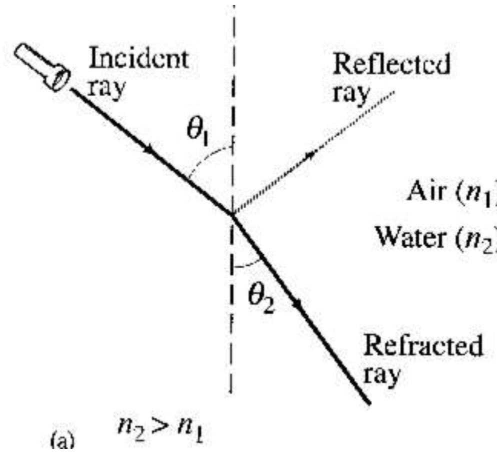
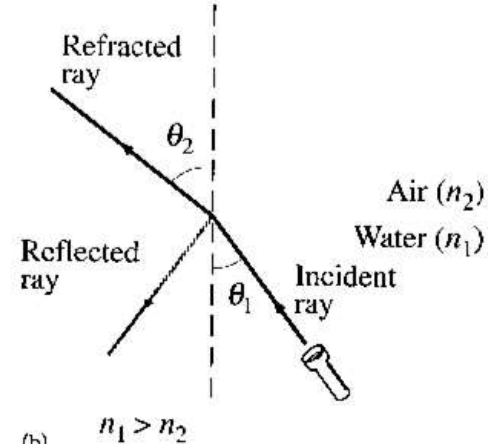
Geometric Optics

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

$$\boldsymbol{\theta}_{\mathbf{low-n}} \rightarrow 90$$

tot internal ref





Ray tracing

- parallel to axis – through f
- through center un-deviated

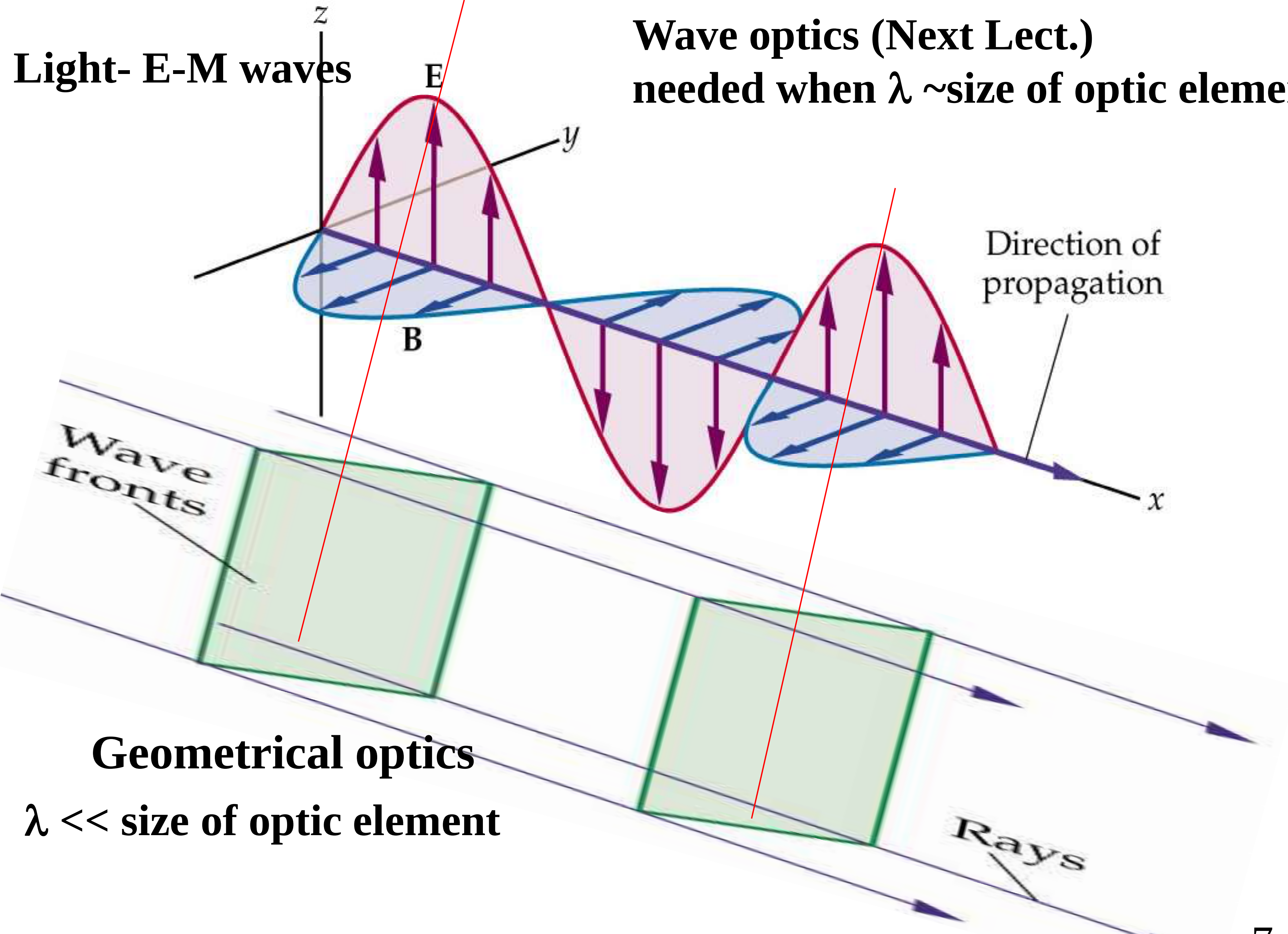
Thin lens formula $$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

Telescopes

microscope

Light- E-M waves

Wave optics (Next Lect.)
needed when λ ~size of optic element

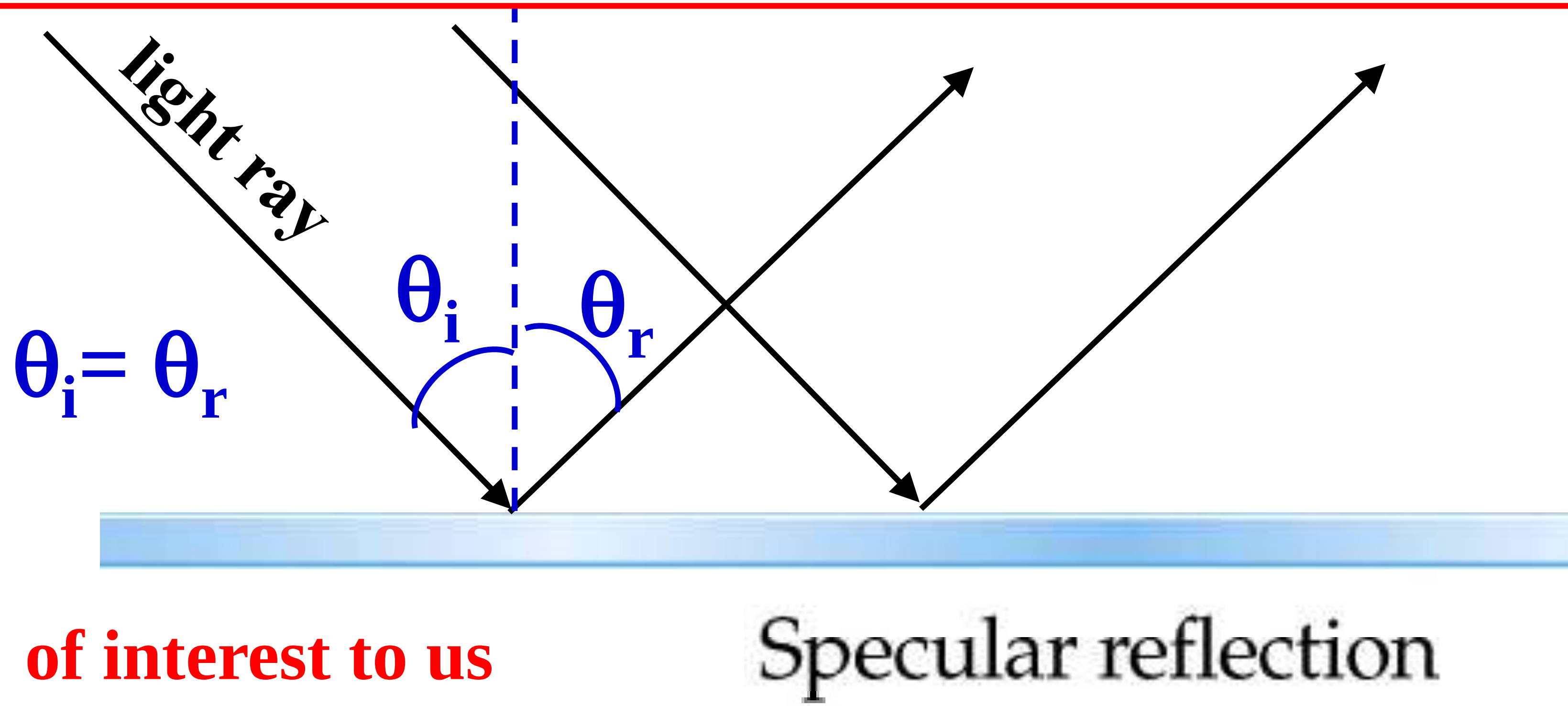


Geometrical optics

λ << size of optic element

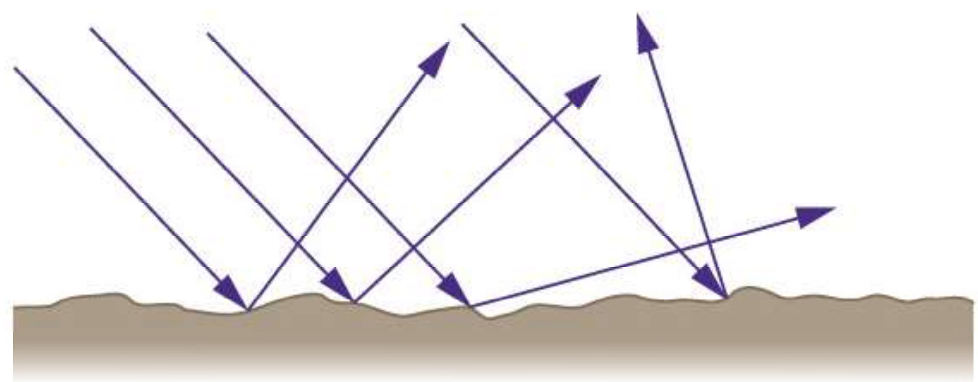
light rays- straight line motion – bent/reflected at surfaces

Reflection



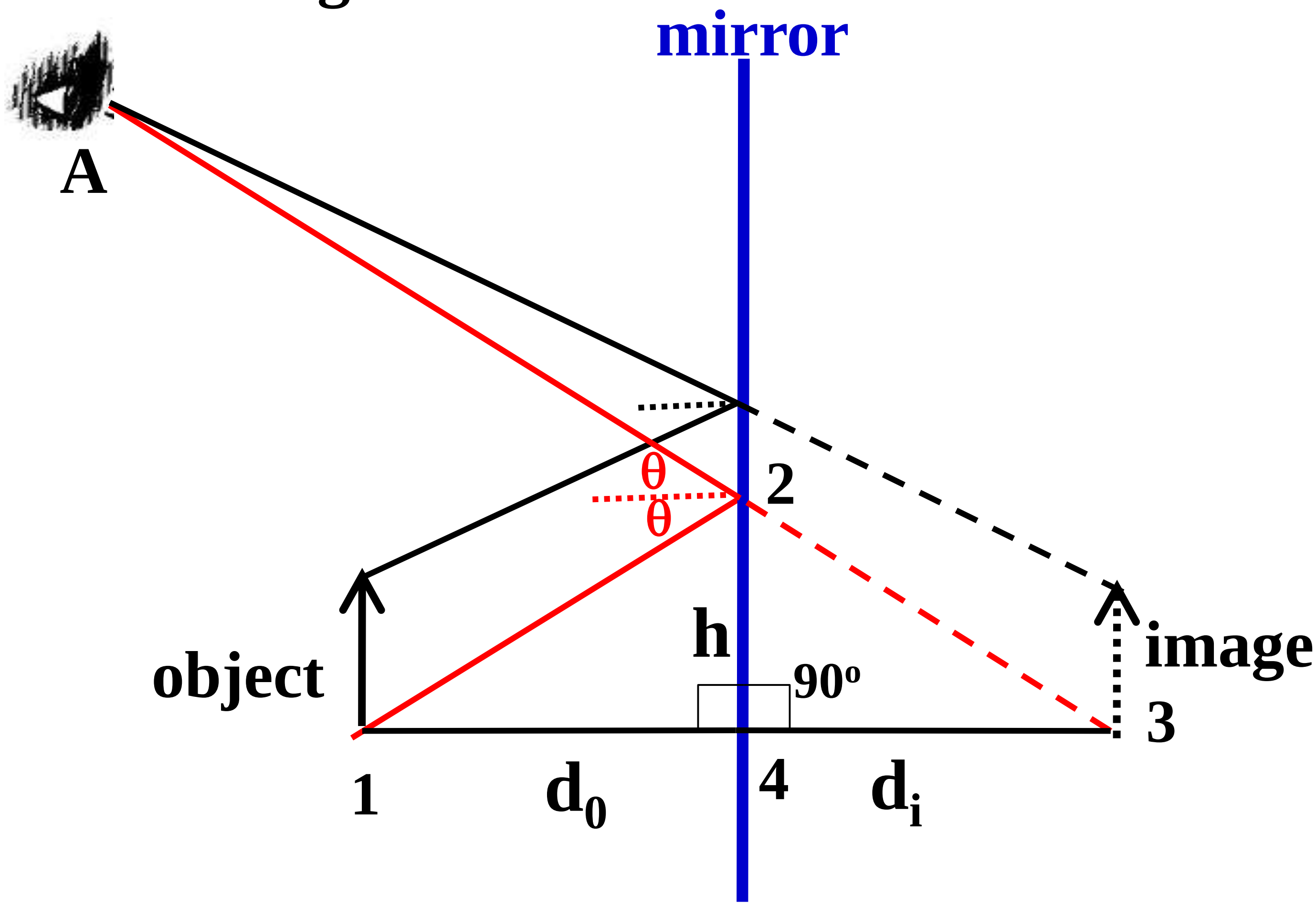
of interest to us

Same but local curvature varied randomly.



