O4e „Focal Length and Principal Planes of a Lens System“

Tasks

1 Determine the focal length and the position of the principal planes of a system consisting of two thin converging lenses for a given lens distance.

2 Determine the focal lengths of both lenses using Bessel’s method. Measure the distance between the lenses and calculate the focal length of the lens system.

3 Draw a diagram to scale showing the positions of the principal planes and the focal points of the lens system; construct an image corresponding to one measured example from *task 1*. Determine the value of the linear magnification from the construction and compare to the experimental value.

Literature

Physikalisches Praktikum, 13. Auflage, Hrsg. W. Schenk, F. Kremer, Optik, 1.0, 1.1, 1.2
Physics, P. A. Tipler, 3rd Edition, Vol. 2, Chap. 31 Geometrical Optics
Physics, M. Alonso, E. J. Finn, Chap. 33.4, 33.5
University Physics, H. Benson, Chap. 36

Accessories

Optical bench with lens system, lamp with scale, eyepiece micrometer

Keywords for preparation

- “Thin” and “thick” lenses, thin-lens equation, lens-maker´s equation, optical power
- Construction of real and virtual images using principal rays
- Multiple lenses
- Measurement of focal length, determination of object and image distances, Bessel´s method
- Lens aberrations (spherical aberration, chromatic aberration, astigmatism)

Remarks

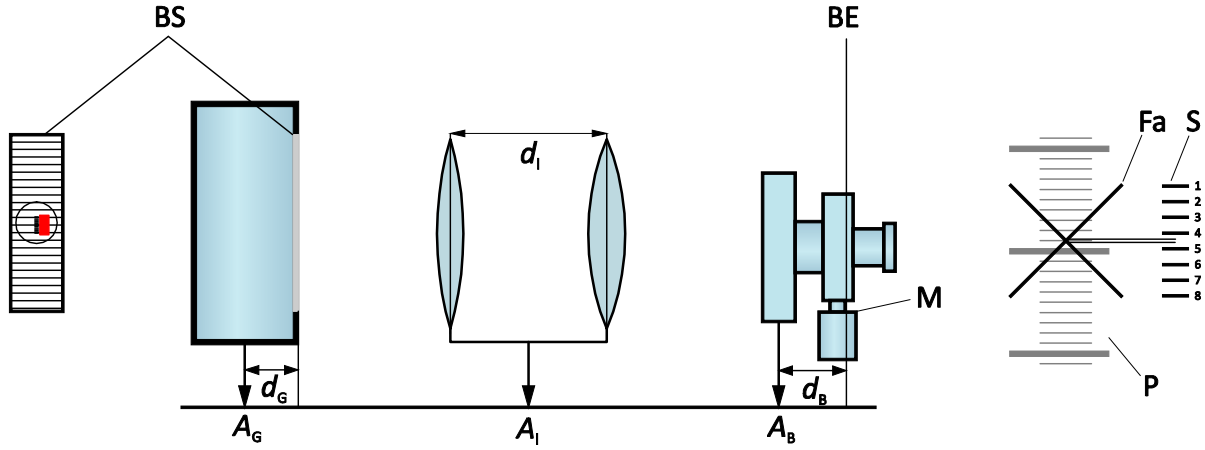

Fig. 1 Experimental setup

Measure the linear magnification for about ten different settings of the image distance using the full length of the optical bench.
To do this the image size is measured with an eyepiece micrometer (fig. 1 P), while a scale (Fig. 1. BS, 0.1 mm resulution) is used to determine the object size. One turn of the micrometer drum (Fig. 1 M) of the eyepiece micrometer moves the reticle (Fig. 1 Fa) by one millimeter. The millimeter value is read of the scale (FIg. 1 S) while decimals can be determined from the micrometer drum.

Note the correction values for the distance between lens system midpoint (Fig. 1 A_l) and object (Fig. 1 d_G) resp. image plane (Fig. 1 d_B). In *task 1* the analysis for the determination of the focal length of the lens system is made graphically (diagrams $b'(\gamma)$ and $g'(1/\gamma)$). From this calculate f_{sys} and the values of h and h'. In *task 3* construct the image in a diagram made to scale for one selected value of the object distance. Determine the image distance b' and the lateral magnification γ from this construction and compare to the experimental values.

Lens system No.	d_G (mm)	d_B (mm)	d_l (mm)
I	40	30	215
II	40	30	245
III	40	30	272
IV	40	30	235

For the lens distance (Fig 1. d_l) the values in the table above should be used.

