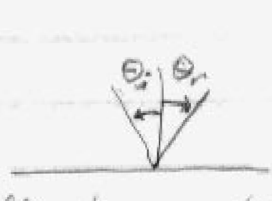
Geometric optics

<u>reflection</u>




$\theta_r = \theta_i$

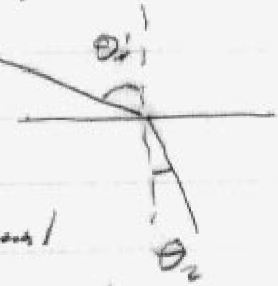
(for a diffraction grating, true only for zero order)

<u>refraction</u> - Snell

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

- represents continuity of phase across boundary

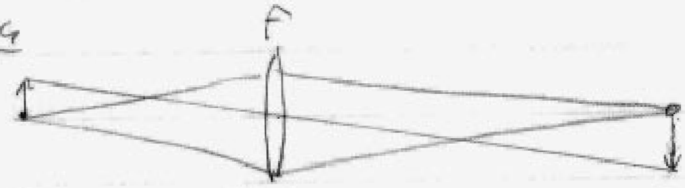
$k_1 \sin\theta_1$ = projection along surface




$n_1 < n_2$ : refract toward normal

$n_1 > n_2$ : " away from normal

<u>lenses</u>




$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ for "thin" lens

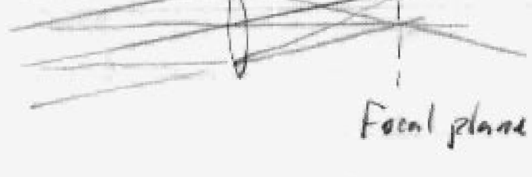
magnification $M = -q/p$ $M<0$ when image is inverted.

ray thru center of lens is undeviated.

$M=-1$ if $p=q=2f$

sign conventions: $q>0$ real image

$f>0$ collimated rays focus

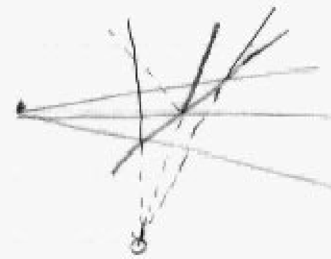


Focal plane


$p=+\infty$ $q<0$

## mirrors

Flat mirrors "fold" the system around mirror axis



curved mirrors

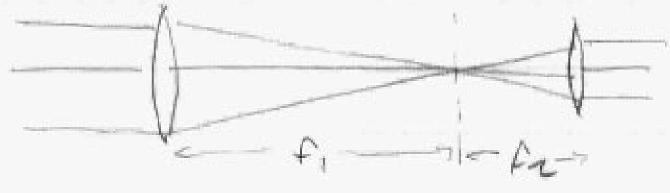
- concave (relative to incident beam)
  act as +'ve lens

R $\quad p = q = R = 2f$

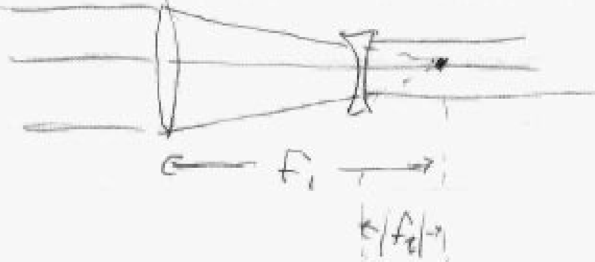
- convex → −'ve lens

simple systems:

telescope



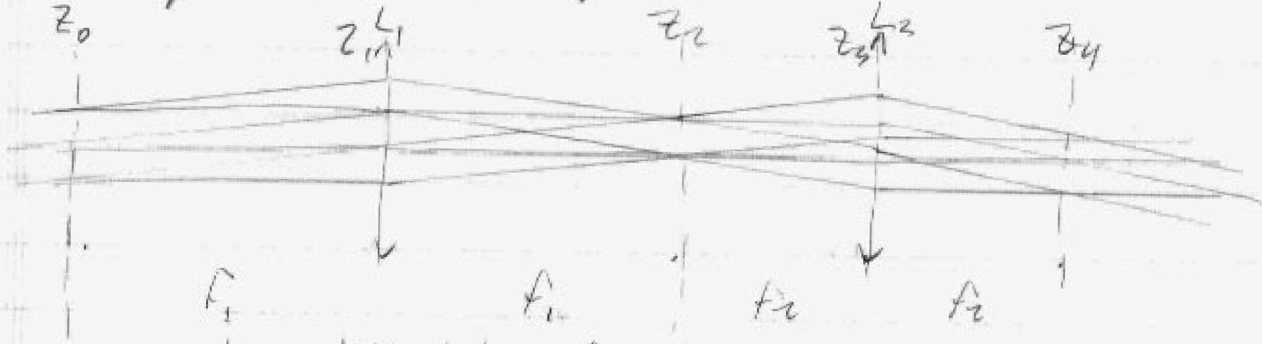

Newtonian




Galilean.

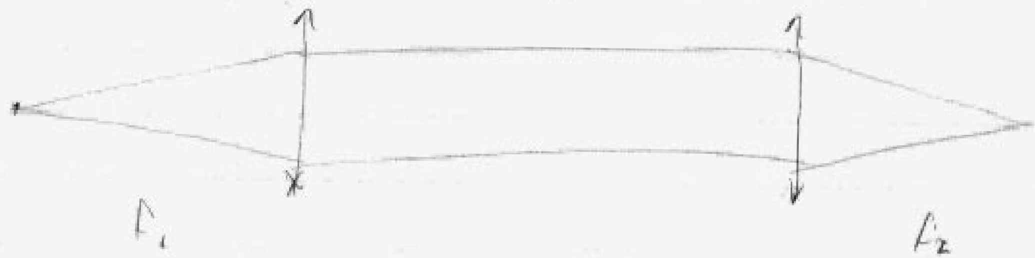
used to change beam size.

relay imaging: 4f system.




any beam tilt at back focal plane of $L_1$ results in no translation of beam at focal plane of $L_2$

- images $z_0$ to $z_4$




wave is reproduced (w/ magnification)

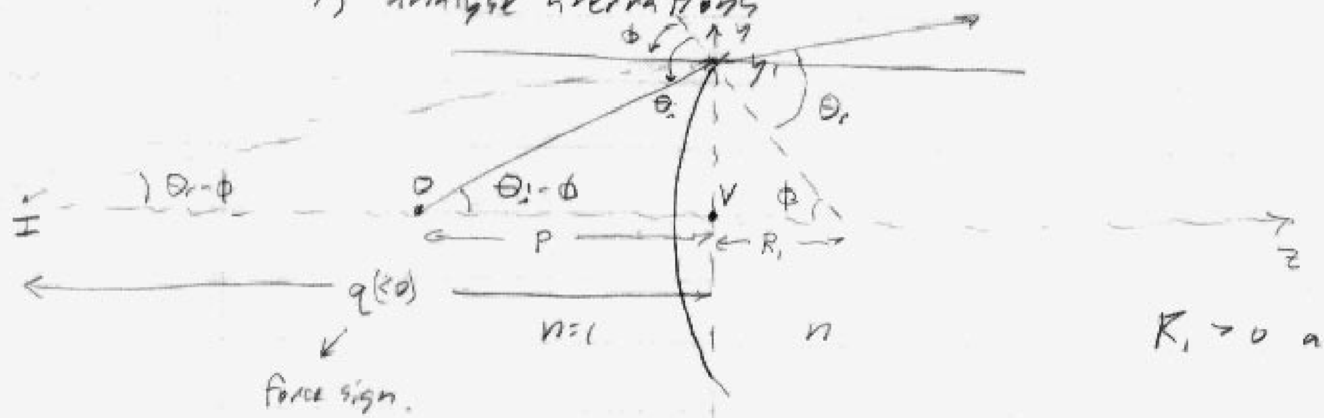
- imaging "removes" diffraction effects.

