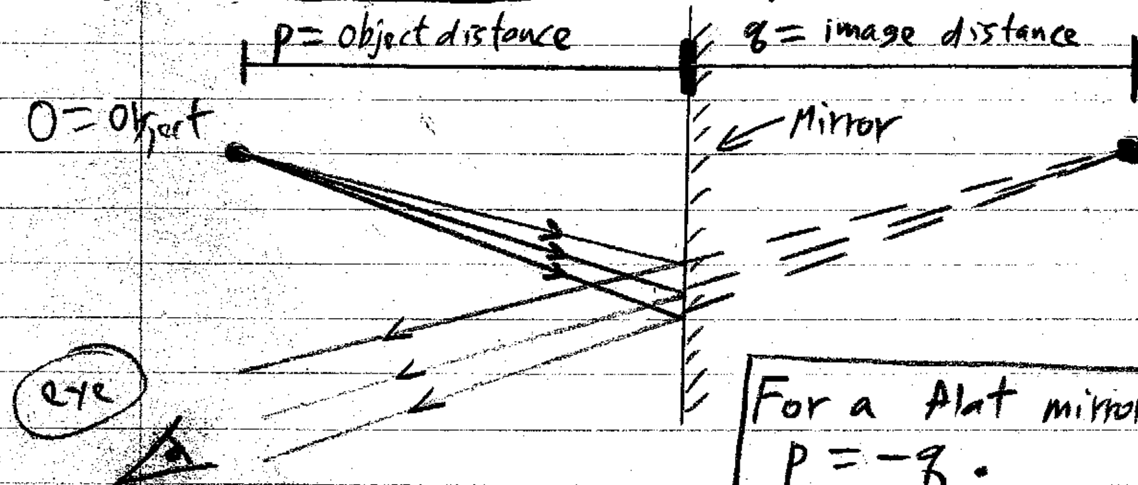
(Today: cover mirrors.
Next class: cover lenses.)

Chapter 35 – Image formation,

with applications of reflection and refraction, with mirrors and lenses.

Plane ("flat") mirrors are the simplest and cheapest mirrors

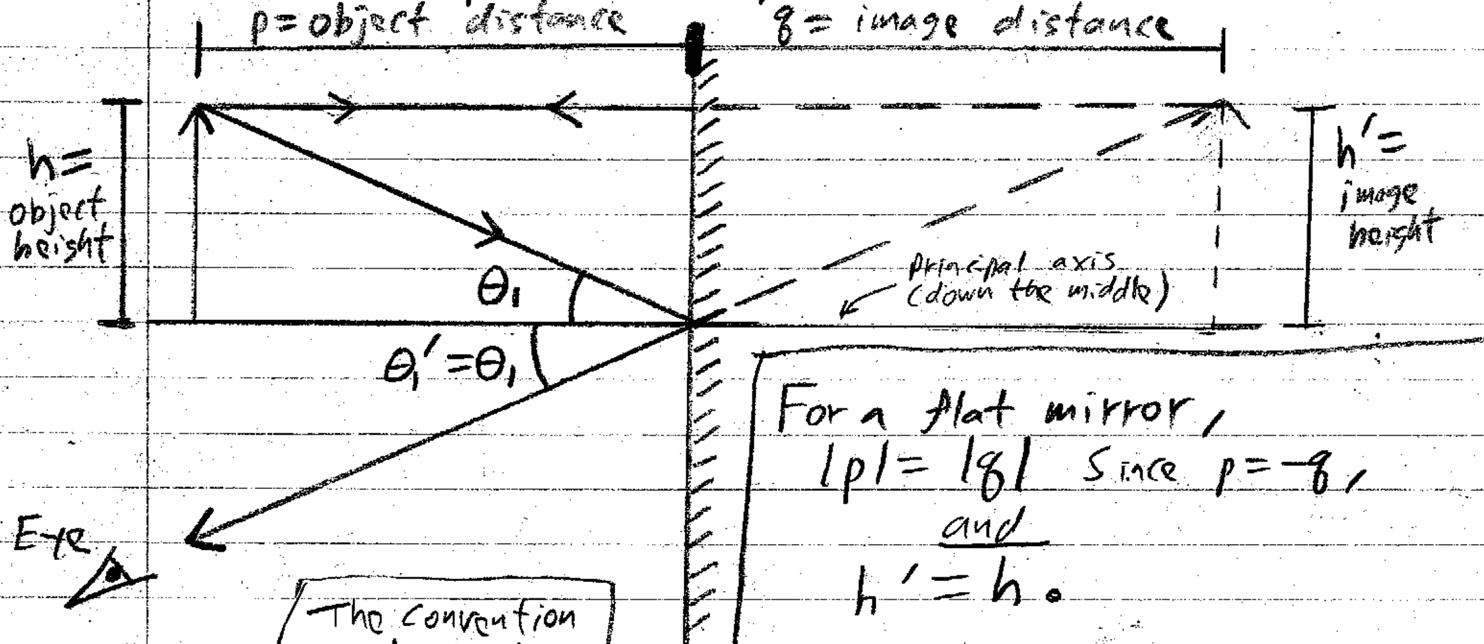


I = image
= where the rays converge (geometrically)
= where your reflection appears to be (physically)

For a flat mirror, $p = -q$.

