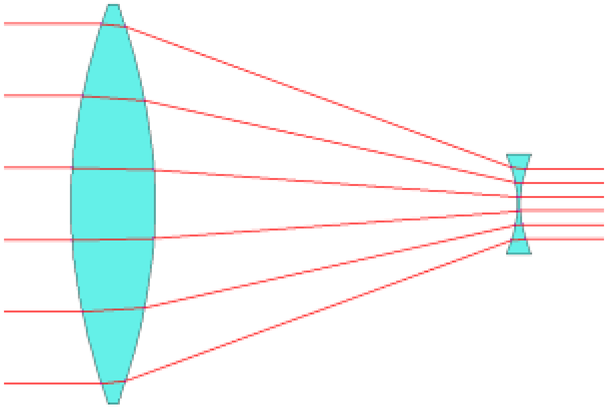
OPAC 101
Introduction to Optics

Lenses



http://www1.gantep.edu.tr/~bingul/opac101

Department of

Optical & Acustical Engineering

Gaziantep University

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Lensmaker's Formula (Thin lens)

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

if t -> 0 (lens size >> center thickness)

$$\frac{1}{f} = \left(\frac{n - n_m}{n_m}\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

if $n_m = 1$ and t -> 0

$$\frac{1}{f} = (n - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Lensmaker's Formula (Thick lens)

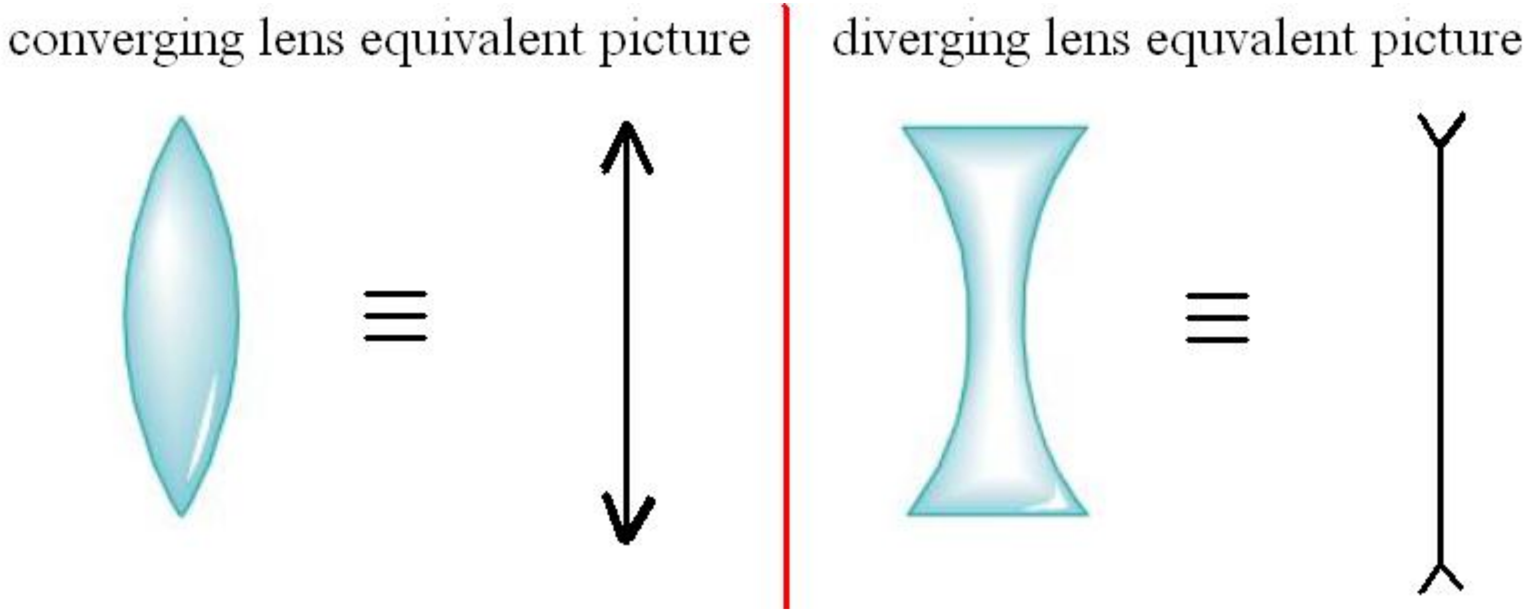
$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

General equation:

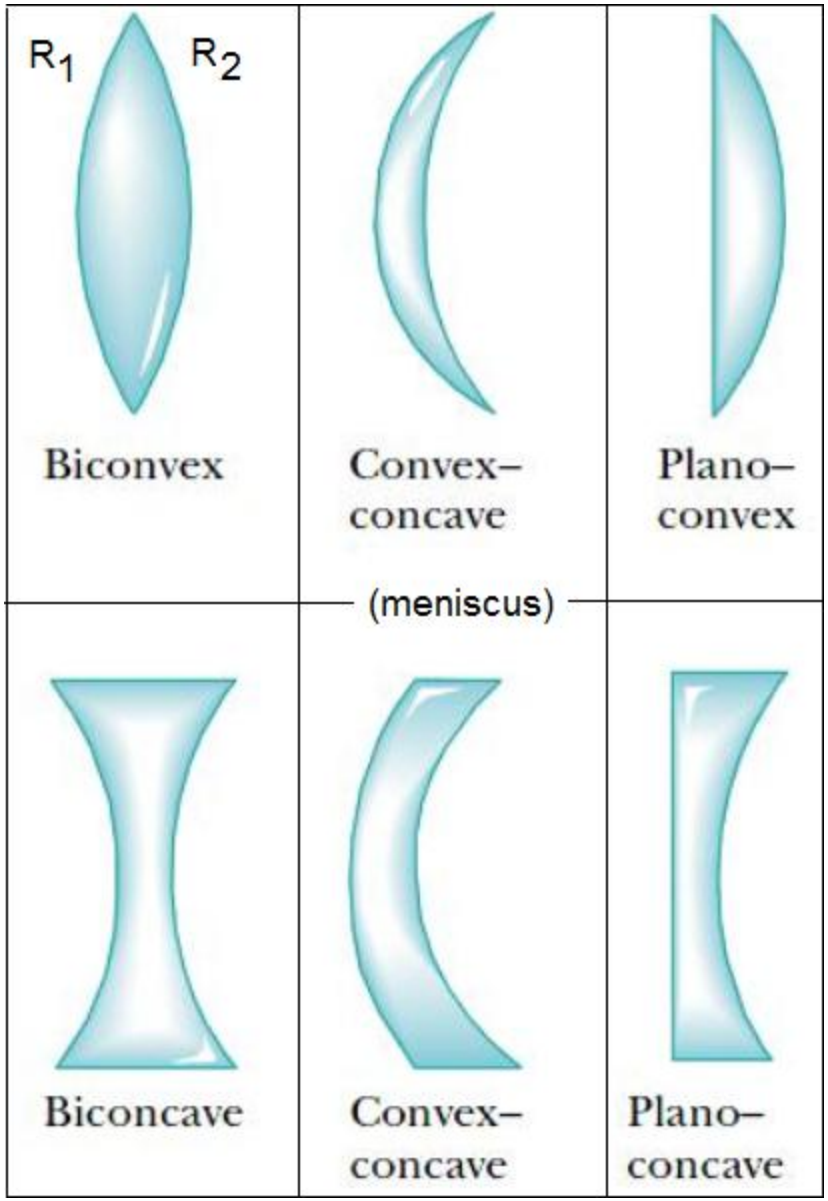
$$\frac{1}{f} = (n-1)[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)t}{nR_1R_2}]$$

