Light & Optics

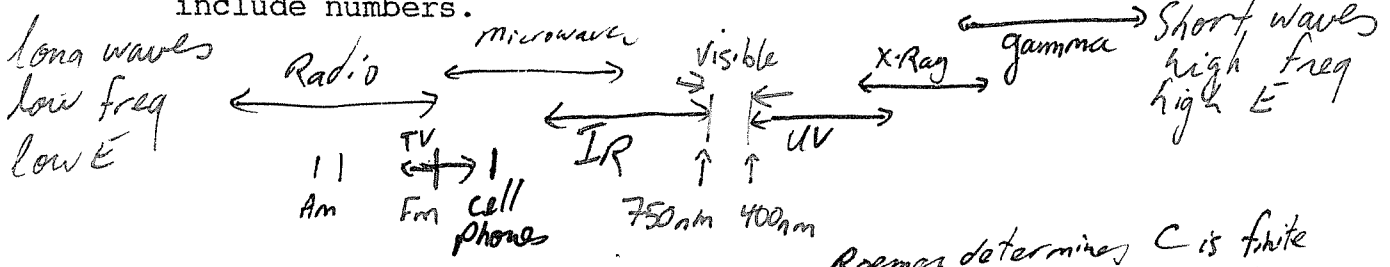
Name _____

Block _____

A. Light as a wave in the electromagnetic spectrum 22-5

1) You should be able to arrange the electromagnetic spectrum according to wavelength and frequency. Copy the chart on P 670 into you notes. You do not need to include numbers.

Recall $V = \lambda f$ $c = \lambda f$



B. Measuring the Speed of Light 22-6 ← Roemer determines C is finite ← Michelson rotating mirror expt

C. The ray model of light 23-1 light travels in straight lines (rays), so rays leave a point, we measure some

D. Index of refraction 23-4

1) What is the index of refraction of a material? How do you calculate it?

ratio of $\frac{\text{speed of light in a vacuum}}{\text{speed of light in a substance}}$ $n_s = \frac{c}{v_s}$

2) Note the table or indicies of refraction on P 696. What is air 1 or 1.0003 water 1.33 fused glass 1.46 ?

E. Refraction: Snell's Law 23-5

1) List Snell's law and describe it very carefully. (remember the soldiers)

$n_i \sin\theta_i = n_r \sin\theta_r$ OR $\frac{n_i}{n_r} = \frac{\sin\theta_r}{\sin\theta_i}$

1] A flashlight beam strikes the surface of a pane of glass (n=1.50) at an angle of 45 deg. What is the angle of refraction? (28.1 deg)

$n_i \sin\theta_i = n_r \sin\theta_r$

$1 \sin 45 = 1.5 \sin\theta_r$

$\sin\theta_r = .471$

$\theta_r = 28.1°$

2] A diver shines a flashlight upward from beneath the water at a 28 deg angle to the vertical. At what angle does the light leave the water? (38.6 deg)

$n_i \sin\theta_i = n_r \sin\theta_r$

$1.33 \sin 28 = 1 \sin\theta_r$

$\theta_r = \sin^{-1}(.624)$

$= 38.6^\circ$

3] What is the speed of light in a clear plastic whose index of refraction is 1.40? (2.14 x 108 m/s)

$\frac{c}{v} = n \quad \frac{c}{n} = v = \frac{3\times10^8}{1.4} = 2.14\times10^8 \frac{m}{s}$

4] A beam of light strikes the surface of a block of glass (n =1.50) and produces a refracted angle of 10°. What is the incident angle? (15.1°)

assume start in air

$n_i \sin\theta_i = n_r \sin\theta_r$

$1 \sin\theta_i = 1.5 \sin 10$

$\sin\theta_i = .26$

$\theta_i = 15^\circ$

5] Monochromatic light has a wavelength of 6.0 x 10-7 m in air and 5.0 x 10-7 m in a clear liquid. What is the index of refraction of the clear liquid? (1.2)

$\frac{c}{v} = n \quad \frac{\lambda_{air}}{\lambda_{liquid}} = \frac{n_{liquid}}{n_{air}} \quad \frac{6}{5} = \frac{n_{liq}}{n_r} = 1.2$

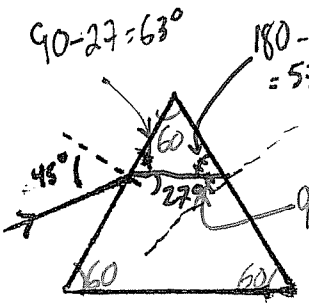
note: $\frac{n_i}{n_r} = \frac{\lambda_r}{\lambda_i}$

