GDYNIA MARITIME UNIVERSITY
FACULTY OF MECHANICAL

PHYSICS LABORATORY
DEPARTMENT OF PHYSICS

Theoretical Introduction

Experiment “R E F R A C T I O N”

Definition of the Refractive Index of Light

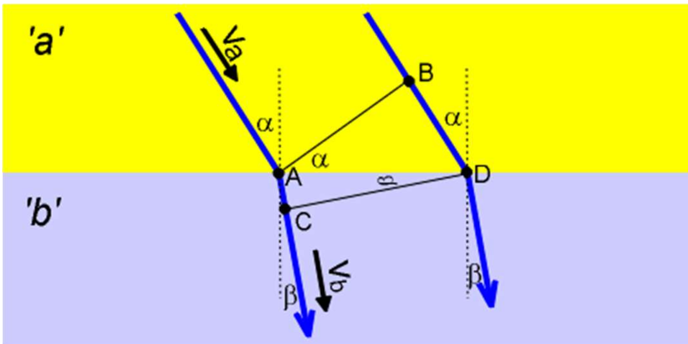
Light is an electromagnetic wave. Its speed in vacuum is: c = 299792458 m/s ±1 m/s. In a material medium, this speed is lower. The refractive index of light in a given medium is equal to the ratio of the speed of light in vacuum c to the speed v in this medium:

$$n = \frac{c}{v}$$

The relative refractive index of medium $b$with respect to medium $a$is defined analogously as the ratio of the speed in medium $a$to the speed in medium b:

$$n_{ba} = \frac{v_a}{v_b}$$

Snell’s law states that light passing from one medium to another changes its direction of propagation, as shown in the figure below.

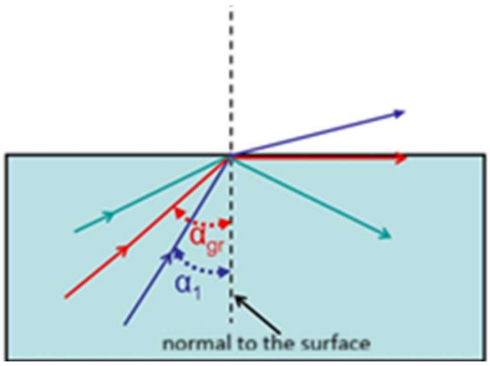


According to Fermat’s principle, the path AC is travelled by light in the same time as the path BD.

Therefore: $t_{A\to C} = t_{B\to D} \;\Rightarrow\; \frac{AC}{v_b} = \frac{BD}{v_a} \;\Rightarrow\; \frac{AC}{AD\ \ b} = \frac{BD}{AD\ \ a} \;\Rightarrow\; \frac{\sin\beta}{v_b} = \frac{\sin\alpha}{v_a} \;\Rightarrow\; \frac{v_a}{v_b} = \frac{\sin\alpha}{\sin\beta}$

that is: $n_{ba} = \frac{\sin\alpha}{\sin\beta}$ which constitutes Snell’s law.

Total Internal Reflection. JIf light passes from a medium in which it propagates at a high speed to a medium in which it travels more slowly, the angle of refraction is smaller than the angle of incidence. In the opposite case, for example water–air, the angle of refraction is greater than the angle of incidence. Therefore, in media where light propagates more slowly, there will be a critical angle of incidence for which the refracted light will glide along the surface of the medium: (β = 90°). For angles greater than the critical angle, internal reflection will occur and light will not pass into the second medium.

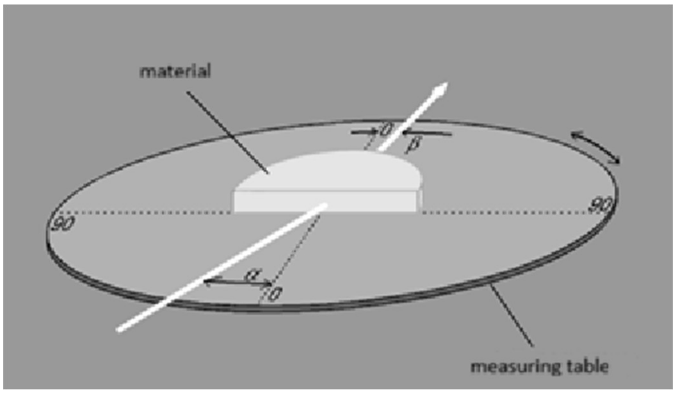


“R E F R A C T I O N”

