

## Measuring the line spectra of inert gases and metal vapors using a prism spectrometer

### Objects of the experiment

- Adjusting the prism spectrometer.
- Calibrating the prism spectrometer with an He-lamp.
- Measuring an “unknown” line spectrum.
- Identifying the “unknown” light source.

### Principles

Inert gases and metal vapors which are excited to luminance emit spectral lines, i.e. a specific selection of wavelengths which are characteristic for the respective element. By precisely measuring these wavelengths, we can draw well-founded conclusions about the nature of these light sources.

We can use a prism to separate these spectral lines. Here, the wavelength-dependency of the refractive index  $n$  of the prism material (here flint glass) is exploited. The light rays are refracted in the prism and deviated to different extents, depending on their wavelengths. Shorter-wave light in the visible range of the spectrum is deviated more than long-wave light.

In the prism spectrometer, emerging light propagates in a diverging manner through the vertical slit  $S$ , for which the width and height can be varied, and falls on the objective lens  $O_1$ ; its distance from the slit is equivalent to its focal length (see Fig. 1). The slit and the lens together form a collimator. Behind the lens, the light falls on the prism  $P$  as a parallel beam, i.e. all rays are incident on the prism at the same angle. The prism refracts the light, and each wavelength is deviated at a different angle. Finally, a second objective lens  $O_2$  focuses all parallel rays of a specific wavelength to an image of slit  $S$  in the focal

plane of the lens. In this way, a pure spectrum is formed in the focal plane, and we can observe this using the ocular  $O'$ . Objective lens  $O_2$  and ocular  $O'$  together form an astronomical telescope focused on infinity.

The prism is positioned so that the beam path is symmetrical for a medium wavelength of the spectrum (about 500 – 600 nm), and the deviation is thus minimal. This in turn maximizes the spectral resolution.

The telescope is mounted on a swivel arm so that the deviation angle can be measured. When the telescope is turned, cross-hairs positioned in the focal plane of the ocular are placed on the individual spectral lines. To enable measurement of the angle and thus the relative position of the lines, the telescope is combined with a graduated circle (a disk with a scale with half-degree graduations) to form a goniometer. The vernier permits the position to be read off to within an angular minute.

The relationship between the refractive index  $n$  and the wavelength is not linear. If the wavelengths of an unknown light source are to be assigned to the deviations through the prism, the spectrometer must first be calibrated. This is accomplished using a lamp for which the spectral lines are known and distributed over the entire visible range. Using the resulting calibration curve, it is then possible to assign the spectral lines of an unidentified light source to the corresponding wavelengths. These are then compared with a suitable reference table to determine the light source.

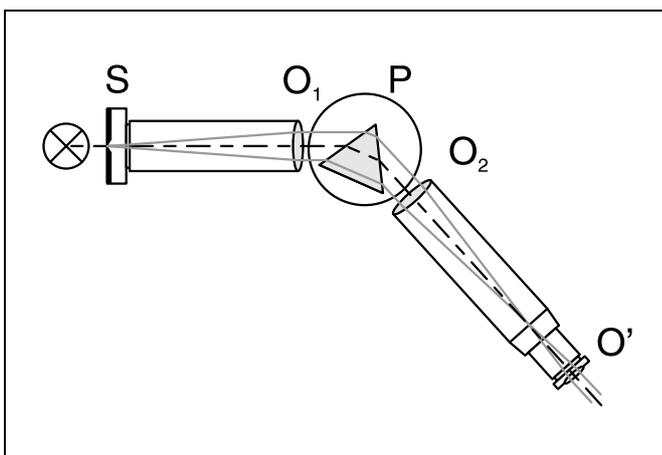


Fig. 1 Beam path in a prism spectrometer

**Apparatus**

1 Spectrometer and goniometer . . . . .	467 23
1 Spectral lamp He, pin contact . . . . .	451 031
1 Spectral lamp Cd, pin contact . . . . .	451 041
1 Housing for spectral lamps with pin contact . . . . .	451 16
1 Universal choke, 230 V, 50 Hz . . . . .	451 30
1 Transformer, 6 V AC, 12 V AC . . . . .	562 73
1 Stand base, small, V-shape . . . . .	300 02
<i>additionally usable:</i>	
1 Spectral lamp Ne, pin contact . . . . .	451 011
1 Spectral lamp Hg/Cd, pin contact . . . . .	451 071
1 Spectral lamp Ti, pin contact . . . . .	451 081
1 Spectral lamp Na, pin contact . . . . .	451 111

