Chapter 4ish - 5ish

wavelength - distance of an oscillation
- one electric field max to another max
- λ, meters, cm, nm

period - time for one oscillation to pass a point as the wave goes by
- T, seconds

kappa cursive kay

wavenumber - $\frac{1}{\lambda}$ K, k

propogation constant $\frac{2\pi}{\lambda} = k$

nu

frequency - $\nu = \frac{1}{T} = \text{Hz}$

angular frequency $\frac{2\pi}{T} = 2\pi\nu$

speed $\rightarrow$ $v = \frac{\lambda}{T} = \lambda \cdot f = \lambda\nu$

in materials, light slows down

$c \rightarrow$ speed of light in vacuum

$\rightarrow v < c$

$\underbrace{\frac{c}{v}} = n \leftarrow$ index of refraction

conventionally $n \geq 1$

but can be negative (metamaterials)

and can be complex (absorptive materials)

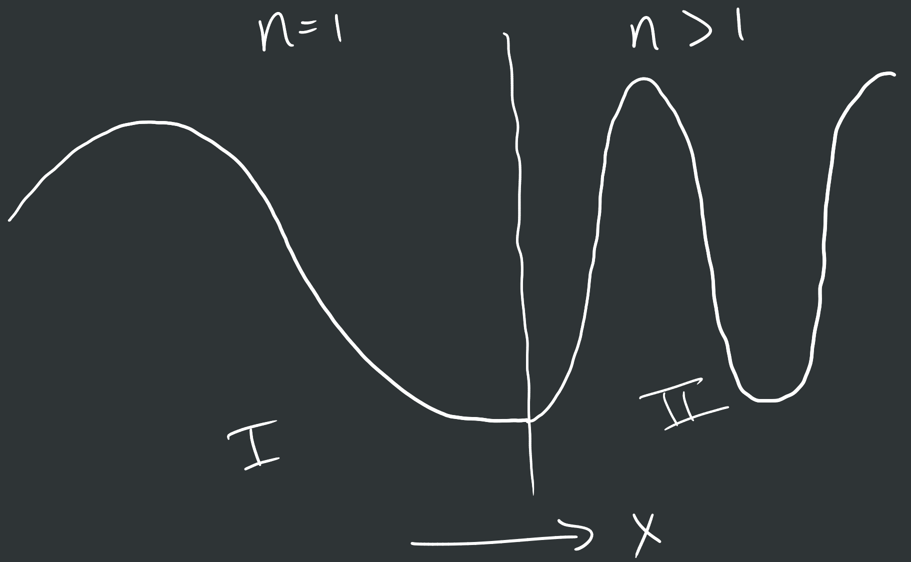
$$v = \frac{c}{n} = \lambda \cdot \nu$$

$\rightarrow$ if n increases at some boundary λ decreases, but not ν.