This is the effective focal length of the lens.

Thin Lens Equivalent Pictures



Various Lens Shapes



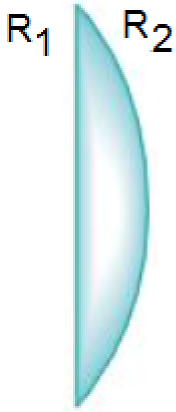
CONVEX	CONCAVE
$R_1 > 0$ $R_2 < 0$ Bi-convex	$R_1 < 0$ $R_2 > 0$ Bi-concave
$R_1 = \infty$ $R_2 < 0$ Planar convex	$R_1 - \infty$ $R_2 > 0$ Planar concave
$R_1 > 0$ $R_2 > 0$ Meniscus convex	$R_1 > 0$ $R_2 > 0$ Meniscus concave

$$\frac{1}{f} = (n-1)[\frac{1}{R_1} - \frac{1}{R_2}]$$

$$R_1 > 0 \text{ and } R_2 < 0$$

$$\frac{1}{R_1} - \frac{1}{R_2} > 0 \quad => \quad f > 0$$

Converging lens

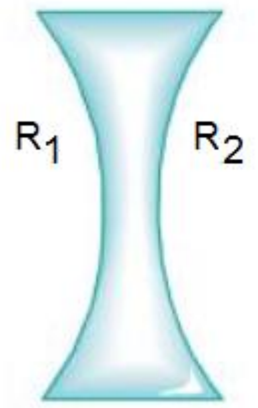


$$R_1 = \infty \text{ and } R_2 < 0$$

$$\frac{1}{R_1} - \frac{1}{R_2} > 0 \quad => \quad f > 0$$

Converging lens

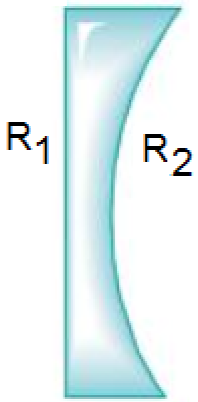
$$\frac{1}{f} = (n-1)[\frac{1}{R_1} - \frac{1}{R_2}]$$



$$R_1 < 0 \text{ and } R_2 > 0$$

$$\frac{1}{R_1} - \frac{1}{R_2} < 0 \quad => \quad f < 0$$

Diverging lens



$$R_1 = \infty \text{ and } R_2 > 0$$

$$\frac{1}{R_1} - \frac{1}{R_2} < 0 \quad => \quad f < 0$$

Diverging lens

Power of a Lens

Power (P) of a lens is defined by:

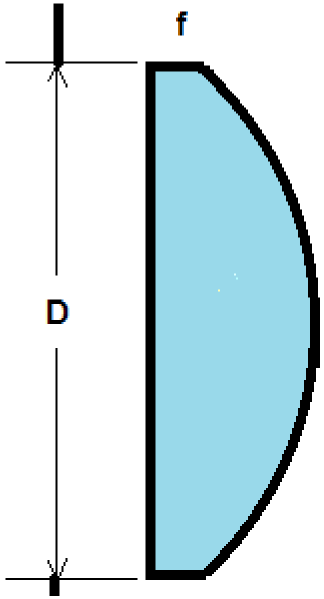
$$P = \frac{1}{f}$$

If focal length is measured in meter (m) then power is measured in Diopter (D)

$$1\ \text{D} = 1\ \text{m}^{-1}$$

This relationship is usually used by opticians.

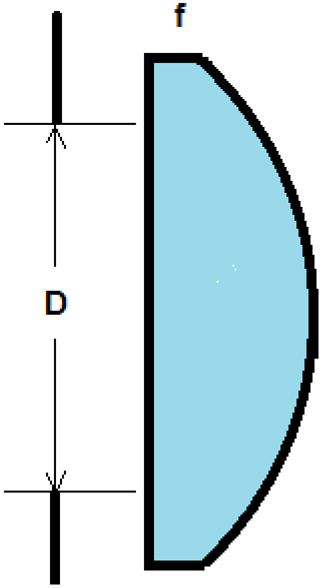
f-number



Aperture (D) is a hole or an opening through which light travels.

