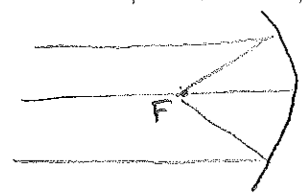
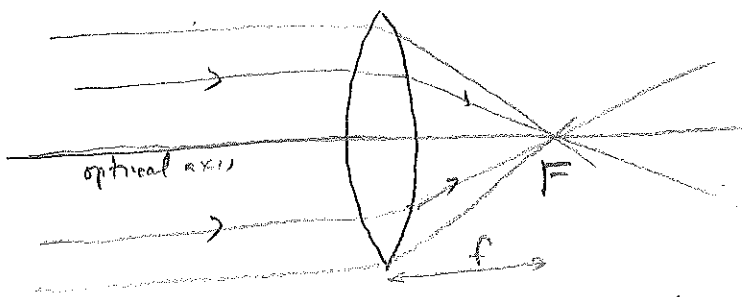
Lenses

[concave mirrors use reflection from curved surfaces to focus light]



Converging lens

[use refraction by curved surfaces to focus light]



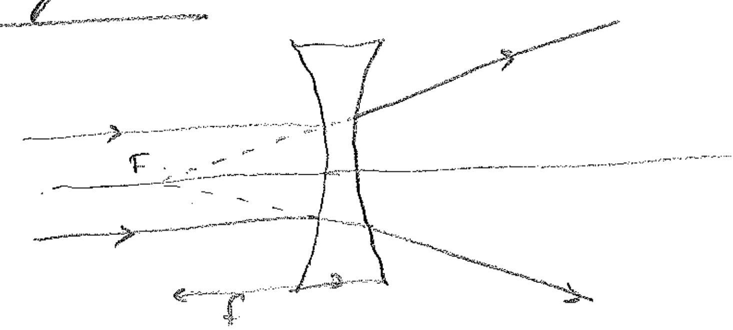
Paraxial rays (parallel rays close to optical axis) are refracted to converge to a focal point F

F is a real focus because rays actually pass through it

$\Rightarrow$ F is on the R-side

$\Rightarrow$ focal length $f > 0$ for a converging lens

Diverging lens



F is a virtual focus because rays appear to come from it but do not actually pass through it

F is on V-side

$f < 0$ for a diverging lens

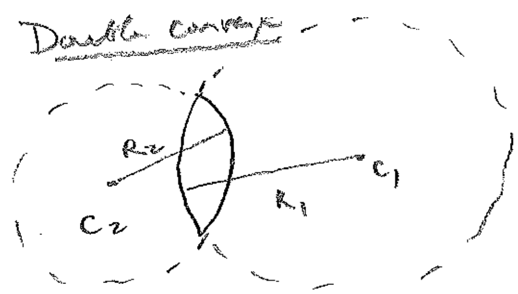
For a mirror $f = \frac{1}{2}R$

But for a lens f depends on both ① shape of lens, ② index of refr

lensmaker's formula: $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

R_1 = radius of curvature of first surface struck by incident light
R_2 = " " " second " " " "

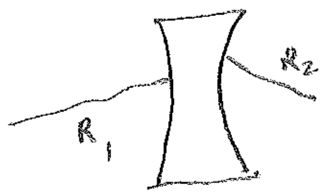
Double convex



$R_1 > 0$ because C_1 is on R-side
$R_2 < 0$ " C_2 " " V-side

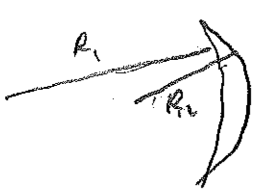
$$\underbrace{\frac{1}{R_1}}_{+} - \underbrace{\frac{1}{R_2}}_{-} > 0 \quad \Rightarrow \quad f > 0$$
converging

Double concave



$R_1 < 0$
$R_2 > 0$ $\Rightarrow$ $f < 0$

[Q about meniscus (convex)] →



$R_1 < 0$, $R_2 < 0$
$|R_1| > |R_2|$

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (n-1)\left(\underbrace{-\frac{1}{|R_1|}}_{\text{smaller}} + \underbrace{\frac{1}{|R_2|}}_{\text{bigger}}\right) > 0$$

meniscus (concave)

$f < 0$

Rule of thumb: thicker in center ⇒ converging ($f > 0$)
thinner in center ⇒ diverging ($f < 0$)

→ (clubble question)

Meniscus:

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

What is sign of f?