6] A ray of light strikes the surface of water (n = 1.33) at an angle of 60.0° <u>from the water surface</u>. What is the angle of refraction? (22.1°)

$\theta_i = 30^\circ$

$\frac{n_i \sin\theta_i}{n_r} = \sin\theta_r \quad \theta_r = 22^\circ$

7] Light is incident on an equilateral crown glass prism at a 45.0 deg angle to one face. Calculate the angle at which light emerges from the opposite face. n = 1.56 (58.2 deg to normal)



$n_i \sin\theta_i = n_r \sin\theta_r$

$\sin\theta_r = \frac{1 \sin 45}{1.56} = 27^\circ$

$90 - 57^\circ = 33^\circ$

$n_i \sin\theta_i = n_r \sin\theta_r$

$1.56 \sin 33 = 1.00 \sin\theta_r$

$\theta_r = 58.2^\circ$

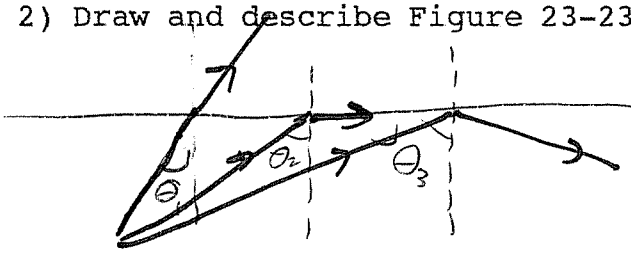
F. Total internal reflection; fiber optics 23-6

1) What is total internal reflection? What is the critical angle?

all light rays reflected from surface

incident angle that gives $\theta_r = 90°$

2) Draw and describe Figure 23-23.



θ_1 < critical angle light refracts into new medium as expected

θ_2 = critical angle, light refracts at 90° to normal (along surface)

θ_3 > crit angle ← all light reflects back into incident medium according to Law of Reflect

8] What is the critical angle for a diamond-water interface? (33.3 deg) look up n's on P 696

n_i n_r

$2.42 \sin\theta_c = 1.33 \sin 90$

$\theta_c = \sin^{-1}\left(\frac{1.33}{2.42}\right) = 33°$

9] The critical angle for a certain liquid-air surface is 57 deg. What is the index of refraction of the liquid? (1.19)

n_i n_r

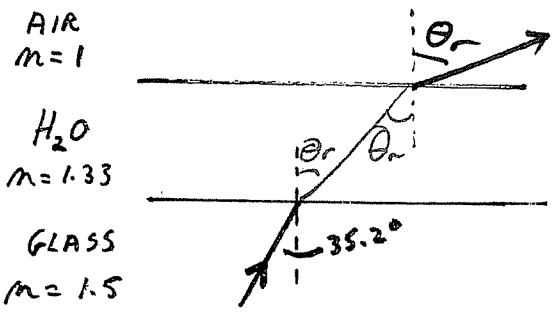
$n_i \sin 57 = 1.0003 \sin 90$

$n_i = 1.19$

10] What is the critical angle for an air-glass interface if the index of refraction of glass is 1.50? (41.8°)

$\sin\theta_c = \frac{1.0003 \sin 90}{1.5} = 42°$ n_r n_i

11] A ray of light travels from glass (n=1.5) into water (n = 1.33) into air as shown in the diagram. Illustrate the path followed by the light and calculate the angle that the light leaves the water-air interface. (59.8°)



$\frac{1.5 \sin 35.2}{1.33} = \sin\theta_r = .659$

$\theta_r = 41.2°$

becomes new θ_i

$\frac{1.33 \sin 41.2}{1.0003} = \sin\theta_r$

$\theta_r = 60°$

NOTE: If you did not have to draw it, if you could just do: $1.5 \sin 35.2 = 1.0003 \sin\theta_r$ Why does this work?

Problems

1] Light entering a block of glass at an angle of incidence of 18.5 degs leaves the boundary betweenthe air and the glass at an angle of 12 degs. What is the index of refration of this type of glass?

Θ_i ↓ ↑ Θ_r

$\frac{1.0003 \sin 18.5}{\sin 12} = n_r = 1.53$

2] A beam of light is incident on a sheet of glass in a window at an angle of 30 degs. Describe exactly what path the light beam will take as it a) enters the glass (n = 1.5) and as it b) leaves the other side of the glass.

$\frac{1 \sin 30}{1.5} = \sin \Theta_r$ ↑ 30° ← ray refraction is reversed!

$\Theta_r = 19.5^\circ$

3] Calculate the critical angle for diamond (n = 2.42).