ν is constant

- $E = h \cdot \nu = \frac{hc}{n\lambda}$

$\rightarrow$ Planck's constant



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

$$\frac{c}{n_1 \lambda_1} = \nu = \frac{c}{n_2 \lambda_2}$$

$$\frac{\cancel{c}}{n_1 \lambda_1} = \frac{\cancel{c}}{n_2 \lambda_2}$$

$$\frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2}$$

$$\frac{n_2}{n_1} = \left(\frac{\lambda_2}{\lambda_1}\right)^{-1}$$

I is vacuum

$$\frac{n}{1} = \left(\frac{\lambda_2}{\lambda_0}\right)^{-1}$$

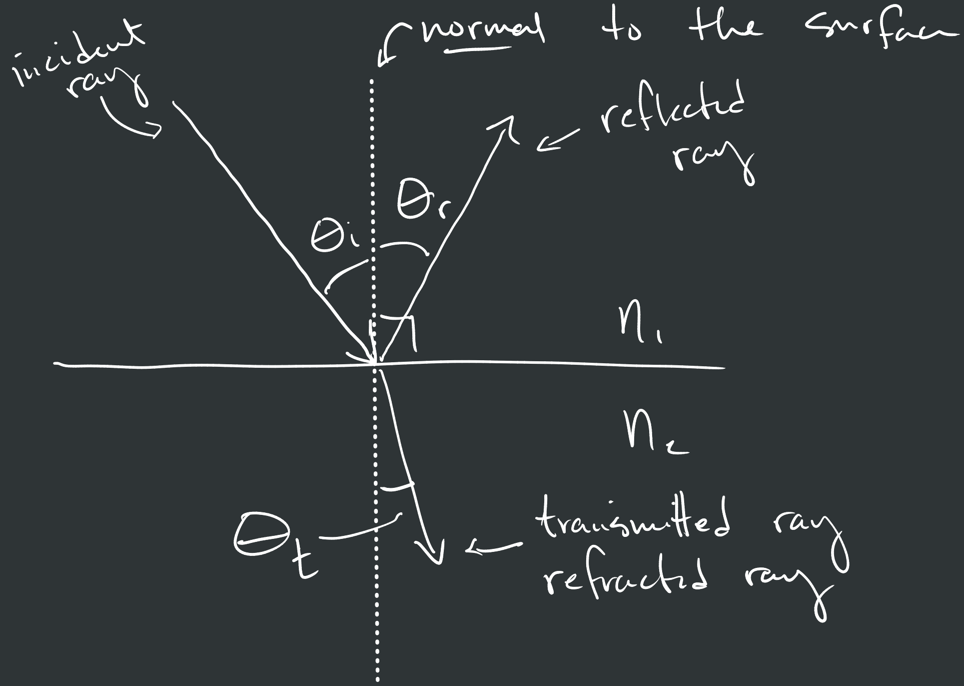
n=1 in vacuum

in vacuum

$$\lambda_2 = \frac{\lambda_0}{n}$$

$n > 1$

so this goes down w/ n



Law of Reflection

$$\rightarrow \theta_i = \theta_r$$

Law of Refraction (Snell's Law)

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

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

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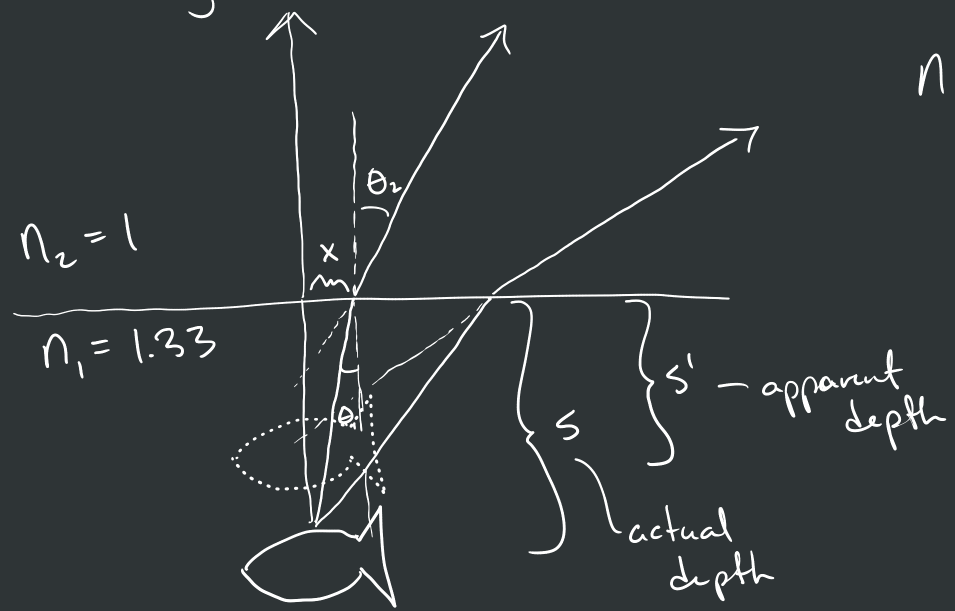
fishing



