Physik-Praktikum: OPA

Introduction

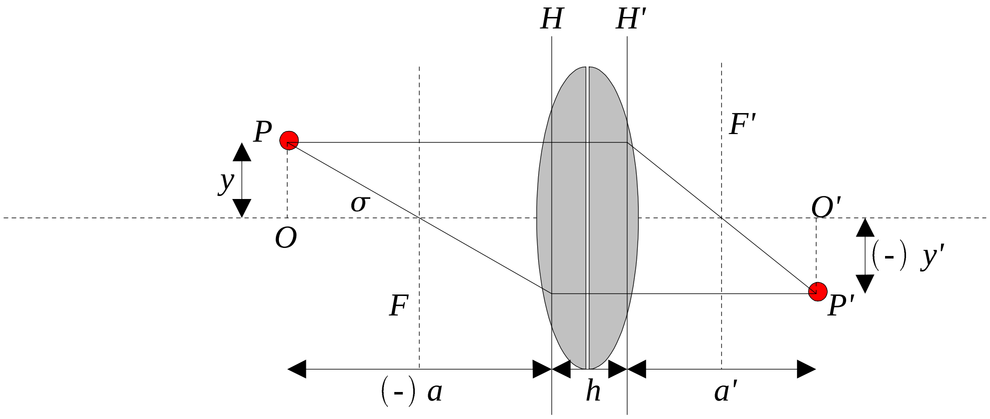
In geometrical optics (using lenses, prisms and mirrors) light is considered as composed of single beams that can be described by geometry. Because of the big scale of the experiment (that means, the wavelength of light is much smaller than the components used) the wave character and interference can be ignored.

The following assumptions are made in geometrical optics:

- Light can be described by separate rays. One ray describes a direct line in a homogeneous medium.
- Different rays may intersect but aren't influenced by each other.
- On the interface between two media with different speeds of light, the direction of a beam may change.

In addition the principal of Fermat applies:

Light covers the distance between two points by travelling (with regard to time) the shortest way. Because of different speeds of light in different media, the way that can be travelled in the shortest time, is not necessarily the shortest distance.



Because in these experiments the angle σ is rather small, we can make even more simplifications: we use two main planes (H, H') and two focal planes (F, F') to describe the rays of light.

Experimental Setting

Optical components used:

- optical bench (with a scale from 1 cm to 140 cm)
- lenses: type A, B, C, D, E, G, H (all lenses can be considered as thin lenses)
- light source (halogen lamp)
- objects to be projected:
  - slide with grid
  - slide with a small drawing of a car
- clips (to fix the lenses, frames ... on the optical bench)
- frames (to hold a white screen, mirror ...)

1st Experiment: Which of the lenses A, B, C, D, E, G, H are condensor lenses, which are dispersion lenses?

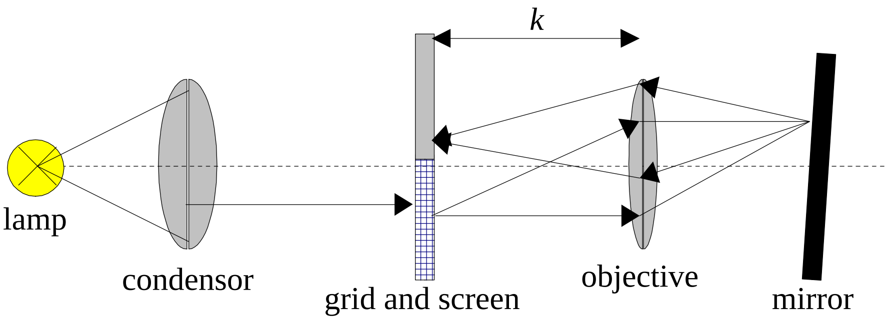
By looking through the lenses that are held closely over a paper with grid pattern one can easily see whether the grid is magnified or not; only condensor lenses magnify images (In this case: the object is nearer than the focal plane of the magnifying glass, the spectator sees a magnified virtual image on the object side).

Result

Condensor lenses: A, B, C, D, G, H
Dispersion lenses: E

2nd Experiment: Determine the focal distances of lens B, C and D by means of autocollimation.

Setup



The halogen lamp, the "A" lens, a frame with a grid-pattern slide and the screen, the lens (whose focal distance should be determined) and a frame with a mirror are fixed on the optical bench. The distance between the "A" lens and the lamp is adjusted in such a way that the slide in the frame directly behind this lens is equally illuminated (that means, the lamp is in the focus of the "A" lens). In the distance k behind the slide/screen-combination is the lens and directly behind the mirror. The mirror is slightly turned so the projection of the grid is to be seen on the screen beside the slide.

