

Kepler's telescope and Galileo's telescope

Objects of the experiment

- Verifying that the length of a telescope is given by the sum of focal lengths of the objective and the ocular
- Determining the magnification of a telescope

Principles

The angle of vision determines the size of the image on the retina of the eye. 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 is too small or
- the object distance is too large.

The first case concerns to the observation of small objects with a magnifier or microscope and is described in experiment P5.1.4.1. The latter case concerns to the observation of distant objects using a telescope. In the most simplest case a telescope is composed of two lenses: the objective and ocular.

In an astronomic telescope (Kepler's telescope) a real intermediate image is formed in the focal plane P of the objective L1 (Fig. 1). This real intermediate image is observed through an eyepiece (ocular) L2 which is used as a magnifier.

A magnified virtual image is observed which is inverted in respect to the distant object. The magnification is the quotient of the visual angle with and without telescope. From Fig. 1 follows for sufficiently small angles ($\tan \varphi \approx \varphi$):

$$V = \frac{|\tan \varphi|}{|\tan \varphi_0|} = \left| \frac{f_1}{f_2} \right| \quad (I)$$

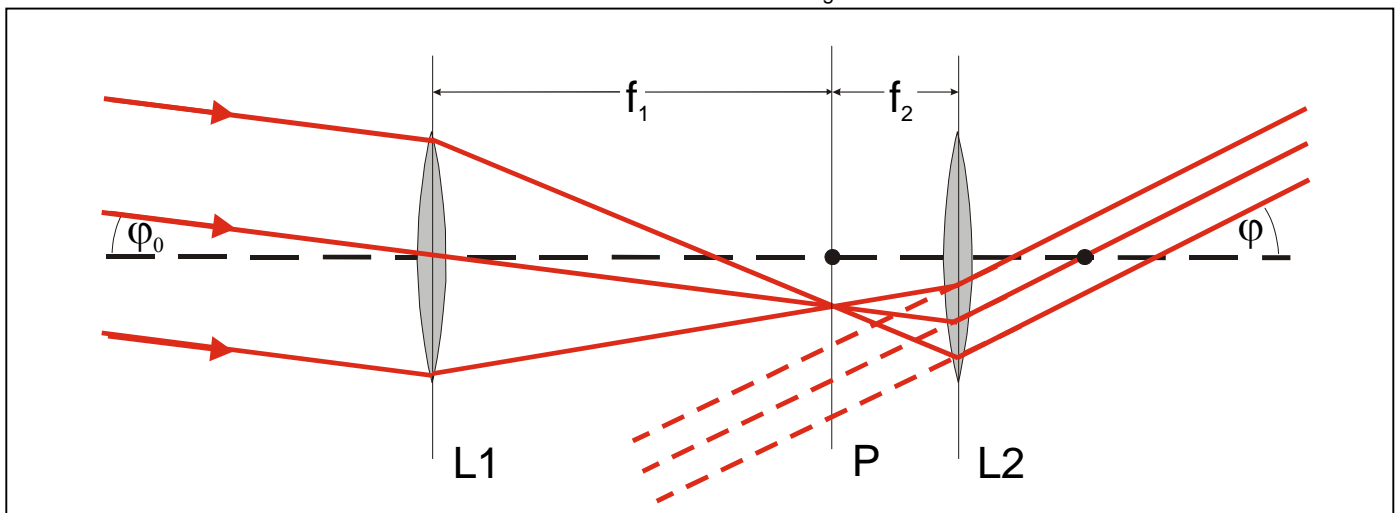
φ : angle of vision with optical instrument

φ_0 : angle of vision without optical instrument

f_1 : focal length of objective

f_2 : focal length of ocular

Fig. 1: Schematic representation of the ray path of a Kepler's telescope: L1: objective L2: ocular, f_1 : focal length of objective, f_2 : focal length of ocular, P, focal plane of objective, φ_0 and φ angle with and without instrument.



The Kepler's telescope uses converging lenses both for the objective and for the ocular. Exchanging the ocular L2 by a diverging lens leads to the Galilei's telescope (Fig. 2). In contrast to the Kepler's telescope no real intermediate image is formed. The convergent beam is made divergent by the ocular before a image is formed by the objective. The resulting virtual image is magnified and not inverted in respect to the distant object. The focal points of the objective and the ocular co-incide in the direction towards the eye (Fig. 2).

