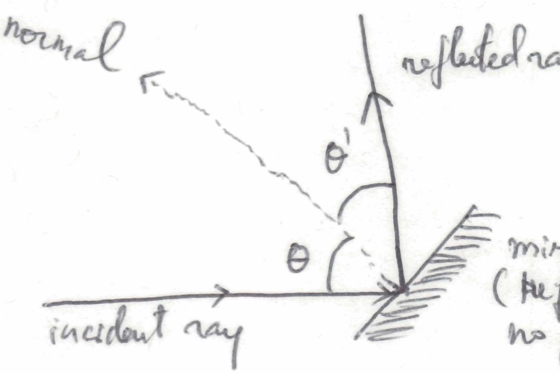
Ch 30: Reflection & Refraction:

Geometrical Optics: propagation of light using light rays (ignoring wave properties such as interference, diffraction, polarization → Physical Optics in later chapter)

light rays → propagate in straight line

By experiment: **Law of reflection**: $\theta = \theta'$

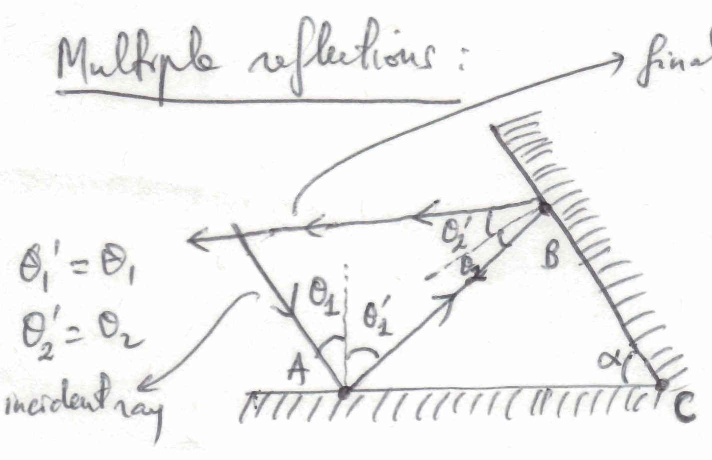


Incident angle θ: angle b/w incident ray & normal to mirror.

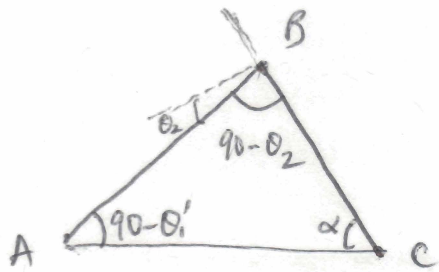
Reflected angle θ': angle b/w reflected ray & normal

Multiple reflections: → final reflected ray.

Using geometry we can write θ_2' in term of θ_1



↳



$$180^\circ = 90-\theta_1' + 90-\theta_2 + \alpha \Rightarrow 0 = \cancel{180} - \theta_1' - \theta_2 + \alpha$$

$$\Rightarrow \theta_2 = \alpha - \theta_1'$$

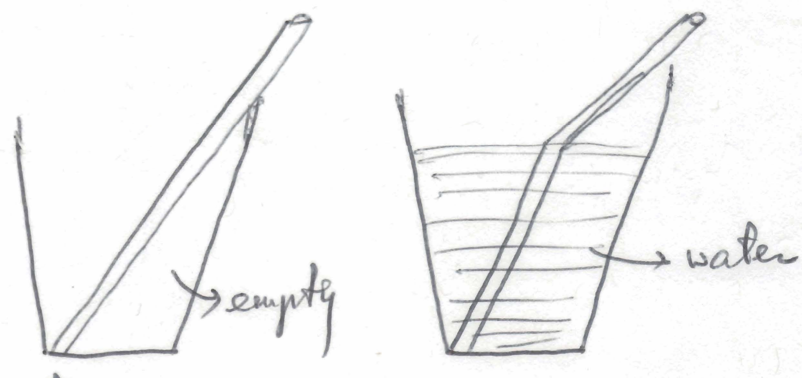
$$\Rightarrow \theta_2' = \theta_2 = \alpha - \theta_1 \Rightarrow \boxed{\theta_2' = \alpha - \theta_1}$$

Final reflected angle

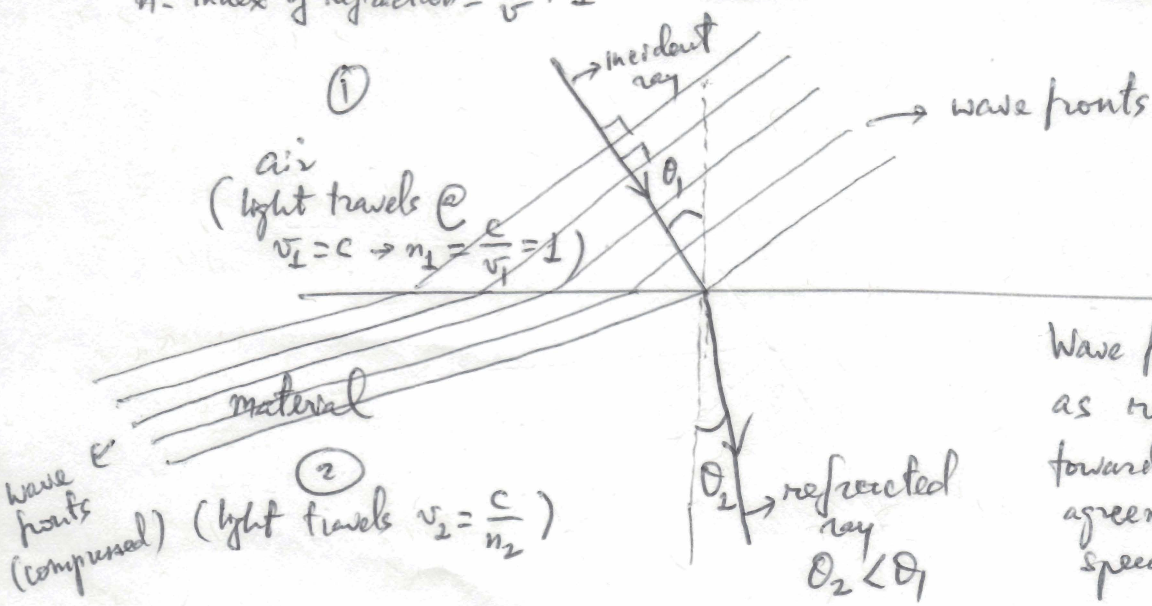
incident angle

Refraction: when light rays travel from one medium to another: (light goes slower in a medium)

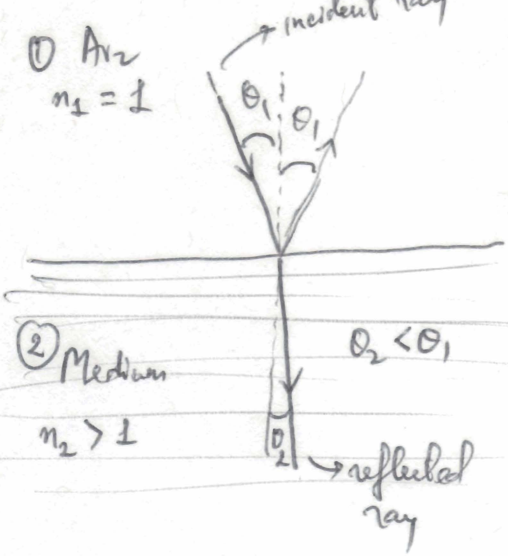
Broken straw:

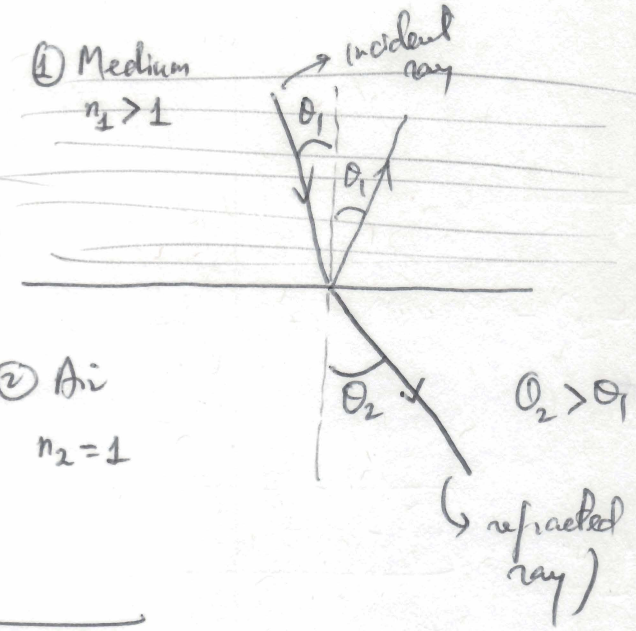


n: index of refraction $\equiv \frac{c}{v} > 1$



Wave fronts are compressed as refracted ray bends toward the normal → in agreement with lower speed in a medium.





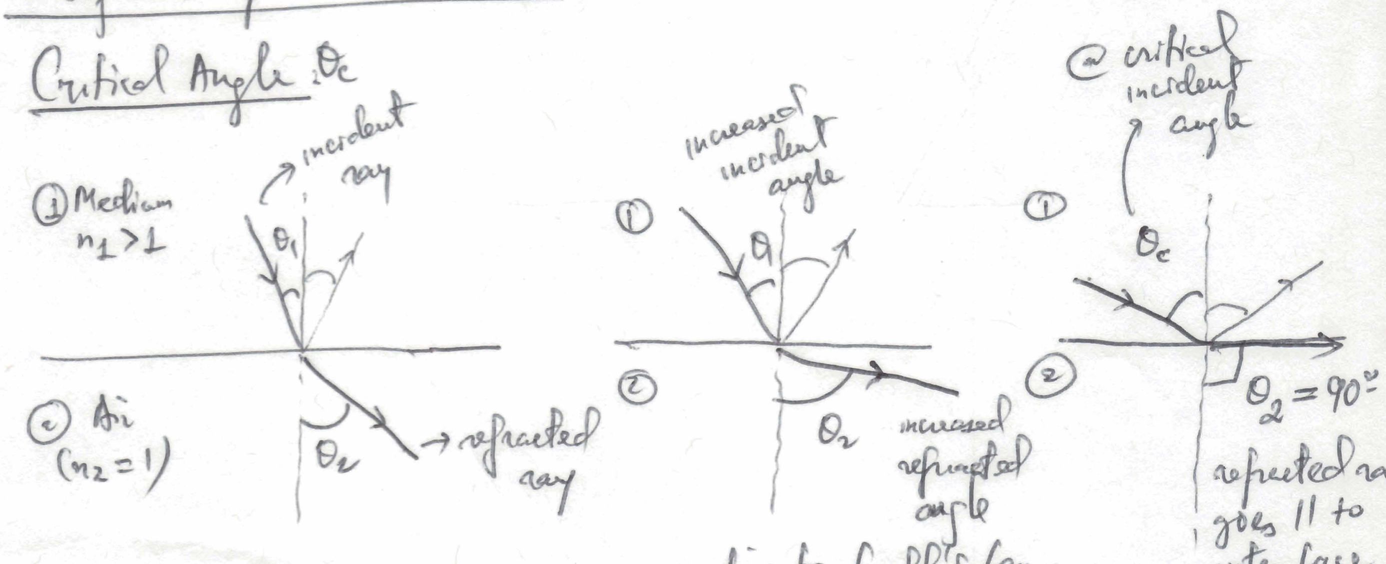
Snell's Law or Law of refraction:

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

n_1 → index of refraction of medium 1
θ_1 → inc. angle
n_2 → index of medium 2
θ_2 → refracted angle

Consequences of Snell's Law:

Critical Angle θ_c



according to Snell's Law.

