

Refraction, lens equation, optical power

A lens is most commonly used for refraction imaging. A lens is the simplest optical system. It consists of a transparent medium (most often glass, sometimes plastic) bounded by two refractive surfaces (usually spherical).

There are two types of lenses:

- **Converging** : parallel rays intersect at the image focus \rightarrow the focus is real ($f > 0$);
- **Diverging** : parallel rays diverge in the image focus; they intersect during retrograde extension at the subject focus \rightarrow the focus is virtual ($f < 0$).

A lens can be:

- **Thin** : the thickness of the lens is negligible compared to its focal length;
- **Thick** : the thickness of the lens is not negligible compared to its focal length.

A lens is called **thin** if its thickness is small compared to the radii of its spherical surfaces. In a homogeneous environment: $f = f'$.

Lens equation

Thick lens

$$\left(\frac{n_2}{n_1} - 1\right) \left(\frac{1}{r_1} + \frac{1}{r_2}\right) = \frac{1}{f}$$

- n_2 : index of refraction of the lens material n_1 : index of refraction of the surrounding medium;
- r_1 a r_2 : radii of curvature.

Thin lens

$$\frac{1}{a} + \frac{1}{a'} = \pm \frac{1}{f}$$

- a : object distance,
- a' : image distance,
- f : focal length.

This equation is valid for both converging and diverging lenses. When substituting the values a , a' we follow the sign convention:

- $a > 0$: the object is located in the object space (in front of the lens);
- $a < 0$: the object is located in the image space (behind the lens);
- $a' > 0$: the image is located in the image space; it is real;
- $a' < 0$: the image is located in the object space; it is virtual.

Optical power

Optical power is a quantity expressing the refractive power of a lens.

Calculation of optical power

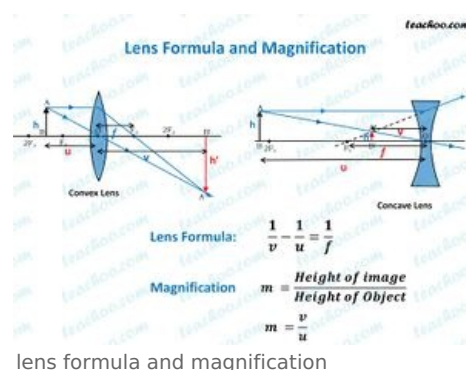
$$\varphi = \frac{1}{f}$$

- φ : optical power,
- f : focal length.

Unit: diopter (D) = m⁻¹ (f must be given in meters!). 1 D is the optical power of a lens with a focal length of 1 m. $\varphi > 0$ applies to converging lenses and $\varphi < 0$ to diverging lenses.

Image formation on ray diagram

(Note: The distance of the object (x) from the lens: what is the image)



- $x > 2f$: real, inverted and reduced;
- $x = 2f$: real, inverted, same size as object;
- $x < 2f$: real, inverted, magnified;
- $x = f$: the image is at infinity;
- $x < f$: apparent, direct, magnified.

In case of a diverging lens, its distance from the lens does not matter. The image is always apparent, direct and reduced.

Links

References

SVOBODA, Emanuel. *Přehled středoškolské fyziky*. - edition. 2005. 531 pp. ISBN 9788071963073.

JIRÍ, Beneš, – DANIEL, – FRANTIŠEK, Vítek,. *Základy lékařské fyziky*. - edition. Charles University in Prague, Karolinum Press, 2015. 322 pp. ISBN 9788024626451.

• Image formation by lenses :

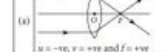
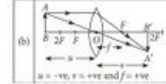
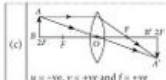
Convex lens			
Ray diagram	Position of object	Position of image	Nature of image
(a)  $u = -\infty, v = +ve$ and $f = +ve$	At infinity	At F	Real, inverted and highly diminished
(b)  $u = -ve, v = +ve$ and $f = +ve$	Between infinity and 2F	Between F and 2F	Real, inverted and diminished

image formation convex lens

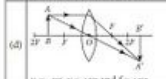
(c)


 $u = -ve, v = +ve$ and $f = +ve$

At 2F

At 2F

Real, inverted and same sized

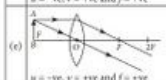
(d)


 $u = -ve, v = +ve$ and $f = +ve$

Between F and 2F

Beyond 2F

Real, inverted and enlarged

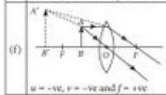
(e)


 $u = -ve, v = +ve$ and $f = +ve$

At F

At infinity

Real, inverted and enlarged

(f)


 $u = -ve, v = -ve$ and $f = +ve$

Between F and O

On the same side of the lens

Virtual, erect and enlarged

image formation convex lens