The length L_T of a Kepler's and Galilei's telescope (i.e. the distance between objective and ocular) is given by the sum of the focal lengths:

$$L_T = f_1 + f_2 \quad (II)$$

Apparatus

1 Optical bench, standard cross section 1 m	460 32
2 Optics rider 60/50	460 373
or	
1 Optical bench S1 profile 1m	460 310
2 Optics rider	460 312
1 Lens in frame $f = +50$ mm	460 02
1 Lens in frame $f = +100$ mm	460 03
1 Lens in frame $f = +200$ mm	460 04
1 Lens in frame $f = +500$ mm	460 05
1 Lens in frame $f = -100$ mm	460 06
1 Vertical scale, $l = 1$ m	311 22
1 Saddle base	300 11

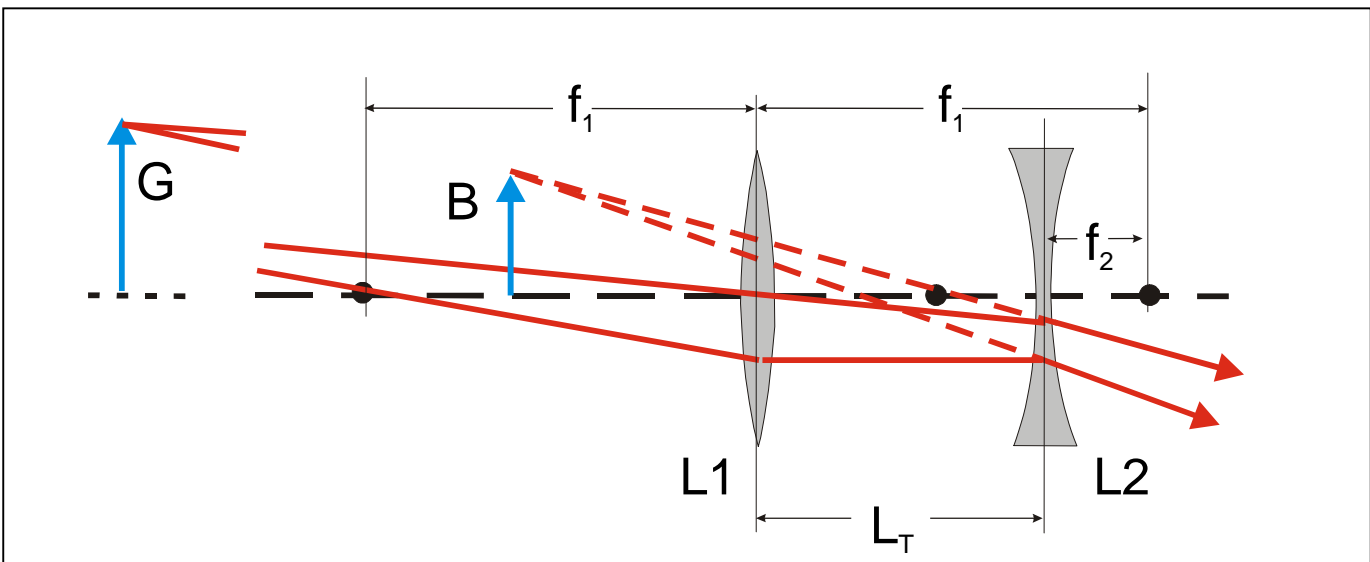
Setup

The experiments can be performed with both the optical bench (460 32) or the optical bench S1 profile (460 310).

Fig. 3 (left) shows the principle setup of a telescope to determine the length of the telescope. The Kepler's telescope uses two converging lenses. The Galilei's telescope uses a converging lens for the objective and a diverging lens for the ocular.

Fig. 3 (right) shows the vertical scale which has to be placed at a distance of approx. 10 m in front of the optical bench to determine the magnification of the telescope. The experiment can also be performed at smaller distances between objective and vertical scale.

Fig. 2: Schematic representation of the ray path of a Galilei's telescope: L1: objective L2: ocular, f_1 : focal length of objective, f_2 : focal length of ocular, G: object at a far distance, B: size of virtual image, L_T : length of telescope.



