Magnifier and Microscope

Objects of the experiment

- Using a simple eye model to investigate the increase of the angle of vision when using a magnifier and a microscope
- Investigating how a collecting lens can be used as magnifier – determining the magnification of a magnifier
- Setting up a simple microscope – determining the magnification of a microscope

Principles

The angle of vision φ determines the size of the image on the retina of the eye. According Fig. 1 φ is defined by:

$$\tan\varphi = \frac{G}{g} = \frac{B}{b} \qquad \text{(I)}$$

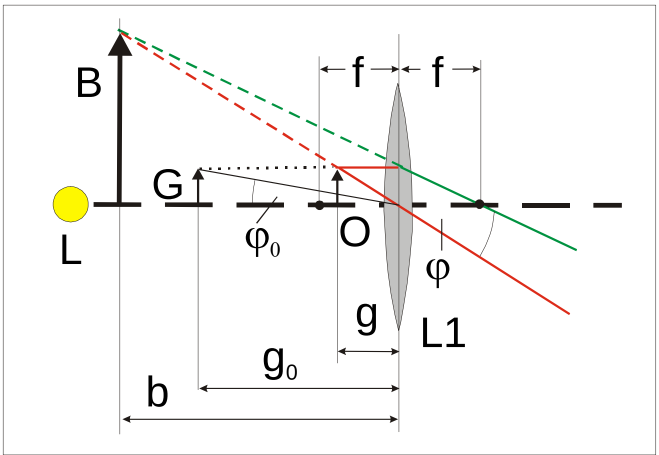
G: object size, B: image size

g: object distance, b: image distance

Basically, there are two reasons why the angle of vision φ is too small (i.e. the object cannot be seen as a sharp image on the retina of the eye). Either

- the object size G is to small or
- the object distance g is too large

Fig. 1: Schematic representation of the magnification: L: lamp L1: collecting lens, f: focal point, G: object size. g: object distance, b: image distance, B: image size, φ and φ_0: angle of vision without and with optical instrument, respectively.



The first case concerns the observation of small objects when even the reduction of the object distance g to a minimum distance of g_0 = 25 cm (i.e. the clear field vision) does not result in a small angle of vision. The latter case of a large object distance g is described in experiment P5.1.4.2.

The magnifier, the microscope and the telescope are optical instruments which primarily increase the angle of vision. The magnification is defined as follows:

$$V = \frac{\tan\varphi}{\tan\varphi_0} \qquad \text{(II)}$$

φ: angle of vision with optical instrument

φ_0: angle of vision without optical instrument

In the first experiment it is shown that a collecting lens L1 works as a magnifier if the object is located between the focal point f and the lens. The eye observes the image closely behind the lens. The magnifier produces a magnified, not inverted, virtual image. The magnification becomes a maximum if the object is placed in the focal point of the lens L1. The observation of this image takes place with a fully relaxed eye (i.e. eye is adjusted to observe an object at infinity). Using equation (I) and (II) gives the magnification of the magnifier (with g = f):

$$V_L = \frac{\tan\varphi}{\tan\varphi_0} = \frac{G/f}{G/g_0} = \frac{g_0}{f} \qquad \text{(III)}$$

with

f: focal point of collecting lens L1

g_0: clear field of vision

In the second experiment a microscope is assembled in its simplest form using two collecting lenses. The first lens, the objective, produces a real, magnified and inverted intermediate image. The second lens, the ocular (or eyepiece) is used as a magnifier to view the intermediate image (Fig. 2).

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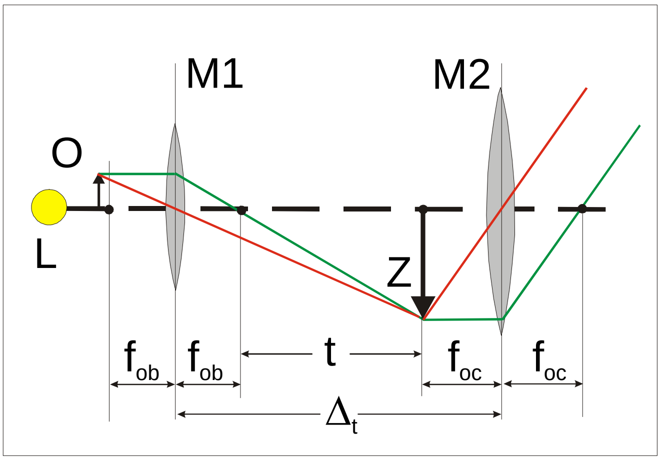


