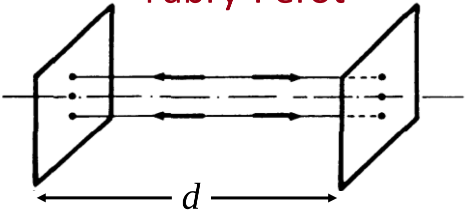
Optical resonators

Fabry-Perot

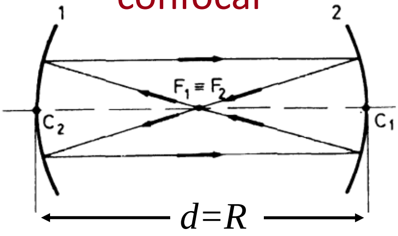


Longitudinal modes:

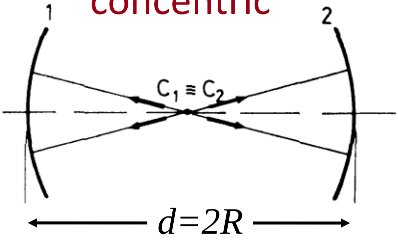
$$\nu_m = m\left(\frac{c}{2d}\right)$$

$$\Delta\nu_{sep} = \frac{c}{2d}$$

confocal

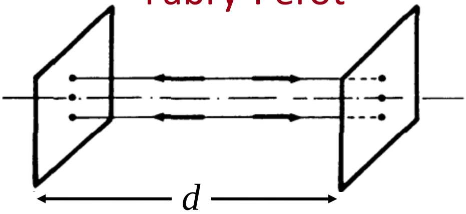


concentric



Optical resonators

Fabry-Perot

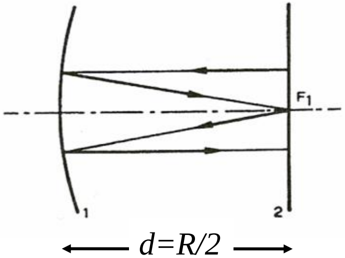


Longitudinal modes:

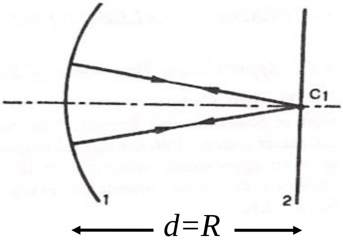
$$\nu_m = m\left(\frac{c}{2d}\right)$$

$$\Delta\nu_{sep} = \frac{c}{2d}$$

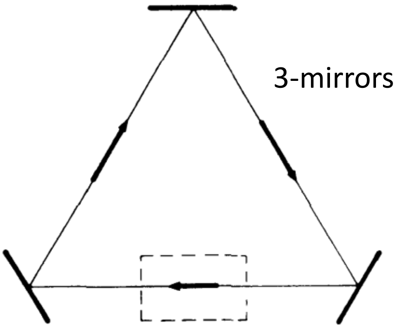
emifocal

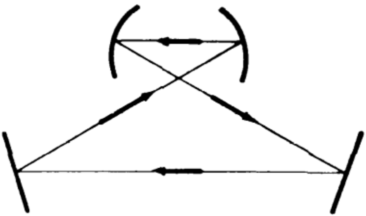


emiconcentric



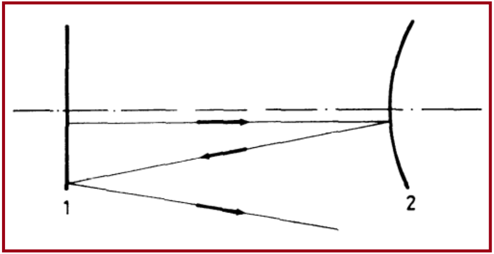
Ring resonators

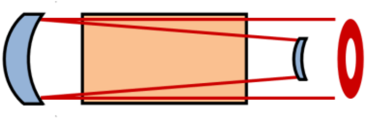


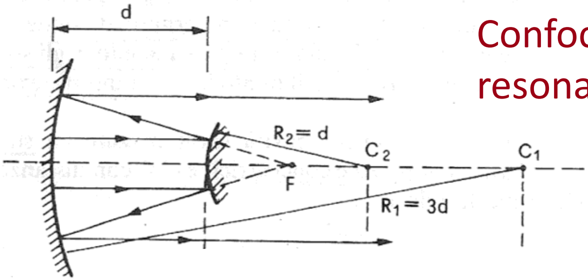


Longitudinal modes: $\nu_m = m\left(\frac{c}{L_p}\right)$ $\Delta\nu_{sep} = \frac{c}{L_p}$