$2.42 \sin \Theta_i = 1.0003 \sin 90$

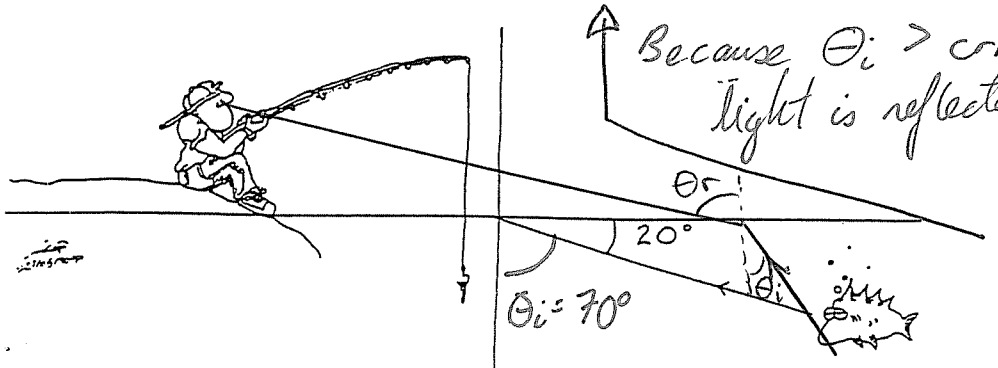
$\Theta_i = 24.4^\circ$

4] A certain material has a critical angle of 52 degs. What is its index of refraction?

assume w/ air

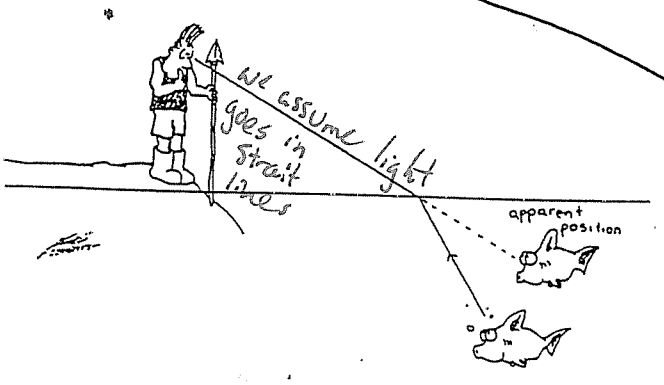
$n_i \sin 52 = 1.0003 \sin 90$ $\quad n_i = 1.27$

5] Why can the fisherman **not** see the specific light ray coming from the fish? Can the fisherman see the fish at all?



Yes, some light leaving fish could be at lower Θ_i giving appropriate Θ_r as shown

6] a) The fisherman wants to spear the fish. Where should he aim?
b) a "high tech" fisherman wants to "zap" the fish with a laser. Where should she aim?



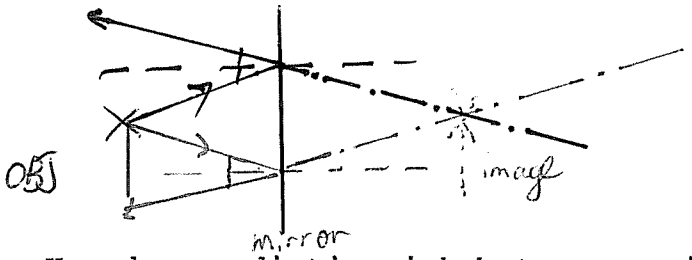
deeper & closer to shore

at the fish ← laser light will refract into H_2O

G. Section 23-2 Reflection; Image Formation by a Plane Mirror

What is the law of reflection? θ_i = angle of reflection

Illustrate the formation of a virtual image by a plane mirror. Label the image distance, object distance, virtual image. (Figure 23-7)



Draw any 2 rays leaving same point & bouncing off mirror by law of reflect
divergent rays traced back into world of the mirror

How do you distinquish between a virtual and a real image?