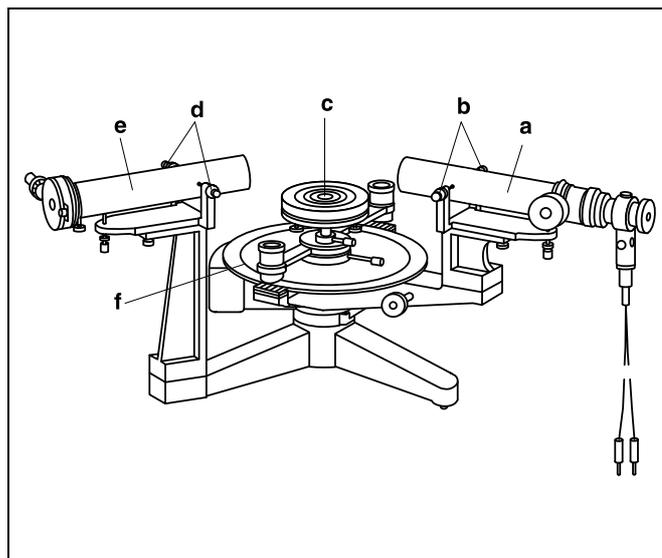


Fig. 2 Spectrometer

- a Telescope
- b Adjusting screw for laterally displacing the collimator
- c Prism table
- d Adjusting screw for laterally displacing the telescope
- e Collimator
- f Spectrometer base unit

**Adjusting the spectrometer**

*In order to conduct precise measurements, the apparatus must be carefully adjusted.*

*The slit and the crosshairs must be positioned exactly in the focal plane of the respective objective lens (telescopic beam path).*

*The slit and the prism surfaces must be aligned parallel to the rotary axis of the telescope.*

*Some of the adjustment steps, as well as the measurements of line spectra, are more easily carried out when the room is darkened somewhat.*

**Preliminary adjustment:**

*The inclination of the prism table can be varied only to a limited extent. To ensure that enough play is left for adjustment, align the table as horizontally as possible (by eye) during preliminary adjustment.*

- Align the telescope (a), the prism table (c) and the slit tube (collimator) (e) horizontally by eye (see Fig. 2).
- Center the telescope and the collimator laterally using the screws for lateral adjustment (b), (d) and then screw them tight. Do not loosen the adjusting screws too much on one side, as these support the telescope and the collimator.

**Focusing the telescope to infinity:**

*Note: Experimenters requiring vision correction can see distant objects clearly with the telescope; however, in this case the telescope by definition is not set precisely to infinity. It is still*

*possible to carry out precise measurements when the collimator and the telescope are adjusted by the same experimenter. When other experimenters wish to observe the spectra, subsequent focusing may only be carried out by moving the ocular (a4).*

- Remove ocular (a4), mount illumination source (a3) in the telescope and replace the ocular with the opening for the illumination source (a5) facing downward (see Fig. 3).
- Focus the crosshairs by moving the ocular (a4) in the ocular tube and aligning it if necessary. Make sure that the opening for the illumination source (a5) is still facing downward.
- Focus the horizontally aligned telescope on a distant object (> 500 m) using the focus adjustment knob (a1).

*As the image of the observed object and the crosshairs must both be in the focal plane of the objective lens when the setting is correct, there should be if possible no parallax between the observed object and the crosshairs.*

**Safety notes**

- Do not exceed the maximum permissible voltage for the He-lamp of the illumination system ( $U_{\max} = 8 \text{ V}$ ).

The spectral lamps and the housing become very hot during operation.

- Allow lamps to cool before changing or replacing.