Implementation

The position of the lens and mirror is adjusted until there is a sharp image on the screen. Because the lens can be considered as thin lens, the rule

$f = \frac{k+l}{2} = k$ (because the lens is symmetric, k and l are approximately equal)

applies.

Lens type	$f = k$
B	$k = (10.1 \pm 0.2)$ cm
C	$k = (20.4 \pm 0.2)$ cm
D	$k = (52.0 \pm 0.3)$ cm

3^{rd} Experiment: Create a lens system of lens B and E (the distance between the lenses should be 40 mm) and measure the focal distance f and the principal plane distance.

Using the method of autocollimation

Setup

Like the second experiment; instead of just one lens we use the described lens system. To fix the lenses we put each lens in its own clip (the two clips directly one behind the other, and the lenses are put into the outer holes of the clips); so the lenses have the distance of exactly 40 mm.

Implementation

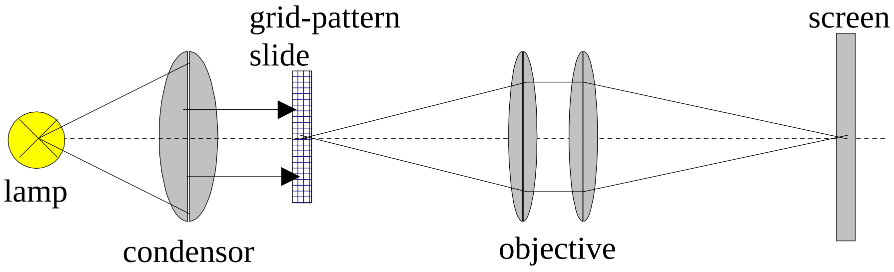
During the first measurement, lens 1 is our lens B and lens 2 is our lens E. The system of lenses is again moved until we see on the screen a sharp projection of the object. Now we turn the system by 180°, so that lens 1 becomes lens E and lens 2 becomes lens B and a new measurement is performed.

B-E	E-B
$k = (15.6 \pm 0.3)$ cm	$l = (33.3 \pm 0.3)$ cm

Using the method of Bessel

Setup

The mirror is removed and the screen is put at the other side of the lens system in a distance of 1250 mm behind the slide (which now is alone in its frame).



Implementation

Again, the position of the lens system is moved until there is a sharp projection of the slide on the screen.. In the Bessel method exist two positions where a sharp image of the slide appears on the screen, so we search for these positions and measure the distance between them.

Result: $d = (35.8 \pm 1.2)$ cm

Summary

With

$$f' = \frac{1}{2} \cdot \sqrt{(e - k - l)^2 - d^2}$$

we can calculate the focal distance of the system of lenses:

e = 1250 mm
k = 156 mm
l = 333 mm
d = 358 mm

$\Rightarrow\ f = -336\ \text{mm}\ ;$

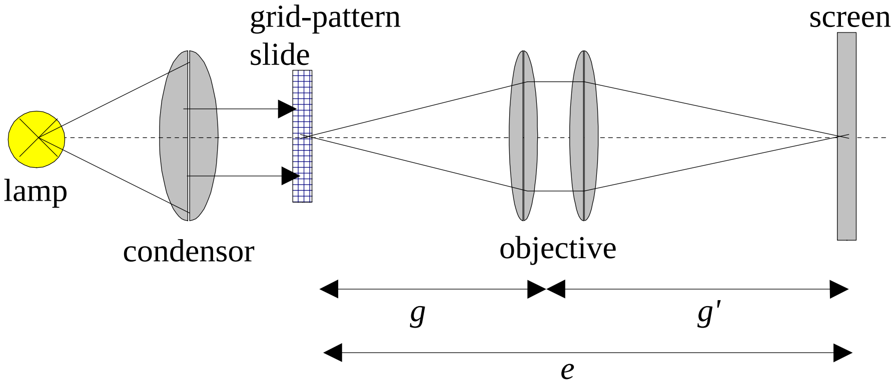
The distance of the principal plane is

$h = k + l - 2\ f = (156 + 333 - 2 \cdot 336)\ \text{mm} = 183\ \text{mm}\ .$

Using the method of Abbé

Setup

The setup is actually the same as with the method of Bessel:



Implementation

The screen is put in a distance of e = 1400 mm from the slide and the lens is adjusted that a sharp image is to be seen on the screen. The distance g between the slide and the middle of the lens system, the distance g' between the system and the screen and the gridwidth y' of the projected image is noted.