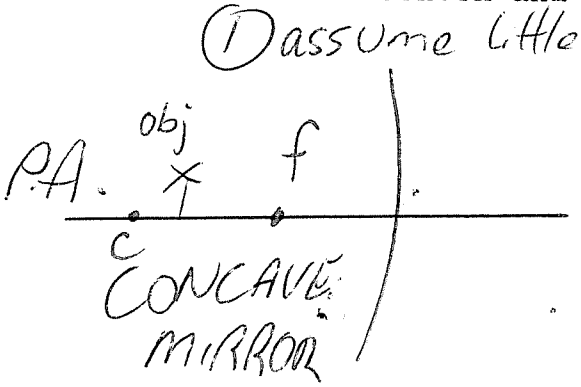
divergent rays ↗ ↖ convergent rays

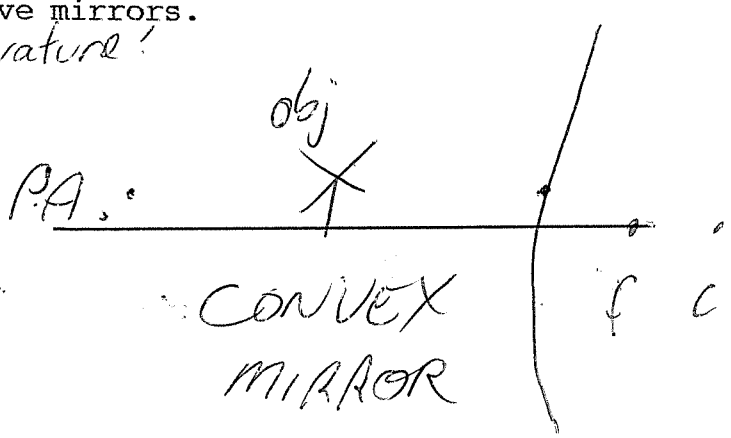
12] Suppose that you want to take a photograph of yourself as you look at yourself as you look at your image in a flat mirror 2.5 m away. For what distance should the camera lens be focused? (5.0 m)

$d_i = d_o$
$= 2.5m$ total dist between you(obj) & image $= d_i + d_o = 5m$

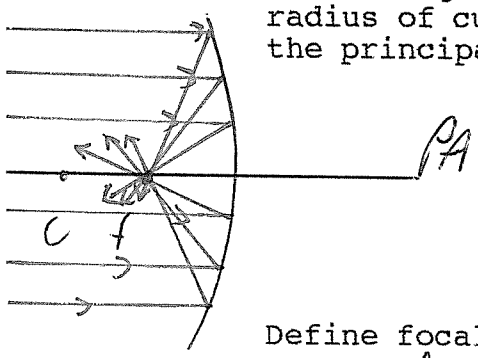
H. Section 23-3 Formation of Images of Spherical Mirrors
Draw and describe convex and concave mirrors.

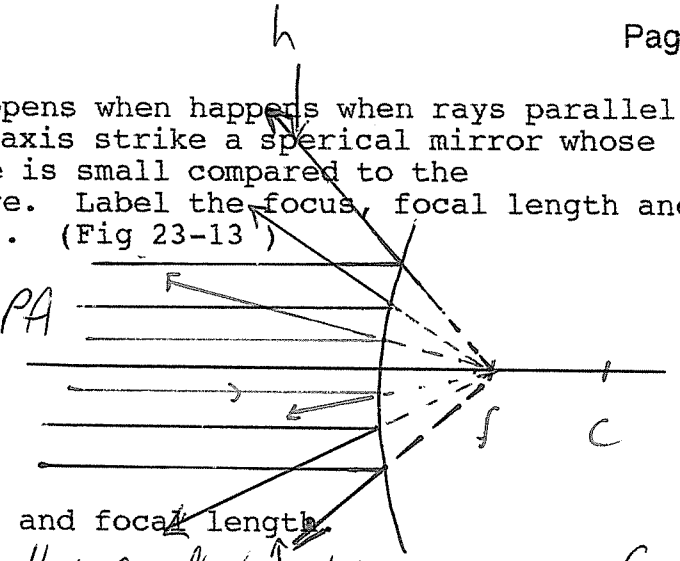
(1) assume little curvature!





Illustrate what happens when happens when rays parallel to the the principal axis strike a sperical mirror whose reflecting surface is small compared to the radius of curvature. Label the focus, focal length and the principal axis. (Fig 23-13)





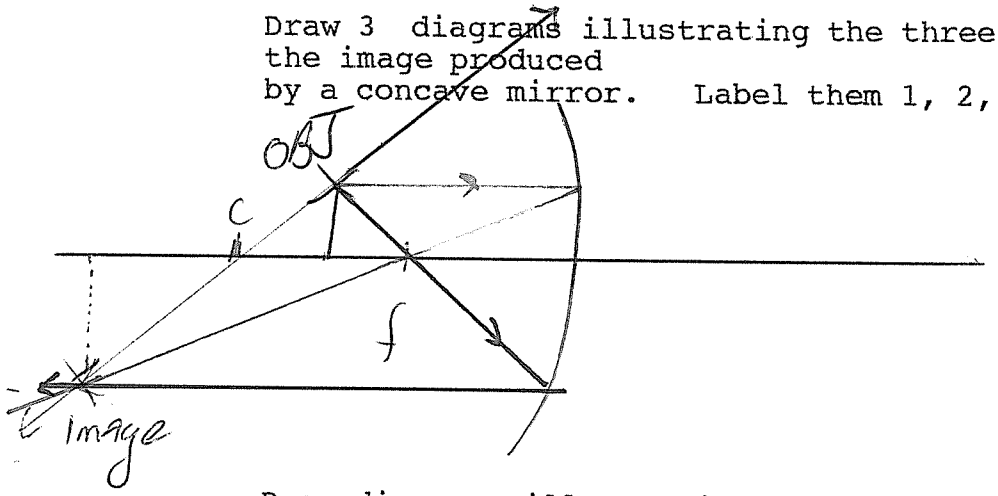
Define focal point and focal length.

