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 $\downarrow$ $\swarrow$ cursive kay

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

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

nu

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

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

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

in materials, light slows down

C → speed of light in vacuum

↳ $V < C$

$\underbrace{\frac{C}{V}} = n$ ← index of refraction

conventionally $n \geq 1$

but can be negative (metamaterials)

and can be complex (absorptive materials)

$$V = \frac{C}{n} = \lambda \cdot \nu$$

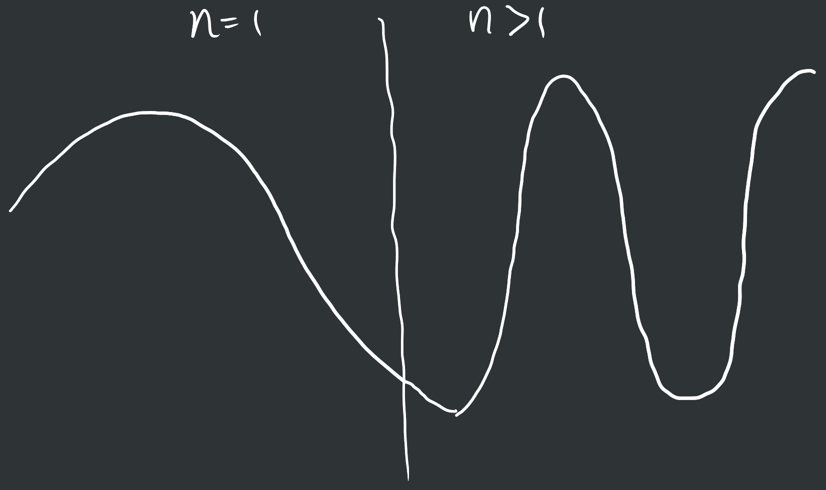
↳ if n increases at some boundary

λ decreases, but not ν.

