theta_2 = 90°.$$

We can then write Snell's Law as:

$$n_1 \sin\theta_c = n_2 \sin 90°$$

Solving for θ_c gives:

$$\begin{aligned} n_1 \sin\theta_c &= n_2 \sin 90° \\ \sin\theta_c &= \frac{n_2}{n_1}(1) \\ \therefore \theta_c &= \sin^{-1}\left(\frac{n_2}{n_1}\right) \end{aligned}$$

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Question: Given that the refractive indices of air and water are 1 and 1,33, respectively, find the critical angle.

Answer

Step 1 : Determine how to approach the problem

We know that the critical angle is given by:

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Step 2 : Solve the problem

$$\begin{aligned} \theta_c &= \sin^{-1}\left(\frac{n_2}{n_1}\right) \\ &= \sin^{-1}\left(\frac{1}{1{,}33}\right) \\ &= 48{,}8° \end{aligned}$$

Step 3 : Write the final answer

The critical angle for light travelling from water to air is $48{,}8°$.

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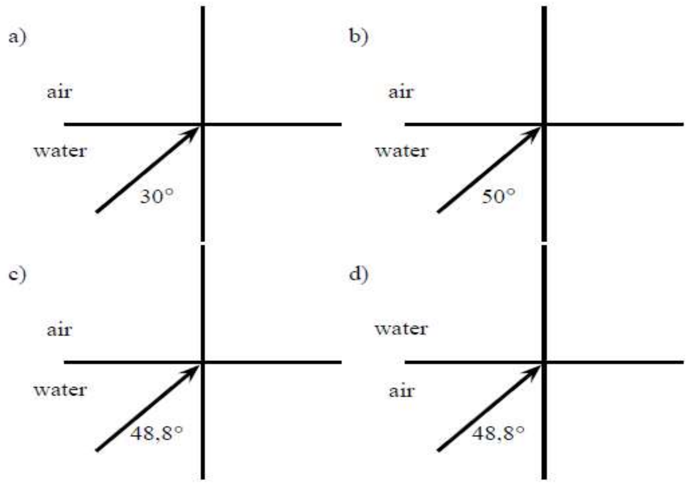
Question: Complete the following ray diagrams to show the path of light in each situation.



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Answer

Step 1 : Identify what is given and what is asked

The critical angle for water is $48{,}8°$.

We are asked to complete the diagrams.

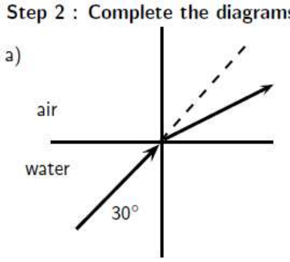
For incident angles smaller than $48{,}8°$ refraction will occur.

For incident angles greater than $48{,}8°$ total internal reflection will occur.

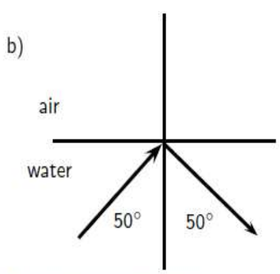
For incident angles equal to $48{,}8°$ refraction will occur at $90°$.

The light must travel from a high optical density to a lower one.

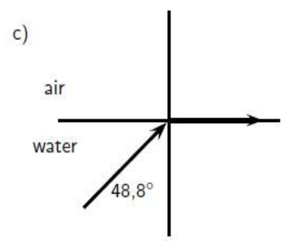
Step 2 : Complete the diagrams



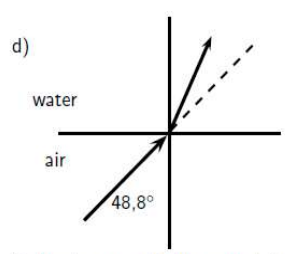
Refraction occurs (ray is bent away from the normal)



Total internal reflection occurs



$\theta_c = 48{,}8°$



Refraction towards the normal (air is less dense than water)

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Terms related to Plane Mirror

- **Object**: It is the "thing" that forms an image on the screen
- **Image**: It is the reflection of the object on the screen
- **Virtual Image**: The image that cannot be obtained on a screen (a surface where image is formed)
- **Real Image**: The image that is formed directly on the screen

