Investigation of centered optical systems

Purpose: Study the laws of image formation in centered optical systems (COS).
Tasks to solve:
- ✓ To gain experience in adjustment of centered optical systems.
- ✓ To learn the methods of measuring focal distances of converging and diverging lenses.
- ✓ To observe in an experiment how the image depends on the position of the object with respect to the focal length of the lens.

Optical elements and accessories:
1. Small optical rail on a support.
2. Incandescent lamp in a case and power supply.
3. Aspheric condenser with a holder for a diaphragm.
4. Semi-transparent screen.
5. Converging lenses with different focal lengths (f = 50, 100, 150, 200, and 300 mm).
6. Diverging lens with the focal length of −100 mm.
7. Two transparent glasses with a drawing for studying image formation.
8. Measuring reel (2 m).

<u>Exercise 1</u>. Determination of the focal length of a converging thin lens.

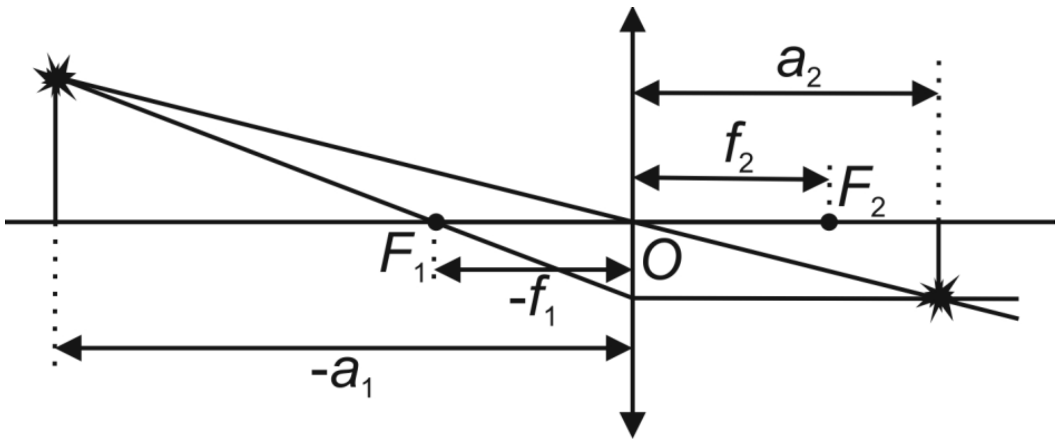

Fig. 1. Ray paths in a thin lens.

If the distance between an object and a lens ($-a_1$) is changed, then the image is formed at different distances a_2 from the lens. Since the values of a_1 and a_2 are connected by the correlation

$$\frac{1}{-a_1}+\frac{1}{a_2}=\frac{1}{f_2} \quad (1),$$

the focal length f_2 (or $-f_1$) of the lens can be determined from the plot of the dependency of $1/a_2$ on $1/(-a_1)$ as the inverse value to the segment which is cut off on the vertical axis by this plot. Remember that *distances* $a_2 > 0$, $(-a_1) > 0$!

Algorithm of measurements

1. Mount the lamp, converging lens, and screen on the optical bench (Fig. 2).

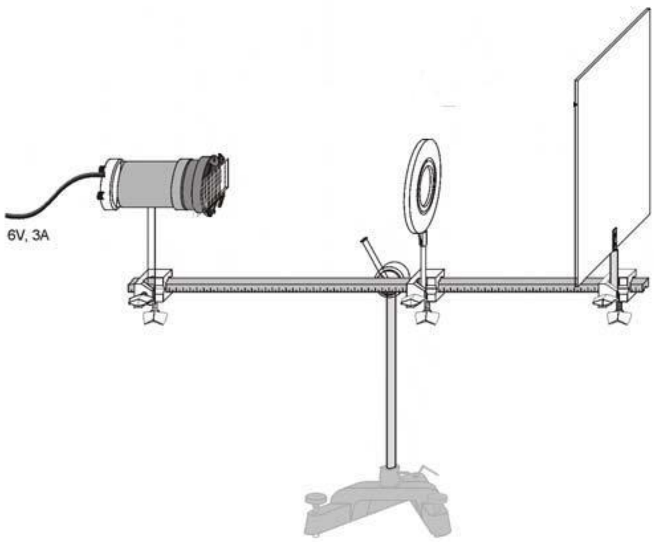

Fig. 2. Experimental setup for determination of the focal length of a converging lens.

