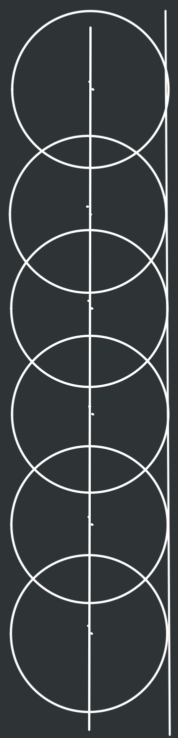
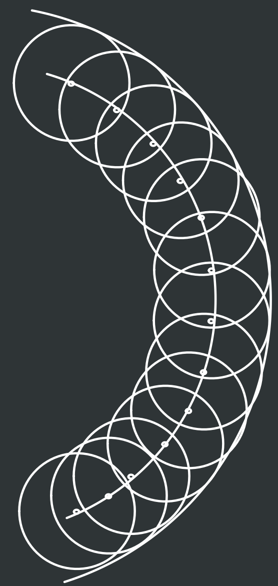
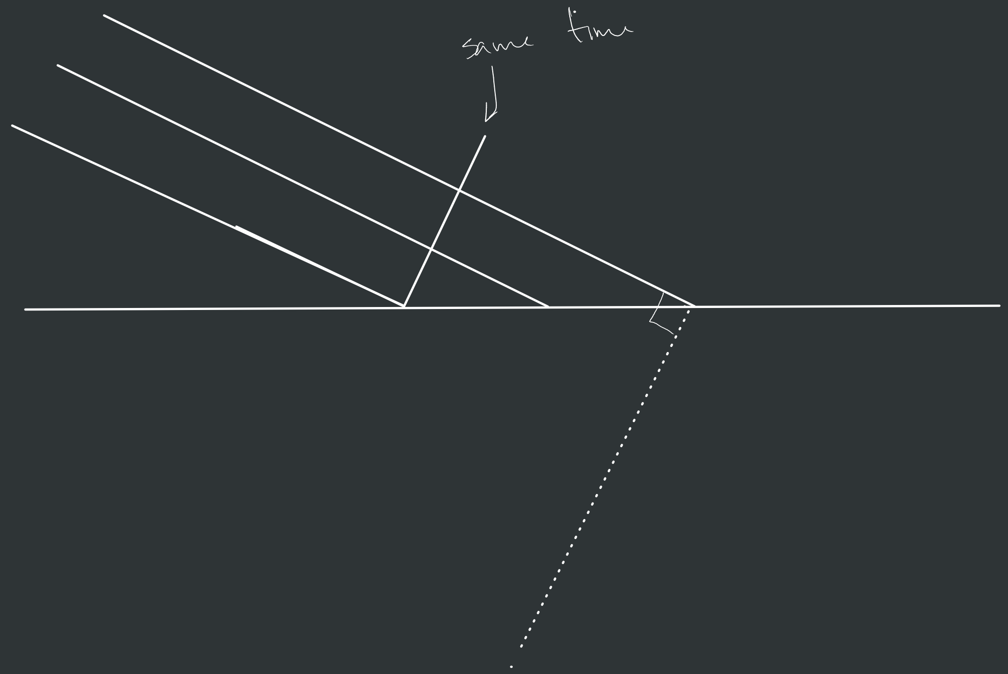
