HOCHSCHULE SCHMALKALDEN UNIVERSITY OF APPLIED SCIENCES	Schmalkalden University of Applied Sciences	Exp 2
	Applied Physics Lab Course	
	Spectroscopy	

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Tasks

1. Determine the grating constant of a transmission grating using a sodium vapor lamp with the known wavelength of 589.0 nm
2. Determine the theoretical resolving power of this grating
3. Determine the wavelengths of the spectral lines of an unknown spectral lamp
4. Determine the wavelength dependency of the optical refractive index of a glass prism and discuss the spectral course of the dispersion. Calculate the Abbe number ν_e of the glass prism from the $n(\lambda)$-curve
5. Determine the examined material by comparing the data measured in (4) and the given tables

Theoretical basics:

Diffraction and dispersion are typical properties of waves. A wave is a periodic change of a physical quantity in time and space. In the case of water waves, this physical quantity is the deflection of the water surface compared to the equilibrium position, in the case of sound waves in air this quantity is the deflection of the air molecules from the equilibrium position. In the first experiment, the wave properties of light are demonstrated. Light, like radio waves or X-rays, is an electromagnetic wave. The physical variables that change over time and space are the electric and magnetic field. Both quantities oscillate perpendicularly to each other and perpendicularly to the direction of propagation (see Fig. 1). Light waves are thus transverse waves.

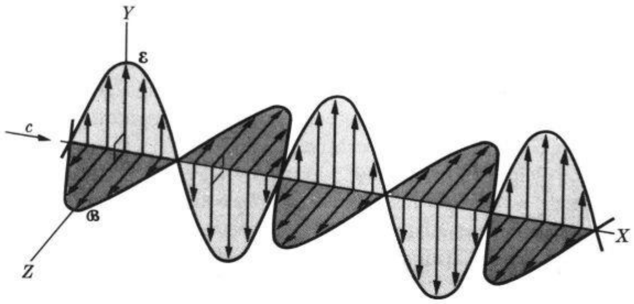


Fig. 1 *Schematic representation of a one-dimensional electromagnetic wave propagating in the X-direction with the oscillation directions of the electric field strength in the Y-direction and the magnetic field strength in the Z-direction*

Harmonic waves can be represented by sine or cosine functions. In Eq. (1), an expression is given for a one-dimensional harmonic wave propagating in the x-direction:

$$u(x,t) = u_0 \cdot sin(\omega t - kx + \varphi_0) \tag{1}$$

Here $u(x,t)$ is the physical quantity that oscillates in space and time (e.g. the electric field strength).

$$\omega = 2\pi f = \frac{2\pi}{T} \tag{2}$$

is the **angular frequency** of the wave and

$$k = \frac{2\pi}{\lambda} \tag{3}$$

is the so-called **wave number** (λ wavelength), and φ_0 is an initial phase.

One can visualize the propagation of a wave by plotting u as a function of x at different times (see Fig. 2).
The distance between adjacent points of the same phase (e.g. two wave crests or two wave troughs) is the wavelength λ. Since the wave advances by exactly λ during a period T, the speed of the wave can be written as: $c = \frac{\lambda}{T} = \lambda \cdot f$ (4)

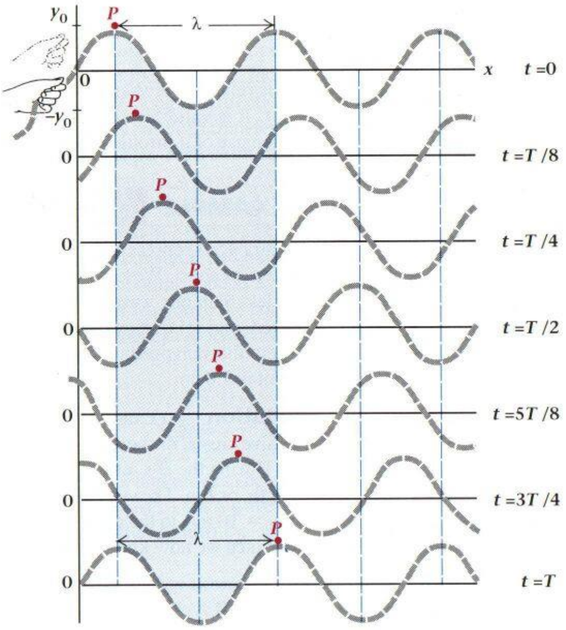


Fig. 2 *The propagation of a rope wave is recorded by taking several snapshots of the wave at different times.*

Interference of waves can be observed when two (or more) waves interfere with each other that have the same wavelength, the same frequency, and a fixed phase. The result of the interference depends on the phase difference or the path difference of the two waves. The resulting wave is obtained by simply adding the individual waves according to the superposition principle (see Fig. 3). There are two extreme cases of interference:

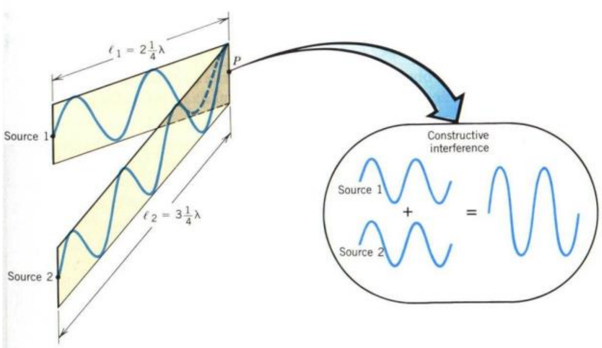
a) Constructive interference (amplification)

Constructive interference occurs when the phase of the waves is zero or an integer multiple of 2π. In this case, wave crest meets wave crest, or wave trough meets wave trough. If the amplitude of the output waves are equal, the resulting wave has twice the amplitude of the individual waves. The phase condition for constructive interference is therefore $\Delta\varphi = \pm 2\pi m$ with $(m = 0, 1, 2, 3, \dots)$. Consequently, the path difference Δ is zero or a multiple of λ for constructive interference: $\Delta = \pm m\lambda$ with $(m = 0, 1, 2, 3, \dots)$.

b) Destructive interference (extinction)

Destructive interference is observed when both waves oscillate in phase opposition, i.e. when the phase difference between the two waves is π or an odd multiple thereof: $\Delta\varphi = \pm(2m+1)\pi$ with $(m = 0, 1, 2, 3, \dots)$. The path difference is therefore an odd multiple of half the wavelength: $\Delta = \pm(2m+1)\,\lambda/2$ with $(m = 0, 1, 2, 3, \dots)$. In the case of destructive interference, both waves cancel out each other. The resulting amplitude is equal to zero if the output amplitudes of the individual waves are the same.

However, any intermediate phase can also lead to interference and can be calculated. By continuously varying the phase difference of both waves $\Delta\varphi$, the amplitude of the resulting wave can take any value between $0 \dots 2u_0$.



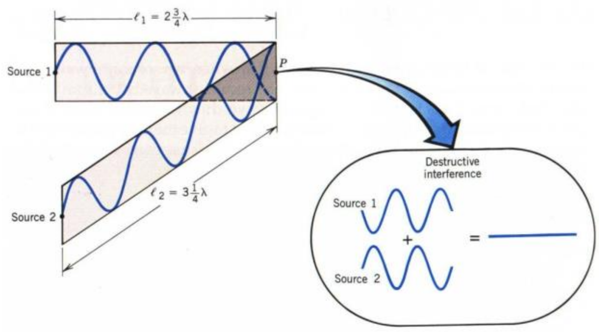


Fig.3 *Constructive and destructive interference of two waves of the same amplitude*

We speak of **diffraction** when the propagation of the waves deviates from that of a straight line. All diffraction phenomena can be understood with the help of **Huygens' principle** and can also be explained quantitatively. Huygens' principle can be formulated as follows:

Each point of a wave front is the starting point of a new elementary wave. The new position of the wave front results from the superposition (interference) of all elementary waves (elementary waves are spherical in 3 dimensions, circular in 2 dimensions).

If a plane wave interacts with a slit whose width is in the order of magnitude of the wavelength (see, for example, a 2-dimensional representation in Fig. 4), the slit can be regarded as the starting point of an elementary wave due to its small width. The wave fronts are circular behind the slit.

An optical transmission grating consists of a periodic arrangement of many parallel slits. For a grating with 1200 lines/mm and a grating width of 70 mm, the number of slits is 1200 x 70 = 84000. The distance between adjacent slits is equal to the grating constant s. For optical gratings, the grating constant is of the order of 1 µm, i.e. in the order of the wavelength. Each individual slit therefore functions as the starting point of a new elementary wave. At a large distance from the grating, constructive interference can be observed at an angle α (see Fig. 4) when two neighboring elementary waves are intensifying, i.e. the path difference between the elementary waves is an integer multiple of the wavelength. Following this argument, we get the diffraction orders at:

$$\Delta y = s \cdot \sin\alpha = m \cdot \lambda, \tag{5}$$

where $m = 0,1,2, \ldots$ are the so-called diffraction orders.

