PRISM SPECTROMETER

OBJECTIVE

Set up and calibrate a prism spectrometer

SUMMARY

A prism spectrometer utilises the dispersion of light into its spectral components by means of a prism to measure optical spectra. In order to measure wavelengths, it is necessary to calibrate the system since the angular dispersion is non-linear. In this experiment the known spectrum of a mercury (Hg) lamp will be used for calibration purposes and then measurements will be made for a cadmium (Cd) lamp.

EXPERIMENT PROCEDURE

- **Make adjustments to a prism spectrometer and calibrate it using the spectral lines from a mercury lamp.**
- **Measure the minimum angle of deflection when λ = 546.07 nm.**
- **Determine the refractive index of flint glass when λ = 546.07 nm and the Cauchy parameters *b* and *c* for the wavelength-dependent refractive index.**
- **Calculate a calibration curve according to the Hartmann dispersion formula.**
- **Make measurements on an unknown line spectrum.**

You can find technical information about the equipment at 3bscientific.com

REQUIRED APPARATUS

Quantity	Description	Number
1	Spectrometer-Goniometer	1002912
1	Control Unit for Spectrum Lamps (230 V, 50/60 Hz)	1003196 or
	Control Unit for Spectrum Lamps (115 V, 50/60 Hz)	1003195
1	Spectral Lamp Hg/Cd	1003546
1	Spectral Lamp Hg 100	1003545

BASIC PRINCIPLES

Prism spectrometers are used to measure optical spectra using the dispersion of light into its spectral components when it passes through a prism. This dispersion results from the fact that the refractive index is dependent on wavelength. It is non-linear and therefore the prism spectrometer needs to be calibrated in order to measure wavelengths.

Inside the spectrometer, the light being investigated passes through slit S to strike the objective O_1. These two components form a collimator and produce a wide, parallel beam of light (see Fig. 1). After refracting at two surfaces of the prism, a parallel beam exits the prism and is focussed to an image of the slit in the focal plane of objective O_2. This can then be viewed via the ocular lens OC. The telescope formed by objective O_2 and ocular OC is attached to a swivelling arm which is rigidly connected to the vernier scale N.

The double refraction of the light by the prism can be described by the angles α_1, α_2, β_1 and β_2 (see Fig. 2). The following relationships are true for an equilateral prism:

(1) $$\sin\alpha_1 = n(\lambda)\cdot\sin\beta_1(\lambda),\ \ n(\lambda)\cdot\sin\beta_2(\lambda) = \sin\alpha_2(\lambda),\ \ \beta_1(\lambda)+\beta_2(\lambda) = 60°.$$

The angle of incidence α_1 can be altered by turning the prism with respect to the parallel beam which enters it. Angles α_2, β_1 and β_2 are dependent on the wavelength λ since the refractive index *n* is wavelength-dependent.

The angle of deflection between the collimator and the telescope is determined from the angle of incidence α_1 and the exit angle α_2:

(2) $$\delta(\lambda) = \alpha_1 + \alpha_2(\lambda) - 60°.$$

The angle is at its minimum δ_{min}, when the path of the beam is symmetrical with respect to the prism. At the same time the angular dispersion dδ/dλ will be at its maximum. Prism spectrometers are therefore adjusted in such a way that a symmetrical beam path is attained for a reference wavelength λ_0. In this experiment, the green spectral line (λ_0 = 546.07 nm) of a mercury lamp is chosen for this.

The refractive index of the prism at the reference wavelength can be determined from the minimum angle of deflection. This is because the symmetry implies that $\beta_1(\lambda_0) = \beta_2(\lambda_0) = 30°$ and $\alpha_2(\lambda_0) = \alpha_1$, therefore:

(3) $$\sin\alpha_1 = n(\lambda_0)\cdot\frac{1}{2}\ \text{ where }\ \alpha_1 = \frac{\delta_{min}}{2} + 30°.$$

The dispersion means that the other spectral lines are shifted from δ_{min} by small angles Δδ. You will be able to read off these angles to an accuracy of minutes using the vernier scale. Since the changes in refractive index Δn remain small over the entire visible part of the spectrum, it is sufficient to consider only the linear terms in the changes. Therefore from equations 1 – 3 the following relationship can be derived between the wavelengths and deflection:

(4) $$\Delta\delta(\lambda) = \Delta\alpha_2(\lambda) = \frac{\Delta n(\lambda)}{\cos\alpha_1} = \frac{\Delta n(\lambda)}{\sqrt{1-\frac{\left(n(\lambda_0)\right)^2}{4}}}.$$

In the visible part of the spectrum, the refractive index *n* decreases as the wavelength λ increases. This can be described by the Cauchy equation in the following form:

(5) $$n(\lambda) = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}.$$

In principle, it is possible to obtain a mathematical description for a calibration curve from equations (4) and (5). However, the Hartmann dispersion formula turns out to be better suited to the purpose.