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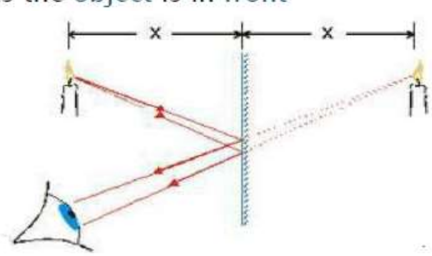
PROPERTIES OF IMAGE FORMED BY A PLANE MIRROR

- The image formed in a plane is mirror is…
  1. Virtual and Erect
  2. Of the same size as of the object
  3. At the same distance from the mirror as the object is in front of it
  4. Laterally inverted



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SPHERICAL MIRRORS: CONCAVE AND CONVEX

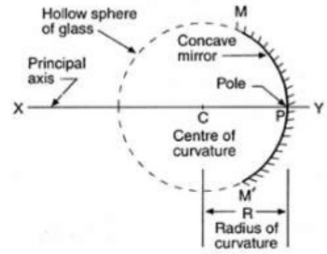
- Concave Mirror: A spherical mirror that has its reflecting surface curved inwards
- Convex Mirror: A spherical mirror that has its reflecting surface curved outwards
- There are some important terms to be explained first in terms of Spherical mirrors. They are:
  - Center of curvature (C):

    It is the centre of the sphere of which the mirror is a part
  - Radius of curvature (CP):

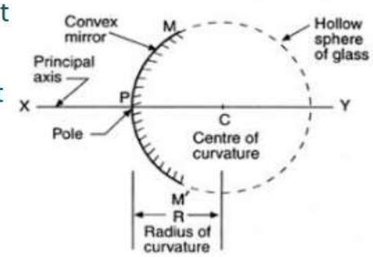
    It is the radius of the sphere of which the mirror is a part
  - Pole (P):

    It is the centre of the spherical mirror
  - Principal axis (X–Y):

    It is the straight line passing through the centre of curvature and the pole



Concave Mirror



Convex Mirror

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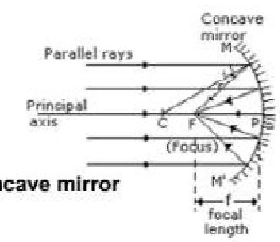
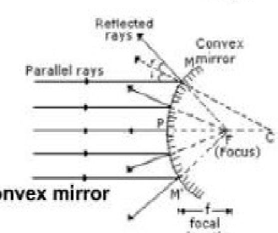
FOCUS AND FOCAL LENGTH OF SPHERICAL MIRRORS

- Principal Focus:
  - Focus of Concave Mirror: It is a point on the principal axis, where all the rays parallel to the principal axis converge
  - Focus of Convex Mirror: It is a point on the principal axis, where the reflected rays appear to converge



Concave mirror



Convex mirror

- Focal length of Spherical Mirrors:
  - The distance between the pole and the principal focus is called the focal length of the spherical mirror
  - The Radius of Curvature is two times the Focal Length of any spherical mirror

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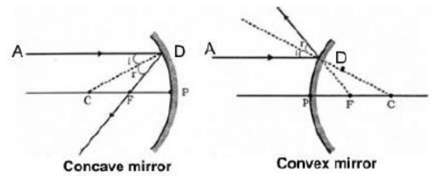
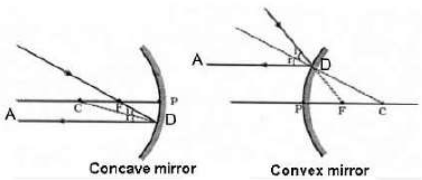
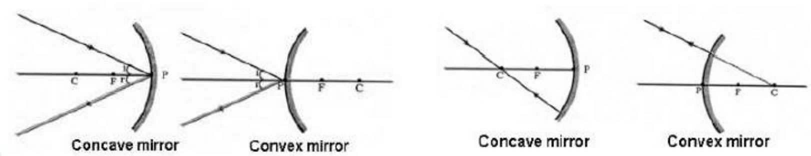
RULES FOR REFLECTION OF LIGHT THROUGH SPHERICAL MIRRORS