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

for small θ, $\sin\theta \approx \tan\theta \approx \theta$

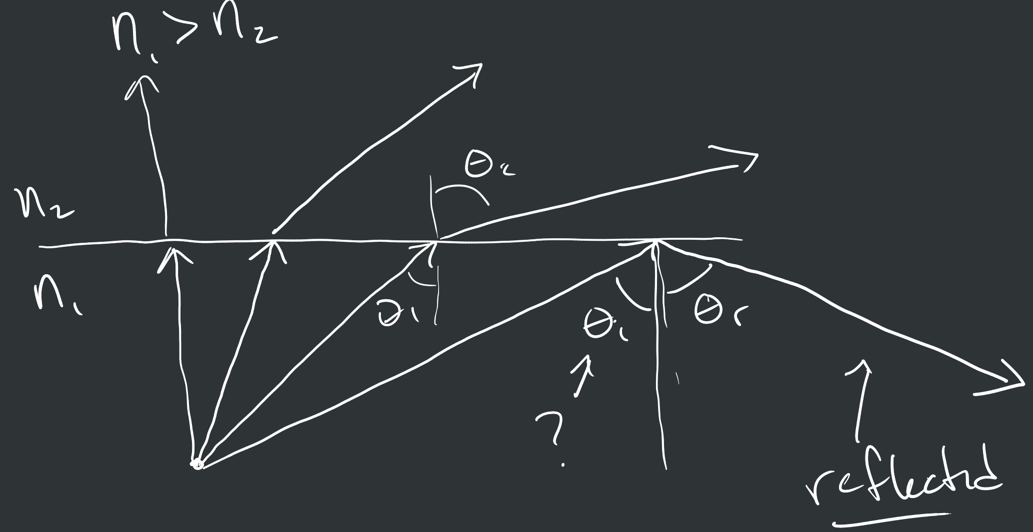
$$n_1 \tan\theta_1 = n_2 \tan\theta_2$$

$$\frac{n_1 \cancel{x}}{s} = \frac{n_2 \cancel{x}}{s'}$$

$$\frac{s'}{s} = \frac{n_2}{n_1} = \frac{1}{1.33} \approx 0.752$$

$$s' = 0.752 \cdot s$$

critical angle



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

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

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_1\right)$$

what θ_1 causes θ_2 to be 90°

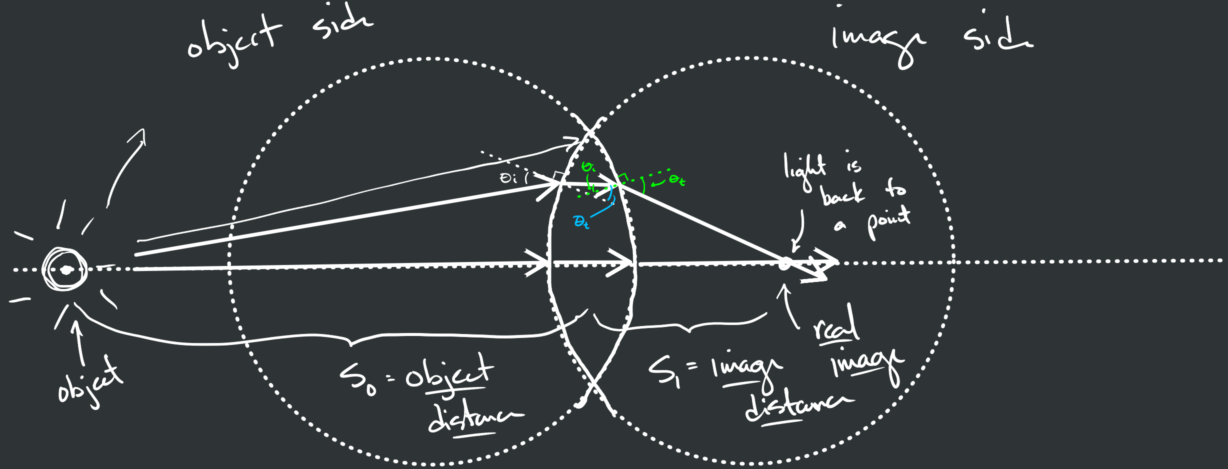
$$\underbrace{\sin\theta_2}_{} = \underbrace{\frac{n_1}{n_2}\sin\theta_1}_{\text{when this is } \geq 1}$$

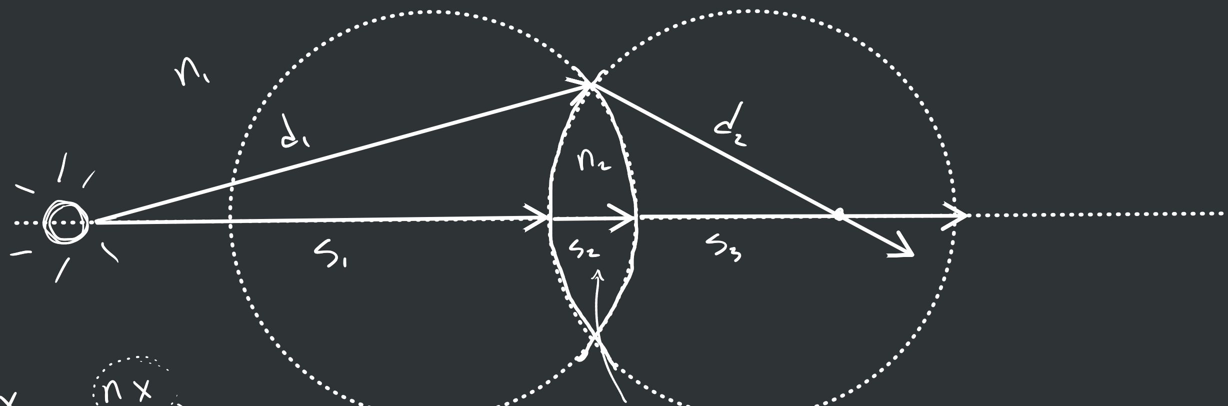
$$1 = \frac{n_1}{n_2}\sin\theta_1$$

critical angle $\longrightarrow$ $\theta_1 = \theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

< 1

HW: Chapter 4: 6, 7, 8, 21, 24





$$t = \frac{x}{v} = \frac{n\,x}{c}$$

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

optical path length

$$\frac{n_1 d_1}{\cancel{c}} + \frac{n_1 d_2}{\cancel{c}} = \frac{n_1 s_1}{\cancel{c}} + \frac{n_2 s_2}{\cancel{c}} + \frac{n_1 s_3}{\cancel{c}}$$

$$n_1 d_1 + n_1 d_2 = n_1 s_1 + n_2 s_2 + n_1 s_3$$ } optical path lengths are the same!