(b) Diffuse reflection

image in flat mirror



$\angle 124 = \angle\ 324$ $h = h$ $\angle\ 142 = \angle\ 342 = 90^o$ $\Delta 124 = \Delta 324$

$\Rightarrow$ $d_0 = d_i$

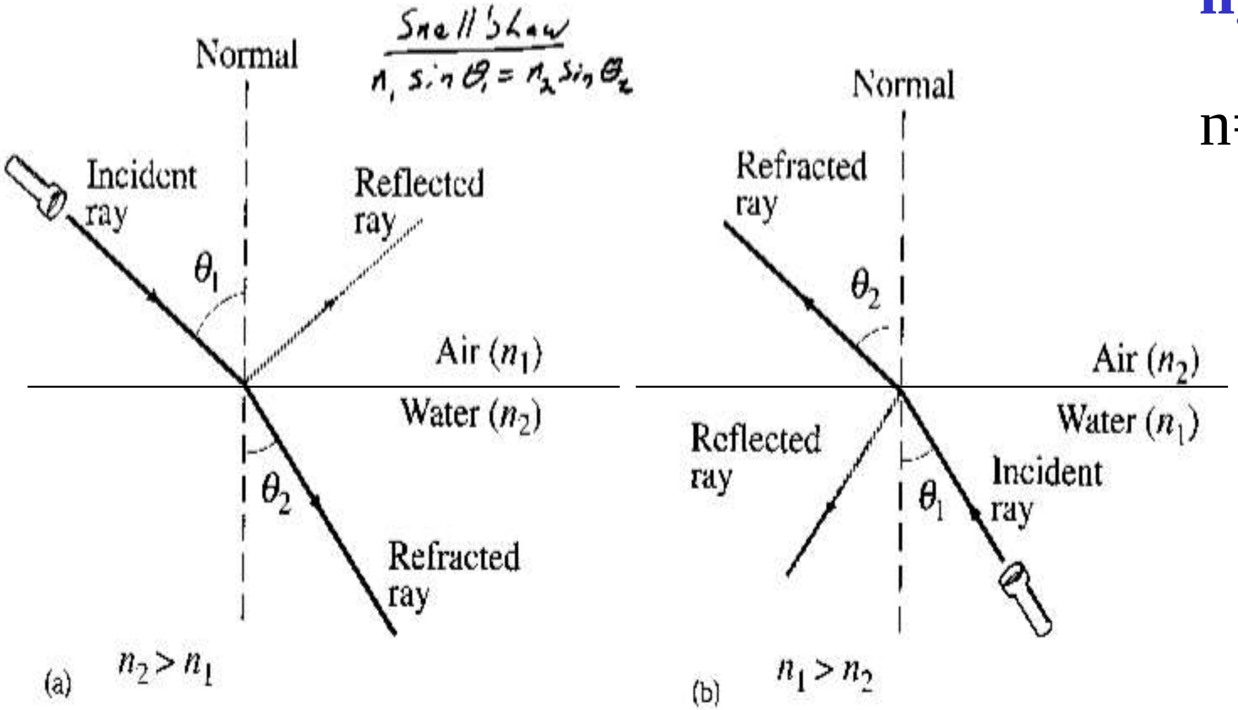
image and object at = distance from mirror

7-1b

Refraction = bending of light between media with different light v

n= refractive index=c/v

Q: What is the speed of light in water?



n= 1.33 water

$$v = \frac{c}{n} = \frac{3(10)^8 \frac{m}{s}}{1.33}$$

$$v = 2.3(10)^8 \frac{m}{s}$$

75% of that in vac.

	n
AIR	1.000293
ICE	1.309
WATER	1.333
GLASS	1.523
DIAMOND	2.419

reverse

link prob

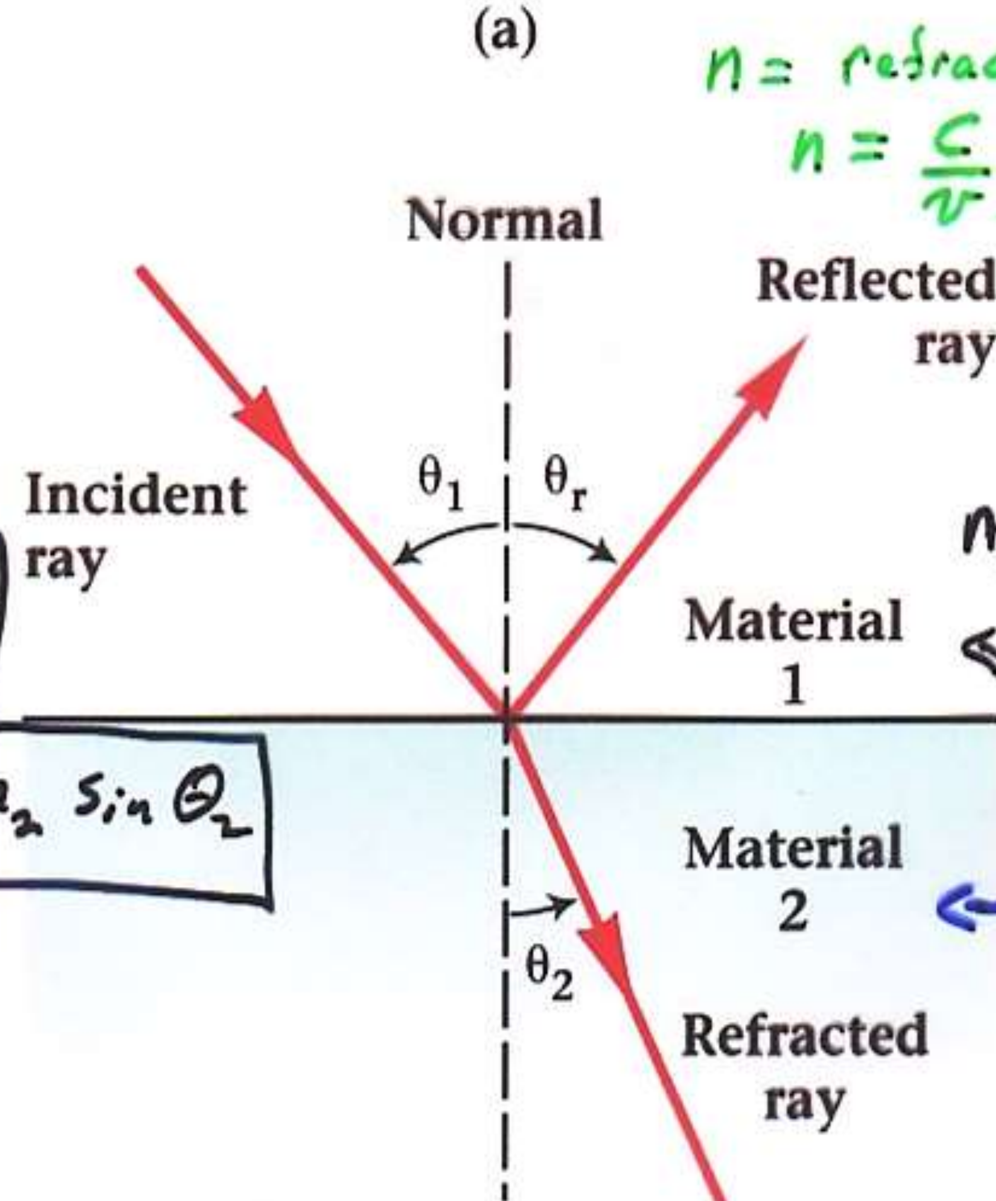
http://arana.cabrillo.edu/~jmccullough/Applets/Flash/Optics/ReflectionRefraction.swf

http://arana.cabrillo.edu/~jmccullough/Applets/Flash/Optics/ReflectionRefraction.swf

http://stwww.weizmann.ac.il/Lasers/laserweb/Java/Twoangles2.htm

$n =$ refractive index

$n = \frac{c}{v}$ $\begin{array}{l} \text{– in vac.} \\ \text{– in material} \end{array}$



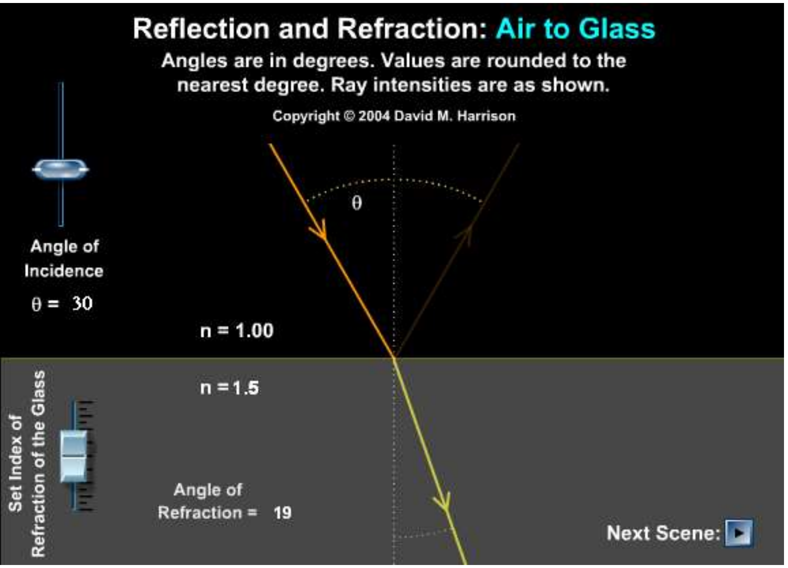
n_1

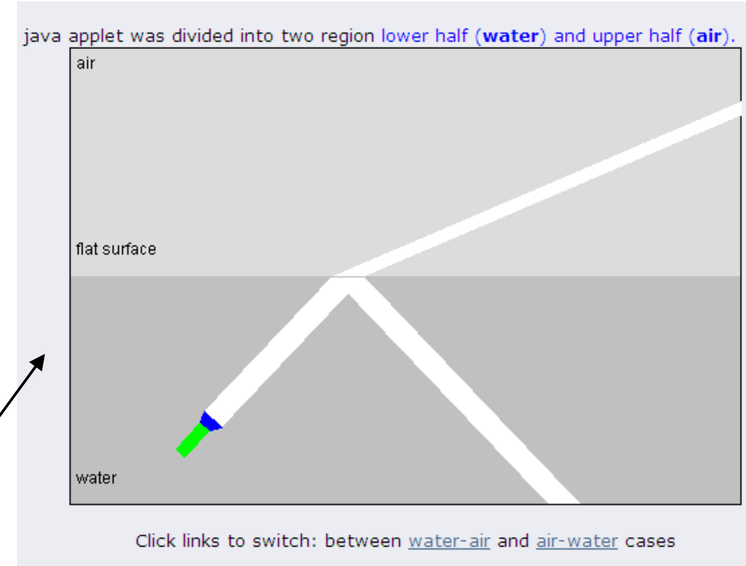
Snell's Law

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

$n_2 > n_1$

http://arana.cabrillo.edu/~jmccullough/Applets/Flash/Optics/ReflectionRefraction.swf