Point thru which rays // to PA reflect dist from mirror to f = $\frac{1}{2}$ C

How does the focal length relate to the radius of curvature?

$f = \frac{1}{2} C$

Draw 3 diagrams illustrating the three rays used to find the image produced by a concave mirror. Label them 1, 2, and 3.



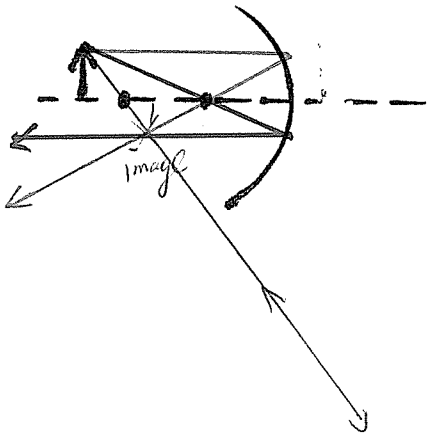
Ray ① parallel to P.A. reflects thru f

Ray ② thru f, reflects // to PA

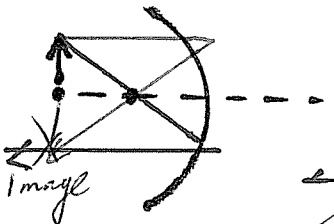
Ray ③ thru C, reflects on itself

Draw diagrams illustrating the image formation in the following situations.

$d_o > R$

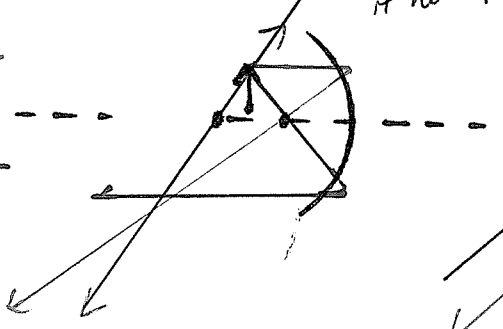


$d_o = R$

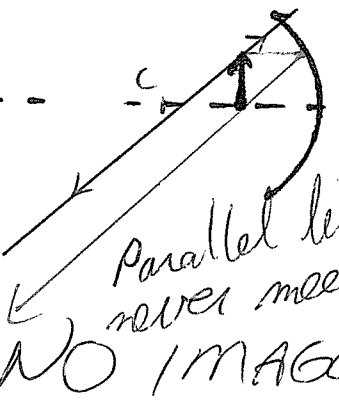


$d_o < R > f$

Pretend it hits!



$d_o = f$



Parallel lines never meet

NO IMAGE!

List and describe the mirror equation.

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

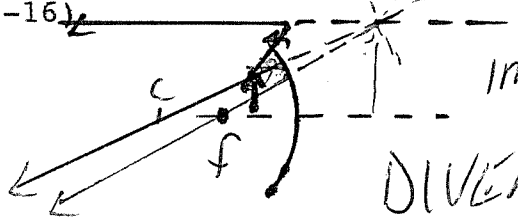
List and describe the magnifcation formula. Explain the negative sign.

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

indicates real images inverted

Study example 23-3 and 23-5.

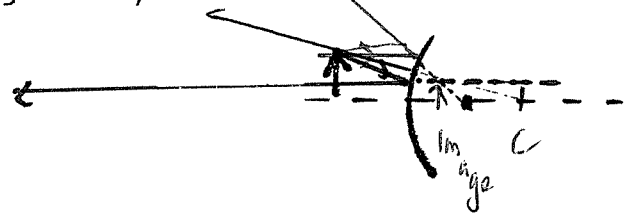
Describe the image you get if the object is within the focal point ? (Fig 23-16) Illustrate as well.



Virtual erect larger

DIVERGING RAYS : trace back into mirror

Illustrate and describe the image formed by a convex mirrors. (Fig 23-17)



virtual erect smaller

Study Example 23-6 and read Problem Solving (P695) carefully.

Summarize the sign conventions for concave and convex mirrors.