perfect images

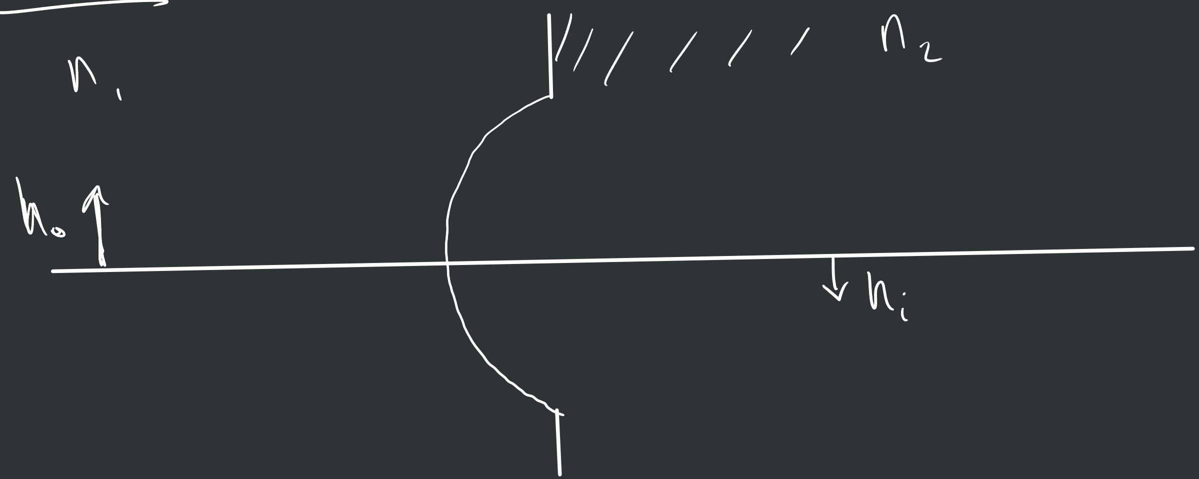
reflection

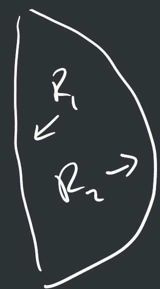
- ellipsoid
- hyperboloid
- parabola

refraction

- ellipsoid
- hyperboloid
- cartesian oval

Refraction





Thin lens

$$\frac{n_1}{S_o} + \frac{n_2}{S_i} = \frac{n_2 - n_1}{R}$$

object distance

image distance

thin lens (Lens Makers Equation)

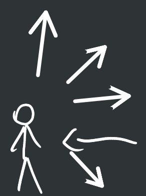
$$\frac{1}{S_o} + \frac{1}{S_i} = (n_\ell - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f} = (n_\ell - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

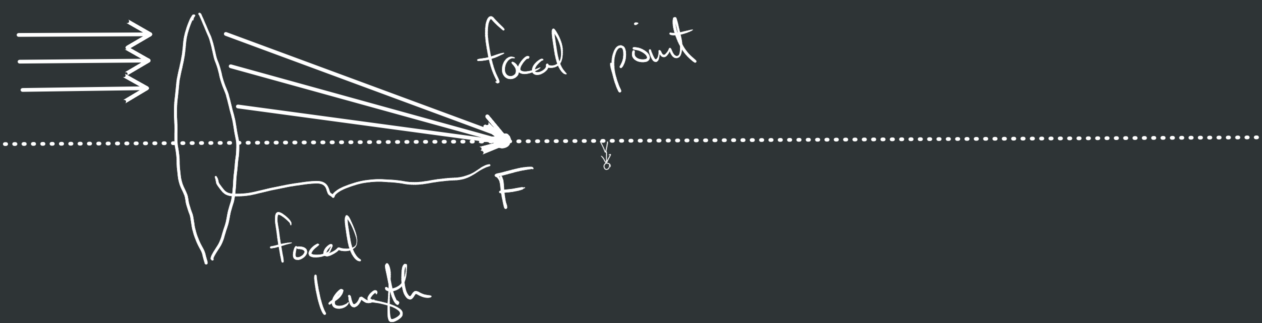
focal length

(Thin Lens Equation)

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$$



infinity far away



	+	−
s_o	real object	virtual object
s_i	real image	virtual image
f	converging lens	diverging lens
y_o	upright object	inverted object
y_i	upright image	inverted image

Optics Lab:

Conjugate Points: $\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$

Focal Length Exp: $\overset{\to 0}{\cancel{\frac{1}{s_o \to \infty}}} + \frac{1}{s_i} = \frac{1}{f}$