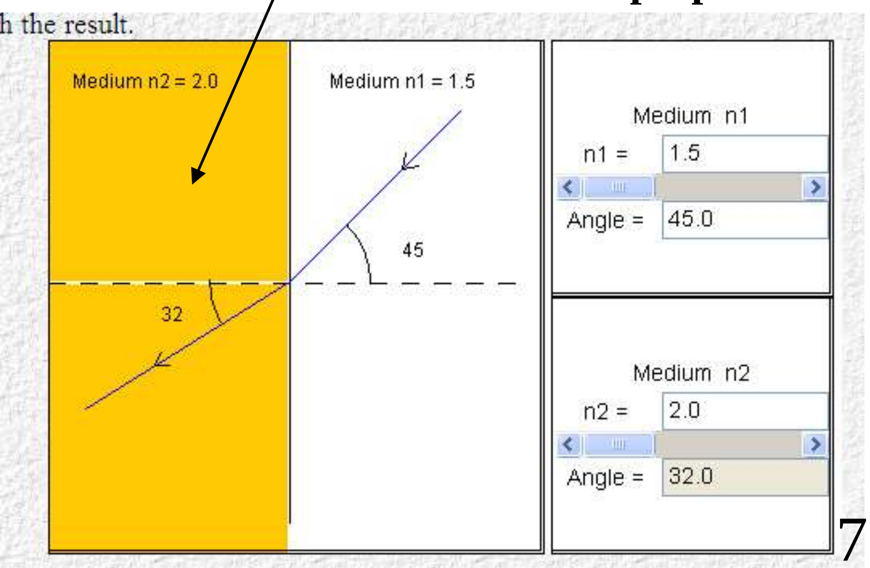


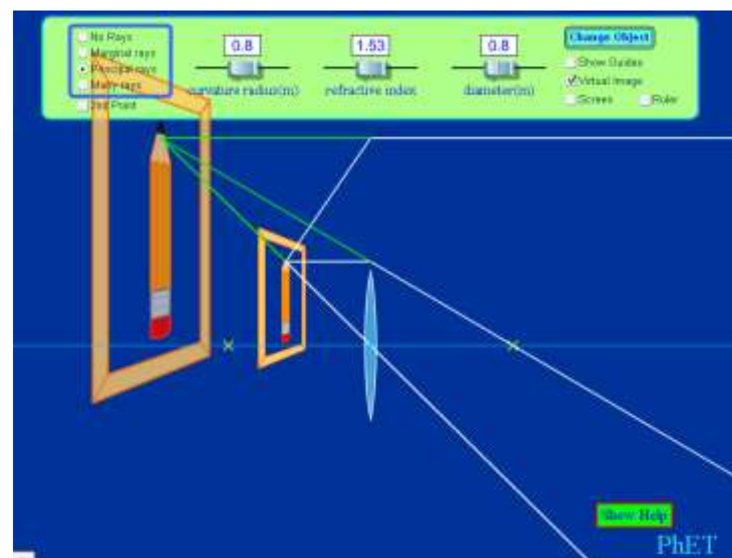


http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=49

http://stwww.weizmann.ac.il/Lasers/laserweb/Java/Twoangles2.htm

http://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html



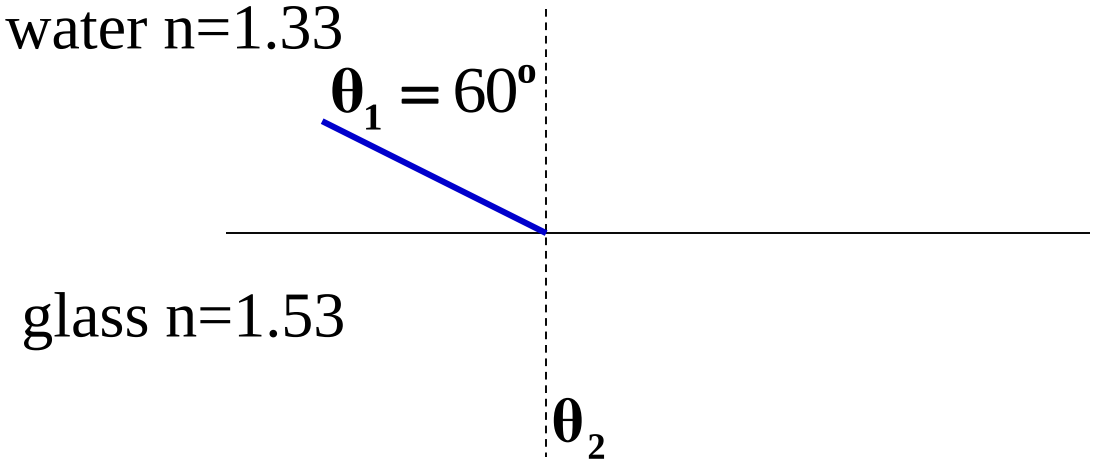


http://interactagram.com/physics/optics/refraction/

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

bigger

smaller

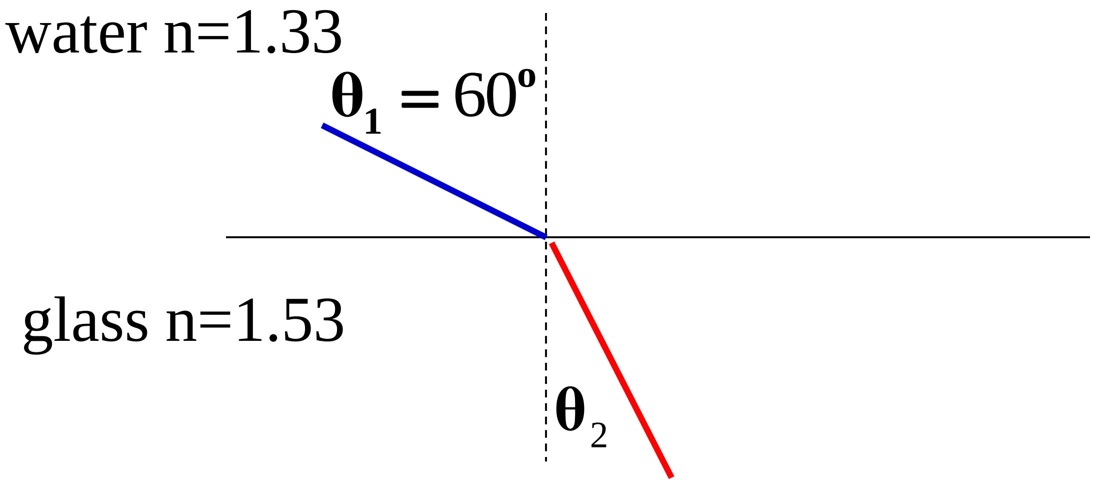


7-3.3

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

bigger

smaller

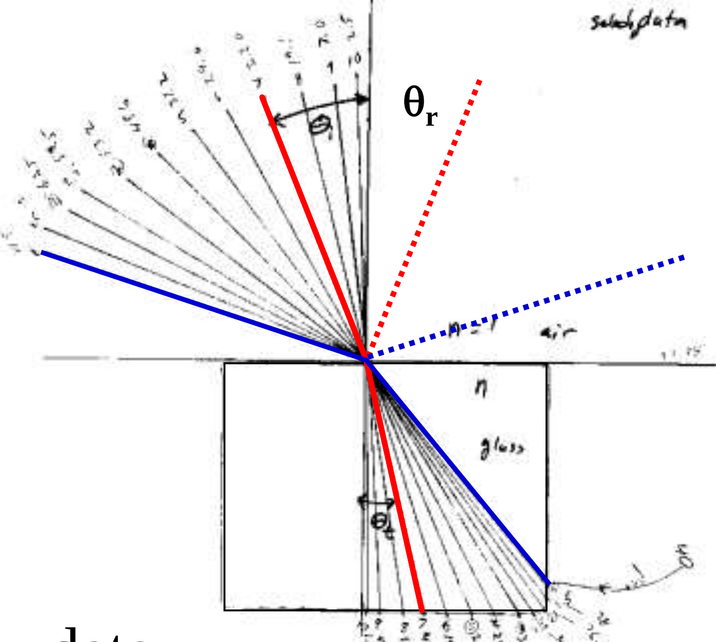


$$(1.33)\sin(60) = 1.53\sin(\theta_2)$$

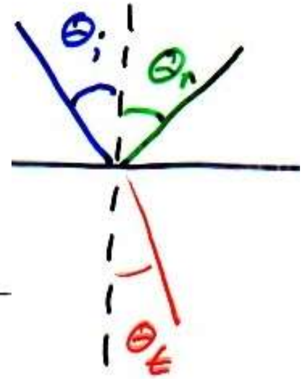
$$\sin(\theta_2) = \frac{(1.33)\sin(60)}{1.53} = .869(.866) = .7525$$

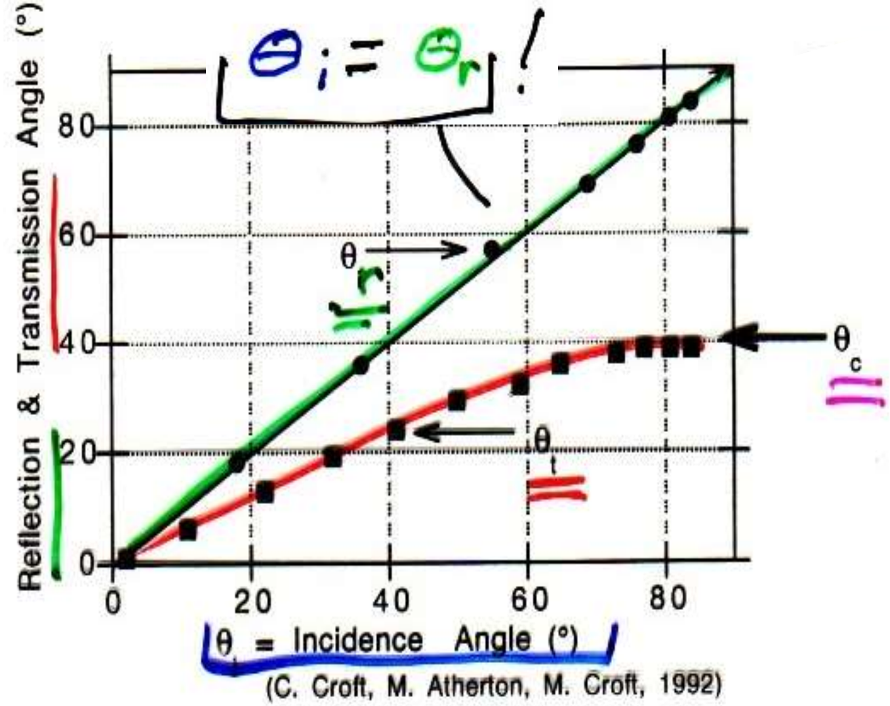
$$\theta_2 = \sin^{-1}(.7525) = 48.8^o$$

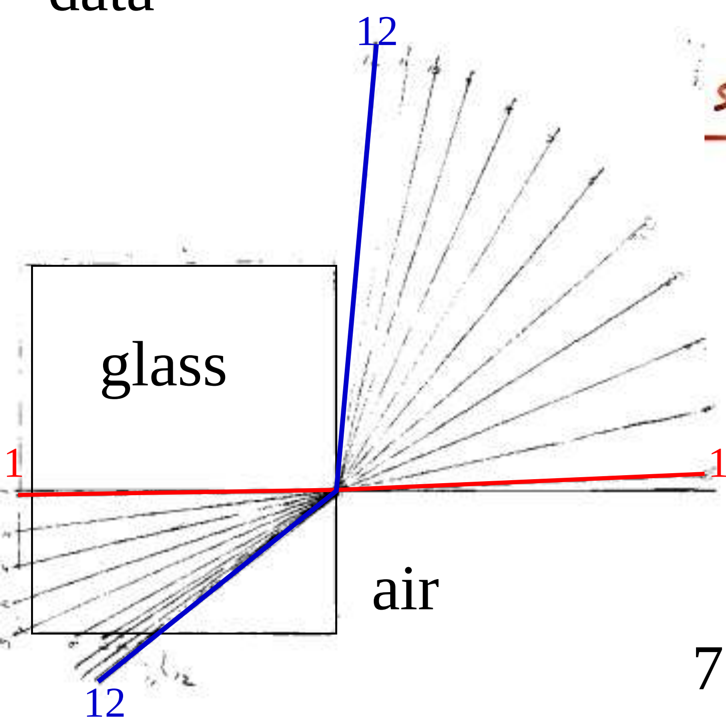
7-3.31



data

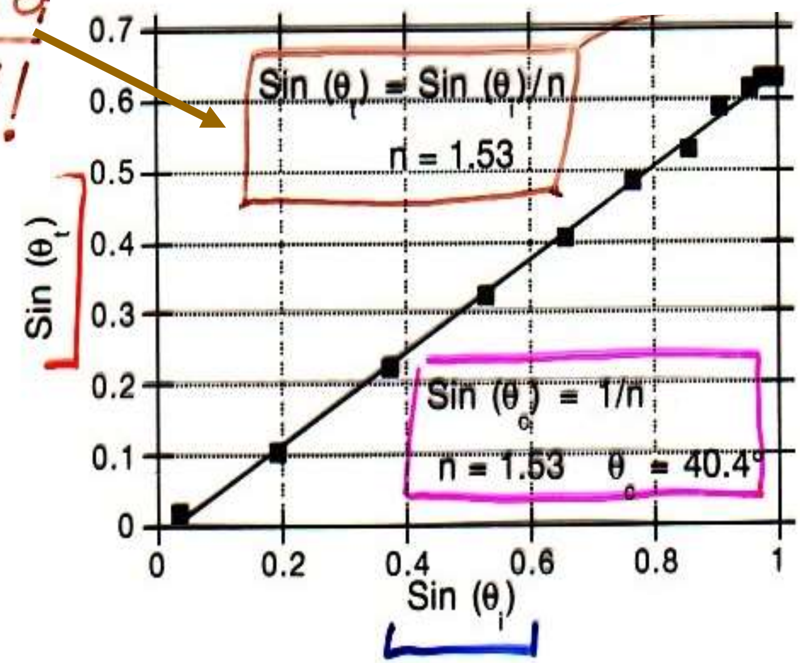




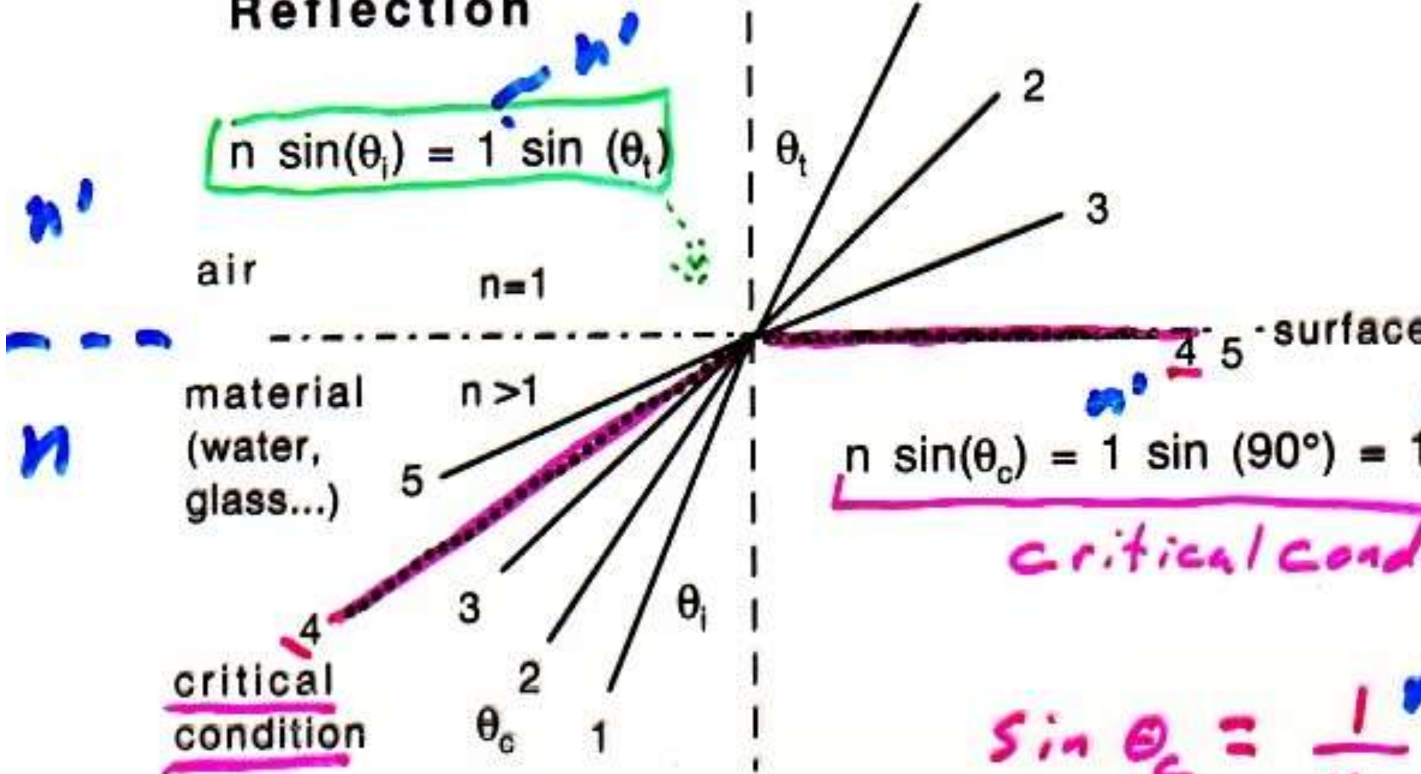


$\sin(\theta_t) = 1 \sin \theta_i$

$\underbrace{n = 1.53}$!!