**Adjusting the illumination source:**

- Aim the telescope at the collimator (open the slit slightly).
- Connect the illumination source (a3) to the voltage  $U = 6 \text{ V}$ .
- Using arresting screw (a2), mount the illumination device on the telescope so that the inside of the slit is well illuminated, without altering the position of the ocular.

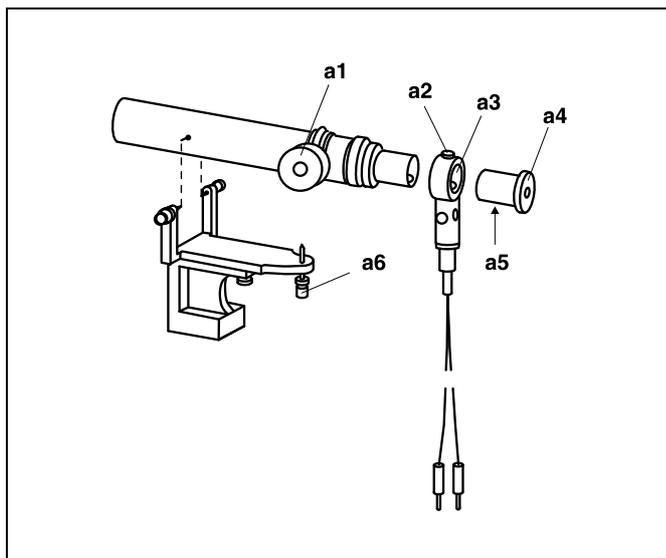


Fig. 3 Telescope with illumination source  
**a1** Focus adjustment knob  
**a2** Arresting screw for illumination source  
**a3** Illumination source  
**a4** Ocular  
**a5** Opening for illumination source (not visible)  
**a6** Height adjustment screw for telescope

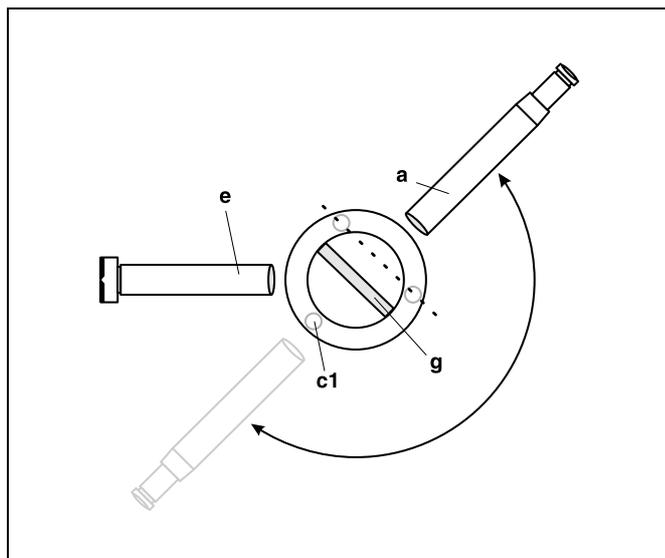


Fig. 4 Spectrometer with flat glass plate  
**a** Telescope  
**b** Leveling screws for prism table  
**c** Collimator  
**d** Flat glass plate in holder

