Determination of the focal lengths of divergent lenses and lens systems (Item No.: P1410503)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physics	Age 14 -16	Optics	Lenses	Determination of the focal length of divergent lenses and lens systems

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	40 Minutes	1 Student

Additional Requirements:

Experiment Variations:

Keywords:

Task and equipment

Introduction

Real images only occure for projections with converging lenses (convex lenses) with a positive focal length (f). In contrast, using a diverging lens (concave lens) with ($f < 0$)only virtual images can be generated. For the determination of the focal length, a system combing both lens types is used.

Task

This experiment also uses the already known methods for focal length determination on a system of lenses combining converging and diverging lenses.

1. Determination of the focal length of a system with two converging lenses (with both the lens formular and Bessel's method).
2. Determination of the focal length of a system with a converging and a diverging lens (with both methods).

Equipment

Position No.	Material	Order No.	Quantity
1	Optical profile-bench, l = 1000 mm	08370-00	1
2	experimental lamp hex 1	08130-99	1
3	Slide mount for optical bench	09822-00	2
4	Mount with scale on slide mount	09823-00	2
5	Lens, mounted, f +100 mm	08021-01	1
6	Lens, mounted, f +200 mm	08024-01	1
7	Lens, mounted, f +300 mm	08023-01	1
8	Lens, mounted, f -200 mm	08028-01	1
9	Diaphragm holder, attachable	11604-09	1
10	Object -L-, glass bead	11609-00	1
11	Screen, white, 150x150 mm	09826-00	1

Setup and procedure

Setup

The setup is shown in fig. 1:

- Insert the experimental lamp into the hole in the mount and fasten it. Place the mount onto the optical bench in such a way, that the white mark sits at $2,3\mathrm{cm}$.
- Plug in the power plug and turn on the lamp.
- Place a mount with and attach a diaphragm holder with inserted glass bead "L". The glass bead should point away from the lamp. Furthermore, it is adsived to turn the "L" in a horizontal position.
- The object should be illuminated completly. If not, move the lamp with the horizontal slider to focus the light.
- The lens / lens system and a screen hold by their mounts are positioned onto the optical bench.

Procedure

It is advantageous to lay the long leg of the perl-L horizontally. With the help of the slider on the luminaire housing, the lamp is now shifted so that the perl-L, which always remains stationary, is currently illuminated.

The resulting focal lengths of two lens systems must be determined. One system consists of the two converging lenses with the focal lengths $f_1 = +100\mathrm{mm}$ and $f_2 = +300\mathrm{mm}$, the other lens with the focal lengths $f_1 = +50\mathrm{mm}$ and $f_2 = -50\mathrm{mm}$.

If the lampholders are correctly nested, the spacing of their principal planes is $t = 14\mathrm{mm}$. Now, for different positions of the lens systems by moving the screen are sharp to produce enlarged and reduced images.

ATTENTION: When determining the locations of the object and lens system, the following must be considered:
the correct position of the Perl-L is $1\mathrm{cm}$ in front of the bar at the foot of the corresponding holder the median plane of a lens system is about $0.35\mathrm{cm}$ before the stroke of the rider The total focal length of the system from the two converging lenses is determined once by the lens formula (3) and by the Bessel method (4) for comparison. The measurement with the combination of collection and diverging lens is carried out only according to the Bessel method.

Results and evaluation

Results

Table 1 shows the measured values and the results for a lens system consisting of two converging lenses with the focal lengths $f_1 = +100\mathrm{mm}$ and $f_2 = +300\mathrm{mm}$.

table 1: power of lenses f_g of a lens system containing two convergent lenses.