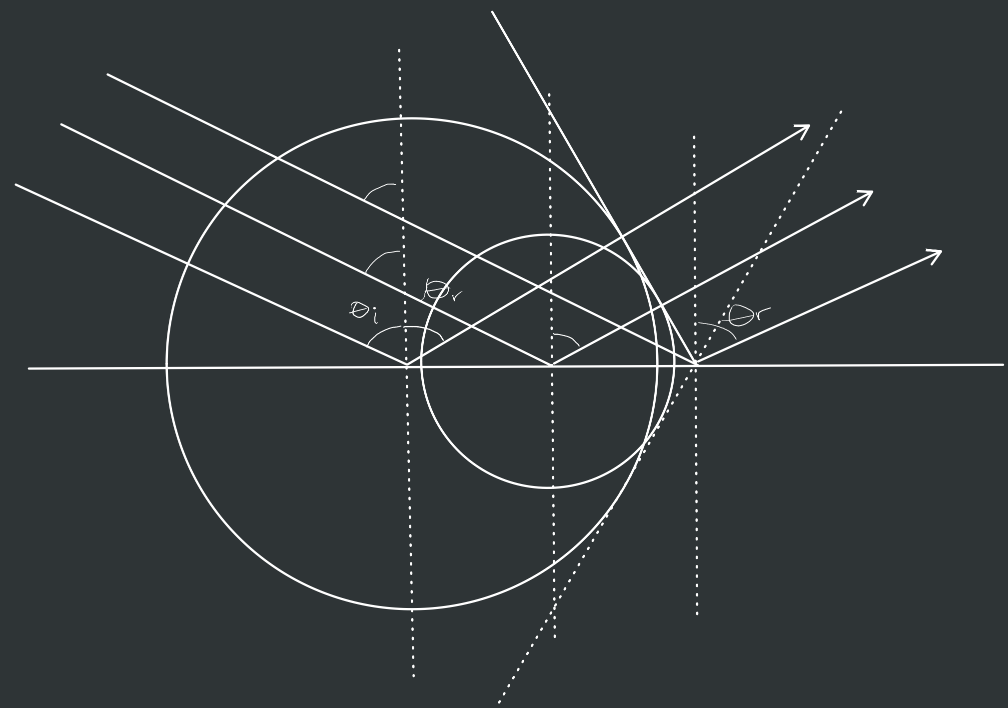
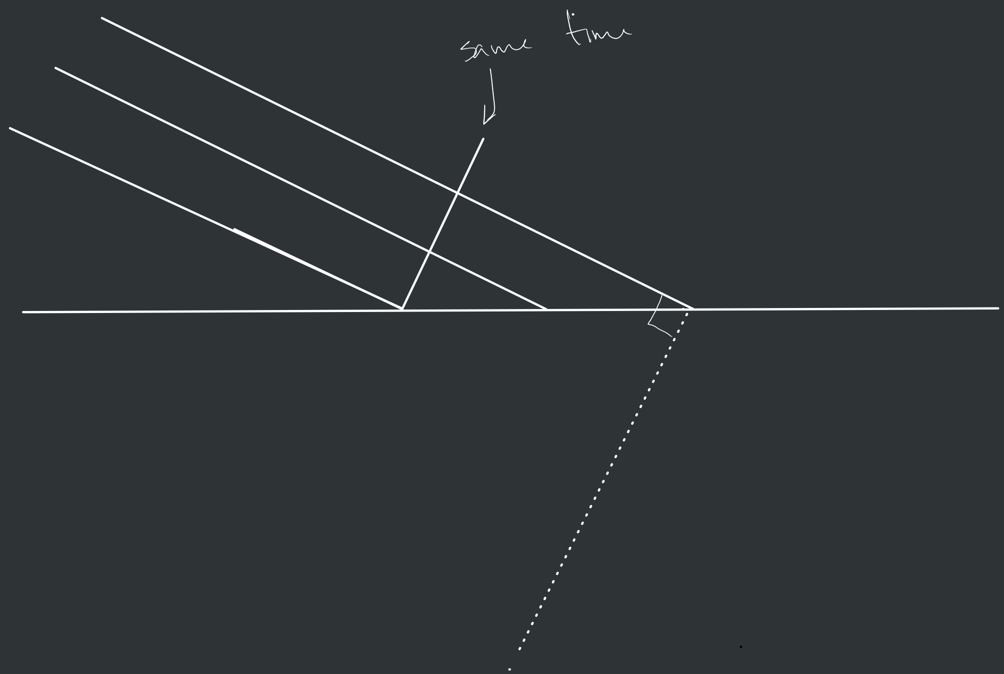
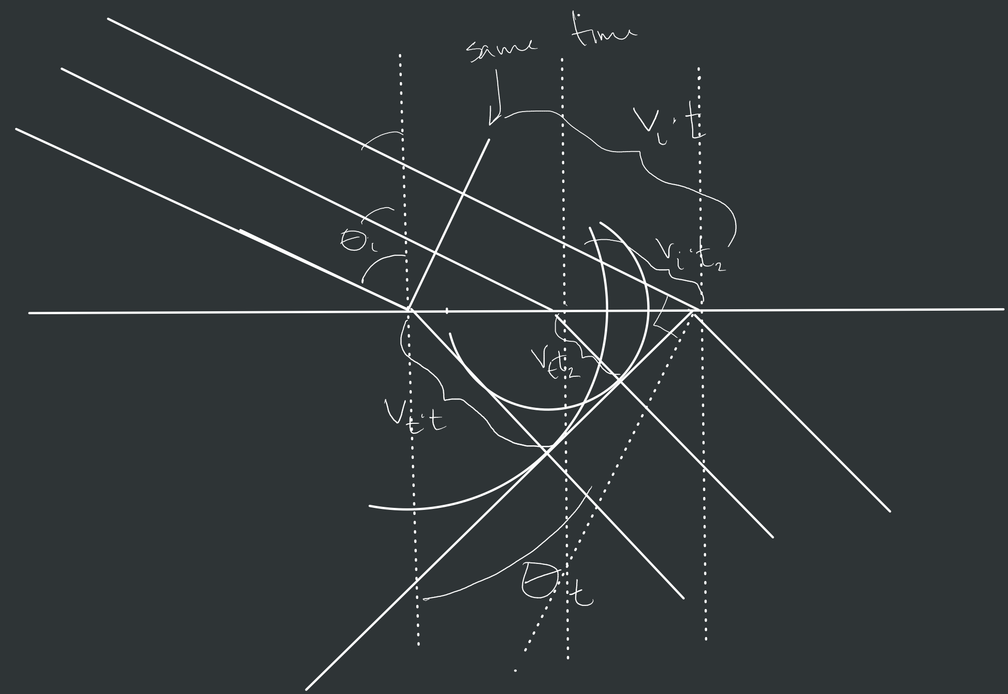