$\frac{1}{s_i} = \frac{1}{f} \Rightarrow s_i = f$ for $s_o \to \infty$

Diverging Lens: $$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{-f}$$

$$\frac{1}{S_i} = \frac{1}{-f} - \frac{1}{S_o}$$

$$S_i = \frac{1}{\frac{1}{-f} - \frac{1}{S_o}}$$

Finding a virtual image:

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$$

$$\frac{1}{S_i} = \frac{1 S_o}{f S_o} - \frac{1 f}{S_o f} = \frac{S_o - f}{f S_o}$$

$$S_i = \frac{S_o \cdot f}{S_o - f}$$

MINE: $S_o = 27$ cm

$f = -15$ cm

$$S_i = \frac{27(-15)}{27+15} = -9.60 \text{ cm}$$

Now for the check:

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

$s_i = 16.2$ cm

$f = 10$ cm

$s_o = 26.13$

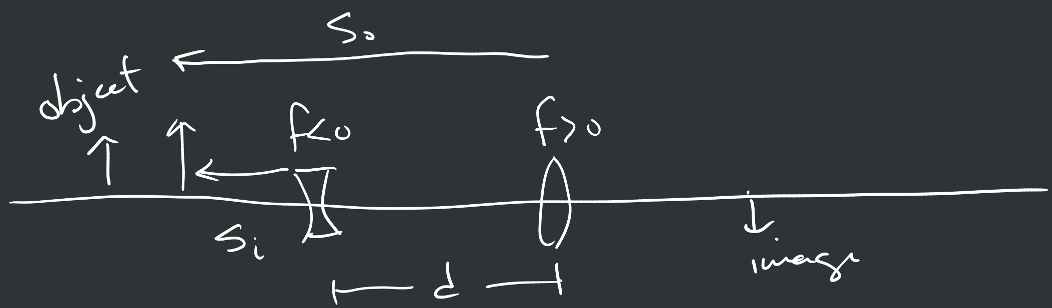
$$s_o = \frac{s_i \cdot f}{s_i - f}$$

$$s_o = \frac{16.2 \cdot 10}{16.2 - 10}$$

$$s_o = 26.13$$

So now we need to compare

$$s_o = d - s_i$$



$26.13 = d - (-9.6)$

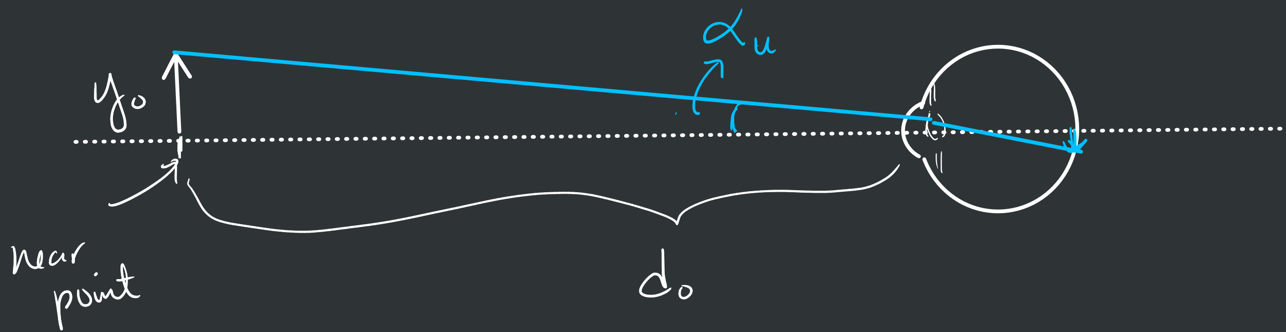
$16.53 = d$

17.3 <u>measured</u>

Optical Devices

Magnifying Glass

Unaided Eye



magnifying power

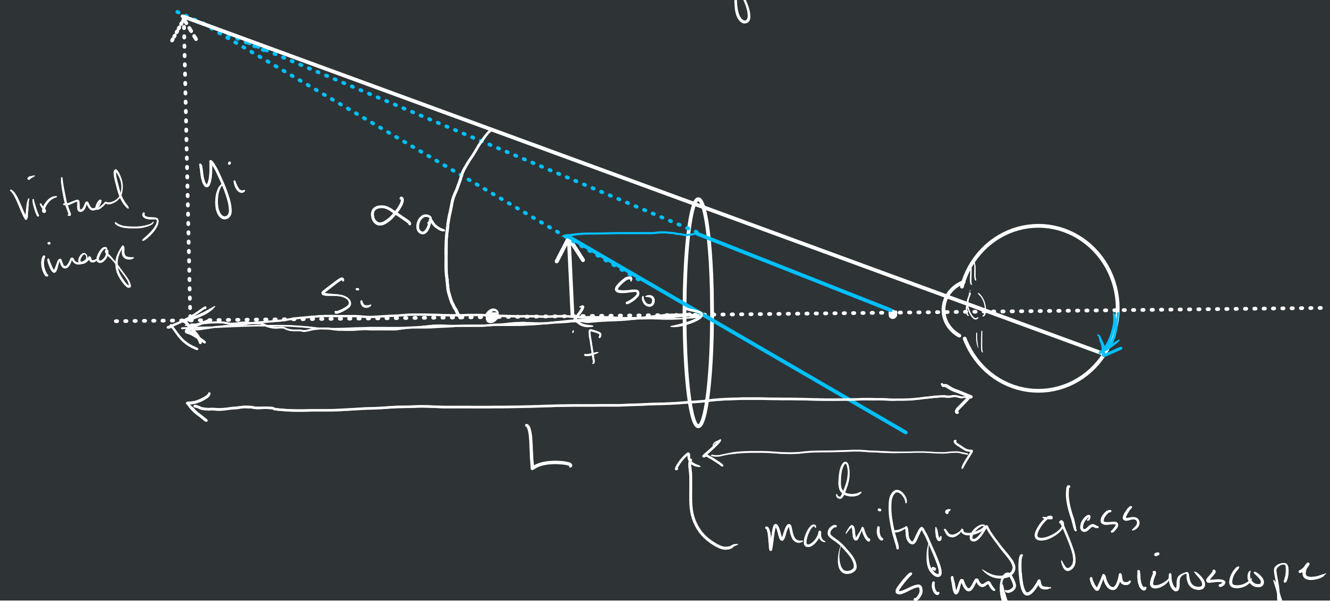
angular magnification

$$MP = M_A = \frac{\alpha_a}{\alpha_u}$$

radians

$$\tan \alpha_u = \frac{y_o}{d_o} \approx \sin \alpha_u \approx \alpha_u$$

Aided Eye



$$\tan \alpha_a = \frac{y_i}{L} \approx \alpha_a$$

$$MP = \frac{y_i}{L} \cdot \frac{d_o}{y_o}$$

this is positive

$$M_t = \frac{y_i}{y_o} = -\frac{s_i}{s_o}$$

