Determination of the focal lengths of convergent lenses - lens formula and magnification (Item No.: P1410403)

Curricular Relevance

Area of Expertise: Physics → **Education Level:** Age 14 -16 → **Topic:** Optics → **Subtopic:** Lenses → **Experiment:** Determination of the focal length of convergent lenses - lens formula and magnification

Difficulty	**Preparation Time**	**Execution Time**	**Recommended Group Size**
Difficult	10 Minutes	30 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

lens formular, Law of lenses, focal length, convex lens, converging lens, real image, virtual image, magnification

Task and Material

Introduction

A transmissive optical devise which focusses parallel inciding light beams into the focal point are called convex lenses.
The knowledge about their properties are important for the building of optical instruments.

Related Topics

A first impression on imaging with convex lenses was already given by the experiment "Real images on a converging lens (on the optical bench)" (P1435800). There, the image size was determind in dependency of the object distance, although, it focused more on the image size and not as much on the focal distance of a lens.

Task

1. Determination of the magnification and focal length of a converging lense with law of thin lenses.
2. Determination of the focal length using Bessel's method.

Material

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	Diaphragm holder, attachable	11604-09	1
7	Object -L-, glass bead	11609-00	1
8	Screen, white, 150x150 mm	09826-00	1
9	Measuring tape, l = 2 m	09936-00	1

Setup and Procedure

Setup

Fig. 1 shows the experimental setup.

- Insert the stem of the lamp into the hole of the mount and attach it to the optical bench at 2.0 cm. Using the horizontal slider, move the lamp towards the beginning of its case, so that the object is fully illuminated.
- The lamp is turned on by plugging in the power plug.
- Position a slide mount without angle scale directly in front of the lamp (mark at 15.0 cm). Attache a diaphragm holder with the inserted glass bead 'L'.
- The lens (f = +100 mm) and screen attached to a mount are both placed on the optical bench.

Please note: The position of the glass bead -L- varies with 0.5 cm to the position of the mount's white mark.

Fig.1: Experimental Setup

Procedure

For easier measurements, it is advised to turn the long side of the glass bead -L- in horizontal position.

1. For different lens positions, the screen is slided back/forth until a clear image of the 'L' is projected onto it. Choose the lens positions in such way, that magnified and minimized images occure. Using the meter scale, measure the size of the long side of 'L' (distance between the center of the outer points). Furthermore, take down object and image distance. (Distance between object and lens, and image and lens).
2. The second measurement for comparision is taken by Bessel's method. Place the screen in fixed distances towards the object. Hence, move the lens and find both clear images on the screen. (Displacement of the lens in both directions from the middle line of the screen-object-distance.) For more information, look at fig. 3. At both lens positions, take down the object distance.

Results and Evaluation

Method

An object O can be projected onto a screen with a thin converging lens of focal length f. Depending on the distance between object and the center of the lens, real magnified or minimized and even virtuall images I can occure. In fig. 2, the projection is scetched, with the object within the $2f$ length in fig. 2a and beyond in fig. 2b. With three partricular rays, the parallel ray, the focal ray and the central ray, the image can be constructed. Depending on the position of the object, the image is magnified or minimized but always turned upside down (real images). The image becomes virtuall, when O is within the focal length.

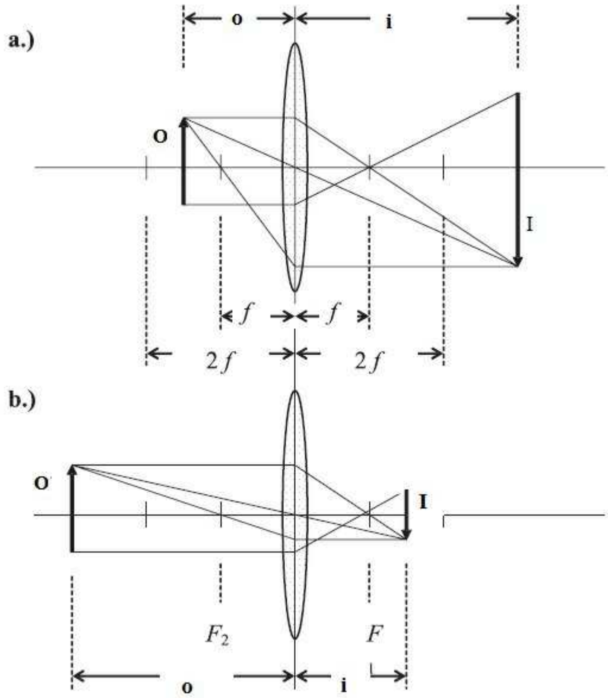

Fig. 2: Imaging with convex lens a: Object O within double focal length, b: O beyond double focal length

The law of similar triangles gives
$M = \frac{I}{O} = \frac{i}{o}$
with the magnification M, the image distance i and the object distance o.
Using fig. 2, gives the following relation:
$\frac{I}{i-f} = \frac{O}{f}$ and $\frac{O}{o-f} = \frac{I}{f}$.
Convert both formulas gives the lens formular for thin lenses.