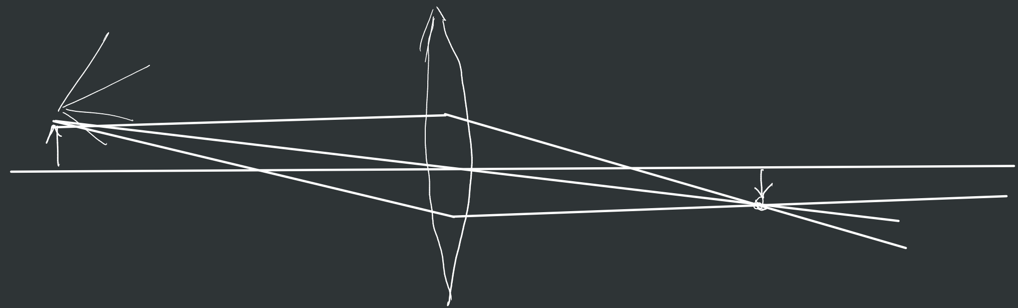

same time

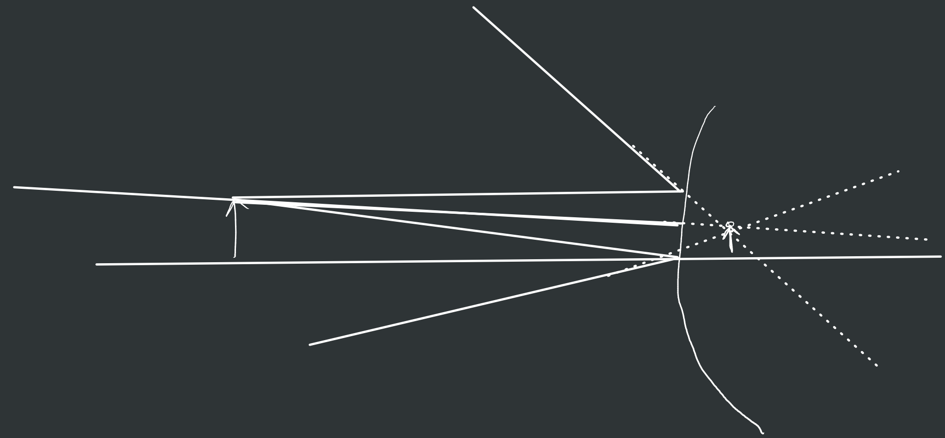

θ_i
θ_r
θ_r

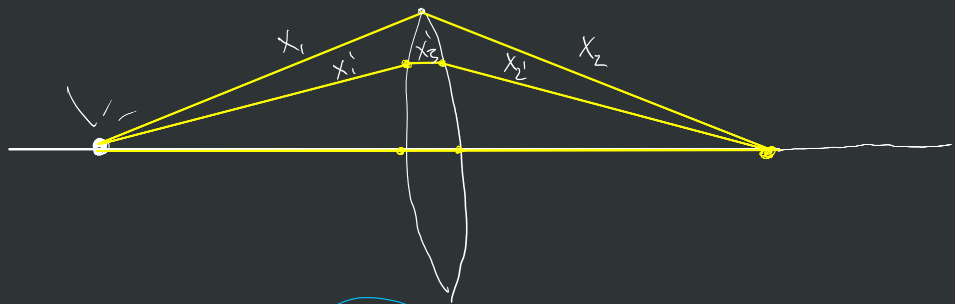

same time


same time
$V_i \cdot t$
θ_i
$V_i \cdot t_2$
$V_t \cdot t_2$
$V_t \cdot t$

Chapter 2 problems: 3, 4, 9, 11, 13, 19, 22, + one more







$$\rightarrow \quad t = \frac{x}{v} = \frac{n \cdot x}{c}$$

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

$$\frac{n x_1}{\cancel{c}} + \frac{n x_2}{\cancel{c}} = \frac{n x_1'}{\cancel{c}} + \frac{n_2 x_3'}{\cancel{c}} + \frac{n x_2'}{\cancel{c}}$$

$$n x_1 + n x_2 = n x_1' + n x_2' + \underline{n_2 x_3'}$$

through the lens

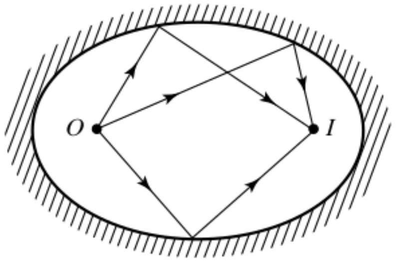
$$\rightarrow \quad \frac{\#\text{ of}}{\text{wavelengths}} = \frac{x_1}{\lambda} = \frac{n \cdot x_1}{\lambda_0}$$

$$\lambda = \frac{\lambda_0}{n} \quad \leftarrow \text{in vacuum}$$

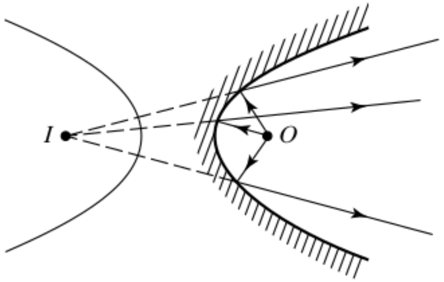
$$\frac{n x_1}{\cancel{\lambda_0}} + \frac{n x_2}{\cancel{\lambda_0}} = \frac{n x_1'}{\cancel{\lambda_0}} + \frac{n x_2'}{\cancel{\lambda_0}} + \frac{n_2 x_3'}{\cancel{\lambda_0}}$$