2. Put the arrow-shaped diaphragm in the holder of the condenser.
3. Switch on the lamp.
4. Move the screen to the end of the rail.
5. By moving the lens between the screen and the object (diaphragm), get a well-defined image of the arrow on the screen.
6. Measure the distances $(-a_1)$ and a_2.
7. Decrease the distance between the object and the screen by 3–4 cm and find again the distances $(-a_1)$ and a_2 which provide a clear image.
8. Repeat this step 4 or 5 times.
9. Build a plot with the values $x = 1/(-a_1)$ and $y = 1/a_2$ on the axes, and determine the focal distances from obtained dependency.

<u>Exercise 2</u>. Determination of the focal length of converging lenses by the Bessel's method.

If the object and the image are separated by a distance longer than $4f$, one can find two positions of the lens, one of which yields a magnified, and the other yields a decreased image (Fig. 2). The distance between the screen and the object in this experiment remains constant.

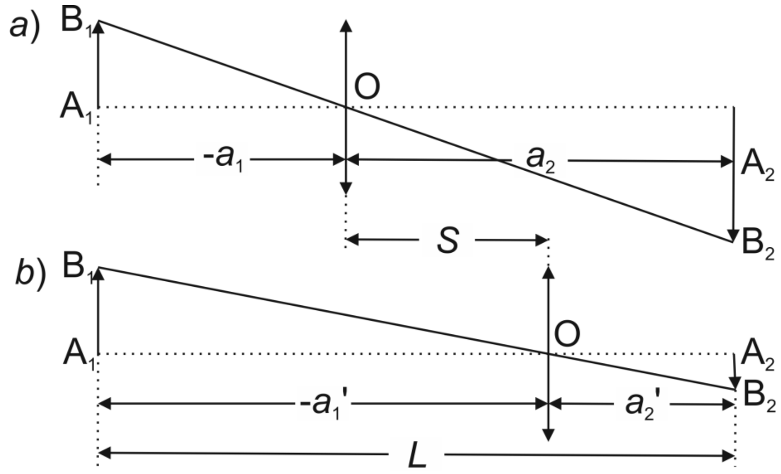

Fig. 3. Scheme of determination of the focal length of a converging thin lens by the Bessel's method.

Let us introduce the values $S = (-a_1) - (-a_2)$ and $L = (-a_1) + a_2$. Allowing for Eq. (1), we can derive the Bessel's formula for finding the focal length:

$$f = \frac{L^2 - S^2}{4L}. \quad (2)$$

Algorithm of measurements

1. Mount the lamp with the aspheric condenser on one end of the optical rail. Put the glass with a drawing in the holder for diaphragms.
2. Locate the semi-transparent screen at a distance about 50 cm from the object.
3. Take the lens with f = 100 mm and put it between the diaphragm and the screen (Fig. 4).

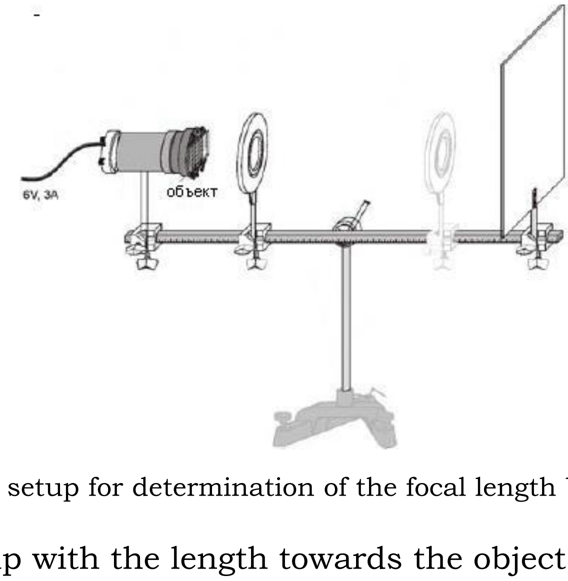

Fig. 4. Experimental setup for determination of the focal length by the Bessel's method.

4. Move the clamp with the length towards the object until a well-defined image appears on the screen, and after that measure the distance a_2 between the lens and the screen.
5. Move the lens towards the screen until you get another clear image. Measure the distance a'_2 between the lens and the screen.

6. Determine $S = (-a'_1) - (-a_1) = a_2 - a'_2$, and calculate the focal length of the lens following the Eq. (2).
7. Repeat the experiment with the length with f = 150 mm.

<u>Exercise 3</u>. Determination of the focal length of a converging lens by the autocollimation method.