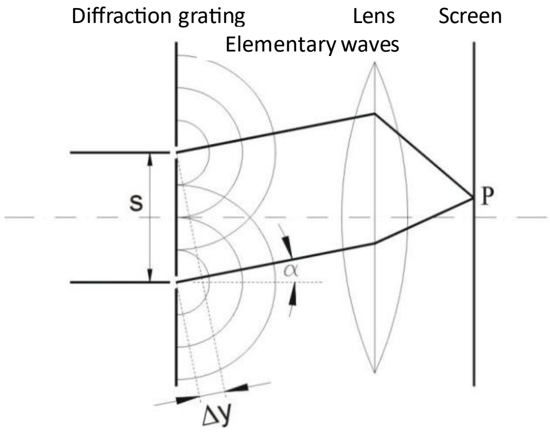


Fig. 4 *Interference of neighboring elementary waves of an optical grating. A line can be observed on the screen at such angles α (intensification) if the path difference of both waves Δy is a multiple of the wavelength.*

For all other angles, there is cancellation, because then for every slit another can be found whose elementary waves have a path difference of exactly $\lambda/2$, so that cancellation occurs. In the case of optical gratings that are illuminated with monochromatic light, diffraction lines can only be observed at the angles that satisfy equation (5). At all other angles, the diffraction intensity is nearly zero.

The resolving power of a spectral apparatus is defined as $A = \frac{\lambda}{\Delta\lambda}$. λ is the wavelength of the optical radiation and $\Delta\lambda$ is the wavelength difference between two adjacent spectral lines, which can just about be separated with the spectral apparatus. A good measure for $\Delta\lambda$ is the broadening that a very narrow spectral line (e.g. of an Hg calibration lamp) undergoes by the spectral apparatus (see Fig. 5). The theoretical resolving power of an optical grating in the first diffraction order is given by the number of illuminated grating columns, which can be calculated from the grating constant s and the illuminated grating width b. So the resolving power can be calculated by

$$A = \frac{\lambda}{\Delta\lambda} = m \cdot N = m \cdot \frac{b}{s}, \tag{6}$$

where m is the diffraction order.

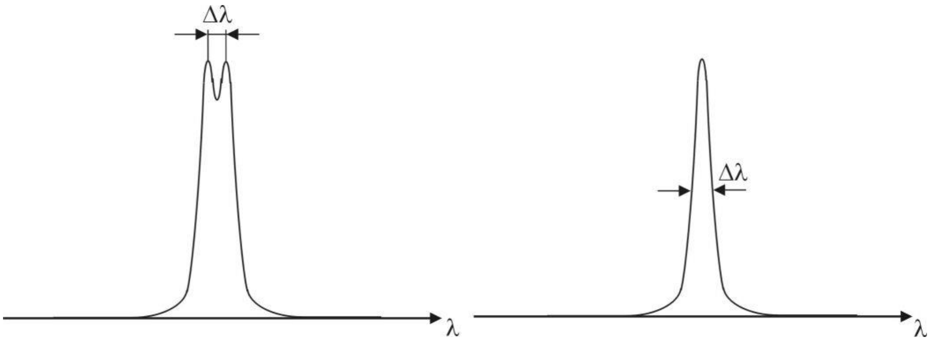


Fig. 5 *Spectrum of two spectral lines that can just be distinguished from each other. The line width of a very narrow spectral line, which is determined by the resolving power of the spectral apparatus, can be used as a good estimate of* $\Delta\lambda$.

Dispersion:

Like diffraction and interference, **dispersion** is a typical wave property, but it only occurs when a wave propagates through a medium. A medium, in which a wave is propagating, shows dispersion if the group and phase velocities differ in this medium. The phase velocity is the speed at which an ideal monochromatic wave of only one wavelength or frequency propagates. For one-dimensional propagation, such a wave can be described mathematically very simply with equation (1).
The group velocity, on the other hand, is the propagation speed of a group of waves that differ in frequency or wavelength, respectively. With the ideal monochromatic wave mentioned above, it is not possible to transmit information. In order to transmit information, a wave must be amplitude or frequency modulated. For example, so-called pulse code modulation (PCM) is used in optical communication. An information bit is transmitted as an optical square-wave pulse (wave packet). The Fourier analysis of such a square wave shows that, in addition to the fundamental frequency, waves of other frequencies are also contained. It is therefore a group of waves whose combined speed is the group speed. If the propagation medium shows the property of dispersion, not only do the phase and group velocities differ, but the wave packet also diverges, which leads to increased error rates in message transmission when certain distances are exceeded.

