Reflection of light at straight and curved mirrors

Objects of the experiment

- Validation of the law of reflection at a planar mirror.
- Determination of the focal length of a concave mirror.
- Determination of the virtual focal length of a concave mirror.

Introduction

Optics has certainly changed the world in which we live: In medicine lasers are used as scalpels in operations together with classical optical devices. Optoelectronics has revolutionized the data reading, data storage and data communication. Tiny laser diodes, photo detectors, coated prism mirrors and silicon lenses are arranged on surfaces (length scale of about 1 mm) as interface between electronic circuits and the glass-fiber type material.

In this experiment the basic laws of reflection of light are studied at a planar, a concave and a convex mirror. Here, the propagation of light can be adequately described simply by defining the ray path.

The examination of the ray path of light in lenses, prismatic and circular bodies is described in P5.1.1.2.

Principles

Geometrical optics (ray optics) approximates light as light rays which propagate rectilinearly in vacuum and homogeneous media.

The course of a light ray before and after reflection at a polished surface (mirror) can be described by the angle of incidence α and the reflection angle β.

At a **plane mirror** light rays are always reflected so that the angle of incidence and the reflection angle are equal:

$$\alpha = \beta \qquad \text{(I)}$$

α: angle of incidence

β: angle of reflection

The optical path of a reflected ray at a plane mirror is reversible ("principle of reversibility in case of reflection").

Because of the law of reflection, i.e. equation (I), hollow or concave mirrors of circular sections are simplest optical elements with image forming properties.

The **concave mirror** combines light parallel to the principal axis after reflection. The point of intersection is given for rays near the principal axis by (Fig. 1.):

$$f = +\frac{r}{2} \qquad \text{(II)}$$

f: focal length

r: radius of curvature

Rays which are not close to the principle axis of the mirror will not be combined in the focal point f. As a consequence a diffuse image is obtained. The intersection of light rays at different distances between the focal point f and the mirror's surface is called "spherical aberration". The spherical aberration can be avoided by using a mirror whose section in a plane is a parabola.

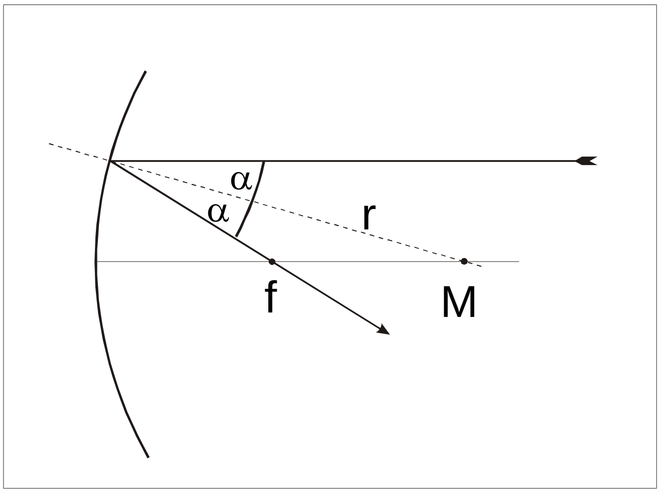

Fig. 1: Reflection at a concave mirror. r: radius of curvature, M: center of curvature, f: focal length.

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Apparatus

1 Optical disc with accessories 463 52
1 Lamp housing with cable 450 60
1 Incandescent lamp 6 V / 30 W 450 51
1 Transformer 6 V / 12 V 521 210
1 Small optical bench... 460 43
1 Diaphragm with 5 slits....................................... 463 51
1 Lens in frame f = +150 mm 460 08
1 Stand base, V-shape, 28 cm............................. 300 01
4 Leybold multiclamp 301 01
1 Stand rod, 25 cm 300 41

For the **convex mirror** the geometrical conditions are the same. However, the point of intersection of the rays is not in front of the mirror. The rays which are parallel to the principal axis diverge after reflection and appear to come from a virtual focal point which has a distance from the pole of the mirror equal to the negative focal length:

$$f' = -\frac{r}{2} \qquad \text{(III)}$$

This focus point f' can be found by producing the reflected rays backwards (Fig. 2).

Safety notes

The He-Ne laser meets the requirements according to class 2 of EN 60825-1 “Safety of laser equipment”. If the corresponding notes of the instruction sheet are observed, experimenting with the He-Ne laser is safe.

- Never look into the direct or reflected laser beam.
- No observer must feel dazzled.