Autocollimation method is based on the reversibility of the light propagation. If an object is placed at the focus of a lens, then after the lens there will be a light beam parallel to the optical axis. A plane mirror placed beyond the mirror reflects this beam so that the object's image will be observed near the object (Fig. 5). The distance *d* between the lens and the image will be equal to the lens' focal distance *f*.

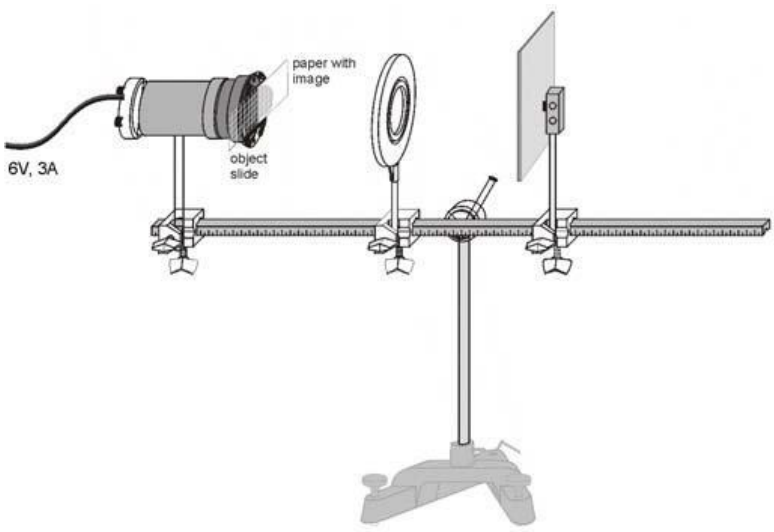

Fig. 5. Experimental setup for determination of the focal length by the autocollimation method.

Algorithm of measurements

1. Mount the lamp with the aspheric condenser on the optical rail as shown in Fig. 5.
2. Locate the lens with f = +150 mm so that light passes through the lens parallel to the optical axis. The distance between the lens and the holder for diaphragms should be nearly the same as the focal length of the lens.
3. Insert the glass with a drawing (the object) and a white sheet of paper (which serves as a screen for observing the object) into the holder for diaphragms according to Fig. 5. Both paper and the object should cover one half of the condenser lens.
4. Locate the mirror beyond the lens. The distance from the lens and the mirror may be smaller than the focal length.
5. Adjust the position of the lens until you get a well-defined image on the paper. It may happen that you will need to adjust the positions of the mirror and lens until the image becomes of the same size as the object.
6. Measure the distance *d* between the lens and the object (drawing) plane.
7. Repeat the experiment with other lenses.

Exercise 4. Determination of the focal length of the diverging lens

Focal distance of a diverging lens is determined with the aid of an additional positive (converging) lens.
If we put a diverging lens 2 on the path of the rays which are emitted from the source S and converge at the point S_1 after being refracted in a converging lens 1, so that the distance a_1 is smaller than the focal length of this diverging lens, then the image of the source S will move farer from the lens 1. Imagine that it will move into the point S_2. Now S_1 is the object and S_2 is the corresponding image for the lens 2.
According to formula (1), the back focus of the negative (diverging) lens can be found as

$$f_2 = \frac{a_1 a_2}{a_1 - a_2}. \qquad (3)$$

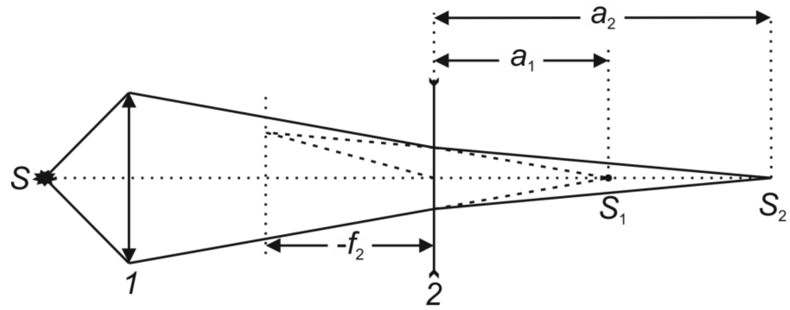

Fig. 6. Determination of the focal length of a diverging lens.