A more precise theoretical analysis provides the following expressions for the group and phase velocities:

Phase velocity: $c = \frac{\omega}{k}$ (7) Group velocity: $c_{gr} = \frac{d\omega}{dk}$ (8)

If we set eq. (7) into eq. (8), we can find a relationship between the phase and group velocity. Using equations (2) and (3) we get:

$$c_{gr} = c - \lambda \frac{dc}{d\lambda} \qquad (9)$$

From Equation (9), it is immediately apparent when a propagation medium exhibits dispersion. The group and phase velocities differ when the phase velocity of the wave is wavelength-dependent: $dc/d\lambda \neq 0$.
In case of optical waves, the phase velocity of light in media can be expressed by the refractive index n (refractive index) of the medium:

$$c = \frac{c_0}{n} \qquad (10)$$

The propagation speed of light in optically transparent materials is lower than the vacuum speed of light ($c_0 = 3 \cdot 10^8$ m/s). The refractive index n is generally not a constant but a function of the wavelength. Using Eq. (10) we can write equation (9) in the following form:

$$c_{gr} = c + \frac{c}{n} \cdot \frac{dn}{d\lambda} \cdot \lambda \qquad (11)$$

Depending on the size of $\frac{dc}{d\lambda}$ or $\frac{dn}{d\lambda}$, there are 3 cases of dispersion:

Normal dispersion: $c_{gr} < c$ → $\frac{dc}{d\lambda} > 0$, $\frac{dn}{d\lambda} < 0$

Anomalous dispersion: $c_{gr} > c$ → $\frac{dc}{d\lambda} < 0$, $\frac{dn}{d\lambda} > 0$

No dispersion: $c_{gr} = c$ → $\frac{dc}{d\lambda} = 0$, $\frac{dn}{d\lambda} = 0$

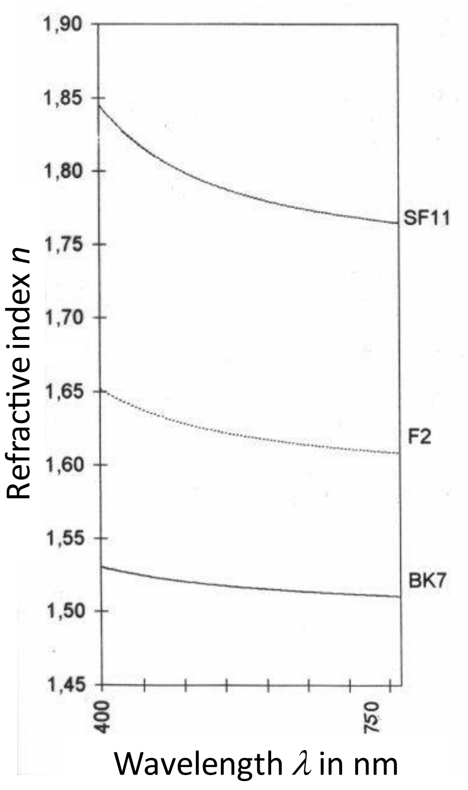
Thus, dispersion of light waves occurs in materials, in which the refractive index is wavelength dependent, i.e. $dn/d\lambda \neq 0$. Normal dispersion is observed when the refractive index decreases with increasing wavelength. This is the case with most optical glasses, but also with other solid or liquid optically transparent materials. The slope of the $n(\lambda)$-curve, i.e. $\left|\frac{dn}{d\lambda}\right|$, is taken as a measure of the dispersion (whether there is strong or weak dispersion). A steep slope in a given wavelength range means high dispersion and a flat slope means small dispersion. Anomalous dispersion is usually observed in wavelength ranges where the optical material shows strong absorption. Typical dispersion curves for anomalous and normal dispersion are shown in Fig. 6a and 6b.
In principle, to obtain the full dispersion properties of an optical material, the entire $n(\lambda)$-curve, such as that shown in Fig. 6, must be known. A very good empirical description of the dispersion curves of optically transparent glasses is given by the **Sellmeier formula**:

$$n(\lambda) = \left[\frac{B_1 \cdot \lambda^2}{(\lambda^2 - C_1)} + \frac{B_2 \cdot \lambda^2}{(\lambda^2 - C_2)} + \frac{B_3 \cdot \lambda^2}{(\lambda^2 - C_3)} + 1\right]^{1/2}$$

The coefficients $B_1, B_2, B_2, C_1, C_2, C_3$ depend on the material and are tabulated for different types of glass. The Sellmeier formula delivers a very good accuracy of < 0.00001 in the visible spectral range. However, the dispersion properties of an optically transparent material in the visible spectral range are often determined in a simplified procedure using the so-called Abbe number ν:

$$\nu_d = \frac{(n_d - 1)}{(n_F - n_C)} \quad \textbf{(old)} \qquad \text{or} \qquad \nu_e = \frac{(n_e - 1)}{(n_{F'} - n_{C'})} \quad \textbf{(new)}$$

Here n_e, $n_{F'}$ and $n_{C'}$ are the refractive indices of the material at the e, F' and C' Fraunhofer lines (546.07 nm, 479.99 nm and 643.85 nm), with the e line in the middle of the visible spectral range and the F' and C' lines are at the lower and upper ends of the visible spectral range, respectively. The smaller the Abbe number, the greater the dispersion of the optical material.