BUBBLE LENS

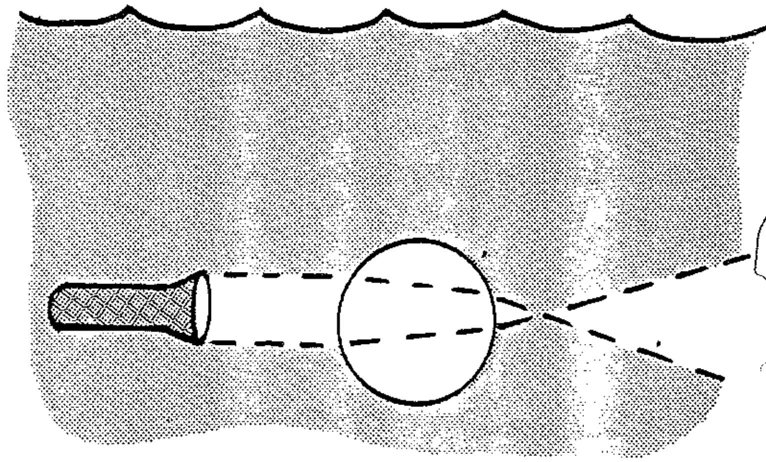
84

Good exercise

Underwater is a bubble. A light beam shines through it. After passing through the bubble the light beam

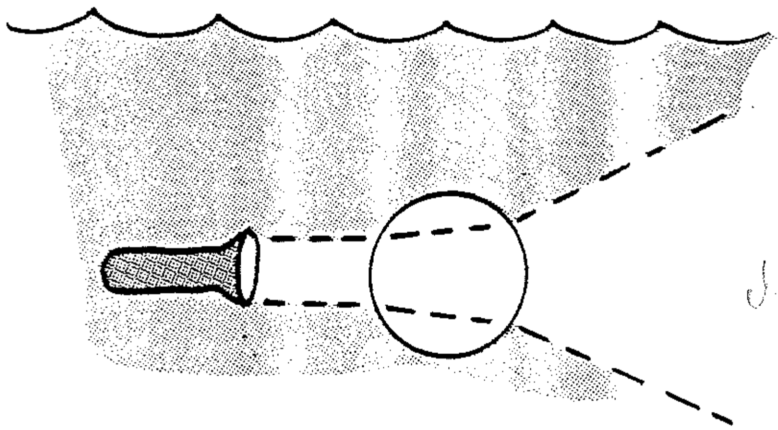
all evenly divided b/w (a) & (b)

a) converges



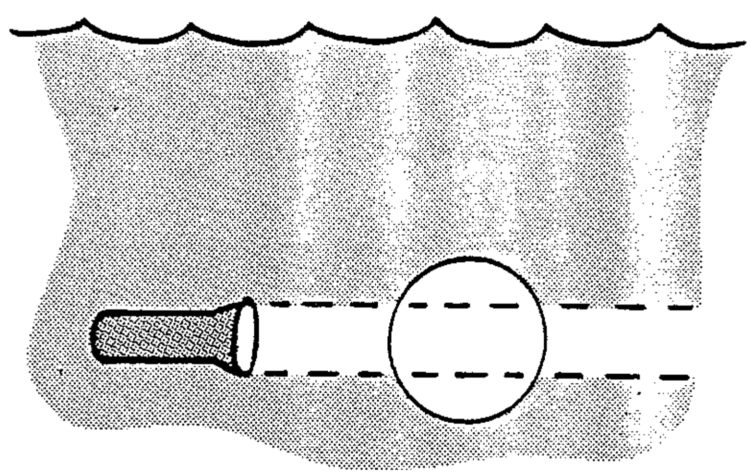
Have them ~~thrash it out!~~ discuss it w/ each other

b) diverges



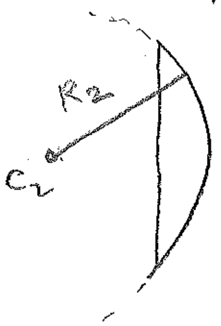
then the class converge on (b)!

c) is unaffected



Lens makers formula $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Consider a special case: plano-convex