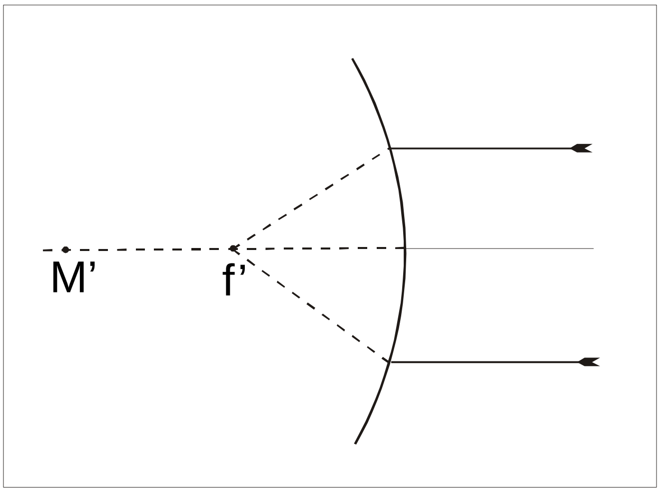

Fig. 2: Reflection at a convex mirror. r: radius of curvature, f': virtual focal length, M' = 2·f: center of curvature.

Setup

The course of a light beam before and after reflection at a mirror can be made visible against the matt white background of the optical disk. The various mirrors are fixed normal to the disk.

Set up the lamp, the condenser lens f = +150 mm (without the diaphragm with 5 slits) and the optical disk on the small optical bench as shown in Fig. 3.

When illuminating the disk with the 6 V lamp adjust the lamp's insert that the lamp filament is aligned horizontally (for details see chapter 3 in instruction sheet 463 52). The optical disk might be readjusted in such a manner that the light beam glances the optical disk.

Set the distance between the lamp and the lens so that a parallel light beam can be observed on the optical disk.
It is helpful to chose the distance between the optical disk and the lens in such a manner that the disk can be rotated like shown in Fig. 5.

For an easy demonstration of different angles of incidence loose slightly the screw of the Leybold multiclamp holding the optical disk. Thus various angles of incidence can be demonstrated by just rotating the optical disk.

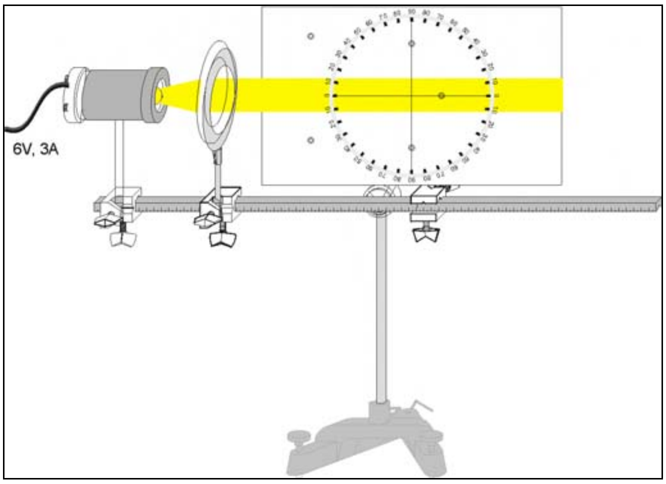

Fig. 3: Experimental setup to examine the reflection of light rays at mirrors with the optical disk.

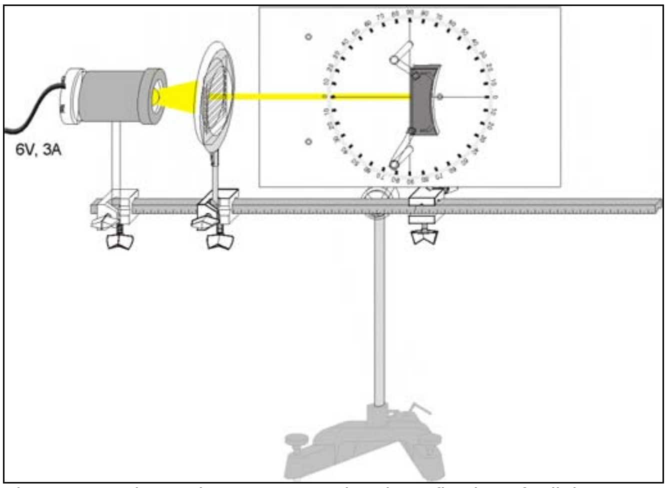

Fig. 4: Experimental setup to examine the reflection of a light rays at a plane mirrors for $\alpha = \beta = 0$ degree.