Total Internal Reflection

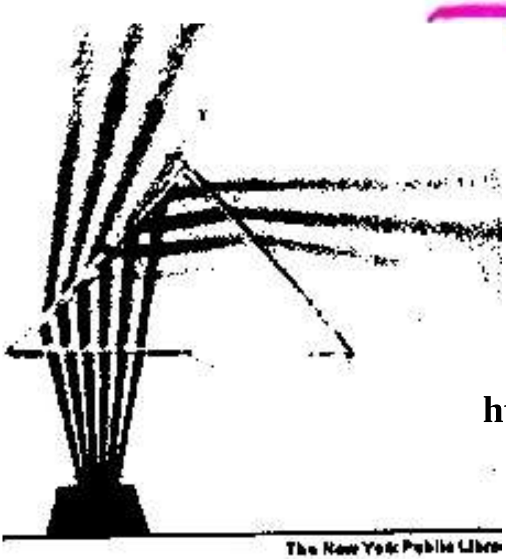


$n \sin(\theta_c) = 1 \sin(90°) = 1$

critical condition

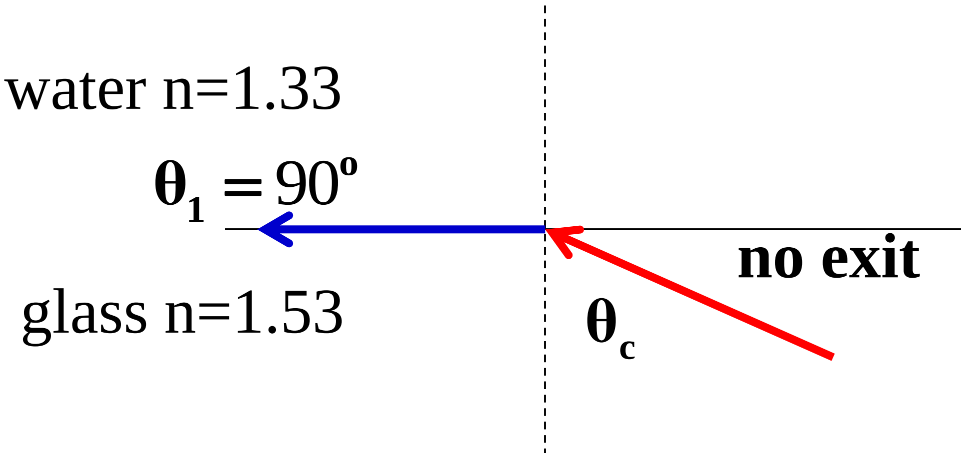
$\sin \theta_c = \frac{1}{n}$

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



http://arana.cabrillo.edu/~jmccullough/Applets/Flash/Optics/ReflectionRefraction.swf

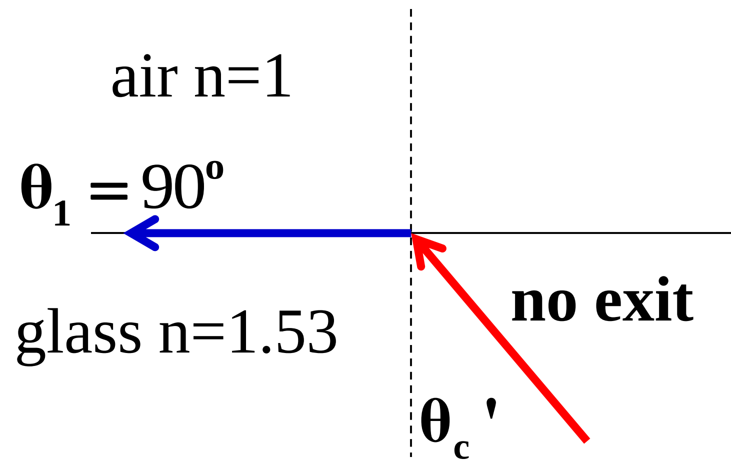
http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=49



$$(1.33)\sin(90) = 1.53\sin(\theta_c)$$

$$\sin(\theta_c) = \frac{(1.33)\sin(90)}{1.53} = .869(1) = .869$$

$$\theta_2 = \sin^{-1}(.869) = 60.3^o$$



$$\sin(\theta_c') = \frac{(1.)\sin(90)}{1.53} = .6536$$

$$\theta_2 = \sin^{-1}(.6536) = 40.8^o$$

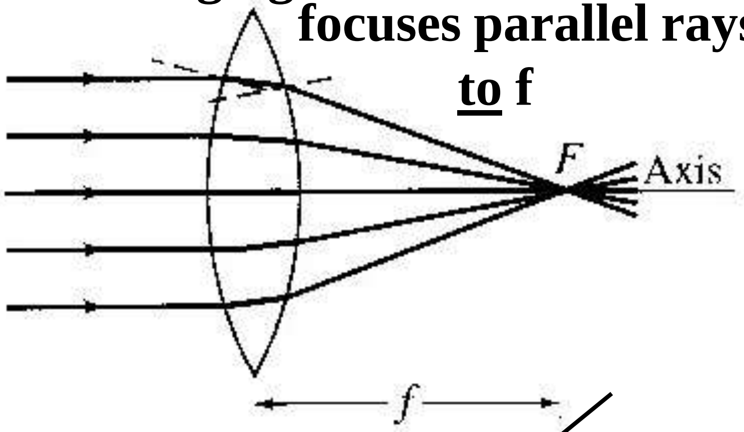
Ray tracing rules for thin lenses

- Focal point (f) defined by where rays paralel to axis converge on other side of the lens
- If all rays paths are reversed a new physically realizable situation arises
- Rays passing through the center of the lens are not bent
- Rays (or their extensions) passing through the focus on one side are parallel to the lens axis on the other {and vise versa}
- Where rays from the same point on the object define the image location

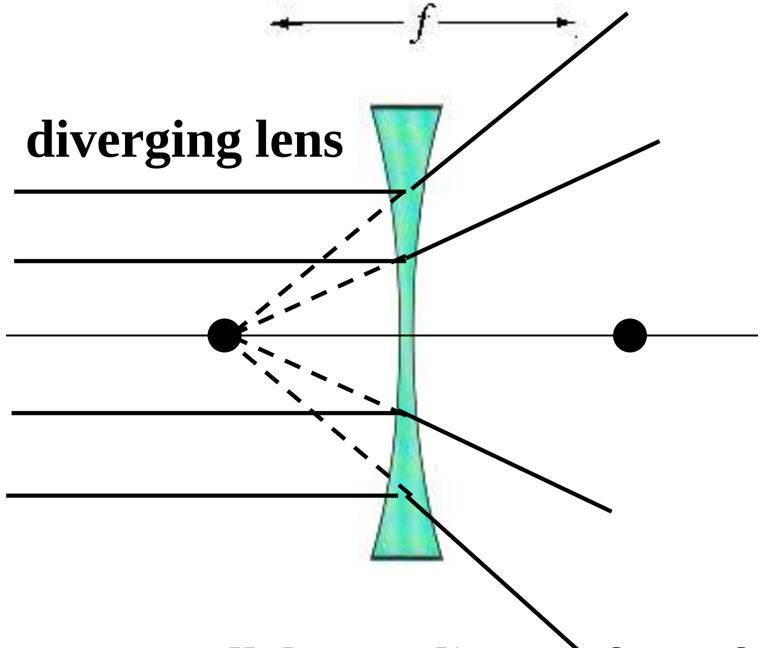
Note: Converging & Diverging Lenses

Note: Converging & Diverging Mirrors behave similarly but light always enters and exits from same side (of course).