<u>optical path length</u>

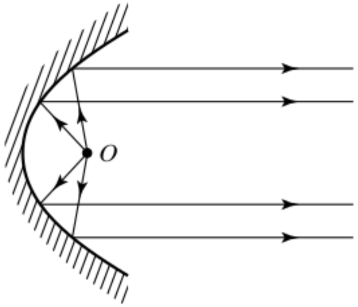
REFLECTION



(a) Ellipsoid



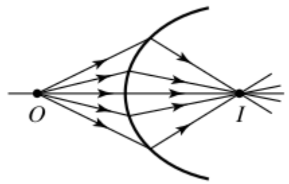
(b) Hyperboloid



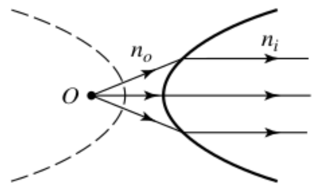
(c) Paraboloid

Figure 11 Cartesian reflecting surfaces showing conjugate object and image points.

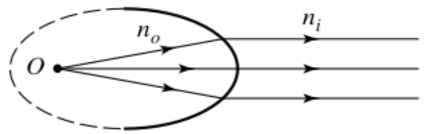
REFRACTION



(a)



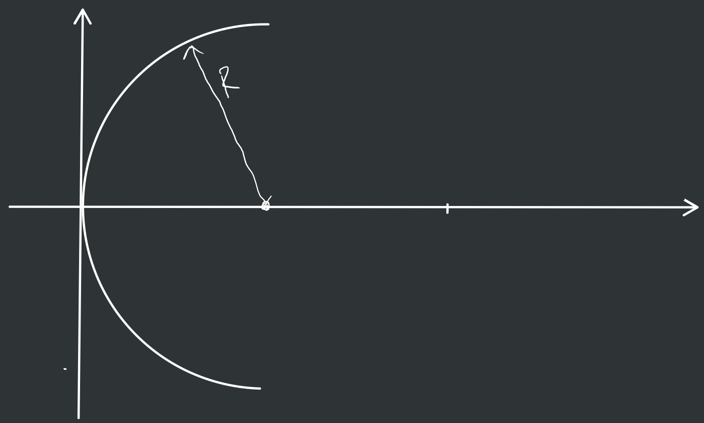
(b)



(c)

Figure 13 Cartesian refracting surfaces. (a) Cartesian ovoid images O at I by refraction. (b) Hyperbolic surface images object point O at infinity when O is at one focus and $n_i > n_o$. (c) Ellipsoid surface images object point O at infinity when O is at one focus and $n_o > n_i$.

→ Reflection from Spherical Surfaces



$$y^2 + (x-R)^2 = R^2$$

$$y^2 + x^2 - 2xR + \cancel{R^2} - \cancel{R^2} = 0$$

$$x^2 - 2Rx + y^2 = 0$$

$$a = 1 \quad b = -2R \quad c = y^2$$

$$x = \frac{+2R \pm \sqrt{4R^2 - 4y^2}}{2}$$

$$x = R \pm \sqrt{R^2 - y^2}$$

$$x < R$$

$$x = R - (R^2 - y^2)^{1/2}$$

$$x = R - \left(R^2\left(1 - \frac{y^2}{R^2}\right)\right)^{1/2}$$

$$x = R - R\left(1 - \frac{y^2}{R^2}\right)^{1/2}$$

paraxial region

$$x \approx R - R\left(1 - \frac{1}{2}\cdot\frac{y^2}{R^2}\right)$$

$$x \approx R - R + \frac{1}{2}\frac{y^2}{R}$$

$$x \approx \frac{1}{2}\frac{y^2}{R} \xleftrightarrow[\text{to}]{\text{compare}} x = \frac{y^2}{4f}$$

$$2R = 4f \rightarrow f = \frac{R}{2}$$

binomial series

k

$$\underbrace{(1+x)^n = 1 + nx}_{} + \frac{1}{2}n(n-1)x^2 + \frac{1}{6}n(n-1)(n-2)x^3 + \dots$$

$$= \sum_{k=0}^{\infty} \binom{n}{k} x^k$$

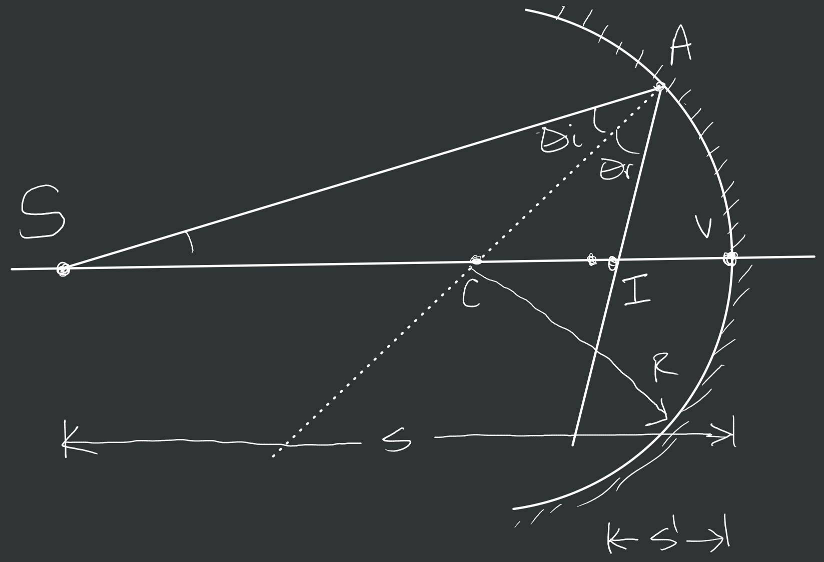
$$\binom{n}{k} = \frac{n!}{k!(n-k)!}$$

← combination

← multiplicity!