Unstable resonators

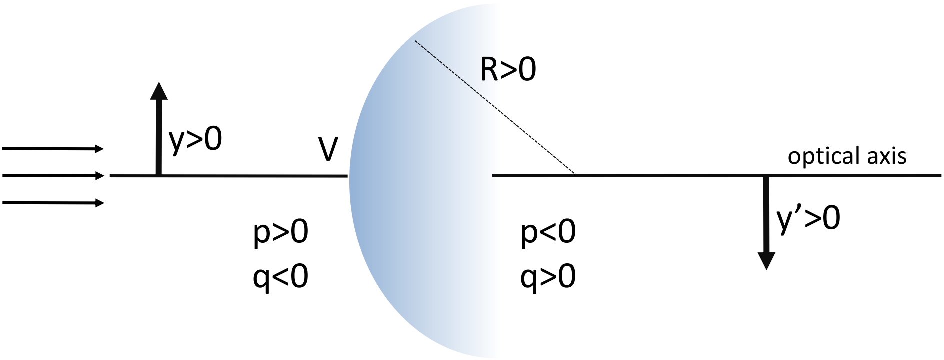




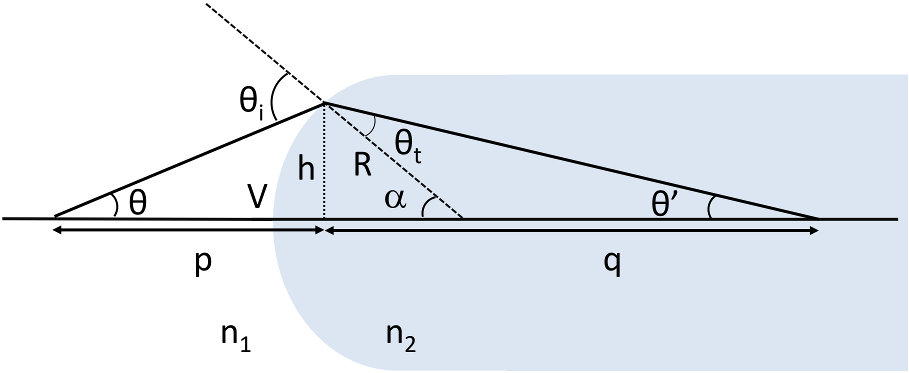


Confocal telescopic resonator

Sign convention



Spherical diopter

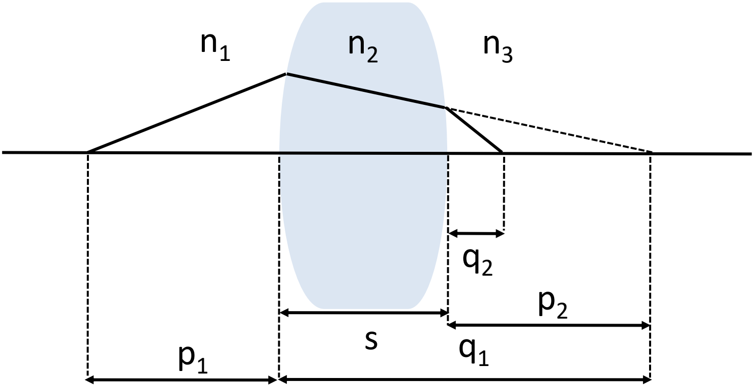


Paraxial approximation

$$\boxed{\frac{n_1}{p}+\frac{n_2}{q}=\frac{n_2-n_1}{R}}$$

Equation of the **spherical diopter**

Thin lens



Thin lens equation

$$\boxed{\frac{1}{p}+\frac{1}{q}=\frac{1}{f}}$$

$$s \longrightarrow 0$$

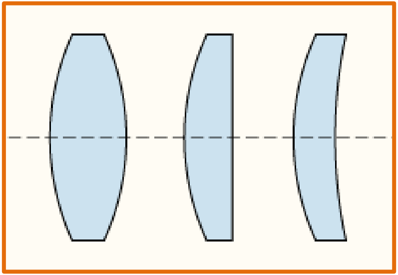
$$n_1 = n_3$$

Lens-maker's equation

$$\boxed{\frac{1}{f}=\frac{n_2-n_1}{n_1}\left(\frac{1}{R_1}-\frac{1}{R_2}\right)}$$