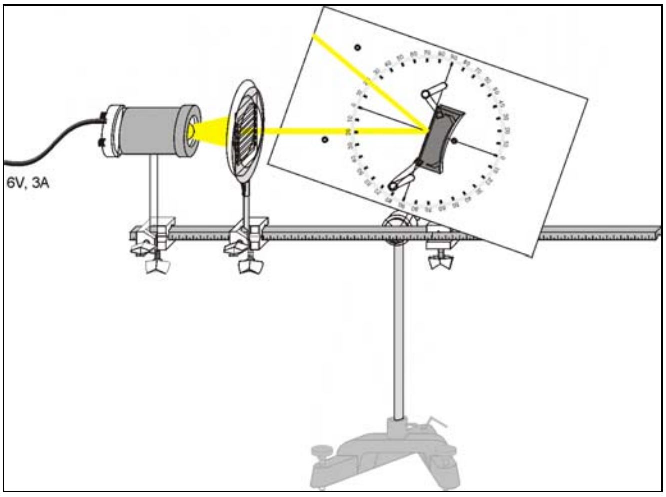

Fig. 5: Experimental setup to examine the reflection of a light rays at a plane mirrors for $\alpha \neq \beta$.

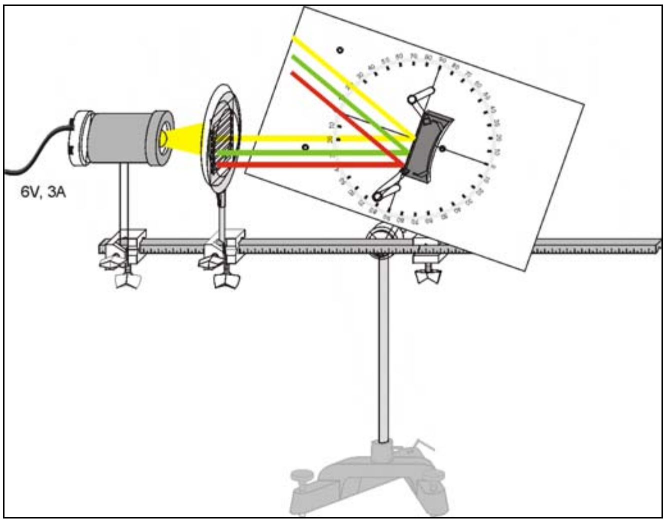

Fig. 6: Experimental setup to examine the reflection of several light rays at a plane mirrors for $\alpha \neq \beta$.

Carrying out the experiment

a) Reflection of light at a plane mirror

- Attach the mirror holder with the planar mirror towards the lamp in the optical disk as shown in Fig. 4.
- Attach the diaphragm with 5 slits on the condenser lens f = 150 mm and adjust the setup with one slit like depicted in Fig. 4.
- Measure the angle of reflection β for various angles of incidence α by turning the optical disk (Fig. 5).
- Observe for a specific angle of incidence, e.g. $\alpha = 10°$. Rotate the optical disk in such a manner that the angle of incidence is equal to $\alpha = -\alpha$ to demonstrate the reversibility of the optical path when a ray is reflected at the surface of a plane mirror.

b) Reflection of light at a concave mirror

- Attach the mirror holder with the concave mirror towards the lamp in the optical disk (Fig. 7).
- First, open only the central slit of the diaphragm on the condenser lens f = +150 mm and align the concave mirror that the light impinges on the centre of the mirror.
- Observe the reflection of this light ray for $\alpha = 0°$.
- Open 3 slits and observe the intersection of the light rays and estimate the focal length f.
- Observe the reflection of 5 light beams.
- For demonstrating that not all light rays intersect in one focus move the diaphragm with 5 slits in front of the condenser lens to alter the distances of the parallel beams from the axis.

c) Reflection of light at a convex mirror

- Attach the mirror holder with the convex mirror towards the lamp in the optical disk (Fig. 8).
- First, open only the central slit of the diaphragm on the condenser lens f = +150 mm and align the convex mirror that the light impinges on the centre of the mirror.
- Observe the reflection of light ray for $\alpha = 0°$.
- Open 3 slits and observe the intersection of the light rays and estimate the virtual focal length f.
  For the estimation of the focal length use a sheet of white paper. Attach the folded sheet of paper to the optical disk like depicted in Fig. 9. Trace the reflected rays with a pencil.
- Remove the sheet of paper, unfold it and determine the intersection of the projection of the delimiting lines of the light beam (Fig. 9).
- Measure along the center line the distance f between the fold and the point of intersection of the light beam.

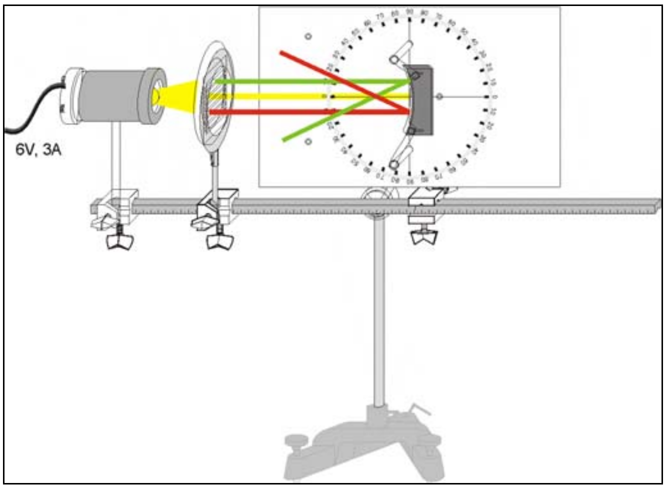

Fig. 7: Experimental setup to examine the reflection of three light rays at a concave mirror.