The ratio f/D is called the f-number (lens speed) of a lens:

$$f - \text{number} = \frac{f}{D}$$



f/4 means f-number = f/D = 4

Production of lenses

Show video …

Image Formation by lens

Focal length:

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

Magnification:

$$m = \frac{h_i}{h_o} = -\frac{q}{p}$$

Newton's equation:

$$f^2 = x_o x_i$$

x_o = distace between focus and object.

x_i = distance between focus and image.

```
f     + for converging lens
      - for diverging  lens

p     + for real     object
      - for virtual object

q     + for real     image
      - for virtual image
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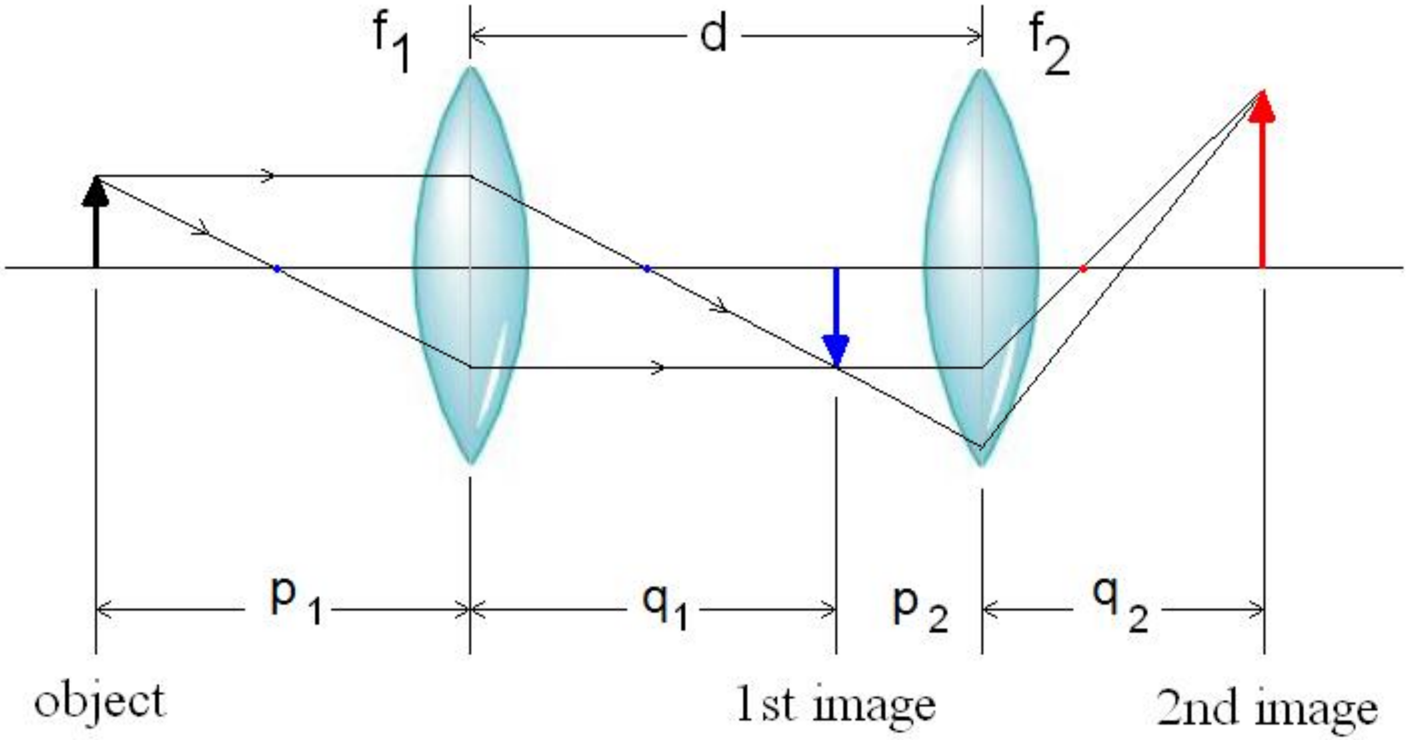
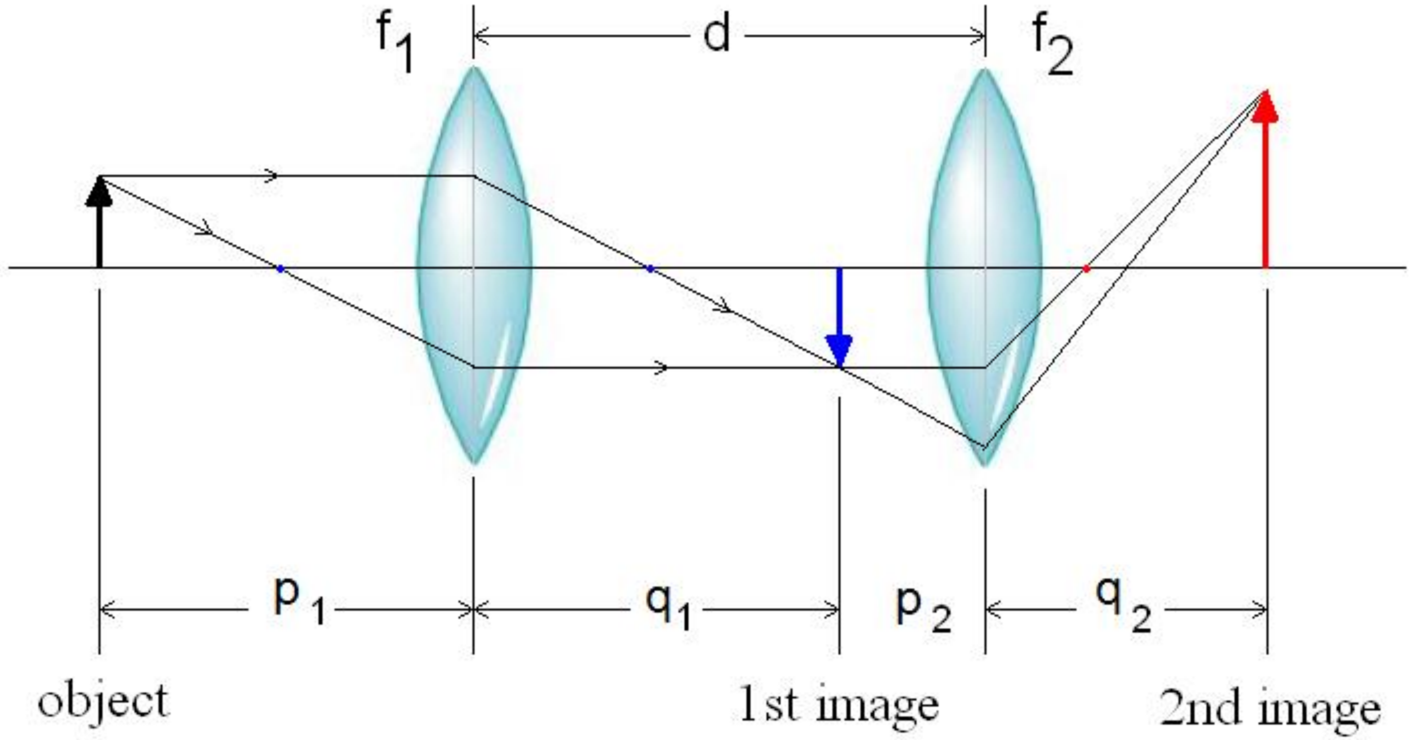
Lens Combinations



- Consider we have two thin lenses with common optical axis. They are seperated by distance *d* and their focal lengths are f_1 and f_2 respectively.
- The main idea of lens system is *image of an object obtained from first lens can be considered as an object for the second one*.