- If in a concave mirror, a ray of light parallel to the principal axis after reflection will pass through the focus or appear to diverge from the focus in case of convex mirror
- A ray passing through the focus of a concave mirror, after reflection, will emerge parallel to the principal axis



- A ray passing through the centre of curvature, after reflection is reflected back along the same path
- A ray incident obliquely to the principal axis towards the pole on the spherical mirrors is reflected back obliquely





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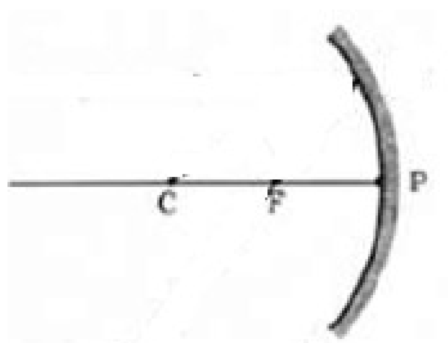
FORMATION OF DIFFERENT TYPES OF IMAGES BY CONCAVE MIRRORS

- We can place the object at six positions from the mirror:
  - At infinity
  - Beyond C
  - At C
  - Between C and F
  - At F
  - Between F and P



Concave mirror

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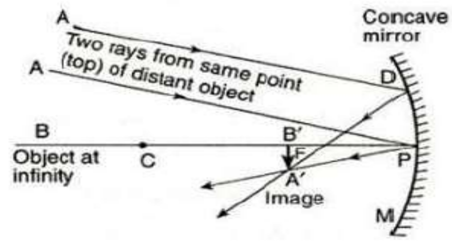
FORMATION OF DIFFERENT TYPES OF IMAGES BY CONCAVE MIRRORS

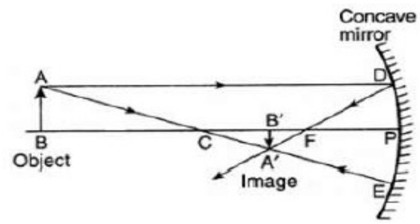
1. At infinity:

- The image formed is:
  - Real and Inverted
  - Highly diminished, Point-sized
  - Formed at F



2. Beyond C:

- The image formed is:
  - Real and Inverted
  - Between F and C
  - Diminished



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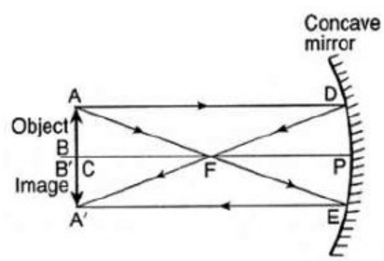
FORMATION OF DIFFERENT TYPES OF IMAGES BY CONCAVE MIRRORS

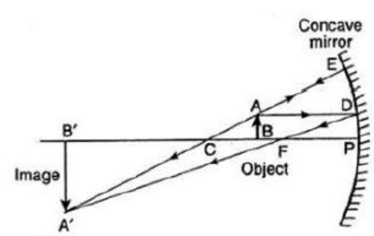
3. At C:

- The image formed is:
  - Real and Inverted
  - At C
  - Of the same size as the object



4. Between F and C:

- The image formed is
  - Real and Inverted
  - Beyond C
  - Magnified



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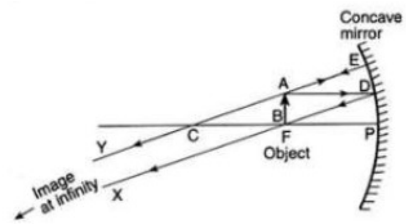
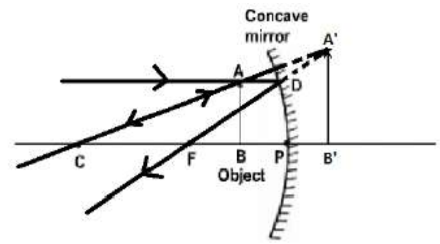
FORMATION OF DIFFERENT TYPES OF IMAGES BY CONCAVE MIRRORS