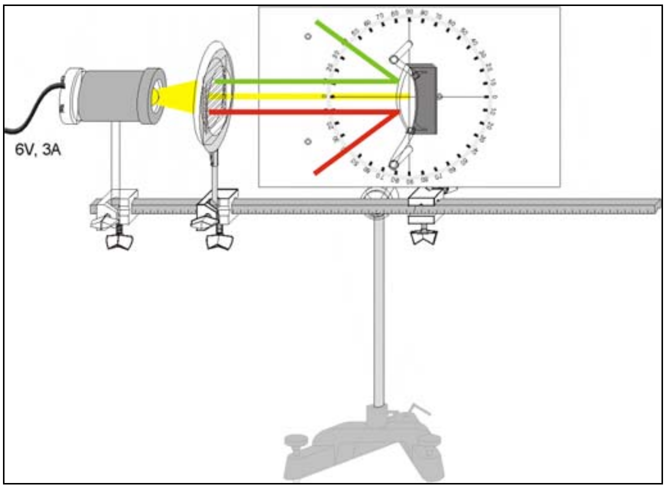

Fig. 8: Experimental setup to examine the reflection of three light rays at a convex mirror.

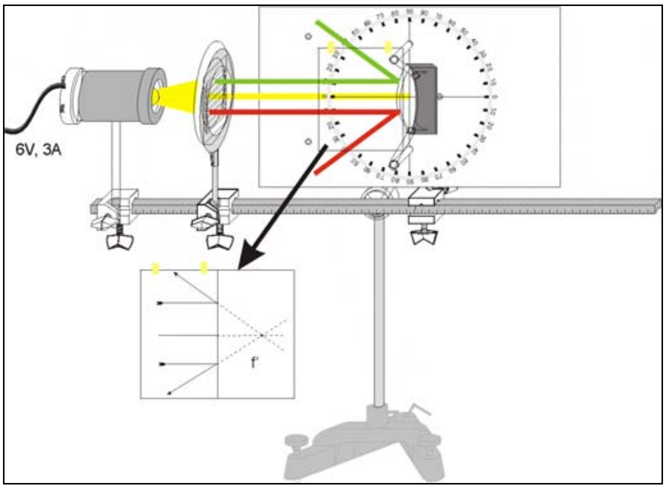

Fig. 9: Determination of the virtual focal length f' (insert).

Measuring example

a) Reflection of light at a plane mirror

Table. 1: Measured reflection angle β for different angle of incidence.

$\frac{\alpha}{\text{deg}}$	10	20	40	60
$\frac{\beta}{\text{deg}}$	10	20	40	60

b) Reflection of light at a concave mirror

$f = +3$ cm

c) Reflection of light at a convex mirror

$f' = -2.9$ cm

Evaluation and results

a) Reflection of light at a plane mirror

The angle of incidence α is the angle the incident ray of light makes with the normal of the reflecting surface at the point of incidence.

The angle of reflection β is the angle the reflected ray makes with the normal of the reflecting surface at the point of incidence.

The incident ray and the reflected ray and the normal to the surface of reflection lie in the same plane (first law of reflection) which states that the angle of incidence is equal to the angle of reflection (second law of reflection).

If the light bundles impinge perpendicularly (α = β) they are reflected back onto themselves.

If the light bundles impinge obliquely they are reflected into other directions, but remain parallel.

b) Reflection of light at a concave mirror

If the light bundles impinge perpendicularly they all intersect in a single point (focal point f) on the central ray.

If the light bundles impinge obliquely the inner light bundles intersect in another point than the outer light bundles (spherical aberration).

c) Reflection of light at a convex mirror

The reflected light bundles diverge. The virtual focal length f' corresponds with the focal length of the concave mirror for the same curvature radius.

Supplementary information

The mirrors are optical elements which are used in various optical devices, e.g. in grating spectrometers.

Makeup and shaving mirrors are concave mirrors. The object (face) is between the focal point and the mirror. The observed image is virtual, upright and its sides are exchanged. The image size is larger than the object size. Satellite disks, too, are concave mirrors with the receiver located at the focus point.

Convex mirrors are used as rear mirror in vehicles. The observed image appears behind the surface of the mirror and is upright. The image size is smaller than the object size. The rear mirror has a larger angle of view than a plane mirror of the same size.

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