

Spherical aberration in lens imaging

Objects of the experiment

- Investigation of the spherical aberration of a lens.
- Determination of the image defect due to spherical aberration.

Introduction

Lenses are optical elements which are used in many applications like (digital) cameras, microscopes, telescopes, glasses, spectroscopes and optoelectronic applications. In constructing such optical systems lens errors and imaging errors have to be corrected.

A spherical lens only images a point into an ideal point if the ray traces intersect the optical axis at small angles, and, if the angle of incidence and the angle of refraction are also small for the ray passing the lens. This condition of the so-called Gauss' optic is fulfilled only to a limited extend in practice, aberrations (image defects) are unavoidable.

In this experiment the "spherical aberration" is investigated. Further imaging errors of lenses, i.e. "chromatic aberration", "imaging distortions" (barrel and cushion) and "curvature of the image field in lens imaging". These errors are studied in the closely related experiments P5.1.3.2 to P5.1.3.4.

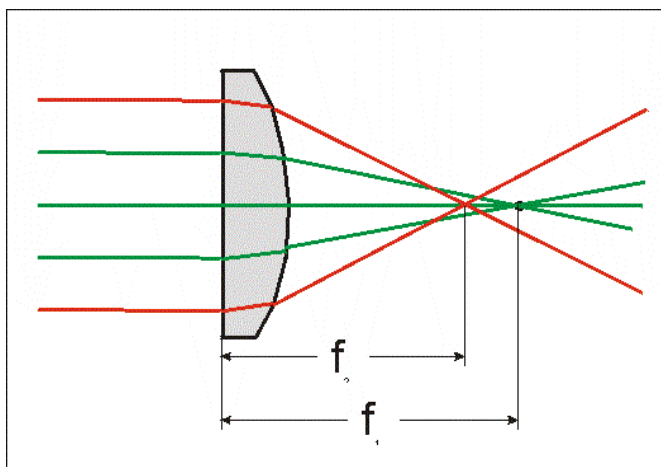


Fig. 1: Intersection of paraxial and abaxial rays. Only rays near the optical axis intersect at the focal point of the lens. Marginal rays intersect the optical axis between the lens and the focal point.

Principles

Spherical aberration is one of the various image defects to be found in lenses. In a ray path parallel to the optical axis, paraxial rays striking a lens of large aperture are not all united at one focal point. The focal length is shorter for marginal rays than for rays close to the optical axis (Fig. 1). As a result in the focal plane the rays near (around) the optical axis form a small circular area.

This lens aberration can be reduced by various means, for example by suitably selecting the radii of the curvature of the front and rear lens surface.

Apparatus

1 Pair of stops for spherical aberration	461 61
1 Set of 2 transparencies	461 66
1 Lamp housing	450 60
1 Lamp 6 V / 30 W	450 51
1 Aspherical condensor	460 20
1 Transformer 6 V / 12 V	521 210
1 Lens $f = +150$ mm	460 08
1 Iris diaphragm	460 26
1 Translucent screen	441 53
1 Small optical bench	460 43
1 Stand base, V-shaped, 20 cm	300 02
4 Leybold multiclamp	301 01

Setup

- Set up the lamp with the aspherical condensor on the optical bench as depicted in Fig. 2.
- When illuminating with the 6 V lamp turn the insert of the lamp in the lamp housing so that an sharp image of the lamp filament can be observed on the opposite wall (The distance between lamp and wall should be in the order of 3 m to obtain parallel light.).

- Align the insert of the lamp so that the image of the lamp filament is horizontally. The parallelism of the light beam might be checked by, e.g. allowing the light to pass across a piece of paper just touching the surface. If necessary, readjust the lamp by the three adjusting screws at the rear of the lamp housing.
- Set up the translucent screen like shown in Fig. 3 and place the lens $f = +150$ mm with its convex side towards the lamp between lamp and translucent screen.
- Insert the transparency with the grid (spacing 5 mm x 5 mm) into the slide holder attached to the aspherical condenser.
- Place the iris diaphragm in front of the lamp and open it completely.
- Shift the lens (towards the lamp) until a sharp image of the grid can be observed on the translucent screen.