* Critical angle only when going from higher index to lower index

* $n_1 \sin \theta_c = n_2 \sin 90° \rightarrow \boxed{\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$ @

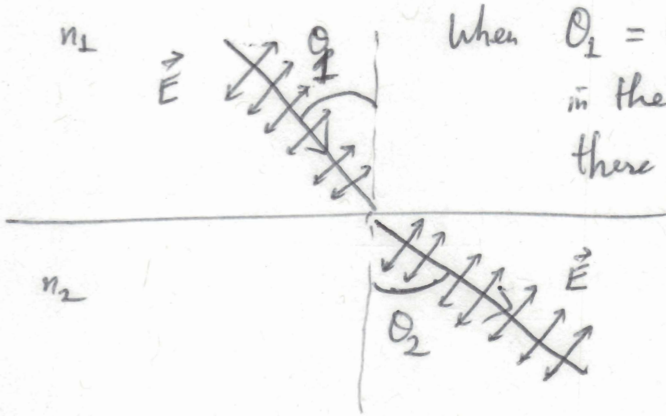
* @ θ_c : no refraction into medium #2 = "Total internal reflection"

<u>Critical angle</u>: (higher index to lower index) happens when we all reflection, none refraction.

Any situation where we have none reflection & all refraction?

YES! it happens @ the <u>polarizing angle or Brewster's angle</u>

$$\theta_p \text{ or } \theta_B = \tan^{-1}\left(\frac{n_2}{n_1}\right)$$



When $\theta_1 = \theta_p$ or θ_B & $\vec{E}$ oscillates in the plane of the page → there <u>none</u> reflection & <u>all</u> refraction (all energy goes to medium #2)

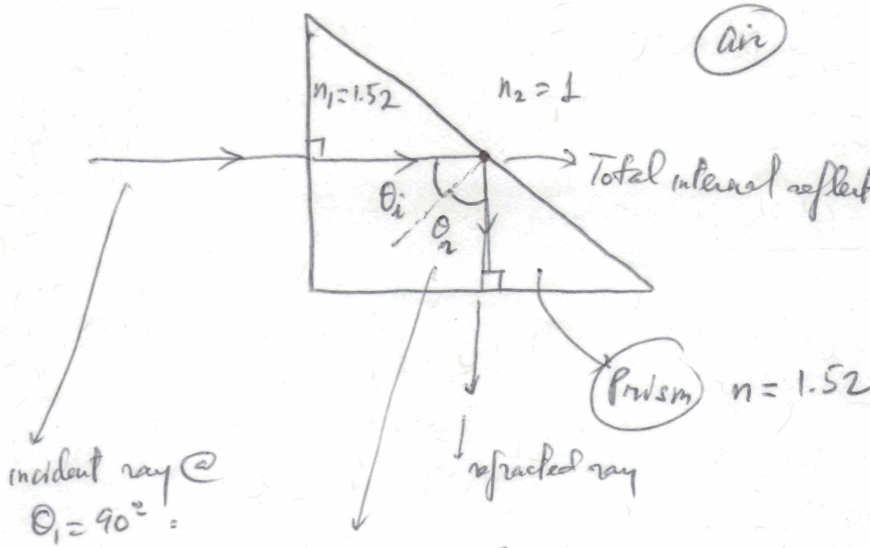
$\theta_2 \neq \theta_1$

→ Good when taking picture of something behind glass

<u>Note</u>: in general if $\vec{E}$ is such that it has some component perpendicular to the page → you still have some reflection @ Brewster's angle for this component of the electric field.

This is why the Brewster's angle is called the polarizing angle: since if you observe any reflection @ θ_B incident angle → this reflection will be polarized (direction ⊥ to page)

30.44



Total internal reflection: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ → higher to lower index

$= \sin^{-1}\left(\frac{1}{1.52}\right)$

$= 41°$

$\theta_r = \theta_i$ (Law of reflection)

In this case $\theta_i = 45°$ (half of $90°$)

$\theta_i \geq \theta_c = 41°C$ → Total internal reflection ✓

→ If I immerse prism in a liquid → $1 < n_2 < 1.52$ | what is n_2 such that we no longer have total internal reflection?

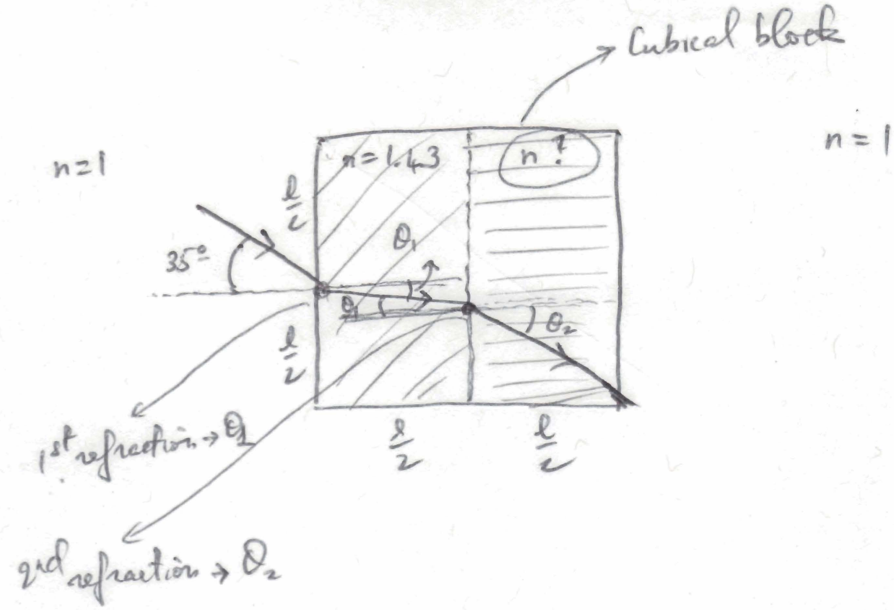
Since $\theta_i = 45°$ → if n_2 is such that $\theta_c = \boxed{\sin^{-1}\left(\frac{n_2}{1.52}\right) = 45°}$

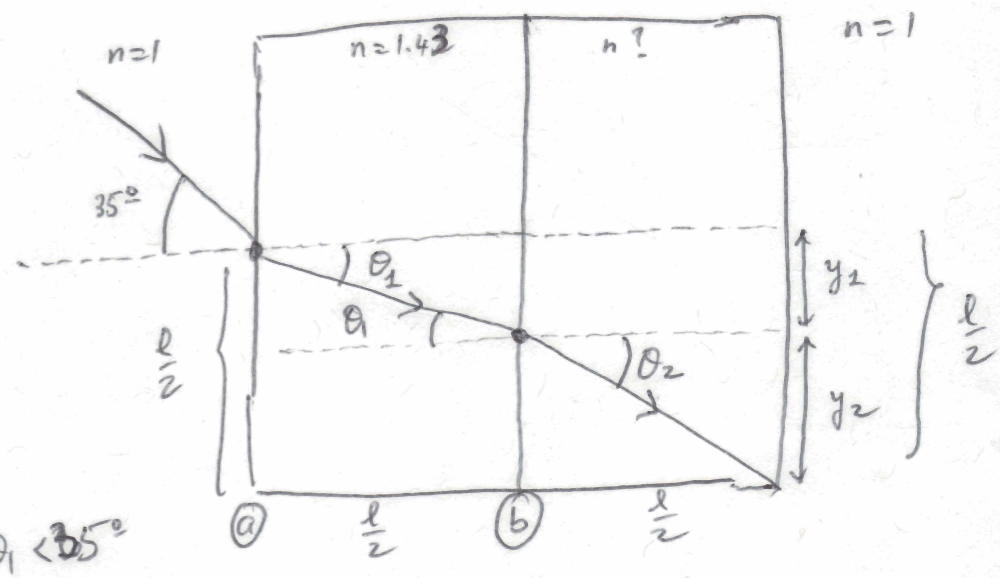
→ we may no longer have total internal reflection:

$n_2 = 1.52 \sin 45°$
$= 1.07$

→ Conclusion if $n_2 \geq 1.07$ → $\theta_c \geq 45°$ → our incident angle of $\theta_i = 45°$ will be short for total internal reflection.

30.57





$\theta_1 < 35°$

Incident angle on boundary ⓐ is 35°
Refracted angle @ boundary ⓐ is θ_1 = incident angle @ boundary ⓑ
Refracted angle @ boundary ⓑ is θ_2

<u>Snell's law</u>: ⓐ $1 \sin 35° = 1.43 \sin\theta_1 \rightarrow \theta_1 = \sin^{-1}\left(\frac{\sin 35°}{1.43}\right)$

$$\boxed{\theta_1 = 23.6°}$$

ⓑ $1.43 \sin 23.6° = n \sin\theta_2 \rightarrow$ 2 unknowns n & θ_2

→ One more equation: from the geometry:

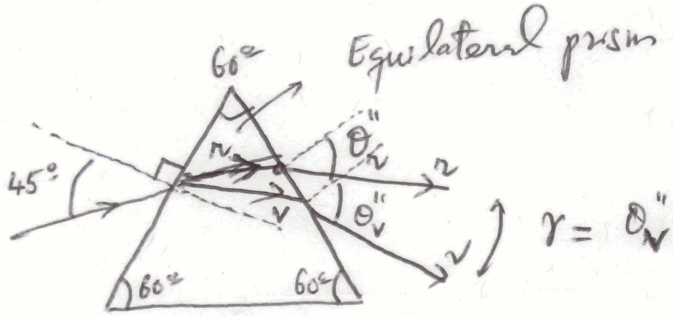
$$\tan\theta_2 = \frac{y_2}{\frac{\ell}{2}} = \frac{\frac{\ell}{2} - y_1}{\frac{\ell}{2}} = \frac{\frac{\ell}{2} - \frac{\ell}{2}\tan\theta_1}{\frac{\ell}{2}}$$

$\rightarrow \tan\theta_2 = 1 - \tan\theta_1 \rightarrow \theta_2 = \tan^{-1}(1 - \tan 23.6°) = 29.3°$

(1) $n = \dfrac{1.43 \sin 23.6^\circ}{\sin 29.3^\circ} = 1.17$

Check: according to our figure: $\theta_2 > \theta_1 \Rightarrow n_2 < n_1 = 1.43$ ✓

(30.28)



$\gamma = \theta''_v - \theta''_r$: angular dispersion

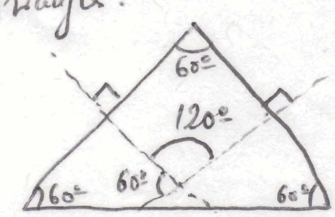
White light
↓
mix of all λ's

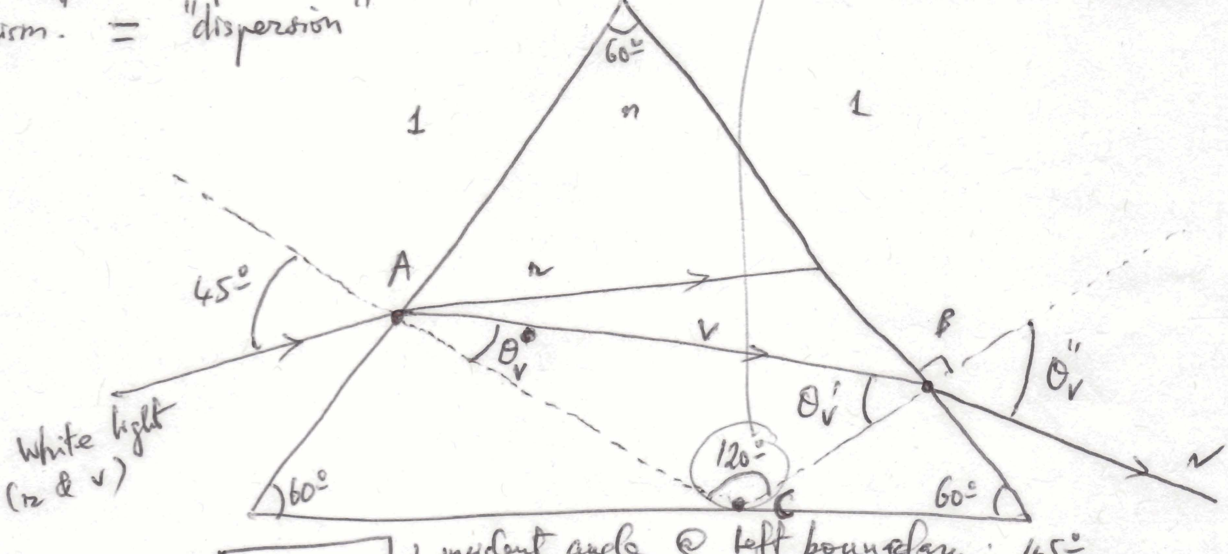
$\lambda_{red} \longleftrightarrow \lambda_{violet}$
↓ ↓

