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# Exercise 366

## Determination of refractive index *n* of the glass prism by means of the measurement of the angle of minimum deviation

### I. Determination of the angle of the prism

| Position of I wall | | Position of the II wall | | Difference in positions, $\Psi_i$ | | $\varphi_i = \lvert 180° - \Psi_i \rvert$ | | Angle of prism |
|---|---|---|---|---|---|---|---|---|
| A | B | A | B | A | B | A | B | $\varphi = \overline{\varphi}$ |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

### II. Determination of the angle of minimum deviation

| Telescope position | | | | Difference in positions | | Angle of minimum deviation |
|---|---|---|---|---|---|---|
| at the minimum deviation, $\alpha_i$ | | in front of the collimator, $c_i$ | | $\delta_i = \lvert \alpha_i - c_i \rvert$ | | |
| A | B | A | B | A | B | $\delta = \overline{\delta}$ |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| Refractive index for material of prism | | | | | | $n =$ |

# Exercise 366. Determination of refractive index *n* of the glass prism by means of the measurement of the angle of minimum deviation

## *Reflection and refraction*

When describing the interaction of light with macroscopic objects we use geometrical optics, an approximate treatment of light in which light waves are represented as straight-line rays. The axis of light rays determines the direction of propagation of light energy. The course of light rays in transparent medium can be determined on the basis of the basic assumption of geometric optics, that the light in the homogeneous and isotropic medium propagates along straight lines, and intersecting narrow beams of light do not interact with each other.

When a beam of light (the incident beam) encounter a boundary between two transparent media part of the light is reflected by the surface, forming a beam directed upward toward the right, traveling as if the original beam had bounced from the surface. The rest of the light travels through the surface and into the second media, forming a beam directed downward to the right. The travel of light through a surface (or interface) that separates two media is called refraction, and the light is said to be refracted. Unless an incident beam of light is perpendicular to the surface, refraction changes the light's direction of travel. For this reason, the beam is said to be "bent" by the refraction.

The light travel from the medium **1** to **2** is shown in Fig. 1. Note that the bending occurs only at the surface; within the second medium, the light travels in a straight line. The beams of light in the figure 1 are represented with an incident ray, a reflected ray, and a refracted ray. Each ray is oriented with respect to a line, called the normal, that is perpendicular to the surface at the point of reflection and refraction. In Fig.1, the angle of incidence is $\alpha_1$, the angle of reflection is $\alpha_1$', and the angle of refraction is $\alpha_2$, all measured relative to the normal. The plane containing the incident ray and the normal is the plane of incidence, which is in the plane of the page in Fig. 1

Reflection and refraction are governed by two laws.

**Law of reflection:**
A reflected ray lies in the plane of incidence and has an angle of reflection equal to the angle of incidence (both relative to the normal). In Fig.1 this means that:

$$\alpha_1 = \alpha_1' .$$

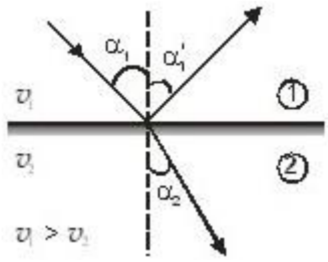

Fig.1

**Law of refraction**:
A refracted ray lies in the plane of incidence and has an angle of refraction $\alpha_2$ that is related to the angle of incidence $\alpha_1$ by:

$$\frac{\sin\alpha_1}{\sin\alpha_2} = n_{2,1}, \quad (1)$$

where symbol $n_{2,1}$ is a *relative refractive index* of an optical medium 2 with respect to another (reference) medium 1. It can be shown that the relative refractive index depends on the speed of light in both media:

$$n_{2,1} = v_1/v_2 , \quad (2)$$

$v_1$ — the speed of light in medium **1**, $v_2$ — the speed of light in medium **2**. The refractive index of the medium relative to the vacuum is called *the absolute refractive index n,*

$$n = c/v , \quad (3)$$

*c* — the speed of light in a vacuum, *v* — its speed in a given medium. The absolute refractive index differs very little from the refractive index to air due to the fact that the speed of light in the air $v_p$ is approximately equal to the speed of light in vacuum *c*. By transforming the formula (2) we will get

$$n_{2,1} = \frac{v_1}{v_2} = \frac{c/v_2}{c/v_1} = \frac{n_2}{n_1} , \quad (4)$$

which implies that the relative refractive index $n_{2,1}$ of two adjacent media is equal to the ratio of the absolute refractive indices of these media.

The frequency *f* of a light wave is determined by the light source and does not depend on the medium in which the light travels. On the other hand, the speed of light in a dielectric medium depends on dielectric and magnetic permeability of medium.

