Geometrical Optics. Practical 3.
FOCAL LENGTH MEASUREMENT OF THIN LENSES

Equipment and accessories: an optical bench with a scale, an incandescent lamp, a glass plate with a ”mesh”, a screen, an arrow, and a telescope.

1 Introduction

A *lens* is a transmissive optical device that focuses or disperses a light beam by means of refraction. A simple lens consists of a single piece of transparent material, while a compound lens consists of several simple lenses (elements), usually arranged along a common axis.

In optics, a *thin lens* is a lens with a thickness (distance along the optical axis between the two surfaces of the lens) that is negligible compared to the radii of curvature of the lens surfaces. Lenses whose thickness is not negligible are sometimes called *thick lenses*. The thin lens approximation ignores optical effects due to the thickness of lenses and simplifies ray tracing calculations.

The lens formula in Gaussian form is:

$$\frac{1}{d_1} + \frac{1}{d_2} = \frac{1}{f}, \tag{1}$$

where d_1 is the object distance, d_2 is the image distance, and f is the focal length of the lens. Also, the sign rule should be used:

1) for *real* objects and images, $d_{1,2}$ are **positive**,
2) for *virtual* objects and images, $d_{1,2}$ are **negative**,
3) for a *converging* (also referred to as *positive* or *convex*) lens, the *focal length* is **positive**,
4) for a *diverging* (also referred to as *negative* or *concave*) lens, the *focal length* is **negative**.

However, in many practical cases, *Cartesian*[1] sign convention is used:

1) the lens formula is written as:

$$-\frac{1}{d_1} + \frac{1}{d_2} = \frac{1}{f}. \tag{2}$$

2) The origin of the Cartesian coordinate system coincides with the centre of the lens, and the light traverses along the X-axis, e.g., all figures are drawn with light travelling from left to right.
3) All distances are measured from a reference surface, such as a wavefront or a refracting surface. Distances to the left of the surface are negative.
4) The refractive power of a surface that makes light rays more convergent is positive. The focal length of such a surface is positive.
5) The distance of a real object is negative. The distance of a real image is positive.
6) Heights above the optic axis are positive. Angles measured clockwise from the optic axis are negative.

2 Experimental setup

Experimental setup is assembled on an optical bench and includes a source of light which is an incandescent lamp; an object, which is formed by a glass plate with a "mesh". The image of the object is obtained on a screen with the help of lenses. All the required distances are measured using a centimetre scale. At the end of the optical bench a telescope is installed.

[1] *Cartesian* means of or relating to the French philosopher René Descartes from his Latinized name *Cartesius*.

3 Measurement and data processing

3.1 Task 1. Measurement of a converging lens focal length by directly measuring distances d_1 and d_2

Turn on the lamp and move the lens along the optical bench until you get a clear image of the object on the screen. Measure the distances d_1 and d_2. Calculate the focal length using the lens formula (1) or (2) using an appropriate sign convention. Repeat the measurement three times, calculate mean value of the focal length and perform the error analysis. Fill out a table using your data. The final result should be written as $f = \overline{f} \pm \overline{\Delta f}$. Using a pencil and ruler make a drawing which demonstrates how the image was formed.

3.2 Task 2. Measurement of a converging lens focal length by displacement of the lens (the Bessel method)

Set the screen on the optical bench at a distance $D > 4f$ apart from the object. Now, moving the lens between the object and the screen one may always find two distinct positions of the lens, where a clear image of the object is formed. At one position of the lens, the image will be reduced, and at the other - enlarged. By measuring the distance b between these two positions of the lens and knowing the distance D it is possible to find the focal length of the lens, see a schematic in Fig. 1.

1) Derive the formula for the focal length of the converging lens using the lens formula (1) or (2) and distances D, b.
2) Repeat the measurement three times using the same lens. It is possible to change distances D, b.
3) Calculate mean value of the focal length and perform the error analysis.
4) Fill out a table using your data. The final result should be written as $f = \overline{f} \pm \overline{\Delta f}$.
5) Make a drawing which demonstrates how the image was formed.

3.3 Task 3. Measurement of a converging lens focal length using a spotter scope

The spotter scope, tuned to infinity is set at the end of the optical bench, against the object. By moving the lens along the bench, get a clear image of the grid in the scope's ocular. After that, having measured the necessary distance (please, find out what distance should be measured), find the convex lens focal length. Repeat the measurement three times.

Calculate f_{avg} using results of Task 1 - Task 3. Find the optical strength of the lens under study (in dioptres).

3.4 Task 4. Measurement of the concave lens focal length using a convex lens

Using the convex lens, obtain the grid image on the screen (S_1) which is placed at a distance l_1 apart from the convex lens (L_1). If a concave lens L_2 is placed on the optical bench between the screen and the lens L_1, the grid image on the screen disappears, but it can be resumed by moving the screen to position S_2 by a distance l_2 apart from the L_1. Using the lens formula, find the focal length of the concave lens for which the object distance is d_1 and the image distance is d_2. (See Fig. 2).

1) Repeat the measurement three times using the same lenses.
2) Calculate mean value of the concave lens focal length and perform the error analysis.
3) Fill out a table using your data. The final result should be written as $f = \overline{f} \pm \overline{\Delta f}$.
4) Make a drawing which demonstrates how the image was formed.