#### Aligning the optical axis of the telescope perpendicular to the spectrometer axis:

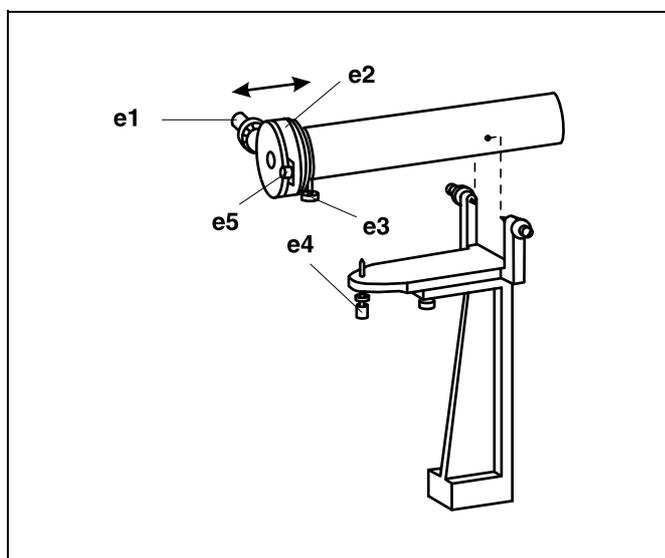
- Place the flat glass plate in its holder (**g**) in the center of the prism table at an angle of  $45^\circ$  to the collimator (**e**) so that the (imaginary) line between two of the adjusting screws of the prism table is parallel to the side surfaces of the flat glass plate (see Fig. 4).
- Align the telescope (**a**) perpendicular to one of the side faces of the flat glass plate so that the cross-hairs are reflected in this surface.
- Adjust the horizontal cross-hair so that it is coincident with its reflection. In making this adjustment, correct half the difference using the height-adjustment screw of the telescope (**a6**) (see Fig. 3) and the other half using the leveling screw (**c1**) of the prism table.
- Repeat the following two steps until the horizontal cross-hair and its mirror image coincide on both sides of the flat glass plate:
  - 1) Turn the telescope  $180^\circ$  as shown in Fig. 4 so that the cross-hairs are reflected on the opposite side of the flat glass plate.
  - 2) Check whether the cross-hair and its mirror image coincide. If not, correct half the difference using the height-adjustment screw of the telescope (**a6**) (see Fig. 3) and the other half using the leveling screw (**c1**) of the prism table, as described above.
- Secure the height-adjustment screw of the telescope (**a6**) using a lock nut.
- Remove the flat glass plate with holder from the prism table.
- Disconnect the illumination source from its voltage supply.

#### Adjusting the collimator:

- Illuminate the slit from the outside using e.g. a light bulb or one of the spectral lamps.

- Aim the telescope at the collimator and open the slit slightly using the micrometer screw for slit width (**e1**).
- Set the slit to a suitable, observable slit height using the slide (**e5**).
- With the height adjustment screw of the collimator (**e4**), align the middle of the slit with the horizontal cross-hair and lock the slit in position.

Fig. 5 Collimator  
**e1** Micrometer screw  
**e2** Collimator tube  
**e3** Arresting screw for collimator tube  
**e4** Height adjustment screw for collimator  
**e5** Slide for adjusting slit height



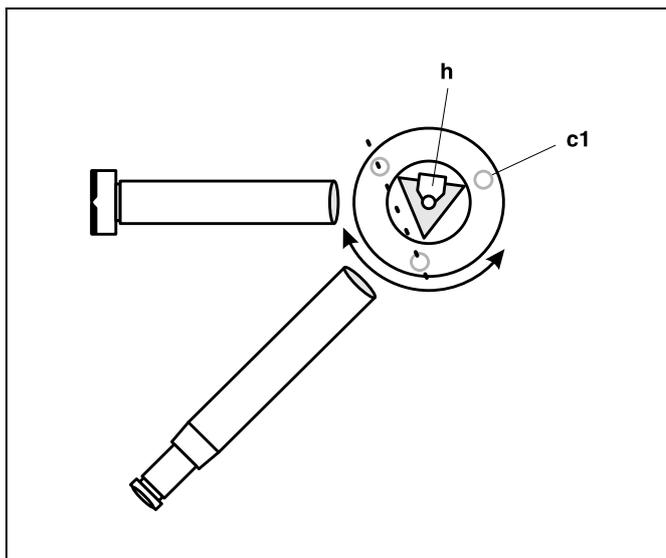


Fig. 6 Aligning the prism surfaces  
**c1** Leveling screws for prism table  
**h** (Flint) glass prism in holder