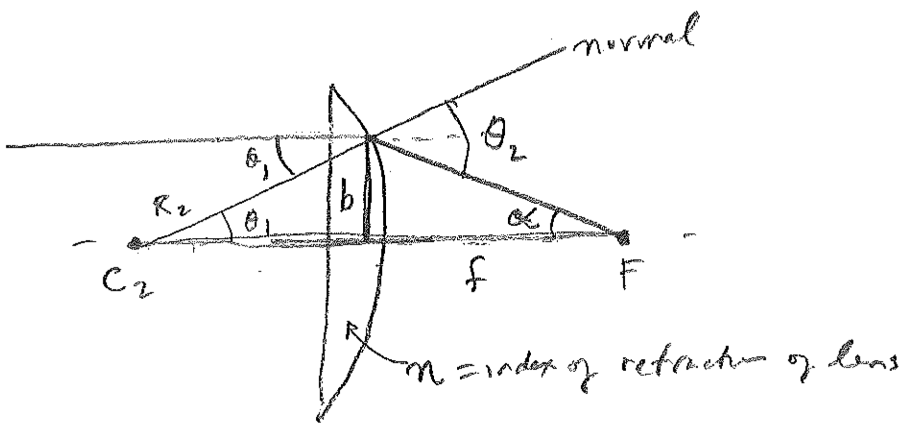


$R_1 = \infty \implies \frac{1}{R_1} = \infty$

$R_2 < 0$

$\frac{1}{f} = (n-1)\frac{1}{|R_2|}$

We'll now derive this.



Snell: $n \sin\theta_1 = \sin\theta_2$

Geometry: $\theta_1 + \alpha = \theta_2$

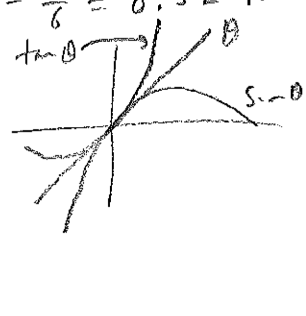
$\sin\theta_1 = \frac{b}{|R_2|}$

$\tan\alpha = \frac{b}{f}$

Paraxial rays: all angles are small

Small angle approximation $\sin\theta \approx \theta$ (radians)

[What?! $\sin 30 = \frac{1}{2}$. But $30\left(\frac{\pi}{180}\right) = \frac{\pi}{6} = 0.52$ radians. $\sin(0.52) \approx 0.50$]
4%



Also $\tan\theta \approx \theta$

Snell: $\theta_2 \approx n\theta_1$

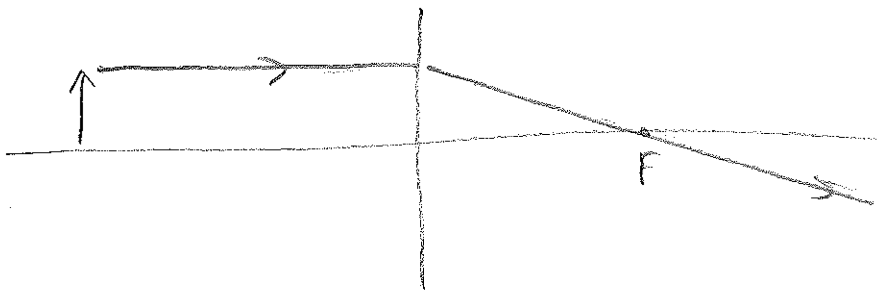
$\theta_1 + \alpha = \theta_2 = n\theta_1$

$\alpha = (n-1)\theta_1$

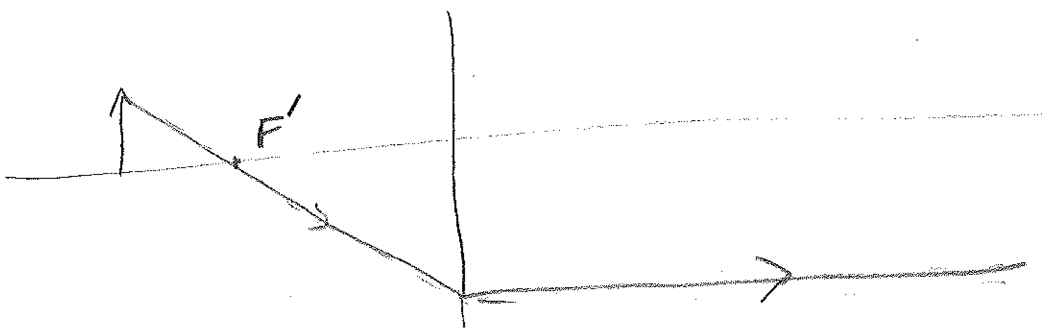
$\frac{b}{f} = \frac{(n-1)b}{|R_2|} \implies \frac{1}{f} = (n-1)\frac{1}{|R_2|}$