	power of lenses			Bessel methode		
n	g/cm	b/cm	f_g/cm	d/cm	e/cm	f_g/cm
1	16,0	16,3	8,07	70,0	51,4	8,06
2	17,0	15,7	8,16	68,0	49,2	8,10
3	18,0	14,6	8,06	66,0	46,9	8,17
4	19,0	14,0	8,06	64,0	45,0	8,09
5	20,0	13,3	7,99	62,0	43,0	8,04
6	21,0	13,0	8,03	60,0	40,6	8,13
7	22,0	12,5	7,97	58,0	38,5	8,11
8	23,0	12,2	7,97	56,0	36,4	8,09
9	24,0	11,9	7,96	54,0	34,1	8,12
10	25,0	11,6	7,92	52,0	31,9	8,11

The focal length calculation is carried out both with the aid of the lens formula (3) and according to the Bessel method (4). For the total focal length f_g the following mean values result:

Evaluation according to the lens formula:

$$f_g = (8{,}02 \pm 0{,}14)\mathrm{cm}; \Delta f/f = \pm 1{,}7\,\%$$

Evaluation according to Bessel methode:

$$f_g = (8{,}10 \pm 0{,}07)\mathrm{cm}; \Delta f/f = \pm 0{,}86\,\%.$$

The distance t of the main planes HE of the two converging lenses is $t = 14\mathrm{mm}$.

With this value and the details of the focal lengths, the focal length of the lens system is calculated according to (1) as:

$$D_g = (1/10 + 1/30)\mathrm{cm}^{-1} + 1{,}4(1/10 \cdot 1/30)\mathrm{cm}^{-1} = 0{,}138\mathrm{cm}^{-1}$$

and $f_g = 1/D_g = 7{,}25\mathrm{cm}$.

It can be seen that the experimentally determined value of f_g according to the Bessel method provides a better match with the calculated value.

Table 2 contains the measured values for a lens system determined by the Bessel method, which consist of a convergent lens $f = +50\mathrm{mm}$ and a diverging lens $f = -50\ textmm$ exists.

table 2: power of lenses $f_g$of a lens system containing one converging lens $f = +50$mm and one diverging lens $f = -50$mm

	Bessel methode		
n	d/cm	e/cm	f_g/cm
1	96,0	58,0	15,24
2	93,0	55,0	15,12
3	90,0	51,0	15,28
4	87,0	47,0	15,4
5	84,0	44,0	15,24
6	81,0	40,5	15,19
7	78,0	36,5	15,23
8	75,0	33,5	15,01
9	72,0	29,5	14,98

The mean value of the total focal length is:

$$f_g = (15{,}19 \pm 0{,}21)\mathrm{cm};\ \Delta f_g/f_g \approx \pm 1{,}4\,\%.$$

With this value, for the focal length f_z, the diverging lens is obtained according to (1) and again with $t = 14\mathrm{mm}$:

$f_z = -17{,}86$ cm.

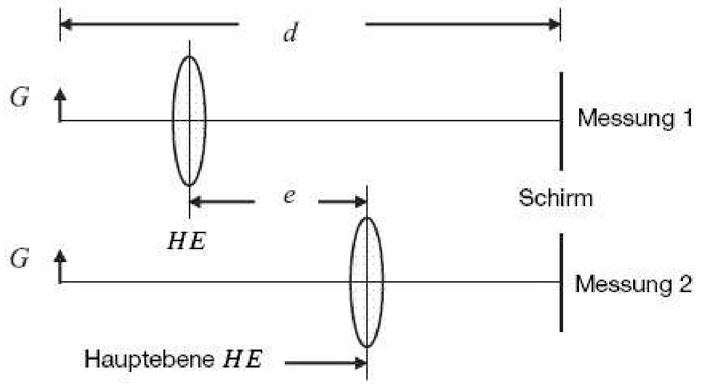


fig. 4: Bessel methode

Evaluation

Methode

A lens with the focal length f, has a power of lens $D(1\,dpt = 1/\mathrm{m})$.

