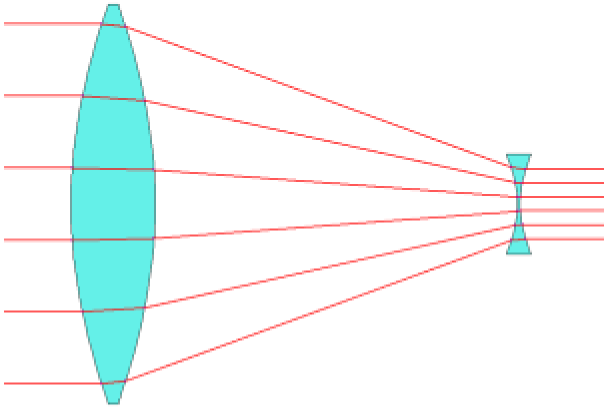
EP 324
Applied Optics

Topic 3

Lenses



Department of

Engineering of Physics

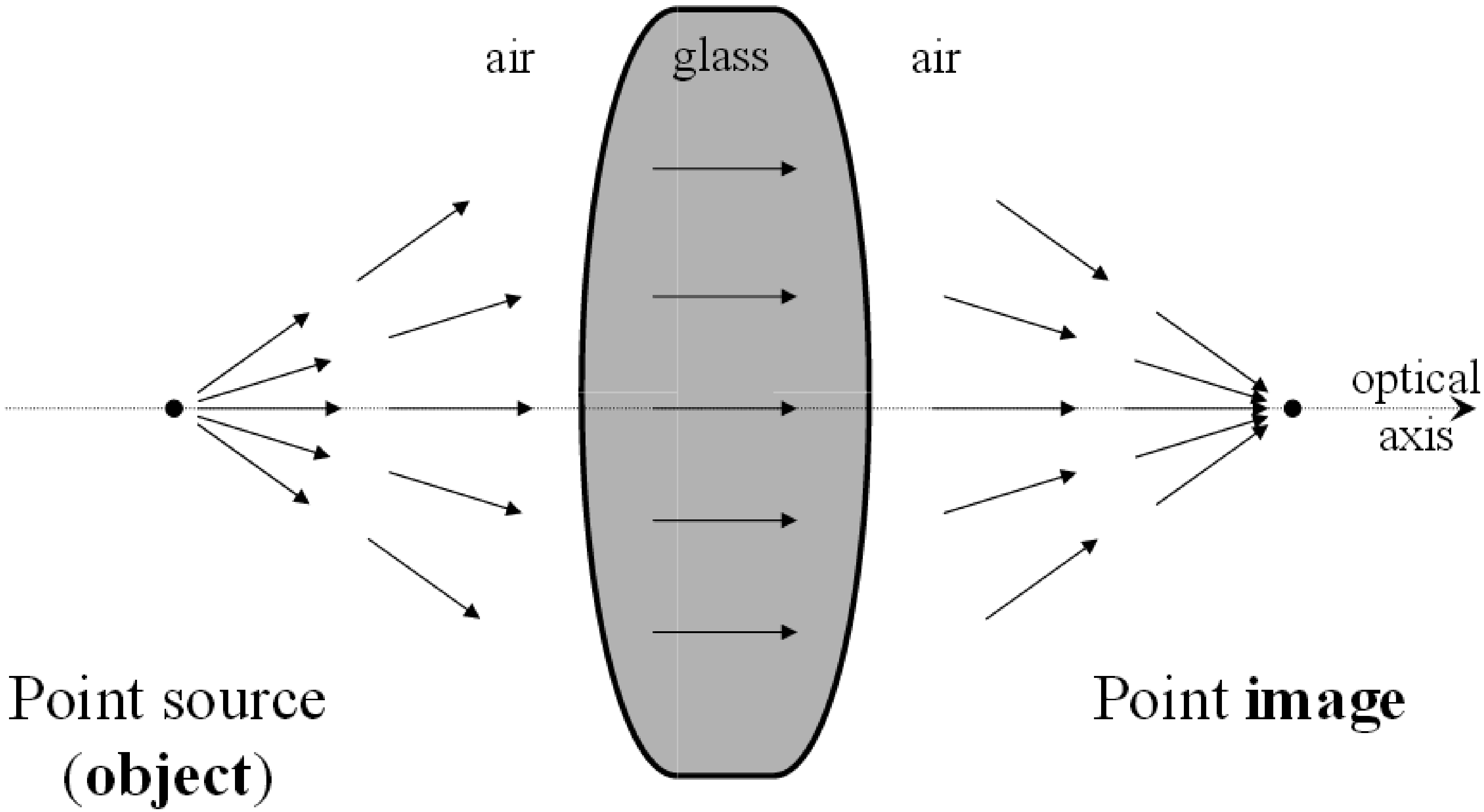
Gazíantep University

Oct 2015

PART I

SPHERICAL LENSES

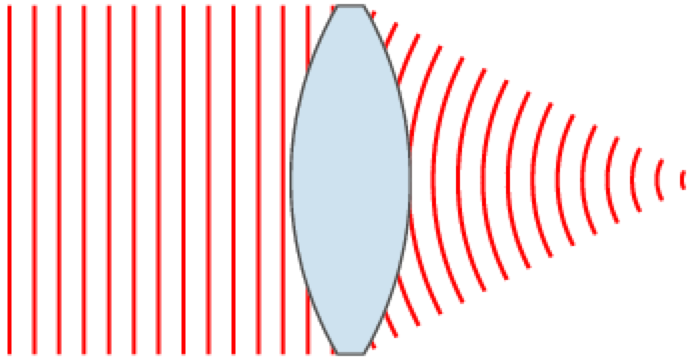
Lens: *The main instrument for image formation*



The curved surface makes the rays bend proportionally to their distance from the "optical axis", according to Snell's law. Therefore, the divergent wavefront becomes convergent at the right-hand (output) side.

Lens

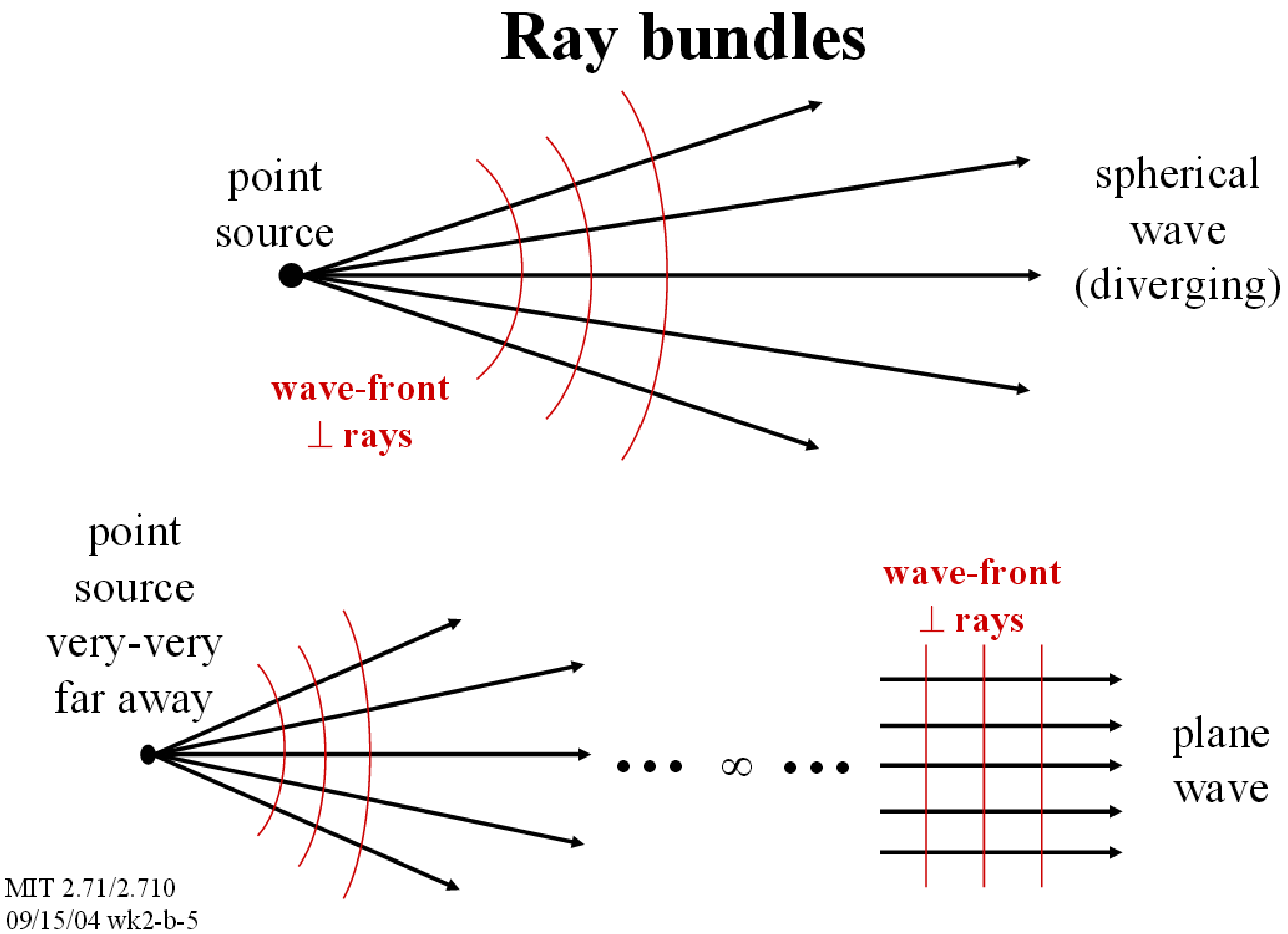
A lens transmits and refracts light, converging or diverging the beam.