- These kind of lens system is used in many optical devises such as: Telescopes and microscopes.

Back Focal and Front Focal Lengths



$$m = m_1\, m_2$$

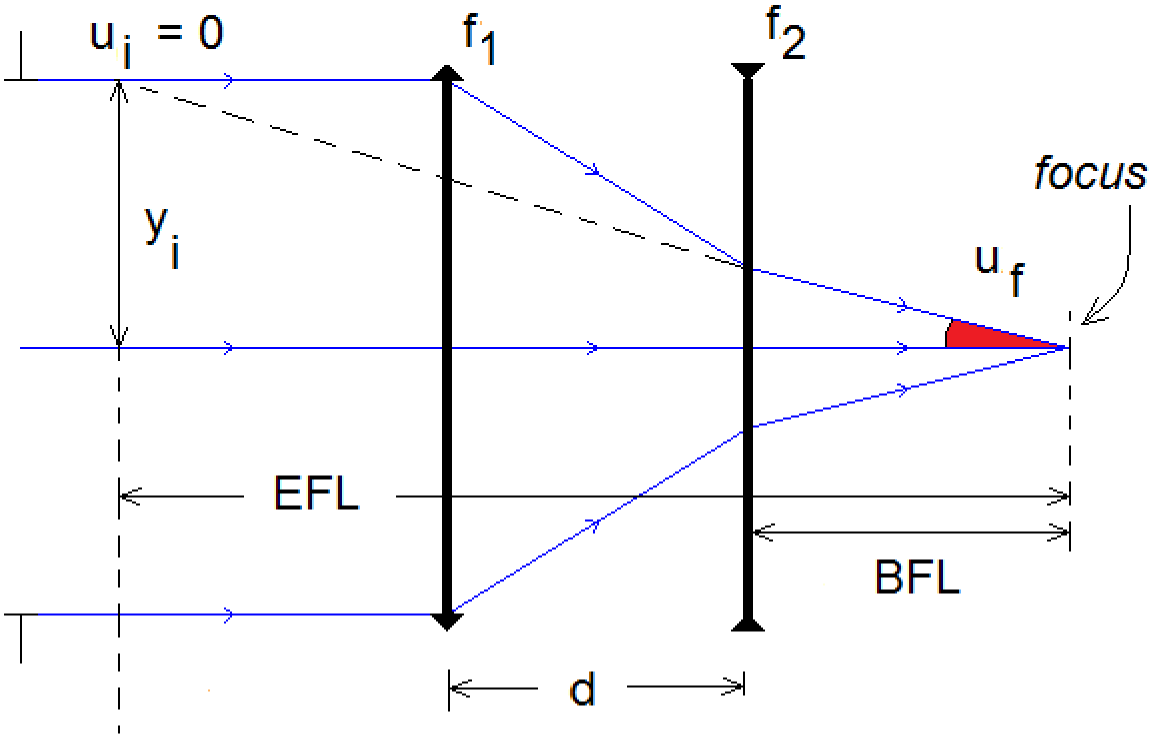
$$B.F.L = \frac{f_2(d - f_1)}{d - (f_1 + f_2)} \qquad F.F.L = \frac{f_1(d - f_2)}{d - (f_2 + f_1)}$$

EFL and BFL of an Optical System

EFL: Effective Focal Length is defined as

$$f = -\frac{y_i}{u_f}$$

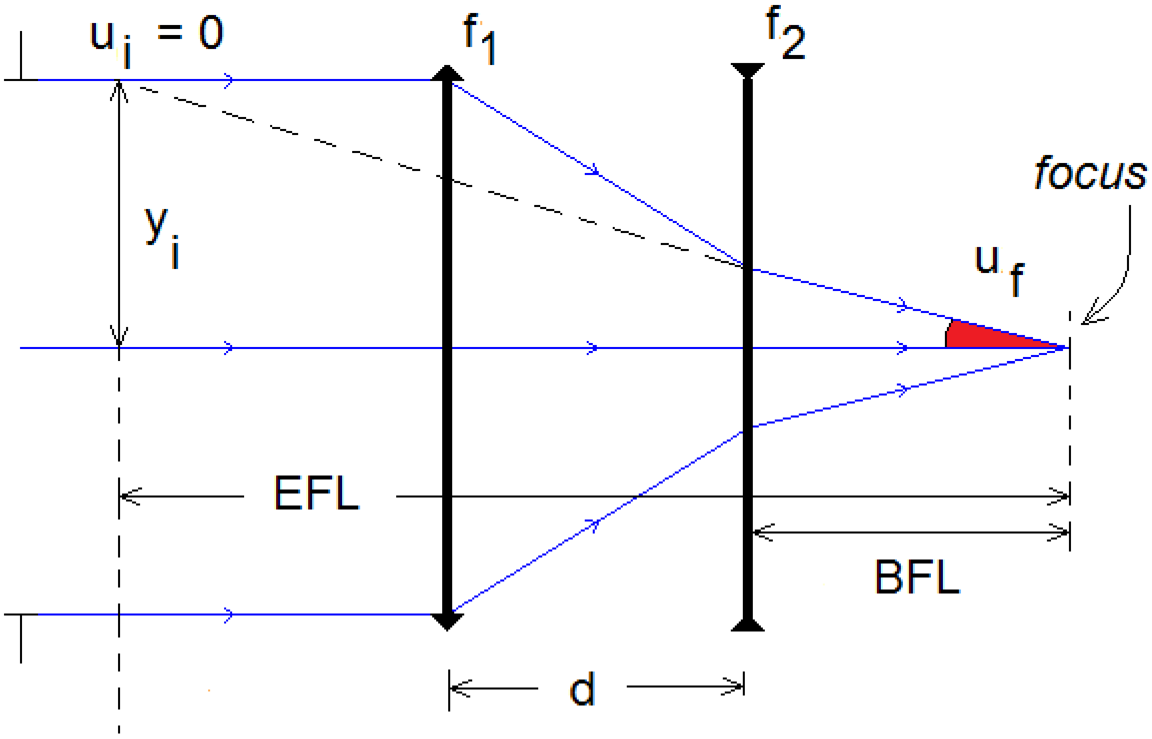
BFL: Back Focal Length (BFL) is the distance from the last element to focus.



EFL and BFL of an Optical System

For an optical system containing two lenses