Fig. 2: Schematic representation of the microscope. M1: objective, M2: ocular, L: lamp, O: (small) object, Z: intermediate image, t: tube length, Δ_t: distance between objective and ocular, f_{ob}: focal length of objective, f_{oc}: focal length of ocular

The distance between the object and the objective is a little bit larger then the focal length of the objective. The distance between the intermediate image and the ocular corresponds to the focal length of the ocular.

The microscope magnifies the object in to steps. For the total magnification the following applies:

$$V_M = V_{ob} \cdot V_{oc} \quad \text{(IV)}$$

V_M: total magnification of the microscope

V_{ob}: magnification of the objective

V_{oc}: magnification of the ocular

With

$$V_{ob} = \frac{b}{g} \approx \frac{t}{f_{ob}} \quad \text{(V)}$$

b: image distance of the objective

t: tube length of the microscope,
i.e. the distance between the internal focal points (Fig. 2)

f_{ob}: focal length of the objective

and

$$V_{oc} = \frac{g_0}{f_{oc}} \quad \text{(VI)}$$

g_0: clear field of vision

f_{oc}: focal length of the ocular

follows:

$$V_M = \frac{t \cdot g_0}{f_{ob} \cdot f_{oc}} \quad \text{(VII)}$$

In order to obtain quantitative conclusions about the magnification V_L and V_M the eye is approximated by a simple model using a collecting lens and a translucent screen. Thus the magnification can be determined experimentally and compared with V_L and V_M.

Apparatus

1 Optical bench, standard cross section 1 m	460 32
2 Optics rider 60/50	460 373
4 Optics rider 60/34	460 370
or	
1 Optical bench S1 profile 1m	460 310
2 Optics rider	460 311
4 Optics rider	460 312
1 Lamp housing with cable	450 60
1 Incandescent lamp 6 V / 30 W	450 51
1 Transformer 6/12 V	521 210
1 Holder with spring clips	460 22
1 Aspherical condenser with diaphragm holder	460 20
1 Lens in frame f = +50 mm	460 02
1 Lens in frame f = +100 mm	460 03
1 Lens in frame f = +150 mm	460 08
1 Lens in frame f = +200 mm	460 04
1 Translucent screen	441 53
1 Steel tape measure, l = 2 m/78"	311 77
1 Glass scale, l = 5 cm	311 09
or	
1 Pair of objects for investigating images	461 66

Setup

The experiments can be performed with both the optical bench (460 32) or the optical bench S1 profile (460 310). In this leaflet the various setups are depicted with the optical bench S1 profile.

As object either the glass scale (311 09) or the pair of objects for investigating images (461 66) can be used.

Fig. 3: How to use the holder with spring clips with various objects: (left) with grid object (taken from the pair of objects 461 66), (right) with glass scale (311 09).

Note: If your experimental setup has only 5 optics riders you may need to attach the object in some experiments directly to aspherical condenser (Fig. 4). If you have 6 optics riders the object can be placed into the holder with spring clips in all experiments (Fig. 3).

Fig. 4: How to setup the object directly at the aspherical condenser (460 20). For the resulting image on translucent screen (i.e. retina of the eye) see Fig. 6 left.

