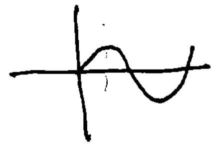
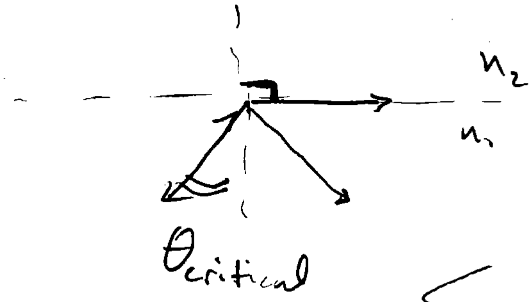
Suppose $\theta_T = 90°$





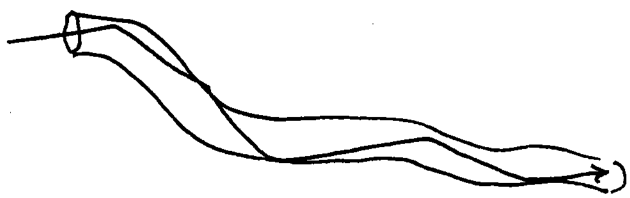
$n_1 \sin\theta_c = n_2 \sin 90°$ (where $\sin 90° = 1$)

$\sin\theta_c = \frac{n_2}{n_1}$

$\theta_I \geq \theta_c$ gives no refracted light - only reflected light

=> Total internal reflection

Fiber optics



laser surgery
endoscopic surgery
etc

Thin lenses

lens eqn $\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$

o: object distance, i: image distance, f: focal length

Thickness of lens is small compared to o, i, or f.

Ray Diagram is often useful in Analysis

Parallel ray

central ray

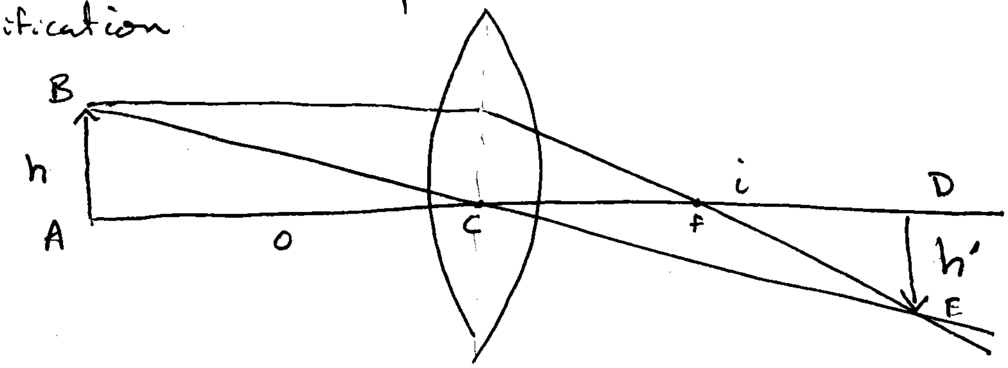
focal ray

Do converging lens diagram

Sign Conventions

	f	o	i
converg lens	+		
diverging lens	−		
real object		+	
virtual object		−	
real image			+
virtual image			−

Magnification



Triangle ABC is similar to Triangle DEC

$$m = -\frac{h'}{h} = -\frac{i}{o}$$ gives relative size of ~~ob~~ image to object

"−" means <u>inverted</u> image

"+" would mean an <u>upright</u> image

<u>Examples</u>

Object 2mm high 100 cm from converging lens of focal length 20 cm

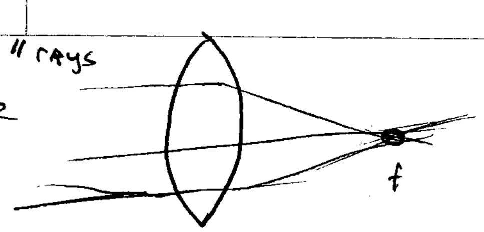
Where and how large is image?