(If you are 1m in front of the mirror, your image looks like it's 1m in back of the mirror.)

In standard optical notation, this is:



The convention in standard optical notation is for the incoming light to go from left to right.

For a flat mirror,
$|p| = |q|$ since $p = -q$,
and
$h' = h$.

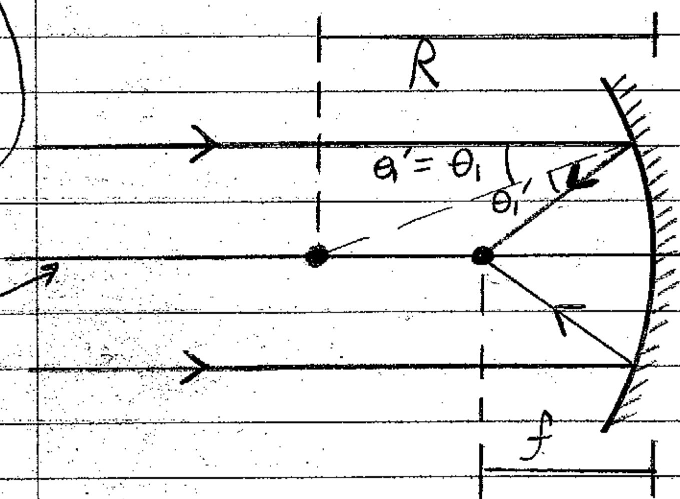
Magnification $M \equiv \frac{h'}{h} = -\frac{q}{p}$, always.

For a flat mirror, $M = 1$.

Spherical mirrors – have radius R, "radius of curvature"

Pass around vanity mirrors

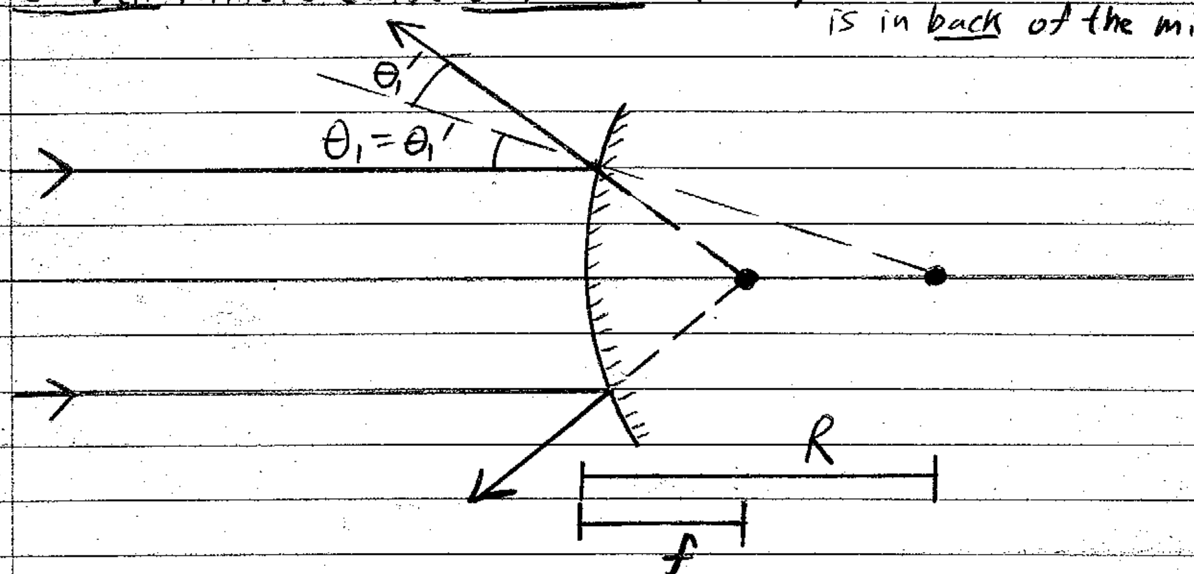
Concave mirrors curve inward: $R > 0$, since the center of curvature is in front of the mirror.