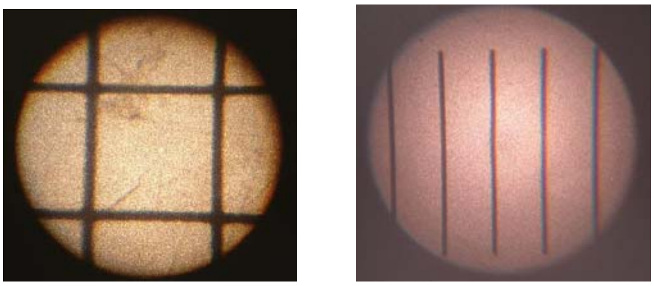
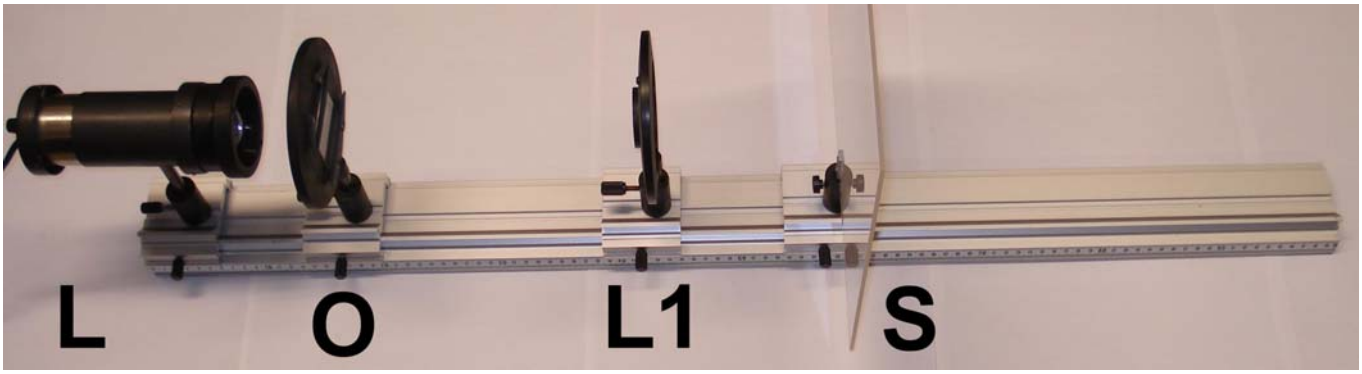


Fig. 6: Schematic representation of the image obtained on the translucent screen S for objects shown in Fig. 3 and Fig. 4: (left) for grid object (taken from the pair of objects 461 66), (right) for glass scale (311 09).

Fig. 5: Schematic representation of the experimental setup for the model of the focused eye. L: lamp, O: holder with object, L1: lens (of the eye), S: translucent screen (retina of the eye).



Carrying out the experiment

It is recommended to perform the experiment in a darkened room.

a) Model of the relaxed eye

- Set up the translucent screen at the right end of the optical bench. The screen corresponds to the retina of the eye.
- Position the lens f = +150 mm at a distance of 15 cm in front of the translucent screen. The lens corresponds to the lens of the eye.
- If you look at the translucent screen in the direction of the lens to a far point you should see a picture on the translucent screen. This corresponds to a view of a totally relaxed eye.

b) Model of the focused eye

- Set up the lamp L with the aspherical condenser as shown in Fig. 5 at the left side of the optical bench.
- Set up the object O in front of the lens (Fig. 5) using the holder of spring clips (Fig. 3) and switch on the lamp.
- Position the lens L1 (f = +100 mm) at a distance of 25 cm in front of the object. This corresponds to the clear field of vision of the eye, i.e. g_0 = 25 cm.
- Position the translucent screen S at a distance of approx. 15 cm behind the lens. The screen corresponds to the retina of the eye.
- Depending on the object you use you should see an image similar to the images in Fig. 6.
- Measure the graduation distance on the translucent screen S (i.e. size of the image on the retina of the eye model).

