

Ministry of Health of Ukraine  
Ukrainian Medical Stomatological Academy

It is approved  
on meeting of department of  
medical informatics, medical and biological physics  
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Head of department \_\_\_\_\_ O.V.Silkova

**Methodical instructions**

for students' self-preparation work at preparation for a practical lesson  
at home and at the classroom

Subject matter	<b>Medical and biological physics</b>
The unit	2. Bases of medical physics
Theme of lecture:	<b>Refractometry. Determination of fluid refractivity index.</b>
Year	1
Faculty	Medical, Stomatological
Speciality	Medicine, Stomatology

Poltava - 2020

**The topic significance:**

The majority of biological liquids have heterogeneous structures: they are solutions of some substances: dissolved ions, various size molecules, and besides contain the not dissolved compounds. Therefore optical properties of liquids depend on concentration and character of included substances. Refraction index is sensitive physical parameter, which definition gives an opportunity to receive the information about change of the contents of these substances in a liquid, which is the certificate of change of processes in the human body.

The refractometry which is carried out with the help of refractometers, is one of wide-spread methods of identification of chemical compounds, the quantitative and a structure analysis, determination of the physicochemical parameters of substances. This method is used in the food, pharmaceutical and the biochemical industry, in services of ecological monitoring and the state sanitary-and-epidemiologic supervision, the scientific and educational organizations.

**Specific targets:**

To know the reflection and a refractive optical phenomena, their laws, use of these phenomena in the medical equipment ;

To acquire physical sense of refractive index ;

To learn to grade a refractometer, to determine the content of material in a solution .

**Basic knowledge, experience, skills necessary for studying the topic in connection with other subjects:**

Previous (providing disciplines)	Obtainable skills
Physics	Laws of reflection and refraction of light, velocity of light spreading in air; dielectric constant.

**Materials for the before-class self-preparation work:**

List of main term, parameters, characteristics, which student have to learn at preparation to class:

Term	Definition
<b>Refraction</b>	Change of light ray spreading direction at ray passing through boundary of two mediums.
<b>Index of refraction</b>	The <i>relative index of refraction</i> shows how many times the velocity of light $v_1$ in the first medium is greater than the velocity of light $v_2$ in the second medium: $v_1/v_2 = n_{2,1}$ , that is $\sin\alpha/\sin\gamma = v_1/v_2 = n_{2,1}$ . The <i>absolute index of refraction</i> of the medium indicates how many times the velocity of light in vacuum $c$ is greater than that in the given medium $v$ , i.e. $n_1 = c/v_1$ ; $n_2 = c/v_2$ .
<b>Total internal reflection</b>	Total ray energy reflection, when refraction angle is more then $90^\circ$ , incident angle is more then $\alpha_{cr}$

**Theoretical questions to class:**

1. Basics of geometrical optics.
2. Laws of geometrical optics.
3. Relative index of refraction.
4. Absolute index of refraction.
5. Phenomenon of total internal reflection. It application in medicine.
6. Refractometry. Explain how refractometry is used in medicine.

**Practice work executed at class:**

Study of the dependence of the index of refraction of a solution on its concentration.

Turn up the upper prism with the handle. Put a few drops of the distilled water on the lower prism. Press the upper prism to the lower prism firmly but with care.

Direct the light from the light source (mirror, lamp, sun) to the slot. Focus the ocular lens.

Move the spyglass upward or downward slowly until the light–shadow boundary appears in the field of view.

If the boundary is blurred and colored, move the handhold of the equaliser up to the disappearance of rainbow effect.

Move the ocular marks (viewfinder – three touches) to coincide with the light–shadow boundary slow. Read the refraction index on the left scale accurate within 0,001.

Turn the upper prism up and clean the faces of both prisms with cotton. Put 3–4 drops of the solution of known concentration (initial  $C = 0\%$  – clear water).

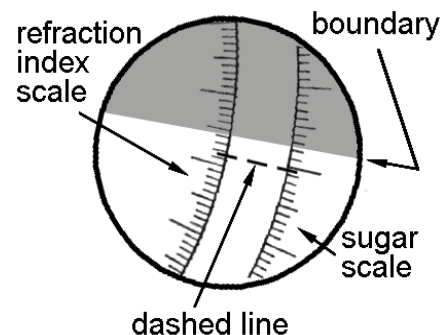
Measure the refraction index of the solution as described above.