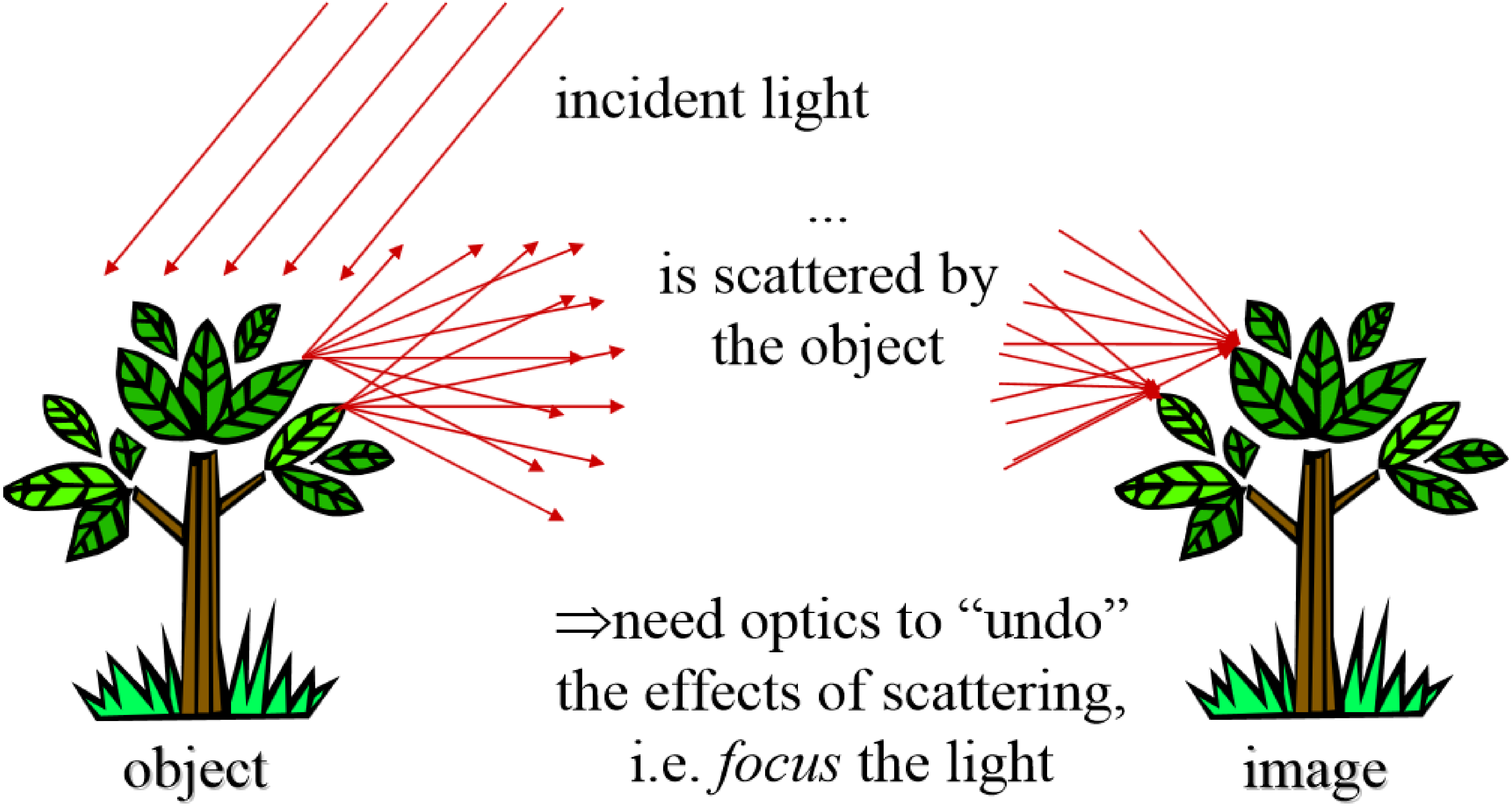
The word lens comes from the Latin name of the lentil, because a double-convex lens is lentil-shaped.

The oldest lens artifact is the Nimrud lens **==>**
(dating back 2700 years to ancient Assyria)

We need focusing elements



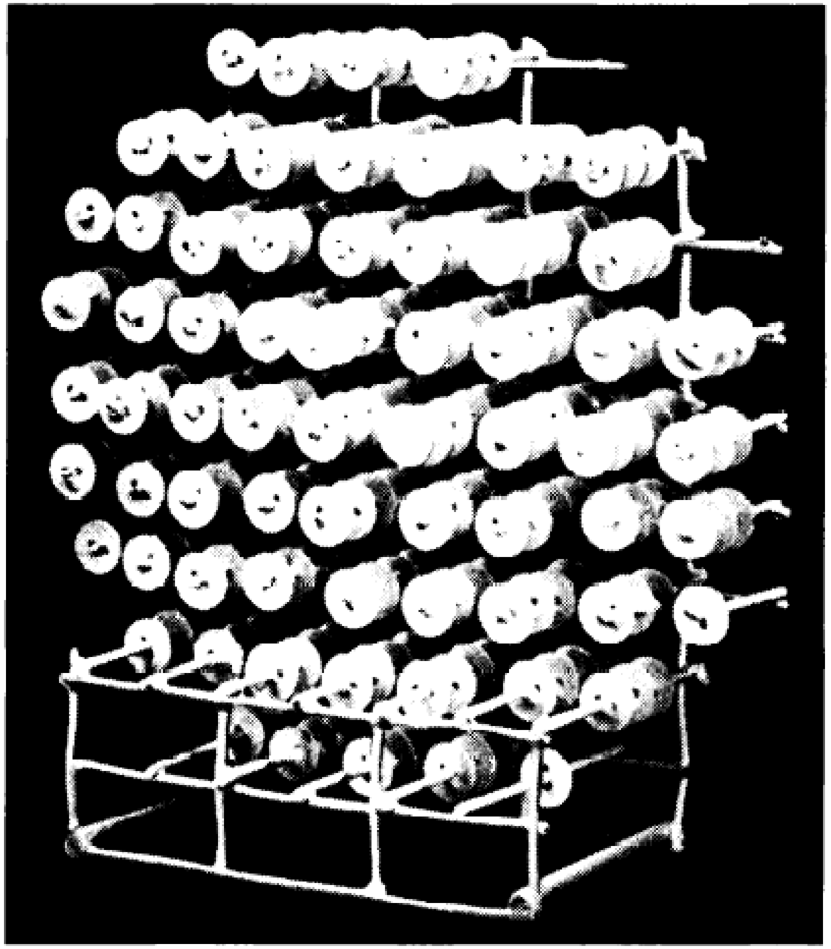
Why are focusing instruments necessary?



Lenses

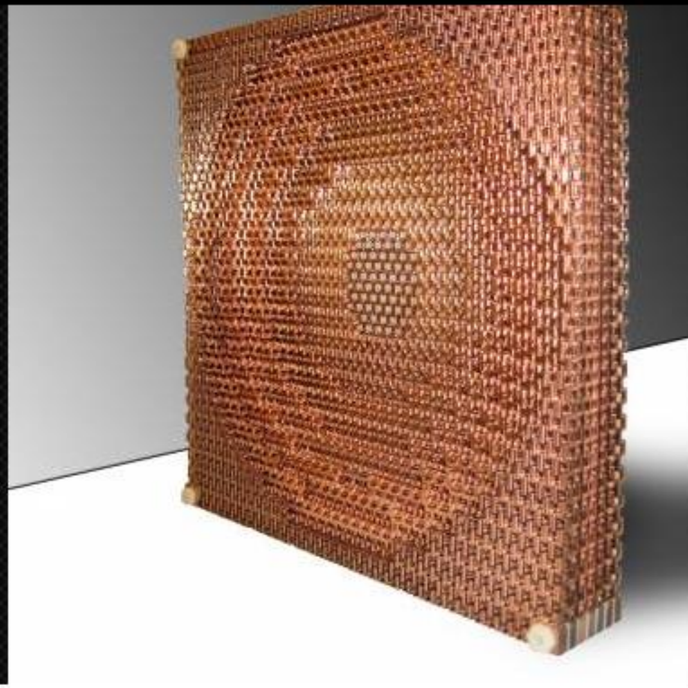
Lenses are made in a wide range of forms.

- Acoustic lens
- Microwave lens
- Glass / Plastic lens



A short-wavelegth radiowave lens

MIT News Browse or Search



The orientation of 4,000 S-shaped units forms a metamaterial lens that focuses radio waves with extreme precision, and very little energy lost.

Photo: Dylan Erb

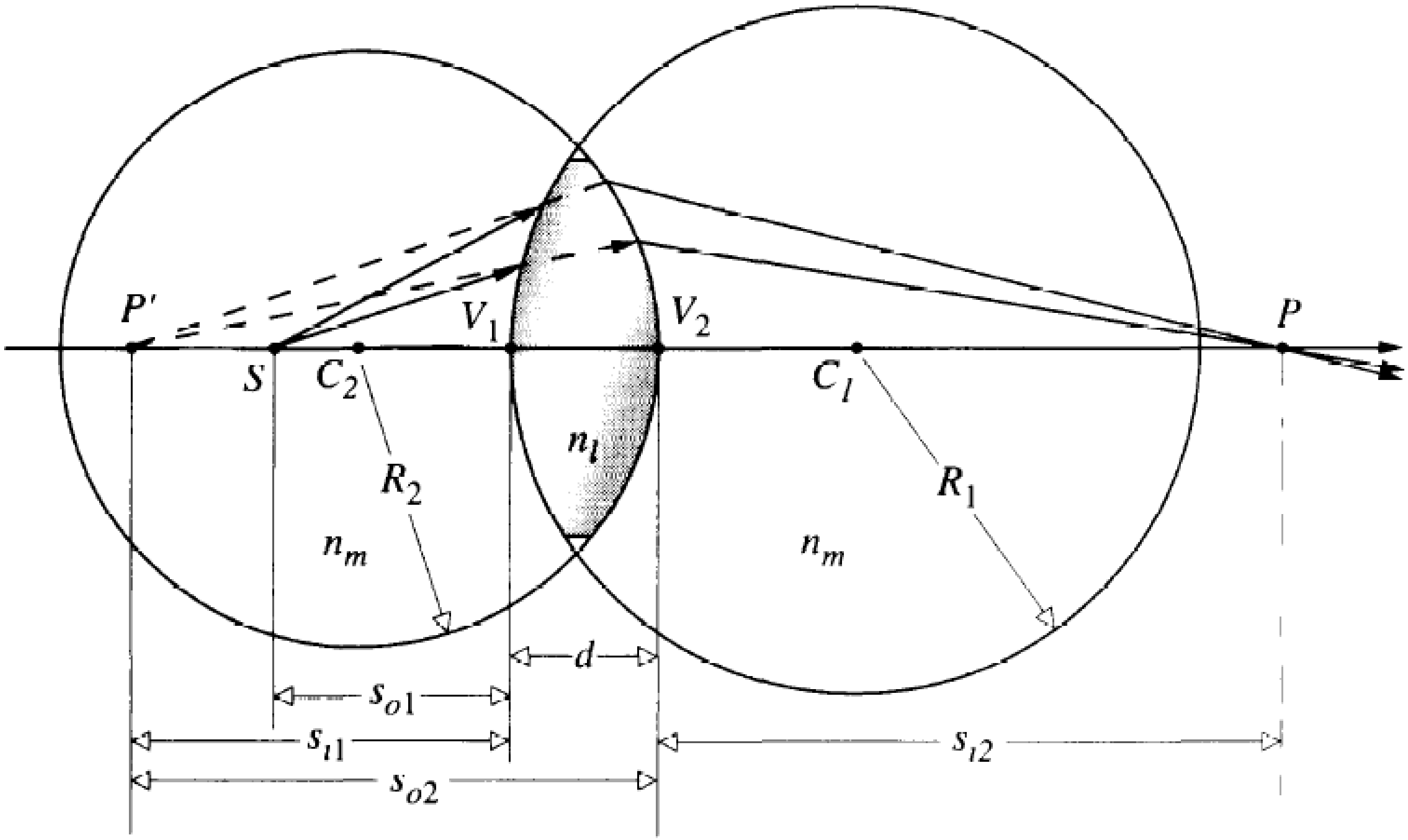
New metamaterial lens focuses radio waves

