Geometrical Optics
Practical 2. Part II. OPTICAL SYSTEMS

Introduction

Optical systems can consist of a one element (a one lens or a mirror, a magnifying glass), two or three lenses (an eyepiece, theatrical binoculars) and many lenses and mirrors (a telescope, a microscope, a spectrograph, etc.).

In *the Practical* the simplest optical systems are studied. The systems are the basic optical instruments: the telescope, the microscope and the slide projector.

Telescopic systems

2.1 Study of the ray path in a telescopic optical system

Form a parallel light beam using *Lens 1* and the filament of a lamp as a source. Such an operation is often called collimation of a light beam, and a collimator is an optical system that supplies a parallel light beam.

Place the converging *Lens 3* at a distance of about 20 cm from *Lens 1* and get a beam converging at its focus (see Figure 1). Then put *Lens 2* into the path of the diverging beam. The focuses of the *Lenses 2* and *3* must coincide. Make sure that the parallel beam is still behind *Lens 2*.

The system of *Lens 2* and *Lens 3* obtained in this way is a special case of the telescopic system that transforms the parallel beam, entering into the system, into a parallel beam of a different diameter.

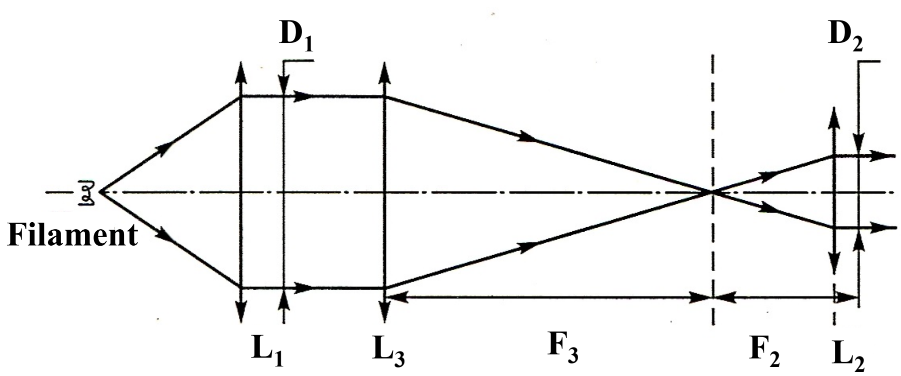

Figure 1: Implementation of the rays path in a telescopic optical system

The angular magnification of the optical system can be defined as:

$$N_{tel} = F_3/F_2, \tag{1}$$

or

$$N_{tel} = D_1/D_2. \tag{2}$$

Calculate the angular magnification of the given optical system using formulas 1 and 2. Compare the result. Draw the ray path diagram.

Task 2.2 Modelling Kepler's telescope

Form a parallel beam using the object (the letter *'F'*) as the object. Place a frosted glass and a plate with a letter into the slit in front of the lamp. Move the collimator *Lens 1* so that the source object is in the focus of the lens. Setting the object at the focus of the collimator lens is equivalent to removing the object to an infinitely large distance from the previously constructed telescopic lens system of *Lens 2* and *Lens 3*.

With a naked eye, observe the image of the object (letter) in the formed telescope. It is called Kepler's telescope. *Lens 3* in this case is called an objective, and the *Lens 2* is an eyepiece (or ocular).

Note that the length of Kepler's telescope is equal to the sum of the focal lengths of the objective lens and the eyepiece.

Draw the ray path diagram.

Task 2.3 Modelling Galileo's telescope

Replace the eyepiece lens (*Lens 2*) of Kepler's telescope with a concave one (use the *Lens 4*). The system should remain telescopic (see Figure 2). Observe a direct image of the object in the constructed telescope. It is called Galileo's telescope. Calculate the magnification. Draw the ray path diagram.

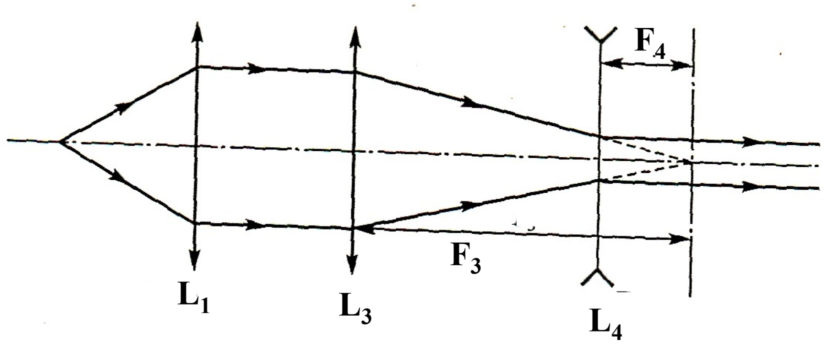

Figure 2: Modelling Galileo's telescope

The magnifying glass and the microscope

To observe an enlarged image of small objects, optical systems usually include one converging lens (in this case it is called a magnifying glass) or several lenses (it is typical for microscopes).