Prism: $\underbrace{n_{red} = 1.582 \qquad n_{violet} = 1.633}$

Different wavelengths travel @ different speeds inside prism. = "dispersion"

Geometry of equilateral triangle:





$\boxed{\text{Violet ray}}$ $\begin{cases} \text{incident angle @ left boundary} : 45^\circ \\ \text{refracted angle @ " " } : \theta_v \\ \text{incident angle @ right boundary} : \theta'_v \\ \text{refracted angle @ " " } : \theta''_v \end{cases}$

$\Delta ABC: \ \theta_v + \theta'_v + 120 = 180^\circ \rightarrow \boxed{\theta'_v = 60 - \theta_v}$

Snell's law @ left boundary: $1 \sin 45° = n_v \sin \theta_v$

$$\rightarrow \theta_v = \sin^{-1}\left(\frac{\sin 45°}{1.633}\right) = 25.5°$$

$$\rightarrow \theta_v' = 60 - \theta_v = 60° - 25.5° = 34.5°$$

Snell's Law @ right boundary: $n_v \sin \theta_v' = 1 \sin \theta_v''$

$$\rightarrow \theta_v'' = \sin^{-1}\left(\frac{1.633 \sin 34.5°}{1}\right)$$

$$\boxed{\theta_v'' = 67.7°}$$

For γ, we also need θ_r'': same process except $n_v \rightarrow n_r = 1.582$

Red ray

Snell's law @ left boundary: $1 \sin 45° = n_r \sin \theta_r$

$$\rightarrow \theta_r = \sin^{-1}\left(\frac{\sin 45}{1.582}\right)$$

$$\rightarrow \boxed{\theta_r = 26.5°}$$

Equilateral prism

$$\theta_r' = 60 - \theta_r = 60 - 26.5° = 33.5°$$

Snell's law @ right boundary: $n_r \sin \theta_r' = 1 \sin \theta_r''$

$$\rightarrow \theta_r'' = \sin^{-1}(1.582 \sin 33.5°)$$

$$\boxed{\theta_r'' = 60.8°}$$

Angular dispersion: $\boxed{\gamma = \theta_v'' - \theta_r'' = 67.7 - 60.8 = 6.85°}$

Ch 31 Images & Optical Instruments

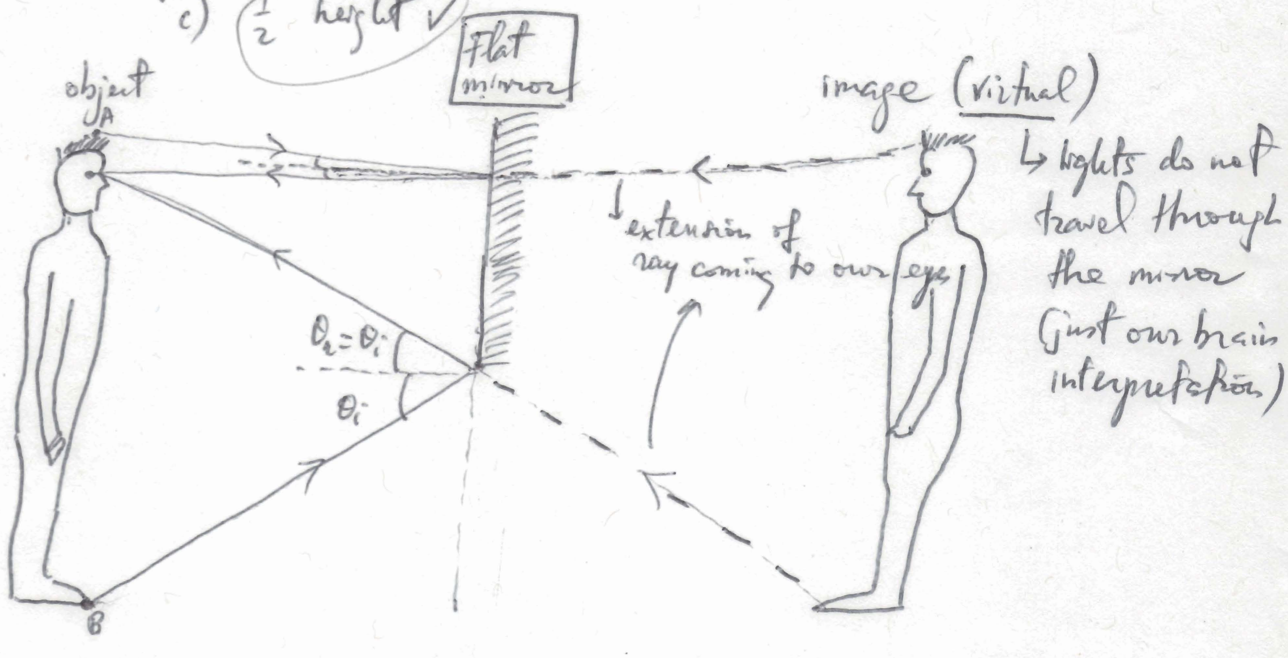
↳ { Mirrors & Lenses } Geometrical Optics

How to form an image of an object through a mirror or a lense?

Image formation by a mirror:

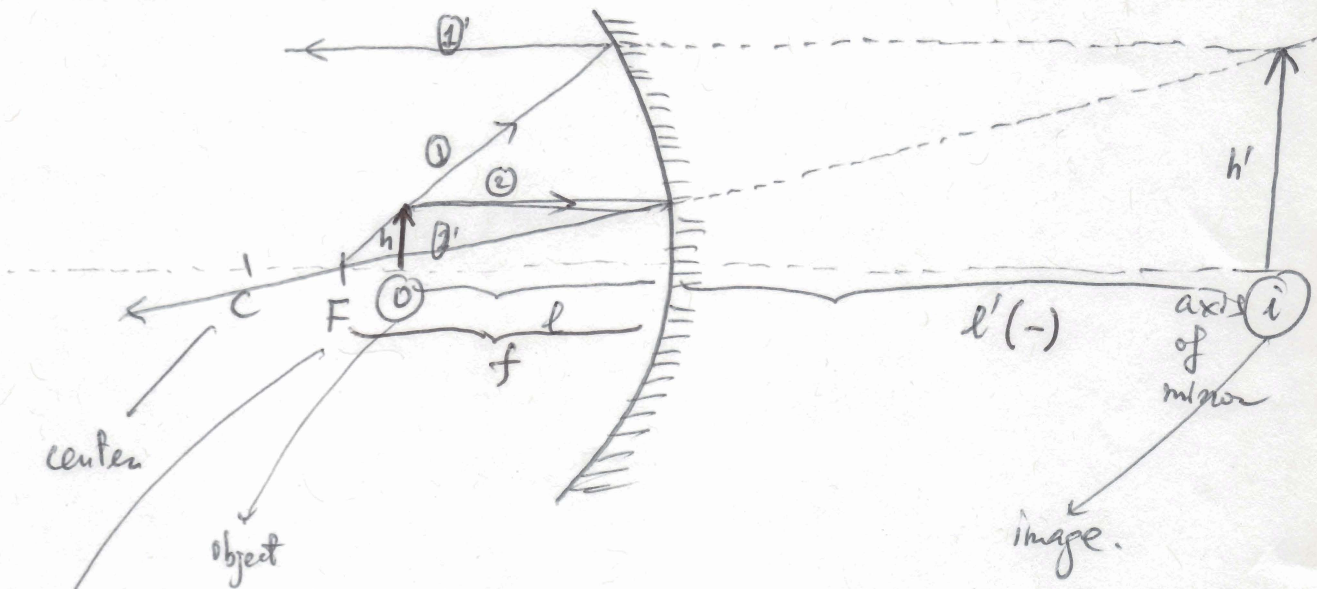
↳ How tall a mirror so we could see our whole body?

a) as tall as the body
b) $\frac{2}{3}$ height
c) $\frac{1}{2}$ height ✓



Virtual image: formed by extension rays, not real rays. No lights actually converging @ the virtual image.

Curved mirror:



Focal point F:
1) incident rays ∥ axis, will reflect thru F
2) incident rays thru F. will reflect parallel to axis

Again: image formed by extension rays → virtual image

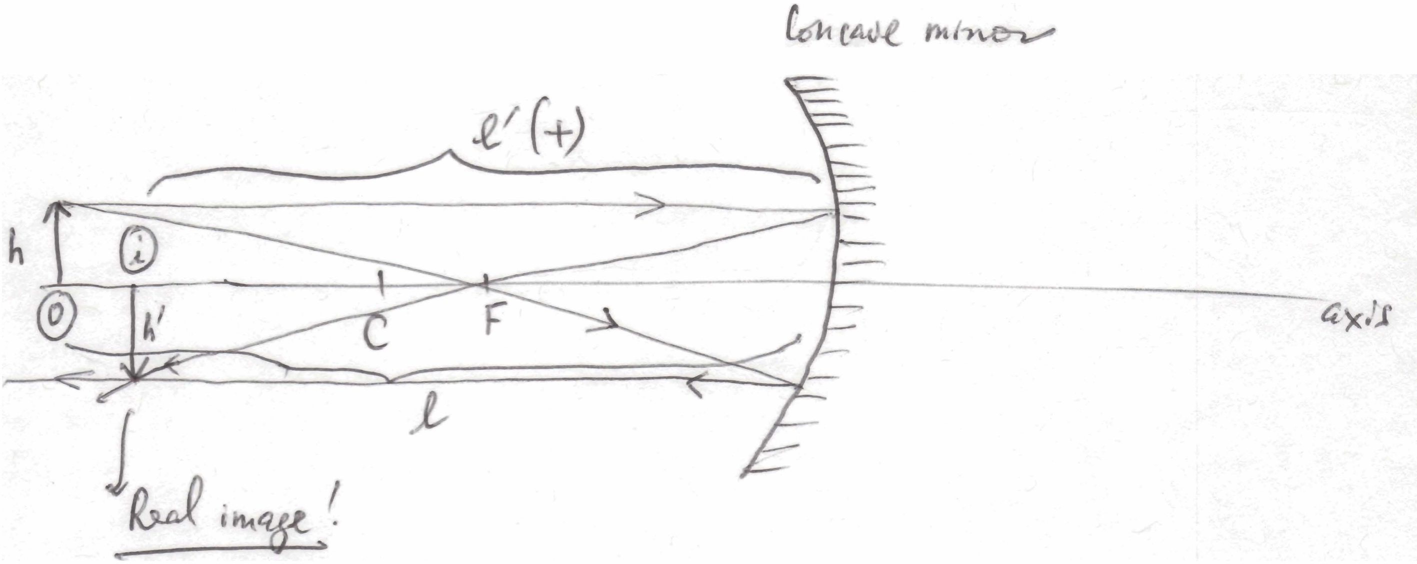
Mirror equation: $\boxed{\dfrac{1}{l} + \dfrac{1}{l'} = \dfrac{1}{f}}$ from geometrical optics.