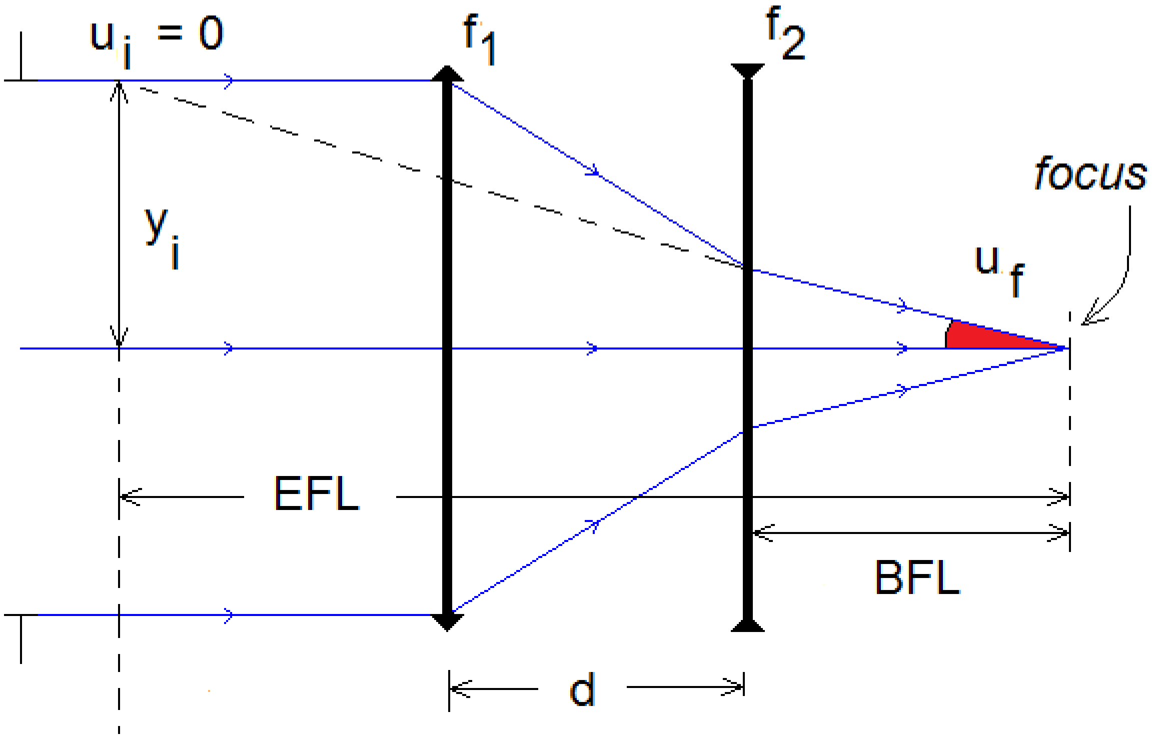
$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} \qquad B.F.L = \frac{f_2(d - f_1)}{d - (f_1 + f_2)}$$



EFL and BFL of an Optical System

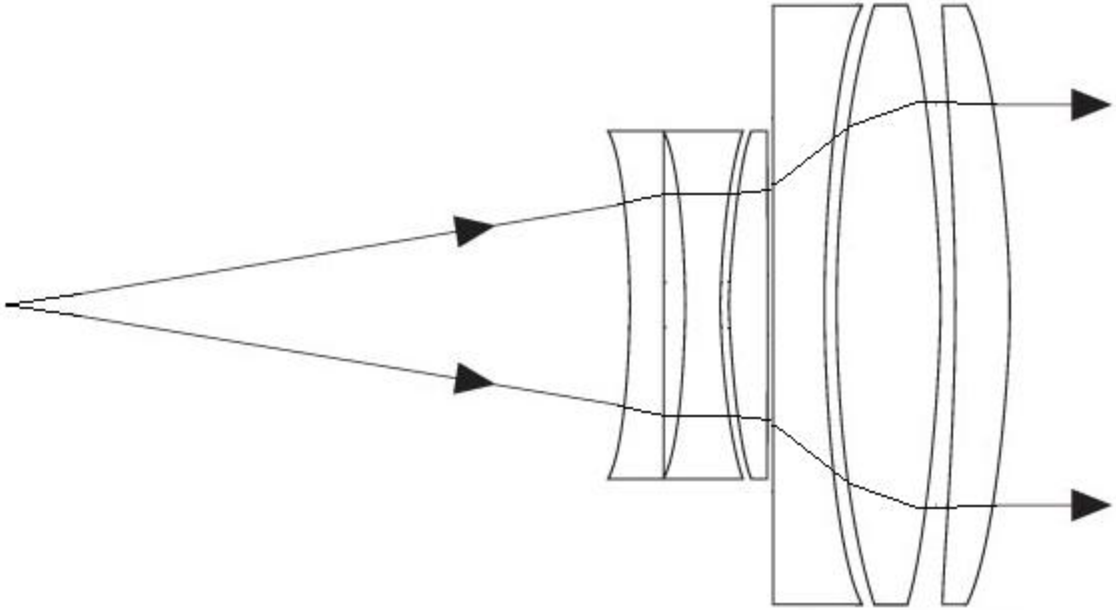
Figure below shows a telephoto lens system.

Calculate effective focal length and back focal length of the system if f_1 = 20 mm, f_2 = -10 mm and d = 14 mm.



Lens Combinations

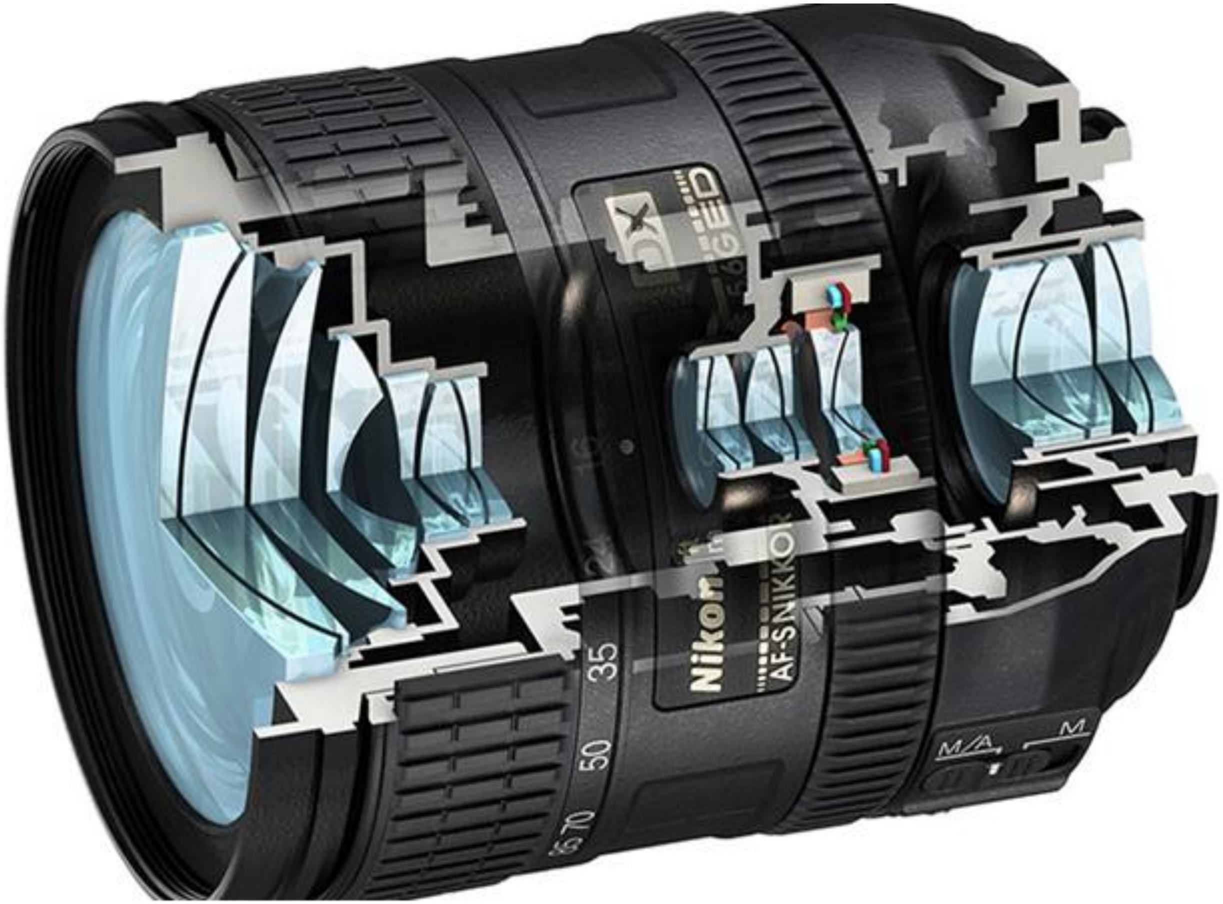
For *n* lens in contact:



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