Do the similar measurements with the other solutions of known concentration. Each solution must be put with a separate dropper, and the prisms must be cleaned by distilled water and dried by touch of cotton (not rub! not wipe!).

Put the obtained data into the table:

Concentration, C, %	0	1	2	3	4	5	6	7	8	9	$X_1$	$X_2$
Index of refraction, n												

Draw the graph “concentration – refraction index”: dependence index of refraction on solution concentration. Connect points by approximation **straight line**.



**Fig.49. Field of vision of refractometer eyepiece. Ocular mark (viewfinder) – dashed line.**

Measure the refraction index of the solutions of unknown concentration.  
 Find unknown concentrations  $X_1$  and  $X_2$  by the graph: take the unknown concentration from the approximation graph by refraction index value.  
 Make the conclusion.

**The contents of the topic:**

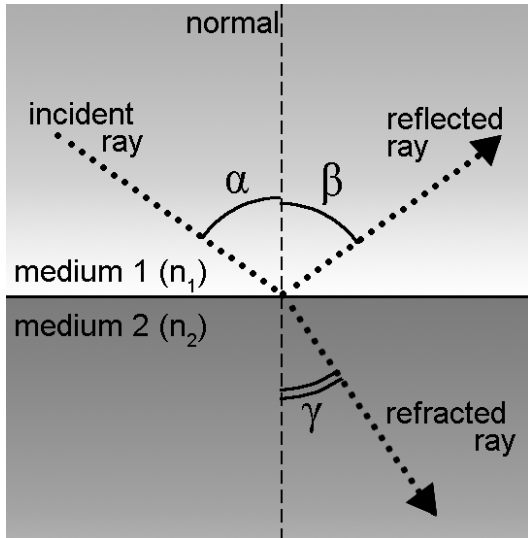


Fig.1. Reflection and refraction on the mediums border.

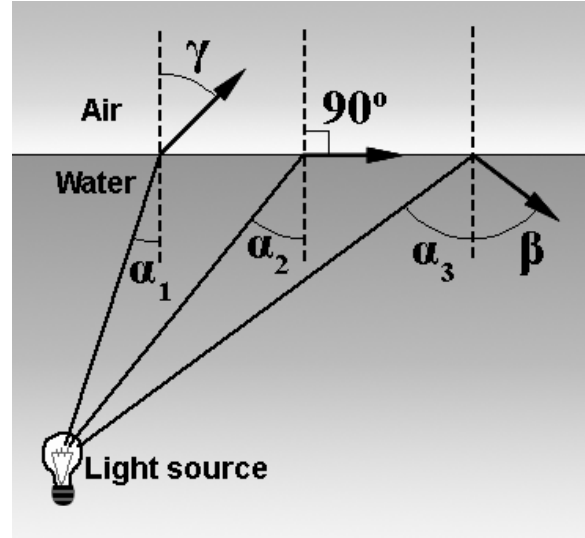


Fig.2. Conditions of total internal reflection.  $\alpha_2$  – critical angle of total internal reflection.

The operation principle of many optical devices applied in clinics, and medical and biological laboratories, is based on the laws of geometrical optics.

Geometrical (ray) optics is the branch of optics that uses the concepts of light rays. A light ray is an imaginary line, along which the luminous energy propagates.

The wave nature of light is not taken into account in geometrical optics, i.e. one may neglect the effects of light interference and diffraction. It is known that wave effects cease to be essential when the light wavelength tends to zero ( $\lambda \rightarrow 0$ ). Thus, geometrical (ray) optics is the ultimate case of wave optics on the assumption of a very small wavelength.

When light passes from one medium to another one, its velocity of propagation and wavelength change, though its frequency does not.

Geometrical optics is based on the following laws:

- 1) the incident ray, the reflected ray, the refracted ray and the perpendicular (normal) to the boundary of two media, which is at the point of ray incidence, are in one plane (fig. 1);
- 2) the **law of light reflection**: the angle of reflection  $\beta$  is equal to the angle of incidence  $\alpha$ ;
- 3) the **law of light refraction**: the ratio of the sine of angle of incidence  $\alpha$  and the sine of angle of refraction  $\beta$  is a constant value for given two media. This constant is called relative index of refraction of the second medium with respect to the first one (**the relative index of refraction  $n_{2,1}$** ). The relative index of refraction shows how many times the velocity of light  $v_1$  in the first medium is greater than the velocity of light  $v_2$  in the second medium:

$$v_1/v_2 = n_{2,1}, \quad \text{that is} \\ \sin\alpha/\sin\beta = v_1/v_2 = n_{2,1}.$$

The relative index of refraction  $n_{2,1}$  is equal to ratio of the *absolute indices of refraction* of the second and first media, i.e.  $n_2/n_1 = n_{2,1}$ .