(6) $$\delta(\lambda) = \delta_H + \frac{K}{\lambda - \lambda_H}$$

The modifying parameters δ_H, *K* and λ_H in the above do not, however, have any specific physical meaning.

For this reason, in the experiment the spectral lines of the mercury lamp are utilised for calibration purposes with the help of equation (6) and afterwards the lines of an "unknown" spectrum will be measured (see Table 1).

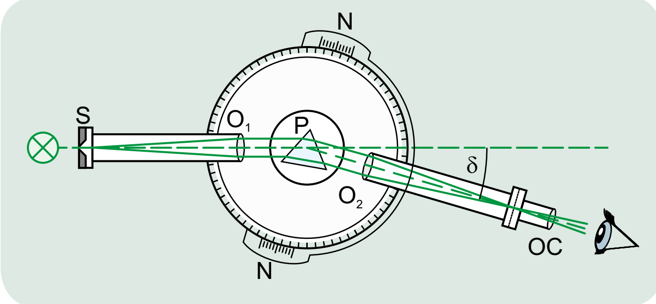

Fig. 1: Schematic of a prism spectrometer
S: Entry slit, O_1: Collimator objective, P: Prism, O_2: Telescope objective, OC: Telescope eyepiece (ocular), δ: Angle of deflection

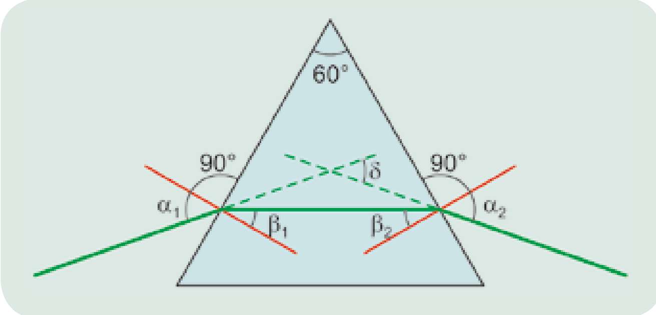

Fig. 2: Beam path through prism

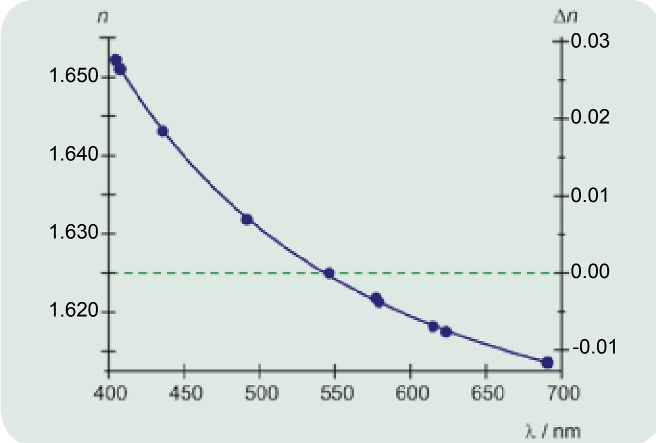

Fig. 3: Wavelength-dependent refractive index for flint glass prism

EVALUATION

The refractive index *n*(λ0) is given from equation 3 The Cauchy parameters for the refractive index can be calculated by fitting a parabolic curve to the equation $\Delta n = n(\lambda) - n(\lambda 0) = f(1/\lambda^2)$.

Table1: Wavelengths of lines in Cd spectrum

Colour	Measurement λ / nm	Table value λ / nm
Blue (medium deflection)	466	466
Blue (large deflection)	468	468
Cyan (medium deflection)	479	480
Dark green (large deflection)	509	509
Dark green (less deflection)	515	516
Red (large deflection)	649	644

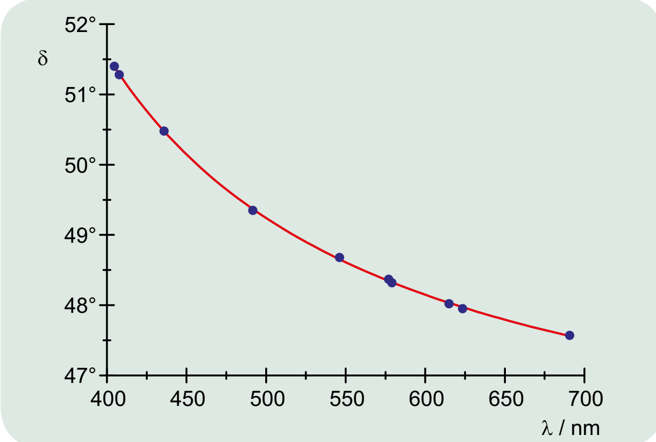

Fig. 4: Calibration curve for prism spectrometer