converging lens
focuses parallel rays <u>to</u> f

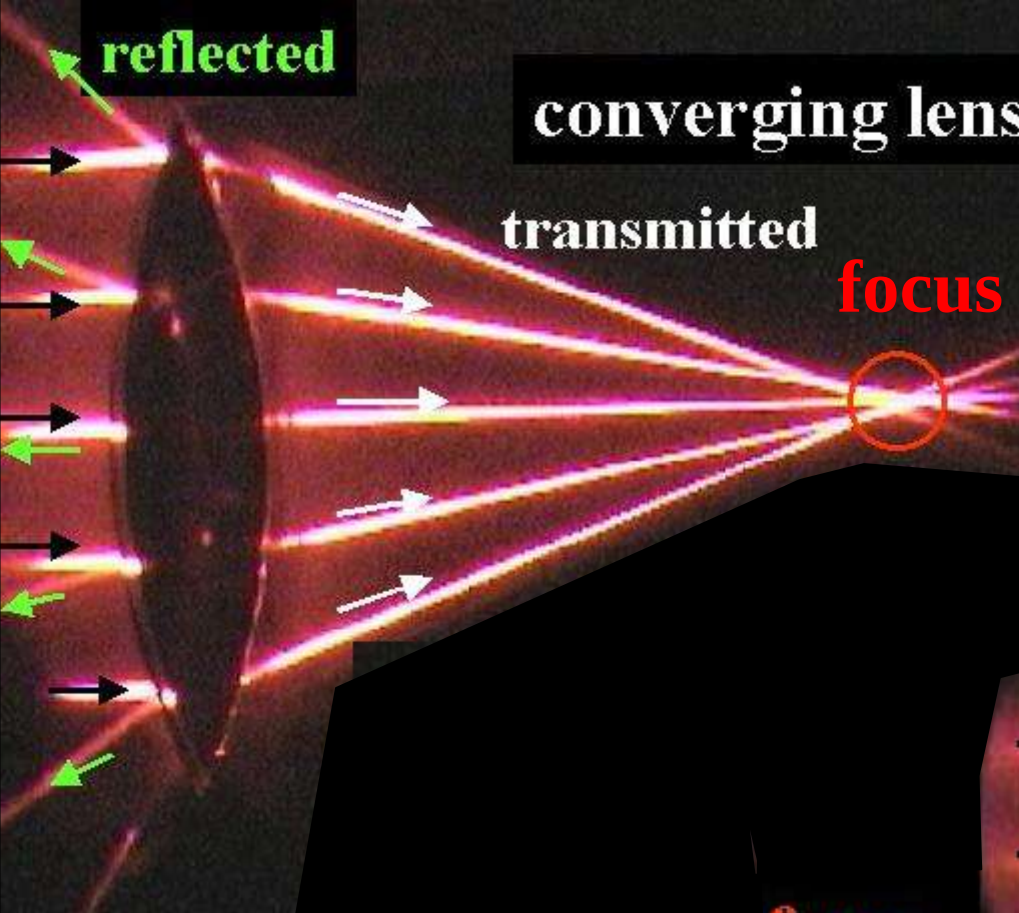


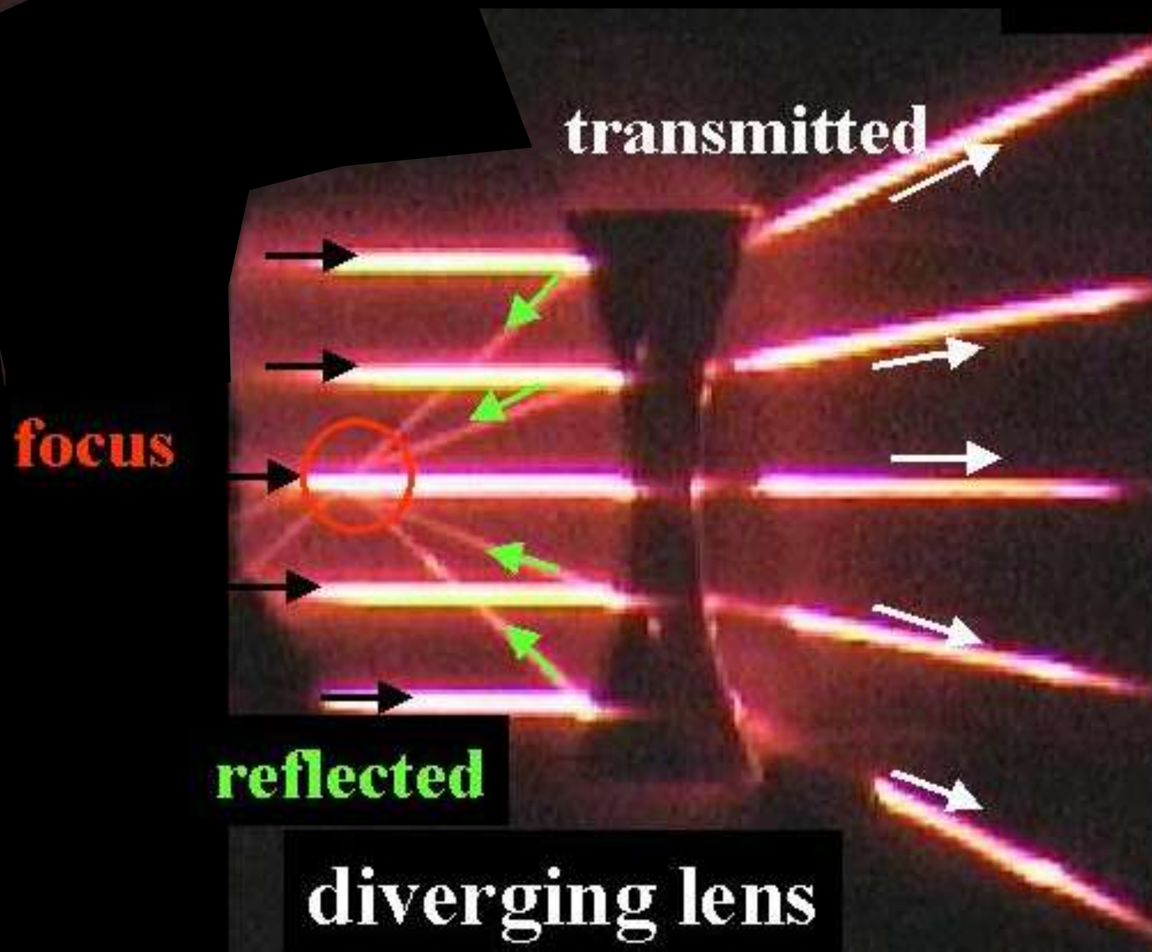
diverging lens



parallel rays diverge <u>from</u> f

- parallel to axis – through f
- through center un-deviated

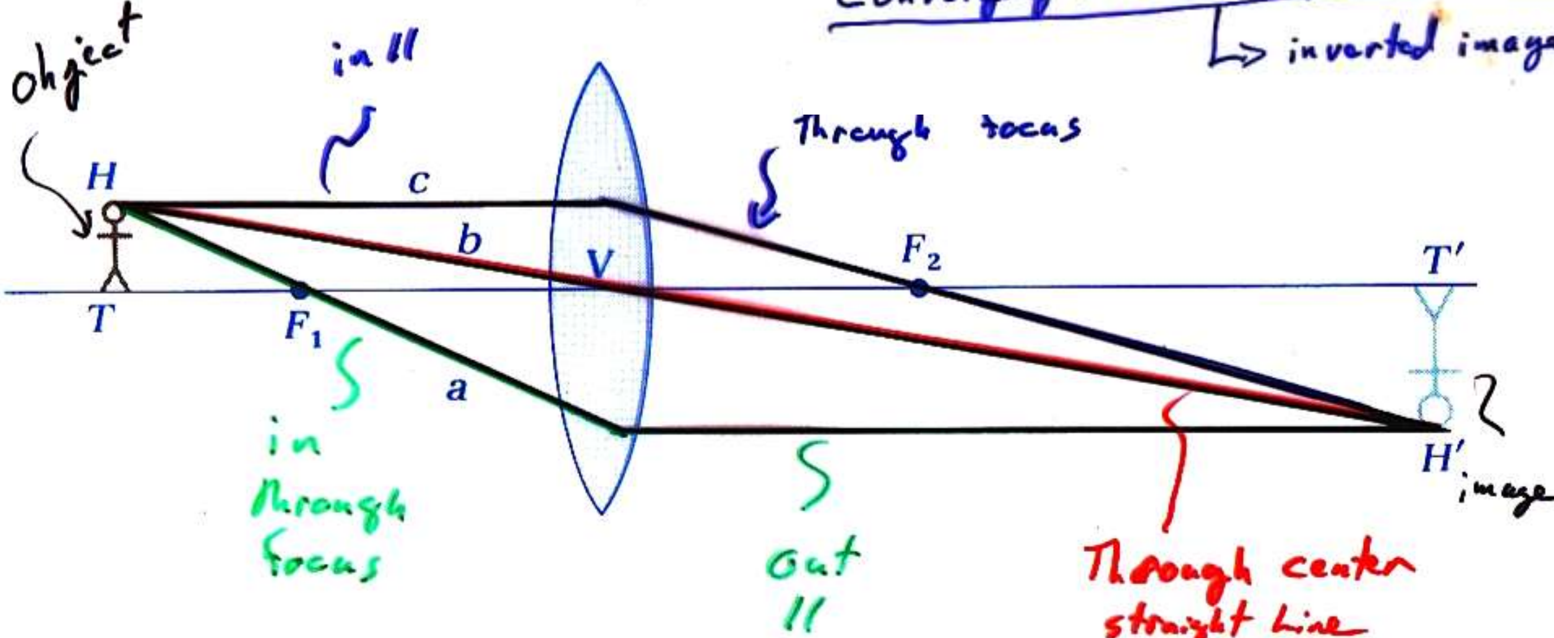

reflected
converging lens
transmitted
focus


transmitted
focus
reflected
diverging lens

7-6a

Converging Lens : Object beyond focal point

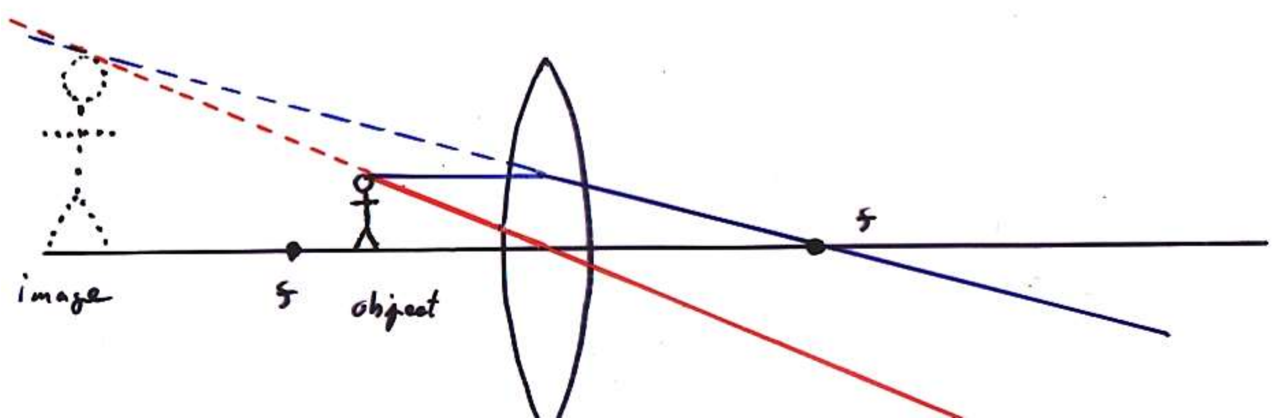
↳ inverted image beyond focal point



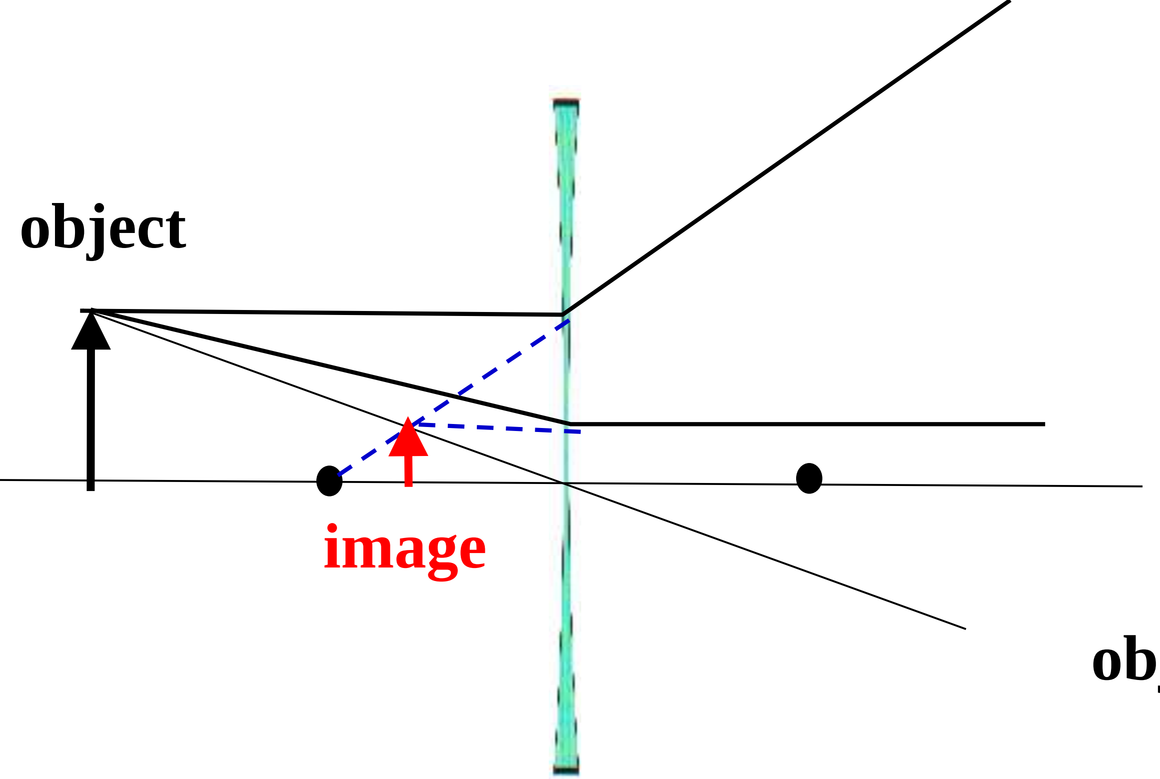
Converging Lens : Object inside focal length

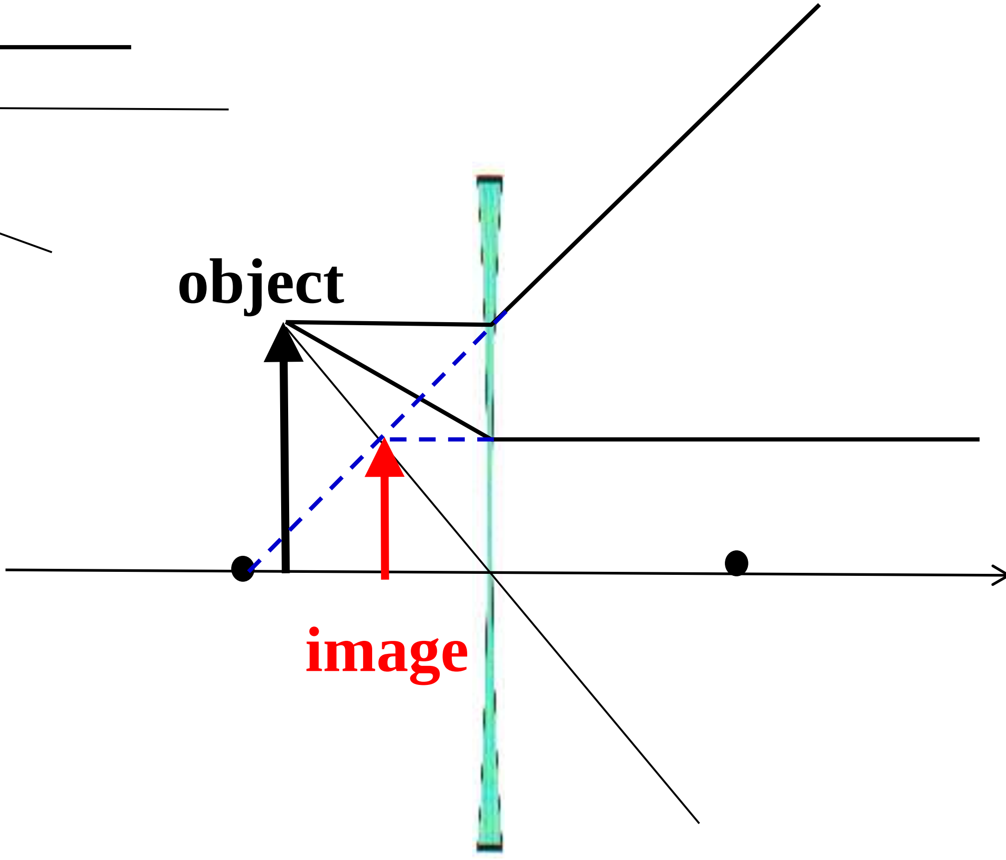
↳ erect virtual image on same side of lens

[magnifying glass



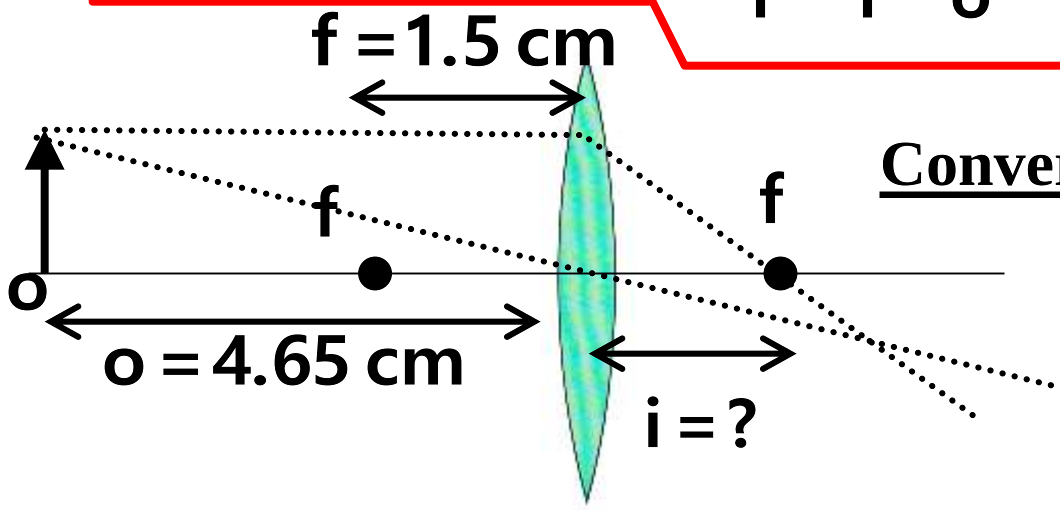
Diverging lens





7-7a

Thin lens formula $\frac{1}{f}=\frac{1}{i}+\frac{1}{o}$ (Derivation see Appendix)