While reducing e in intervals of 25 mm, each time the lens system is re-adjusted to get a sharp image and e, g, g' and y' are noted down.

Results

Because a really sharp projection could hardly be achieved and the interval in which the image was quite sharp in some parts, the measurements are very inaccurate. We tried to take the measurements in the middle of this range.

e [mm] ± 5 mm	g [cm] ±0.1 cm	g' [cm] ±0.1 cm	y' [mm] ±1 mm	V	1-V
1400	24.6	115.4	16	-2.2	0.69
1375	24.4	113.1	16	-2.2	0.69
1350	24.5	110.5	15.5	-2.1	0.68
1325	26.0	106.5	14	-1.8	0.64
1300	26.0	104.0	13.5	-1.7	0.63
1275	26.7	100.8	13	-1.6	0.62
1250	27.0	98.0	12.5	-1.5	0.60
1225	28.9	93.6	11	-1.2	0.54
1200	29.4	90.6	10.5	-1.1	0.52
1175	30.7	86.8	9.5	-0.9	0.47

1150	32.0	83.0	9	-0.8	0.44
1125	33.5	79.0	8	-0.6	0.38
1100	35.5	74.5	7	-0.4	0.29
1075	37.5	70.0	6.5	-0.3	0.23
1050	43.0	62.0	5	0	0

The magnification factor is $V = \frac{y'}{y} = \frac{y'}{5\text{ mm}}$.

$$g = f \cdot \left(1 - \frac{1}{V}\right) + h_1 \; ; \; g' = f' \cdot (1 - V) + h_2 \; ;$$

see diagram “Graph 1” and the sketch:

$$\Rightarrow \; m_1 = f = 28.2 \text{ cm} \; ; \; m_2 = f' = 22.7 \text{ cm} \; ; \; \Delta\, h = 22 \text{ cm} \; ;$$

Calculate the focal distance of the system's dispersion lenses from the focal distances determined in 3.3.1 and 3.3.2 by means of equation (6) with t = 40 mm

$$f' = \frac{f'_1 \, f'_2}{\Delta} = \frac{f'_1 \, f'_2}{t - f'_1 - f'_2}$$

$$f'_1 \, f'_2 = f' \; t - f' \; f'_1 - f' \; f'_2$$

$$f'_2 = \frac{f' \; (t - f'_1)}{f' + f'_1} = \frac{227\,(40 - 94)}{227 + 94} = -38 \text{ mm} .$$

5th Experiment: Slide Projector

See question 3. We messed around with different objective lenses to create an image that is as big as possible (with a lens system as the objective).

Questions

What is a ray of light?

A ray of light is a thin bunch of parallel light. One can assume that different rays are independent of each other. A ray of light crosses straightforward a homogeneous medium in three dimensional space and the laws of refraction and reflection apply.

What is the ratio of the two images that correspond to position 1 and 2 (picture 3)?

The scaling factors β_1 and β_2 are calculated as follows:

$$\beta_1 = \frac{y_1 '}{y_1} \overset{(4)}{=} \frac{a_1 '}{a_1} = \frac{a'}{a} \quad \text{with} \quad \begin{array}{l} a = a_1 = -a_2 ' = (d + h - e)/2 \\ a' = a_1 ' = -a_2 = (d - h + e)/2 \end{array}$$

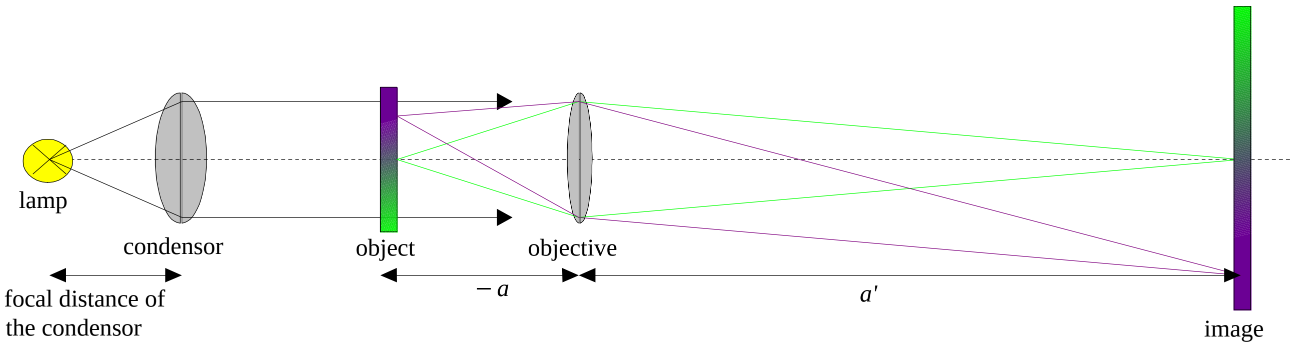
$$\beta_2 = \frac{y_2 '}{y_2} \overset{(4)}{=} \frac{a_2 '}{a_2} = \frac{a}{a'} = \frac{1}{\beta_1}$$