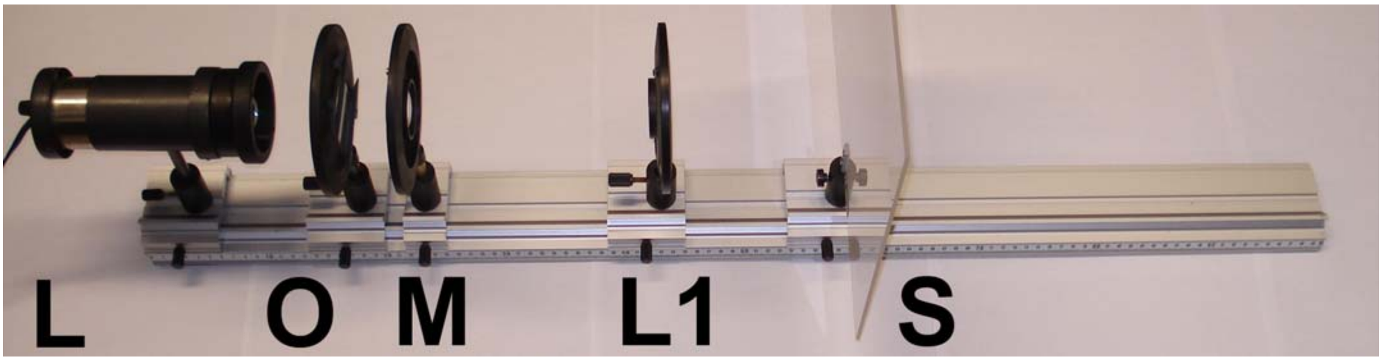


Fig. 7: Schematic representation of the experimental setup for the model of the **magnifier**. L: lamp, O: holder with object, M: magnifier (i.e. collecting lens) and model of eye, i.e.: L1: lens (of the eye), S: translucent screen (retina of the eye).

c) Determining the magnification of a magnifier

- Perform experiment b).
- Position the collecting lens M (f = 50 mm) at a distance of 5 cm in front of the object O (Fig. 7). The lens M corresponds to the magnifier.
- Replace the lens L1 (f = +100 mm) by a lens f = +150 mm.
- Position the lens L1 at a distance of 15 cm in front of the translucent screen to view the object with the relaxed eye.
- You should observe a sharp image of the object O at the translucent screen S (i.e. the retina of the eye).
- Measure the graduation distance of the magnified image on the translucent screen (i.e. size of the image on the retina of the eye model).

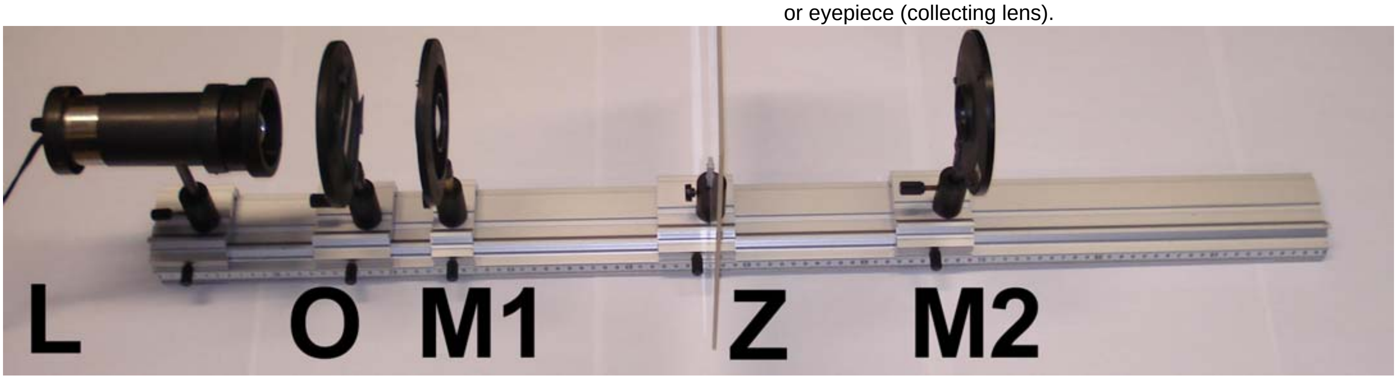
Additional experiment:

- Shift the eye (i.e. the lens L1 (f = +150 mm) and the translucent screen S together) to the end of the optical bench (i.e. opposite to the lamp L).
- Observe the effect on the image on the translucent screen when shifting the eye (i.e. the distance between the lens L1 and the translucent screen S is kept constant while shifting the "eye model").
- Measure the graduation distance of the magnified image on the translucent screen (i.e. size of the image on the retina of the eye model).

d) Determining the magnification of a microscope

- Set up the lamp L with the aspherical condenser at the left side of the optical bench as shown in Fig. 8 and switch on the lamp. The lamp corresponds to the microscope's illumination of the object.
- Set up the object O in front of the lens (Fig. 8) using the holder of spring clips (Fig. 3). The holder with spring clips corresponds to the object holder of the microscope.
- Position the lens M1 with f = +50 mm (objective) at a distance d ≈ 75 cm in front of the object (i.e. f < d < 2 f).
- Position the translucent screen Z on the optical bench at distance of approx. 30 cm after objective M1 (Fig. 8) to view the intermediate image of the microscope.
- Shift the object O (i.e. the object holder of the microscope) until you obtain a sharp intermediate image on the translucent screen Z.
- Position the lens M2 with f = +200 mm (ocular) at a distance f of 20 cm after the translucent screen Z (Fig.8).
- Setup the eye after the ocular M2 as shown in Fig. 9: Position the translucent screen S at the end of the optical bench. Place the eye lens L1 with f = +150 mm at a distance of 15 cm in front of the translucent screen S.
- Measure the graduation distance of the magnified image on the translucent screen (i.e. size of the image on the retina of the eye model) m and the distance Δ_t (Fig. 2).