Since the product of frequency *f* and wavelength $\lambda$ is equal to its velocity *v*,

$$\lambda \cdot f = v,$$

then using the relationship (3) we will get the formula

$$\lambda = \frac{c}{n \cdot f},$$

from which it follows that when a light wave reaches an interface travelling from a higher optically dense medium to a lower one the wave speeds up (the length of the light wave decreases). *Optical density* is not the same as physical density, i.e. mass per unit volume, it is measured in terms of refractive index – higher refractive index material having higher optical density.

Physical phenomenon of the dependence of the speed of light in a given material medium, and thus the refractive index *n* of this medium on the wavelength of incident light, is called *chromatic dispersion*. In relation to visible light, transparent media generally exhibit *normal dispersion*, i.e. *n* decreases with an increase of wavelength □, ($dn/d\lambda < 0$) — red light is bend less than blue light (the speed of red light is greater than blue). The dispersion in the air is very weak, and in a vacuum it does not occur (the speed of light in a vacuum is the same for all wavelengths).

A beam of white light, for example produced by bulb, consists of components of all (or nearly all) the colours in the visible spectrum with approximately uniform intensities. When such a beam in air is incident on a glass prism surface, rays will be refracted at different angles, that is, the light will be spread out by the refraction according to its wavelengths or colours. Chromatic dispersion occurs at the first surface of glass prism and is increased at the second surface. producing a divergent beam of light. When this beam falls on the screen, we observe a colour image – *visible light spectrum* .Glass has a greater index of refraction at shorter wavelengths, that is, it bends blue light more than red light. Note that beams of monochromatic (of a single wavelength) light, for example produced by lasers, do not show chromatic dispersion.

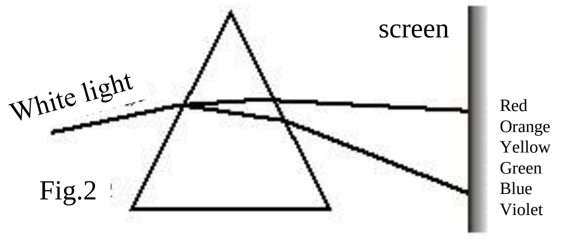


Fig.2

### *Determination of the refractive index based on the deviation of the light beam passing through the prism*

A prism is called a light-refracting medium, bounded by two planes, creating *an angle of prism* $\varphi$ with each other. In the exercise we use triangular glass prism with a triangular base and rectangular sides. When a light ray falls on the surface of of the prism it refracts inside the prism until it falls on the second wall and emerges from the prism. The light ray refracts twice. The emerged light ray deviates from its path by a certain angle, which is called *the angle of deviation* $\delta$, Fig. 3. The value of this angle depends on the angle of incidence $\alpha$, the angle of the prism $\varphi$ and refractive index of prism.

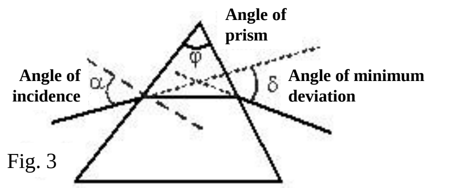


Fig. 3

The angle of deviation reaches *a minimum* when inside the prism the light ray is perpendicular to the internal bisection of angle of prism □, Fig. 4. In this case, the angle $\delta = \delta_{min}$ is the sum of the non-adjacent angles in the triangle ABC, that is $\delta = 2(\alpha - \beta)$. Angles □ and $\varphi/2$ are equal because their arms are perpendicular to each other. Putting $\beta = \varphi/2$ to the equation $\delta = 2(\alpha - \beta)$ shows that angle of incidence □ is given by:

$$\alpha = (\delta + \varphi)/2 . \qquad (5)$$

Equation (5) and $\beta = \varphi/2$ enable us to calculate the refractive index *n* of the material of prism:

$$n = \frac{\sin\left[(\delta + \varphi)/2\right]}{\sin\left[\varphi/2\right]} . \qquad (6)$$

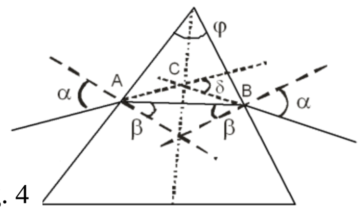

Fig. 4

The angle of prism and the angle of the minimum deviation $\delta$ are determined using *prism spectrometer*.

***Construction of the spectrometer***

The spectrometer, Fig. 5, is an instrument that allows accurate measurement of the angle of deviation of the light ray passing through the prism. The light is emitted of the source and goes to the collimator through a slit of adjustable width. After passing through the collimator, the light beam becomes approximately parallel (the length of the collimator is chosen so that the slit lies in the focal plane of the lens located at the other end of the collimator). This beam can enter the telescope directly or after deviation through the prism set on the prism table. The collimator is fixed to the base of spectrometer, and the vernier table and the telescope can rotate around the same axis independently of each other. The telescope is permanently connected to the angular scale visible in the window of the vernier table, which adheres to two verniers, shifted by $180^{\circ}$ (verniers are connected to the base of the prism table). At the base of the spectrometer there are fine adjustment screws that block accidental movement of the Vernier table and telescope when reading angle values. After tightening the locking screws, the precise positioning of the prism table and the telescope is achieved using the screws shown in the figure below.