The magnification of the optical system is approximately calculated, knowing its focal length F, and the so-called best-sight distance L (that is equal to 250 mm for the average normal eye):

$$N = L/F = 250mm/F(mm). \tag{3}$$

In the simplest case the microscope consists of an objective with a focal length F_{ob} and an eyepiece with a focal length F_{ep}. The magnification of the microscope can be calculated with the distance of the best view of L and the distance between the focal points of the objective and the eyepiece (it is called the optical length of the microscope):

$$N_m = L/F_{ob}F_{ep}. \tag{4}$$

Both the magnifying glass and the microscope give virtual image of objects; it should be remembered that real image is always formed on the retina of the eye, with the help of the magnifying glass or the microscope.

Expressions (2) and (3) are not completely definite, since the magnification also depends on the parameters of the eye, in particular, on its optical force, which, as is known, varies when looking at objects located at different distances from the eye (the accommodation).

Task 3.1 Studying the magnifying glass and determination of its magnification.

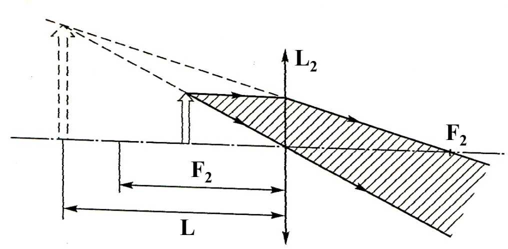

Figure 3: Studying the magnifying glass and determination of its magnification

As a magnifying glass, use the converging *Lens 2* (see Figure 3). Put in front of the lens a scale with millimetre divisions and observe an enlarged image of the scale. Knowing the focal length of the lens, calculate the magnification of the lens using expression (2).

Task 3.2 Modelling the microscope

Assemble the microscope system (see Figure 4). As an object, use the object-micrometer (with a scale 1 division = 0.1 mm) applied to a glass placed in a rectangular frame. Place the object-micrometer onto a table and insert a frosted glass into the slot in front of the lamp. Place *Lens 1* on the bench so that the distance between the object (that is in the frame) and the lens is slightly larger (by 2-3 cm) than the focal length of the lens.

Find the place where the actual enlarged image of the scale is formed. Place the eyepiece (*Lens 2*) at the end of the bench. You can use it as in a magnifying glass. You can see by a naked eye a real image of the scale (the entire field of view must be uniformly illuminated, and the scale divisions are extremely sharp).

Place a ruler below the axis in the focal plane of the eyepiece (ocular), observe both scales simultaneously and determine the subjective magnification of the microscope. To do this, you need to know the scale division of the object scale (1 division = 0.1 mm), the scale division of the ruler and the magnification of the eyepiece:

$$N_{mic} = N_{ob} \cdot N_{oc}, \tag{5}$$

with N_{ob} and N_{oc} being the objective and ocular magnification, respectively.

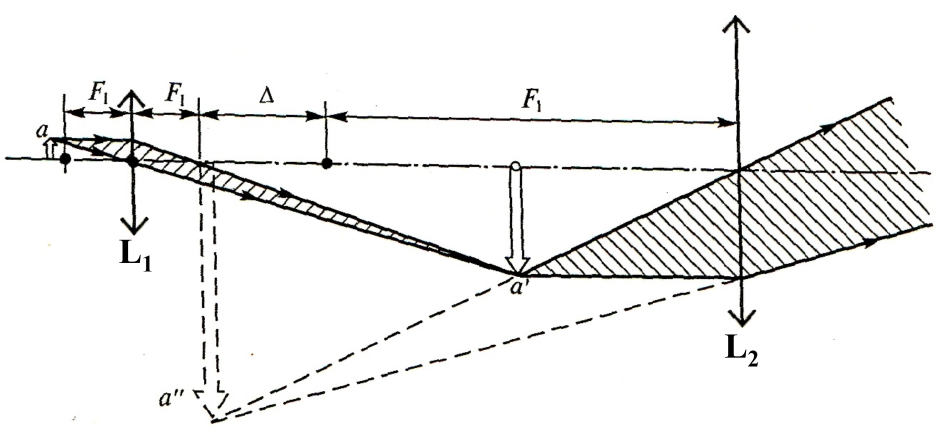

Figure 4: Modelling the microscope

Calculate the magnification of the microscope by measuring the optical distance of the microscope on the bench (see Fig. 4), knowing F_{ob} and F_{ep} and using expression (3).

Reduce the distance between the subject and the lens (do not forget that it should not be less than the focal length of the lens!). Using the procedure described previously, measure the new value of the subjective magnification of the microscope and compare it with formula (3).