Magnification factor: $M = \dfrac{h'}{h} = -\dfrac{l'}{l}$

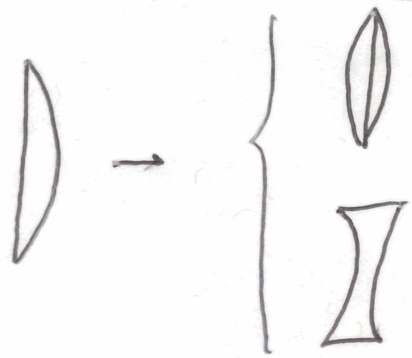
Sign convention → Mirrors

- f (Focal length)
  - $+$ concave mirror
  - $-$ convex mirror
- l' (image position)
  - $+$ image located in same side as object (real image)
  - $-$ image located in the other side of the mirror (virtual image)

Can we obtain a real image w/ a concave mirror?



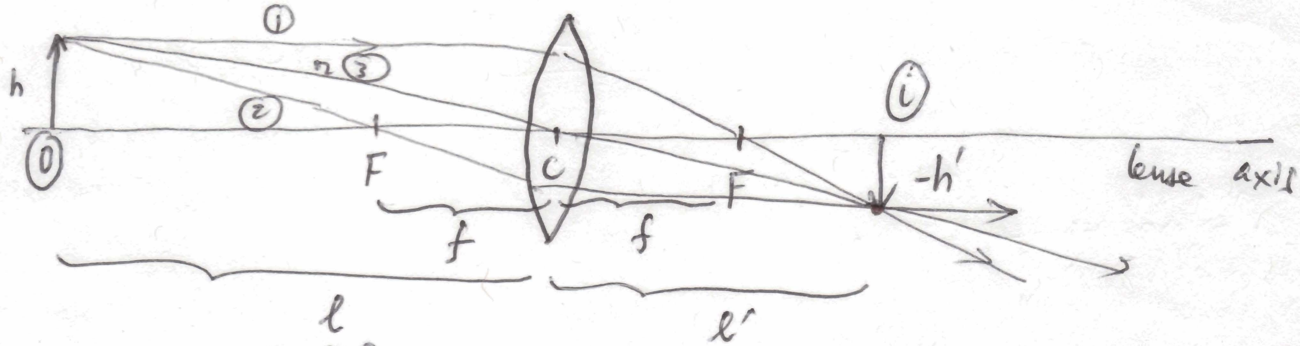
Lenses:



converging lense or convex lense

diverging lense or concave lense

Image formation in lenses:



Need 2 rays {
1) Parallel to axis incident ray emerges through F in the other side of the lense
2) Incident ray thru F emerge ∥ axis the other side of lense
or 3) Incident ray thru C keep its direction

<u>lense equation</u>: $\boxed{\dfrac{1}{\ell} + \dfrac{1}{\ell'} = \dfrac{1}{f}}$

↳ <u>sign convention – Lenses.</u>

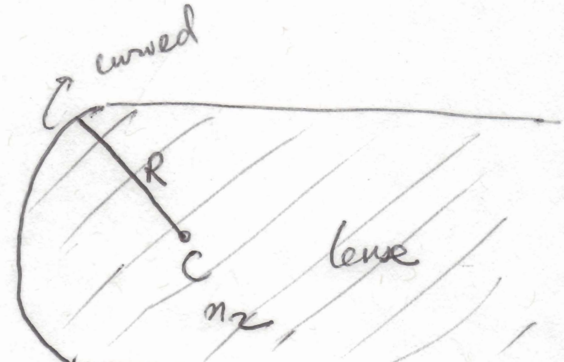
f { − concave lenses (diverging)
   { + convex lenses (converging)

ℓ' { + image located in the other side of the lense
   { − image located same side as object.

$$\boxed{M = \frac{h'}{h} = -\frac{\ell'}{\ell}}$$

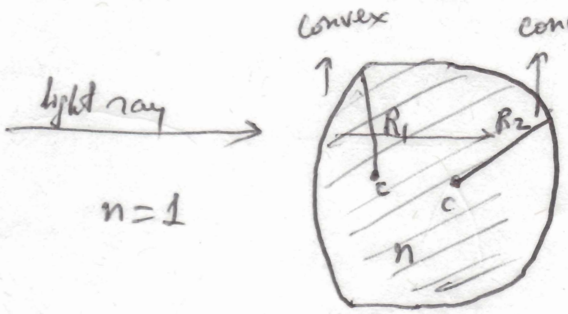
<u>Other type of lenses</u>:

1)



Equation: $\dfrac{n_1}{\ell} + \dfrac{n_2}{\ell'} = \dfrac{n_2 - n_1}{R}$

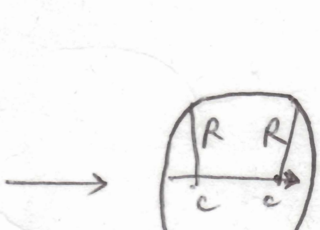
2) With different radii of curvature on the left & right side.



<u>lense maker's equation</u>: $\dfrac{1}{f} = (n-1)\underbrace{\left(\dfrac{1}{R_1} - \dfrac{1}{R_2}\right)}$

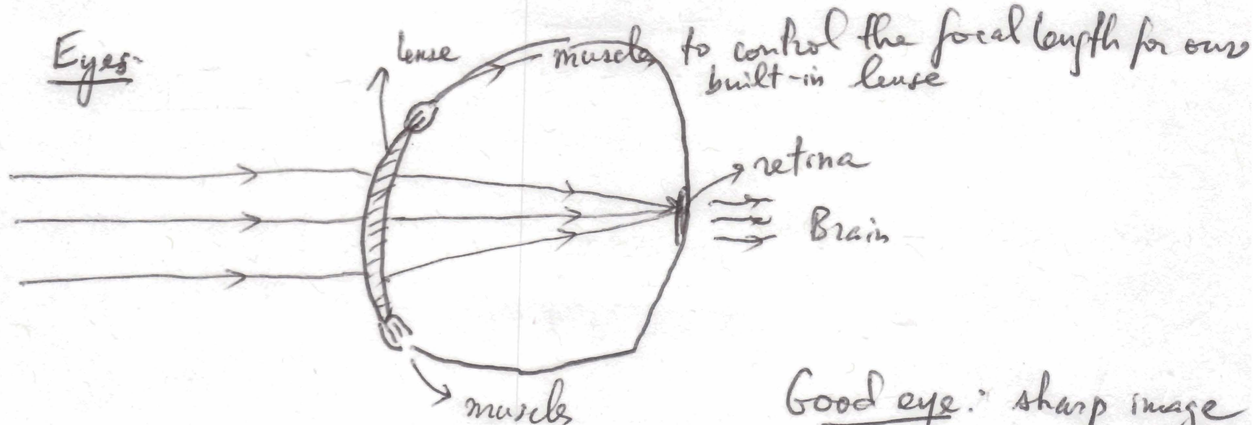
sign convention:
$R = \begin{cases} + & \text{convex} \\ - & \text{concave} \end{cases}$

Note:



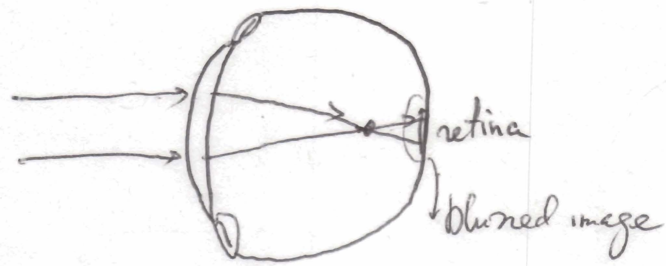
$$\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{2}{R}$$

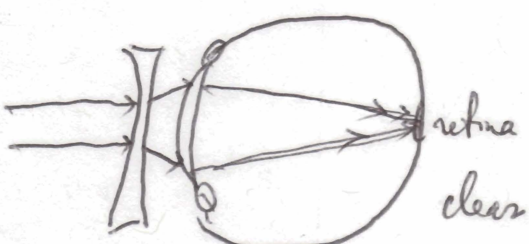
Eyes.



Good eye: sharp image

Near sighted (myopic)





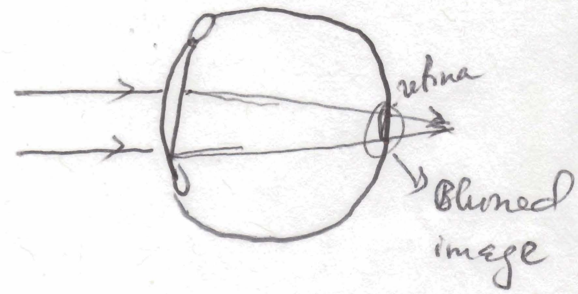
clear or sharp image w/ corrective lenses.

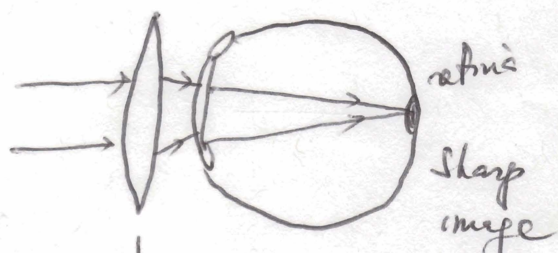
corrective lenses

↳ focal length f (−)

dioptre $= \dfrac{1}{f}$ → in meters

Far sighted (hyperopic)



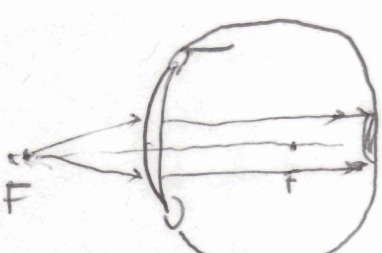


corrective lense

↳ focal length f (+)

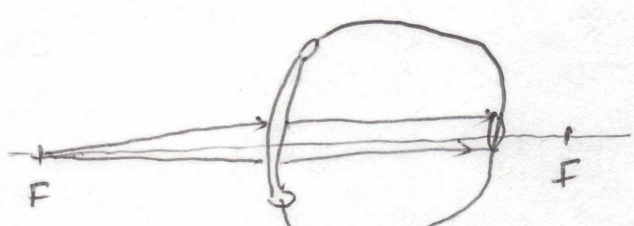
dioptre $= \dfrac{1}{f}$ → in m

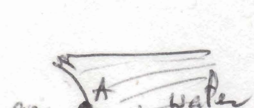
Nearsighted



can see
closer objects clear

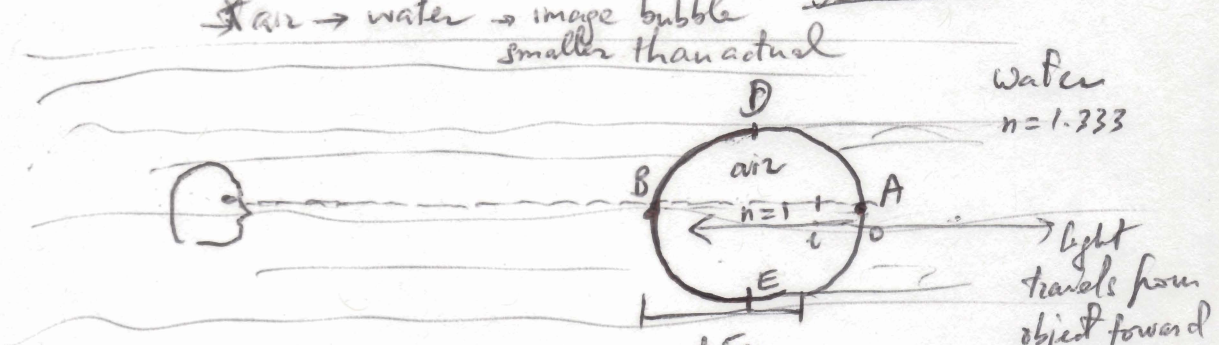
Far sighted.