Ray tracing rules: converging lenses

① a ray parallel to axis is refracted thru F (= true focus since $f > 0$)



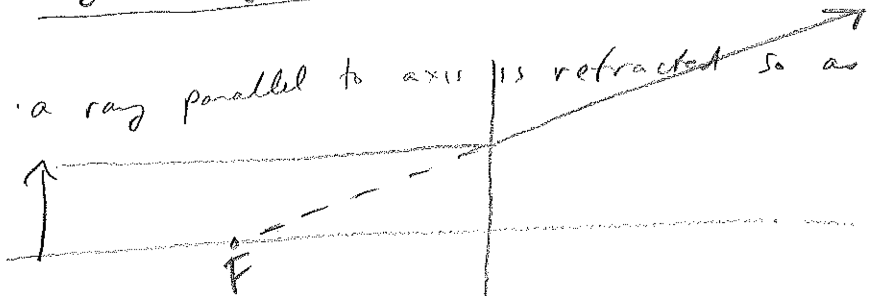
② a ray passing thru F′ is refracted parallel to axis
(F′ is on opposite side of lens from F, & same distance from lens)



③ a ray passing thru center of lens is undeviated
[parallel surfaces]

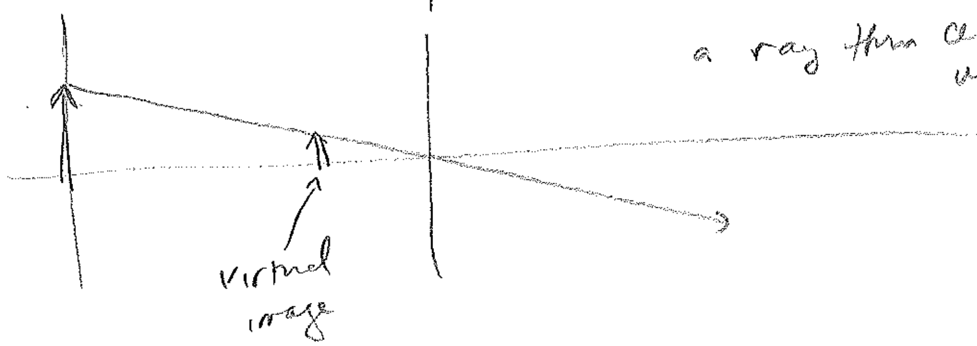
Ray tracing rules for diverging lenses

a ray parallel to axis is refracted so as to appear to come from F



a ray that would have passed thru F' is refracted parallel to axis

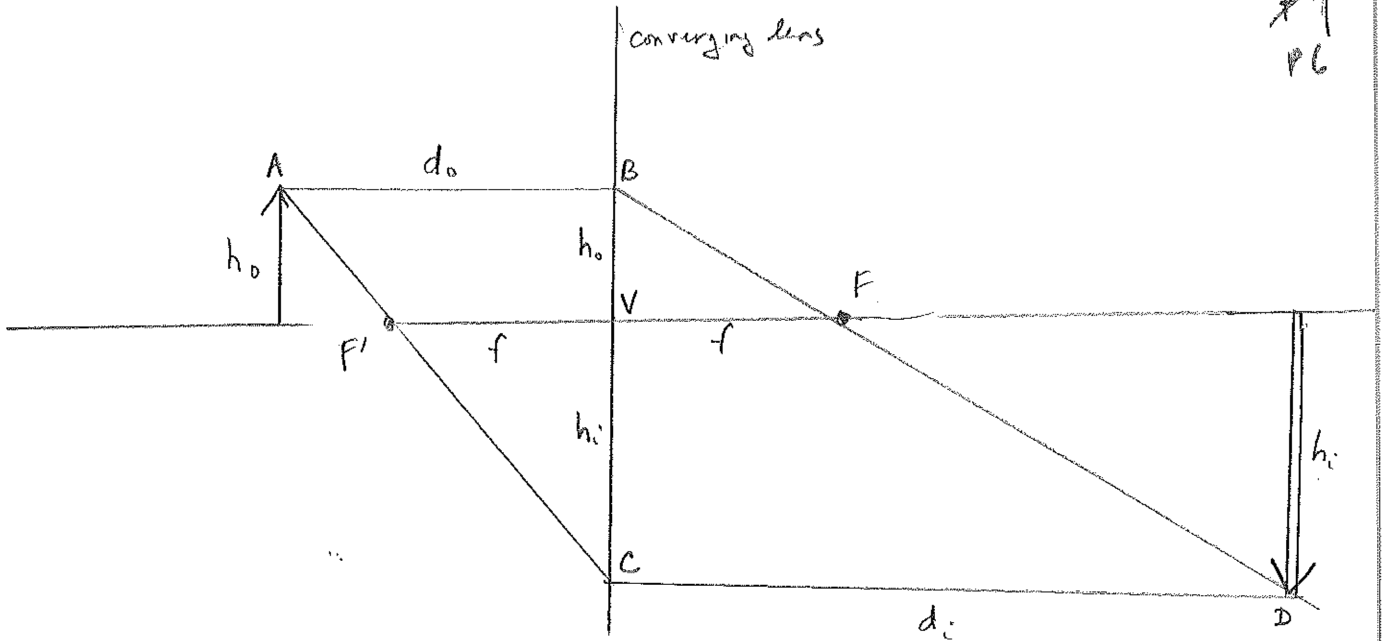
a ray thru center is undeviated



Important exception to sign convention!

An object on the V-side of a lens is nevertheless a real object, and $d_o > 0$

An object on the R-side of a lens is a virtual object, and $d_o < 0$



Similar triangles

$ABC \approx F'VC$