Converging lens formula example

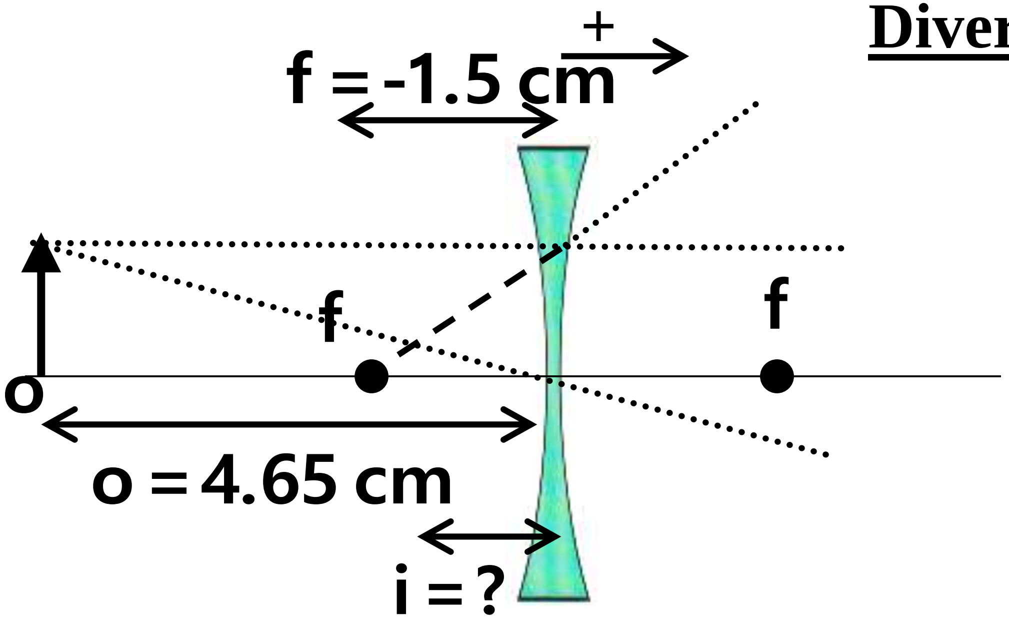
$$\frac{1}{1.5}=\frac{1}{i}+\frac{1}{4.65}$$

$$\frac{1}{i}=\frac{1}{1.5}-\frac{1}{4.65}=0.66-0.21=0.45$$

$$i=\frac{1}{0.45}=2.2\,\text{cm}$$

$$m=\frac{-i}{o}=\frac{-2.2}{4.65}=-0.47$$

Diverging lens formula example



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

-# !!

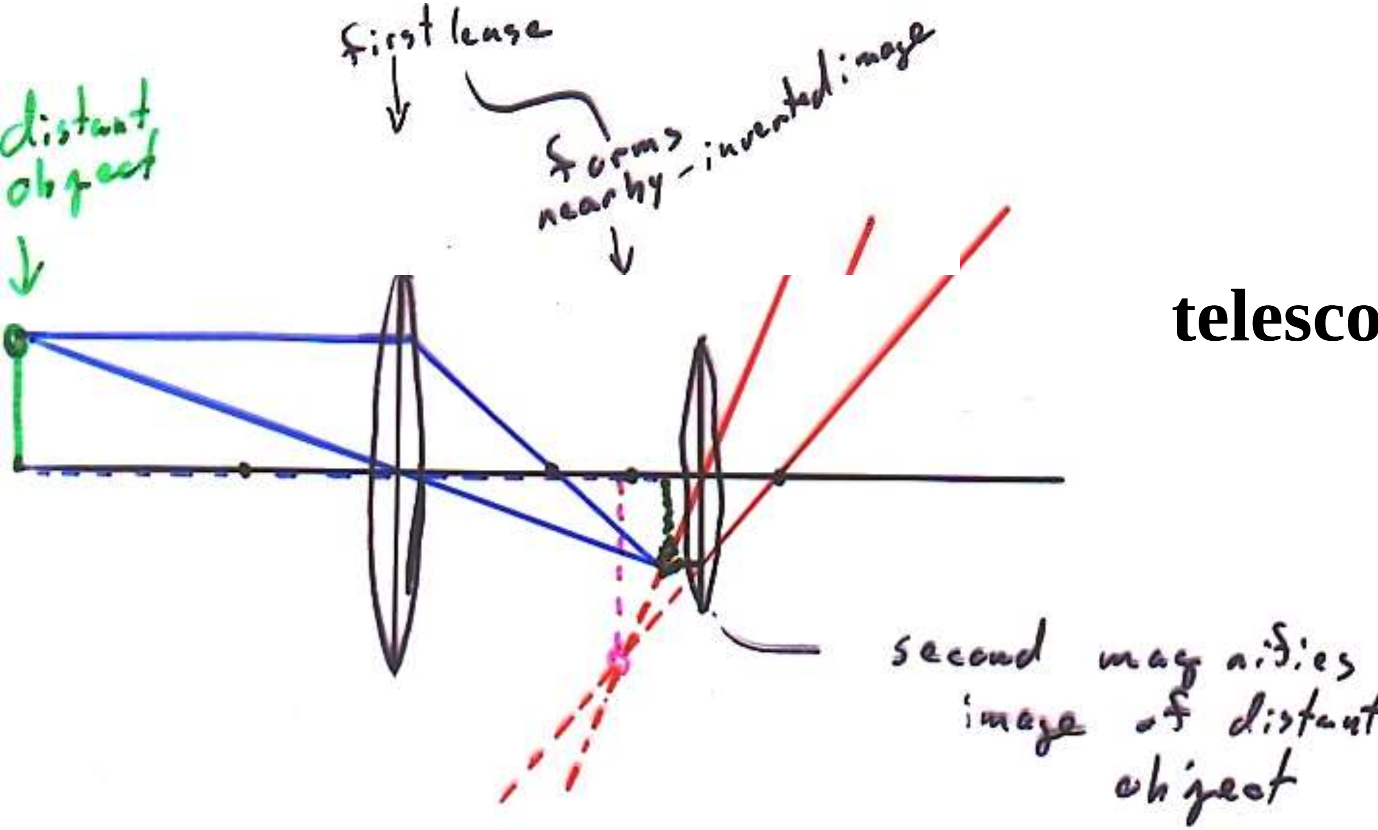
$$\frac{1}{i} = \frac{1}{(-1.5)} - \frac{1}{(4.65)}$$