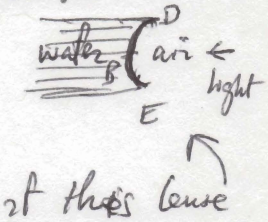
31.32

air → water → image bubble smaller than actual

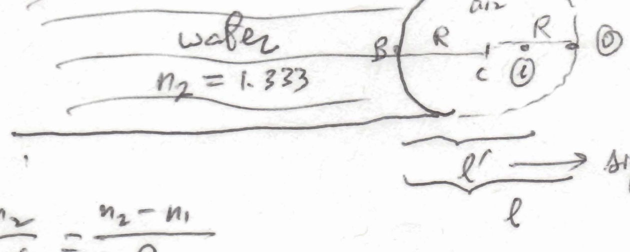


Actual diameter of air bubble (spherical) if it appears to be 1.5 cm along your line of sight : image of the far side (A) which is the object ~~app~~ is 1.5 cm behind point (B) :

(i) is image of (o) or (A) thru the concave lense DBE



→ Actual diameter = location of object (o) or (A) wrt this lense



l' → sign = − (image same side as object in a lense)

$\boxed{l' = -1.5\text{ cm.}}$

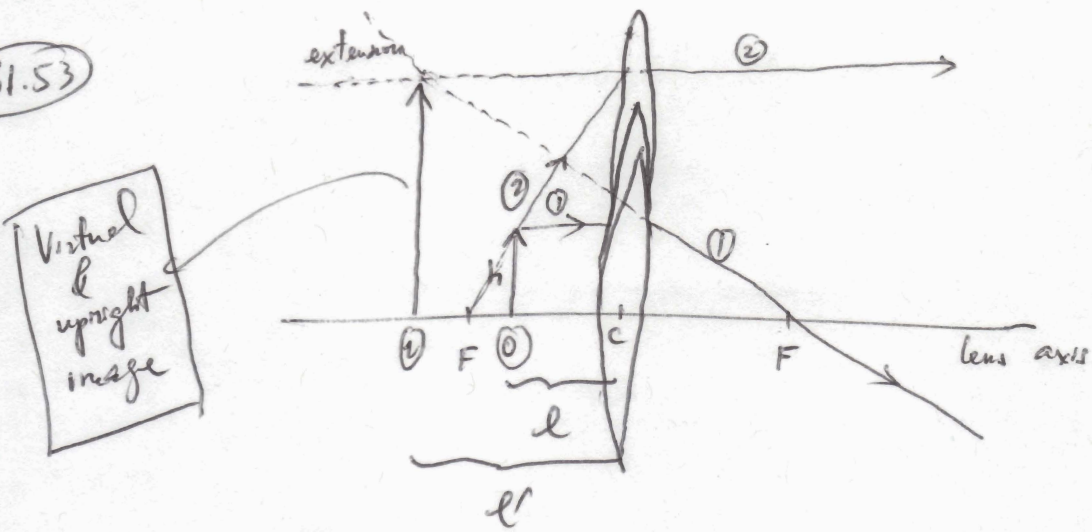
$$\frac{n_1}{l} + \frac{n_2}{l'} = \frac{n_2 - n_1}{R}$$

$$\frac{1}{2R} + \frac{1.333}{-1.5\text{cm}} = \frac{0.333}{-R} \rightarrow \frac{1 + 0.666}{2R} = \frac{1.333}{1.5} \rightarrow \boxed{2R = 1.87\text{cm}}$$

Actual Diameter of bubble

concave lense for object @ (A)

31.53



$f = 25\text{cm}$ (+)

converging lens or convex

Location of an object to get an upright image $M = 1.8$

$$M = \frac{h'}{h} = 1.8$$

$$\left\{ \begin{array}{l} M = \dfrac{h'}{h} = -\dfrac{\ell'}{\ell} = 1.8 \\[2ex] \dfrac{1}{\ell} + \dfrac{1}{\ell'} = \dfrac{1}{f} \end{array} \right\} \rightarrow \left. \begin{array}{l} -\dfrac{\ell'}{\ell} = 1.8 \\[2ex] \dfrac{1}{\ell} + \dfrac{1}{\ell'} = \dfrac{1}{25\text{cm}} \end{array} \right\}$$

2 eqs w/ 2 unknowns
we need ℓ
(object location)

$$\rightarrow \ell' = -1.8\ell \rightarrow \frac{1}{\ell}\left(1 - \frac{1}{1.8}\right) = \frac{1}{25\text{cm}}$$

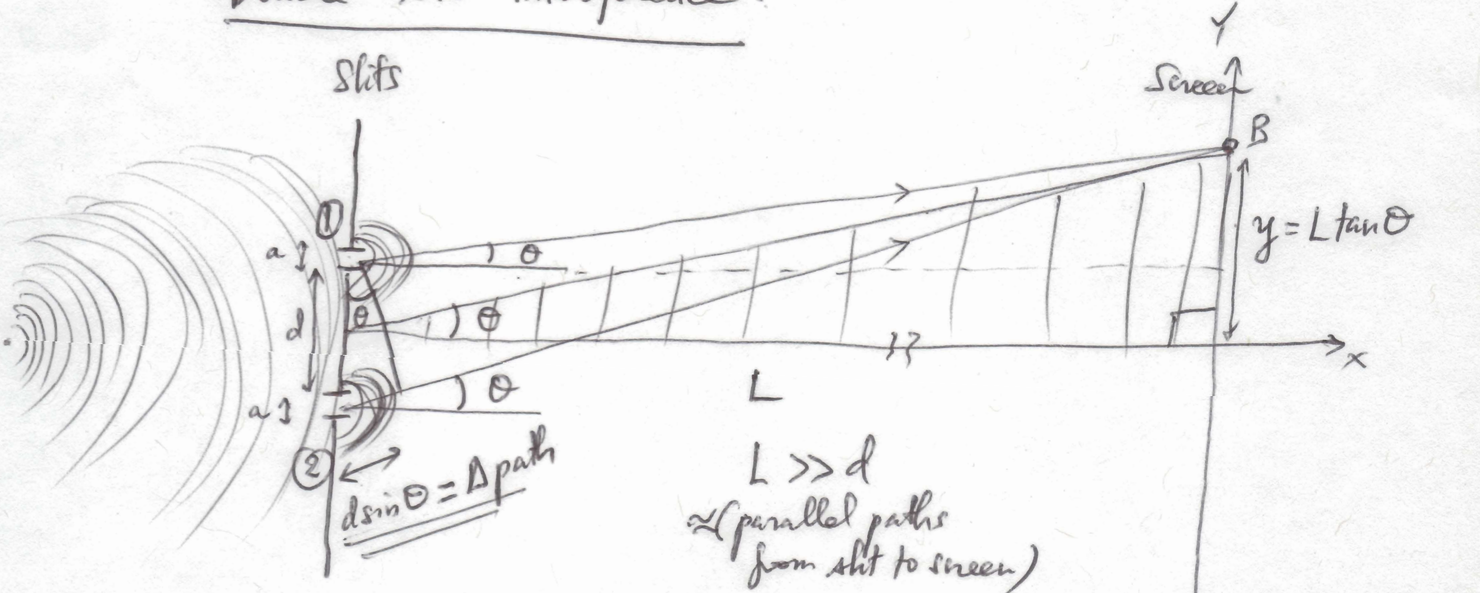
$$\ell = 25\text{cm}\left(1 - \frac{1}{1.8}\right) = 11.1\text{cm}$$

Ch 32 Interference & Diffraction

Physical optics: using wave properties of light in addition to geometry of the problem.

→ superposition of waves { constructive (in phase); destructive (out of phase π or 180°)

Double-slit interference



Screen along Y axis

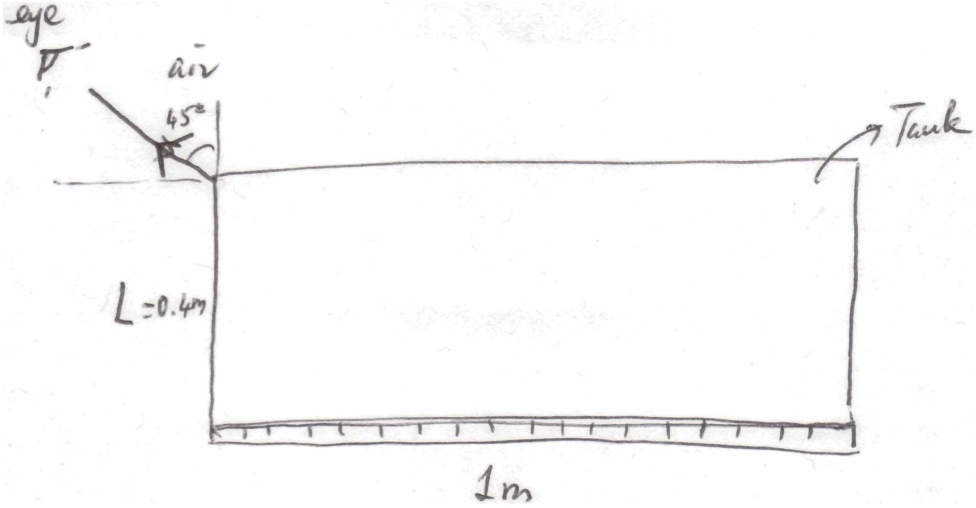
One source → two identical light waves after double slit

Waves 1 & 2 will arrive @ B with different phases b/c of the different paths they followed. ~~These phase~~ The phase difference comes from Δpath (assume $L \gg d$ → waves travel along parallel paths)

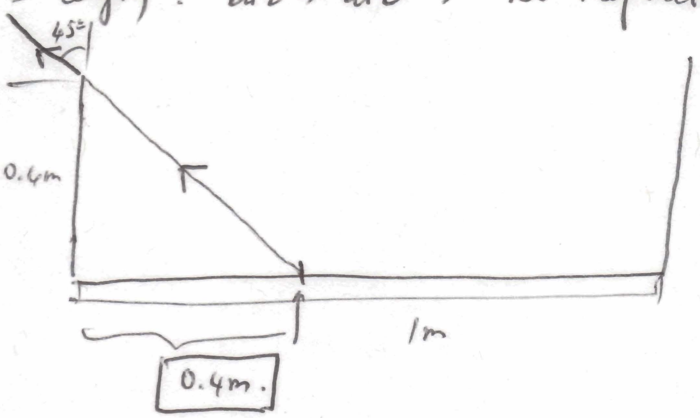
→ { $\Delta path = m\lambda$ $(m = 0, 1, 2, 3, \ldots)$
in phase or constructive interference
→ bright spot @ B

$\Delta path = (2m+1)\frac{\lambda}{2}$ $(m = 0, 1, 2, 3, \ldots)$
out of phase or destructive interference

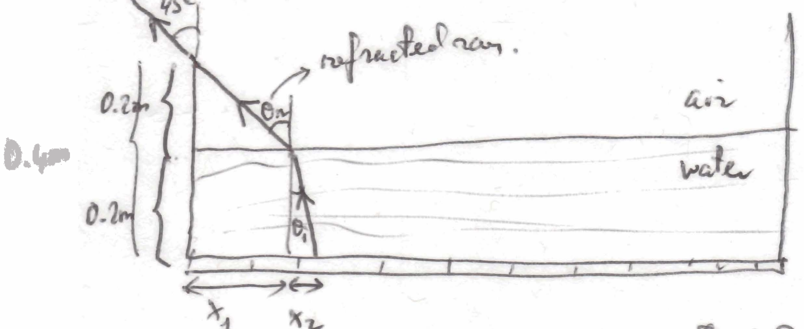
30.33



a) Tank is empty : air → air : no refraction.



b) Tank is half full: refraction: water → air : higher to lower index
→ ray goes further from the normal
↓
vertical in this problem.