ν is constant

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

↳ 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

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

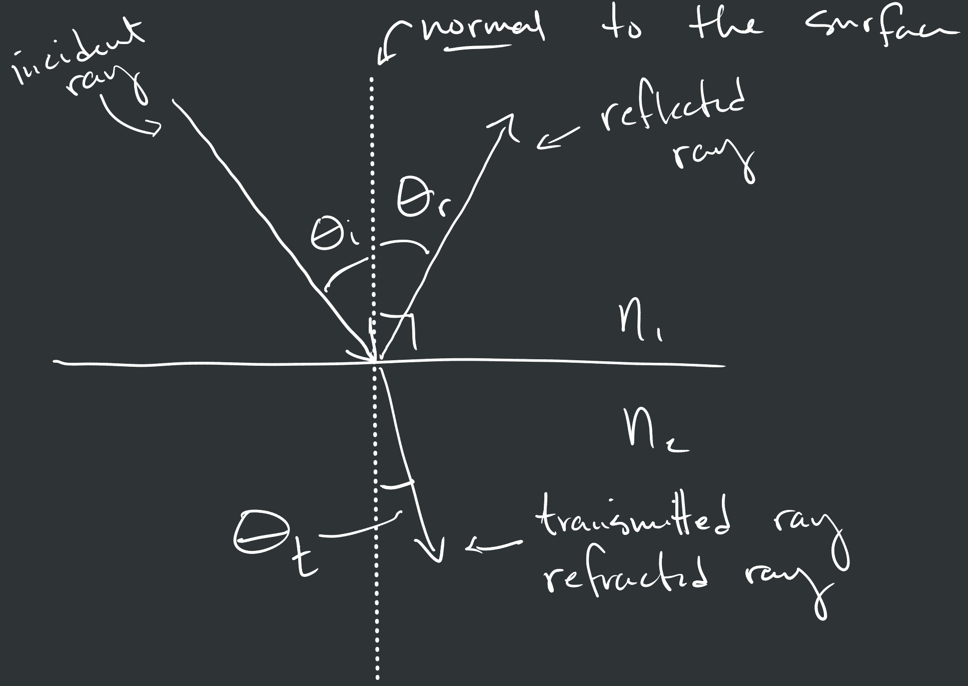
n=1 in vacuum

in vacuum

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

n > 1

so this goes down w/ n



Law of Reflection

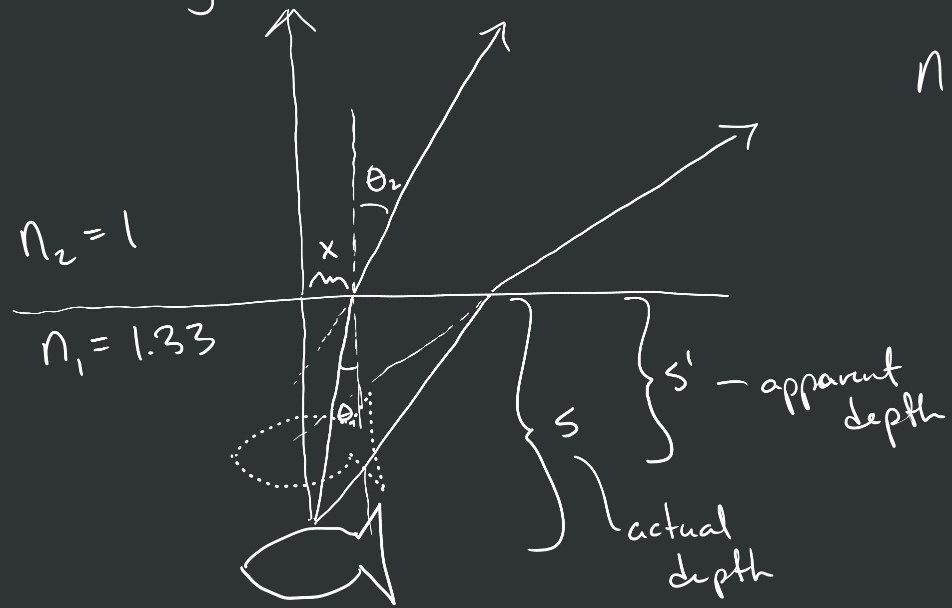
→ $\theta_i = \theta_r$

Law of Refraction (Snell's Law)