Concave mirror → f +

d_i + or −

M − or +

h_i − or +

convex → f −

mirror

d_i −

M +

h_i +

h_o & d_o always +

13] What is the radius of a concave reflecting surface that brings parallel light of a focus 22.4 cm in front of it? (44.8cm)

$f = \frac{1}{2}C \quad C = 2f = 44.8\text{ cm}$

14] You try to look at yourself in a silvered ball of diameter 64.0 cm when you are 2.70 m away. Where is your image? Is it real or virtual ? Can you see yourself clearly? (-15.1 cm, virtual, 18 x smaller--hard to see)

$C = \frac{64}{2}$ pretty small

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} \quad \frac{1}{-16} = \frac{1}{d_i} + \frac{1}{2.7}$ Convex shows virtual (a convex tells us too)

$\frac{1}{d_i} = -6.62 \quad d_i = \frac{-1}{6.62} = -15\text{cm}$

15] A dentist wants a small mirror that, when 2.20 cm from a tooth, will produce a 5.5 x upright image. What kind of mirror must be used and what must its radius of curvature be? (concave, converging {concave}, r=5.38 cm) ← C

only way to get virtual & larger is concave mirror with $d_o < f$

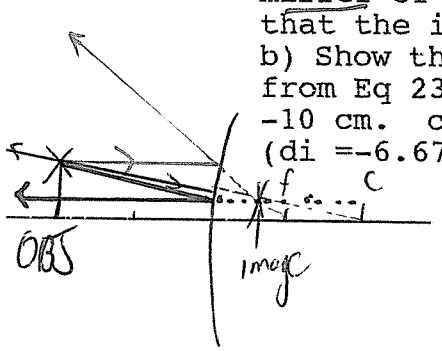
larger virtual $M = \frac{-d_i}{d_o} \quad +5.5 = \frac{-d_i}{2.2} \quad d_i = -12.1\text{cm}$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{-12.1} + \frac{1}{2.2} \quad \frac{1}{f} = .37 \quad f = 2.69\text{ cm} \quad C = 5.38\text{cm}$

16] A luminous object 3.0 mm high is placed 20 cm from a convex mirror of radius of curvature 20 cm a) Show by ray tracing that the image is virtual and estimate the image distance. b) Show that to compute this (negative) image distance from Eq 23-2, it is necessary to let the focal length be -10 cm. c) Compute the image size using Eq 23-3. (di =-6.67 cm, hi = 1.0 mm)

f negative!

Use a carefully measured diagram



well $f = \frac{1}{2}C$ and $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$\frac{1}{-6} + \frac{1}{20} = \frac{1}{f} \quad f = -8.6\text{cm}$ ← a close estimate to -10cm

-6cm (from diagram)

$h_i = \frac{(-6)(.3)}{20} = 0.09\text{cm}$ or 9mm ← again a close estimate

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

17] A 2.70 cm tall object is placed 32.0 cm from a spherical mirror. It produces a virtual image 3.80 cm high.
a) What type of mirror is being used?
b) Where is the image located?
c) What is the radius of curvature of the mirror?
(concave, di is 45 cm behind mirror, 222 cm)

larger ← only large virtual is concave w/ $d_o < f$

Concave!

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} \quad \frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$\frac{3.8}{2.7} = \frac{-d_i}{32} \quad d_i = -45.0\text{cm}$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{-45} + \frac{1}{32}$

$\frac{1}{f} = .009 \quad f = 11\text{cm} \quad C = 2f = 222\text{cm}$

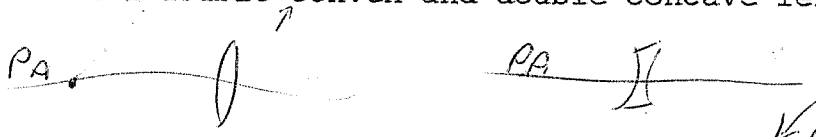
18] The magnification of a convex mirror is 0.45 x for objects 3.0 m away. What is the focal length of this mirror? (-245 cm)

$M = \frac{-d_i}{d_o}$ $\quad .45 d_o = -d_i \quad d_i = -1.35\,m$ $\quad \frac{1}{f} = -.4 \quad f = -2.45\,m$

$.45 = \frac{-d_i}{d_o}$ $\quad \frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{-1.35} + \frac{1}{3} =$

I. Section 23-7 Thin Lenses; Ray Tracing

Draw a double convex and double concave lens.