$\theta_1 < \theta_2$

We will see mark set by $x_1 + x_2$:

$x_1 = 0.2m$

$x_2 \rightarrow \dfrac{x_2}{0.2} = \tan\theta_1$

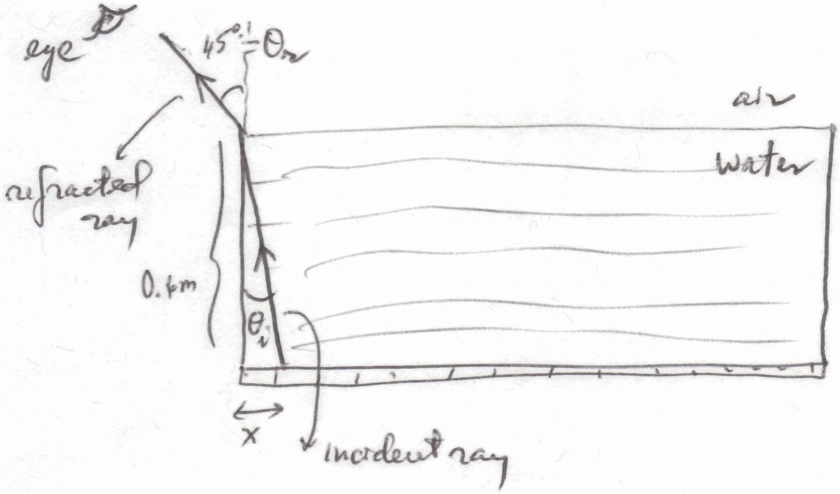
$1.333 \sin\theta_1 = 1 \sin\theta_2$

$\theta_2 = 45° \rightarrow \theta_1 = \sin^{-1}\left(\dfrac{\sin 45}{1.333}\right)$

$\hookrightarrow x_2 = 0.2 \tan\left(\sin^{-1}\left(\dfrac{\sin 45}{1.333}\right)\right) = 12.5\,cm. = 0.125\,m$

$\boxed{x_1 + x_2 = 0.325\,m}$

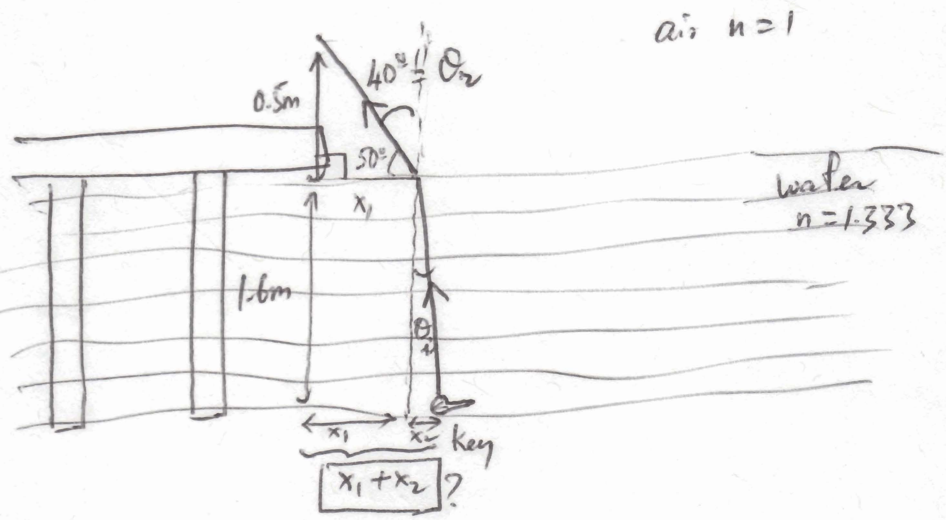
c) Tank is full of water



$$1.333 \sin\theta_i = 1 \sin 45° \rightarrow \theta_i = \sin^{-1}\left(\frac{\sin 45}{1.333}\right)$$

$$\rightarrow x = 0.4 \tan\theta_i = 25\,cm \rightarrow \boxed{0.25\,m.}$$

30.37



$$\frac{0.5}{x_1} = \tan 50° \rightarrow x_1 = \frac{0.5\,m}{\tan 50°} = 0.42\,m \quad ; \quad \frac{x_2}{1.6} = \tan\theta_i \rightarrow x_2 = 1.6\tan\theta_i$$

Snell's Law: $$1.333 \sin\theta_i = 1 \sin 40° \rightarrow \theta_i = \sin^{-1}\left(\frac{\sin 40°}{1.333}\right) = 28.8°$$

$$x_2 = 1.6 \tan 28.8° \Rightarrow \quad \boxed{x_1 + x_2 = 0.42\,m + 1.6\tan 28.8° = 1.3\,m}$$

Double-slit experiment: (cont.)

on screen:

bright spot: constructive interference b/w two waves 1 & 2 from the two slits.

$\underbrace{\Delta\text{path}} = m\lambda \quad (m = 0, 1, 2, 3, \text{etc})$

$d\sin\theta_m = m\lambda \rightarrow y_m = L\tan\theta_m$

$\hookrightarrow \theta_m = \sin^{-1}\left(\frac{m\lambda}{d}\right) \rightarrow y_m = L\tan\left[\sin^{-1}\left(\frac{m\lambda}{d}\right)\right]$

Location 1st bright spot: $m=1$

$y_1 = L\tan\left[\sin^{-1}\left(\frac{\lambda}{d}\right)\right]$

2nd bright spot: $y_2 = L\tan\left[\sin^{-1}\left(\frac{2\lambda}{d}\right)\right]$

...

dark spot: destructive interference b/w waves 1 & 2

out of phase $\underbrace{\Delta\text{path}}_{d\sin\theta_m} = (2m+1)\frac{\lambda}{2} \quad (m = 0, 1, 2 ..)$

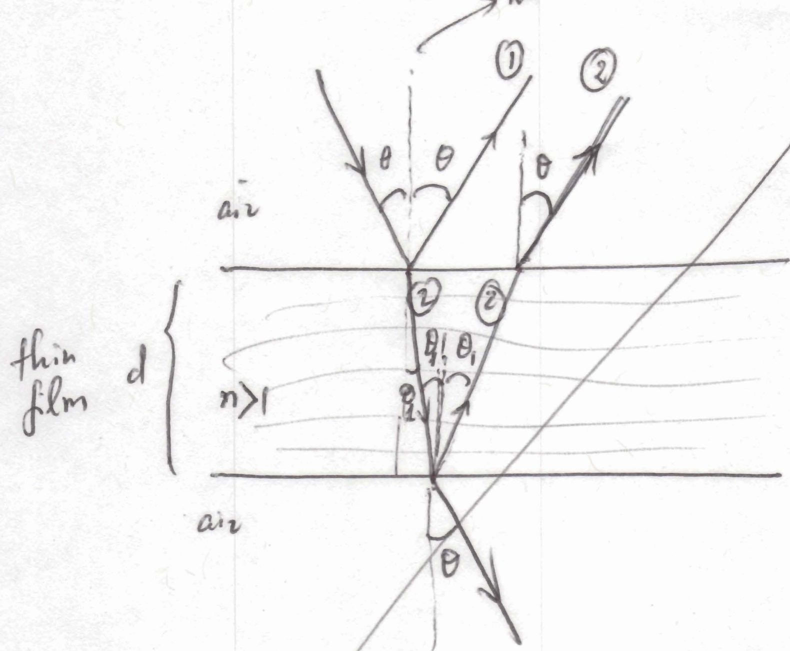
loc. of dark spots: $\rightarrow y_m = L\tan\left[\sin^{-1}\frac{(2m+1)\lambda}{2d}\right]$

$y_0 = L\tan\left[\sin^{-1}\frac{\lambda}{2d}\right]$

$y_1 = L\tan\left[\sin^{-1}\frac{3\lambda}{2d}\right]$

...

Thin film interference:



Interference b/w 1 & 2 : waves going in parallel like in the double-slit experiment. However they are not identical:

a) 1 is a reflection from lower to higher index → gets inverted → includes an extra phase of π or $\Delta path = \frac{\lambda}{2}$

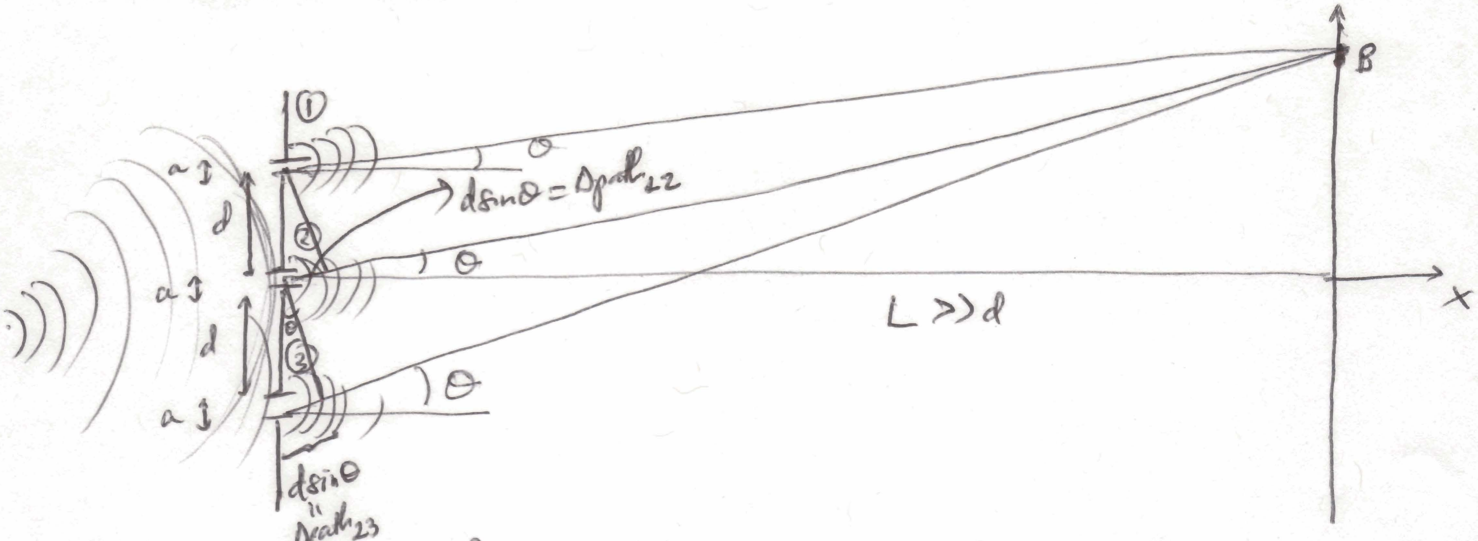
b) 2 causes a Δpath of $2d$ (approx of vertical paths inside film)

Constructive or in phase: $\underbrace{2d}_{②} = n\lambda + \underbrace{\frac{\lambda}{2}}_{①} = (2n+1)\frac{\lambda}{2}$ $(n = 0, 1, 2, 3 \text{ etc})$

Destructive or out of phase: $\underbrace{2d}_{②} = (2n+1)\frac{\lambda}{2} + \frac{\lambda}{2} = (n+1)\lambda$ $(n = 0, 1, 2, \text{etc})$

→ Diffraction
→ Interference in 3 slits. } tomorrow.