$$x = \frac{y^2}{2R} + \Delta x$$

$$\Delta x = \underbrace{\frac{y^4}{8R^3} + \frac{y^6}{16R^5}}_{\text{only significant for large values of } y.}$$



CA is an angle bisector
$\angle SAI$

$$\boxed{\frac{SC}{SA} = \frac{CI}{IA}}$$

$SA \approx s$

$IA \approx s'$

$SC \approx s - |R|$

$SC = s + R$

$CI \approx |R| - s'$

$CI = -R - s'$

$$\frac{s+R}{s} = -\frac{R+s'}{s'}$$

$$1 + \frac{R}{s} = -\frac{R}{s'} - 1$$

$-1 \quad +R/s' \quad +R/s' \quad -1$

$$\frac{R}{s} + \frac{R}{s'} = -2$$

$$\frac{1}{s} + \frac{1}{s'} = \frac{-2}{R}$$

$$f = \lim_{s \to \infty} s'$$

$$\frac{1}{s'} = -\frac{2}{R} \equiv \frac{1}{f}$$

mirror equation

$$\boxed{f = -\frac{R}{2} \qquad \frac{1}{s} + \frac{1}{s'} = \frac{1}{f}}$$

Sign convention for mirrors

- light travels from left to right
- mirror surfaces point leftward

real object, $s > 0$, to the left of mirror vertex

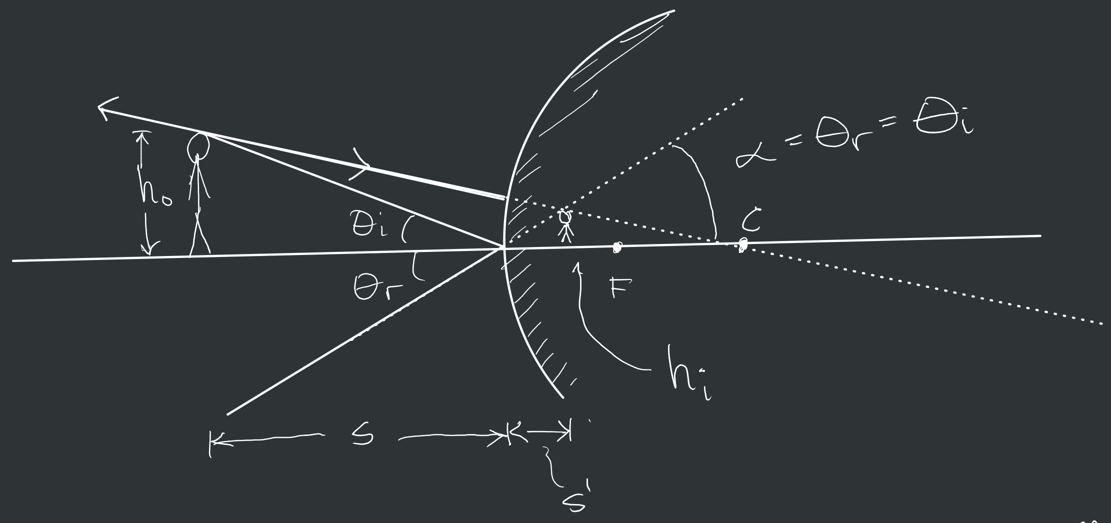
real image, $s' > 0$, to the left of mirror vertex

radius of curvature, $R > 0$, to the right of mirror vertex (convex)

$R < 0$ for concave

$f > 0$ for concave

$f < 0$ for convex



$$\frac{h_o}{s} = \frac{h_i}{s'} \quad \Big\} \text{ all magnitudes}$$

$$m = \frac{h_i}{h_o} = -\frac{s'}{s} \quad \Big\} \text{ incorporates sign convention}$$