$$\frac{1}{i} = -0.66 - 0.21 = -.87$$

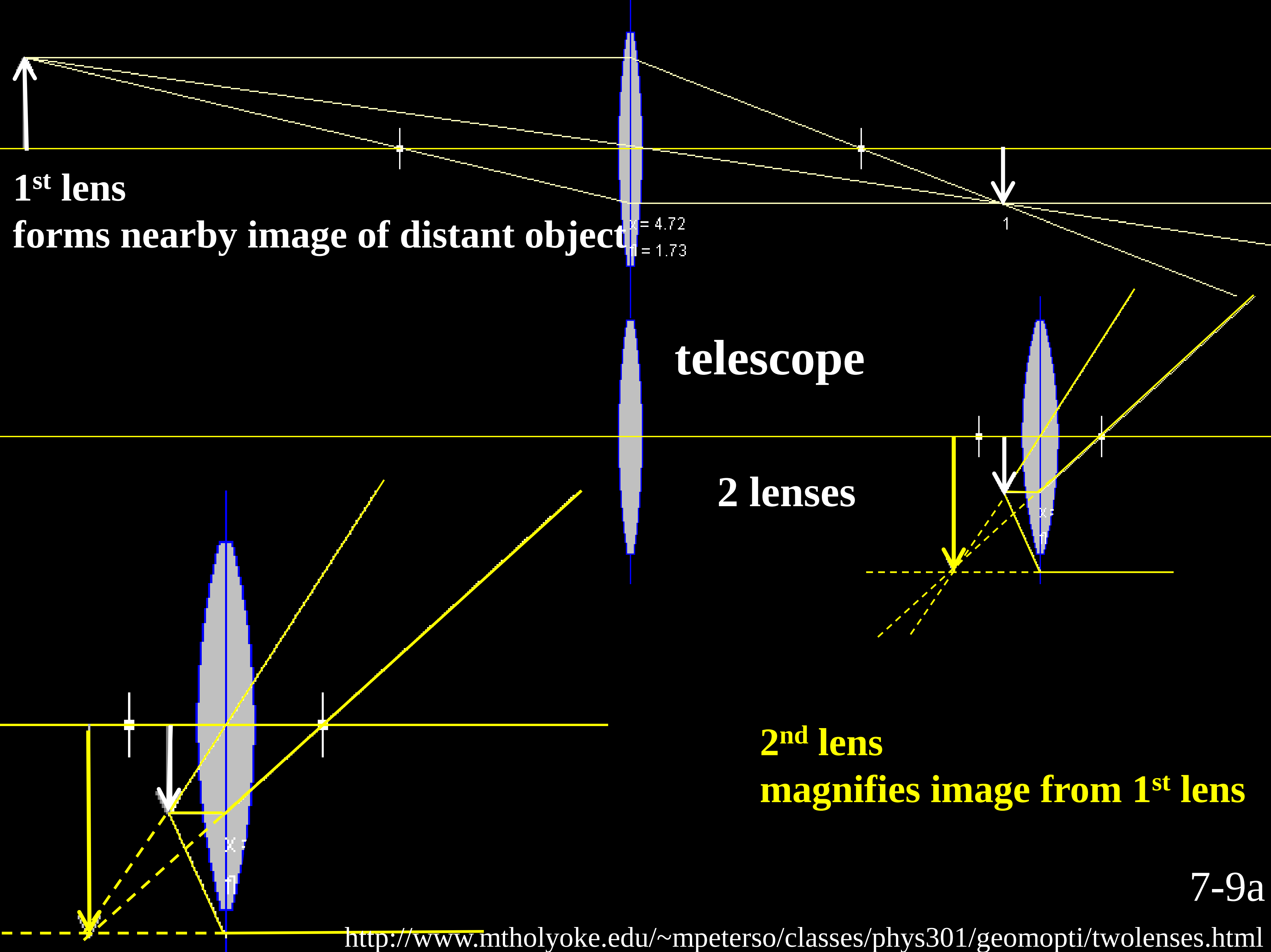
$$i = -1.15 \text{ cm}$$

$$m = \frac{-i}{o} = \frac{-(-1.15)}{4.65} = 0.247$$

telescope



http://www.mtholyoke.edu/~mpeterso/classes/phys301/geomopti/twolenses.html



1st lens
forms nearby image of distant object

telescope

2 lenses

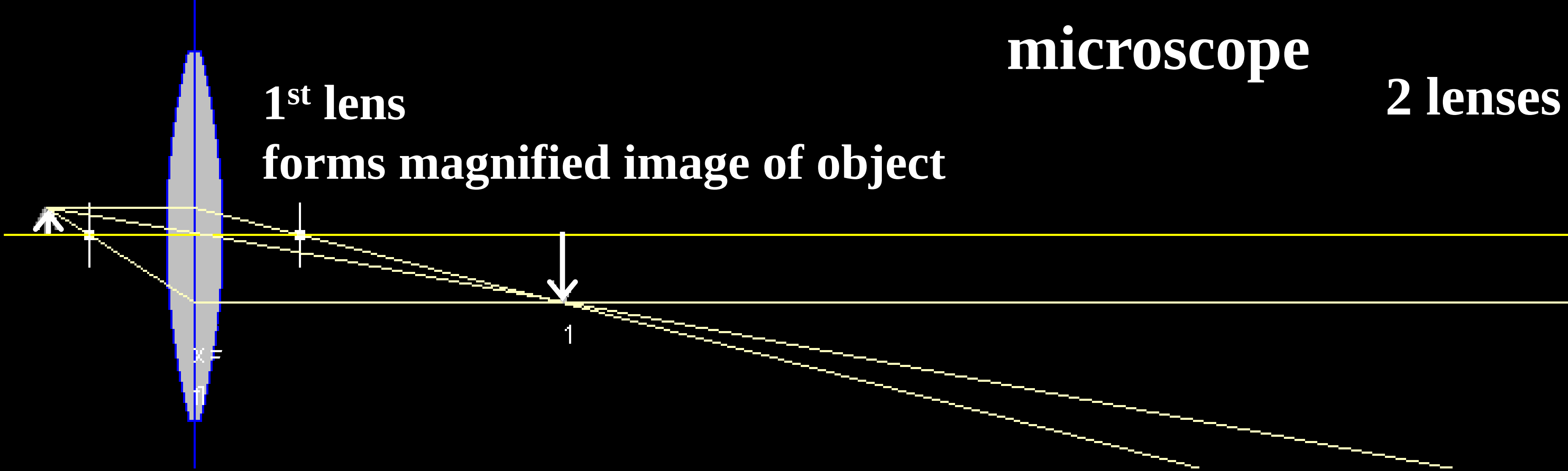
2nd lens
magnifies image from 1st lens

http://www.mtholyoke.edu/~mpeterso/classes/phys301/geomopti/twolenses.html

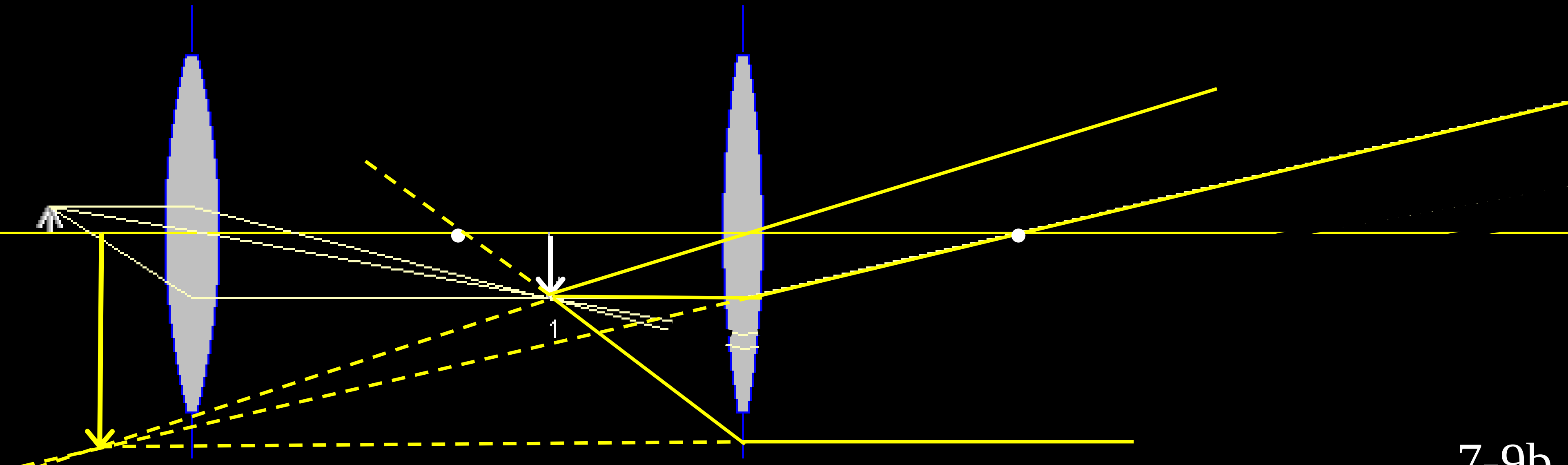
microscope

2 lenses

1st lens
forms magnified image of object



http://www.mtholyoke.edu/~mpeterso/classes/phys301/geomopti/twolenses.html

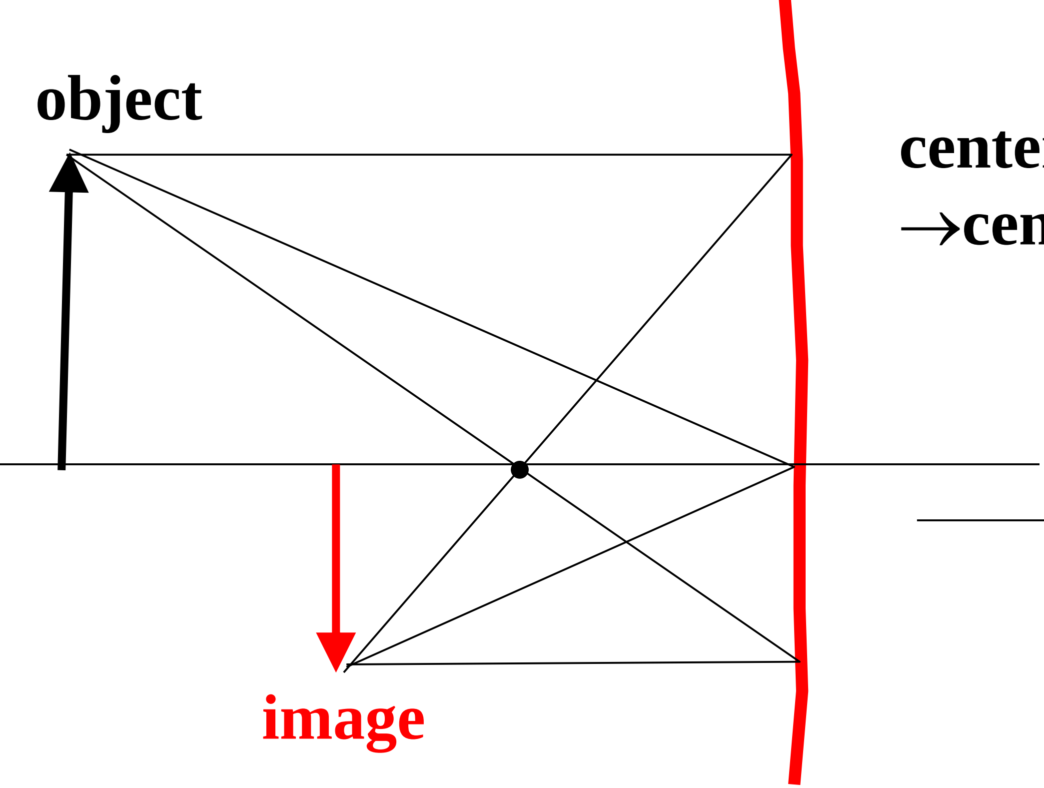


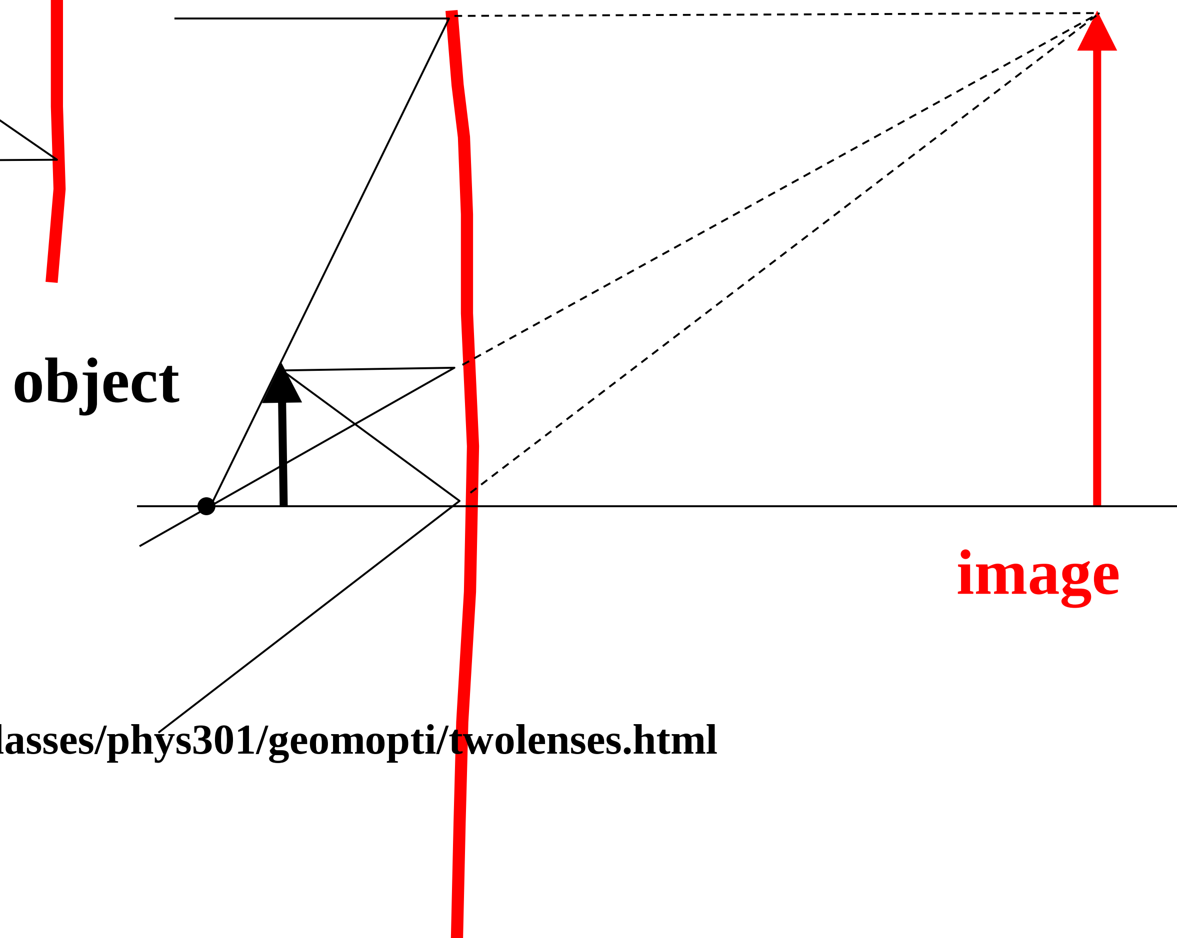
2nd lens
further magnifies image from 1st lens

Converging mirrors

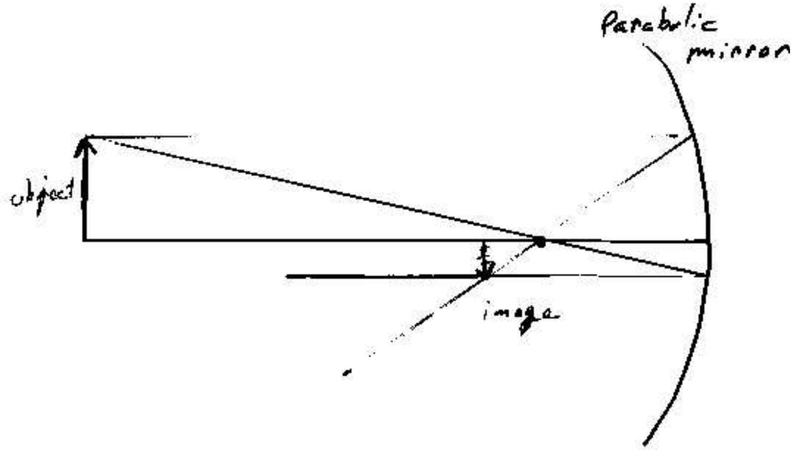
center un-deviated (lenses)

→center angle incidence=reflected (mirror)

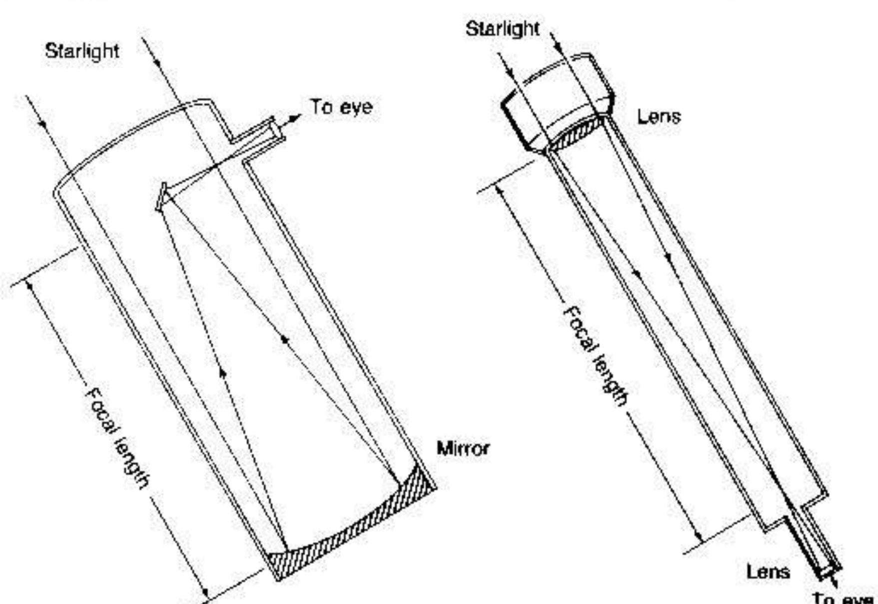




http://www.mtholyoke.edu/~mpeterso/classes/phys301/geomopti/twolenses.html



Reflecting vs. refracting telescopes

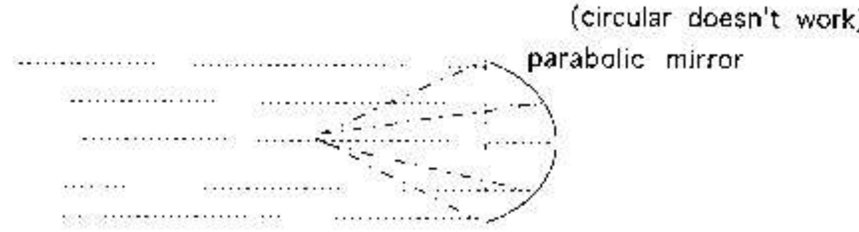


(a) Reflector (b) Refractor

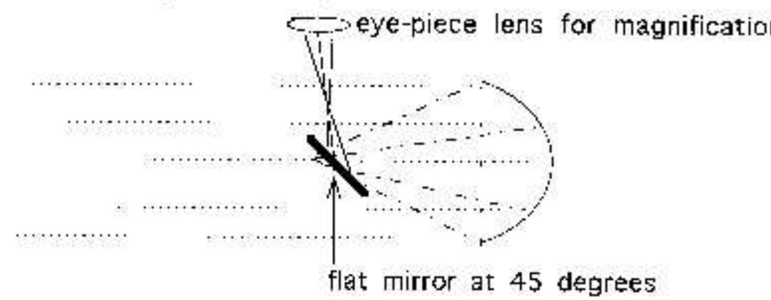
Problem with refracting telescope
different wavelengths of light are bent by different amounts (prism effect) !!