Three-slit interference:



One source → 3 identical waves
↳ Huyghens principle

Approximation: (good)
$L >> d$ → paths are parallel (we assume)

Note: $\Delta path$ $\begin{cases} \text{b/w ① \& ② is } d\sin\theta \\ \text{b/w ② \& ③ is } d\sin\theta \\ \text{b/w ① \& ③ is } 2d\sin\theta \end{cases}$

A) If $\Delta path$ = multiple of the wavelength → constructive interference @ B:

$$\left.\begin{aligned} 1\,\&\,2 &\rightarrow & d\sin\theta_m &= m\lambda \\ 2\,\&\,3 &\rightarrow & d\sin\theta_m &= m\lambda \\ 1\,\&\,3 &\rightarrow & 2d\sin\theta_m &= 2m\lambda \end{aligned}\right\} \quad \boxed{d\sin\theta_m = m\lambda}$$

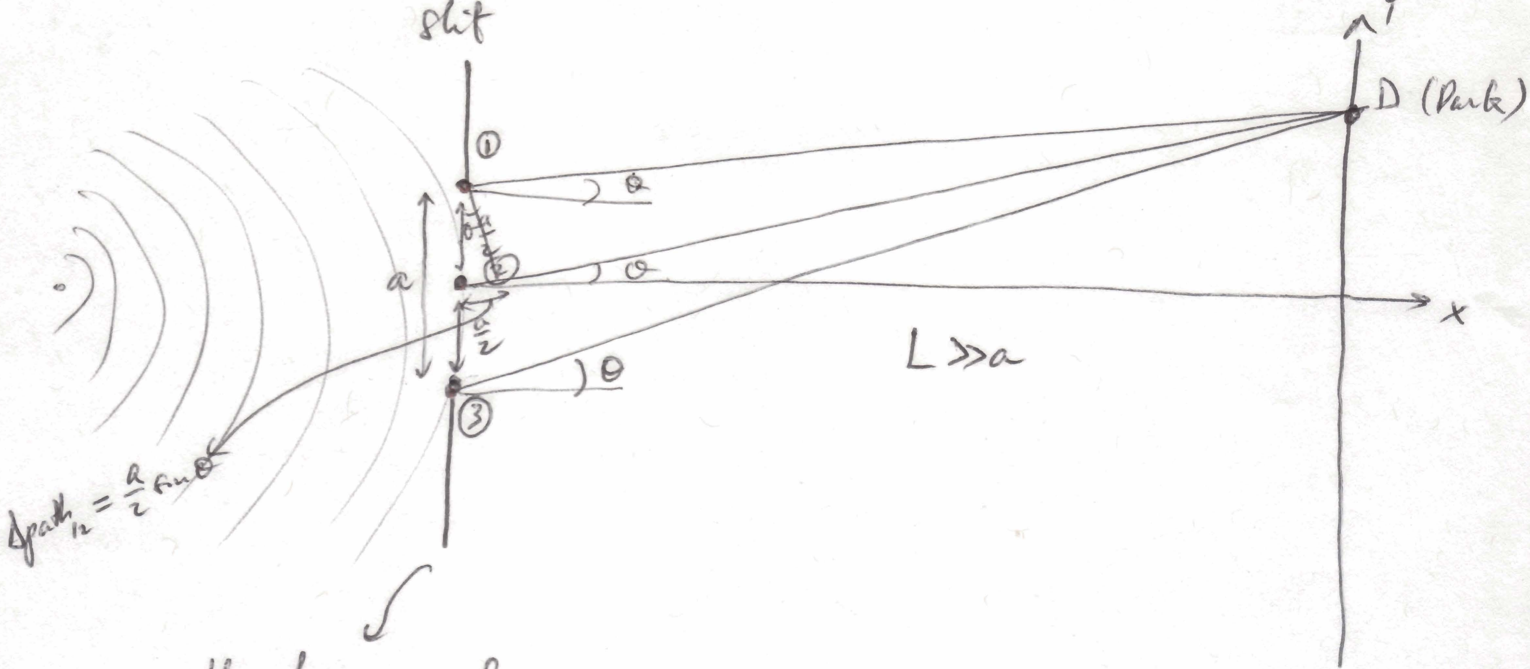
B) If $\Delta path$ is such that
→ b/w 2 waves: out of phase by $\frac{\lambda}{2}$ or an odd multiple of $\frac{\lambda}{2}$ → π or $180°$ ↑↓ = 0
→ b/w 3 waves: out of phase by $\frac{\lambda}{3}$ → $\frac{2\pi}{3}$ or $120°$

↳ Destructive interference

# of slits

⇒ Location of dark spots: $d\sin\theta_n = \left(n + \frac{1}{3}\right)\lambda$ (3 slits)
$d\sin\theta_n = \frac{n}{N}\lambda$ → (N slits)

Diffraction: superposition of waves coming from one slit.



Huyghens principle:
each point on the wave front will become a new source of waves → each point within one slit will be a source of wave

→ Destructive interference: $\Delta path_{12} = \frac{a}{2}\sin\theta = (2n+1)\frac{\lambda}{2}$

$(n = 0, 1, 2, \text{etc.})$

$$\boxed{a \sin\theta_n = (2n+1)\lambda \quad (n = 0, 1, 2, \text{etc.})}$$

Location of dark spots for diffraction.

also b/w 2 & 3 and 1 & 3

Destructive interference for 1 slit

Diffraction $\boxed{a \sin\theta_m = m\lambda \quad m = 1, 2, 3, \text{etc.}}$

Diffraction limit:

Optical instrument: $\theta_{min} = \frac{1.22\lambda}{D}$

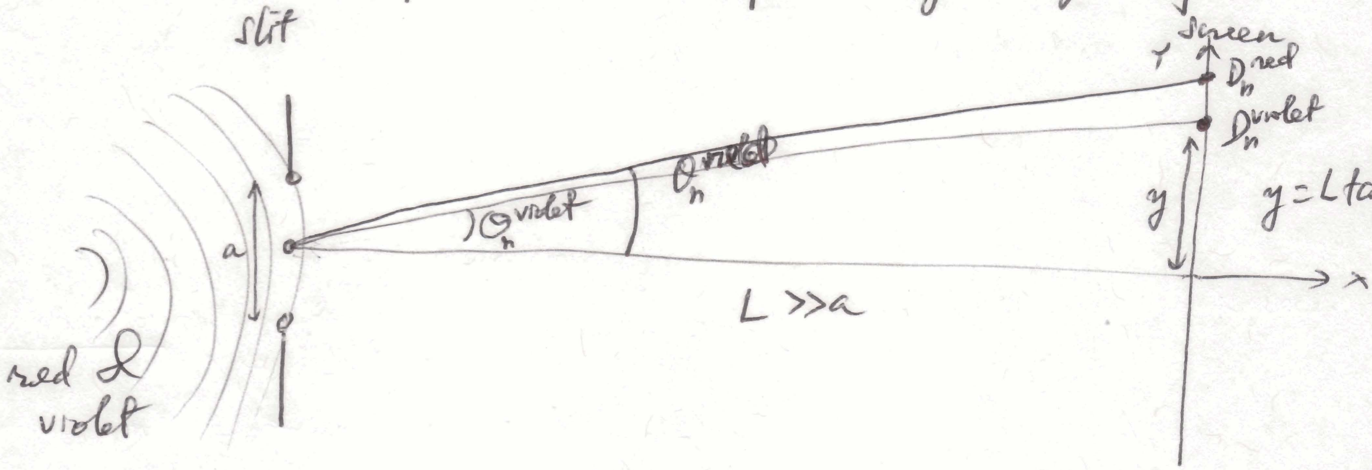
D → diameter of slit.

32.42 Visible light $\begin{cases} \lambda_v = 400\,nm & (\text{higher } f \to \text{higher energy}) \\ \lambda_r = 700\,nm & (\text{lower } f \to \text{lower energy}) \end{cases}$

↓

red to violet

→ lowest pair of consecutive orders for some overlap b/w visible spectra as dispersed by a grating?



Dark spot on screen: $a \sin\theta_n = n\lambda$

$\theta_n \to$ location of spot of order n $(y_n = L\tan\theta_n)$ on screen.

↳ $\begin{cases} \theta_n^{red} = \sin^{-1}\left(\dfrac{n\lambda_{red}}{a}\right) \\ \theta_n^{violet} = \sin^{-1}\left(\dfrac{n\lambda_{violet}}{a}\right) \end{cases}$ For a same order n dark spot for red is further up from the midline (or x axis) than that for violet.

→ We may have an overlap: a dark spot for red of order n coincides with a dark spot for violet of order $n+1$

→ $\sin\theta_n^{red} = \sin\theta_{n+1}^{violet}$

$$\boxed{\frac{n\lambda_{red}}{\cancel{a}} = \frac{(n+1)\lambda_{violet}}{\cancel{a}}}$$

$$\rightarrow n(\lambda_{red} - \lambda_{violet}) = \lambda_{violet} \rightarrow n = \frac{\lambda_{violet}}{\lambda_{red} - \lambda_{violet}}$$

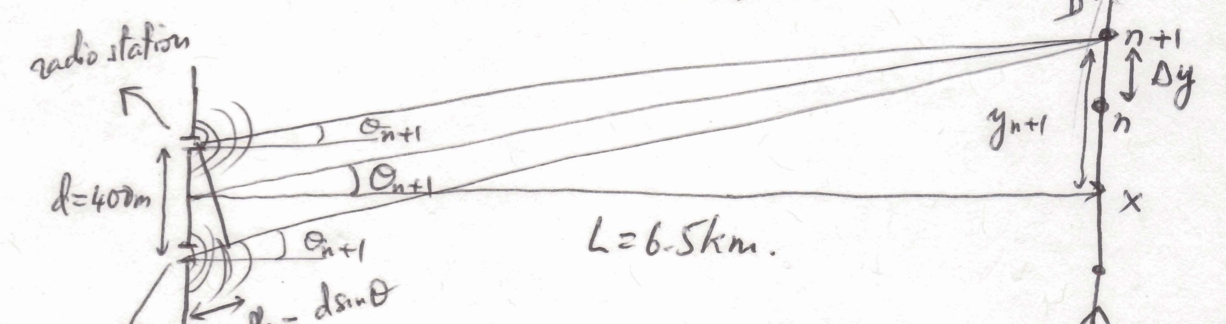
$$\rightarrow n = \frac{400\,nm}{700\,nm - 400\,nm} = \frac{4}{7-4} = \frac{4}{3} = 1.33$$

n can only be integer $\rightarrow$ $n = 2$ (red)

$n+1 = 3$ (violet)

32.70

103.9 MHz FM radio station



reflection off a building.

$$y_{n+1} = L\tan\theta_{n+1}$$

$$y_n = L\tan\theta_n$$

dark spots: $d\sin\theta_n = (2n+1)\frac{\lambda}{2}$

$$d\sin\theta_{n+1} = (2n+2+1)\frac{\lambda}{2}$$

driving along this line @ 60 km/h.

How often you hear the radio signal fade?

Radio wave an EM wave $\rightarrow$ behaves as a light wave

$\rightarrow$ interference $\rightarrow$ like the double-slit interference

If we knows Δy = separation b/w consecutive dark spots

$\rightarrow$ How often: $\frac{\Delta y}{v}$ = time b/w fadings.

$$\Delta y = y_{n+1} - y_n = L\left[\tan\theta_{n+1} - \tan\theta_n\right]$$

$$= L\left[\tan\left(\sin^{-1}\frac{(2n+3)\lambda}{2d}\right) - \tan\left(\sin^{-1}\frac{(2n+1)\lambda}{2d}\right)\right]$$

We don't have n → small angle approximation

$\theta_n, \theta_{n+1} \sim$ small $(L \gg d)$

$\sin\theta_n \simeq \theta_n \rightarrow \tan\theta_n \simeq \theta_n$

$\sin\theta_{n+1} \simeq \theta_{n+1} \rightarrow \tan\theta_{n+1} \simeq \theta_{n+1}$

$\Delta y = y_{n+1} - y_n = L(\theta_{n+1} - \theta_n)$

Dark spot: $d \sin\theta_n = (2n+1)\frac{\lambda}{2} \rightarrow \begin{cases} \theta_n = \frac{(2n+1)\lambda}{2d} \\ \theta_{n+1} = \frac{(2n+3)\lambda}{2d} \end{cases}$

$\Delta y = L \frac{(2n+3)\lambda - (2n+1)\lambda}{2d} = \frac{L2\lambda}{2d} = \frac{L\lambda}{d}$