$57.3° \leftarrow 1\,\text{rad} \cdot \frac{180}{\pi} = 57.3°$

$\tan 1\,\text{rad} = 1.557$

$\tan 0.1\,\text{rad} = 0.10033$

$\hookrightarrow 5.73°$

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$$

$$S_i \left[\frac{1}{S_o} = \frac{1}{f} - \frac{1}{S_i} \right] S_i$$

$$\frac{S_i}{S_o} = \frac{S_i}{f} - 1$$

$$-\frac{S_i}{S_o} = \boxed{1 - \frac{S_i}{f}}$$

$$MP = -\frac{S_i}{S_o} \cdot \frac{d_o}{L}$$

$$MP = \left(1 - \frac{S_i}{f}\right) \frac{d_o}{L}$$

$$S_i = -(L - \ell)$$

$$MP = \left(1 + \frac{L - \ell}{f}\right) \cdot \frac{d_o}{L}$$

$\frac{1}{f} = \mathcal{D} \leftarrow$ dioptric power

$\mathcal{D}$

$\mathcal{D}$

$$\boxed{MP = \left(1 + (L - \ell)\mathcal{D}\right) \cdot \frac{d_o}{L}}$$ eq. 5.76

Case 1: $l = f$

$$[MP]_{l=f} = \left(1 + (L - l)\frac{1}{f}\right) \cdot \frac{d_o}{L}$$

$$= \left(\cancel{1} + \frac{\cancel{L}}{f} - \cancel{\frac{l}{f}}^{1}\right) \cdot \frac{d_o}{\cancel{L}}$$

$$[MP]_{l=f} = \frac{d_o}{f} = d_o \mathcal{D}$$

Case 2: $l = 0$

$$[MP]_{l=0} = \left(1 + (L - \cancel{l}^{0})\mathcal{D}\right) \cdot \frac{d_o}{L}$$

$$= (1 + L\mathcal{D})\frac{d_o}{L}$$

$$[MP]_{l=0} = \left(\frac{1}{L} + \mathcal{D}\right) \cdot d_o$$

if we chank L to d_o,

$$[MP]_{\substack{l=0 \\ L=d_o}} = \left(\frac{1}{d_o} + \mathcal{D}\right) \cdot d_o$$

$$[MP]_{\substack{l=0 \\ L=d_o}} = 1 + \mathcal{D} \cdot d_o$$

Case 3: We put the object at the focal point, $s_o = f$.