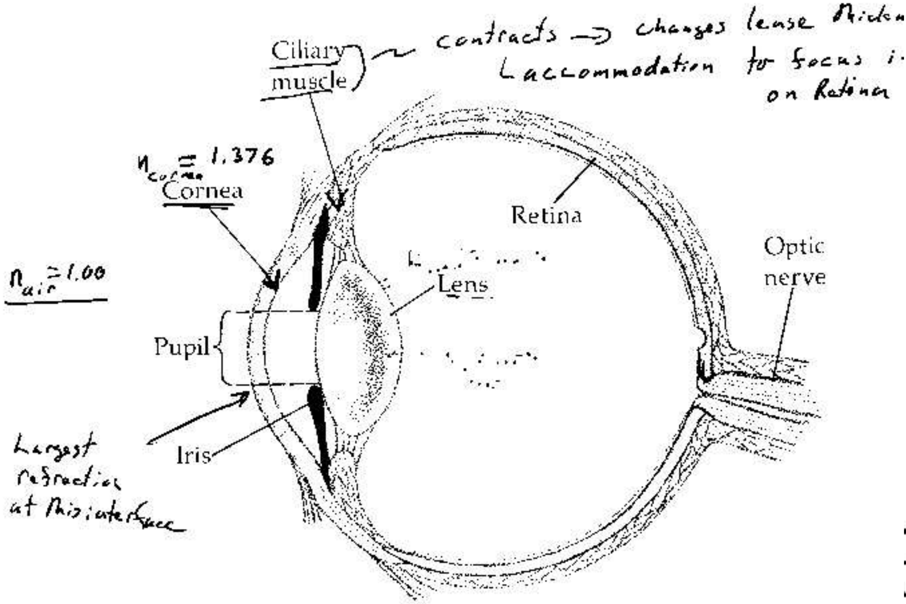
This gives chromatic aberration -- red and blue will come to focus at different points

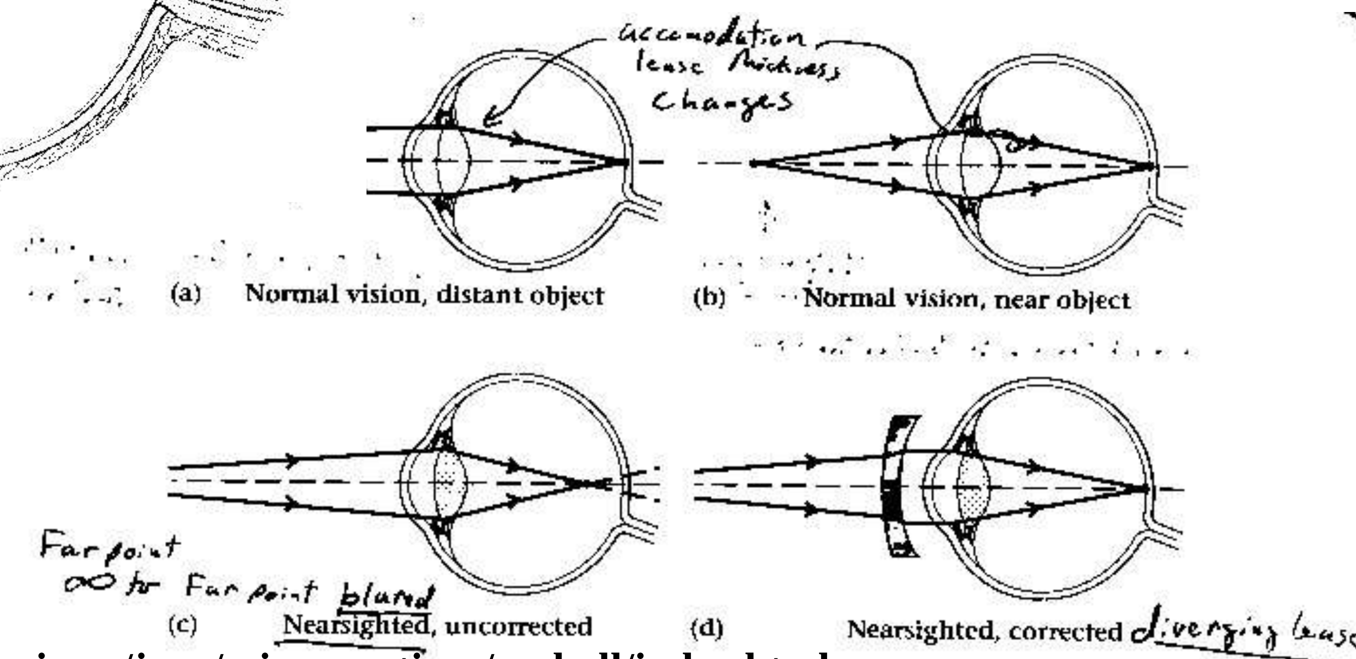
To beat this Newton replaced first (collecting) lens with a parabolic mirror.



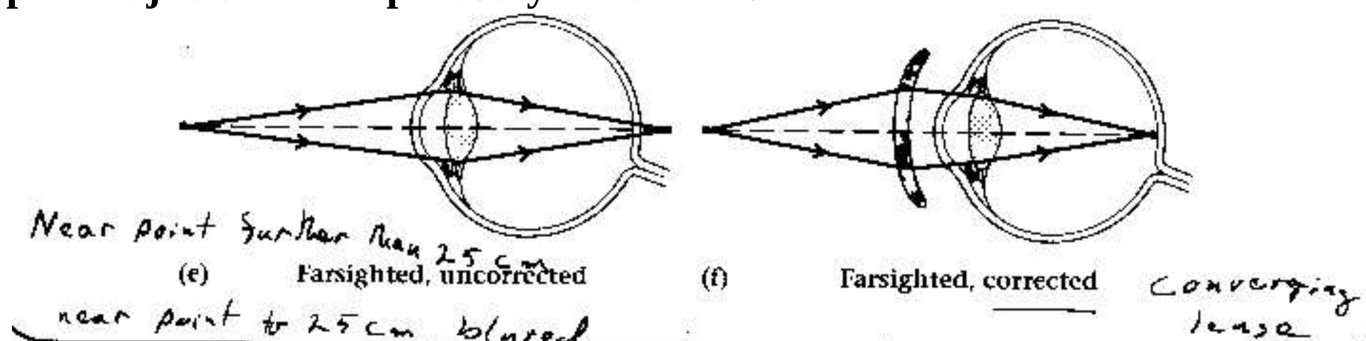
Newtonian (Reflecting) Telescope

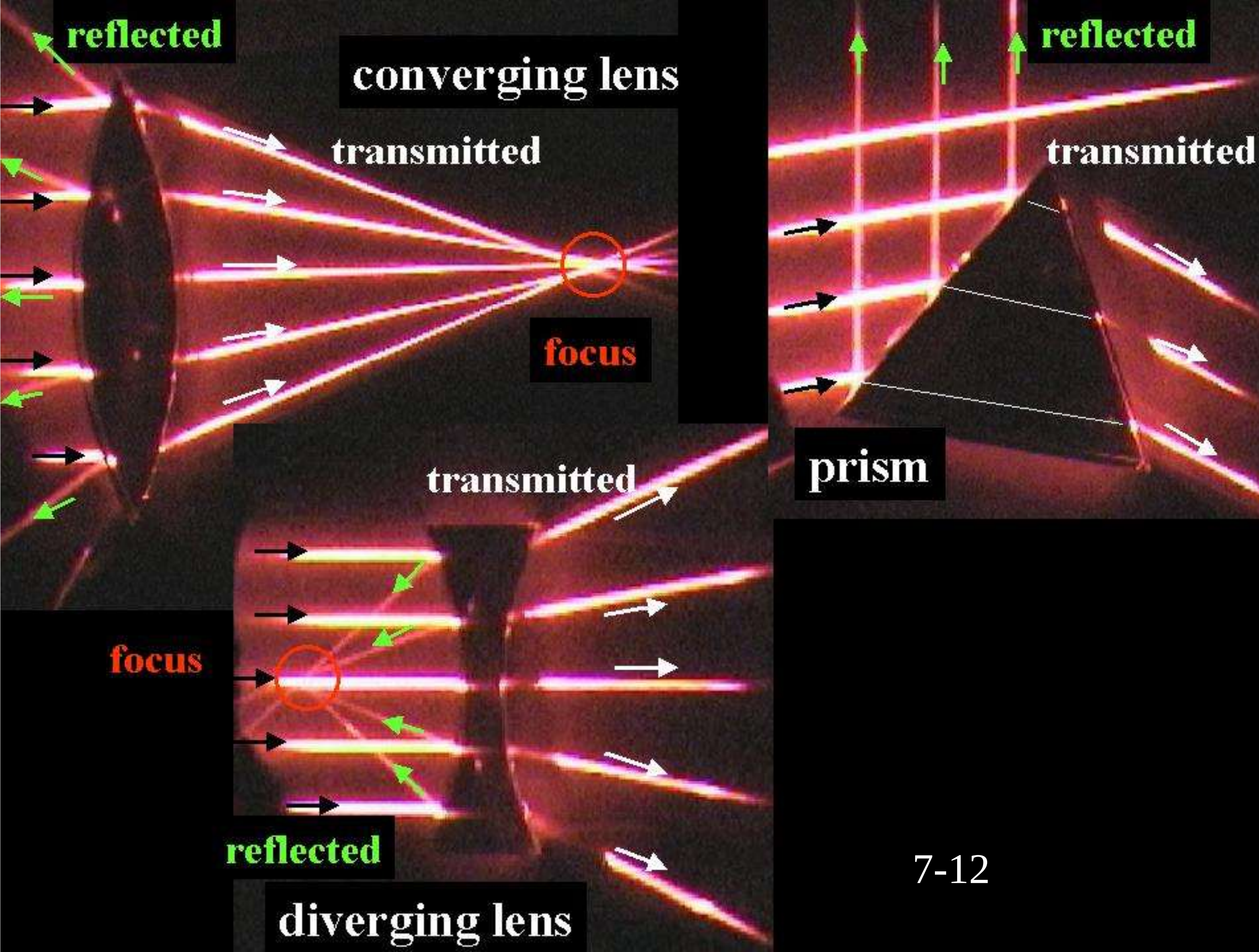






http://micro.magnet.fsu.edu/primer/java/scienceopticsu/eyeball/index.html




reflected
converging lens
transmitted
focus
reflected
transmitted
prism
transmitted
focus
reflected
diverging lens


YES! IT'S... STUPENDOUS MAN! FRIEND OF FREEDOM! OPPONENT OF OPPRESSION! LOVER OF LIBERTY!
GREAT MOONS OF JUPITER! CALVIN (STUPENDOUS MAN'S 6-YEAR-OLD ALTER EGO) HAS THREE PAGES OF BORING HOMEWORK TO READ! IT'S TYRANNY!
ALTHOUGH STUPENDOUS MAN COULD EASILY READ THE ASSIGNMENT WITH STUPENDOUS HIGH-SPEED VISION, THE MASKED MAN OF MIGHT HAS A BOLDER PLAN!
WITH STUPENDOUS POWERS OF REASONING, THE CAPED COMBATANT CONCLUDES THERE'S NO NEED FOR HOMEWORK IF THERE'S NO SCHOOL TOMORROW!
A BLINDING BOLT OF BLAZING CRIMSON CAREENS ACROSS THE SKY! IT'S STUPENDOUS MAN!
7-13
SECONDS LATER, THE AMAZING MARVEL ALIGHTS UPON AN OBSERVATORY TELESCOPE AT MOUNT PALOMAR!
WITH STUPENDOUS STRENGTH, STUPENDOUS MAN CAREFULLY UNSCREWS THE GIANT LENS...
...AND BLASTS INTO SPACE WITH IT!
STUPENDOUS MAN CIRCLES THE EARTH WITH A 200-INCH TELESCOPE LENS!
ALIGNED PERFECTLY WITH THE SUN, THE MAGNIFYING LENS FOCUSES THE TERRIBLE SOLAR ENERGY...
...AND FRIES A CERTAIN ELEMENTARY SCHOOL CLEAN OFF THE MAP!
NOW MILD-MANNERED CALVIN HAS NO NEED TO DO HIS HOMEWORK EVER AGAIN! LIBERTY PREVAILS!
HOW'S YOUR HOMEWORK COMING, CALVIN?

In his youthful enthusiasm/imagination our Calvin (see previous page) has made two physics (geometrical optics) errors.
Pick all the correct answers from the following.

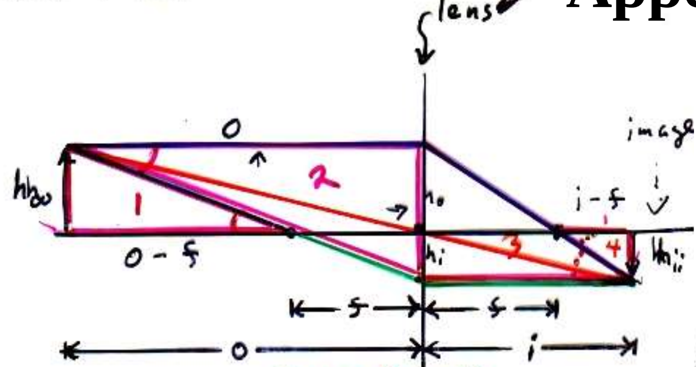
a.) The focal length of the primary lens in a refracting telescope must be shorter than the length of the telescope. Therefore Calvin should not have blasted into space but should have hovered ~ 10-20m above his school to have a chance of incinerating it.

b.) Any 200 in. telescope must be a reflecting telescope (not a refractor) therefore the primary light gathering optical element must be a parabolic mirror at the base not a lens mounted on the end. No one could possibly manage to fabricate a precision lens that big let alone support it on the end of a tube and keep gravity from distorting it differently at every angle of elevation.

Appendix

Thin Lens Formula : Derivation

object



1 similar 2

3 similar 4

$$\frac{h_o}{o-f} = \frac{h_o + h_i}{o}$$

$$\frac{h_i}{i-f} = \frac{h_o + h_i}{i}$$

$$m = \frac{h_i}{h_o} = \text{magnification}$$

$$\frac{1}{o-f} = \frac{1+m}{o}$$

$$\Downarrow$$

$$m = \frac{o}{o-f} - 1$$

$$\frac{m}{i-f} = \frac{1+m}{i}$$

$\Downarrow$ WALBOA

$$fi = (i-f)o$$

$$\boxed{m = \frac{h_i}{h_o} = -\frac{i}{o}}$$

magnification

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

Thin Lense formula

f — focal length

i — image position

o — object position

WALBOA

With a little bit of algebra

$$\frac{o}{o-f} - 1 \qquad \frac{o}{o-f}$$

$$\frac{m}{(i-f)} = \frac{(1+m)}{i} \Rightarrow m = (1+m)\frac{(i-f)}{i}$$

$$\frac{o}{(o-f)} - 1 = \frac{o}{(o-f)}\frac{(i-f)}{i}$$

$$o - (o-f) = \frac{o}{i}(i-f)$$

$$fi = o(i-f)$$

$$fi + fo = oi$$

$$f(i+o) = oi$$

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

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

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