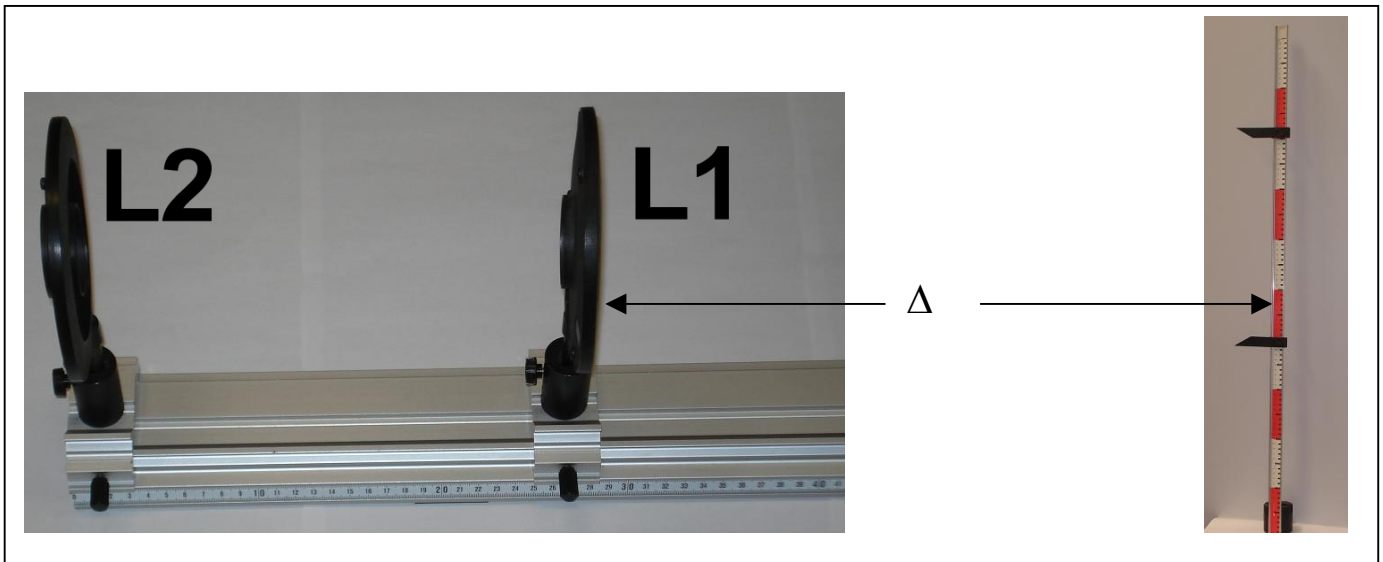


Fig. 3: (left): Experimental setup of a telescope – here with optical bench S1 profile (460 310). L1 : objective, L2 ocular.
(right): vertical scale as distant object. The recommended distance between scale and telescope is $\Delta \approx 10$ m.

Carrying out the experiment

It is recommended to perform the experiment in room which allows to observe distant objects through the window.

a) Observing distant objects with a Kepler's telescope

- Set up the lens L2 with $f = +50$ mm at the end of the optical bench. The lens L2 corresponds to the ocular of the telescope (Fig. 3 left).
- Position the lens L1 with $f = +100$ mm at a distance of approximately 160 mm behind the lens L2. The lens L1 corresponds to the objective of the telescope (Fig. 3 left).
- Lock through the ocular lens L2 and shift the lens L1 towards the lens L2 until a sharp image is observed.
- Measure the length of the telescope L_T .
- Exchange objective $f = +100$ mm by a lens $f = +200$ mm and repeat the experiment.
- Exchange objective $f = +200$ mm by a lens $f = +500$ mm and repeat the experiment.

b) Observing distant objects with a Galilei's telescope

- Set up the lens L2 with $f = -100$ mm at the end of the optical bench. The lens L2 corresponds to the ocular of the telescope.
- Position the lens L1 with $f = +200$ mm at a distance of approximately 130 mm behind the lens L2. The lens L1 corresponds to the objective of the telescope.
- Lock through the ocular lens L2 and shift the lens L1 towards the lens L2 until a sharp image is observed.
- Measure the length of the telescope L_T .
- Exchange objective $f = +200$ mm by a lens $f = +500$ mm and repeat the experiment.