Fig. 8: Schematic representation of the experimental setup to view the intermediate image of the **microscope**. L: lamp, O: holder with object, M1: objective (i.e. collecting lens), Z: translucent screen to view the intermediate image, M2: ocular or eyepiece (collecting lens).



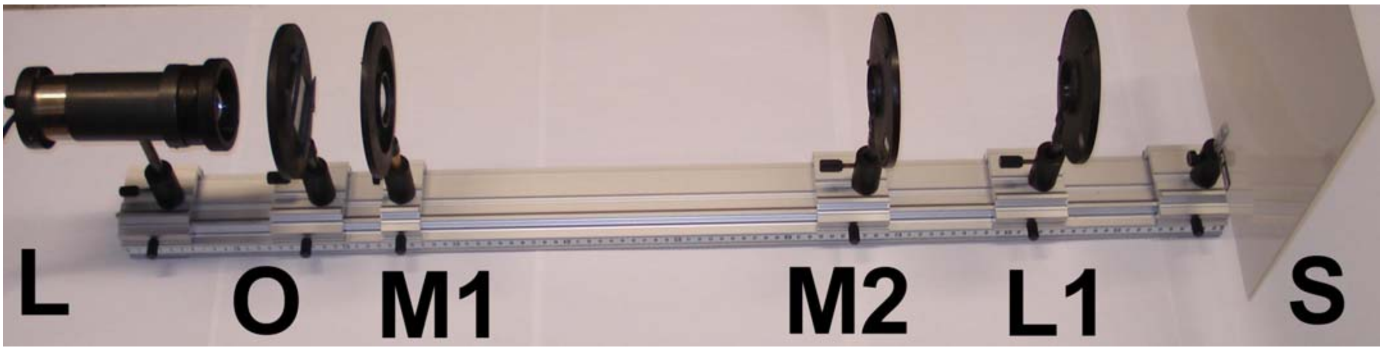


Fig. 9: Schematic representation of the experimental setup of the **microscope**. L: lamp, O: holder with object, M1: objective, M2: ocular (or eyepiece), model of eye consisting of L1: lens of the eye and S: translucent screen (retina of the eye).

Additional experiment: **exchange of the ocular M2**

- Position the translucent screen Z on the optical bench at distance of approx. 30 cm after objective M1 (Fig. 8) to view the intermediate image of the microscope.
- Shift the object O (i.e. the object holder of the microscope) until you obtain a sharp intermediate image on the translucent screen Z.
- Position the lens M2 with f = +100 mm (ocular) at a distance f of 10 cm after the translucent screen Z (Fig.8).
- Setup the eye after the ocular M2 as shown in Fig. 9: Position the translucent screen S at the end of the optical bench. Place the eye lens L1 with f = +150 mm at a distance of 15 cm in front of the translucent screen S.
- Measure graduation distance of the magnified image on the translucent screen (i.e. size of the image on the retina of the eye model) and the distance Δ_t (Fig. 2).

Additional experiment: **change of tube length**

- Position the translucent screen Z on the optical bench at distance of approx. 15 cm after objective M1 to view the intermediate image of the microscope.
- Shift the object O until you obtain a sharp intermediate image on the translucent screen Z.
- Position the ocular M2 with f = +100 mm at a distance of 10 cm after the translucent screen Z.
- Setup the eye after the ocular M2: Position the translucent screen S at the end of the optical bench. Place the eye lens L1 with f = +150 mm at a distance of 15 cm in front of the translucent screen S.
- Measure graduation distance of the magnified image on the translucent screen and the distance Δ_t (Fig. 2).
- Shift the eye (i.e. the lens L1 and translucent screen S together) and note that the magnification does not change.