Diagrams and important equations

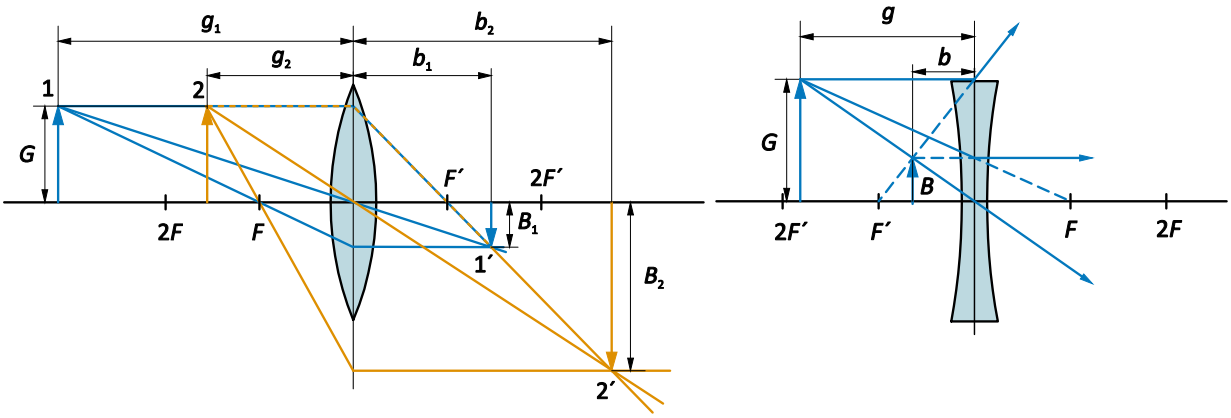

Fig. 2. Image construction for a (a) thin convex and (b) thin concave lens.

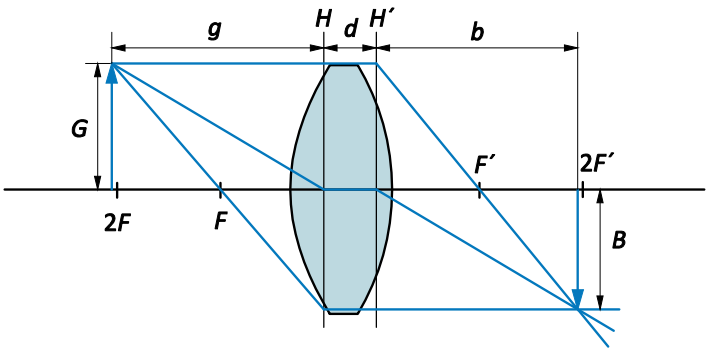

Fig. 3. Image construction for a thick convex lens.

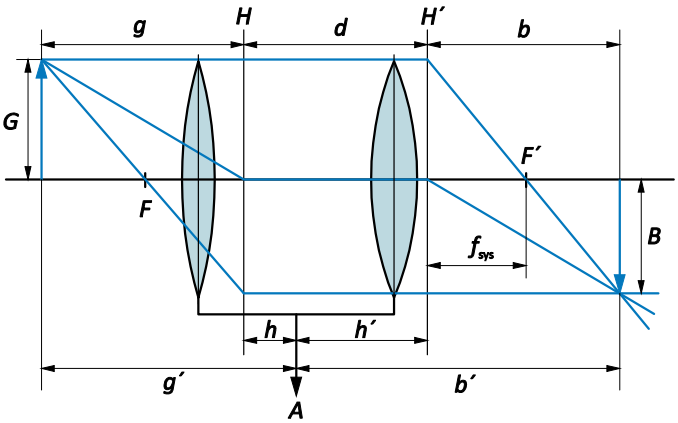

Fig. 4. Double lens system.

g' and *b*' denote the distances between the pointer *A* and the illuminated object *G* or the image *B*, respectively.

h and *h*' denote the distances between the pointer *A* and the principal planes *H* and *H*' of the lens system.

The imaging equations for the lens system are:

$$g' = g + h = f_{\text{sys}}\left(1 + \frac{1}{\gamma}\right) + h \qquad (1)$$

$$b' = b + h' = f_{\text{sys}}(1 + \gamma) + h' \,. \qquad (2)$$

Derive these equations. $\gamma = B/G$ denotes the linear magnification, f_{sys} the focal length of the lens system with

$$\frac{1}{f_{sys}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d_l}{f_1 f_2} \quad , \qquad (3)$$

where d_l denotes the distance between the lenses and f_1, f_2 their focal lengths.

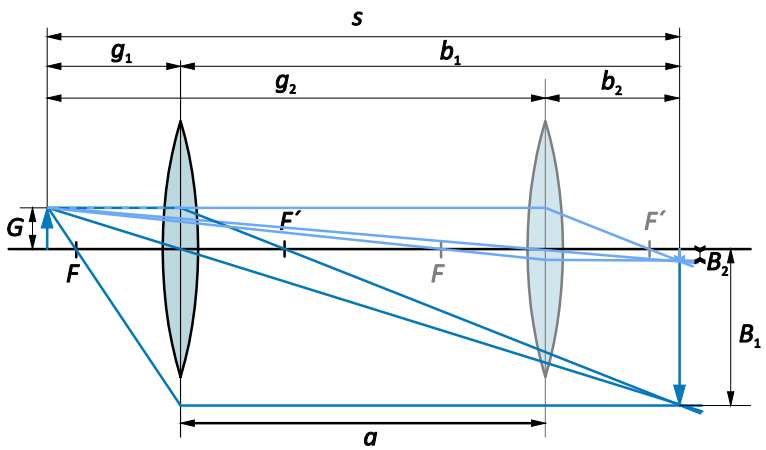

Fig. 5. Bessel's method.

At a fixed distance s between object and screen (Fig. 5) sharp real images are obtained on the screen for two symmetric lens positions 1 and 2, if the distance s is larger than the quadruple of the focal length of the lens. Derive the equation for the determination of the focal length using Bessel's method and give reasons for the restriction on s.