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

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

fishing



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

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

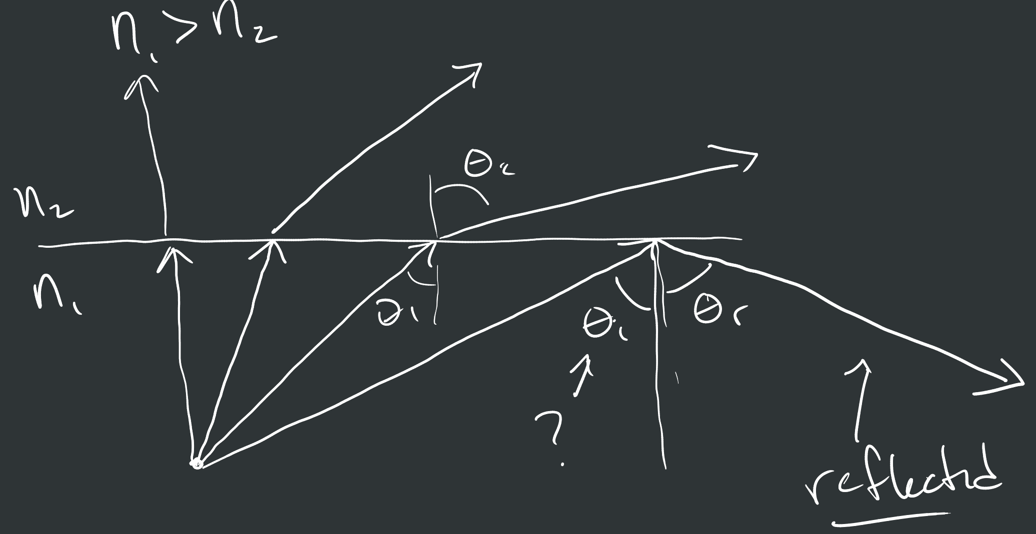
$$n_1 \tan\theta_1 = n_2 \tan\theta_2$$

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

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

$s' = 0.752 \cdot s$

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°

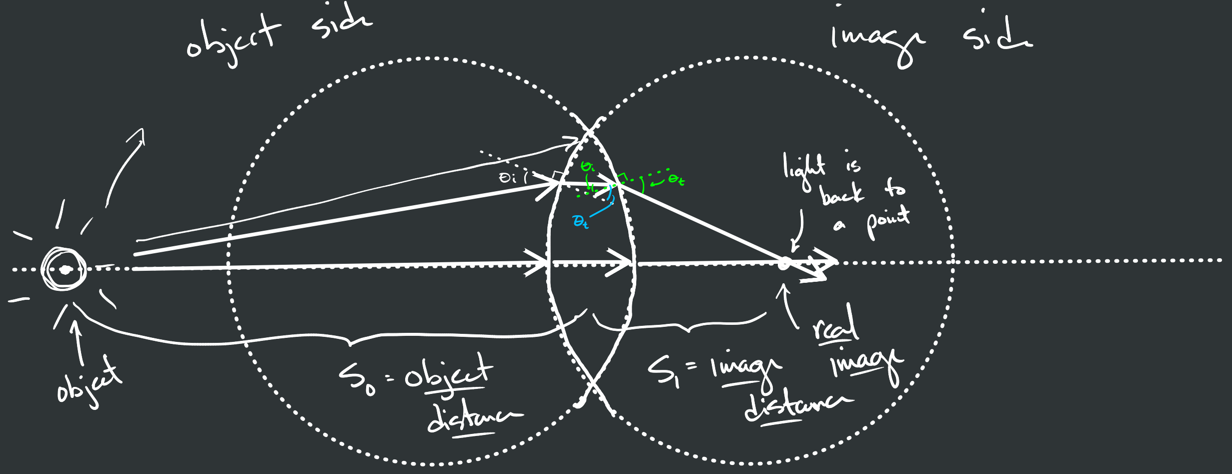
$$\underbrace{\sin\theta_2}_{} = \underbrace{\frac{n_1}{n_2}\sin\theta_1}_{\text{when this is } \geq 1}$$