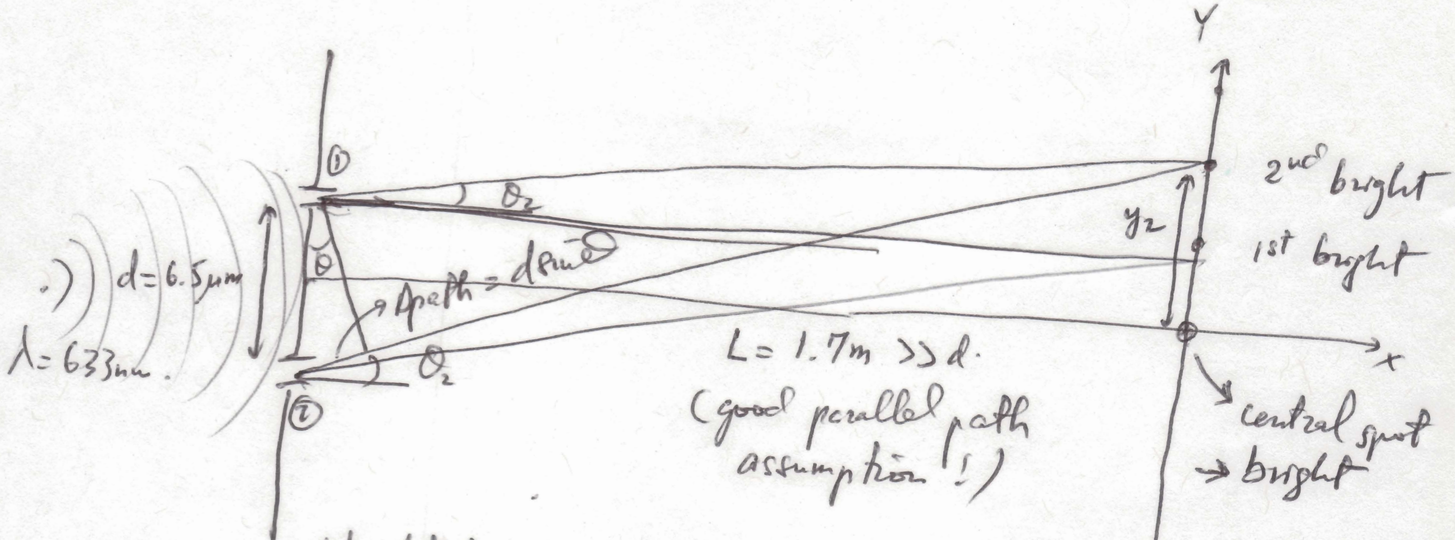
→ time b/w fadings $= \frac{\Delta y}{v} = \frac{\frac{L\lambda}{d}}{v} = \frac{6500 \times \frac{3\times10^8}{103.9\times10^6}}{400 \cdot \frac{60}{3.6}} s$

$\frac{\lambda}{T} = c = \lambda f \rightarrow \lambda = \frac{c}{f}$

$= \boxed{2.82\,s.}$

$v = 60 \frac{km}{h} = \frac{60}{3.6} \frac{m}{s}$

32-38 | Laser $\lambda = 633\,nm$ | 15



$\left\{ \begin{array}{l} \text{bright fringes: const. interf: } \Delta path = n\lambda \\ \qquad\qquad\qquad\qquad\qquad\quad d\sin\theta_n = n\lambda \\ y_n = L\tan\theta_n \end{array} \right.$ $\left\{ \begin{array}{l} \text{1st bright: } \theta_1 = \sin^{-1}\frac{\lambda}{d} \\ \text{2nd bright: } \theta_2 = \sin^{-1}\frac{2\lambda}{d} \end{array} \right.$

a) $y_2 - y_1 = L\tan\theta_2 - L\tan\theta_1$

↓ bright fringes or constructive interference.

$$= L\left[\tan\left(\sin^{-1}\frac{2\lambda}{d}\right) - \tan\left(\sin^{-1}\frac{\lambda}{d}\right)\right]$$

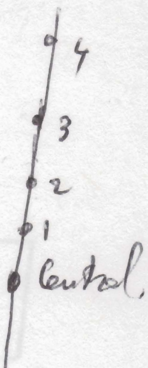
$$= 1.7\left[\tan\left(\sin^{-1}\frac{2\times 633\times 10^{-9}}{6.5\times 10^{-6}}\right) - \tan\left(\sin^{-1}\frac{633\times 10^{-9}}{6.5\times 10^{-6}}\right)\right]$$

$$= 17.17\,cm$$

b) $y_4 - y_3 = L(\tan\theta_4 - \tan\theta_3)$

$$= L\left[\tan\left(\sin^{-1}\frac{4\lambda}{d}\right) - \tan\left(\sin^{-1}\frac{3\lambda}{d}\right)\right]$$

$$= 20\,cm$$

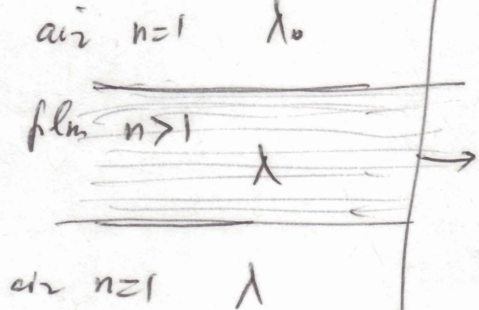


→ b/w 3 & 4 there is more separation than b/w 1 & 2

32-21

Thin soap film: $(n = 1.333)$ for $\lambda_0 = 550\,nm$ light to undergo constructive interference:

Thin film: $\boxed{2d = (2m+1)\frac{\lambda}{2}}$



$$\left.\begin{array}{l} v = \frac{c}{n} = \lambda f \\ c = \lambda_0 f \end{array}\right\} \quad \frac{\lambda_0 \cancel{f}}{n} = \lambda \cancel{f} \rightarrow \boxed{\lambda = \frac{\lambda_0}{n}}$$

order of interference.

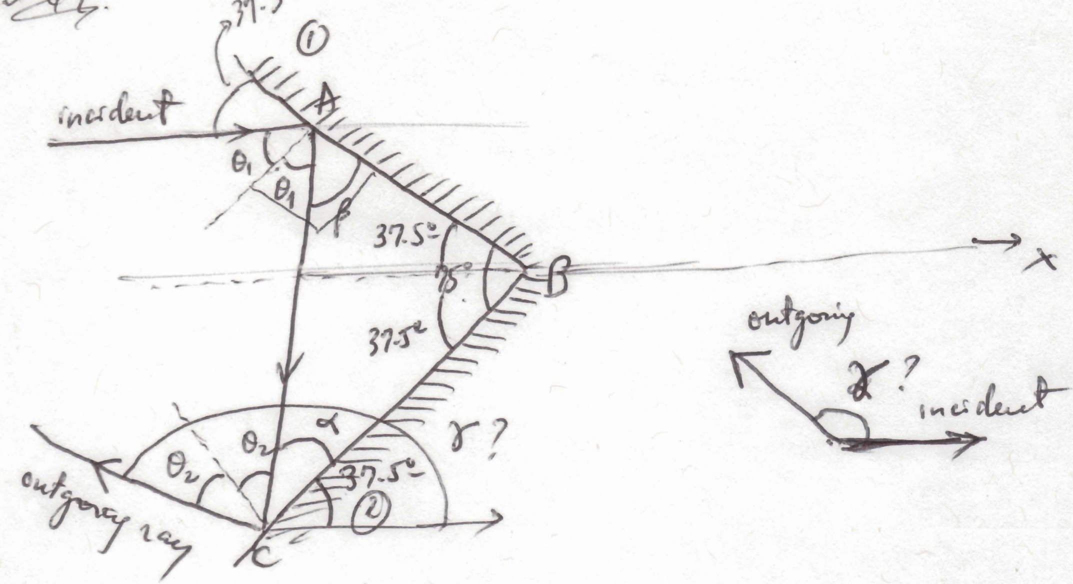
$$2d = (2m+1)\frac{\lambda_0}{2n} \rightarrow \text{thickness: } \boxed{d = \frac{(2m+1)\lambda_0}{4n}}$$

index of refraction for film.

Minimum thickness.

$$d_{min} \underset{m=0}{=} \frac{\lambda_0}{4n} = \frac{550\,nm}{4 \times 1.333} = 103\,nm.$$

30.29 ~~[illegible]~~



→ Physics: Law of reflection on θ_1 & θ_2 ✓

→ Geometry:

$$\gamma = 37.5° + \alpha + 2\theta_2$$

$$\beta = 90 - \theta_1$$

$$\alpha = 90 - \theta_2$$

$$ABC = \alpha + \beta + 75° = 180°$$

$$\theta_1 = 90 - 37.5° = 52.5° \rightarrow \beta = 90 - 52.5° = 37.5°$$

$$\alpha = 180 - 75 - 37.5 = 67.5°$$

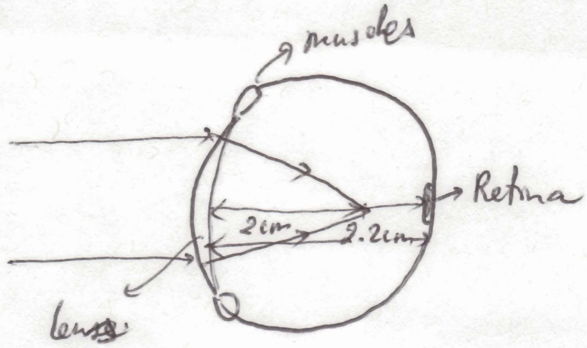
$$\theta_2 = 90 - 67.5° = 22.5°$$

$$\gamma = 37.5° + 67.5° + 2 \times 22.5° = 150°$$

Outgoing ray @ 150° CCW from incident ray.

or 210° CW

31.36

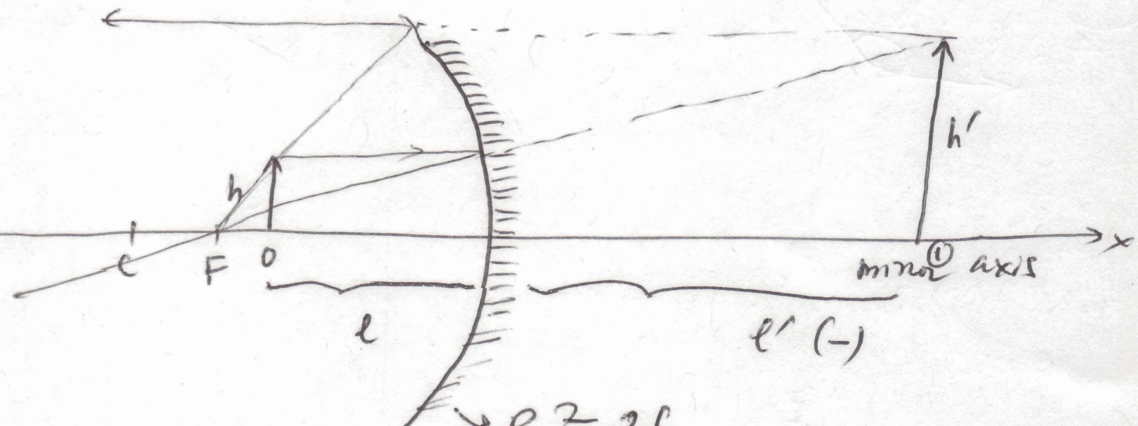


a) Nearsighted

b) Power → diopter $= \dfrac{1}{f(m)}$ $\begin{cases} \text{eye: } \dfrac{1}{0.02m} = 50 \text{ diopters} \\ \text{desired} = \dfrac{1}{0.022m} = 45.5 \text{ diopters.} \end{cases}$ use concave lens.

power -4.5 diopters

31.42



$\to R \stackrel{?}{=} 2f$

$$\begin{cases} \dfrac{1}{\ell} + \dfrac{1}{\ell'} = \dfrac{1}{f} \\ h = 5.7cm \;;\; h' = 9.5cm \;;\; \ell = +22cm \end{cases}$$

$$M = \frac{h'}{h} = -\frac{\ell'}{\ell} \Rightarrow \boxed{\frac{9.5}{5.7}\ell = -\ell'}$$

$$\frac{1}{\ell} + \frac{1}{-\frac{9.5}{5.7}\ell} = \frac{1}{f} \to \frac{1}{\ell}\left(1 - \frac{5.7}{9.5}\right) = \frac{1}{f}$$

$$f = \frac{22cm}{1 - \frac{5.7}{9.5}} = 55cm.$$

$\to R = 2f = 110$ cm.