415. Telescope

Tasks to solve:

- Studying complex centered optical systems on the example of a telescope.
- Conducting operations with a telescope.
- Determination of optical characteristics.

Description of the experiment

Telescope and microscope are optical systems consisting, on the basic level, of two lenses. The first lens is closer to the observed object AB (objective lens O_1, see Figs. 1, 2) and creates a real inverted image A_1B_1 of the object. This image serves as the observation object for the second lens (eye-glass or ocular O_2), which creates an imaginary amplified image A_2B_2 situated at the optimal viewing distance from the observer's eye.

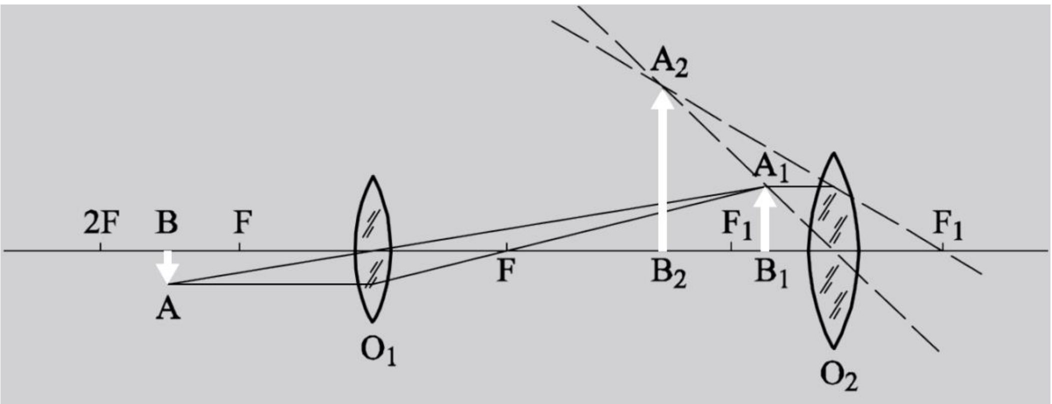

Fig. 1. Path of rays in a microscope.

Objective lens of a microscope is designed to look at small things at a close distance, so it has a short focal length. The object AB is placed slightly beyond the focus of the objective lens, and as a result its image A_2B_2 becomes significantly amplified.

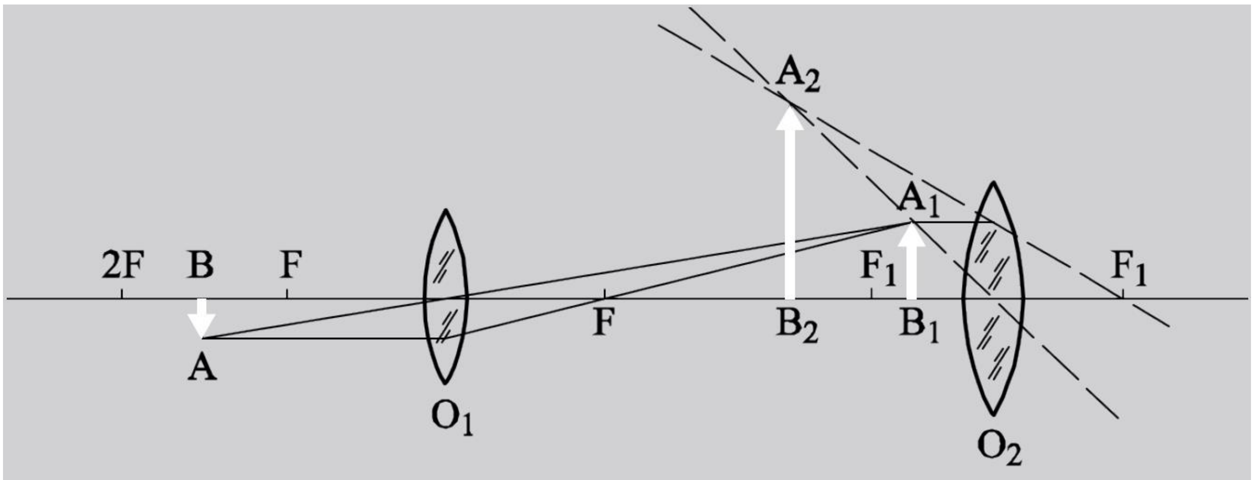

Fig. 2. Path of rays in a telescope.