Focal length $f = R/2$

(Draw with big protractor, to demonstrate $f = R/2$.)

Convex mirrors curve outward: $R < 0$, since the center of curvature is in back of the mirror.



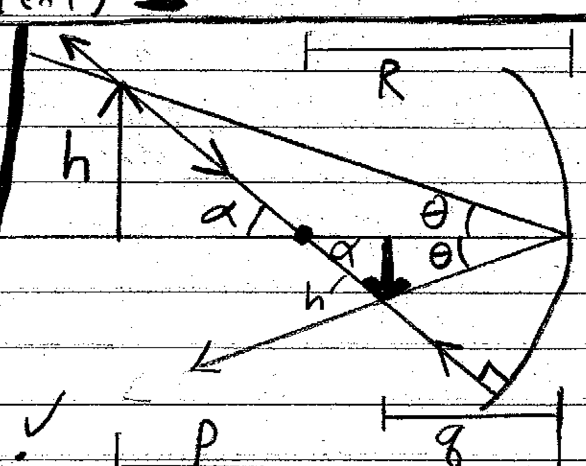
Show overhead – sign conventions for mirrors

The Mirror Equation (derived in text)

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R}$$

p: object distance, q: image distance

Don't show this derivation, unless someone asks.



$$\tan\alpha = \frac{h}{p-R} = \frac{-h'}{R-q}$$

$$\Rightarrow \frac{h'}{h} = -\frac{R-q}{p-R} = -\frac{q}{p} \Rightarrow \text{(algebra)} \ \frac{1}{p} + \frac{1}{q} = \frac{2}{R}. \checkmark$$

(Start 2nd class on Chapter 35)

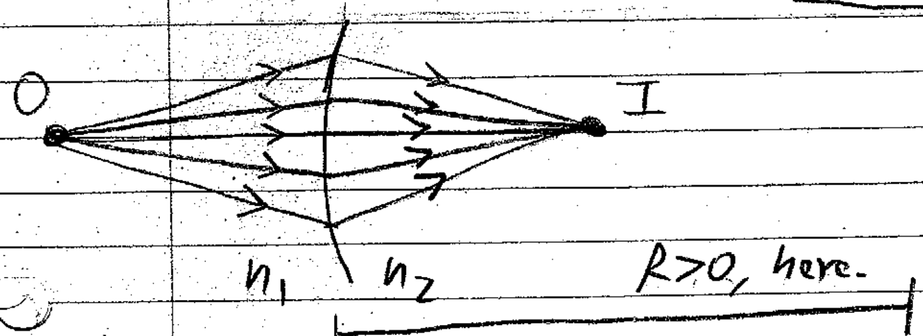
The sign conventions for mirrors are defined such that $\frac{1}{p} + \frac{1}{q} = \frac{2}{R}$ for all mirrors, always.

So are the sign conventions for lenses, which are different: see page 2 of the Phys 4C Formula List.

→ Lenses and mirrors complement each other.

Images formed by refraction (lenses) —

(1) Spherical surface — $$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$ (derived in text)



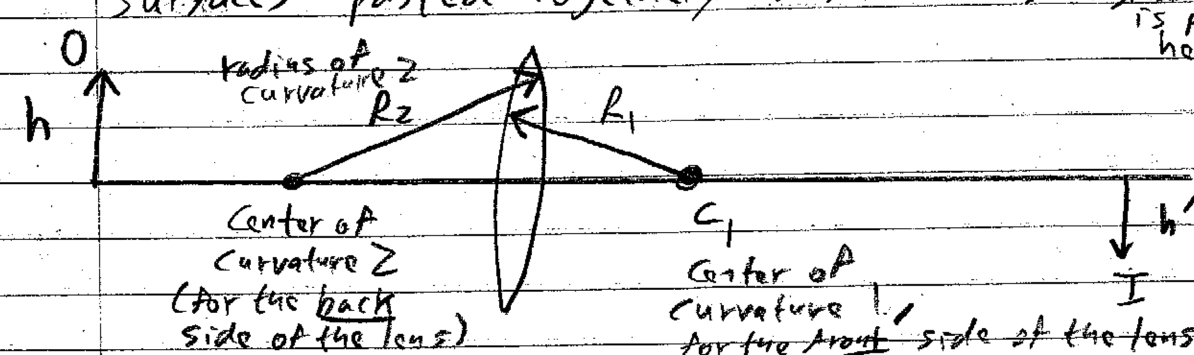
Here, $R > 0$ if the center of curvature is on the back side of the surface, unlike a mirror.