Lens formula: $\frac{1}{f} = \frac{i+o}{i \cdot o} = \frac{1}{o} + \frac{1}{i}$

For distances d between object and image which are larger than $4f$, two lens position project clear images. Both positions are symmetric towards the center line for d. Both positions vary with $e/2$ towards the center of the distance (fig. 3). This is the so called **Bessel method**, which can also be used for focal length determinations.

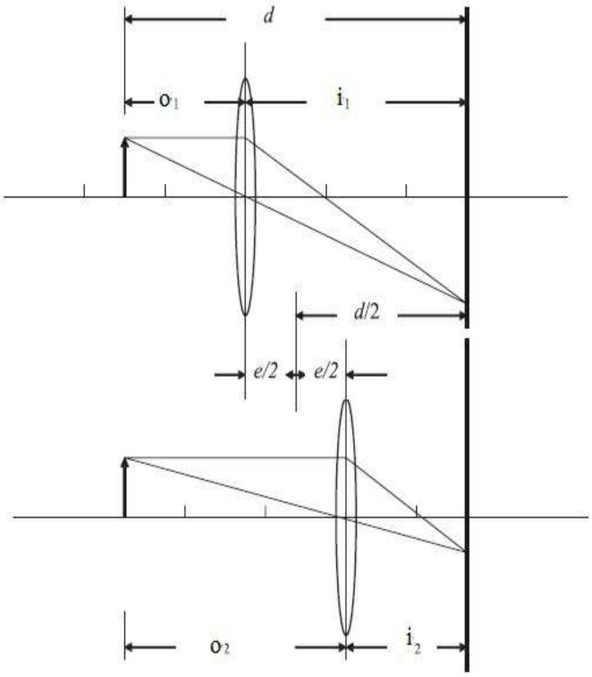

Fig. 3: Determination of focal length with Bessel's-method

Fig. 3 leads to:
$i_1 + o_1 = d$ and $i_1 - \frac{e}{2} = \frac{d}{2}$.
Both equations together can be solved towards i_1 and o_1:
$o_1 = \frac{d-e}{2}$ and $i_1 = \frac{d+e}{2}$.
Inserting this into the formular for thin lenses and solving for f, gives the focal length with Bessel's-method.

Focal Length by Bessel's method: $f = \frac{d^2 - e^2}{4d}$

In table 1, example data and the results for converging lenses with a focal length $f =$ + 100 mm are summerized. The focal length was gained by the lens formular.

To get the magnification M, the hight of the long side of the glass bead L was measured (distance between the center of the outer glass beads) which is 3,0 cm. For the convex lens (f = + 10 cm) a mean of $f = (10,3 \pm 0,06)\mathrm{cm}$ is gained for the focal distance. The result of the comparing measurement with Bessel's method can be found in table 2.

Bessel's method leads to a total mean of $f = (10,7 \pm 0,1)\mathrm{cm}$.
For objects within the single focal length no real image is gained.

The image becomes virtuall and the lens works as a magnifying glass.

For object distances of $2f$, the image and object size is similar ($B = G$).
All the images, no matter whether they are magnified or minimized, are turned upside down.

Table 1: Determination of magnification and focal length of converging lenses

Measurement	Object Distance	Image Distance	Image Size	Object Size	Magnification	Magnification		Focal Length
	o/cm	i/cm	I/cm	O/cm	$M_1 = i/o$	$M_2 = I/O$	M_2/M_1	f/cm
1	13	53.5	12	3.0	4.11	4.0	0.97	10.46
2	15	34.5	6.5	3.0	2.3	2.17	0.94	10.45
3	17	27.4	4.6	3.0	1.61	1.53	0.95	10.49
4	19	22.9	3.4	3.0	1.20	1.13	0.94	10.38
5	21	20.3	2.6	3.0	0.97	0.87	0.89	10.32
6	23	18.5	2.2	3.0	0.80	0.73	0.91	10.25
7	25	17.1	1.7	3.0	0.68	0.57	0.83	10.15
8	27	16.2	1.5	3.0	0.6	0.5	0.83	10.13
9	29	15.9	1.4	3.0	0.55	0.47	0.85	10.27
10	31	15.1	1.2	3.0	0.49	0.4	0.82	10.15

Table 2: Determination of the focal length by Bessel's method

Measurement	distance object-screen d/cm	lens position 1 o_1/cm	lens position 2 o_2/cm	difference position 2 - position 1 e/cm	focal lenght f/cm
1	80	13	68.3	55.3	10.44
2	75	13.3	63.3	50.0	10.42
3	70	13.6	58.0	44.4	10.46
4	65	13.9	52.7	38.8	10.46
5	60	14.2	47.4	33.2	10.41
6	55	14.7	41.6	26.9	10.46
7	50	15.4	36.0	20.6	10.38
8	45	16.8	30	13.2	12.7