$$\frac{h_o + h_i}{d_o} = \frac{h_i}{f}$$

$BVF \approx BCD$

$$\frac{h_o + h_i}{d_i} = \frac{h_o}{f}$$

Add eqns:

$$\frac{h_o + h_i}{d_o} + \frac{h_o + h_i}{d_i} = \frac{h_i}{f} + \frac{h_o}{f} = \frac{h_o + h_i}{f}$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$ thin lens eqn.

Divide eqns:

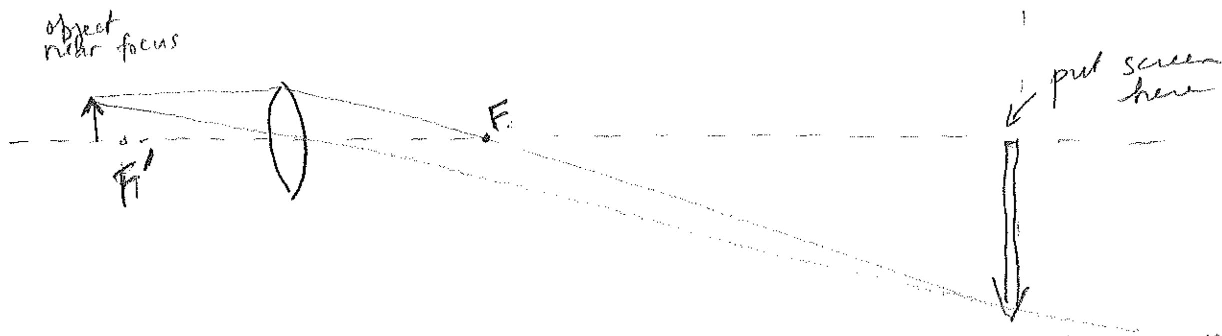
$$\frac{\left(\frac{h_o + h_i}{d_o}\right)}{\left(\frac{h_o + h_i}{d_i}\right)} = \frac{\left(\frac{h_i}{f}\right)}{\left(\frac{h_o}{f}\right)}$$

$$\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

Magnification $m = \underset{\substack{\uparrow \\ \text{inverted}}}{-} \dfrac{h_i}{h_o} = -\dfrac{d_i}{d_o}$

Slide projector [or overhead projector]

[makes a large real image of a small object, in this case a slide or transparency]



careful which OH you use! use the old brown Physics Dept one

[OH: transparency "arrow"]