(2) Flat surface = a "flat" lens, or a pane of glass

$$R \to \infty \Rightarrow \frac{n_1}{p} = -\frac{n_2}{q}, \quad \text{so:} \quad q = -\frac{n_2}{n_1} p$$

⇒ A fish in water looks deeper than it is.

(3) Thin lenses — can be thought of as two spherical surfaces "pasted together," to form a lens (and assuming the glass in between is perfectly transparent, hence negligible)



The Lensmaker's Equation (derived in text)

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

This assumes a glass lens (n) in air.

OR: $$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$ the thin-lens equation = the mirror equation!

The sign conventions for mirrors and lenses (given on page 2 of the Phys 4C Formula List) are different, because they're defined such that the thin lens/mirror equation is always true.

As always, Magnification $M = \frac{h'}{h} = -\frac{q}{p}$.

→ Notice that lenses and mirrors complement each other.

Combinations of lenses —

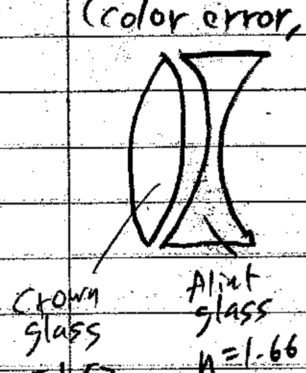
$$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{f}$$

$$M = M_1 M_2$$

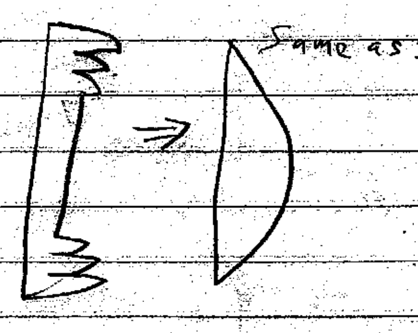
~~Also, for two lenses, $q_1 = p_2$~~ → (Is this OK? CHECK)
~~(the image distance for lens 1 = the object distance for the next lens).~~

Examples —

Achromatic doublet — reduces chromatic aberration (color error, due to refraction)

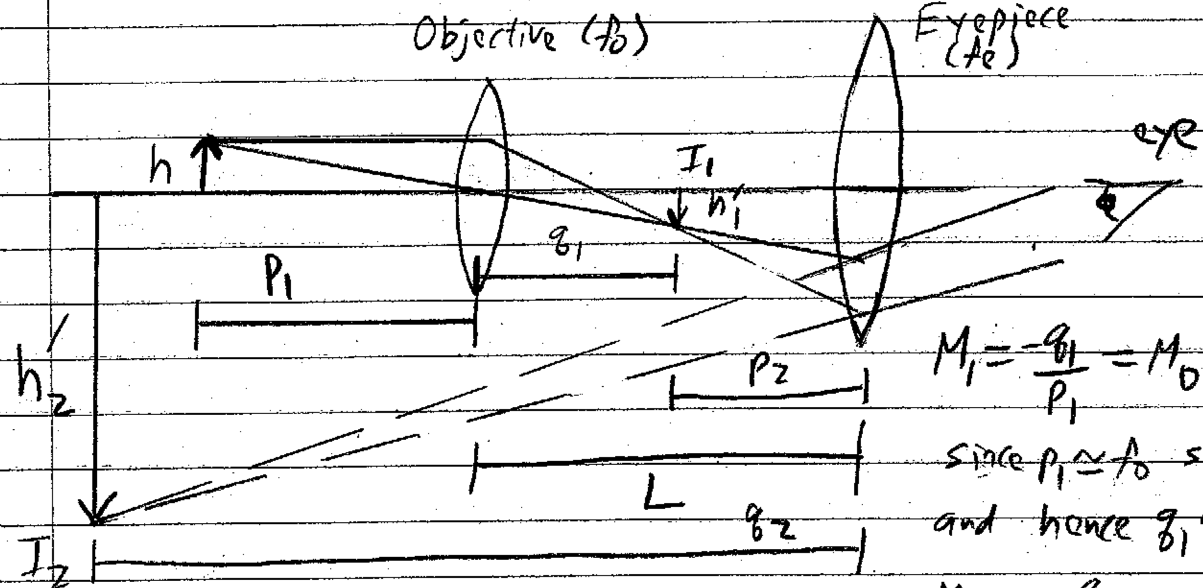


Fresnel lens (in overhead projector) —



SKIP, IF TIME IS SHORT – These are hard to draw! (5)

<u>Microscopes</u> – Show a greatly <u>magnified</u> image for small p_1, that's still in focus. (The rays are nearly parallel.)