Objective lens of a telescope, which is used for observing things at far distances (larger that the double focal length of the objective lens), has a large focal length. It creates a diminished image A_1B_1 (Fig. 2) close to the eye-glass O_2. The ocular lens produces a magnified image of A_1B_1 (A_2B_2).
To characterize the amplification of an optical system, a value called *angle of view* is used. It is the angle between the straight lines connecting the observer's eye with the edge points of the observed object.

Task 1. Determining the amplification of a telescope
Angular amplification is the ratio of the tangent of the viewing angle of the object when observed through a telescope to the tangent of its viewing angle when as it is seen to the naked eye.

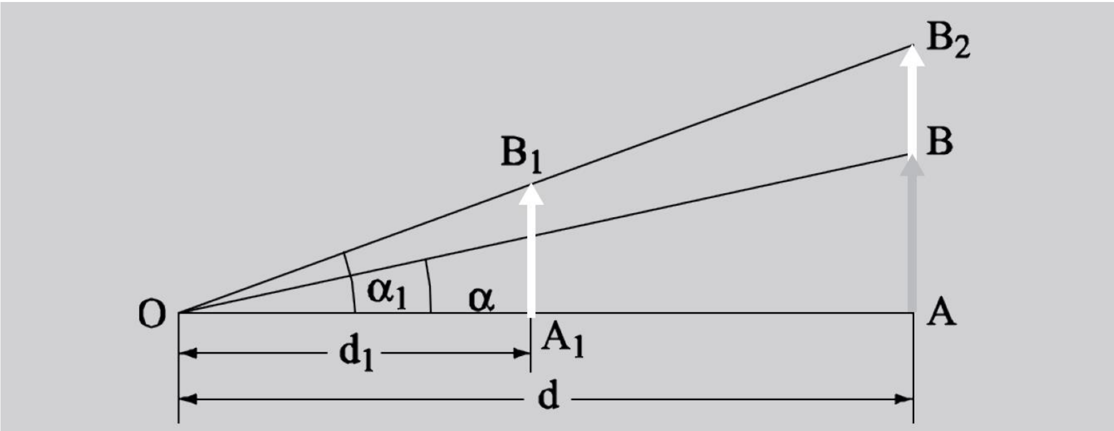

Fig. 3. Amplification of a telescope.

Let the object AB be placed at the distance d from the observer O; A_1B_1 is the image of the object seen through the telescope and situated as the distance d_1 from O; α and α_1 are the corresponding viewing angles (Fig. 3).
Build a projection of the image A_1B_1 onto the plane of the object; this operation yields AB_2. This segment is placed at the distance d from the eye but is still seen at the angle α_1. The angular amplification is

$$\Gamma = \frac{\tan\alpha_1}{\tan\alpha} = \frac{AB_2}{AB}. \qquad (1)$$

To determine the amplification of a telescope in practice, we will use the following procedure. Take a ruler with the distance l_0 between the marks. By observing the rules through the telescope with one eye and directly with the other eye, combine the images so that the image inside the telescope overlaps with the ruler seen by the naked eye (Fig. 4).
Choose an integer number n of the marks which coincide in size with N marks on the ruler's image. Obviously, $nl_0 = NL$, where L is the length of the image of one segment between the marks. Then we have:

$$\Gamma = \frac{L}{l_0} = \frac{n}{N}. \qquad (2)$$

The exterior of the telescope is shown in Fig. 5. Coarse adjustment of the telescope in the vertical plane is made after the screw 1 is loosened. Fine adjustment in horizontal and vertical planes is made with the aid of screws 2 and 3, respectively. A fine image of the cross-hair is achieved by rotating the ocular ring 4. A fine image of the object is built by rotating the screw 5 of the rack mechanism.