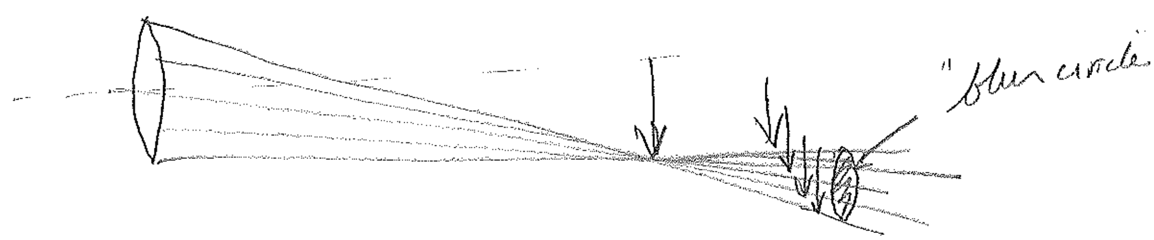
move lens up, goes out of focus

but image is still formed. where? $d_o\uparrow$, $d_i\downarrow$

[Demo: use ground glass or piece of paper to locate it]

Why the blur?

optional



[OH: use black dot to show blur circle or hole cut in paper.

blur caused by outer rays

use stops to reduce it

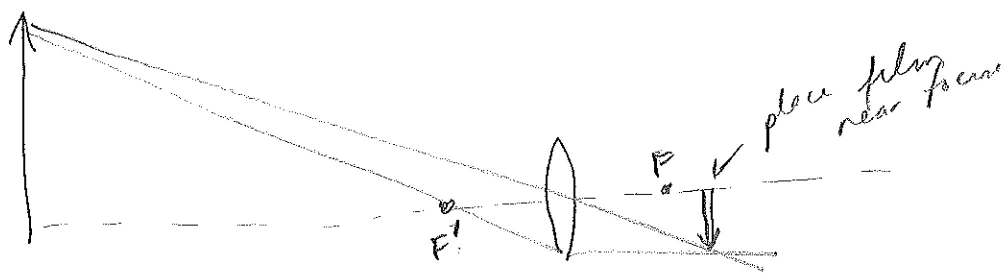
[Demo: mask over OH lens?]

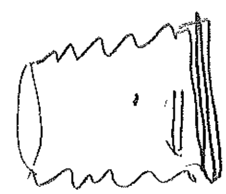
~~myopia~~

later → [~~eye lens can't focus on far objects blur on retina reduce it by looking thru little hole "squint eye"~~ ←

<u>Camera</u>

[same principle but in reverse: big object; small image]





Now objects at different distances will require different positions of lens wrt film

→ Q:

Optional

When near objects are in focus far objects will be blurry; ~~[illegible]~~ later mtg

If use stops, a smaller aperture blur will be less & so a greater range of distances will be "in focus"

"depth of field"

smaller aperture → greater depth of field

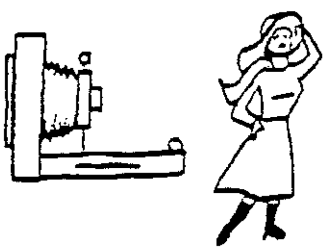
CLOSE-UP

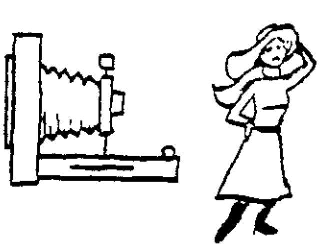
easy

p.6.1

The first sketch shows a camera properly focused on the DISTANT MOUNTAINS. When the camera is re-focused on a very NEAR subject it will be set as shown in

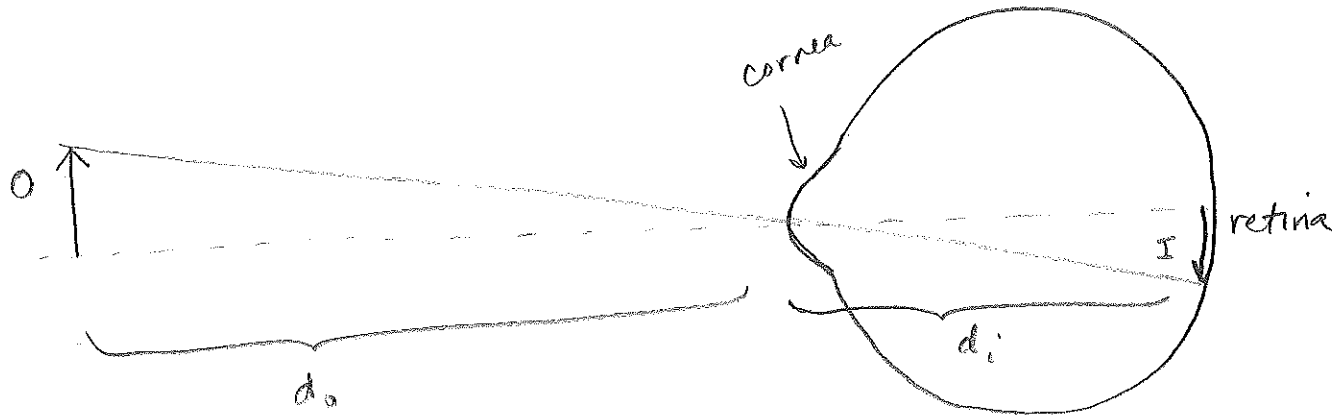
a) the second sketch
b) the third sketch
c) the fourth sketch

a) 

b) 

c) 