Device could improve satellite and molecular imaging.

Jennifer Chu, MIT News Office
November 14, 2012

http://newsoffice.mit.edu/2012/new-metamaterial-lens-focuses-radio-waves-1114

Spherical Thin Lenses



Lensmaker's Formula (Thin lens)

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$

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

Lensmaker's Formula (General)

In any medium

$$\frac{1}{f}=(\frac{n_l-n_m}{n_m})[\frac{1}{R_1}-\frac{1}{R_2}+\frac{(n_l-1)d}{n_l R_1 R_2}]$$

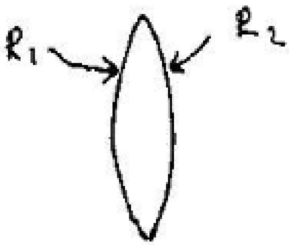
In air:

$$\frac{1}{f}=(n-1)[\frac{1}{R_1}-\frac{1}{R_2}+\frac{(n-1)d}{nR_1 R_2}]$$

d: is the cernver thickness of the lens

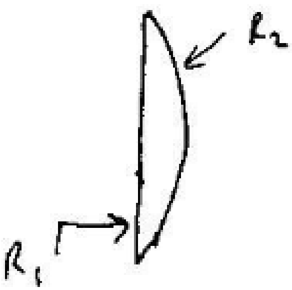
Lensmaker's Formula (in air)

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



$R_1 > 0$ and $R_2 < 0$

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



$R_1 = \infty$

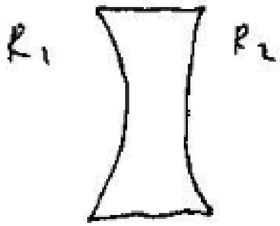
$R_2 < 0$

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

converging lens

Lensmaker's Formula (in air)

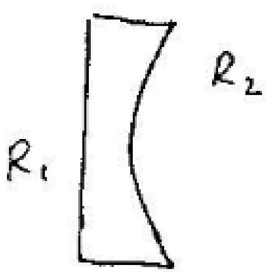
$$\frac{1}{f}=(n-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$



$R_1 < 0$

$R_2 > 0$

$\frac{1}{R_1} - \frac{1}{R_2} < 0 \Rightarrow f < 0$



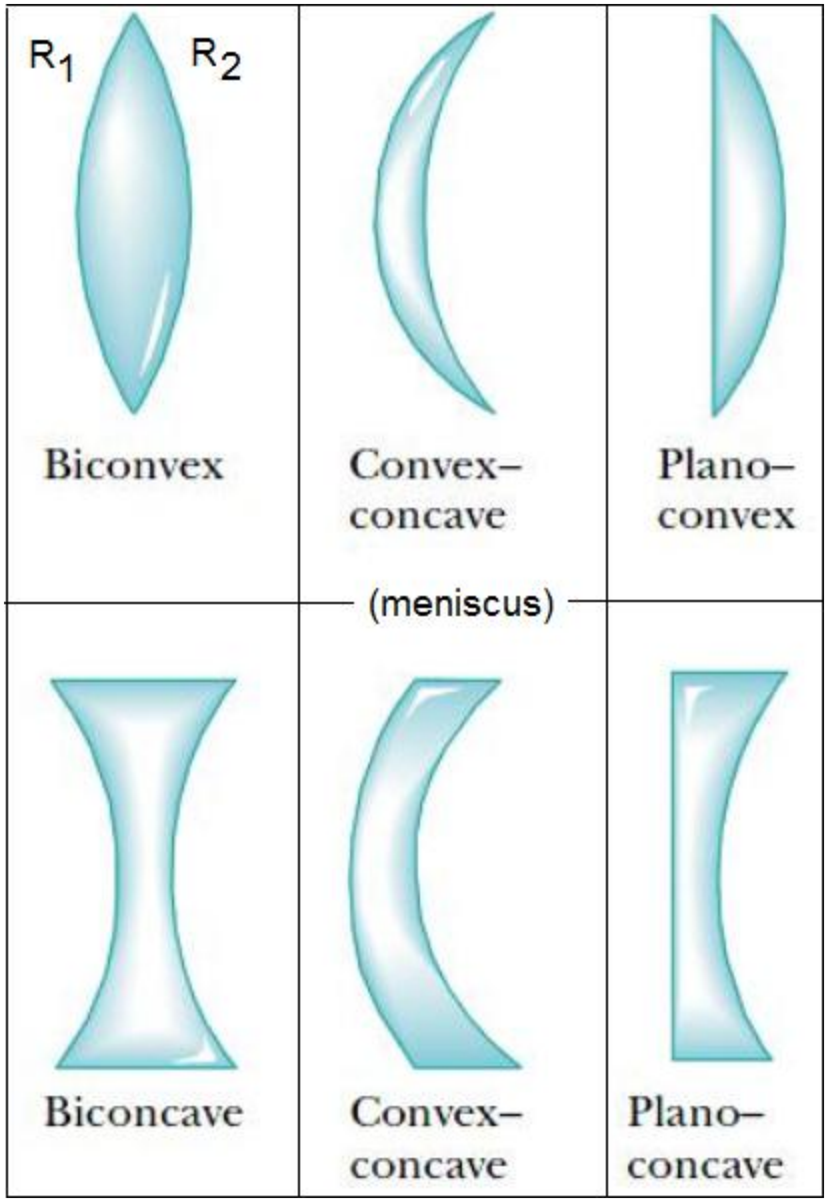
$R_1 = \infty$

$R_2 > 0$

$\frac{1}{R_1} - \frac{1}{R_2} < 0 \Rightarrow f < 0$

diverging lens

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

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.

Example

A biconvex lens of 50 mm focal length is to be made of a glass (n=1.52). One radius of curvature is to be twice that of the other. What is the two radius of curvatures? Ans: [39mm, -78mm]

Example

A contact lens is made of plastic with index of refraction n = 1.5. The lens has an outer radius R1 = +2.0 cm and inner radius of curvature R2 = +2.5 cm. Find the focal length and the power of the lens

(a) in air

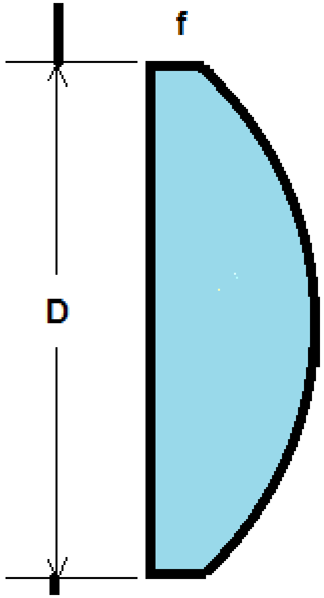
(b) in water (n_{water} = 1.33).

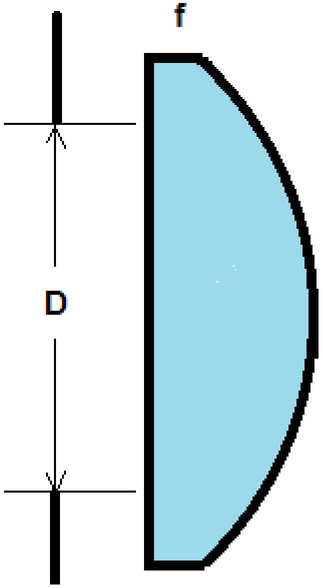
f-number

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

Example

Figure shows a plano-convex spherical lens made of a glass whose index of refraction is *n*.

D = diameter (maximum aperture) of the lens

d = central thickness

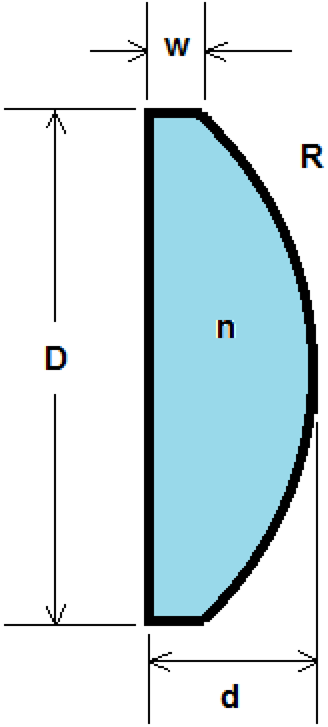
w = width of the edge

(a) Explain why we need an edge in application

(b) Determine the radius of curvature (R)

(c) Determine the paraxial focal length (f)

(d) Determine f-number of the of the lens (f/#).



Construction of simple lenses

Show video …

Temperature Effect

index of refraction is a function of the wavelength.

index of refraction is a function of the temperature.