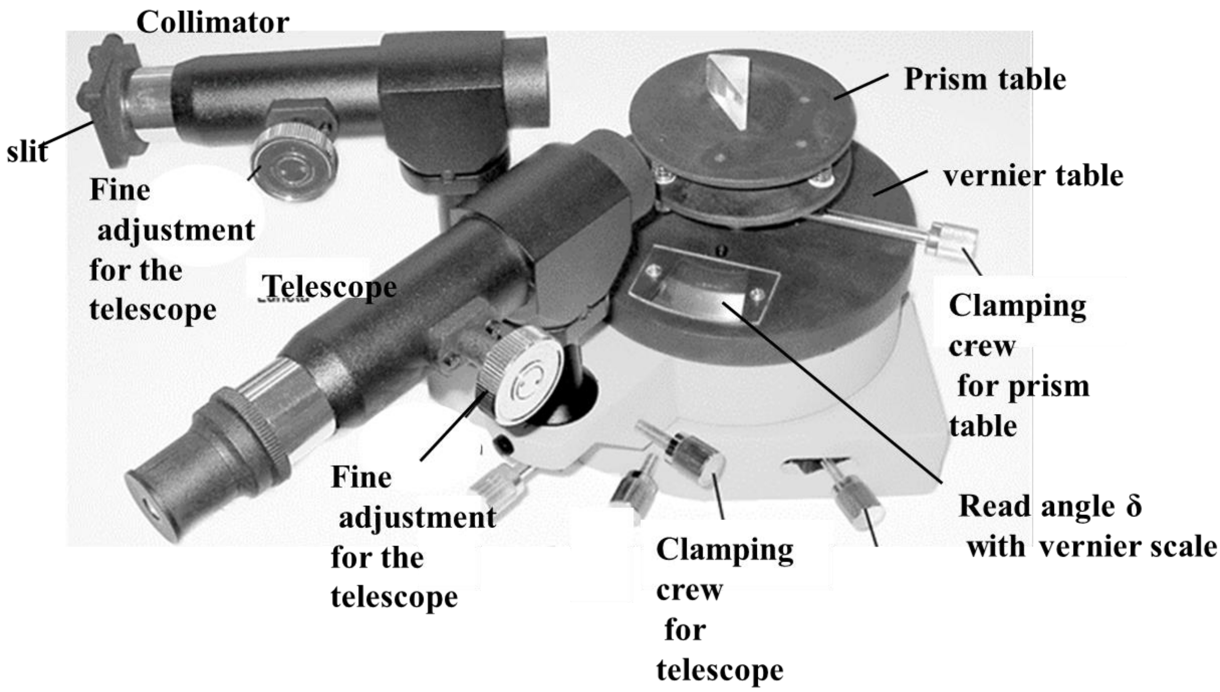


Fig. 5

## *Performance of the task*

Telescope alignment. Place a white light (desk lamp) in front of the slit on the end of collimator. Now rotate the telescope until it is pointed at the collimator. By looking through the telescope, you should be able to line up the crosshair with the slit in the far end of the collimator. To do it accurately use the fine adjustment for the telescope. If you are unable to see the slit, it may be closed to tightly. You can widen and narrow the slit by rotating the adjuster on the collimator (it is located on far end of the collimator). If the slit does not have very crisp edges when you look through the telescope, use fine adjustment for the collimator to focus it.

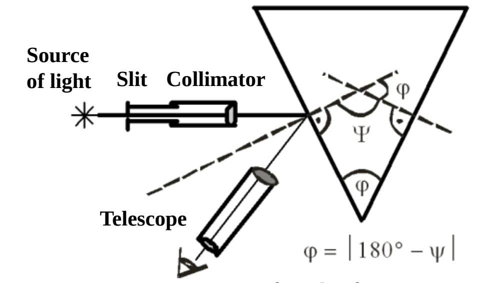

Fig. 6. Measurment of angle of prism

Prism placement. Position the telescope at acute angle to the collimator (please have a look at Fig 6). Lock down the telescope using clamping screw for the telescope

Determination of the prism breaking angle:

1. Place the prism on prism table (please look at Fig.6)
2. Rotate the vernier table to check if all walls of the prism reflects a beam of rays coming out of the collimator, so that you can see the image of the slit in the telescope.
3. Rotate the vernier table in one direction to find a position at which one wall of the prism reflects a beam of rays coming out of the collimator so that the image of the slit in the telescope is exactly in the middle of the crosshair – the reflecting wall is then perpendicular to internal bisection of angle between the collimator and the telescope (see Fig.6).
4. Read and note the angle from angular scale on vernier table specifying the position of the I wall. Use the Vernier scale to read angle to the nearest arc minute. (1 arcmin=1'= 1/60 degree). Notice that there two windows in which you can read the angle (vernier A and vernier B).
5. Rotate the vernier table in opposite direction to obtain in the telescope the reflected image of the split of collimator from the second wall of prism. Read and note the corresponding main scale and vernier scale reading in both vernier (vernier A and Vernier B).
6. Find the difference in position Ψ between of the first and second walls.
7. Find the angle of prism □. As can be seen from Figure 6: $\varphi = |180° - \Psi|$.
8. Determine the angle of prism three times, slightly changing the position of the prism on the table.
9. Calculate the average value of the breaking angle: $\bar{\varphi} = \frac{1}{6}\sum_{i=1}^{6}\varphi_i$ . (three values each for vernier A and B)

Determination of the angle of the minimum deviation $\delta$

1. Remove the white light and replace it with sodium vapor lamp. The lamp should be very close to slit.
2. Position the prism and telescope according to Fig. 7.
3. Look through the telescope and move it along the perimeter of the vernier table until you see certain bands of colours. If your bands do not look nice and sharp, you may have to adjust your slit focus or width. Some lines are better seen if tighten the slit.
4. Rotate the vernier table back and forth just a little bit and observe the direction of movement of the band od colours — choose the direction of rotation at which the deviation of the refracted decreases (the image of the slit should approach the axis of the collimator, (Fig. 7). If, during the rotation of the table, the image goes out of the field of view, move the telescope in the direction of the image

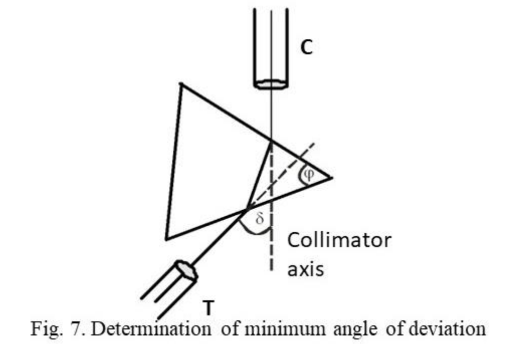

Fig. 7. Determination of minimum angle of deviation

movement. Move of the table until the image of split in the telescope stops and changes the direction of movement. When this occurs the angle of deviation reaches the minimum value.

5. Set the position of the vernier table exactly at the turning point.
6. Position the telescope so that the crosshair lined up on lying yellow band of the spectrum. You can also examine another spectral lines.
7. Gently turn vernier table and check whether the tested band actually line up with the crosshair at the point of return.
8. Note in Table II the indications of both verniers, corresponding to the minimum deviation. $\alpha_i$
9. Remove the prism without moving the table and move the telescope parallel to collimator (in front of the collimator) – set it so that the image of the slit (neon in colour) is in the middle of the crosshair. The indications of the vernier correspond to the position of the telescope for the direct ray. $c_i$
10. Calculate the angle of the minimum deviation $\delta_i$ — it is equal to the difference in the positions of the telescope for the deviated and direct ray: $\delta_i = |\alpha_i - c_i|$.
11. Repeat measurement of the angle of the smallest deviation is $\delta$ three times.
12. Calculate the average value $\delta$ of : $\bar{\delta} = \frac{1}{6}\sum_{i=1}^{6}\delta_i$ , (three values each for vernier A and B).
13. Calculate the refractive index using equation 6.

## *Calculation of the uncertainties*

1. Calculate the measurement error $\Delta\varphi$ as the maximum value of the difference between the mean value of the $\bar{\varphi}$ and each of the values $\varphi_i$: $\Delta\varphi = \max|\bar{\varphi} - \varphi_i|$.
2. Similarly calculate Δδ $\Delta\delta = \max|\delta - \delta_i|$.

If any of these errors are less than double the accuracy of the angle reading, double the readability shall be taken as an error. The reading accuracy is $0{,}1° = 6\ \text{minut}$.

Errors $\Delta\varphi$ and Δδ should be expressed in radians.

3. Calculate the measurement error $\Delta n$ using equation:

$$\Delta n = \frac{\sin[\delta/2]}{2\sin^2[\varphi/2]}\Delta\varphi + \frac{\cos[(\varphi+\delta)/2]}{2\sin[\varphi/2]}\Delta\delta .$$

4. Calculate the relative percentage error: $B_p = (\Delta n/n)\cdot 100\%$ .