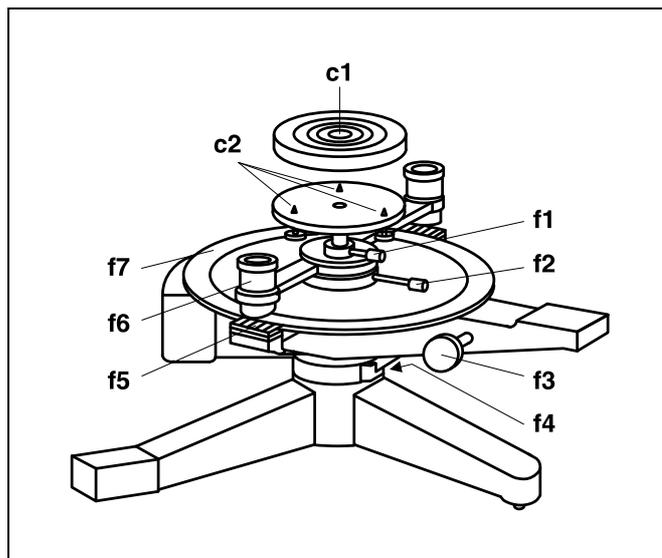


Fig. 7 Spectrometer base unit and prism table  
**c1** Prism table  
**c2** Leveling screws for prism table  
**f1** Arresting screw for prism table  
**f2** Arresting screw for graduated circle  
**f3** Fine-adjustment screw for telescope rotation  
**f4** Arresting screw for telescope (not visible)  
**f5** Verniers  
**f6** Magnifiers  
**f7** Graduated circle

- Loosen the arresting screw for the collimator tube (**e3**) and slide the collimator tube (**e2**) in the direction of the arrow (see Fig. 5) until a sharp image is obtained.
- By turning the tube, align the slit vertically so that it is parallel to the vertical cross-hair, and then tighten the arresting screw for the collimator tube (**e3**).

#### Aligning the prism surfaces parallel to the access of rotation:

- Turn the telescope so that it is at an acute angle to the collimator and fix it in place using the arresting screw (**f4**) (see Fig. 6 and Fig. 7).
- Place the prism in holder (**h**) on the prism table as shown in Fig. 6 so that one surface of the prism is parallel to the imaginary line between two leveling screws of the prism table.
- Turn the prism table until the image of the slit reflected by one face of the prism is visible in the telescope, and tighten the arresting screw (**f1**) for the prism table.
- Using the leveling screw at the back (**c1**), move the reflected slit image to the middle of the cross-hairs.
- Repeat the following two steps until the reflection of the slit does not change vertically when the prism table is turned:
  - 1) Loosen the arresting screw (**f1**) of the prism table and turn the prism table until the image of the slit is reflected by the next prism surface, then retighten the arresting screw of the prism table.
  - 2) Using the leveling screw which is now on the back side of the prism table (as seen from the telescope), bring the reflection of the slit into the middle of the cross-hairs.

### Setup

- Attach the He-spectral lamp in the housing, mount it in the stand base as shown in Fig. 8, connect it to the universal choke and switch it on.
- Illuminate the slit with the He-spectral lamp. Make sure that the He-lamp is positioned in the optical axis of the collimator.
- Position the prism on the prism table and align the telescope so that the light through the slit passes through the prism (when viewed from above, see Fig. 1) and the spectrum can be observed in the telescope.

### Carrying out the experiment

#### a) Setting the angle of minimum deviation:

The resolution increases with decreasing slit widths; however, the light intensity of the spectrum is correspondingly reduced:

- Using the micrometer screw for slit width (**e1**), set the slit to a suitable width.
- Slowly turn the prism table and observe the shift of the spectral lines with the telescope until a “center” line of the spectrum (e.g. yellow,  $\lambda = 587.6 \text{ nm}$ ) just passes through a reversing point (minimum setting).
- Fix the prism table and telescope in the minimum position using the corresponding arresting screws (**f1**) and (**f4**).

#### b) Calibrating the spectrometer using the He-spectral lamp:

*Note: the spectrometer is equipped with two opposing verniers. In order to minimize reading errors and compensate for any eccentricity of the circular graduation with respect to the axis of rotation, find the mean value of two readings.*