- Glass expands/contracts => focal length changes
- Mechanical holders expands/contracts
- It is important to account for the other effects when the temperature change is more than 40 degrees.

Image Formation by lens

Focal length:

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$

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

So    + for real     object
      - for virtual object

Si    + for real     image
      - for virtual image
```

Magnification:

$$m = \frac{h_i}{h_o} = -\frac{s_i}{s_o}$$

Newton’s equation:

$$f^2 = x_o x_i$$

x_o = distace between focus and object.

x_i = distance between focus and image.

Example

A converging lens has a focal length of f = +20 cm.

Find the position and magnification of an object at a distance

(a) 50 cm and (b) 10 cm froma the lens.

[Ans: (a) si = 33.33 cm, m = -0.66, image is real, inverted and smaller.

(b)si = -20.00 cm, m = +2.00, image is virtual, upright and larger].

Example

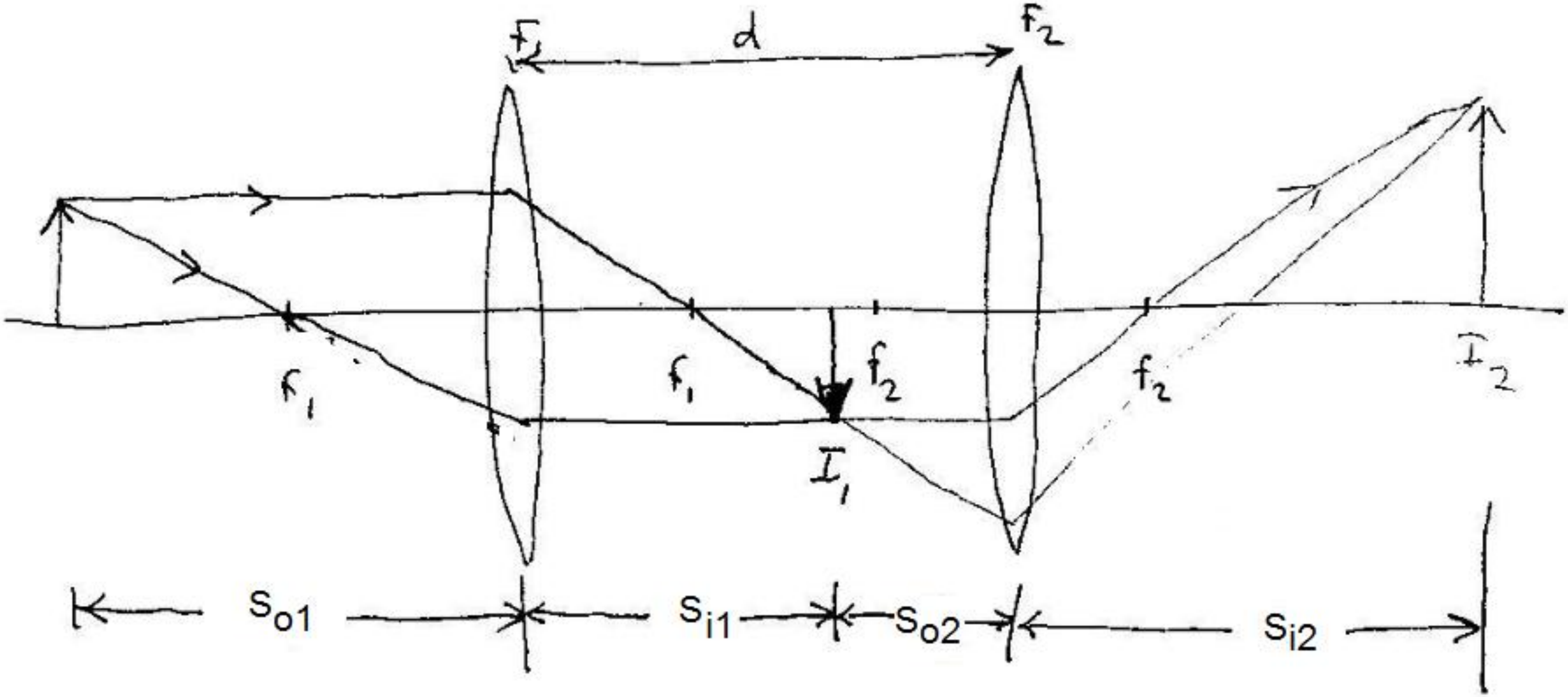
A plano concave lens has an index of refraction n = 1.5.

The radius of spherical face is R = 30 cm.

(a) Find the focal length. [Ans: -60 cm]

(b) Find the image position if s_o = 150 cm. [Ans: -42.9 cm, m = +0,286]