The optical slide projector

A slide projector is designed to obtain an enlarged image of a transparent object (a slide) on the screen. In principle, one converging lens is sufficient for that; the object (a slide) must be at a distance slightly higher than the focus of the lens (see Figure 5):

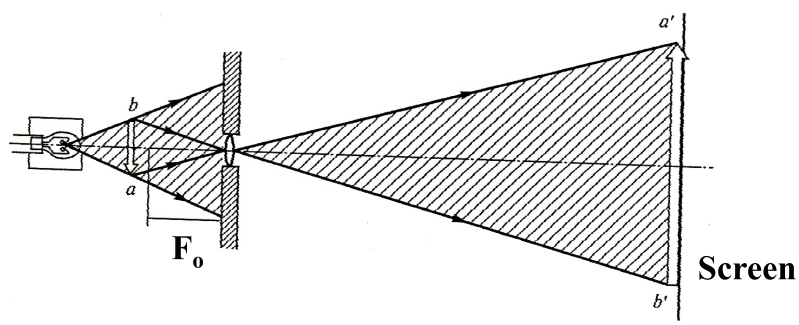

Figure 5: A slide projector

Task 4.1 Modelling the simplest projector

Assemble the optical system as shown in Fig. 5 by placing a slide in the frame at some distance (10 - 15 cm) from the lamp and using the *Lens 2*. Obtain an image of the slide on the screen that is in 30 - 40 cm away from the lens.

Despite the possibility to obtain a sharp image (at least, its central part), the illumination of the image is very weak even when the filament of the lamp is heated intensively.

The fact is that the system is energetically inefficient: only a small fraction of the light flux passes through a relatively small part of the lens. To increase the energy efficiency of the optical system, the slide projector is supplied with a condenser. The condenser is a converging lens, installed between the light source and the object (see Figure 6). The condenser C directs the light flux of the source to the object, and the light beam continues to converge.

In a properly designed projector, the distance from the slide to the lens and from the lens to the screen remains almost the same as in the previous configuration.

Task 4.2 Increase in the energy efficiency of the slide projector

Assemble the optical system using the same lens as in 4.1.

In addition, place the condenser (*Lens 1*) as shown in Fig. 6. Make sure that the light is collected by the condenser and that the *Lens 2* is placed where the light is focused by the condenser. As a result you will get a bright and sharp image of the slide on the screen which now may be moved farther away.

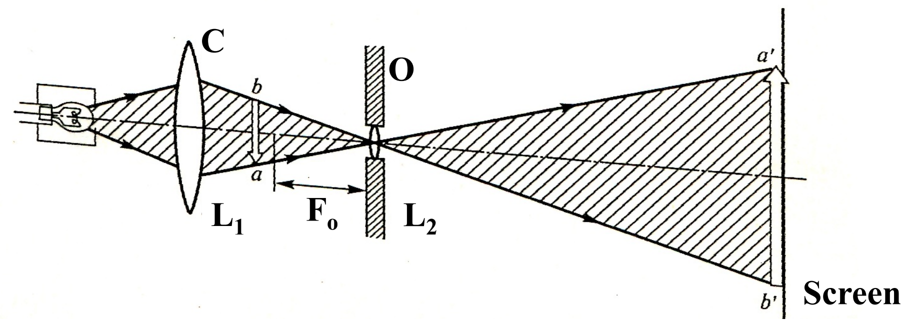

Figure 6: A slide projector with a condenser

All the tasks must be accompanied by ray path diagrams with the indication of the parameters of the optical elements!

Questions

1. What is the optical strength of a telescopic system?
2. Is there a linear magnification in the telescopic system?
3. Why is the beam coming out of the telescopic system sharply limited only in one place? Check it experimentally.
4. What physical considerations should be used in the practical choice of diameter for: a) Kepler's objectice? b) its eyepiece?
5. What elements should be introduced into Kepler's telescope to obtain a direct image? In which systems (or devices) does this configuration apply?
6. What devices use Galileo's optical system?
7. Is it reasonable to construct Galileo's telescope, in the field of view of which there should be a measuring grid (scale)?
8. How can you experimentally estimate the magnification of a magnifying glass without knowing its focal length?
9. Which image, direct or inverted, is observed with a microscope?
10. Can two microscopes that have the same lenses and the same eyepieces have different magnifications?
11. What part of the microscope - the object lens or the eyepiece - should be more free from aberrations of real lenses?
12. Is it possible to observe objects in an optical microscope whose dimensions are smaller than the wavelength of the light wave?
13. How should you insert a slide into the frame of the projector so that the image on the screen is neither upside down nor right-to-left?
14. What should be the minimum size of the condenser in a properly designed slide projector?