c) Determining the magnification of a Kepler's telescope

- Set up the lens L2 with $f = +50$ mm at the end of the optical bench. The lens L2 corresponds to the ocular of the telescope (Fig. 3 right).
- Position the lens L1 with $f = +100$ mm at a distance of approximately 160 mm behind the lens L2. The lens L1 corresponds to the objective of the telescope (Fig. 3 right).
- Setup the vertical scale at a distance of approx. 10 m using the saddle base.

Note: When the distance Δ between the object (i.e. the vertical scale) and the objective L1 is smaller than 10 m the error of the magnification can be estimated approx. by:

$$V \approx \frac{\Delta}{\Delta - 2f_1} \frac{f_1}{f_2} \quad (\text{III})$$

e.g. for the lens combination L1 ($f = +200$ cm) and L2 ($f = +50$ cm) and $\Delta = 10$ m the error is approx. 4%. For smaller distances, i.e. $\Delta = 5$, the error can be approximated by 10%.

- Lock through the ocular L2 and shift the objective L1 towards the lens L2 until a sharp image of the vertical scale can be observed.
- Now look with one eye through the ocular and with the other eye directly to the vertical scale. Move the optical bench until the image of the scale of the direct observation and image of the telescope are close as in picture (Fig. 4)
- Determine the magnification by the comparison of the graduations of the observed images of the vertical scales.
- Repeat the experiment for the objective with $f = +200$ mm.



Fig. 4: Observation of the image of the vertical scale both with telescope (i.e. right eye) and without telescope (i.e. left eye) at the same time.

d) Determining the magnification of a Galilei's telescope

- Set up the lens L2 with $f = -100$ mm at the end of the optical bench. The lens L2 corresponds to the ocular of the telescope.
- Position the lens L1 with $f = +200$ mm at a distance of approximately 130 mm behind the lens L2. The lens L1 corresponds to the objective of the telescope.
- Setup the vertical scale at a distance 10 m using the saddle base.
- Lock through the ocular L2 and shift the objective L1 towards the lens L2 until a sharp image of the vertical scale can be observed.
- Lock through the ocular L2 and shift the objective L1 towards the lens L2 until a sharp image of the vertical scale can be observed.
- Now look with one eye through the ocular and with the other eye directly to the vertical scale. Move the optical bench until the image of the scale of the direct observation and image of the telescope are close as in picture (Fig. 4)
- Determine the magnification by the comparison of the graduations of the observed images of the vertical scales.
- Repeat the experiment for the objective with $f = +500$ mm.

Measuring example

In the following tables the measuring results of the various experiments are summarized:

Kepler's telescope

Table. 1: Measured telescope length L_T and magnification of the graduation of the vertical scale

$\frac{f_1}{\text{mm}}$	$\frac{f_2}{\text{mm}}$	$\frac{L_T}{\text{mm}}$	V_{exp}
+100	+50	150	2
+200	+50	250	4
+500	+50	550	-

Galileo's telescope

Table. 2: Measured telescope length L_T and magnification of the graduation of the vertical scale

$\frac{f_1}{\text{mm}}$	$\frac{f_2}{\text{mm}}$	$\frac{L_T}{\text{mm}}$	V_{exp}
+200	-100	100	2
+500	-100	400	5

Evaluation and results

In the following tables the measuring results are compared with values obtained from theory, i.e. from equation (I) the magnification V and from equation (II) the telescope length L_T .