Lens Combinations

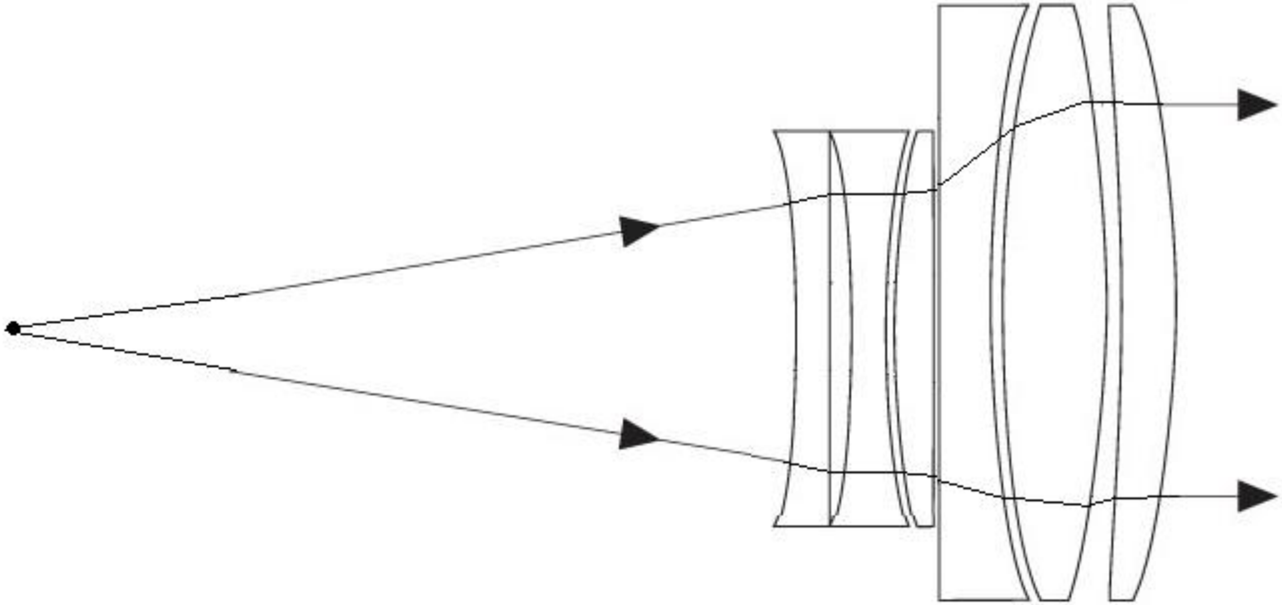


$$m = m_1\, m_2$$

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

Lens Combinations

For *n* lens in contact:



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

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

Example

Find the

BFL (Back Focal Length) and

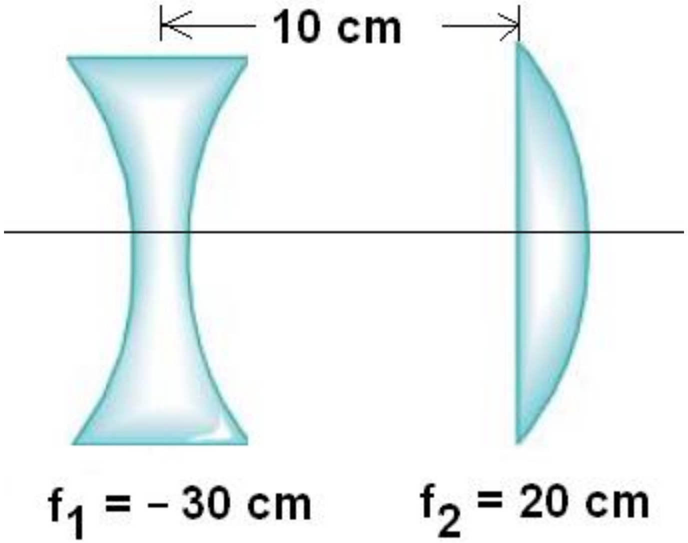
FFL (Front Focal Length)

of the lens system.

Ans:

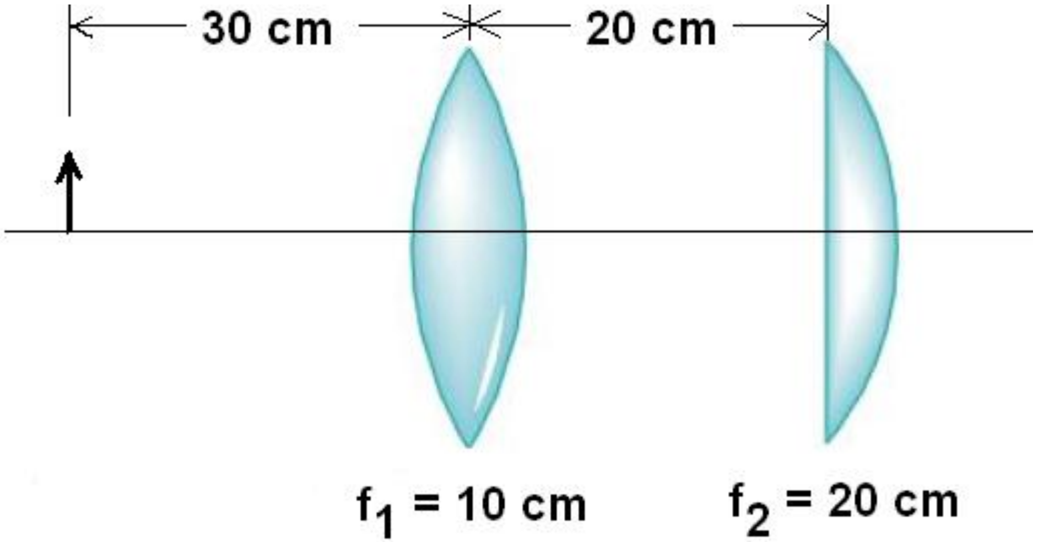
BFL = +40.0 cm.

FFL = +10.0 cm



Example

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

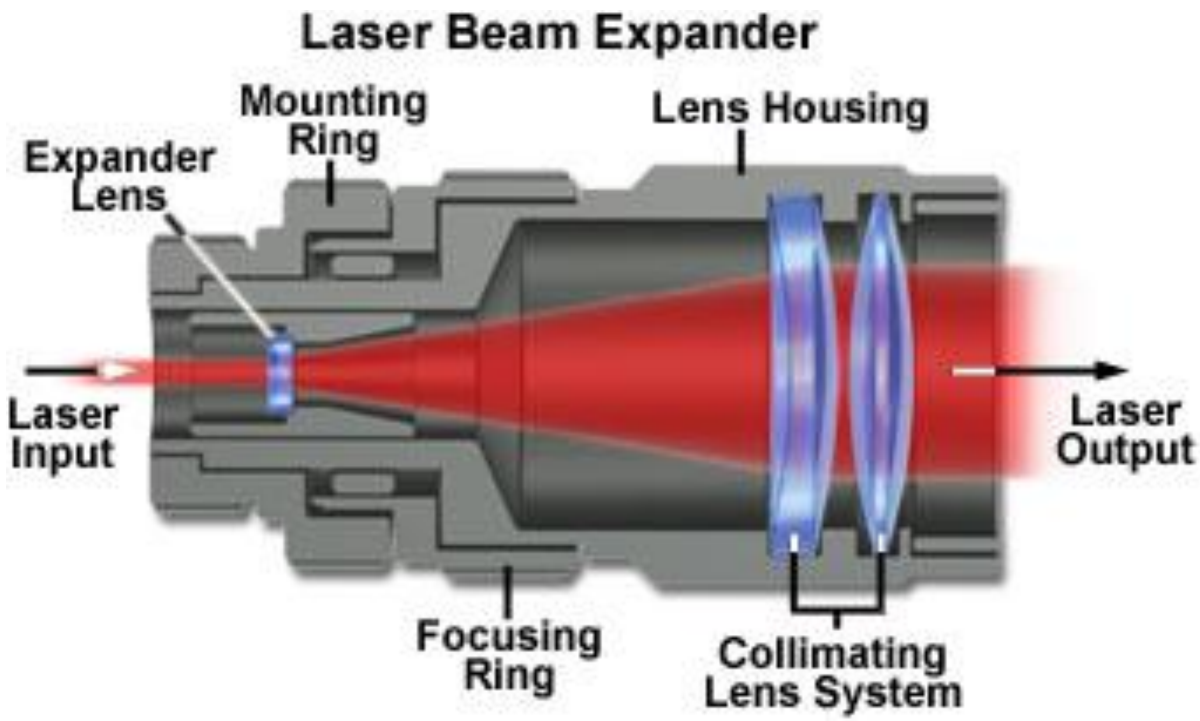


Ans:

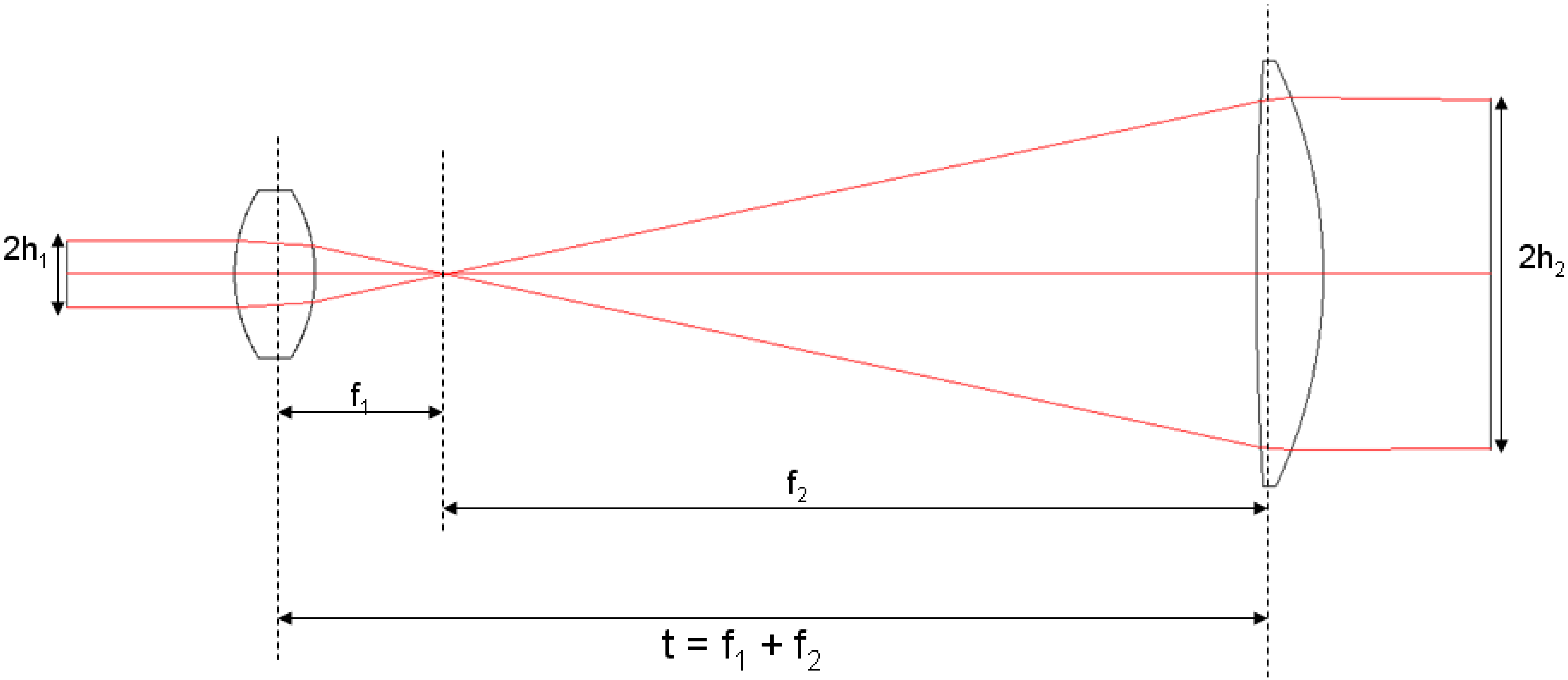
* S_{i2} = - 16.67 cm
  from the second lens.
* $m = m_1 \times m_2 = -0.67$

Beam Expander

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

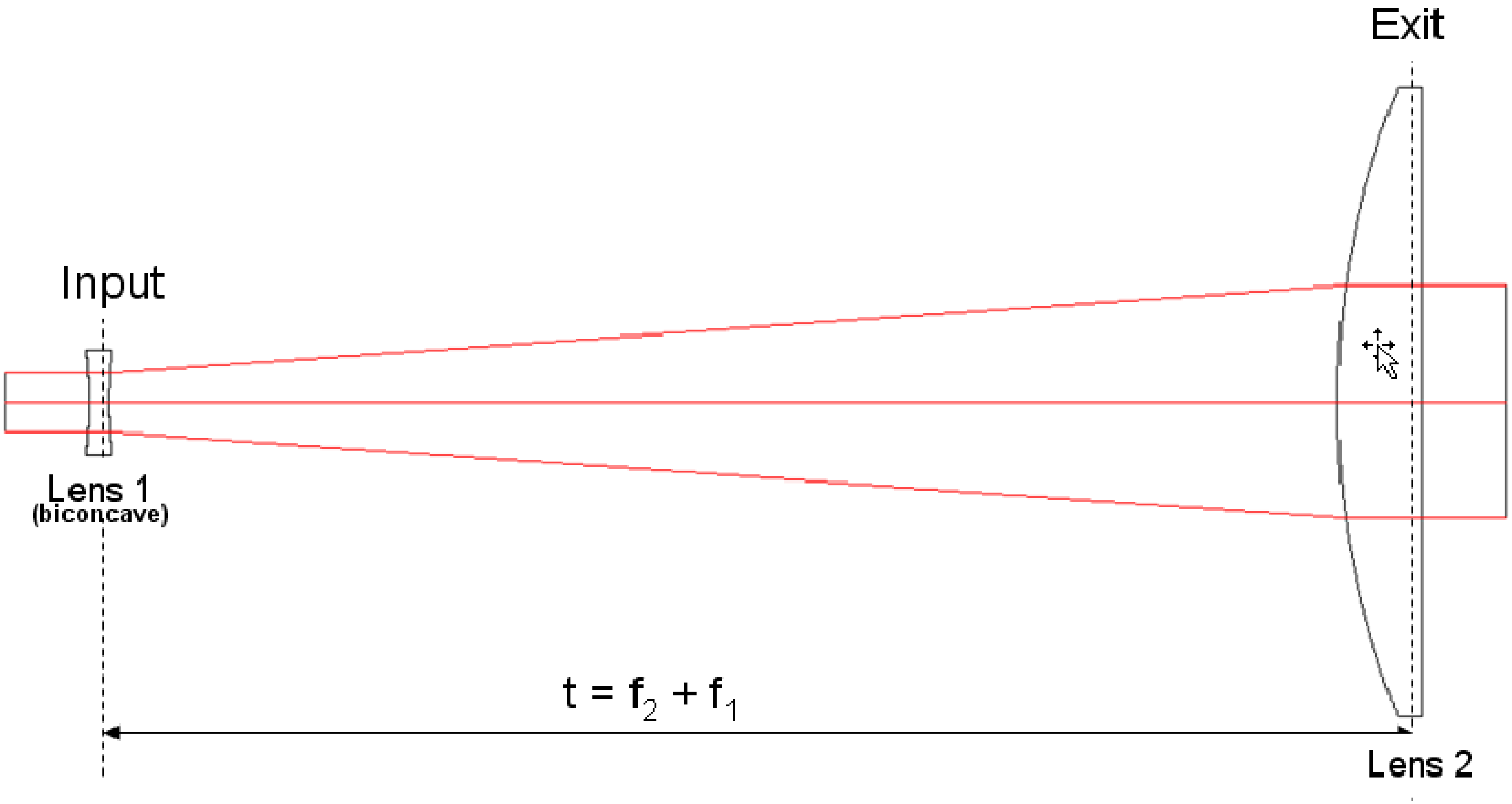


Keplerian Beam Expander (Telescope)



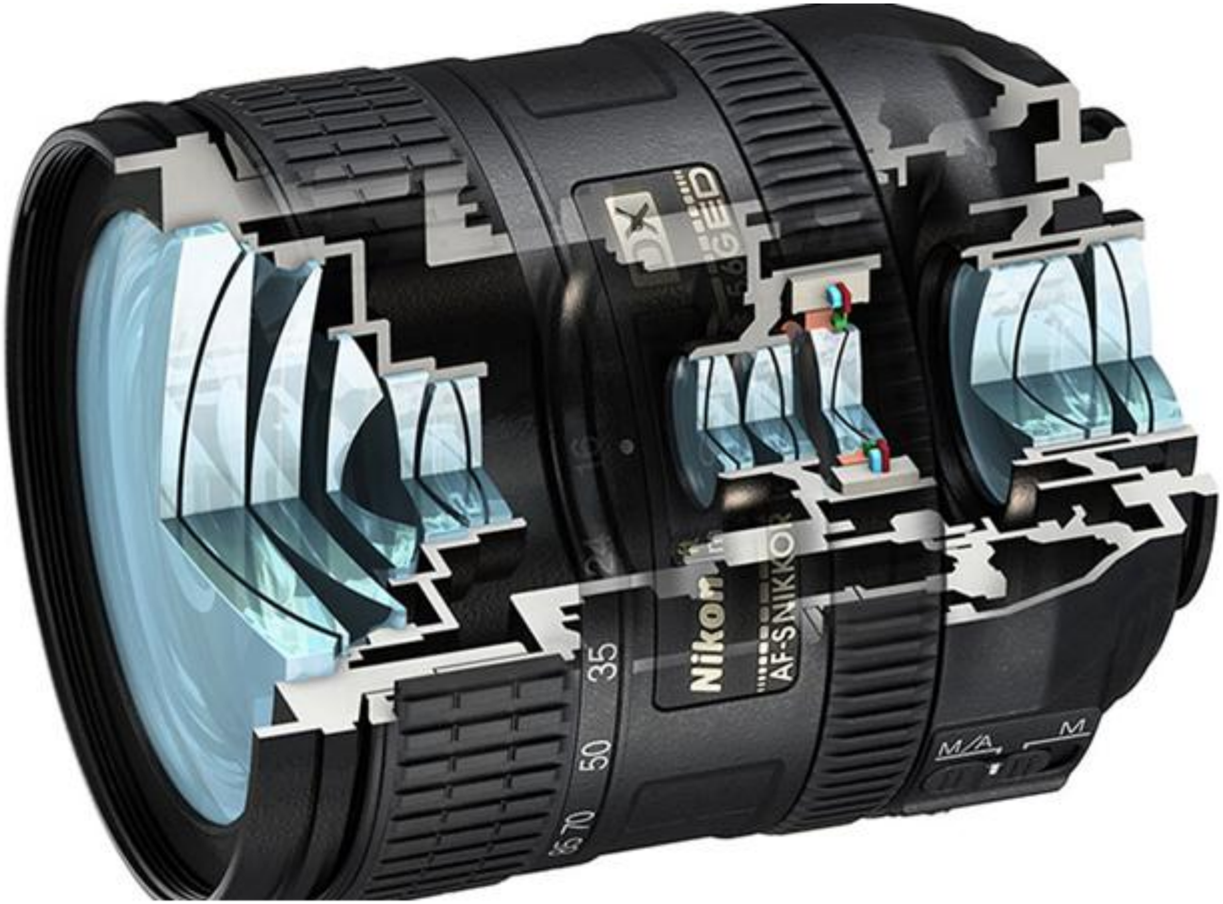
$$m = f_2/f_1 = R_2/R_1 = h_2/h_1$$

Galilean Beam Expander (Telescope)



$$m = -f_2/f_1$$

A Camera Lens System

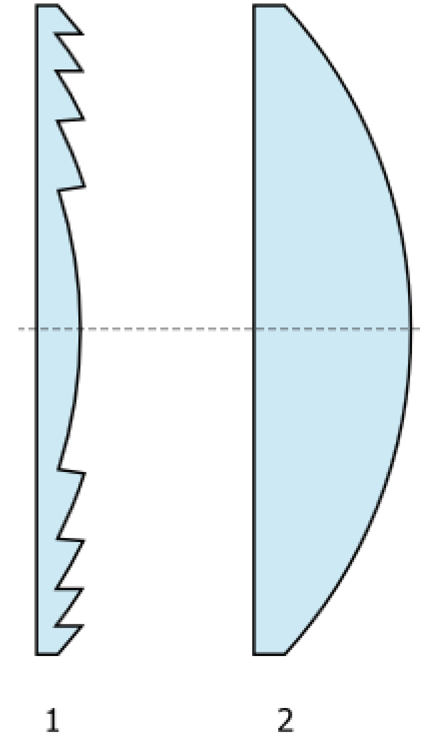


PART II
FRESNEL LENS

Fresnel Lens

A Fresnel lens is a type of compact lens originally developed by Augustin-Jean Fresnel for lighthouses in 1822.