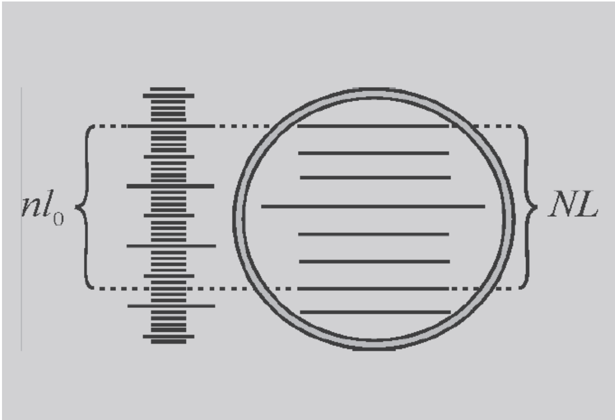

Fig. 4. Determining the amplification of a telescope (example): $n = 27$, $N = 6$, $\Gamma = 27/6 = 4.5$.

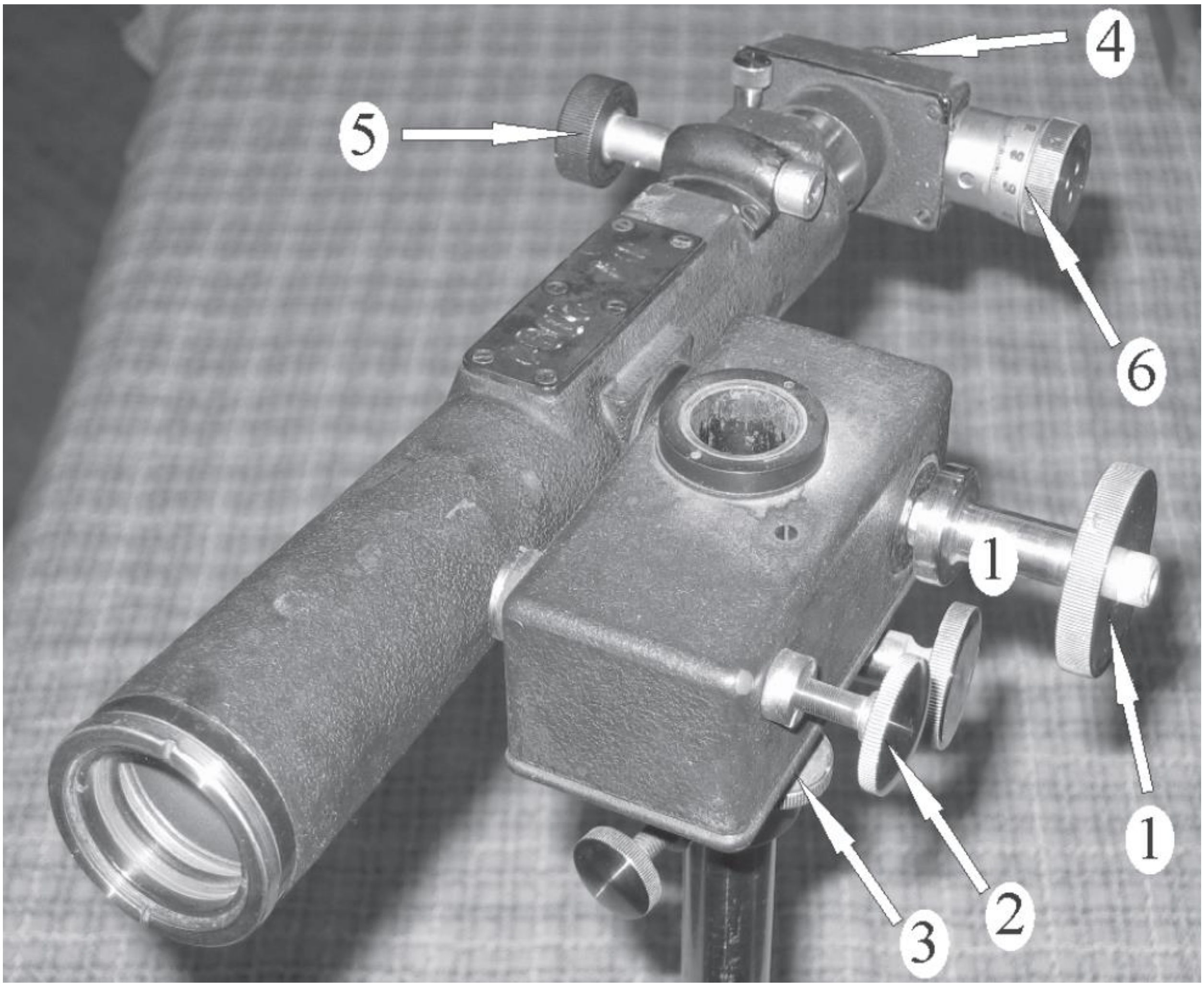

Fig. 5. Exterior of the telescope.

<u>Algorithm of measurements</u>

1. Achieve a fine image of the ruler with marks, when the ruler is several meters away from the telescope.

2. Look at the ruler with one eye through the telescope, and at the same time observe it with the other eye. Adjust your sight so that the image in the telescope overlaps with the real ruler.
3. Count *n* marks of the ruler and corresponding number *N* of marks on the ruler's image (like in Fig. 4).
4. Calculate the amplification factor Γ.

Task 2. Measuring the size of an object

The telescope's ocular is equipped with a measuring cross-hair made of two thin perpendicular threads placed near the focal plane of the eye-glass. The vertical thread can be moved in the field of vision with the aid of the micrometric handwheel 6. One turn of the handwheel moves the cross-hair in the tube by 1 mm. The wheel is divided into 100 parts; therefore, movement of the thread can be performed with the accuracy of 0.01 mm.

<u>Algorithm of measurements</u>

1. Determine the scale interval l' of the micrometer. To do this:
- Put the gauge (ruler) with a known scale interval at the same distance, at which the objects to measure will be placed at the next steps.
- Sight the telescope on the gauge and choose a segment with *m* marks.
- By rotating the micrometric handwheel, superpose the cross-hair with one end of the chosen segment; take the reading from the micrometer.