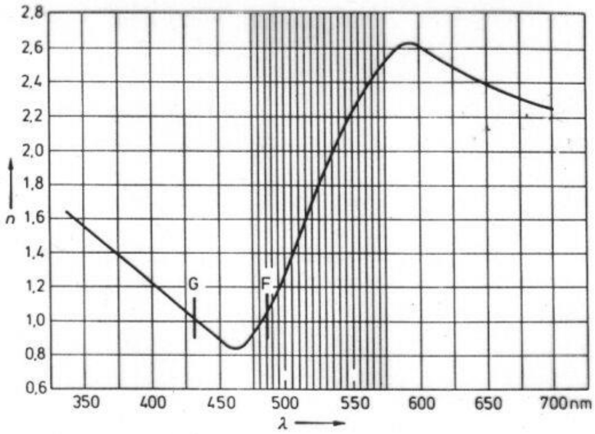


Fig. 6a *Dispersion curve of solid fuchsin near the absorption band. From about 475 nm to 575 nm the $n(\lambda)$-curve has a positive slope. It is therefore an area of abnormal dispersion. Since the penetration depth of the light is smaller than the wavelength due to the strong absorption, the refractive index in this range can only be measured in reflection.*

Fig. 6b *Dispersion curves of 3 types of glass commonly used in optics: BK7 (crown glass), F2 (flint glass), SF11 (heavy flint glass). All glasses show normal dispersion in the wavelength range shown.*

The findings presented here can be applied to optical message transmission with glass fibers. In order to minimize the temporal broadening of optical pulses over a large distance, materials with the smallest possible dispersion should be selected. Glass fibers used today have a dispersion minimum at a wavelength of $\lambda_1 = 1300$ nm (near infrared) and an absorption minimum of $\lambda_2 = 1550$ nm. For this reason, one of these two wavelengths is typically used for optical communication.

The dispersion of glasses can also be exploited for the spectral decomposition of light. White light is composed of light of different colors (wavelengths). For example, heavy flint glass exhibits high dispersion. If white light is radiated onto such a prism, the different spectral components of the light (violet, blue, green, yellow, red) have different angles of refraction and can thus be separated from one another.

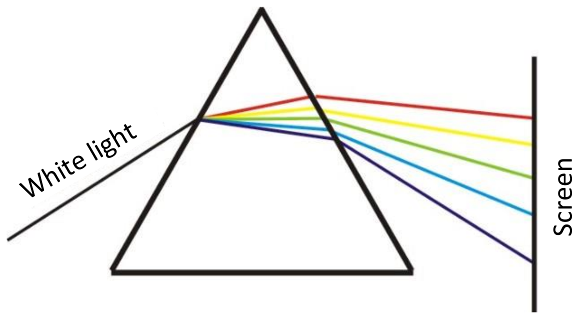


Fig. 7 Spectral decomposition of white light in a prism due to dispersion

Measurement of optical dispersion curves

The minimum deflection method is used to measure the wavelength dependence of the refractive index of optical materials. The material to be examined is given as an isosceles prism with the base angle γ. Parallel light falling on the left side of the prism is refracted twice before leaving the prism. The law of refraction applies to every interface:

$$\frac{\sin \alpha}{\sin \beta} = \frac{n_2}{n_1} \qquad (12)$$

where α and β are the angles of incidence and reflection with respect to the perpendicular and n_1 , n_2 are the refractive indices of the two materials (see Fig. 7).

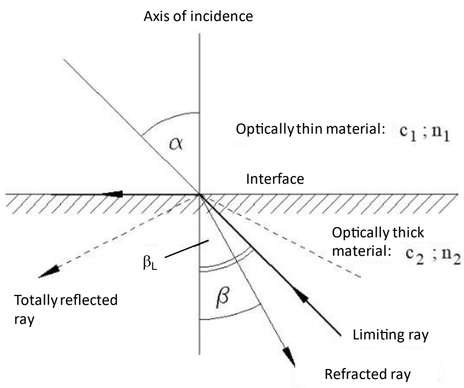


Fig. 7 *Beam path at the interface of two optical media with different refractive indices n_1 and n_2*

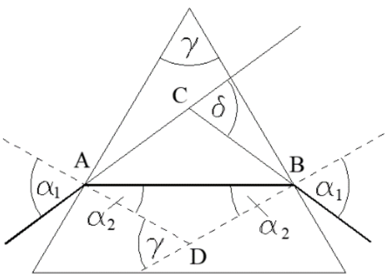


Fig. 8 *Deflection of a light beam in a prism*

It can be shown that the total deflection angle δ between the incoming and outgoing beams has a minimum at a certain position of the prism, namely with a symmetrical beam path, i.e. when the angles of incidence and reflection are the same (see Fig. 8).