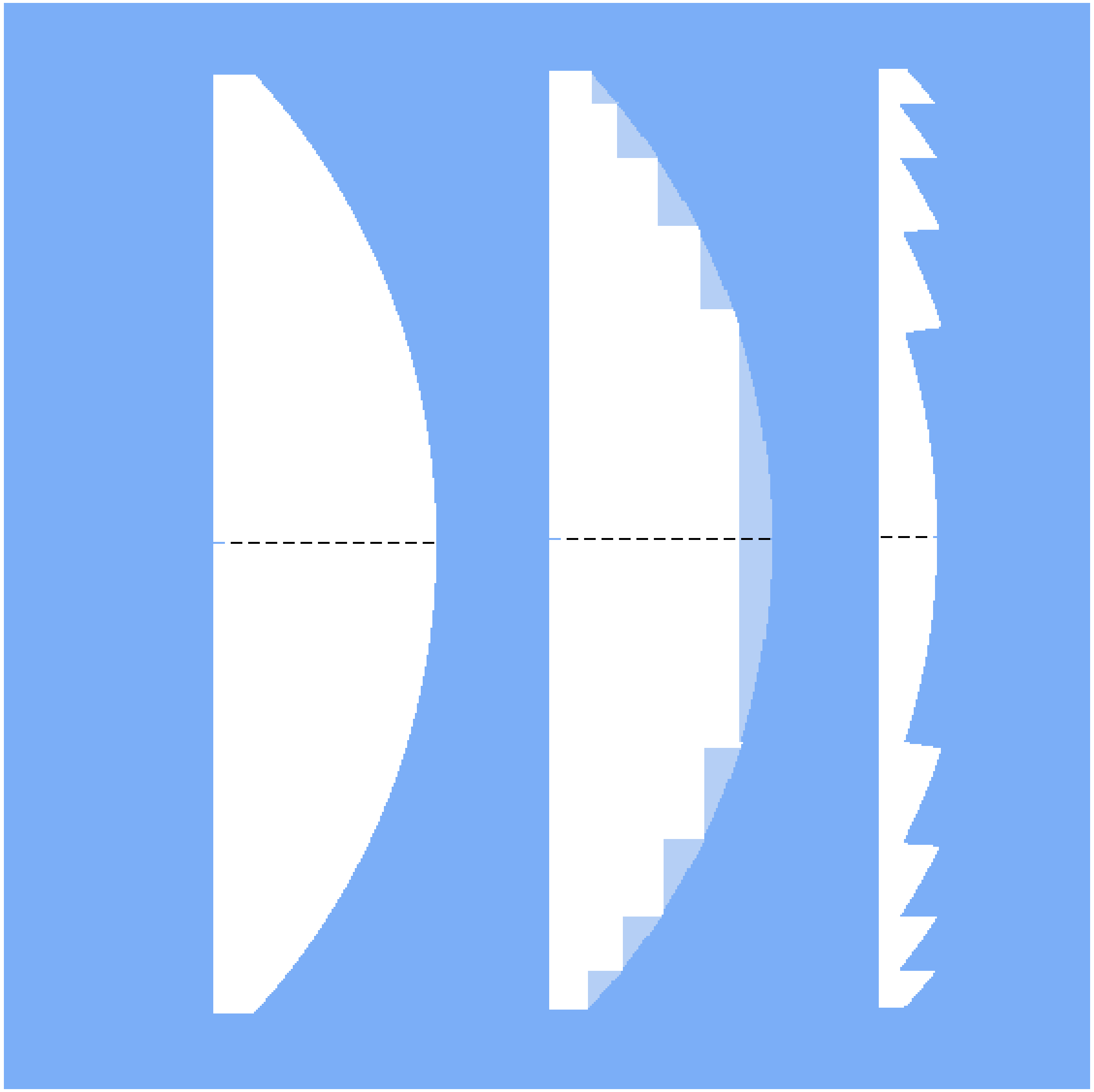
The Fresnel lens reduces the amount of material required compared to a conventional lens by dividing the lens into a set of concentric annular sections.



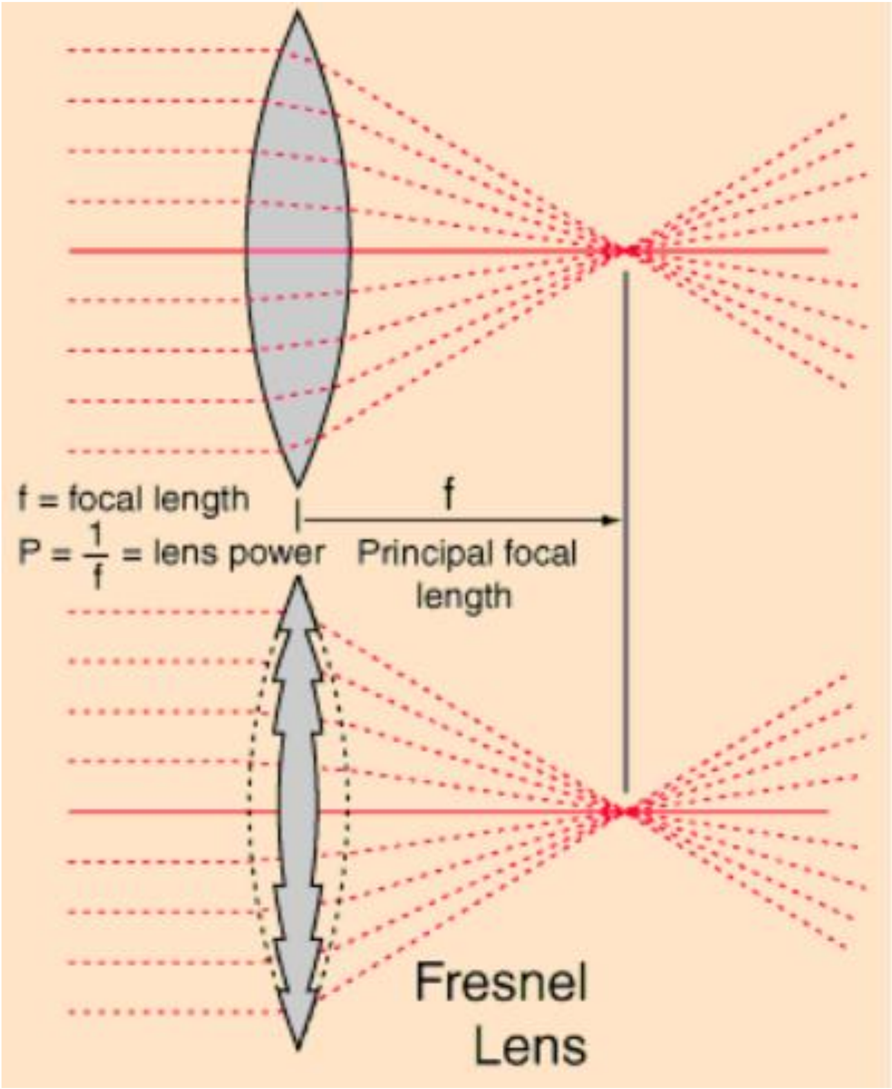
1: Cross section of a spherical Fresnel lens

2: Cross section of a conventional spherical plano-convex lens of equivalent power.

Fresnel Lens



Fresnel Lens



Fresnel Lens

Made from plastic materials:

PMMA (Polymethyl Methacrylate)
PVC (Polyvinyl Cholride)
PC (Polycarbonate)
HDPE (High Density Polyetylene)

Fresnel Lens : Applications

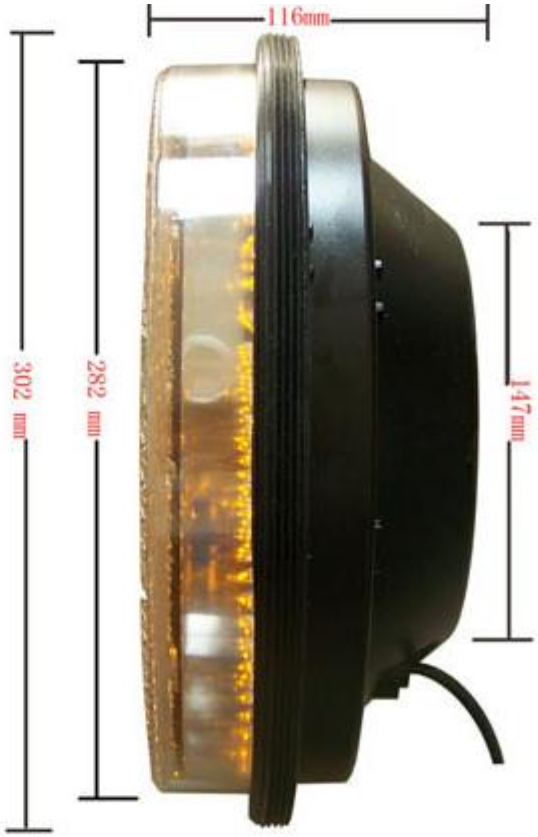
Lighthouses

Fresnel lens is light and easy to rotate.

Fresnel Lens : Applications

Trafic Lights

Fresnel lens exhibits a better performance on rainy and foggy days.

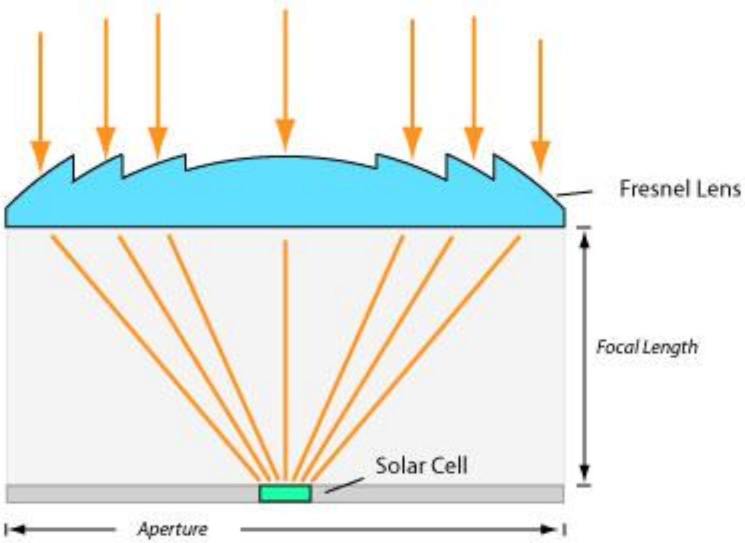


Fresnel Lens : Applications

Projector

Fresnel Lens : Applications

Solar Cell



Fresnel Lens : Applications

Overhead Projector (Tepegöz)

PART III

LED LENS

USED IN ILLUMINATION

LED Lens

Illumination is one of the main requirements of people.

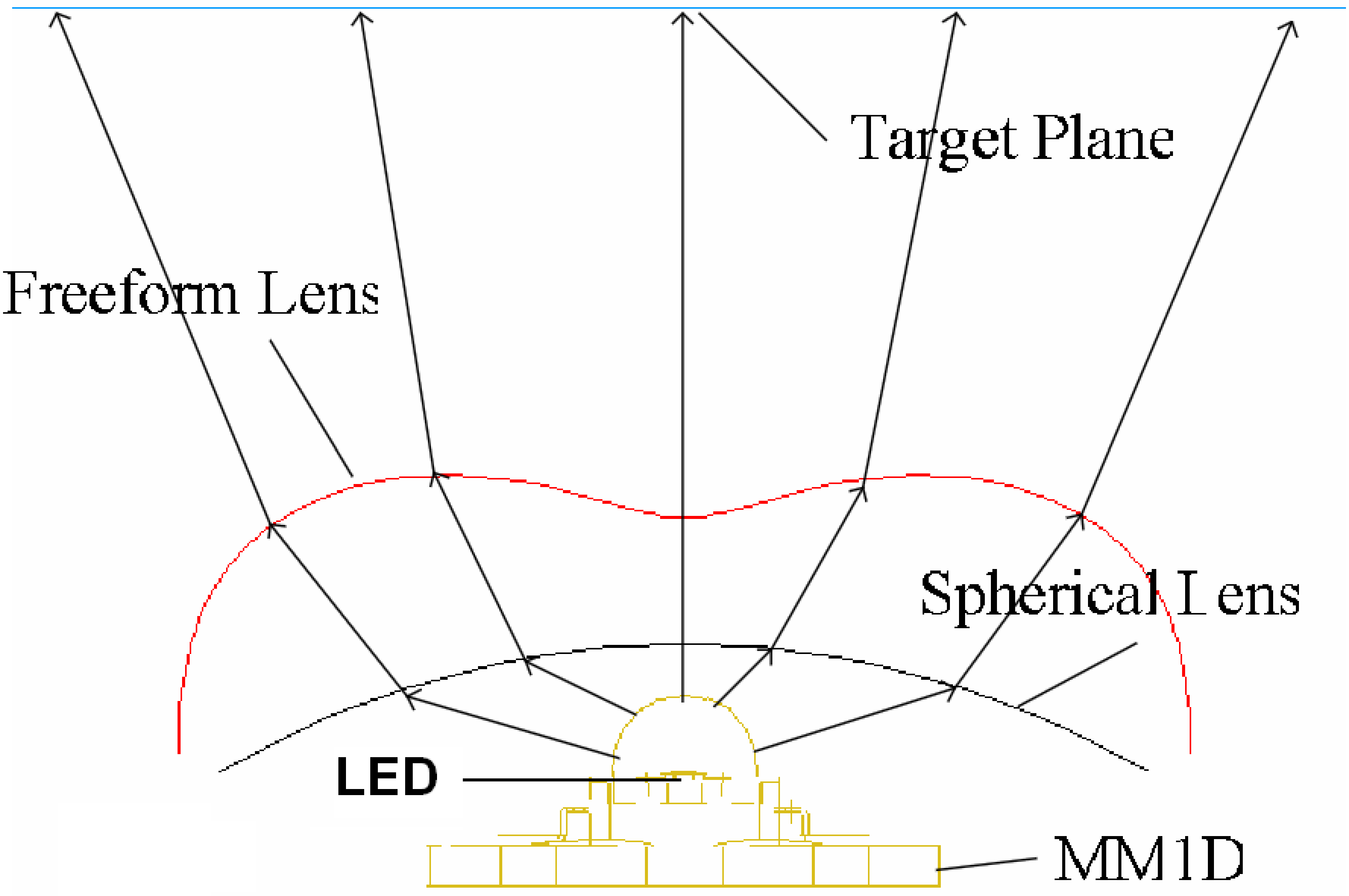
LED (Light Emitting Diode) is an energy-saving light source providing high light efficiency and long life time.