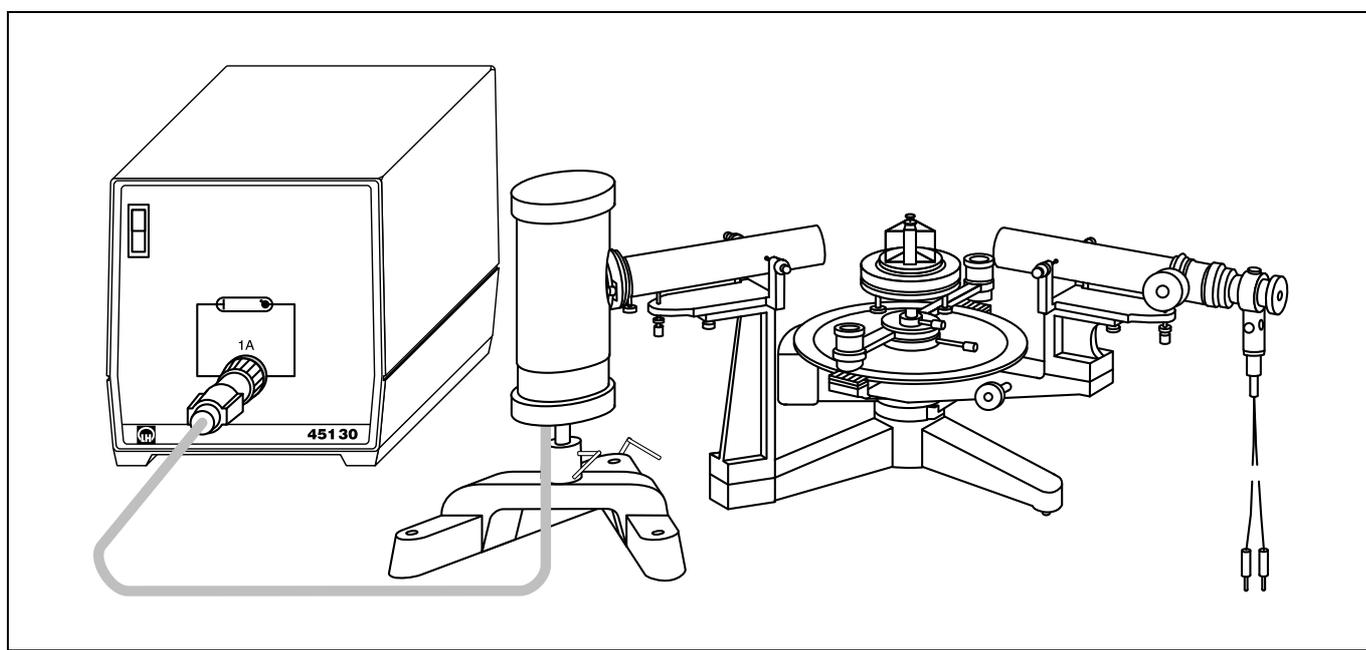
- Align the telescope so that the vertical cross-hair coincides with one of the outer spectral lines (in this measurement example the red line).
- Turn the graduated circle (**f7**) to the  $0^\circ$  and  $180^\circ$  lines of the verniers (**f5**) and lock the graduated circle using the corresponding arresting screws (**f2**).

- Align the vertical cross-hair of the telescope with each of the spectral lines in turn using the fine-adjustment knob (**f3**). Read off the corresponding telescope position on the graduated circle using the magnifiers (**f6**) and write this value in the experiment log.

#### c) Measuring the line spectra of other light sources, e.g. spectral lamp Cd:

- Allow the He-lamp and housing to cool, then exchange lamps and illuminate the slit.
- Align the vertical cross-hair of the telescope with each of the spectral lines one after another as described above using the fine-adjustment knob (**f3**) and read off and write these values in the experiment log.