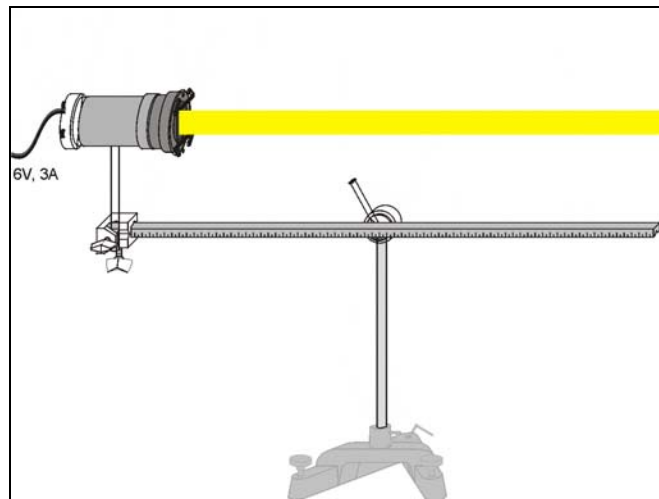


Fig. 2: First adjust of the lamp and aspherical condenser in such a manner that the light beam is parallel along the optical axis.

Carrying out the experiment

- Attach the diaphragm with the central hole on the plane side of the lens to block out the marginal light rays (Fig. 4).
- Produce a sharp image of the grid by moving the lens.
- Read off the lens position f_1 .
- Cut out the central rays by replacing the pinhole diaphragm with the ring diaphragm.
- Shift the lens until a sharp image of the grid is observed. Note: The image due to the marginal rays is less illuminated.
- Read off the lens position f_2 .

Note: Alternatively, the screen can be moved to observe the spherical aberration. The image distance in this setup corresponds to the focal length f_1 and f_2 , respectively.

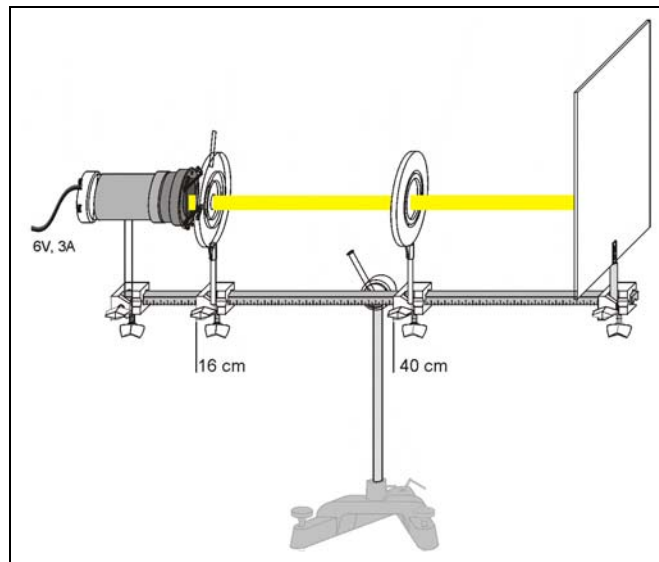


Fig. 3: Experimental setup to investigate the spherical aberration of lenses: Lens position for a sharp image.

Measuring example

The lens position for central and marginal rays are:

$$f_1 = 36 \text{ cm}$$

$$f_2 = 30 \text{ cm}$$

Evaluation and results

The center of the lens has a greater focal length than the edge of the lens. Spherical lenses are therefore subject to spherical aberration due to which a point object is imaged into a spot on the screen.

The image defect of the lens $f = +150$ mm is given by

$$f_1 - f_2 = 6 \text{ cm}$$

Supplementary information

Both convex and concave lenses show spherical aberration. Usually, a system of adapted lenses is used to correct the spherical aberration.

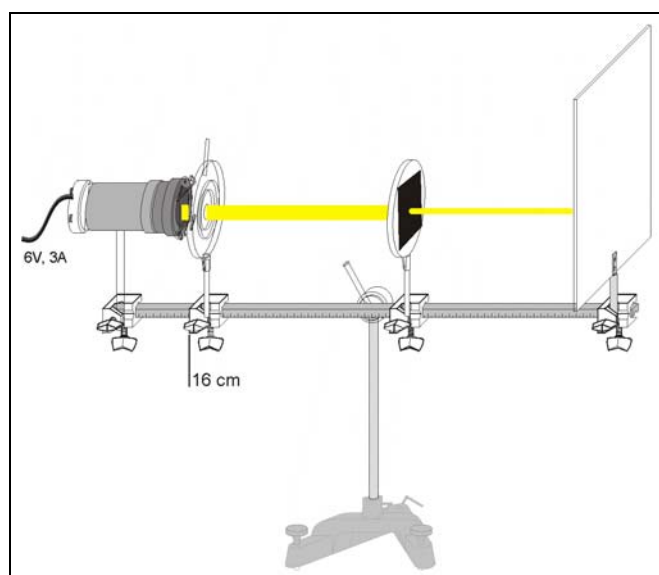


Fig. 4: Experimental setup to investigate the spherical aberration of lenses.