The original size of the object is constant: $y_1 = y_2 = y$

$$\boxed{\frac{y_1'}{y} = \frac{y}{y_2'} \quad \Rightarrow \quad y_1' \cdot y_2' = y^2} \Rightarrow \beta_1 = \frac{1}{\beta_2}$$

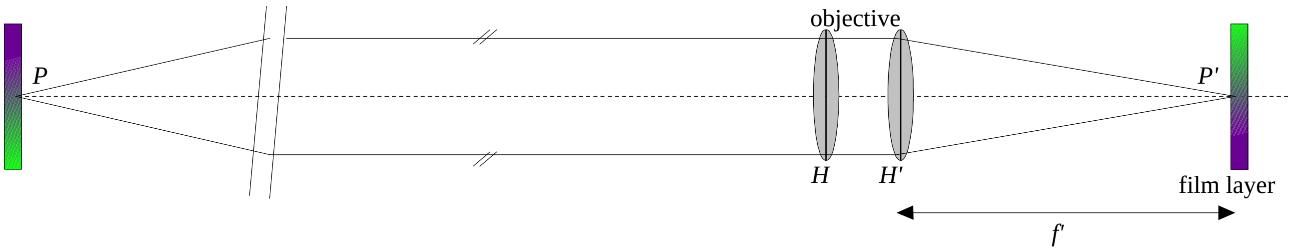
How are in a projector condensor, lamp and objective arranged?

The condensor is located between the lamp and the objective. The condensor is used to distribute the light from the lamp equally on the object (slide), so the lamp should be situated in the focus of the condensor to get parallel rays of light on the object's side. The distance between condensor and object (slide) does not matter.

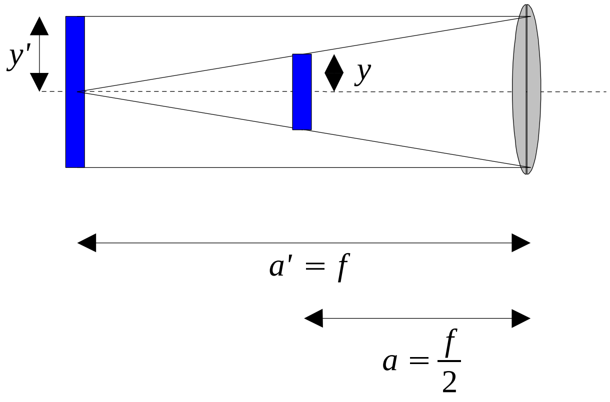


What is the distance between the film and the principal plane on the side of the image using a telephoto with 200 mm focal distance set to infinity?

When the telephoto is set to infinity, the rays of light on the object side of the objective lens system are approximately parallel, so they are focused on the image side of the objective in the focal layer. That means, the distance between the principal plane and the film should be the focal distance.



If an object is in a distance a = 0.5 f from the object side principal plane of a condensor lens, what results for the position, size and type of the image?



$$\frac{1}{f} = \frac{1}{a} - \frac{1}{a'} = \frac{2}{f} - \frac{1}{a'} \Rightarrow \frac{1}{a'} = \frac{1}{f} \Rightarrow a' = f;$$

That means, the distance between the image and the principal plane is the focal distance.

$$\beta = \frac{y'}{y} = \frac{a'}{a} = 2;$$

That means, the image has the double size of the object. It is a virtual image, that means it is on the same side of the lens as the object, and has the same orientation.

How changes the total focal distance of a lens system with two condensor lenses with same focal distance in dependence of the distance t?

$$f' = \frac{f'_1 f'_2}{\Delta} = \frac{f^2}{\Delta} \quad (6);$$

$$h = \frac{t^2}{\Delta} \quad (8); \quad \Delta = \frac{t^2}{h};$$

$$\Rightarrow \quad f' = \frac{f^2}{t^2} \cdot h;$$