3.5 Task 5. Measurement of the concave lens focal length using a spotter scope

The spotter scope, tuned to infinity is set at the end of the optical bench, against the object. Place a convex lens and screen on the bench. Moving the lens and screen, obtain the grid image on the screen (note that the distance between the lens and the screen should be greater than the expected focal length of the concave lens). Note the positions of the lens and the screen on the scale. Between the screen and the convex lens, place the concave lens, and remove the screen. By moving the concave lens, obtain a distinct image of the grid in the scope's ocular. Find the focal length of the concave lens using reconstruction of the optical patch. Repeat the measurement three times.

Find f_{avg} for the concave lens using results of Task 4 and Task 5. Find the optical strength of the concave lens (in dioptres).

4 Questions

1. What is a thin lens?
2. Make a schematic drawing for measurement of the concave lens focal length.
3. Make a schematic drawing for measurement of the convex lens focal length.
4. Prove the lens formula considering the lens refractive index and the curvature of its surfaces.
5. One piece of glass has a refractive index of 1.5, and the other one - 1.7. Of both glasses, the biconvex lenses are made of the same size and shape. Find the ratio of the focal lengths of these lenses.
6. Prove all the formulas used in the practical.
7. Is it possible to determine the focal length of a concave lens using a spotter scope only?
8. Is there a biconvex lens which has a negative optical power?

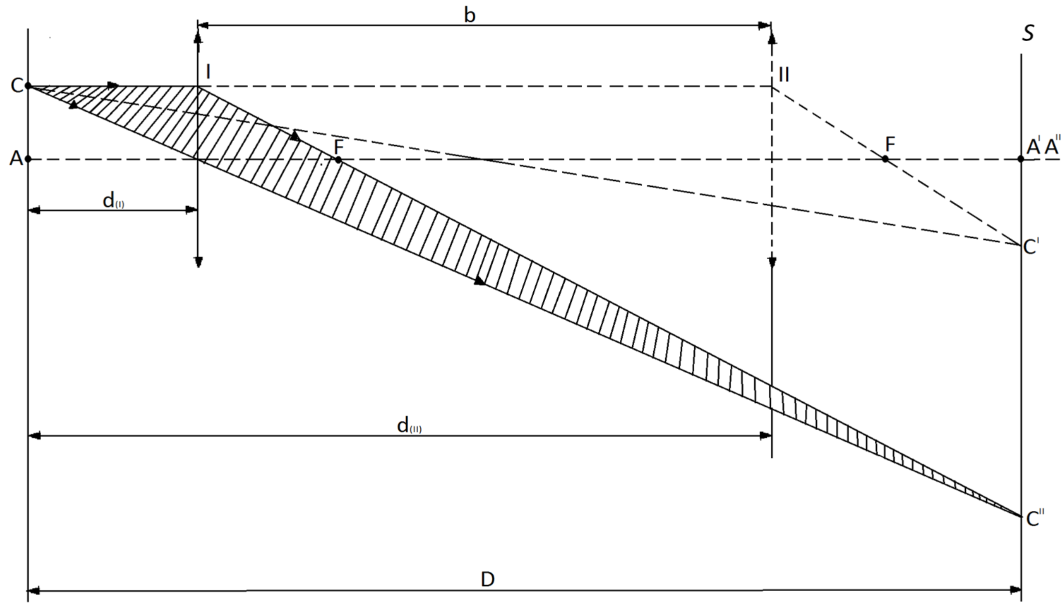

Figure 1: Measurement of a converging lens focal length by displacement of the lens (the Bessel method).

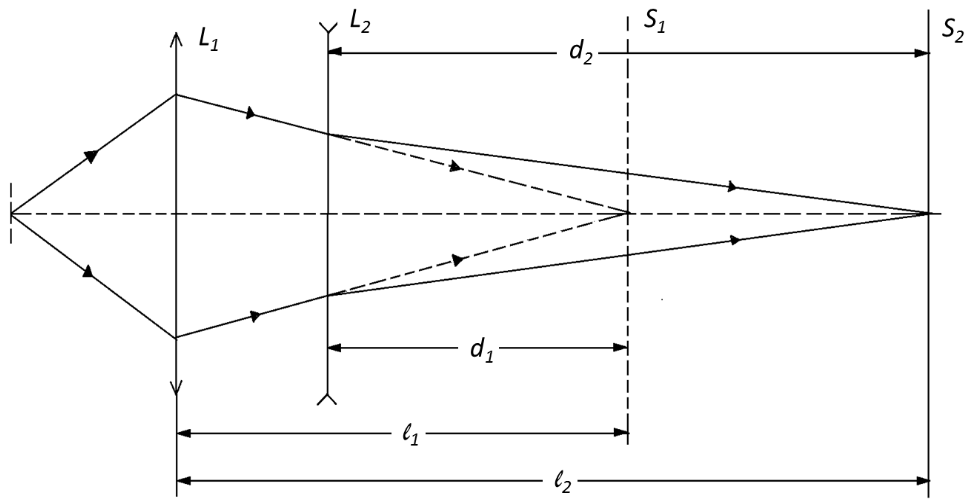

Figure 2: Measurement of the concave lens focal length using a convex lens.