$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$

$$\frac{1}{100\text{ cm}} + \frac{1}{i} = \frac{1}{20\text{ cm}} \qquad i = +25\text{ cm}$$

$$m = -\frac{o}{i} = -\frac{25}{100} = -0.25$$

image is real, inverted and (2 mm)(.25) = 0.5 mm high f is (+) Converging lense

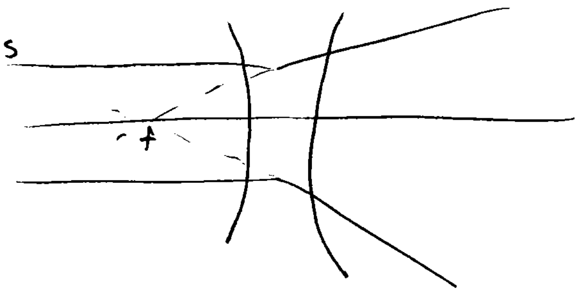


∞ rays converge
Thicker in middle

f is (−) diverging lense
rays

Power of lens $= \frac{1}{f\,(m)}$

Diopters

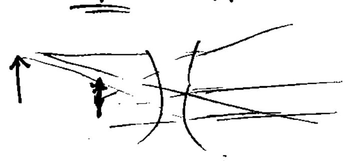


show how rays go in diagrams

Tricky part w/ Thin lens eqn is the Sign Convention
→ do homework problems on this one or else!

Real / virtual image / object Conventions

An image is virtual if the rays diverge from it



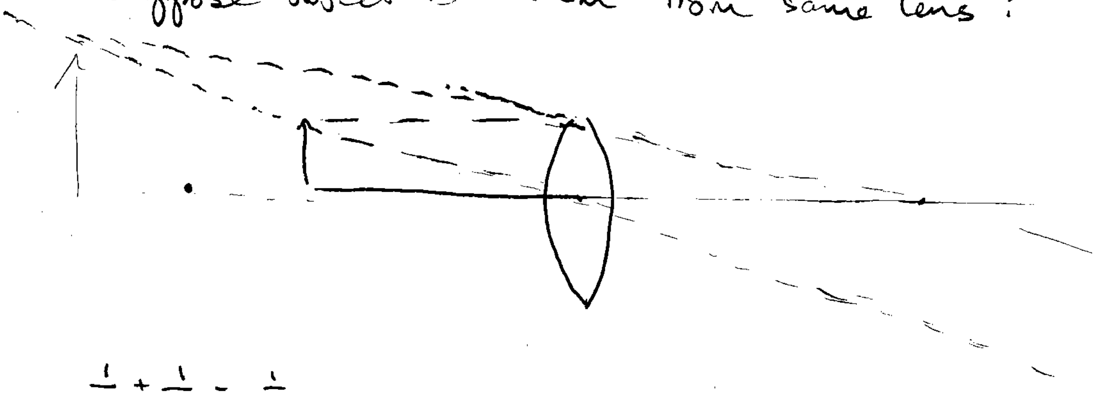
Diverging lens

An image is real if rays converge toward it
(can project on a screen!)

An object is virtual when rays converge toward it
(or to the "image" side of a thin lens)

An object is real when rays diverge ~~From~~ it.

Suppose object is 15 cm from same lens ?



$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$

$\frac{1}{15} + \frac{1}{i} = \frac{1}{20}$ $i = -60$

Image is virtual
Erect
4x lager than object
$(4)(2\,mm) = 8\,mm$

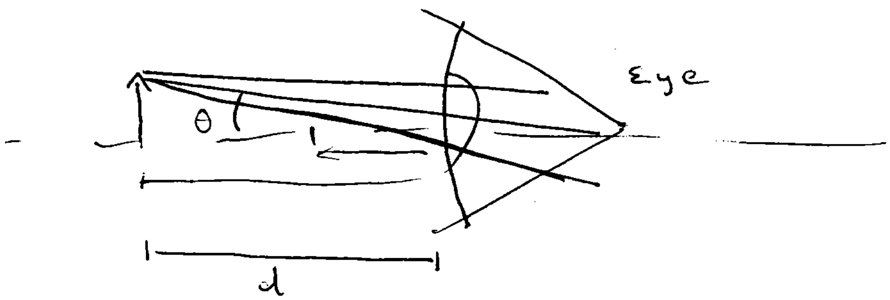
$m = -\frac{(-60)}{(+15)} = +4$

Eye Examples

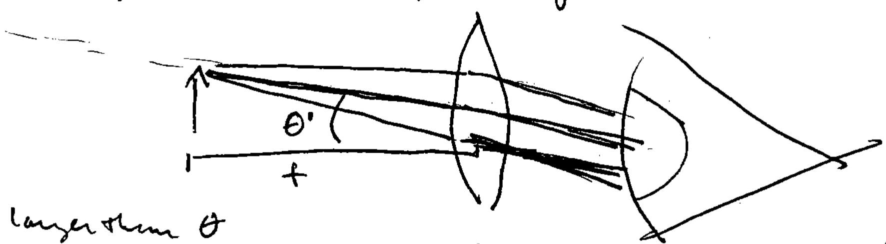
Compound Systems - optical instruments

⇒ image of first lens is the object of the 2ND lens

Magnifier



Natural rays from object diverge. When ~~they~~ d is small enough Your eye can No longer compensate → Near point