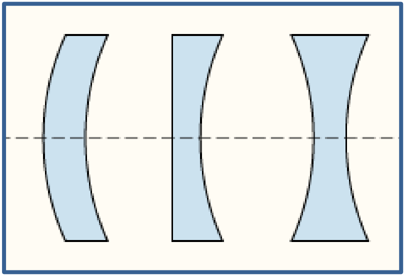
Types of lenses

Converging



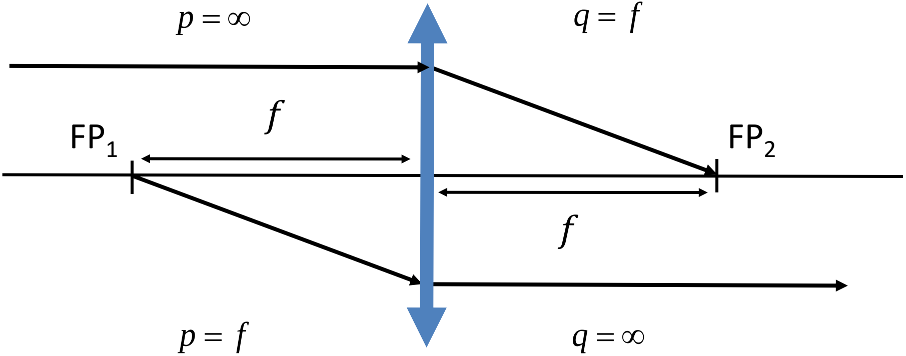
Biconvex | Plano-convex | Meniscus-converging

Diverging



Meniscus-diverging | Plano-concave | Biconcave

Thin lens



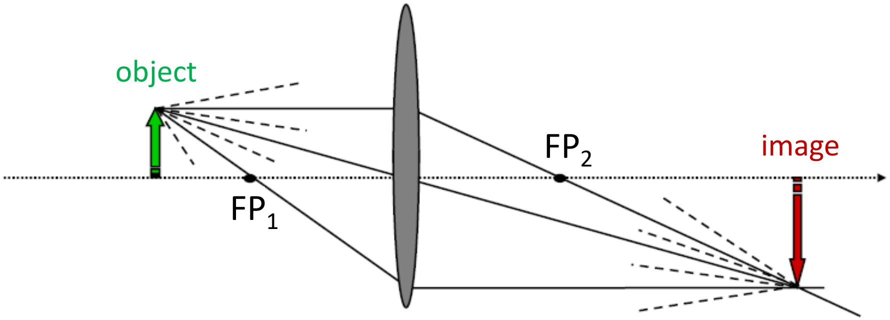
Thin lens equation

$$\boxed{\frac{1}{p} + \frac{1}{q} = \frac{1}{f}}$$

Lens-maker's equation

$$\boxed{\frac{1}{f} = \frac{n_2 - n_1}{n_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