point thru which rays // to PA pass after refraction

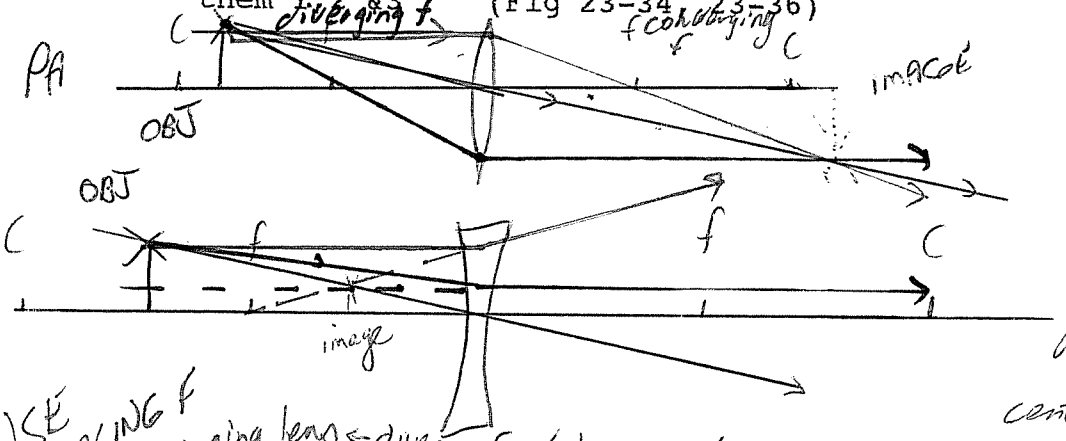
f

f = distance from Centre to f

Define and give the symbol for focal point, focal length, focal plane, converging lens and diverging lens.

Plane of points which parallel incident rays meet (but not // PA)

Illustrate and learn to draw the three rays that can be used to illustrate the image produced by lenses. Label them 1, 2 & 3 (Fig 23-34, 23-36)



Ray ① Parallel to PA, thru *converging f (if converging lens)

Ray ② thru diverging *f Parallel to PA

Ray ③ thru exact centre of lens, does not refract

USE CONVERGING f with converging lens ← diverging f w/ diverging lens

List and describe the lens equation.

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

In point form --list the sign conventions.