**The absolute index of refraction** of the medium indicates how many times the velocity of light in vacuum  $c$  is greater than that in the given medium  $v$ , i.e.

$$n_1 = c/v_1; \quad n_2 = c/v_2.$$

If light is incident on the interface from the side of the optically denser medium (the medium with a higher absolute index of refraction), incident angle is greater than refraction angle. When refraction angle is equal  $90^\circ$ , incident angle  $\alpha_{cr}$  is the so-called *critical angle of total internal reflection*. In that case, when  $\alpha > \alpha_{cr}$ , light does not pass into the second medium, but is totally reflected from the interface (fig.2).

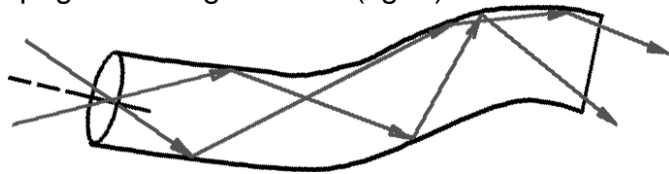
The value of the critical angle of total reflection is determined by the formula:

$$n_{2,1} = \frac{\sin \alpha_{cr}}{\sin 90^\circ} = \frac{n_2}{n_1}, \text{ therefore, } \sin \alpha_{cr} = \frac{n_2}{n_1},$$

where  $n_1$  is the refraction index of the medium, from which light falls on the boundary,  $n_2$  is the refraction index of the medium, in which light passes after refraction.

Phenomenon of total internal reflection is used in many optical devices.

Functioning of *optical fibers* is based on the effect of total internal reflection. The branch of optics dealing with light and image transmission by optical fibers is called *fiber optics*. Optical fibers are transparent fibers enclosed in a substance whose index of refraction is less than that of the fiber. When light enters into a fiber, it reflects repetitively and propagates along the fiber (fig. 3).



Optical fibres are the key components of *endoscopes* (instruments for inspection of internal cavities – the stomach, bronchi, rectum, and others). Medicine harnesses laser radiation by transmitting it along optical fibres into the internal organs for healing tumours.

*Refractometers* are devices that measure the refraction indices of liquids.

In medicine, refractometers are used for determining the concentration of a substance in a solution (for example, the content of a protein in blood serum) as in industry (sugar concentration in syrup, purity of water etc.).