Note: After positioning the eye opposite to the lamp at the end of the optical bench you may easily determine the magnification of the microscope as a function of the tube length t: Change the position of the ocular and adjust the object to obtain a sharp image on the screen.

Measuring example

The distance of the graduation of the object (i.e. the illuminated scale in the object holder) is Δ_0 = 5 mm.

The distance of the graduation of the image (i.e. the magnified image of the scale on the translucent screen) is measured to:

b) Model of the focused eye

Δ_0 = 5 mm (size of object)

Δ = 3 mm (size on screen)

c) Determining the magnification of a magnifier

Δ_0 = 5 mm (size of object)

Δ = 15 mm (size on screen)

d) Determining the magnification of a microscope

Δ_0 = 5 mm (size of object)

Δ = 9 mm (size on screen)

Δ_t = 37 cm (distance between objective and ocular)

Additional experiment: **exchange of the ocular M2**

Δ_0 = 5 mm (size of object)

Δ = 18 mm (size on screen)

Δ_t = 27 cm (distance between objective and ocular)

Additional experiment: **change of tube length**

Δ_0 = 5 mm (size of object)

Δ = 30 mm (size on screen)

Δ_t = 35 cm (distance between objective and ocular)

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Evaluation and results

In the following the magnification obtained by the theory (i.e. equations (III) and (VII) are compared with the magnification determined by the experiment. The experimental magnification is given by the comparison of the image size of the focused eye B_0 and the image size B using an optical instrument.

c) Determining the magnification of a magnifier

The magnification of the lens L1 can be determined according equation (III) to:

$$V_L = \frac{25\,\text{cm}}{5\,\text{cm}} = 5$$

This is in agreement with the experimental result:

$$\frac{B}{B_0} = \frac{15\,\text{mm}}{3\,\text{mm}} = 5$$

<u>Additional experiment:</u>

When shifting the eye towards the end of the optical bench the magnification does not change. However, the shift of the eye changes the observable area of the image on the screen.

d) Determining the magnification of a microscope

With the distance between the objective and the ocular Δ_t = 37 cm the tube length t is determined to:

$t = \Delta_t - f_{oc} - f_{ob}$ = 37 cm - 5 cm - 20 cm = 12 cm

The magnification is determined according equation (VII) to

$$V_M = \frac{12\,\text{cm} \cdot 25\,\text{cm}}{5\,\text{cm} \cdot 20\,\text{cm}} = 3$$

which is in agreement with the experimental result: (B and B_0 image size relaxed eye with microscope and without respectively):

$$\frac{B}{B_0} = \frac{9\,\text{mm}}{3\,\text{mm}} = 3$$

<u>Additional experiment:</u> **exchange of the ocular M2**

With the distance between the objective and the ocular Δ_t = 35 cm the tube length t is determined to:

$t = \Delta_t - f_{oc} - f_{ob}$ = 27 cm - 5 cm - 10 cm = 12 cm

The magnification is determined according equation (VII) to

$$V_M = \frac{12\,\text{cm} \cdot 25\,\text{cm}}{5\,\text{cm} \cdot 10\,\text{cm}} = 6$$

which is in agreement with the experimental result: (B and B_0 image size relaxed eye with microscope and without respectively):

$$\frac{B}{B_0} = \frac{18\,\text{mm}}{3\,\text{mm}} = 6$$

<u>Additional experiment:</u> **change of tube length**

With the distance between the objective and the ocular Δ_t = 35 cm the tube length t is determined to:

$t = \Delta_t - f_{oc} - f_{ob}$ = 35 cm - 5 cm - 20 cm = 10 cm

The magnification is determined according equation (VII) to

$$V_M = \frac{20\,\text{cm} \cdot 25\,\text{cm}}{5\,\text{cm} \cdot 10\,\text{cm}} = 10$$

which is in agreement with the experimental result: (B and B_0 image size relaxed eye with microscope and without respectively):

$$\frac{B}{B_0} = \frac{30\,\text{mm}}{3\,\text{mm}} = 10$$

When changing the objective (or the ocular) the tube length of the microscope and the object holder have to be adjusted to obtain a sharp image. Generally, the magnified image can be observed at an arbitrary distance between the ocular and the eye. However, in a real microscope the eye is close the eyepiece so that the aperture of the ocular corresponds to the aperture of the eye.

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