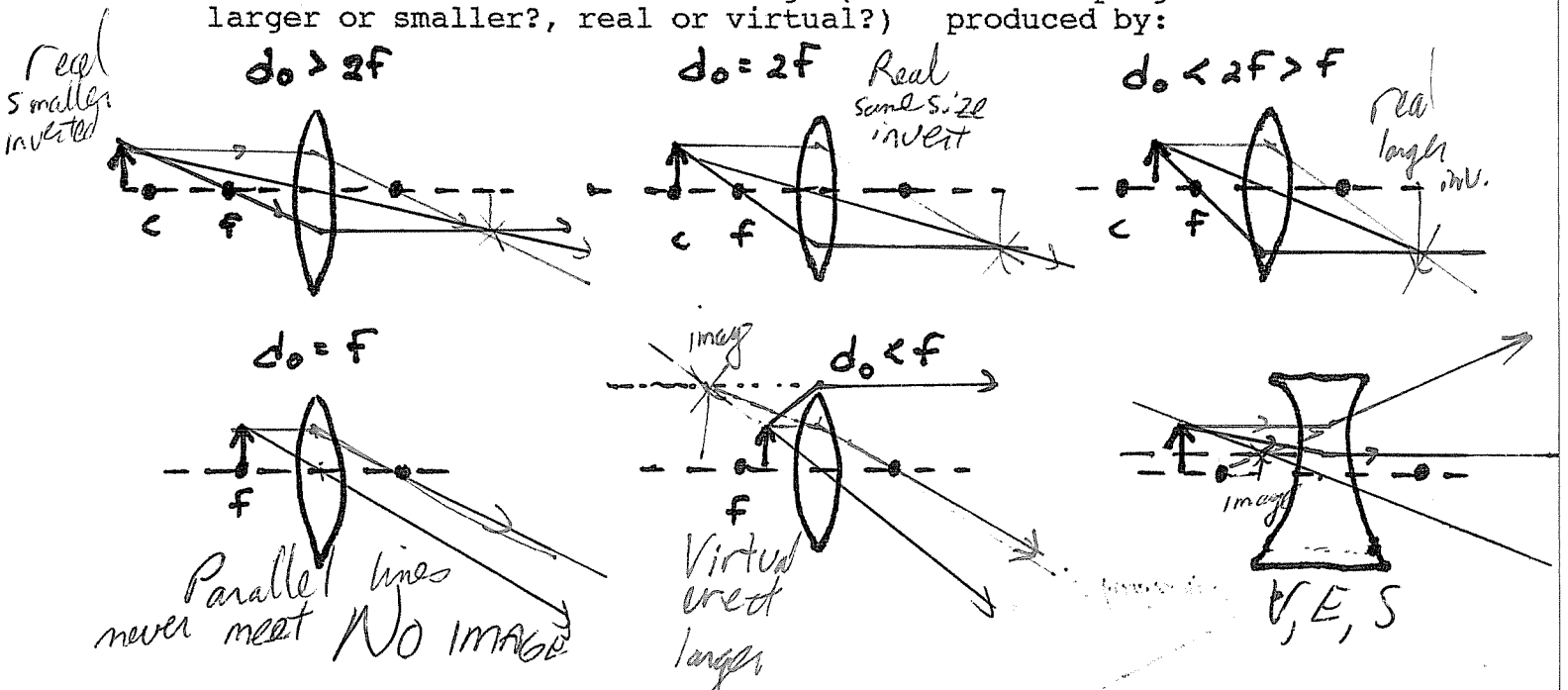
Same as before

List and describe a formula to find lateral magnification. What does a negative magnification mean?

Same as before

** Study Sec 23-9 and Examples 23-11, 23-12, 23-13 ---- very carefully **

Describe and illustrate the image (inverted or upright? larger or smaller?, real or virtual?) produced by:



19] A sharp image is located 58.0 mm behind a 50.0 mm-focal length converginglens. Calculate the object distance. (363 mm)

$\frac{1}{f} - \frac{1}{d_i} = \frac{1}{d_o}$ $d_o = 362.5\,mm$

$= .36m$

20] A leaf is placed 88.0 cm in front of a −710-mm-focal-length lens. Where is the image? Is it real or virtual? (393 mm in front, virtual)

−f will always give virtual

$\frac{1}{f} - \frac{1}{d_o} = \frac{1}{d_i} = \frac{1}{-710} - \frac{1}{88} = -\frac{1}{.92}$

$d_i = -39.2\,cm$

21] A certain lens focuses an object 33.5 cm away as an image 5.0 cm on the other side of the lens. What type of lens is it and what is its focal length? Is the image real or virtual? (4.3 cm, real)

convex (real bc d_i +)

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

$\frac{1}{33.5} + \frac{1}{5} = \frac{1}{f}$ $f = 4.35\text{cm}$

22] a) An object 28.0 cm in front of a certain lens is imaged 8.10 cm in front of that lens (on the same side as the object). What type of lens is this and what is its focal length? Is the image real or virtual?
b) What if the image were located instead, 35.0 cm in front of the lens? (−11.4 cm, +140 cm)

d_i −

$\frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{f}$ tells us it is concave lens

$\frac{1}{-8.1} + \frac{1}{28} = \frac{1}{f}$ $f = -11.4\text{cm}$

$-\frac{1}{35} + \frac{1}{28} = \frac{1}{f}$ $f = 140\text{cm}$ ← + tells us it is convex

---

23] a) How far from a 50.0-mm-focal-length lens must an object be placed if its image is to magnified 2.00x and be real?
b) What if the image is to be virtual and magnified 2.00x?
(75 mm, 25mm)

d_i +, f +, m − (B)

(A) $-2 = \frac{-d_i}{d_o}$ $2d_o = d_i$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} \rightarrow \frac{1}{f} = \frac{1}{2d_o} + \frac{1}{d_o}$

$\frac{1}{50} = \frac{1}{2d_o} + \frac{2}{2d_o} = \frac{3}{2d_o}$ $d_o = \frac{50\times3}{2} = 75\text{ mm}$

(B) $2 = \frac{-d_i}{d_o}$ $-2d_o = d_i$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$ $\frac{1}{50} = \frac{-1}{2d_o} + \frac{1}{d_o}$

$\frac{1}{50} = \frac{-1+2}{2d_o} = \frac{1}{2d_o}$ $\frac{50}{2} = d_o$ $= 25\text{mm}$

24] a) A 2.20 cm high insect is 1.20 m from a 135 mm-focal-length lens. Where is the image, how high is it, and what type is it? b) What if f = -135 mm?

(152 mm, -.279 cm, real and inverted --- -121 mm, .222 cm, virtual and upright)

(A) $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$\frac{1}{.135} = \frac{1}{d_i} + \frac{1}{1.2}$

$\frac{1}{.135} - \frac{1}{1.2} = \frac{1}{d_i} = 6.57$

$d_i = .152\text{m}$ + so real

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

$\frac{h_i}{2.2\text{cm}} = \frac{-.152\text{m}}{1.2\text{m}}$ $h_i = -0.28\text{cm}$ smaller, inverted

(B) $\frac{1}{-.135} - \frac{1}{1.2} = \frac{1}{d_i}$ $d_i = -.12\text{m}$ ← virtual

$\frac{h_i}{h_o} = \frac{-.12}{1.2}$ $\frac{h_i}{2.2} = +.1$ $h_i = .22\text{cm}$ ↖ smaller erect