magnification

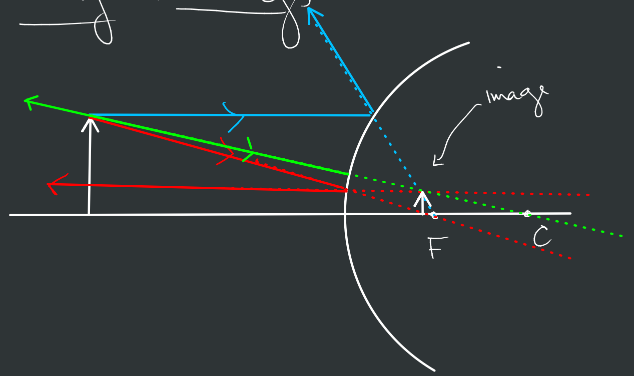
$m > 0 \longrightarrow$ upright, erect

$m < 0 \longrightarrow$ inverted

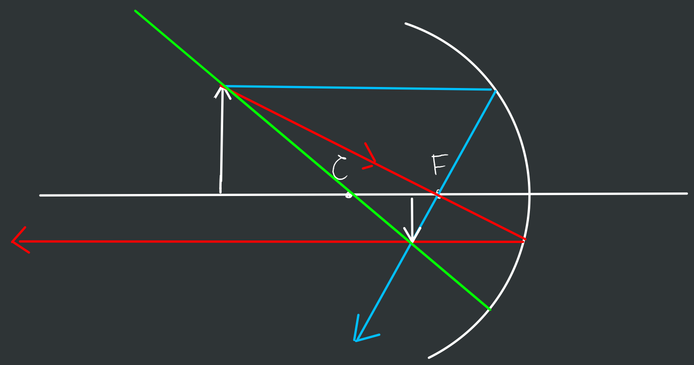
$0 < |m| < 1 \longrightarrow$ diminished, smaller