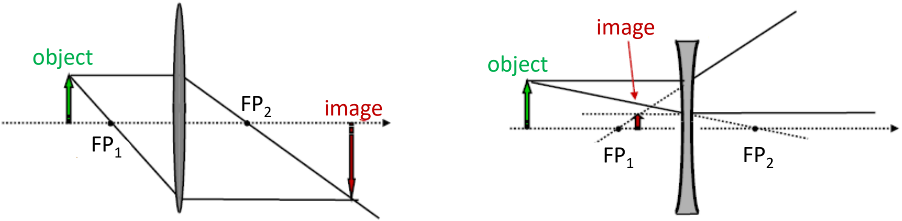
Ray tracing

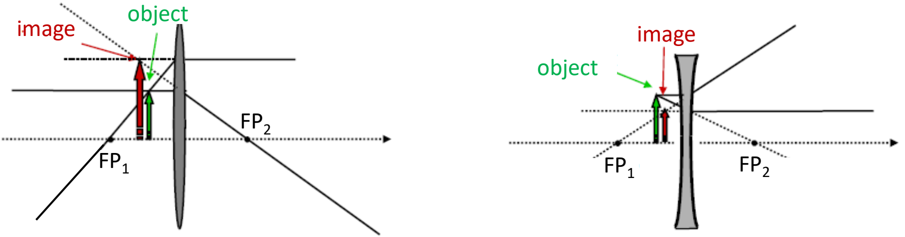


Real and virtual images

Converging lenses

Diverging lenses



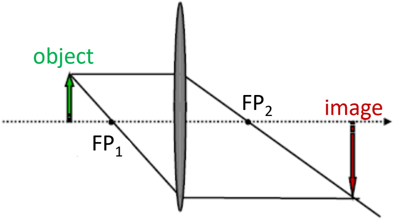


Magnification

Thin lenses equation
$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$

$$\Downarrow$$

$$q=\frac{f\,p}{p-f} \qquad p=\frac{f\,q}{q-f}$$



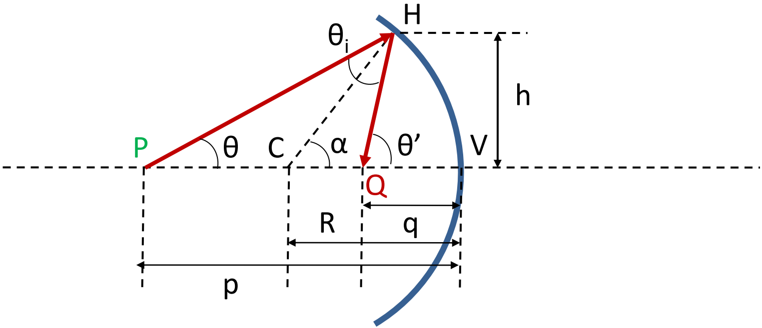
Transverse magnification

$$\boxed{I=\frac{y'}{y}=\frac{q}{p}=\frac{q-f}{f}=\frac{f}{p-f}}$$

Longitudinal magnification

$$\boxed{I_L=\frac{\Delta q}{\Delta p}=-\left(\frac{f}{p-f}\right)^2=-I^2}$$

Spherical mirror



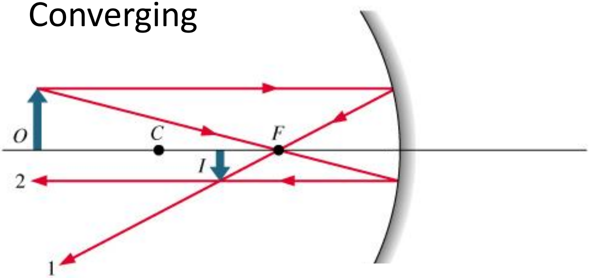
Paraxial approximation

$$\boxed{\frac{1}{p}-\frac{1}{q}=-\frac{2}{R}}$$

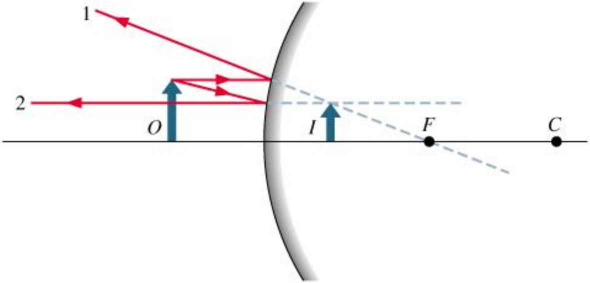
Equation of the **spherical mirror**

Spherical mirror

Converging

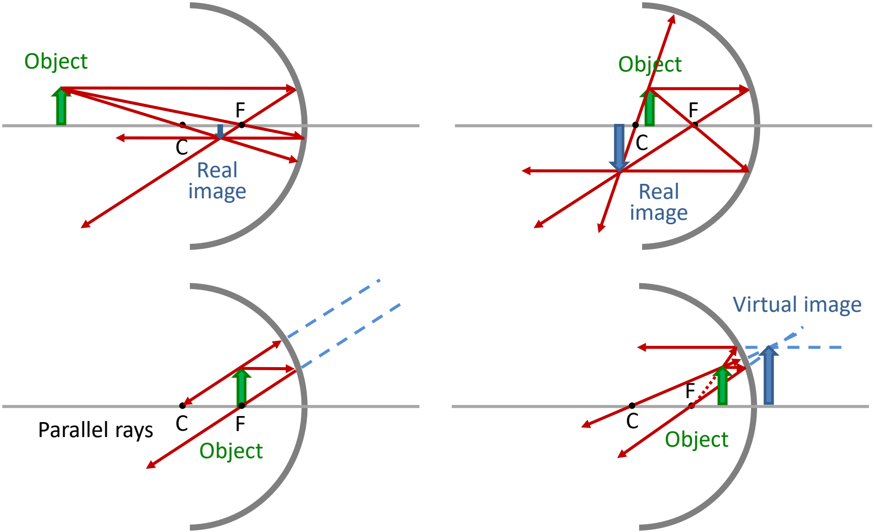


Diverging

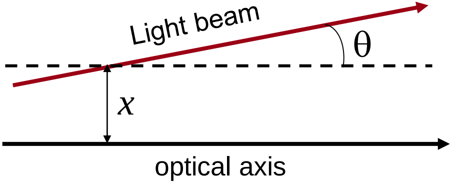


Spherical mirror

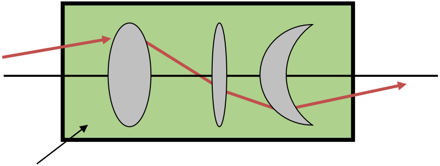