The image ~~is~~ formed

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

$$MP = \left(1 + (L - l)D\right) \cdot \frac{d_o}{L}$$

$$\frac{1}{f} + \frac{1}{s_i} = \frac{1}{f}$$

$$[MP]_{L\to\infty} = \cancelto{0}{\frac{d_o}{L}} + \frac{\cancel{L} \cdot D \cdot d_o}{\cancel{L}} - \cancelto{0}{\frac{l D \cdot d_o}{L}}$$

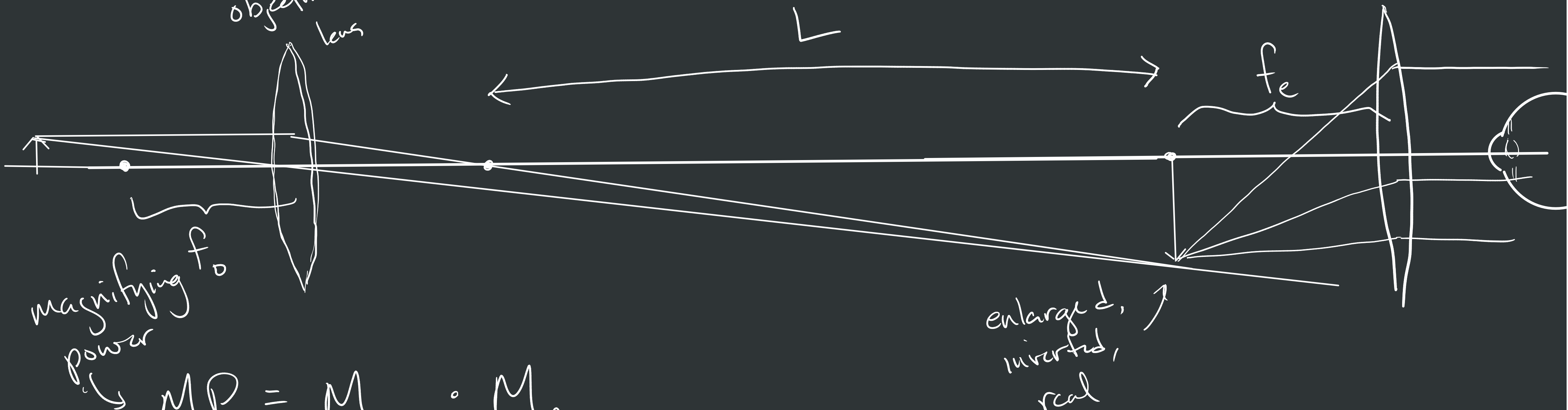
$$\frac{1}{s_i} = 0$$

$$s_i \to \infty$$

$$[MP]_{L\to\infty} = D \cdot d_o = \frac{d_o}{f}$$

HW: ch5. 25, 34, 42

Microscope



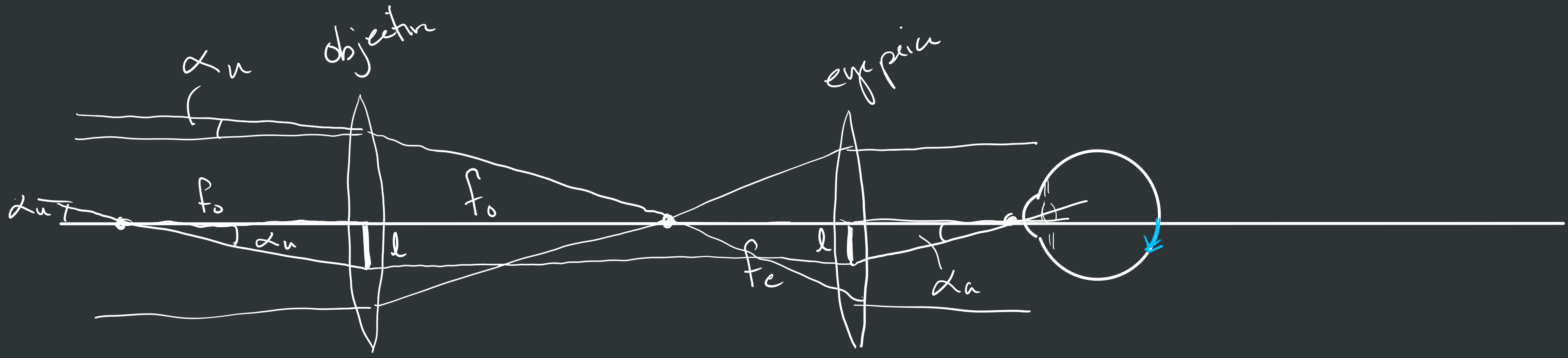
magnifying power

$$MP = M_{To} \cdot M_{Ae}$$

Objective lens usually has a very small focal length.