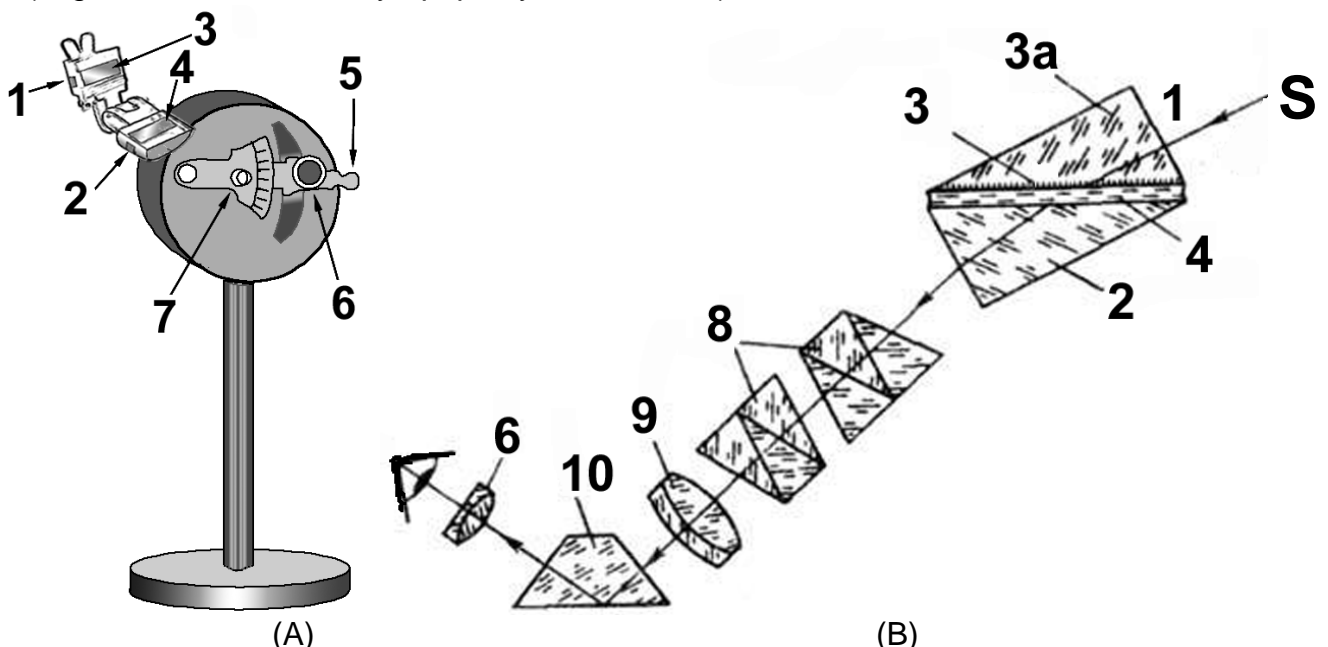


Fig.4. Refractometer appearance (A) and the optical arrangement of a refractometer (B): 1 – a lighting facet of a folding prism with slot; 2 – the basic measuring prism; 3 – an auxiliary folding prism; 3a – a delustered (matted) facet of a folding prism; 4 – an explored fluid; 5 – the handhold of an eyepiece; 6 – an eyepiece of a telescope; 7 – the handhold of the equaliser; 8 – Amici prisms of the equaliser; 9 – the ocular of a spyglass; 10 – a rotary prism.

The basic elements of the refractometer are two rectangular prisms 3a and 2 made of glass with high index of refraction ( $n=1.72$ ) (fig.4). The prisms face to each other with their hypotenuse surfaces; the gap between these surfaces is about 0.1 mm. A drop of a researched liquid is putted onto the hypotenuse facet 4 of the lower prism 2 (fig.4) and then the upper prism 3a is put on it.

At measurement the transparent liquids light on a demarcation of mediums is guided through a small cathetus *A* of the auxiliary folding prism 1 (measurement in a transmitted light), and in case of opaque mediums the mat facet *C* of the basic measuring prism 2 is lit through its major cathetus (measurement in reflected light).

The light from the source *S* goes through the lateral surface *A* (small cathetus) of the upper folding prism and falls at the hypotenuse surface *B*. The light scatters at this matt facet, goes trough the layer of the researched liquid and falls to the hypotenuse facet of the lower prism with different angles of incidence ranged from  $0$  to  $\pi/2$ .

If the refraction index of the prism is higher than that of the liquid, the refracted rays enter in the prism 2 are only if they directed within the limits  $0^\circ$  to  $r_{cr}$  – critical angle of refraction. It results in that a part of the refractometer scale, observed in the eyepiece 6, is illuminated, while the other part is shaded. The position of the boundary between light and shadow is determined by the critical angle of refraction which depends on the index of refraction of the studied liquid.