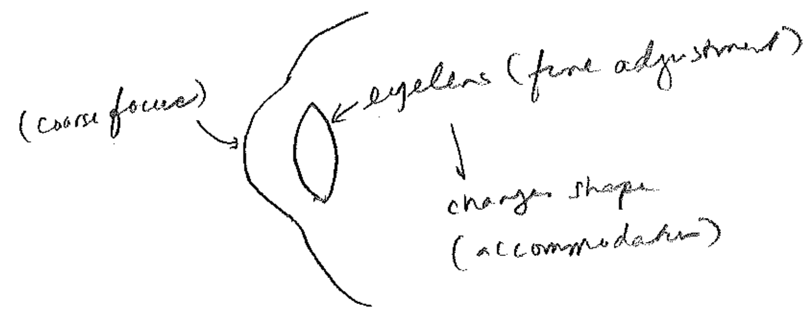
Eye



$$\frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{f}$$

Image must be on retina to be "focused", so d_i is fixed [unlike camera]

∴ If d_o changes, f must change



[DEMO: hold finger in front of one eye (other closed)
Notice if finger is in focus, bkgnd is blurry, & vice versa

Q: difference in ~~?~~ shape of lens in these 2 cases?

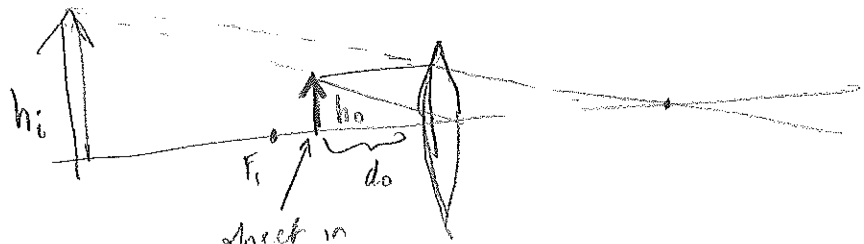
[DEMO: what is closest possible distance?]

"near point", $d_o \cong 25$ cm (10 in)
recedes w/ age (presbyopia) [flexibility of eyelens decreases]

[have to hold things further back, appear smaller → [need magnifying glass or reading glasses]

[chromatic aberration in black light bulbs]

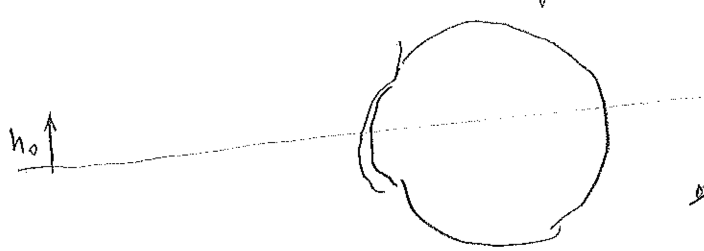
Magnifier: ~~lens that~~ using a lens to create a virtual image



↳ $d_o < f \Rightarrow \frac{1}{d_o} > \frac{1}{f} \Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} < 0 \Rightarrow d_i < 0$

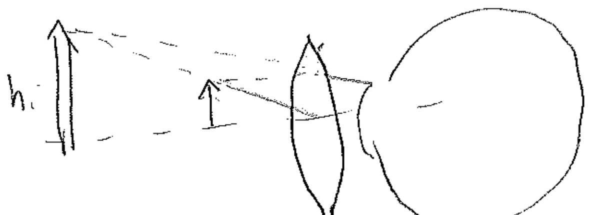
$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} > 1$$

image ~~object~~ is larger than object but also further away, so may not appear larger. Real point is: allows you to put object closer to your eye than would normally be possible ⇒ place image at near pt