Nowadays, many cities across North America, China and Europa start to prefer LED for internal/external/street illumination.

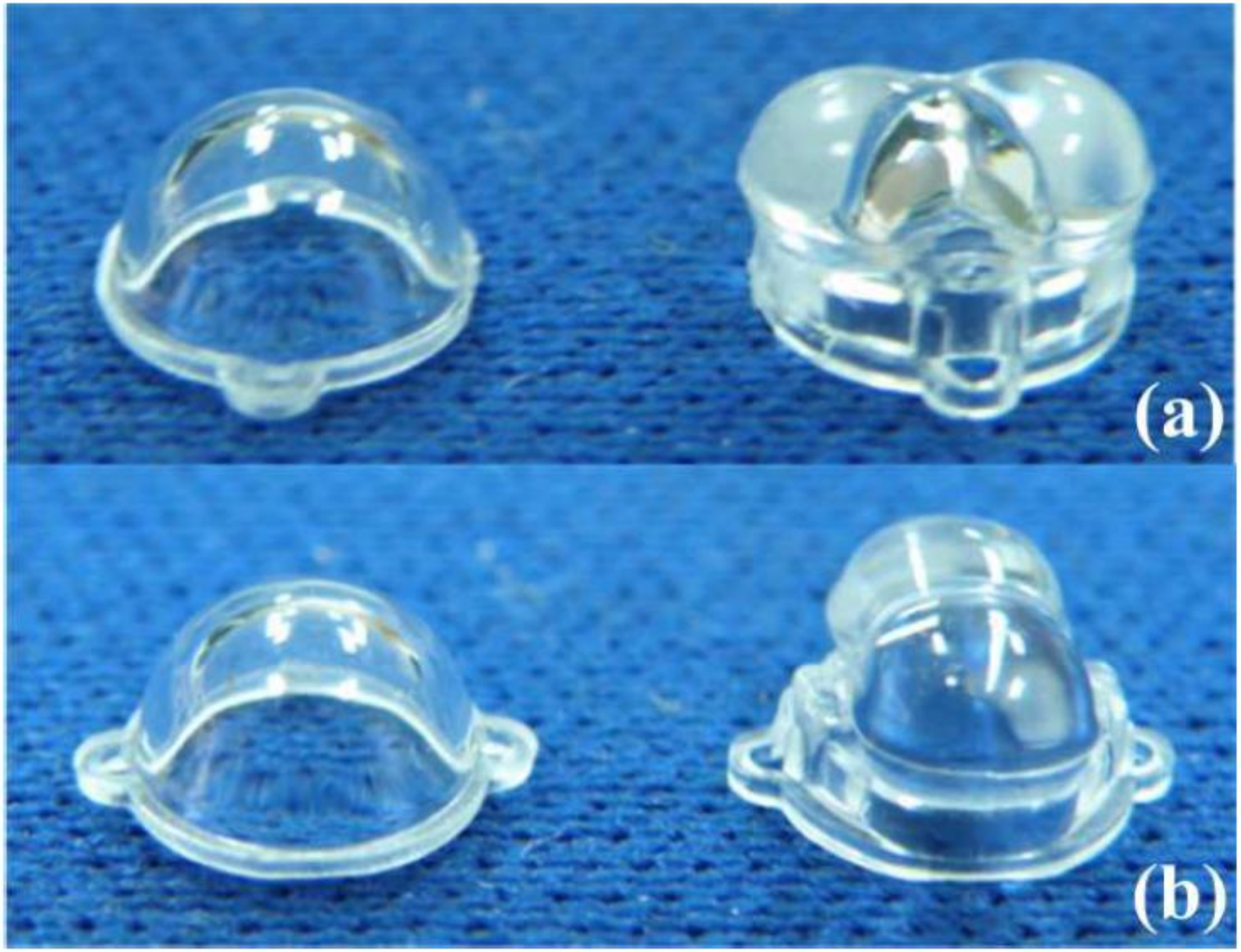
LED Lens

The direct light output of LEDs spreads at obtuse angle (usually greater than 120 degrees). This results in a disadvantage in the use of LEDs when illuminating a surface uniformly at an acute angle. This issue, can be improved either by placing a lens having a suitable geometric form in front of the LED or by using parabolic reflectors. However, lenses being smaller, lighter and cheaper are more useful compared to the reflectors. The illumination lenses used in our country are classical type and provide an illumination in the form of the circular spot on the target surface. But, by changing the lens geometry, the light distribution and pattern can be changed depending on requirements. For example, in the street and outdoor illumination it is better to use a rectangular spot instead of circular spot in terms of getting more light efficiency. This type of illumination lenses having a flexible geometry is known as Free Form Lens. Firstly, the Free Form Lenses are drawn attention in academic society and then they are used by illumination companies.