Algorithm of measurements

1. Mount the lamp, converging lens with f = 100 mm, and screen on the optical rail as shown in Fig. 2 (page 2).
2. Insert the glass with a drawing into the holder for diaphragms.
3. Put the lens at a distance of ~30 cm from the object and obtain a well-defined diminished image of the drawing by moving the screen; remember this position of the screen (point S_1).
4. Put the studied diverging lens between the positive lens and the screen.
5. Find again a sharp image of the object by moving the screen (it will be the point S_2).
6. Having found the distances a_1 and a_2 (Fig. 6), calculate the focal length f of the diverging lens using the formula (3).

Exercise 5. Determination of focal lengths of the converging and diverging lenses using parallel light beams (demonstrative experiment).

Algorithm of measurements

1. Mount the lamp with the aspheric condenser and the semi-transparent screen on the optical rail as shown in Fig. 7. No lens is needed yet.

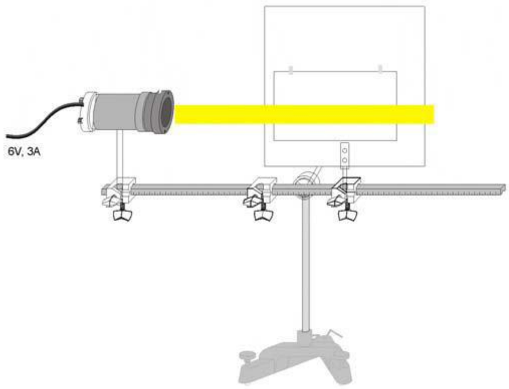

Fig. 7. Initial experimental setup.

2. Make a parallel light beam going along the optical axis. To do this, obtain a sharp image of the lamp's filament (horizontal) in the most distant point (on a wall) by moving the lamp with respect to the condenser.
3. Fasten a white paper sheet on the screen using Scotch tape. Make sure that the beam is a parallel beam.
4. Put the lens with $f = 100$ mm in a clamp before the screen.
5. Mark the point where the refracted light converges (Fig. 8) and measure the focal length.

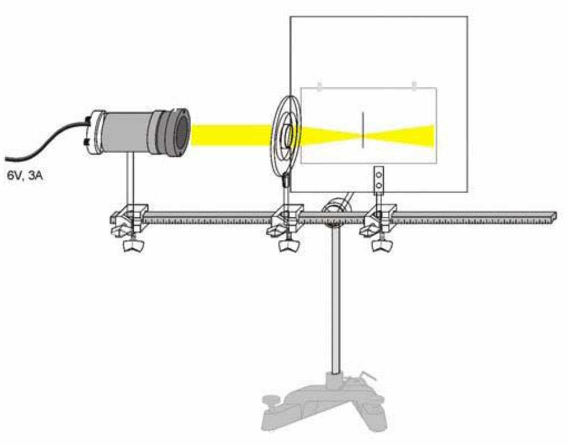

Fig. 8. Experimental setup for determining the focal lengths of positive lenses using parallel beams.

6. To find the focal distance of the diverging lens, fold the paper twice and fix it on the screen so that the fold line coincides with the side of the screen near the lens (Fig.9).
7. Mount the lens with $f = -100$ mm in a clamp before the screen.
8. Represent the shape of the refracted beam on the paper by drawing the lines limiting the illuminated area.
9. Take off the paper, continue the lines until they intersect, and determine the focal length (see Fig. 9).

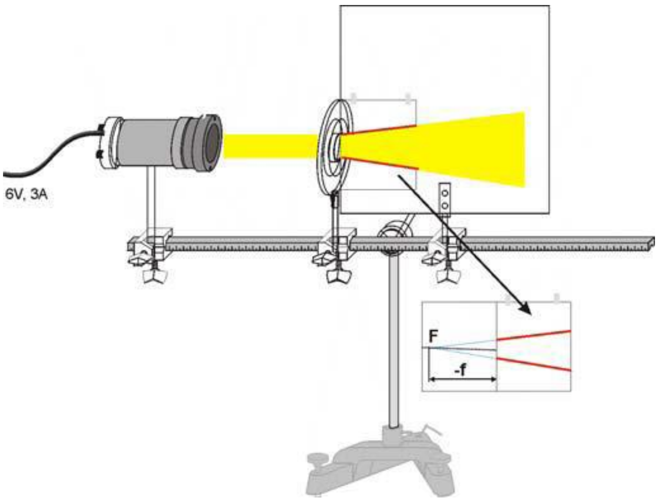

Fig. 9. Experimental setup for determining the focal lengths of negative lenses using parallel beams.

Questions

1. Centered optical system (COS).
2. Cardinal elements of a COS. Image formation in a COS.
3. Thin lens. Optical power.
4. Methods for finding focal distances of converging and diverging lenses.