5. At F:
   - The image formed is:
     - Real and Inverted
     - At infinity
     - Highly magnified



6. Between F and P:
   - The image formed is:
     - Virtual and Erect
     - Behind the mirror
     - Magnified



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FORMATION OF DIFFERENT TYPES OF IMAGES BY CONCAVE MIRRORS

Position of the object	Position of the image	Size of the image	Nature of the image
At infinity	At the focus F	Highly diminished, point-sized	Real and inverted
Beyond C	Between F and C	Diminished	Real and inverted
At C	At C	Same size	Real and inverted
Between C and F	Beyond C	Enlarged	Real and inverted
At F	At infinity	Highly enlarged	Real and inverted
Between P and F	Behind the mirror	Enlarged	Virtual and erect

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USES OF CONCAVE MIRRORS

- Concave mirrors are used as:
  - Shaving mirrors
  - Torches, search lights, and vehicle headlights
  - Used by dentist to get large images of patient's teeth
  - In solar furnaces to concentrate heat

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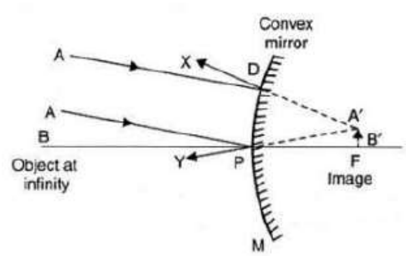
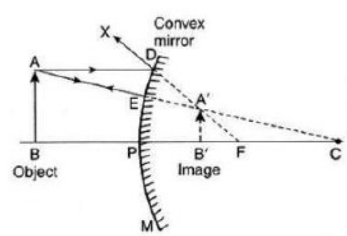
IMAGE FORMATION BY CONVEX MIRROR

1. At infinity:
   - The image formed is:
     - Virtual and Erect
     - Behind the mirror (at F)
     - Highly diminished



2. Between Infinity and P:
   - The image formed is:
     - Virtual and Erect
     - Behind the mirror (between P and F)
     - Diminished



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USES OF CONVEX MIRRORS

- Convex mirrors are used in:
  - Vehicles as rear-view mirrors to see traffic at the rear-side
  - Used as a device to check thefts in shops

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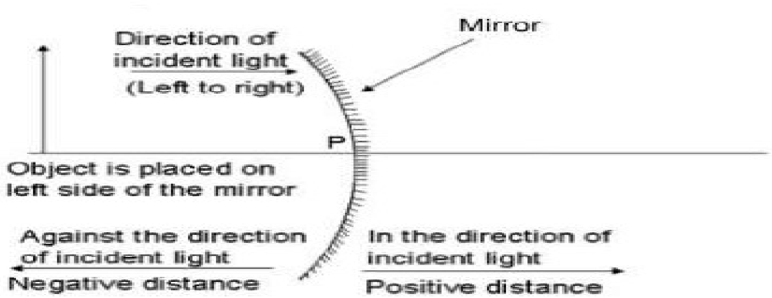
NEW CARTESIAN SIGN CONVENTION

- Object is placed left to the mirror and the pole is taken as the origin
- Distance to the right of origin (+ve X-axis) is positive while that to its left (-ve X-axis) is negative
- Distances above the principal axis (+ve Y-axis) are positive while those below it (-ve Y-axis) are negative



Sign convention for mirror

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MIRROR FORMULA FOR SPHERICAL MIRRORS

- The mirror formula is:

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

Where, **u**= Object distance
v= Image distance
f= Focal length

	Convex Mirror	Concave Mirror
u	Negative	Negative
v	positive	Positive or Negative
f	positive	Negative

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MAGNIFICATION

$$Magnification\ (m)=\frac{heght\ of\ image\ (h_2)}{height\ of\ object\ (h_1)}=\frac{-Image\ distance\ (-v)}{Object\ distance\ (u)}$$

- For Virtual image, m is positive
  Real image, m is negative

- If **m>1**, image is bigger than the object
- If **m=1**, image is of the same size as of the object
- If **m<1**, image is smaller than the object

- If m is positive, then the image is virtual and erect
- If m is negative, then the image is real and inverted

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END OF LECTURE

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