Converging



ABCD matrices



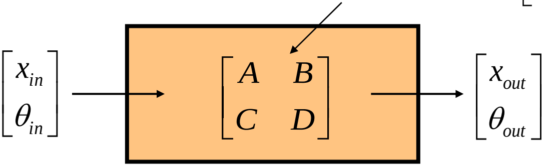
$$\begin{bmatrix} x \\ \theta \end{bmatrix}$$ Ray vector



Optical system ↔ Matrix 2 x 2

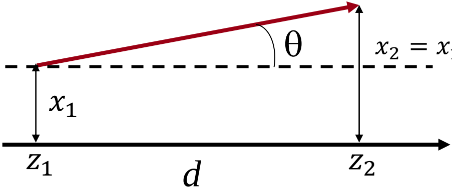
$$\begin{bmatrix} x_{out} \\ \theta_{out} \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} x_{in} \\ \theta_{in} \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_n & B_n \\ C_n & D_n \end{bmatrix} \cdots \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix}$$



ABCD matrices

Free-space propagation (for a distance d)



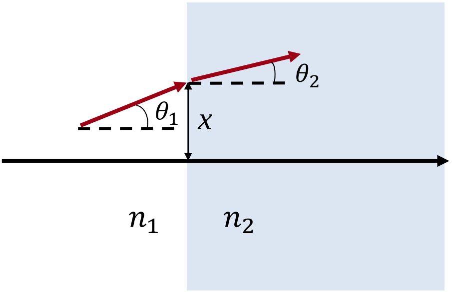
$$x_2 = x_1 + d\, tg\theta \approx x_1 + d\theta$$

$$\begin{cases} x_2 = x_1 + d\theta \\ \theta_2 = \theta_1 = \theta \end{cases}$$

$$\begin{bmatrix} x_2 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} x_1 \\ \theta_1 \end{bmatrix} = \begin{bmatrix} 1 & d \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ \theta_1 \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & d \\ 0 & 1 \end{bmatrix}$$