The total power D_g of a lens system containing two lenses with their individual power D_1 and D_2, that placed in a distance t, is given by (Fig. 2):

$$D_g = D_1 + D_2 - t \cdot |D_1| \cdot |D_2| = \frac{1}{f_s} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{t}{|f_1| \cdot |f_2|} \quad (1)$$

If the lenses are placed really closed together ($t << f_1, f_2$), both lens powers add up:

$$D_g = D_1 + D_2 = \frac{1}{f_s} = \frac{1}{f_1} + \frac{1}{f_2} \quad (2)$$

The power of lenses of a converging lens D_c and therefore, the its focal length is always positive.
In contrast, divergent lenses are always having a negative focal distance. Hence, the power of lenses is always $D_z < 0$ (Fig. 3).

If a lens system only consists of collecting lenses, then real pictures are always created, because in this case $D_g > 0$.
If, on the other hand, a converging lens with the refractive power D_s is combined with a divergent lens of refractive power D_z, then always $|D_s| > |D_z|$ for a real image.

If this is the case, it is possible, with knowledge of the refractive power of a condenser lens with the aid of the lens formula, to determine the unknown refractive power of the diverging lens by imaging an object.

For thin lenses and lens systems, the lens formula applies to imaging with near-axis rays:

$$\frac{1}{f} = \frac{b+g}{b \cdot g} = \frac{1}{g} + \frac{1}{b} \quad (3)$$

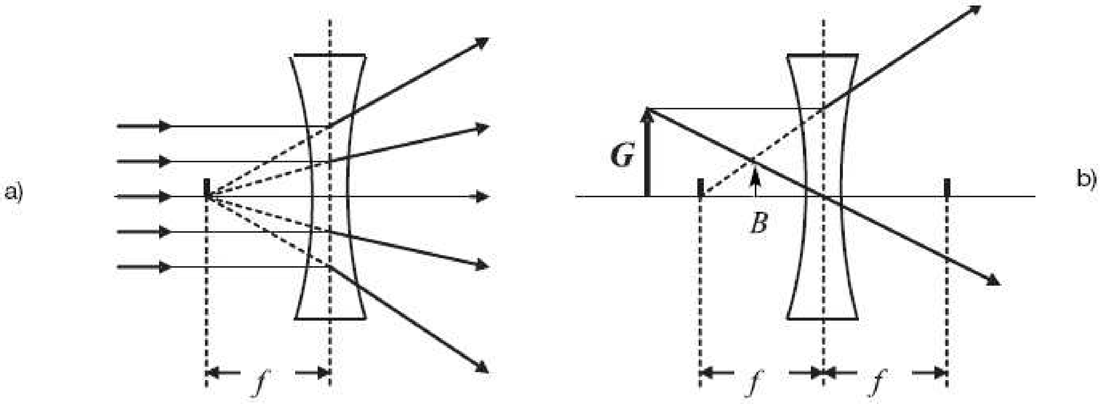
With known object widths g and the associated image widths b the focal length can be determined.

Another method can be used to measure the focal length of a lens system if the distance d between the object and the imaging plane is greater than $4f$. For a given distance d of object and image one can obtain a sharp image (enlarged and reduced) for two positions of the lens system.

If we use e to denote the difference between these two positions (Fig. 4), the following applies to the focal length:

$$f = \frac{d^2 - e^2}{4d} \quad (4)$$

This method, named after the mathematician and astronomer Bessel, offers the advantage that it is not the position of the lens system that has to be absolutely determined, but only the difference between the two positions.



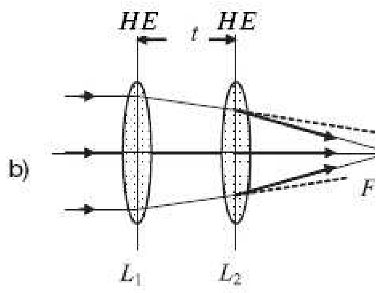


Fig. 2: Resulting focal length of
converging

Fig 3: Optical path through a divergent lens. a) Parallel rays seem to come from the focal point. b) Construction of the virtual image.

Fig. 3a): Incident parallel rays appear to come from the focal point
Fig. 3b): Construction of a virtual image