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Refraction at single spherical surfaces

XII- SCIENCE

SUBJECT : PHYSICS
CHAPTER NUMBER: 9
CHAPTER NAME : RAY OPTICS

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Refraction at single spherical surface

- **Assumptions :** To proceed to derive equation of refraction at single spherical surface the assumption taken are ;
- The spherical surface have small aperture
- Object is on the principal axis .
- All the rays from object are paraxial rays .
- All angles like angle of incidence (i) , angle of refraction (r) , angle by incident ray with principal axis (α), angle by refracted ray with principal axis (β) and angle by incident ray with principal axis (γ) are very small such that these angles tend to zero. So the sine and tangent of these angles tend to the radian value of the angles .

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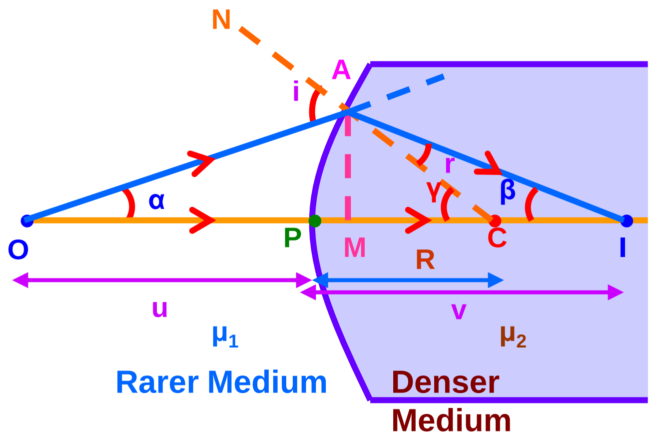
Refraction at single spherical surface



$i = \alpha + \gamma$

$\gamma = r + \beta$ or $r = \gamma - \beta$

$\tan \alpha = \dfrac{MA}{MO}$ or $\alpha = \dfrac{MA}{MO}$

$\tan \beta = \dfrac{MA}{MI}$ or $\beta = \dfrac{MA}{MI}$

$\tan \gamma = \dfrac{MA}{MC}$ or $\gamma = \dfrac{MA}{MC}$

According to Snell's law,

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \quad \text{or} \quad \frac{i}{r} = \frac{\mu_2}{\mu_1} \quad \text{or} \quad \boxed{\mu_1 i = \mu_2 r}$$

Substituting for i, r, α, β and γ, replacing M by P and rearranging,

$$\frac{\mu_1}{PO} + \frac{\mu_2}{PI} = \frac{\mu_2 - \mu_1}{PC}$$

Applying sign conventions with values, PO = - u, PI = + v and PC = + R

$$\boxed{\frac{\mu_1}{-u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}}$$

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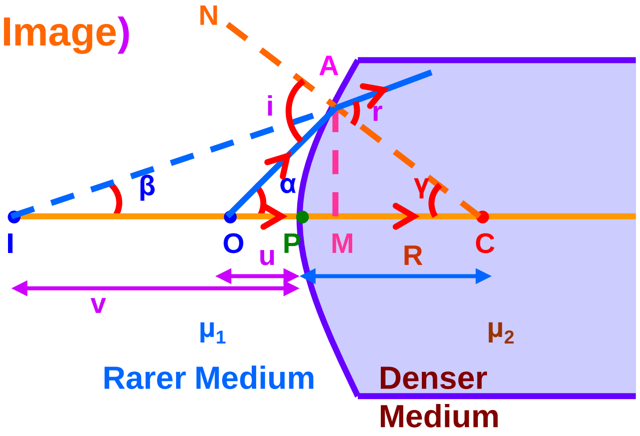
Refraction at single spherical surface

(From Rarer Medium to Denser Medium - Virtual Image)

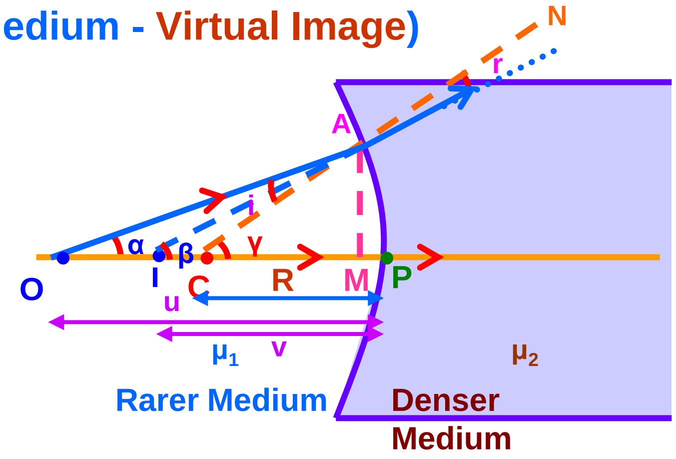
$$\frac{\mu_1}{-u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$$



Refraction at Concave Surface:

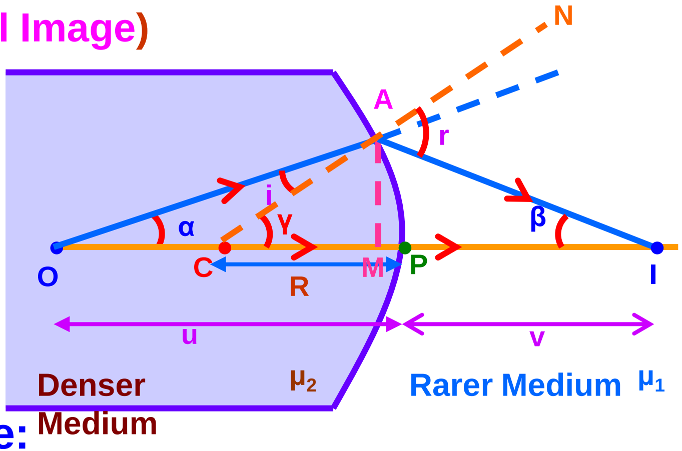
(From Rarer Medium to Denser Medium - Virtual Image)

$$\frac{\mu_1}{-u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$$



Refraction at single spherical surface

(From Denser Medium to Rarer Medium - Real Image)



$$\frac{\mu_2}{-u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R}$$

Refraction at Convex Surface:

(From Denser Medium to Rarer Medium - Virtual Image)

$$\frac{\mu_2}{-u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R}$$

Refraction at Concave Surface:

(From Denser Medium to Rarer Medium - Virtual Image)

$$\frac{\mu_2}{-u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R}$$

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Note:

1. Expression for 'object in rarer medium' is same for whether it is real or virtual image or convex or concave surface.

$$\frac{\mu_1}{-u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$$

2. Expression for 'object in denser medium' is same for whether it is real or virtual image or convex or concave surface.

$$\frac{\mu_2}{-u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R}$$

3. However the values of u, v, R, etc. must be taken with proper sign conventions while solving the numerical problems.

4. The refractive indices μ_1 and μ_2 get interchanged in the expressions.

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Relation between apparent depth and real depth using refraction equation for spherical surface :

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For plane surface R = ∞

Object is in denser medium refractive index μ and real depth = u and apparent depth = v

Light travels from μ → 1 i.e air

By equation of refraction; $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

Using the substitutions of this case; $\frac{1}{v} - \frac{\mu}{u} = \frac{1-\mu}{\infty} = 0$

$$\frac{1}{v} = \frac{\mu}{u} \Rightarrow \mu = \frac{u}{v} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

NUMERICALS

- Numericals : Light from a point source in air falls on a spherical glass surface (n = 1.5 and radius of curvature = 20 cm) . The distance of the light source from the glass surface is 100 cm . At what position the image is formed ?

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- **Numericals : Light from a point source in air falls on a spherical glass surface (n = 1.5 and radius of curvature = 20 cm) . The distance of the light source from the glass surface is 100 cm . At what position the image is formed ?**
- **Solution :**

Solution :

In this case , u = -100 cm as per sign conventions.

R = 20 cm

Light is travelling from air (i.e. n = 1) to glass (i.e. n = 1.5)

So by equation of refraction ; $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R} \Rightarrow \frac{1.5}{v} - \frac{1}{-100} = \frac{1.5-1}{20}$

$$\Rightarrow \frac{1.5}{v} + \frac{1}{100} = \frac{0.5}{20} = \frac{1}{40} \Rightarrow \frac{1.5}{v} = \frac{1}{40} - \frac{1}{100} = \frac{5-2}{200} = \frac{3}{200}$$

$$\Rightarrow v = \frac{200 \times 1.5}{3} cm = 100cm$$

So image is formed 100cm from the separating surface in the direction of light .

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NUMERICALS

- **Numericals : Rays of light parallel to a diameter of a glass sphere (n = 1.5 and radius = 20 cm) fall on it very close to the pole. Find the position w.r.t. centre of the sphere where the rays meet the principal axis of the sphere ?**

NUMERICALS

- **Numericals : Rays of light parallel to a diameter of a glass sphere (n = 1.5 and radius = 20 cm) fall on it very close to the pole. Find the position w.r.t. centre of the sphere where the rays meet the principal axis of the sphere ?**

Solution : In this case at the first face ; u = - ∞ , R = + 20 cm and light travels from n =1 to n=1.5

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So , $\frac{1.5}{v} - \frac{1}{\infty} = \frac{1.5-1}{20} \Rightarrow \frac{1.5}{v} = \frac{0.5}{20} = \frac{1}{40} \Rightarrow v = 60cm$ from P_1 in light direction

i.e. 60cm -40 cm = 20 cm from P_2 in light direction .

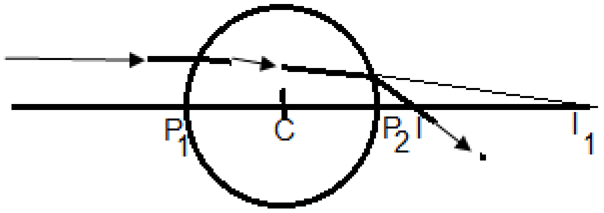
Hence for second surface ; u = + 20 cm , R = -20cm and light travels from n=1.5 to n = 1

So ; $\frac{1}{v} - \frac{1.5}{20} = \frac{1-1.5}{-20} = \frac{0.5}{20} \Rightarrow \frac{1}{v} = \frac{0.5}{20} + \frac{1.5}{20} = \frac{2}{20} = \frac{1}{10}$

$\Rightarrow v = 10cm$ from P_2 in the direction of light

Hence rays meet principal axis at 10 cm from second surface in light direction.

Hence distance from centre = 10 cm + 20 cm = 30 cm



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