Preparation Questions

1. Give the definition of the relative refractive index of light and its unit.
2. Give the definition of the absolute refractive index of light and its unit.
3. What is the value of the refractive index of light for materials such as water, glass and plexiglass?
4. Why is the value of the refractive index of light greater than one?
5. State the law of reflection and show it in a drawing based on geometrical optics.
6. State the law of refraction of light, Snell’s law.
7. Show the law of refraction in a drawing based on geometrical optics and explain what the angle of refraction is.
8. What is the phenomenon of total internal reflection?
9. Which letters in the drawing denote the angles of incidence and refraction?
10. At what angle was light reflected from a mirror if the sum of the angles of incidence and reflection was $60°$?
11. If the angle δin the drawing below is equal to $30°$, what is the value of the angle of incidence?
12. Give the definition of a radian.
13. Give the method of converting degrees into radians, for example how many radians is $10°$?
14. Give the method of converting radians into degrees, for example how many degrees is 1 radian?
15. Give the characteristics of laser light.

Instructions for Performing the Measurements:



1. Set the lens in such a position that its flat surface coincides with the straight line passing through the $90°$angle markings, and the centre of the flat surface coincides with the centre of the disc.
2. Set the laser beam in such a way that it coincides with the straight line passing through the $0°$angle markings.
3. Rotate the disc by the selected angle α. Read the angle of incidence of the laser beam on the flat surface of the lens α, and read the angle of refraction of the laser beam β.
4. By changing the position of the disc, perform measurements up to the angle: α = 60°.
5. Repeat until ten values of angle $\alpha$and ten values of angle $\beta$are obtained.
6. Perform the calculations according to the instruction and prepare a trial graph in a spreadsheet. In the calculations, remember to use the basic SI units for all angles.
7. Prepare a measurement protocol and measurement uncertainties.

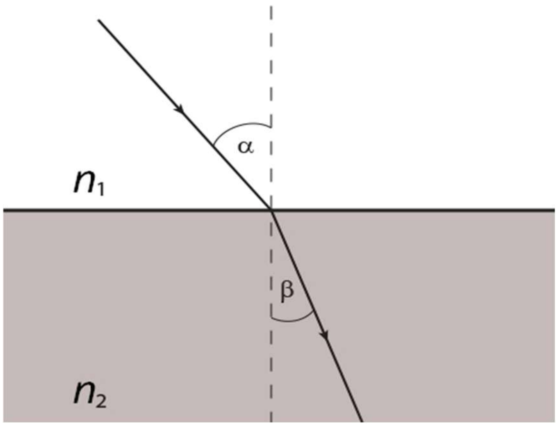
NOTE:

- Due to the excessive width of the refracted light beam and its lower intensity caused by the reflection of part of the light from the lens surface, for an angle of incidence greater than $60°$, the measurements should be limited to angles below this value.

“R E F R A C T I O N”

Methodological Template

Student 1: Determination of the refractive index of light.
Student 2: Sprawdzanie prawa Snella.



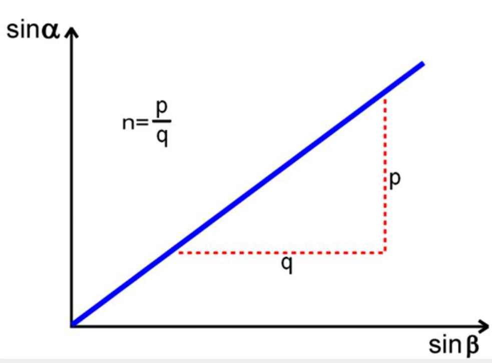
Snell’s law states that the rays, the ray incident on the boundary between media and the refracted ray, as well as the perpendicular to the boundary between media, the normal, lie in one plane, and the angles satisfy the relationship:

$$n_{21} = \frac{n_2}{n_1} = \frac{\sin\alpha}{\sin\beta}$$

where:
n_{21} – relative refractive index of light, medium 2 with respect to medium 1,
n_2 – refractive index of medium 2,
n_1 – refractive index of medium 1.
From Fermat’s principle, it follows that the relative refractive index of light n_{21} is also equal to the corresponding ratio of the speed of the light wave in these media:

$$n_{21} = \frac{n_2}{n_1} = \frac{v_1}{v_2}$$

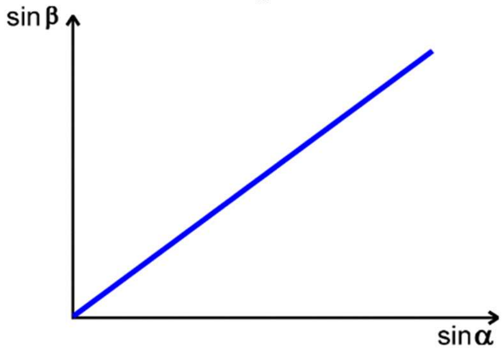
$$\sin\alpha = n \cdot \sin\beta$$



Therefore, in order to determine the refractive index of light by the direct method, one should:

- perform measurements of the dependence of the angle of refraction β on the angle of incidence α,
- prepare a graph of the dependence:
  sinα as a function of: sinβ
- read from it the value of the refractive index of light.

$$\sin\beta = \frac{1}{n} \cdot \sin\alpha$$



Therefore, in order to verify the dependence of the angle of refraction on the angle of incidence, one should:

- perform measurements of the dependence of the angle of refraction on the angle of incidence,
- prepare a graph of the dependence:
  sinβ as a function of: sinα
- analyse its linearity.

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Report Guidelines – Determination

Student 1: Determination of the refractive index of light.

I. **Methodology** (conceptual plan of the exercise)

II. **Course of exercise**

II.1. Course of activities

II.2. Sketch of the measurement setup

III. **Results**

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
α	[º]										
β	[º]										
$\Delta\beta$	[º]										

$\Delta\alpha$ = ...

2. Calculations (example calculations - referring, for example, to measurement no. 3)

$\sin\alpha$ = ...

$\sin\beta$ = ...

$\Delta\sin\alpha = |\sin(\alpha) - \sin(\alpha+\Delta\alpha)| =$ ....

$\Delta\sin\beta = |\sin(\beta) - \sin(\beta+\Delta\beta)| =$ ....

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\sin\alpha$	[-]										
$\sin\beta$	[-]										
$\Delta\sin\alpha$	[-]										
$\Delta\sin\beta$	[-]										

4. Graph

- calculation of n, the slope of the "best-fit" straight line
- calculation of n', the slope of the deviated straight line
- calculation of the accuracy of the method: $\Delta n = | n - n' |$

5. Summary

The determined value of … is …
Accuracy of the method: …
Additional conclusions, observations, causes of measurement uncertainties.

“R E F R A C T I O N”

Report Guidelines – Verification

Student 2: Verification of Snell’s law.

I. **Methodology** (conceptual plan of the exercise)
II. **Course of exercise**
    II.1. Course of activities
    II.2. Sketch of the measurement setup
III. **Results**

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
α	[°]										
β	[°]										
$\Delta\beta$	[°]										

$\Delta\alpha = \ldots$

2. Calculations (example calculations - referring, for example, to measurement no. 3)

$\sin\beta = \ldots.$

$\sin\alpha = \ldots.$

$\Delta\sin\beta = |\sin(\beta) - \sin(\beta+\Delta\beta)| = \ldots.$

$\Delta\sin\alpha = |\sin(\alpha) - \sin(\alpha+\Delta\alpha)| = \ldots.$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\sin\beta$	[-]										
$\sin\alpha$	[-]										
$\Delta\sin\beta$	[-]										
$\Delta\sin\alpha$	[-]										

4. Graph

5. Summary

Since on the graph ….. it is possible to draw a straight line passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from …..

Alternatively:
The deviation from linearity in the range … may result from …..

Additional conclusions, observations, causes of measurement uncertainties.