Figure 8 provides: $\gamma = 2\alpha_2$; $\delta=2(\alpha_1 - \alpha_2)$

It follows: $\gamma + \delta = 2\alpha_1$

Using the law of refraction, we can then calculate: $$n = \frac{\sin\alpha_1}{\sin\alpha_2} = \frac{\sin\left(\frac{\gamma+\delta_{min}}{2}\right)}{\sin\left(\frac{\gamma}{2}\right)} \quad (13)$$

Equation (13) shows that there is a connection between the minimum deflection angle and the refractive index. An accurate measurement of the minimum deflection angle allows an accurate determination of the refractive index n of the prism.

A goniometer with an angular resolution of 1' (1' = 1/60°) is used to measure the minimum deflection angle. Monochromatic light is provided by a combination 50-W halogen lamp and a grating monochromator. In the monochromator, the white light of the halogen lamp is spectrally dispersed using an optical grating (see first of experiment) and a selectable wavelength λ is filtered out with a spectral bandwidth $\Delta\lambda$. The overall structure is shown schematically in Fig 5. A variable goniometer entrance slit B1 is located directly behind the monochromator exit slit. The light coming from the monochromator ($\Delta\lambda = 10$ nm) is divergent and is first parallelized by the lens L2 and directed onto the prism. The light coming from the prism is detected with the eye with an observation telescope, which is formed from the lenses L3 and L4. When the telescope is focused, a sharp image of the entrance slit can be observed (without the prism). The deflection angle can be read from the goniometer table.

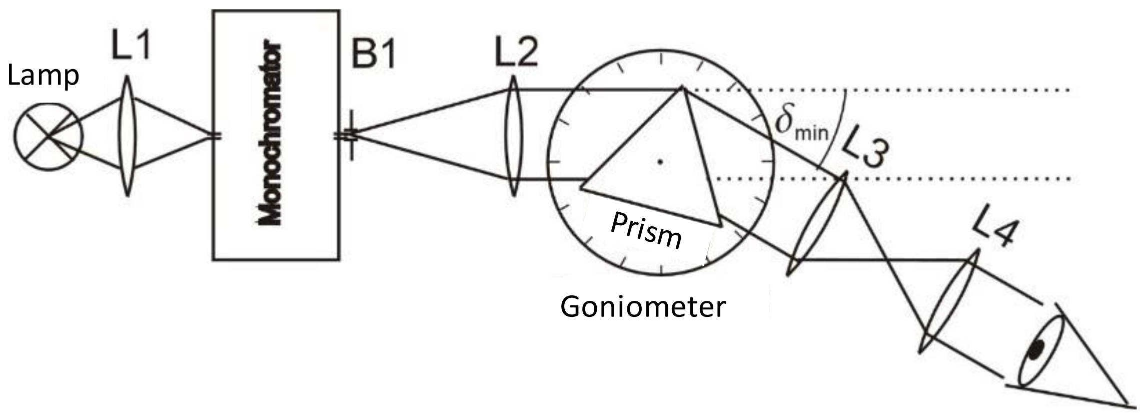


Fig. 9 *Schematic representation of the measurement setup for measuring the refractive index using the minimum deflection method*

Experimental procedure:

Regarding task 1:

The test setup is shown schematically in Fig.10. The components entrance slit, imaging lens, goniometer, grating and observation telescope together form a spectrometer, with which the wavelengths of different spectral lines in the visible spectral range can be determined relatively precisely in a simple manner.

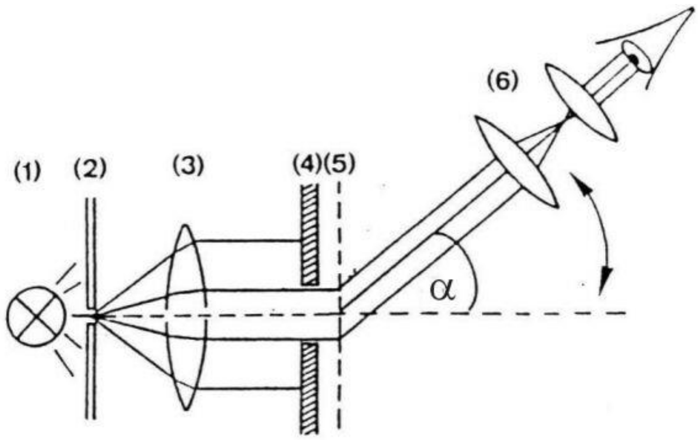


Fig. 10 *Grating spectral apparatus: (1) light source, (2) entrance slit, (3) lens, (4) grating diaphragm, (5) grating and (6) telescope with crosshairs*