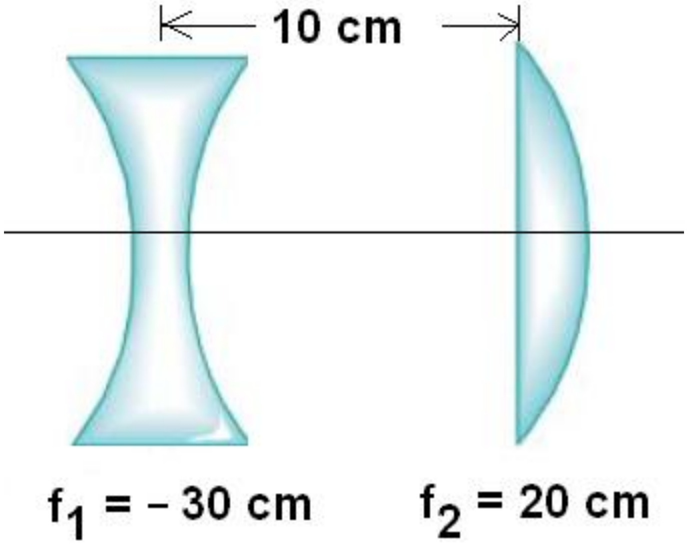
$$m = m_1\, m_2 \cdots m_n$$

A Camera Lens System



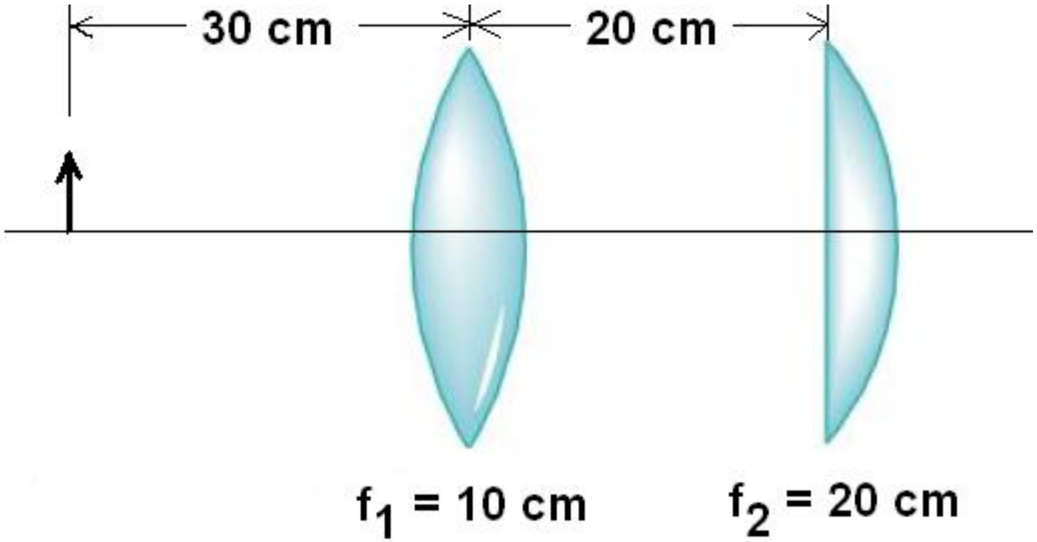
Example

Find the BFL and FFL of the lens system.



Example

Find the position and magnification of the final image produced by the given lens system.

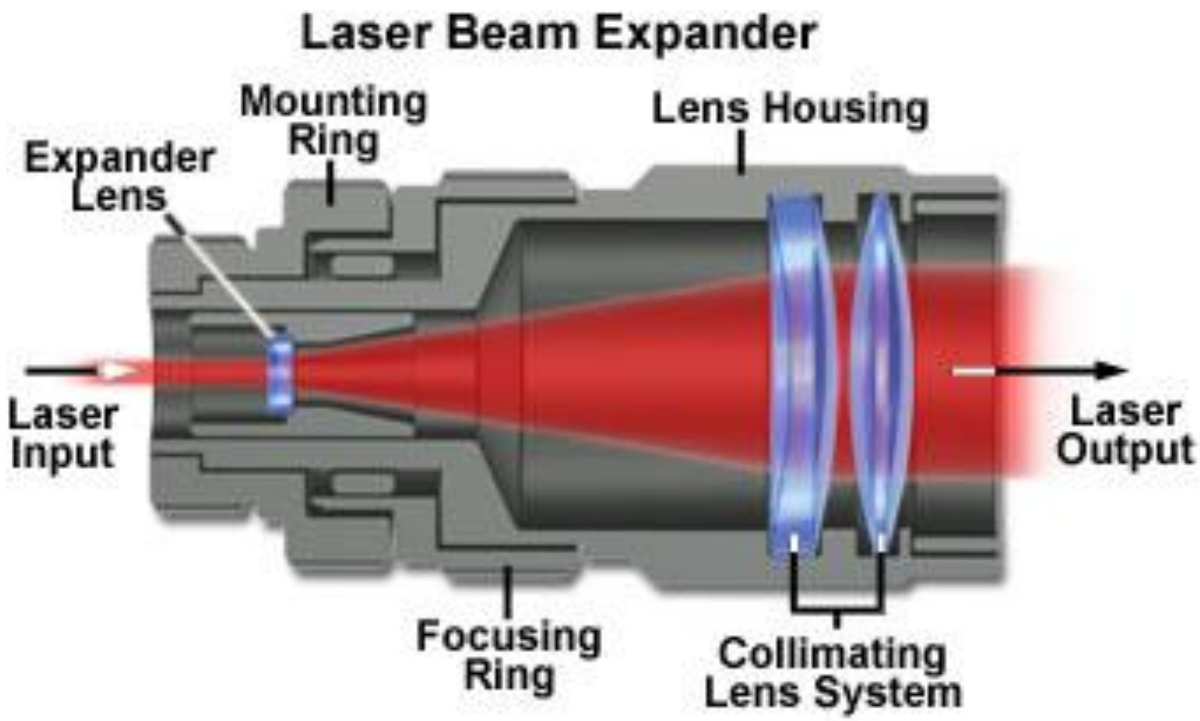


Exercise

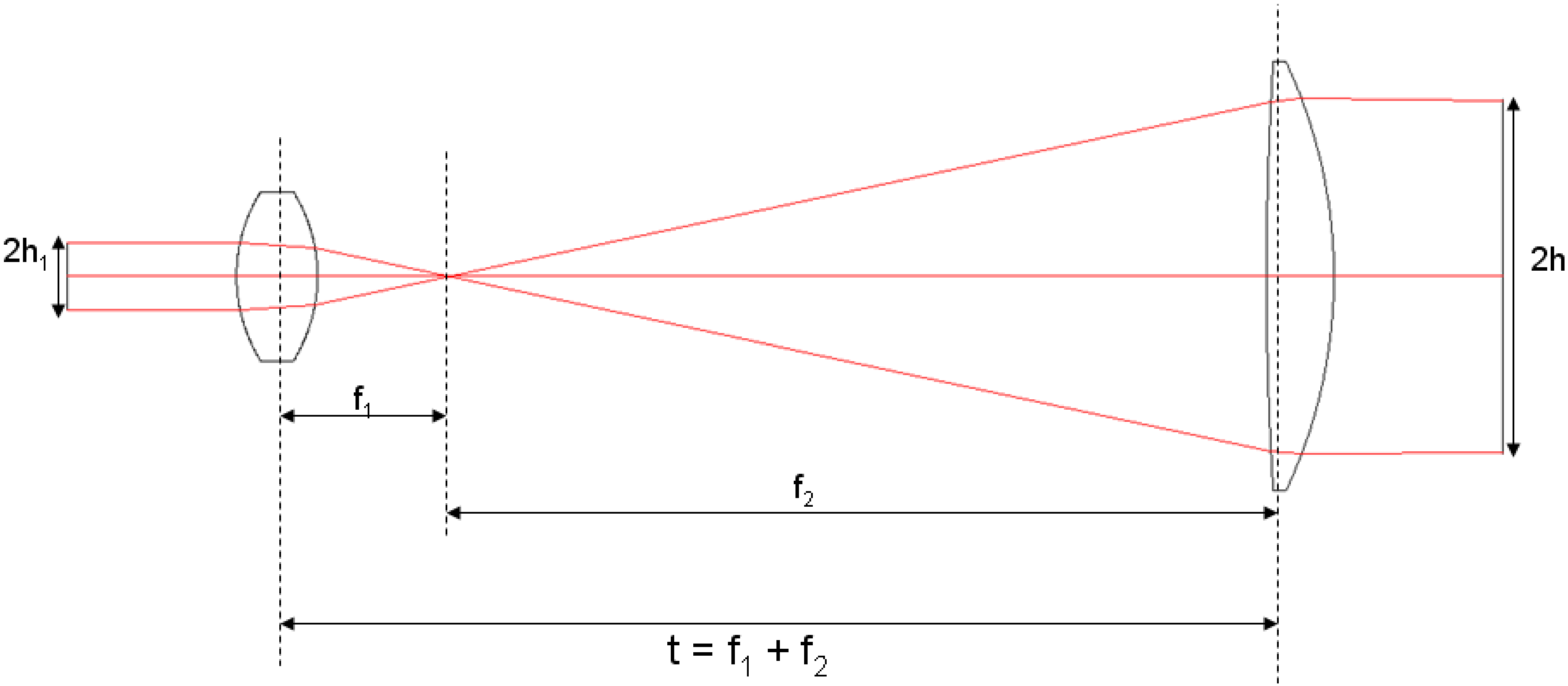
What component powers are necessary in a two-element lens system if one requires a 20-cm focal length, a 10-cm back focus, and a 5-cm air space?

Beam Expander