~~optimally d_i ...~~

$$\frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i}$$



$$m = -\frac{d_i}{d_o} = -\frac{d_i}{f} + 1$$

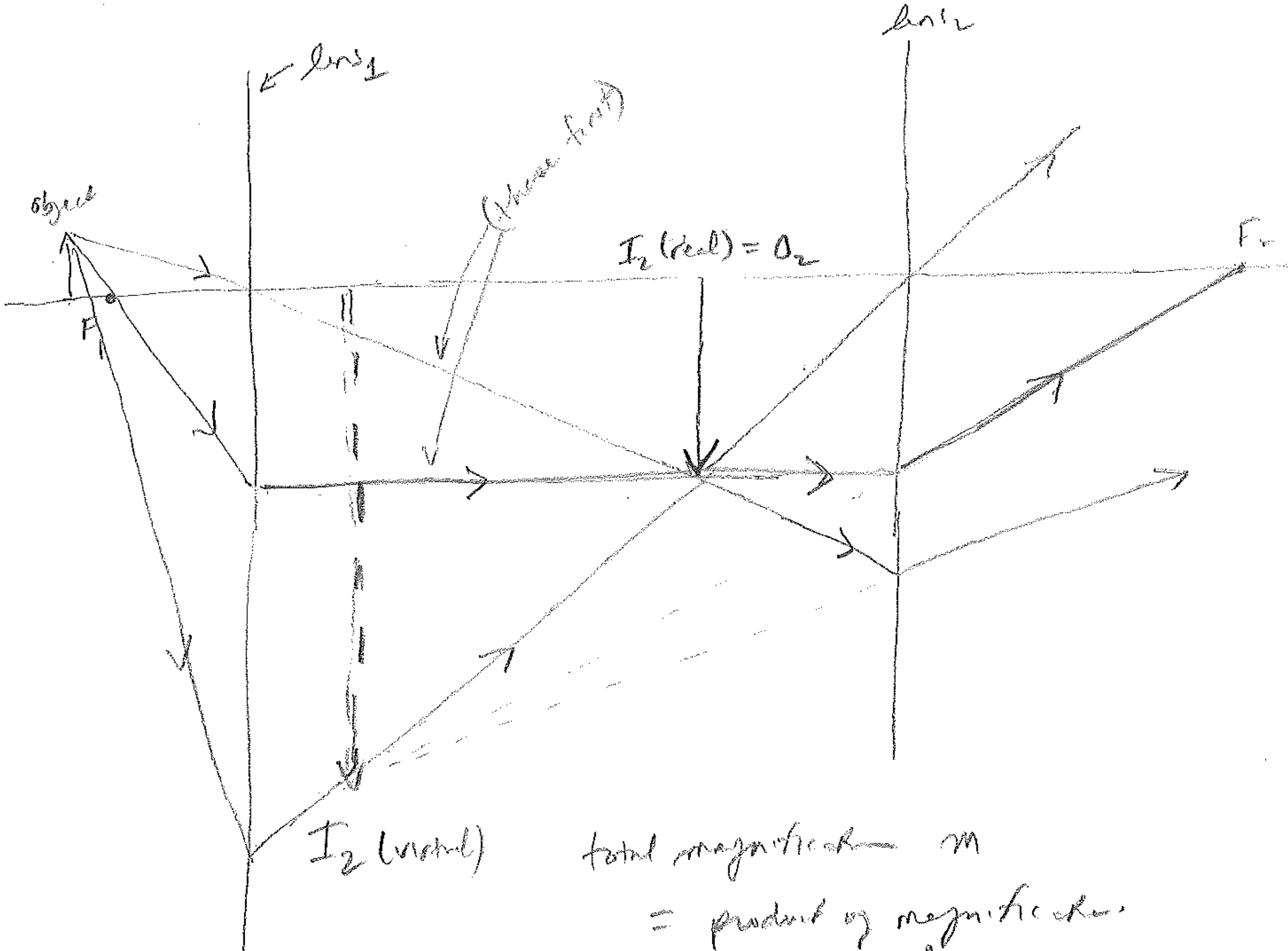
$$= \frac{25\,cm}{f} + 1$$

$$\approx \frac{25\,cm}{f}$$

optimally: $d_i \approx -25$ cm

Compound microscope

The first lens (objective) forms a real image (I_1) which acts as the object (O_2) of the second lens.
The second lens (eyepiece) forms a virtual image (I_2)



total magnification M
= product of magnifications of each lens = $\underline{m_1 m_2}$

↳ [Problem]

[telescope works similarly]