Eyepiece has a larger focal length

Telescope



$$MP = \frac{\alpha_a}{\alpha_u}$$

$$\alpha_u \approx \tan \alpha_u = \frac{l}{f_o}$$

$$\alpha_a \approx \tan \alpha_a = \frac{l}{f_e}$$

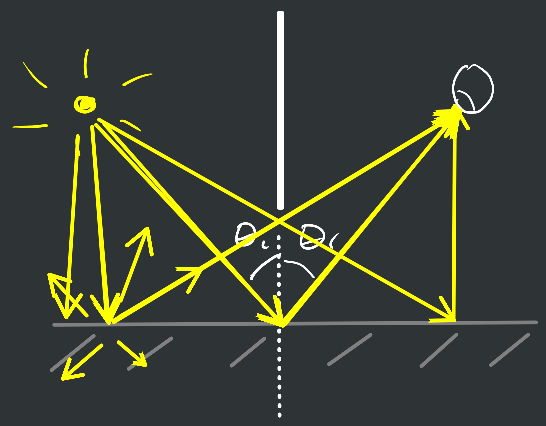
$$MP = \frac{l/f_e}{l/f_o}$$

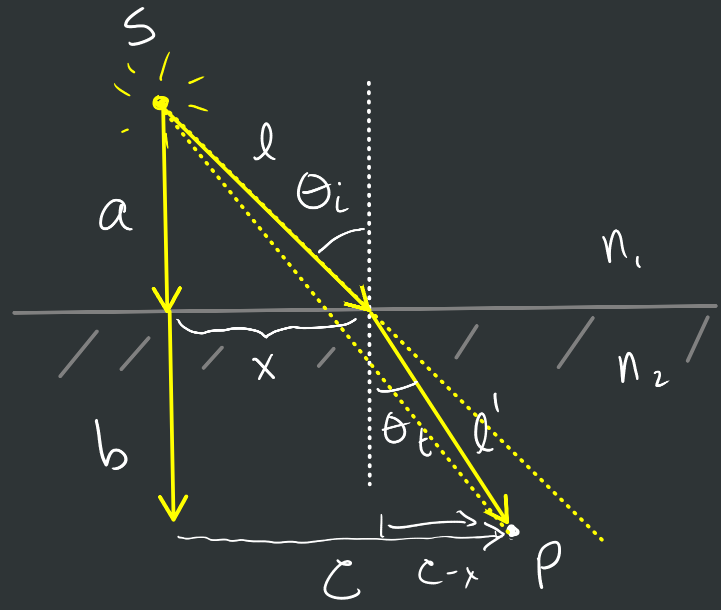
$$MP = \frac{f_o}{f_e}$$

$\longrightarrow$ so we want long focal length objectives

$\longrightarrow$ we want small focal length eyepieces

Law of Refraction: $n_1 \sin\theta_i = n_2 \sin\theta_t$





write an expression for the time:

$$t = \frac{l}{V_i} + \frac{l'}{V_t}$$

$$t = \frac{(a^2 + x^2)^{1/2}}{V_i} + \frac{(b^2 + (c-x)^2)^{1/2}}{V_t}$$

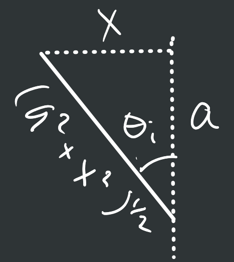
minimize t w.r.t. x

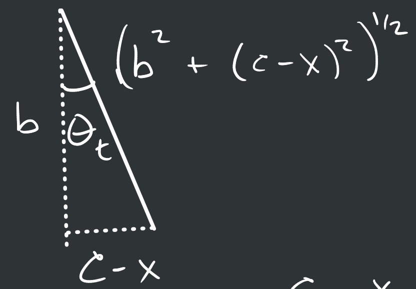
$$\frac{dt}{dx} = \frac{\cancel{1}}{\cancel{2}} \frac{(a^2+x^2)^{-1/2}}{v_i} \cdot \cancel{2}x + \frac{1}{\cancel{2}} \frac{(b^2+(c-x)^2)^{-1/2}}{v_t} \cdot \cancel{2}(c-x) \cdot (-1)$$

$$\frac{dt}{dx} = \frac{x}{v_i (a^2+x^2)^{1/2}} - \frac{(c-x)}{v_t (b^2+(c-x)^2)^{1/2}} = 0$$

minimize

$$\frac{x}{v_i (a^2+x^2)^{1/2}} = \frac{(c-x)}{v_t (b^2+(c-x)^2)^{1/2}}$$





$$\sin\theta_i = \frac{x}{(a^2+x^2)^{1/2}} \qquad \sin\theta_t = \frac{c-x}{(b^2+(c-x)^2)^{1/2}}$$

$$\frac{\sin\theta_i}{v_i} = \frac{\sin\theta_t}{v_t}$$

$$\frac{c}{v_i} = n_1 \qquad \frac{c}{v_t} = n_2$$

$$\frac{1}{v_i} = \frac{n_1}{c}$$

$$\boxed{n_1 \sin\theta_i = n_2 \sin\theta_t}$$

$$PV = N k_B T$$ ← Ideal Gas Law

$$\underbrace{\frac{N}{V}}_{\text{density}} = \frac{P}{k_B T}$$ ← inversely proportional to T

$$(n - 1) \propto \frac{N}{V}$$