The core of the arrangement is a goniometer, which enables very precise angle measurements. The transmission grating, which is to be borrowed from the internship assistant, is to be placed on the goniometer table in such a way that it is perpendicular to the incident light beam. The surface of the grating must not be touched under any circumstances. The yellow double line of a sodium vapor lamp ($\lambda_1 = 589.0$ nm, $\lambda_2 = 589.6$ nm) is used as the monochromatic light source for determining the grating constant. It is important that the same line is always used to measure the lattice constant. For example, the line with $\lambda_1 = 589.0\ nm$ is always on the inside (closer to the 0th order) due to its shorter wavelength. The light from the sodium vapor lamp falls on the entrance slit (2). The light passing through the entrance slit is parallelized by the lens (3) and interacts with the grating (5) perpendicularly. There is an aperture (4) in front of the grating, which determines the width of the grating that is illuminated. The diffracted light can be examined with the help of the observation telescope (6), whereby a sharp image of the entrance slit can be observed. The diffraction angle can be read from the goniometer.
The angles of the positive and negative first diffraction orders ($m = +1$ and $m = -1$) → α_+ and α_- are measured. The diffraction angle results from taking the half of the angle difference between the two orders: $\alpha_k = \frac{|\alpha_+|+|\alpha_-|}{2}$. Assuming that the angle of the zeroth order is around $0°$, the angle of the negative first order $|\alpha_-|$ results from the difference of $360°$ and the read angle. The measurement of the angles must be carried out 5 times to increase the measurement accuracy. The entrance slit is made as small as possible. On the goniometer there is a vernier / nonius scale on the reading scale, which allows the angle to be read precisely to the minute. The vernier scale is divided into minutes ($1° = 60$ min).

Regarding task 2:
From the grating constant determined in task 1 and the illuminated grating width (width of the aperture), the theoretical resolving power of the grating can be calculated using equation (6).

Regarding task 3:
Before the measurements for task 3 can be carried out, the sodium vapor lamp must be replaced with the unknown spectral lamp. This is carried out by the lab assistant. Analogously to task 1, the individual spectral lines are approached by swiveling the observation telescope and the corresponding angles are read off. The diffraction orders $m = +1$ and $m = -1$ are also to be measured once for each line.

Note: For the error calculation, the error of the angle in radians must be used!!

Regarding task 4:
First set the wavelength $\lambda = 540$ nm on the monochromator for adjustment. Align the goniometer with respect to the monochromator so that lens L2 is fully illuminated and has maximum brightness (check behind L2 with a piece of white paper). Now measure the zero angle. This is the angle of the passing beam without a prism. This should be close to 0° and must then be subtracted from all measured angles.

The following procedure should be repeated for each wavelength specified in Table 1:
Center the prism on the prism table. Swivel the spotting scope until an image of the entrance slit can be observed. The slit image is curved with a prism (see Fig. 11). Now turn the prism table until you have found the angle of minimum deflection. This can be read with the help of the vernier and the reading magnifier with a reading accuracy of one minute. If you have any questions about using the vernier, please contact the laboratory engineer.
The wavelength dependence of the refractive index of a glass prism (provided by the laboratory engineer) is to be measured for the wavelengths given in Table 1. The base angle of the prism should be obtained from the lab assistant. The dependency $n = n(\lambda)$ is to be shown in a diagram together with a regression curve.

Hint: Carry out an error calculation for the refractive index at the wavelengths $\lambda_1 = 404.7$ nm and $\lambda_2 = 656.3$ nm. For this, the error of the base angle of the prisms used can be neglected. The angle errors taken into account are to be used in radians.

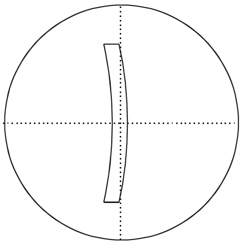


Fig. 11 *Adjustment of the observation telescope to the curved image of the entrance slit.*

Regarding task 5:

Using the refractive index data for Schott glasses given in Tab. 2, try to determine the glass type of the glass prism. Why is the observed slit image (with a glass prism) much wider for small wavelengths (e.g. $\lambda = 404.7$ nm) than for long wavelengths (e.g. $\lambda = 656.3$ nm)? (Answer the question in written form)

Control questions:

1. What is a wave? To which type of waves does light belong?
2. What are transverse and longitudinal waves?
3. Calculate the wave number k for the given frequency of an optical wave $f = 5 \cdot 10^{14}$ Hz for the medium air!
4. What does Huygens' principle state?
5. Explain the concept of interference. How can constructive and destructive interference happen?
6. Besides optical light, name other representatives of electromagnetic waves!
7. What does the diffraction pattern look like behind an optical transmission grating when white light is sent through it?
8. Derive equation (5) using Fig. 4.
9. How many diffraction orders of the yellow sodium lines can be observed with a grating with 500 lines/mm?
10. What influence does the entrance slit have on the resolving power of the spectrometer?
11. Calculate for $m = 1$ (1st order) from Eq. 5 the partial derivatives $\left(\frac{\partial\lambda}{\partial s}\right)$ and $\left(\frac{\partial\lambda}{\partial\alpha}\right)$
12. What is the group and phase velocity of waves?
13. Explain the concept of dispersion!
14. Under what conditions does one speak of normal and anomalous dispersion of optical media?
15. Derive Eq. (9) from the equations (2,3,4,7,8)!
16. How does the wavelength of a monochromatic light wave with $\lambda = 600$ nm change when it passes perpendicularly from a vacuum into a medium with a refractive index of $n = 1.5$? What is the frequency of the light in the vacuum or in the medium?
17. Is a transparent medium with the refractive index n=0.8 conceivable?
18. Explain the structure and the principle of operation of a grating monochromator. Which parameters influence the spectral bandwidth of the monochromator?
19. Explain the basic structure of a prism monochromator. Which of the glasses mentioned in Fig. 6b are most suited for a monochromator?
20. To calculate the error of the refractive index, the partial derivative $\left(\frac{\partial n}{\partial\delta_{min}}\right)$ must be calculated from Eq.13.

Literature:

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Internet: (no guarantee is given for the validity of the pages)

/Int1/ Java applet for diffraction at grating
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/Int2/ Java applet for spectral decomposition of the light from a mercury vapor lamp with an optical grating
http://www.stud.uni-giessen.de/~st5449/medi/HgLinien.htm

/Int3/ Java applet for interference of two waves
http://www.pk-applets.de/phy/interferenz/interferenz.html

/Int4/ Java applet for dispersion, group and phase velocity
http://www.chemgapedia.de/vsengine/vlu/vsc/de/ch/13/vlu/spektroskopie/theorie/dispersion.vlu/Page/vsc/de/ch/13/pc/spektroskopie/theorie/dispersion/disp6.vscml.html

	λ [nm]	$\delta\delta_{min}$ from glass prism (number):	$\delta\delta_{min}$ from liquid (number):	Refractive index from glass prism (number):	Refractive index from liquid (number):
1	404.7				
2	435.8				
3	441.6				
4	457.9				
5	465.8				
6	472.7				
8	480.0				
9	488.0				
10	501.7				
11	514.5				
12	532.0				
13	546.1				
14	589.3				
15	632.8				
16	656.3				

Table 1

Wavelength λ (nm)	Refractive Index, n				
	BK7	SF11	LaSFN9	BaK1	F2
351.1	1.53894	—	—	1.60062	1.67359
363.8	1.53649	—	—	1.59744	1.66682
404.7	1.53024	1.84208	1.89844	1.58941	1.65064
435.8	1.52668	1.82518	1.88467	1.58488	1.64202
441.6	1.52611	1.82259	1.88253	1.58415	1.64067
457.9	1.52461	1.81596	1.87700	1.58226	1.63718
465.8	1.52395	1.81307	1.87458	1.58141	1.63564
472.7	1.52339	1.81070	1.87259	1.58071	1.63437
476.5	1.52309	1.80946	1.87153	1.58034	1.63370
480.0	1.52283	1.80834	1.87059	1.58000	1.63310
486.1	1.52238	1.80645	1.86899	1.57943	1.63208
488.0	1.52224	1.80590	1.86852	1.57927	1.63178
496.5	1.52165	1.80347	1.86645	1.57852	1.63046
501.7	1.52130	1.80205	1.86524	1.57809	1.62969
514.5	1.52049	1.79880	1.86245	1.57707	1.62790
532.0	1.51947	1.79479	1.85901	1.57580	1.62569
546.1	1.51872	1.79190	1.85651	1.57487	1.62408
587.6	1.51680	1.78472	1.85025	1.57250	1.62004
589.3	1.51673	1.78446	1.85002	1.57241	1.61989
632.8	1.51509	1.77862	1.84489	1.57041	1.61656
643.8	1.51472	1.77734	1.84376	1.56997	1.61582
656.3	1.51432	1.77599	1.84256	1.56949	1.61503
694.3	1.51322	1.77231	1.83928	1.56816	1.61288

Table 2
Refractive indices of various Schott glasses