Kepler's telescope

Table. 1: Measured telescope length L_T

$\frac{f_1}{\text{mm}}$	$\frac{f_2}{\text{mm}}$	$\frac{f_1 + f_2}{\text{mm}}$	$\frac{L_T}{\text{mm}}$	$\frac{f_1}{f_2}$	V_{exp}
+100	+50	150	150	2	2
+200	+50	250	250	4	4

Galileo's telescope

Table. 2: Measured telescope length L_T

$\frac{f_1}{\text{mm}}$	$\frac{f_2}{\text{mm}}$	$\frac{f_1 + f_2}{\text{mm}}$	$\frac{L_T}{\text{mm}}$	$\frac{f_1}{f_2}$	V_{exp}
+200	-100	100	100	2	2
+500	-100	400	400	5	5

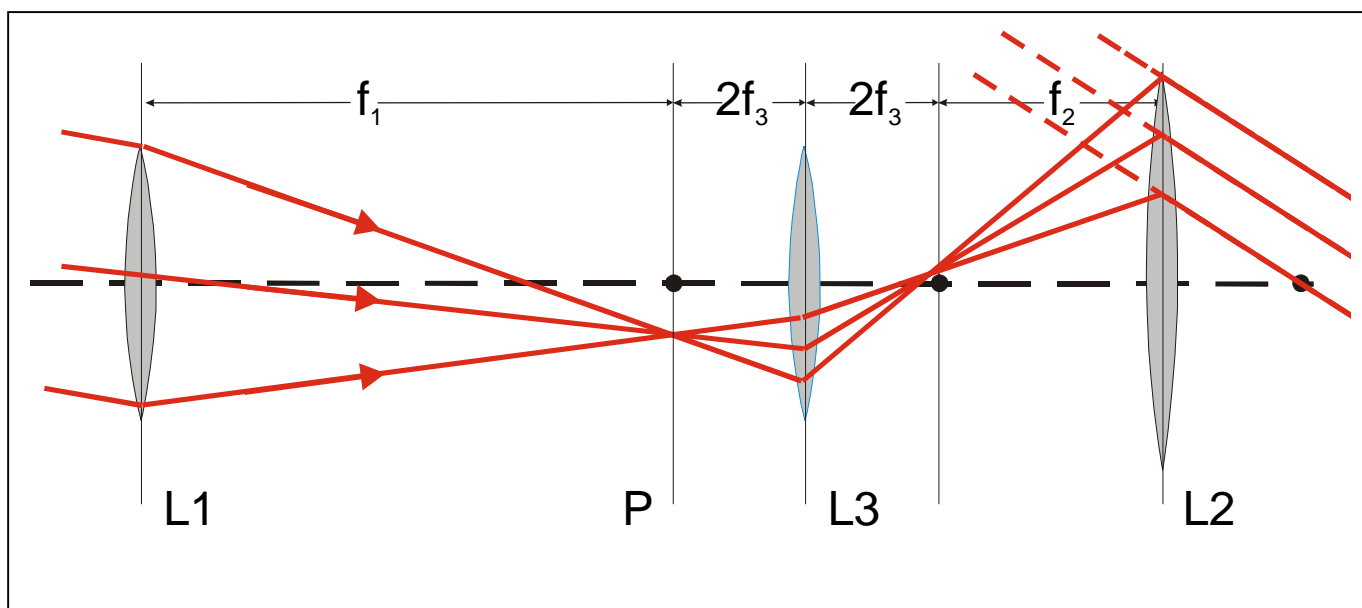


Fig. 5: Schematic representation of the ray path of a terrestrial telescope: L1: objective L2: ocular, L3: lens to invert the intermediate image, f_1 : focal length of objective, f_2 : focal length of ocular, f_3 : focal length of lens L3, P, focal plane of objective. **Note:** this setup can only be performed when the full experiment group P5.1.4 is available.

Supplementary information

If the light passes through the telescope in reverse direction the telescope can be used for expanding a beam of parallel light bundles and focusing on a distant point.

If the complete experiment group P5.1.4 is available, i.e. both experiment P5.1.4.1 and experiment P5.1.4.2, two additional experiments can be performed with the Kepler's telescope:

First the real intermediate image can be viewed by using the translucent screen in the focal plane P of the objective L1 (Fig. 1). If the translucent screen is placed in the focal plane of the telescope an image is observed on the screen when looking through the ocular which is upside down.

Secondly, a terrestrial telescope can be setup as depicted in Fig. 5. The additional lens L3 ($f = +50$ mm) between the objective L1 ($f = +200$ mm) and the ocular L2 ($f = +100$ mm) is used to invert the real image observed in the focal plane P of the objective. The length L_T of the telescope is increased by $4 \cdot f_3$. Thus the image observed with the ocular L2 is not inverted.