Power LED lens



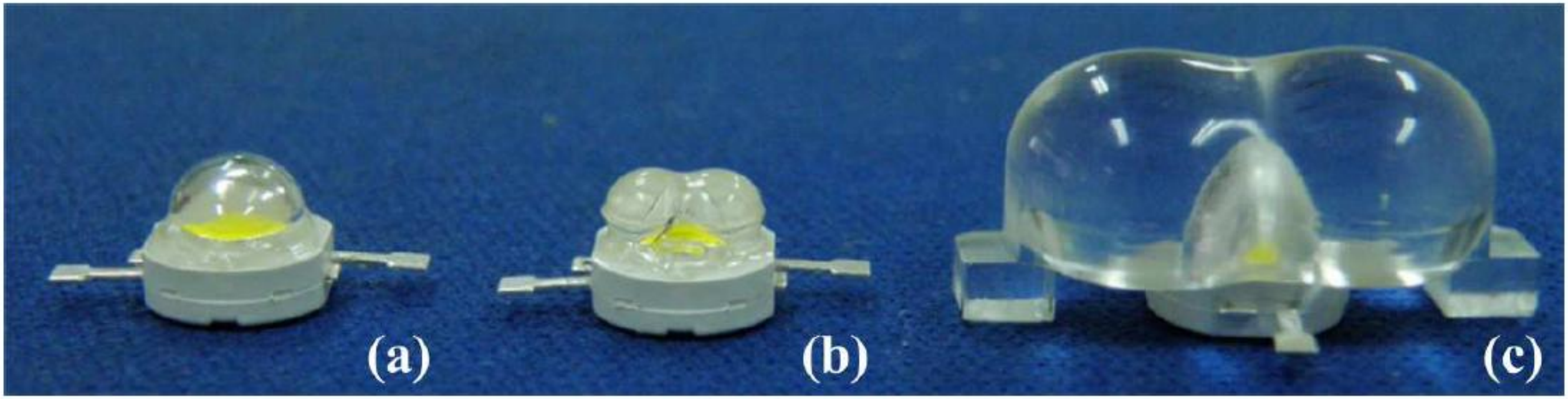
Power LED lens



Power LED lens

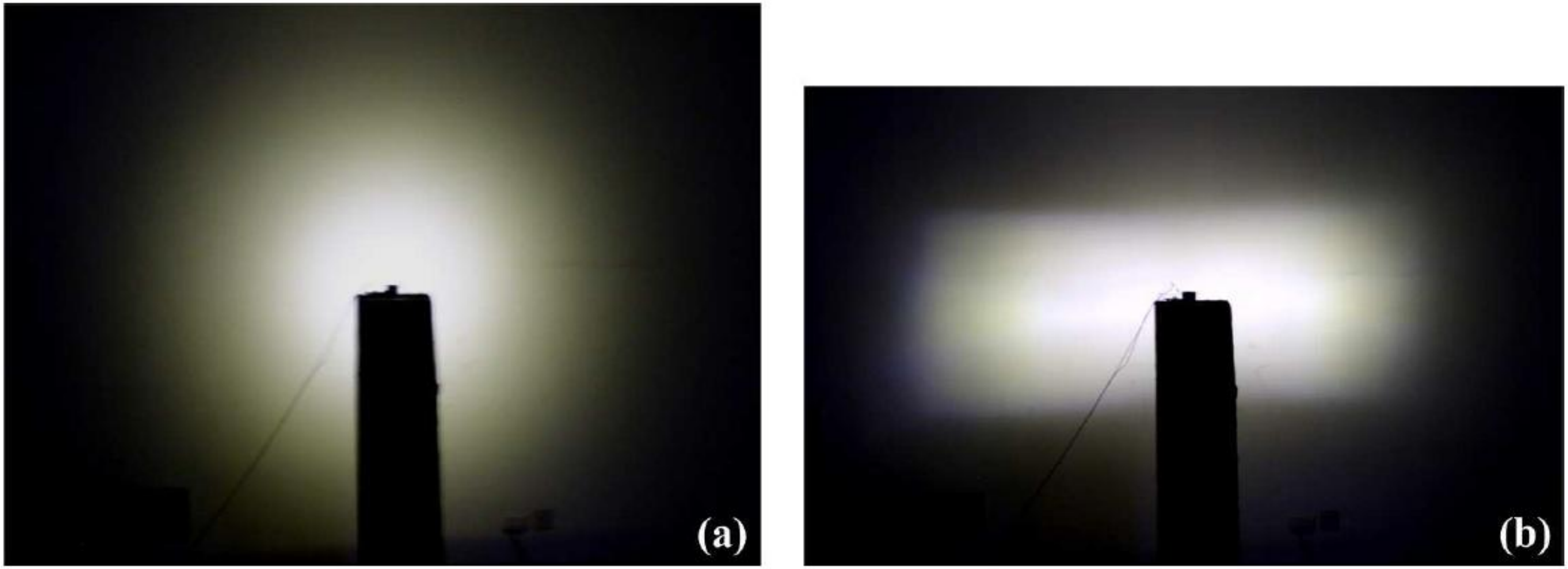
White light ASLP for road lighting

Power LED lens



(a) Traditional LED packaging, (b) ASLP and (c) LED module for road lighting

Power LED lens



Lighting performance of (a) a traditional LED packaging and (b) the ASLP

Exercises

1. Design, 2x, 4x and 10x Keplerian/Galilean Beam Expanders.
2. You have two set of spherical eye-glasses whose powers are:
   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.
3. 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?
4. A bi-convex lens has index 1.5 and radius of curvature 20 cm. Calculate the center thickness of the lens if the focal length is required to be 50 cm. What is the max mass of the lens? (Density of the lens material is 2.4 g/cm^3).
5. Repeat 6 for a bi-concave lens for the focal length −50 cm.
6. Given an biconvex lens, radii 100, thickness 10, and index 1.5, trace a ray (parallel to the axis) through the lens, beginning at a ray height of (a) 1.0, and (b) 10.0.

References

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