Beam expansion or reduction is a common application requirement in most labs using lasers.

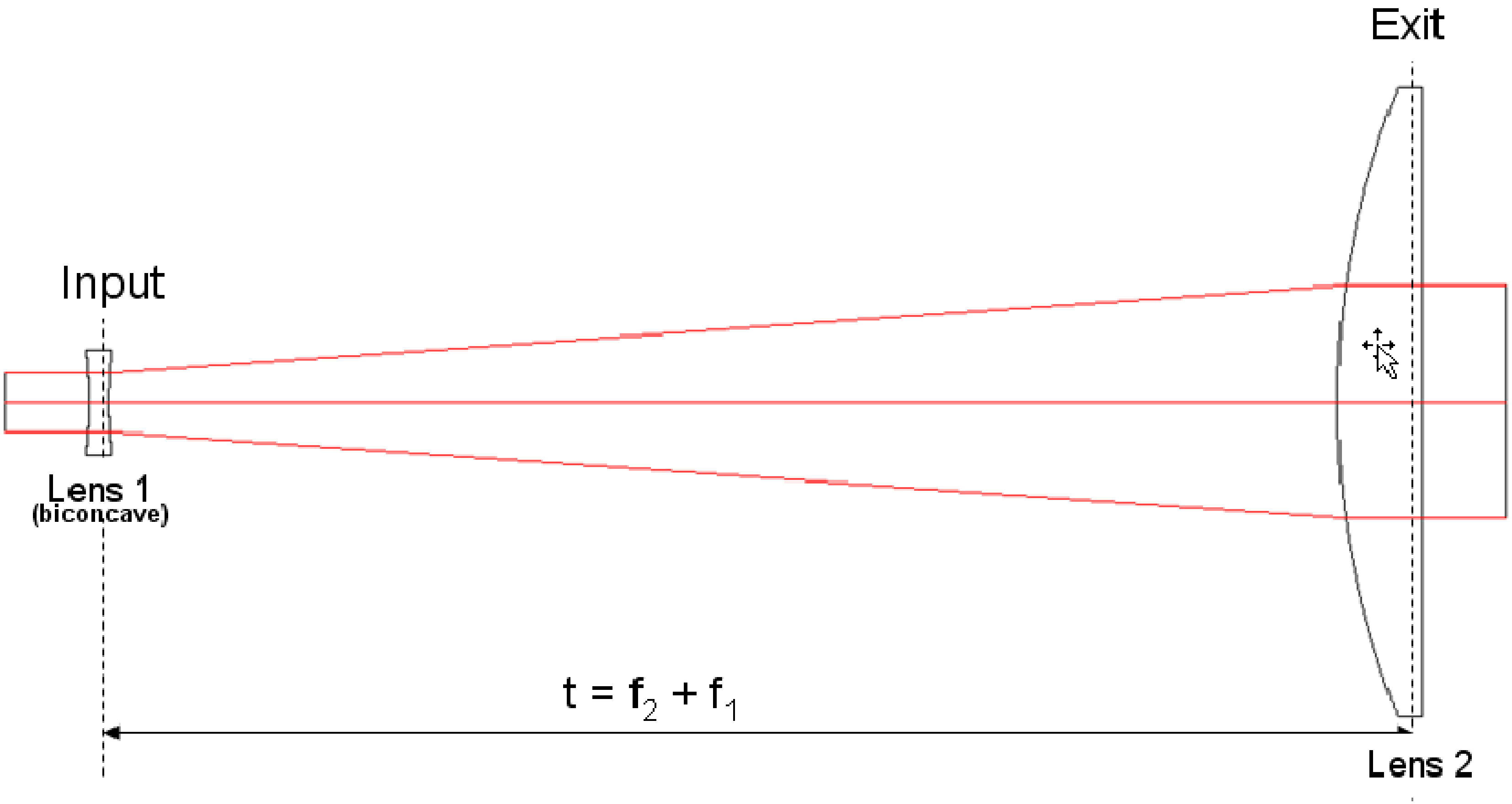


Keplerian Beam Expander (Telescope)



$$m = f_2/f_1 = R_2/R_1 = h_2/h_1$$

Galilean Beam Expander (Telescope)



$$m = -f_2/f_1$$

Exercise

You have two set of spherical eye-glasses whose powers are ranging from ±0.25 D to ±3.00 D, namely

P1 = {−3.00, −2.75, −2.50, ..., −0.50, −0.25}

P2 = {+3.00, +2.75, +.2.50, ..., +0.50, +0.25}

Design a 5x beam expander by using the lenses form these two sets.