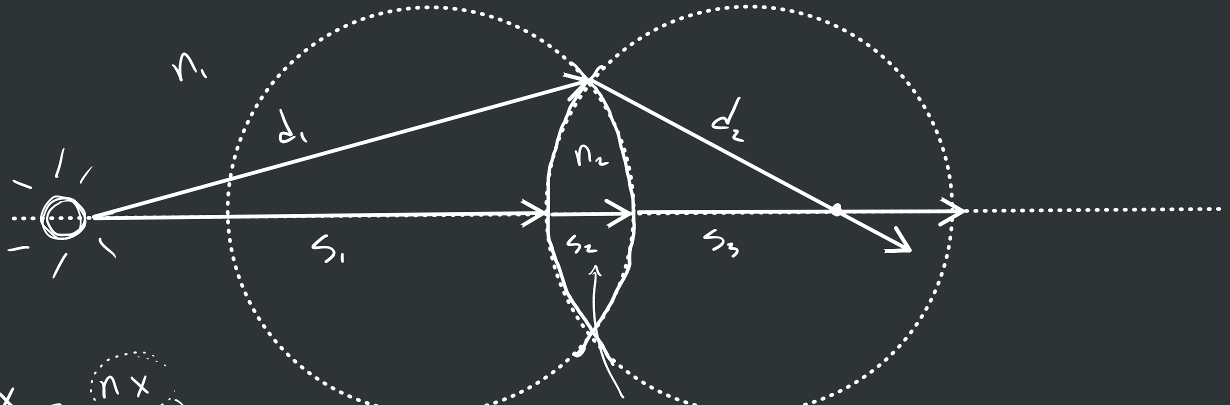
$$1 = \frac{n_1}{n_2}\sin\theta_1$$

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

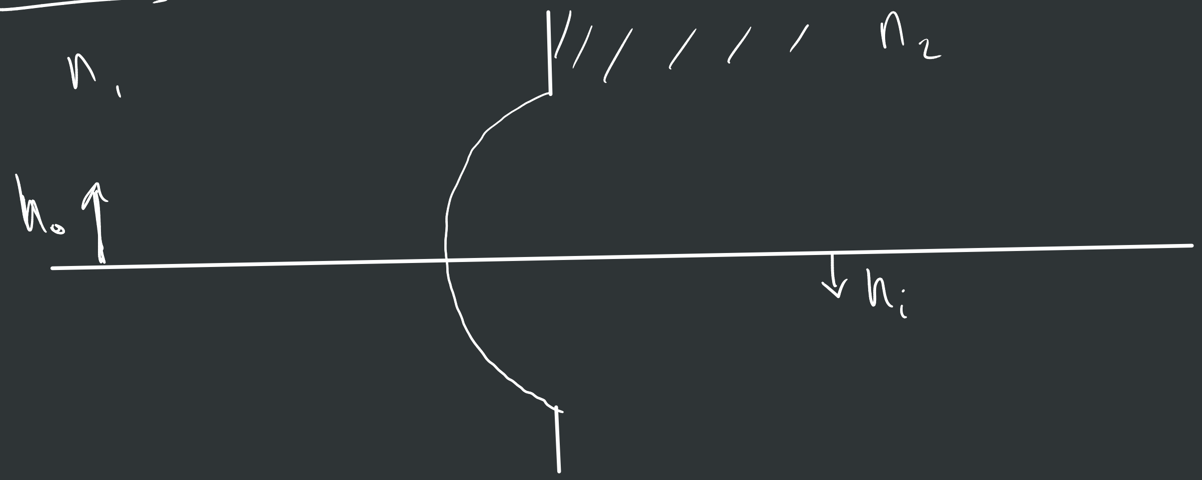
reflection

- 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)

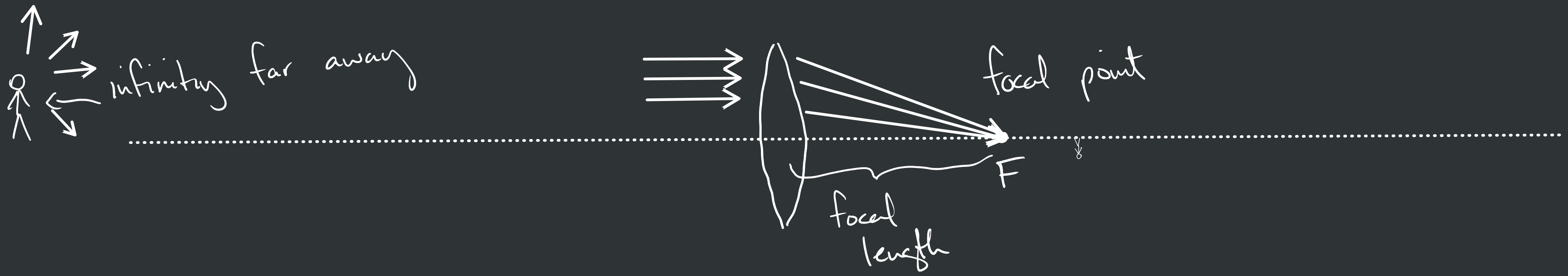
$$\frac{1}{s_o} + \frac{1}{s_i} = (n_\ell - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

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

focal length

(Thin Lens Equation)

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



	+	−
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

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

Now for the check:

$s_i = 16.2$ cm

$f = 10$ cm

$s_o = 26.13$

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

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

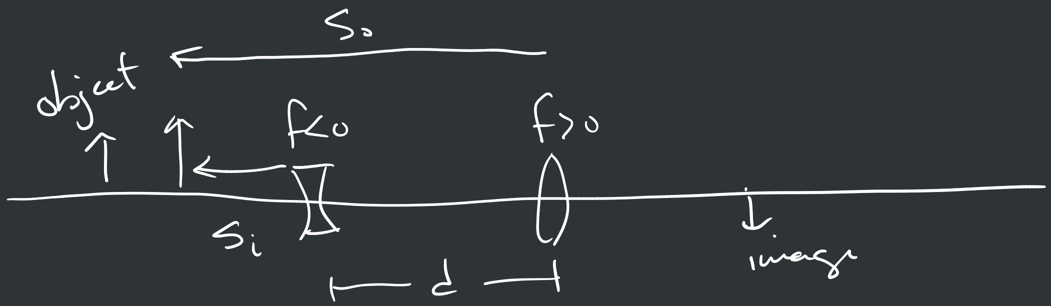
$$s_o = \frac{16.2 \cdot 10}{16.2 - 10}$$