Plane diopter



Snell's law

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

$$n_1\theta_1 = n_2\theta_2$$

paraxial approximation

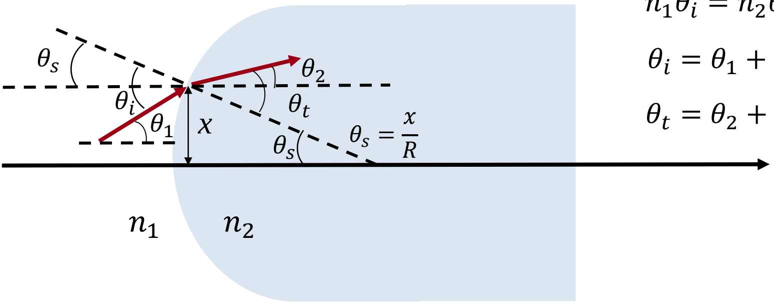
$$\begin{cases} x_2 = x_1 = x \\ \theta_2 = \theta_1 \dfrac{n_1}{n_2} \end{cases}$$

$$\begin{bmatrix} x_2 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} x_1 \\ \theta_1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{n_1}{n_2} \end{bmatrix} \begin{bmatrix} x_1 \\ \theta_1 \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{n_1}{n_2} \end{bmatrix}$$

ABCD matrices

Spherical diopter (with curvature radius R)



$$n_1\theta_i = n_2\theta_t$$

$$\theta_i = \theta_1 + \theta_s$$

$$\theta_t = \theta_2 + \theta_s$$

$$\begin{cases} x_2 = x_1 = x \\ \theta_2 = \theta_t - \theta_s = \theta_i \dfrac{n_1}{n_2} - \theta_s = (\theta_1 + \theta_s)\dfrac{n_1}{n_2} - \theta_s = \left(\theta_1 + \dfrac{x_1}{R}\right)\dfrac{n_1}{n_2} - \dfrac{x_1}{R} \end{cases}$$

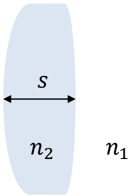
$$\begin{bmatrix} x_2 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} x_1 \\ \theta_1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \dfrac{n_1 - n_2}{n_2 R} & \dfrac{n_1}{n_2} \end{bmatrix} \begin{bmatrix} x_1 \\ \theta_1 \end{bmatrix} \qquad \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \dfrac{n_1 - n_2}{n_2 R} & \dfrac{n_1}{n_2} \end{bmatrix}$$

ABCD matrices

Propagation for a length d in a homogeneous and isotropic medium	$\begin{bmatrix} 1 & d \\ 0 & 1 \end{bmatrix}$
Crossing of a spherical diopter of radius R (that divides two media of indeces n_1 and n_2)	$\begin{bmatrix} 1 & 0 \\ \dfrac{n_1 - n_2}{n_2 R} & \dfrac{n_1}{n_2} \end{bmatrix}$
Plane diopter	$\begin{bmatrix} 1 & 0 \\ 0 & \dfrac{n_1}{n_2} \end{bmatrix}$
Thin lens (of focal f)	$\begin{bmatrix} 1 & 0 \\ -\dfrac{1}{f} & 1 \end{bmatrix}$
Spherical mirror (of radius R)	$\begin{bmatrix} 1 & 0 \\ +\dfrac{2}{R} & 1 \end{bmatrix}$

Thin lens

It is formed by two spherical diopters (with curvature radii R_1 and R_2) that delimit a block of material with refractive index n_2 (embedded in a material with refractive index n_1) and negligible thickness ($s \longrightarrow 0$)



Spherical diopter (with curvature radius R_2)

Spherical diopter (with curvature radius R_1)

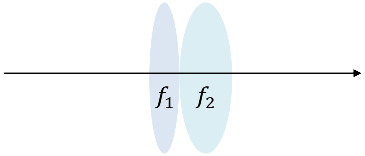
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \dfrac{n_2 - n_1}{n_1 R_2} & \dfrac{n_2}{n_1} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \dfrac{n_1 - n_2}{n_2 R_1} & \dfrac{n_1}{n_2} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\dfrac{1}{f} & 1 \end{bmatrix}$$

$$\frac{1}{f} = \frac{n_2 - n_1}{n_1} \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

Lens' maker equation

ABCD matrices

Thin lens



Combining two thin lenses with focal lengths f_1 and f_2 we get:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\dfrac{1}{f_2} & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -\dfrac{1}{f_1} & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\left(\dfrac{1}{f_1} + \dfrac{1}{f_2}\right) & 1 \end{bmatrix}$$

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