Ray tracing

- no approximation: use CAD programs
- paraxial (small angle to optical axis)
  → ABCD matrix calcs – can be used for Gaussian beams.

design procedure:

1) general approach - find existing design that is similar to need.
2) ray diagram: object, image on-axis, use paraxial
3) " " " " off-axis
   → magnification, test for aperture size.
4) use matrices / computer design to optimize
5) analyse aberrations




$R_1 > 0$ as shown

angles to z-axis are small

$$\theta_i - \phi = y_1/p \qquad \theta_r - \phi = y_1/(-q) \qquad \phi = y_1/R_1$$

$$\frac{\sin\theta_i}{\sin\theta_r} \doteq \frac{\theta_i}{\theta_r} = n = \frac{\phi + y_1/p}{\phi - y_1/q} = \frac{1/R_1 + 1/p}{1/R_1 - 1/q}$$

$$\rightarrow -\frac{n}{q} - \frac{1}{p} = \frac{1}{R_1}(1-n)$$

now add a second surface → $q'$

source appears to come from $-q$ $\qquad p \to -q$

interchange $1 \leftrightarrow n$

$$-\frac{1}{q'} + \frac{n}{q} = \frac{1}{R_2}(n-1)$$

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

$$\rightarrow \frac{1}{q'} + \frac{1}{p} = \underbrace{(n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \equiv \frac{1}{f}}_{\text{lens maker's eqn}}$$

sign convention:

$R>0$ $\qquad$ $R<0$

plano-convex lens $\quad R_1 = \infty \quad R_2 < 0 \qquad f = |R_2|/_{n-1}$

if $\quad n = 1.5 \qquad f = 2\,|R_2|$

ABCD matrices

keep track of ray height and angle $\theta = \frac{dr}{dz}$ $\begin{pmatrix} r \\ r' \end{pmatrix}$

so that $\begin{pmatrix} r_2 \\ r_2' \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} r_1 \\ r_1' \end{pmatrix}$

<u>Translation:</u>

$$r_2 = r_1 + L r_1' \qquad \rightarrow \qquad \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix}$$
$$r_2' = r_1'$$

<u>Flat interface</u>

$n_1 = 1$

$n_2 = n$

$$r_2 = r_1 \qquad \rightarrow \qquad \begin{pmatrix} 1 & 0 \\ 0 & 1/n \end{pmatrix}$$
$$r_2' = n_1 r_1' / n_2$$

<u>window</u>

$$\begin{pmatrix} 1 & 0 \\ 0 & n \end{pmatrix} \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & 1/n \end{pmatrix}$$
$$= \begin{pmatrix} 1 & 0 \\ 0 & n \end{pmatrix} \begin{pmatrix} 1 & L/n \\ 0 & 1/n \end{pmatrix} = \begin{pmatrix} 1 & L/n \\ 0 & 1 \end{pmatrix} \qquad 4.2.4$$

<u>Lens</u>


$$r_2 = r_1$$
$$r_1' = r_1/p \qquad r_2' = -r_1/q$$
$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$
$$r_2' = -\frac{r_1}{f} + \frac{r_1}{p} = -\frac{1}{f} r_1 + r_1'$$
$$\rightarrow \begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix}$$

spherical interface

from before: $$-\frac{n_2}{q} - \frac{n_1}{p} = \frac{1}{R}(n_1 - n_2)$$

$$r_2' = \frac{r_1}{-q} = \frac{r_1}{n_2}\left(\frac{n_1}{p} + \frac{1}{R}(n_1 - n_2)\right)$$

$$= r_1'\left(\frac{n_1}{n_2}\right) + \frac{r_1}{R}\,\frac{n_1 - n_2}{n_2}\Big)$$

$$\rightarrow \begin{pmatrix} 1 & 0 \\ \left(\frac{n_1 - n_2}{n_2}\right)\frac{1}{R} & \frac{n_1}{n_2} \end{pmatrix}$$

w/ $\left(\begin{array}{l} R>0 \\ R<0 \end{array}\right)$