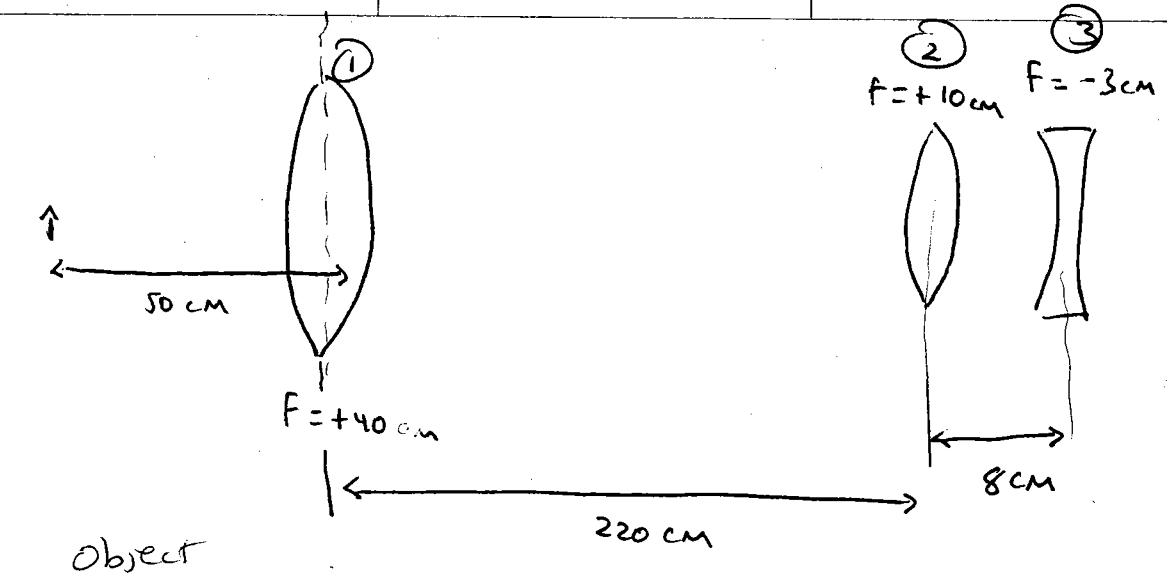


θ' larger than θ because object is closer

$d > f$ $M = \frac{\theta'}{\theta} \approx \frac{d}{f}$

↑ Magnifying glass

Allows one to



~~Image~~ Object is 50 cm to left of lens ①. What is final position, size, and nature of final image?

Lens ①

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f} \qquad \frac{1}{50} + \frac{1}{i} = \frac{1}{40}$$

$i = 200$ cm

$$m_{①} = -\frac{+200}{+50} = -4$$

Lens ②

$o = +20$ cm

$$\frac{1}{20} + \frac{1}{i} = \frac{1}{10} \qquad i = +20 \text{ cm.}$$

$$M_{②} = -\frac{+20}{+20} = -1$$

Lens ③

O position is 12 cm to rt of lens ③

Counts as a virtual ~~image~~ object

$$-\frac{1}{12} + \frac{1}{i} = -\frac{1}{3} \qquad i = -4 \text{ cm}$$

↳ 4 cm to left of lens ③

$$M_{③} = -\frac{-4\text{ cm}}{-12\text{ cm}} = -\frac{1}{3}$$

↓ inverted virtual

$$M_{TOTAL} = M_{①} M_{②} M_{③} = (-4)(-1)(-\tfrac{1}{3}) = -\frac{4}{3}$$

↗ $\frac{4}{3}$ × size of original object

Transparency 48
Figure 34-32, page 1085; Figure 34-33, page 1086; Figure 34-39, page 1089
Ray diagrams for thin lenses

Tipler: **Physics for Scientists and Engineers 4/e**