$$s_o = 26.13$$

So now we need to compare

✓

$$s_o = d - s_i$$



$26.13 = d - (-9.6)$

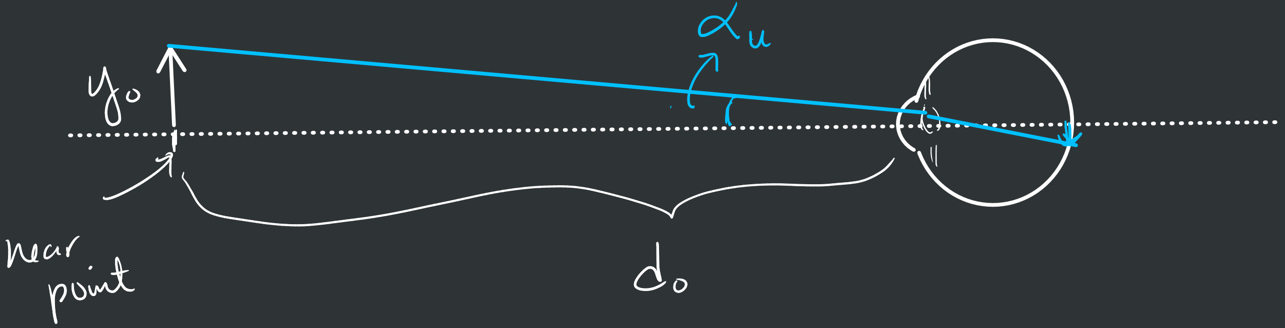
$16.53 = d$

17.3 measured

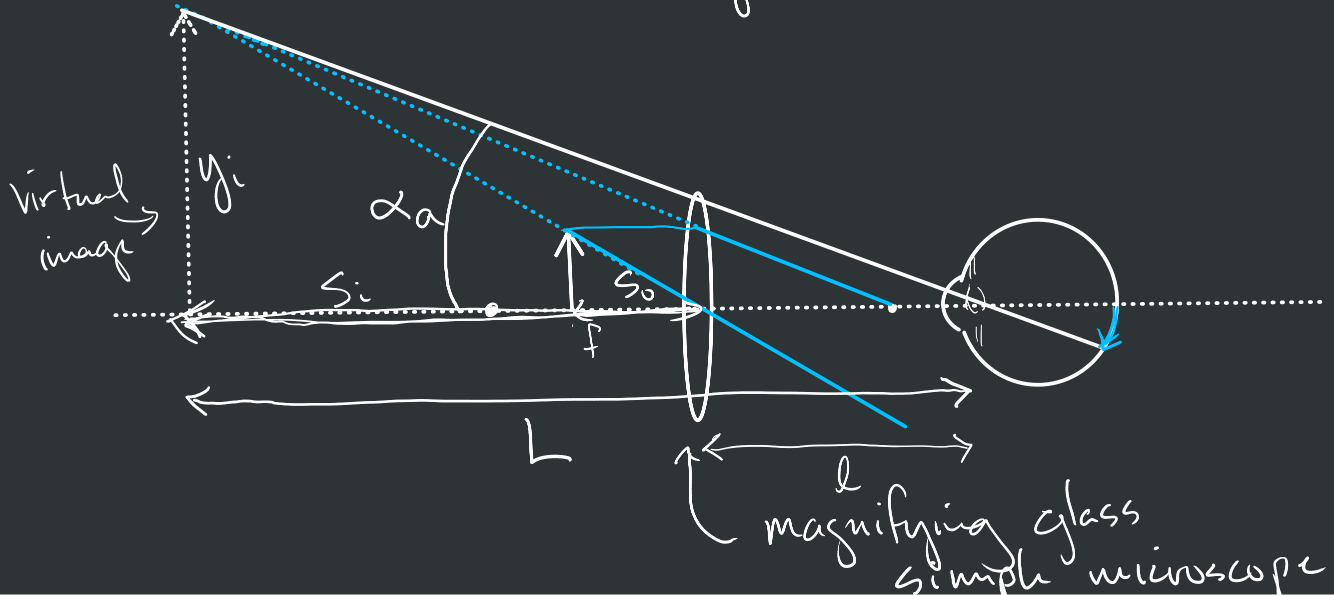
Optical Devices

Magnifying Glass

Unaided Eye



Aided Eye



magnifying power

angular magnification

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

radians

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

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

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

this is positive

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

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

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

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

$\hookrightarrow 5.73^\circ$

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

$$s_i \left[\frac{1}{s_o} = \frac{1}{f} - \frac{1}{s_i} \right] s_i$$

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

$$-\frac{s_i}{s_o} = \boxed{1 - \frac{s_i}{f}}$$

$$MP = -\frac{s_i}{s_o} \cdot \frac{d_o}{L}$$

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

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

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

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

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

$\mathcal{D}$

$\mathcal{D}$

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 change 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

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

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

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

$$s_i \to \infty$$

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

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

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