$|m| > 0 \longrightarrow$ enlarged, larger

Ray tracings

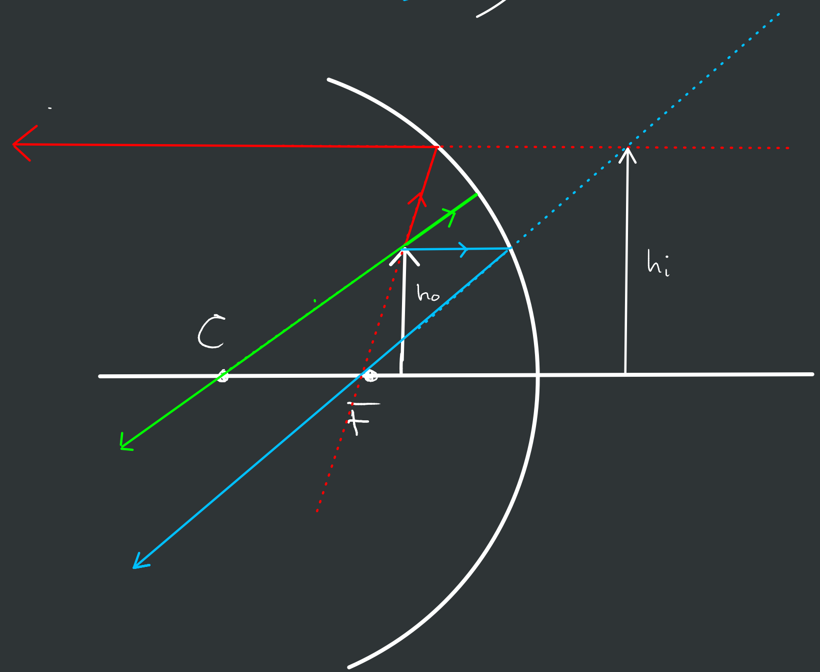


Ray 1 – parallel to axis
goes through the focal point

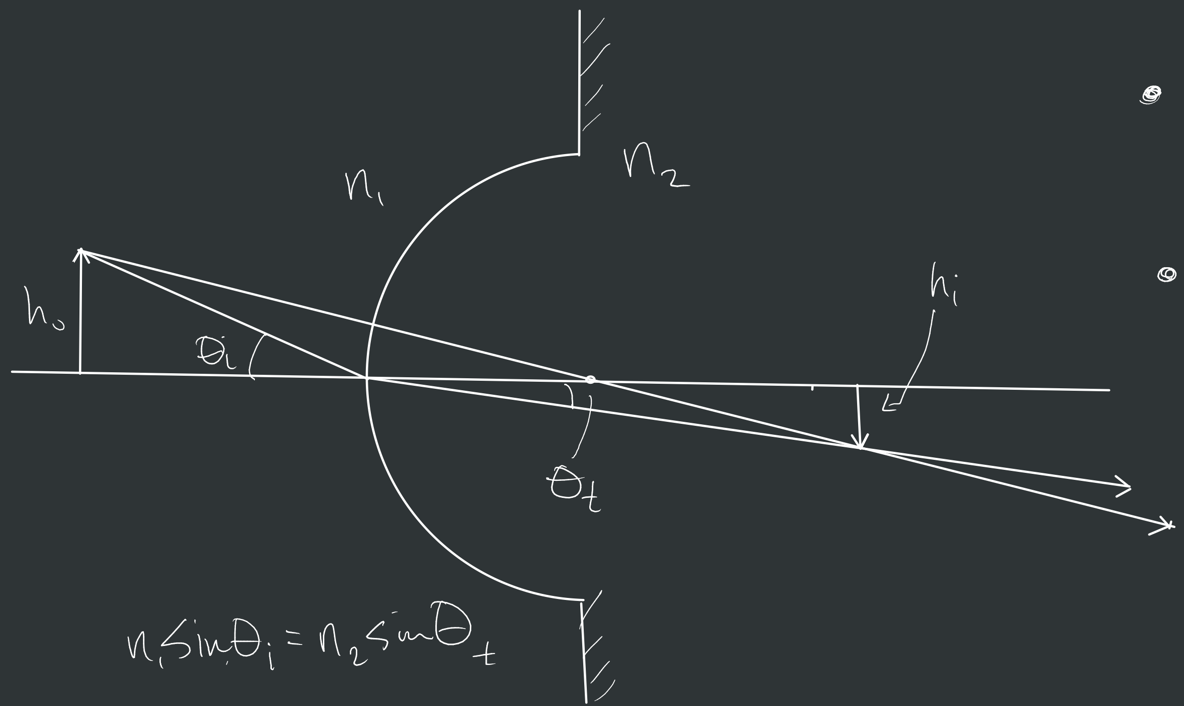


Ray 2 – go through the focal
point and reflect
parallel to the optical axis

Ray 3 – toward center of circle
reflects on itself



Refraction at a Spherical Surface



$n_1 \sin\theta_i = n_2 \sin\theta_t$

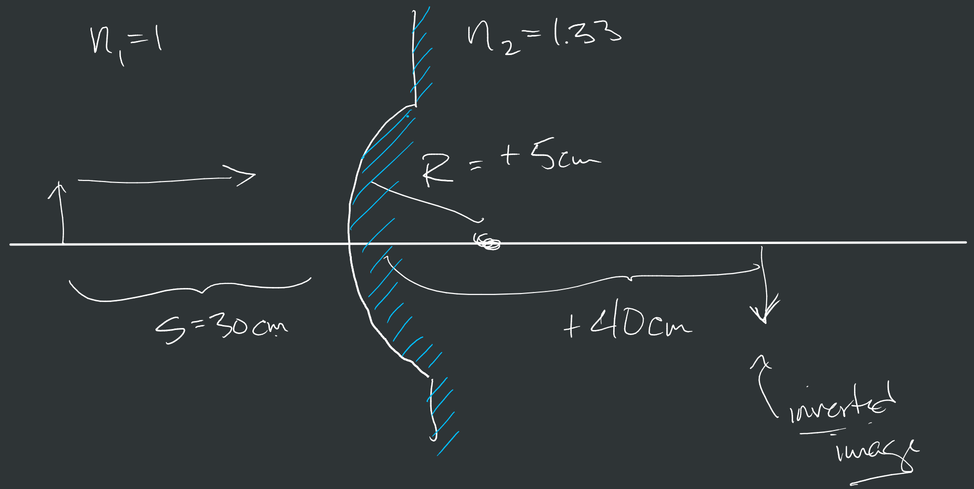
- $$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$$
- $$m = \frac{h_i}{h_o} = -\frac{n_1 s'}{n_2 s}$$

---

what if $R \to \infty$

$$\frac{n_1}{s} + \frac{n_2}{s'} = 0$$

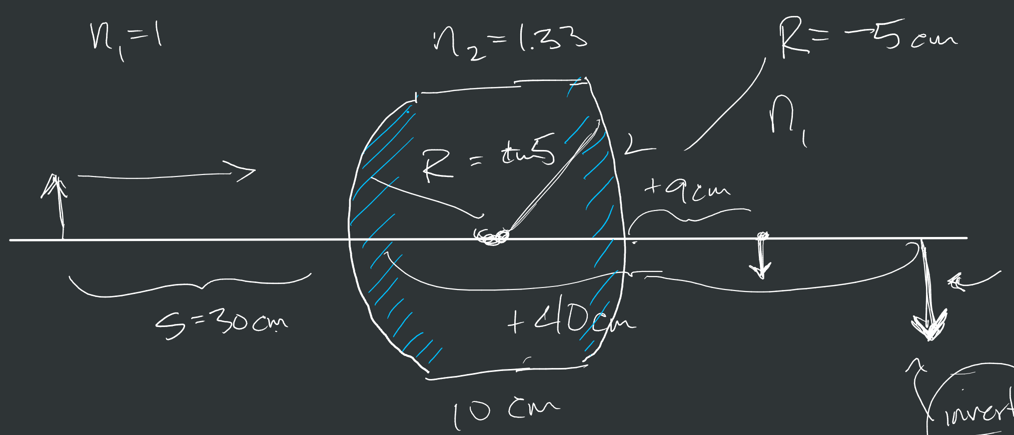
$$\underbrace{s' = -\left(\frac{n_2}{n_1}\right) s}_{\text{apparent depth}}$$



$$\frac{1}{30\text{ cm}} + \frac{1.33}{s'} = \frac{1.33 - 1}{5\text{cm}}$$

$\hookrightarrow s' = +40\text{cm}$

$$m = -\frac{n_1 s'}{n_2 s} = \frac{-1 \cdot 40\text{cm}}{1.33 \cdot 30\text{cm}} = -1$$



object n, image n

$$\frac{1.33}{S_2} + \frac{1}{S_2'} = \frac{1-1.33}{R}$$

−30cm, −5cm

$$\boxed{S_2' = +9 \text{ cm}}$$

w.r.t. sign of object height

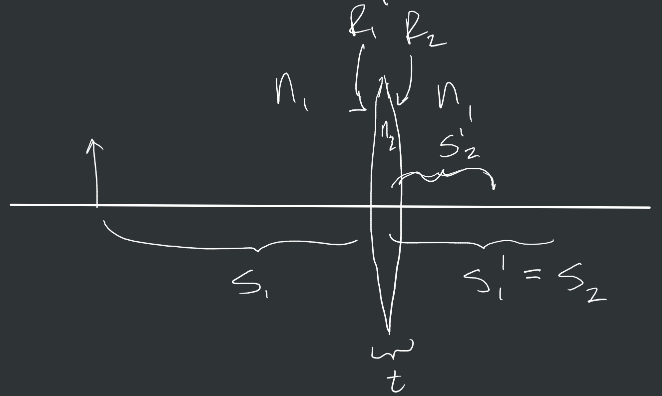
$$m_2 = -\frac{1.33}{1}\cdot\frac{9\text{cm}}{-30\text{cm}} = +0.4$$