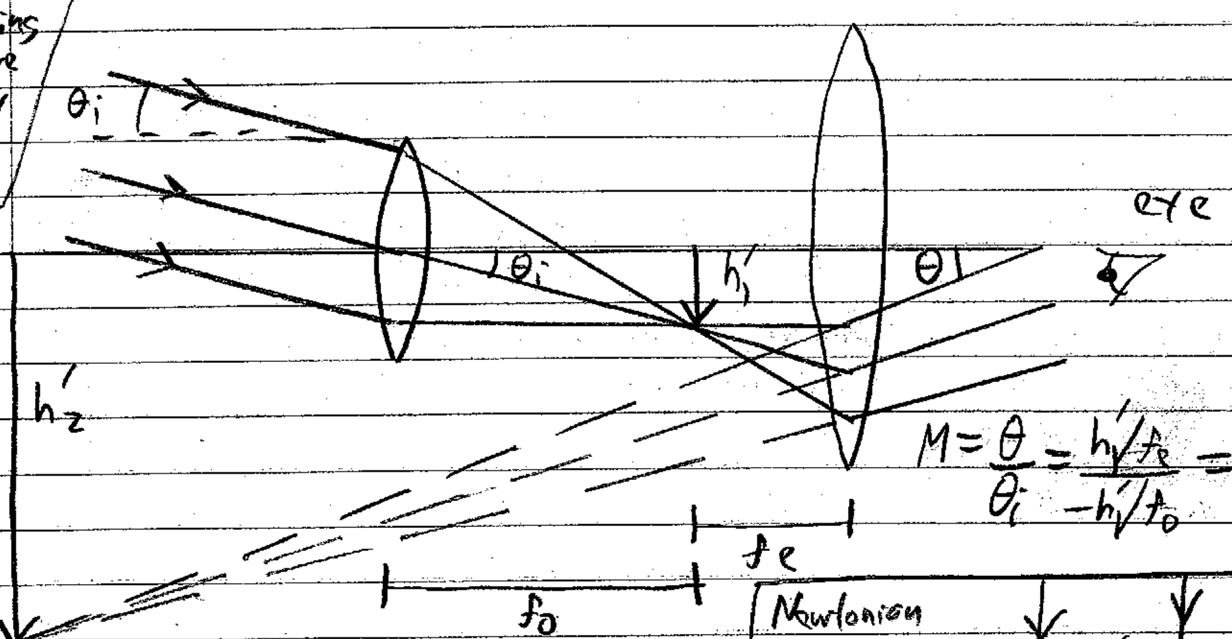
$M_1 = \frac{-q_1}{p_1} = M_0 \simeq -\frac{L}{f_0}$, since $p_1 \simeq f_0$ since $p_1 \ll q_1$ and hence $q_1 \simeq L$.

$M_2 = -\frac{q_2}{p_2} = M_e$ and $p_2 \simeq f_e$

$$\Rightarrow M = M_1 M_2 = M_0 M_e = -\frac{L}{f_0}\left(\frac{q_2}{f_e}\right).$$

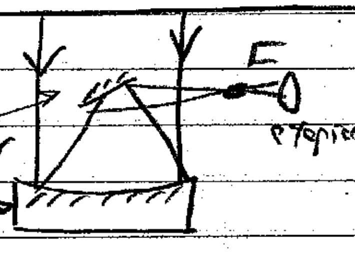
<u>Telescopes</u> – magnify images of <u>distant</u> objects, so $p_1 \to \infty$ and so $q_1 \simeq f_0$.

Incoming rays are parallel, since $p_1 \to \infty$

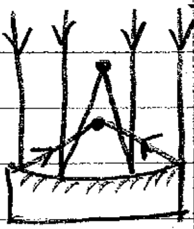


$$M = \frac{\theta}{\theta_i} = \frac{h_1'/f_e}{-h_1'/f_0} = -\frac{f_0}{f_e}$$

Newtonian reflector –



OMIT, if time is short



Aberrations — Chromatic (colors spread out by refraction in lenses)
— coma (can't focus off-axis)
— astigmatism (point sources become lines, especially off-axis)
— spherical (can't focus to a precise point)
— Others!

The Camera — f-number $\equiv \frac{f}{D}$

D = aperture = diameter of objective lens or mirror.

I (onto film or digital detector) $\propto \frac{1}{(f/D)^2} = \frac{1}{(f\text{-number})^2}$

A "fast" lens has $\frac{f}{D} \lesssim 6$ (f/6 or less, e.g. f/2)

Very fast is f/1, a can of tuna!

The Eye —

Nearsightedness: image in front of retina → correct with diverging lens
(Eyes look smaller, through glasses)

Farsightedness: image in back of retina → correct with converging lens
(Eyes look big)