Fig. 8 Complete experiment setup after adjustment



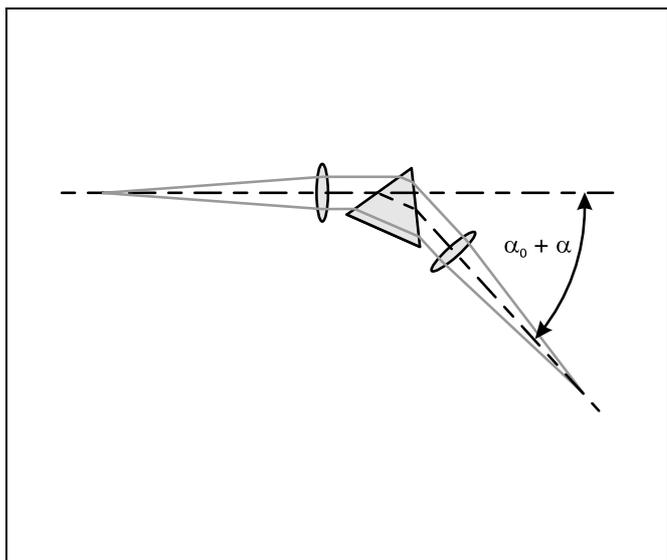


Fig. 9 Schematic diagram for the definition of angle  $\alpha$   
 In the measurement example,  $\alpha^\circ$  has been selected so that the wavelength  $\lambda = 706.5 \text{ nm}$  at the angle  $\alpha^\circ = 0.00^\circ$

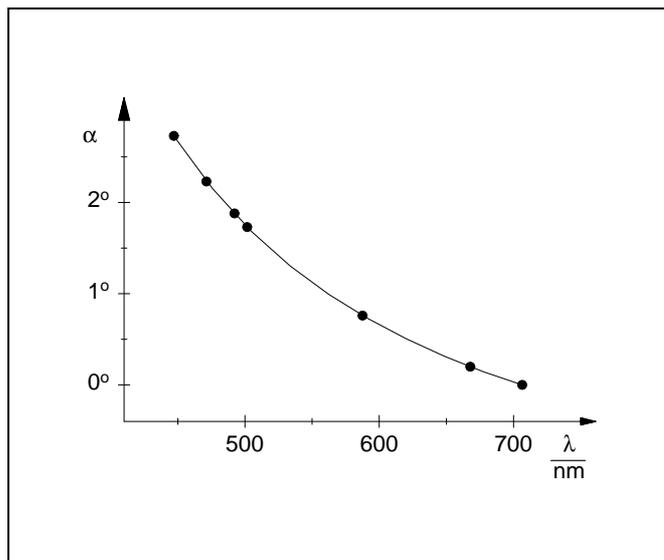


Fig. 10 Calibration curve of the prism spectrometer  
 Dots: measured values from table 1  
 Line: Interpolated curve

### Measuring example and evaluation

*Note: With the prism spectrometer it is also possible to see low-intensity lines which do not belong to the spectrum of the respective metal vapor or inert gas. Due to the manufacturing process, other gases may also be included in the light bulb. In metal vapor lamps, argon (Ar) is additionally used as a base gas.*

Table 1: Measured values for calibrating the spectrometer using the He-spectral lamp; see Fig. 9 for definition of  $\alpha$

$\frac{\lambda_{\text{literature}}}{\text{nm}}$	$\alpha$
706.5	0.00°
667.8	0.20°
587.6	0.76°
501.6	1.73°
492.2	1.88°
471.3	2.23°
447.1	2.73°

To identify unknown light sources, the wavelengths of the spectral lines are read off and compared with the measured angles from the calibration curve (see Fig. 10). The given literature values refer to the wavelengths in a vacuum. The conversion to wavelengths in air is not necessary.

Table 2: Measured values for example lamp Cd; see Fig. 9 for definition of  $\alpha$

$\alpha$	$\frac{\lambda_{\text{evaluation}}}{\text{nm}}$	$\frac{\lambda_{\text{literature}}}{\text{nm}}$
2.30°	468.7	467.8
2.08°	480.4	480.0
1.63°	507.7	508.6
0.43°	631.8	632.5
0.35°	644.1	643.8

### Additional information

The spectrometer and goniometer can also be used as a grating spectrometer (see experiment description P5.7.1.2). In this configuration, a calibration curve is no longer required for determining the wavelengths.

However, the intensity of the spectra is less, so that weak lines are often invisible. Additionally, multiple diffraction orders occur, which, depending on the grating used, can be superposed on one another and thus impede assignment.

When using a diffraction grating, the resolution of the spectrometer is usually better than with the prism spectrometer. For example, the two Na-D lines, which can just barely be differentiated in the prism spectrometer with the slit set to minimum width, can be easily resolved and measured separately in a spectrometer using a Rowland grating.