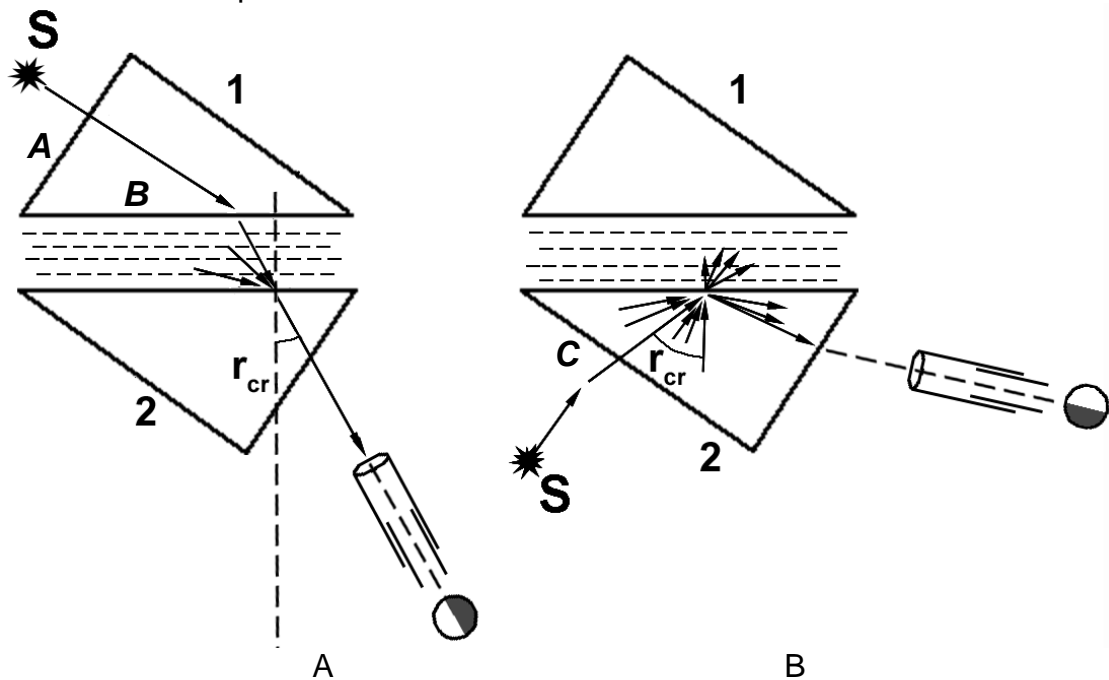


Fig.5. Ray paths in refractometer at study liquids with refraction index more then at prism glass (A), or at study liquids with refraction index less then at prism glass, or muddy, coloured liquids with high absorption factor (B).

**Refractometer-saccharimeter**

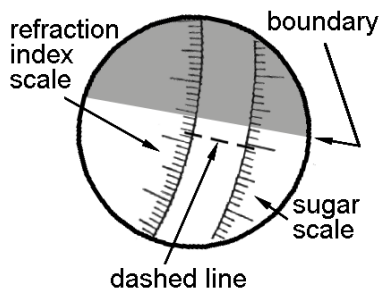


Fig.6. Field of vision of refractometer eyepiece. Ocular mark (viewfinder) – dashed line.

At overlapping a boundary of light and dark fields with dashed line ((viewfinder, cursor) in sight tubes on a scale quantity of  $n$  is read directly. Right scale is graduated in units of sugar concentration.

The boundary can be fuzzy and colored as rainbow due to dispersion effect.

The compensator, consisting of two dispersion prisms, allows to compensate dispersion of the measuring prism and the sample liquid by gyration of compensator prisms in the opposite direction. Boundary becomes distinct. It do possible

to measure value  $n_2$  at use of a source of a white light.

**Self-control material:**

A. Questions and statements to be answered:

1. Basics of geometrical optics.
2. Fundamental concept of geometrical optics.
3. Laws of geometrical optics (laws of reflection, refraction).
4. Physical meaning of relative index of refraction.
5. Physical meaning of absolute index of refraction.
6. Phenomenon of total internal reflection. Qualitative characteristics of total internal reflection.
7. Optical fiber.
8. Application of total internal reflection in medicine.
9. Refractometry.

B. Test task

Critical angle of total internal reflection for turpentine (on the interface turpentine-air) is equal  $42^\circ 23'$ . Calculate light velocity in turpentine.

Answer:  $\approx 2,02 \cdot 10^8$  m/s.

**Literature recommended**

Main sources.

- Chaliy A.V. et al., Biological and medical physics. – A.V. Chaliy et al. – Ed. A.V. Chaliy. – Vinnitsia, Nova Knyha, 2013. – 480 pp.
- Korovina L.D. Biophysics with beginnings of mathematical analysis and statistics. Extended course of lectures. Vol.3. Optics. Quantum phenomena. – Poltava, 2018. – 128 p.

Additional textbook, journals and references::

- Compendium of Medical Physics, Medical Technology and Biophysics for students, physicians and researchers. Nico A.M. Schellart. – Department of Biomedical Engineering and Physics Academic Medical Center University of Amsterdam. – Amsterdam. – 2009 (electronic book).
- Roland Glaser. Biophysics: An Introduction. – 2010.
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**Methodical elaboration have prepared by senior lecturer, PhD biol.Sc. Korovina L.D.**