$h_i<0$

$$m_2 = \frac{h_i}{h_o} = +0.4$$

$h_o<0$

Thin lens equation



#1

- $$\boxed{\frac{n_1}{S_1} + \frac{n_2}{S_1'} = \frac{n_2-n_1}{R_1}}$$
- $$\frac{n_2}{S_2} + \frac{n_1}{S_2'} = \frac{n_1-n_2}{R_2} \rightarrow$$

#2

$$\boxed{-\frac{n_2}{S_1'} + \frac{n_1}{S_2'} = \frac{n_1-n_2}{R_2}}$$

- $S_2 = t - S_1'$

thin lens $t \approx 0$

$$S_2 = -S_1'$$

Add #1 + #2

$$\frac{n_1}{s_1} + \frac{n_1}{s_2'} = \frac{n_2 - n_1}{R_1} + \frac{n_1 - n_2}{R_2} = \frac{n_2 - n_1}{R_1} - \frac{n_2 - n_1}{R_2} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{n_1}{s} + \frac{n_1}{s'} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

object distance

final image distance

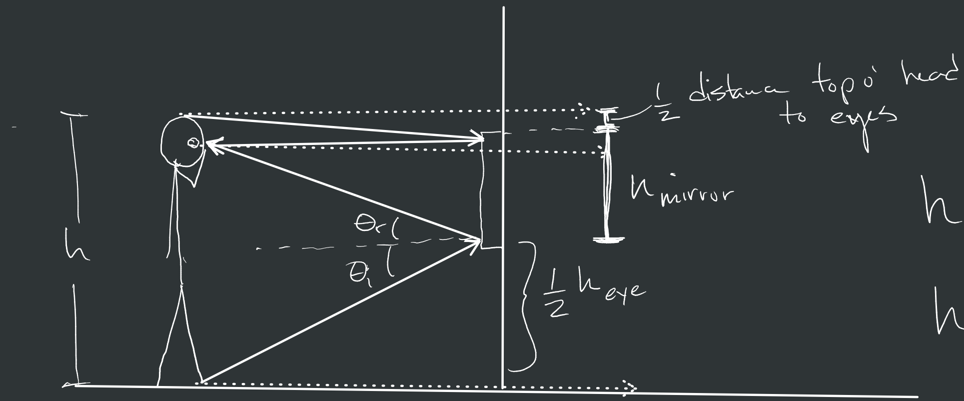
$$\boxed{\frac{1}{s} + \frac{1}{s'} = \frac{(n_2 - n_1)}{n_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

thin lens equation

$$\boxed{\frac{1}{f} = \frac{(n_2 - n_1)}{n_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

lens makers equation

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

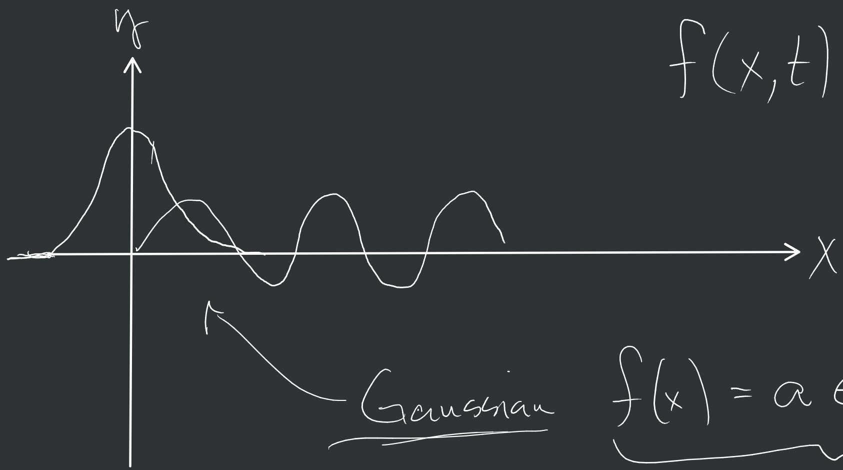


$$h = \frac{1}{2} h_{eye} + h_{mirror} + \frac{1}{2} \text{top o' head to eyes}$$

$$h = \frac{1}{2} \underbrace{\left(h_{eye} + \text{top o' head to eye} \right)}_{h} + h_{mirror}$$

$$h = \frac{1}{2} h + h_{mirror}$$

$$\boxed{\frac{1}{2} h = h_{mirror}}$$



$$f(x,t) = f(x - vt)$$

speed of wave

Gaussian $\underbrace{f(x) = a e^{-kx^2}}$

Gaussian wave $\rightsquigarrow f(x,t) = a e^{-k(x-vt)^2}$

Sine wave

$$f(x) = a\sin(kx) \rightsquigarrow f(x,t) = a\sin\big(k(x-vt)\big)$$

move to the right in time