- Superpose the movable cross-hair with the other end of the segment and take the second reading. The difference *n* of the two readings gives the size of the object's image in the focal plane of the telescope.
- Using the equation $nl' = ml$, calculate the scale interval of the micrometer:
  $l' = ml/n$.
2. Determine the size of an object placed in the same plane where the gauge has been put.

Task 3. Determining the field of vision of the telescope

A part of space (or plane), whose image is seen in an optical system, is called the *field of vision* of the system. For systems designed to observe far objects (telescope, binoculars) the field of vision is described by an angle $\phi = l/L$, where l is the distance between the most distant visible points of the plane containing the observed object, and L is the distance to the object (plane). As an angle, this value can be obtained by the formula

$$\phi = \frac{180°}{\pi}\frac{l}{L} = 57.3°\frac{l}{L} . \qquad (3)$$

In binoculars, the field of vision is typically 5–10°, and in the biggest telescopes it does not exceed a few arc minutes.

Algorithm of measurements

1. Sight the telescope on a ruler on the wall and make a fine image.
2. Define the part of the ruler l which is seen in the telescope.
3. Measure the distance L from the ruler to the objective lens of the telescope (do not touch the lens!).
4. Calculate the field of vision using Eq. (3).

Questions

1. Centered optical system (COS).
2. Cardinal elements of a COS. Image formation in a COS.
3. Thick lens. Thin lens. Optical power of a lens.
4. Linear and angular amplification of an optical system.
5. Telescope. Path of rays in a telescope.
6. Microscope. Path of rays in a microscope.