417. Determination of the refraction index of liquids and solution concentration by a refractometer

Purpose: To learn the method of measuring the refraction index of transparent liquids with the aid of a refractometer.
Tasks to solve: learn the principle of operation of a refractometer. Determine the concentration dependency of the refraction index of glycerol solutions. Find an unknown solution concentration.

Refractometer is a device used to find the refraction index of transparent liquids. Principle of operation of a refractometer is based on the phenomenon of total internal reflection which occurs at the interface between two media when a light ray passes from a more optically dense medium to the less optically dense one.

The main part of a refractometer is a system of two right angle prisms: illuminating prism $A_1B_1C_1$ and refracting prism ABC made of glass with a high refraction index (Fig. 1).

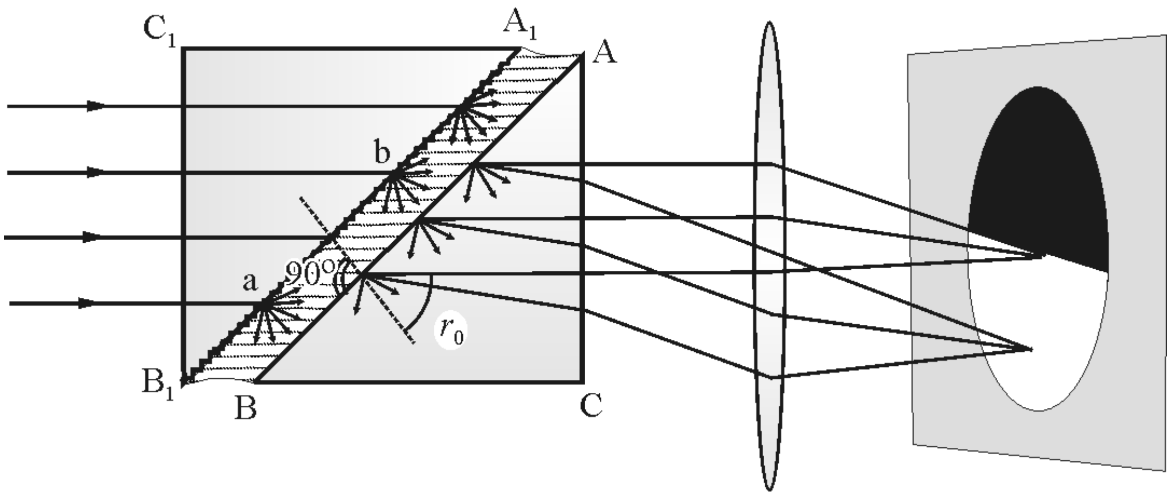

Fig. 1.

The illuminating prism has a frosted side A_1B_1; the side AB of the refracting prism is polished. There is a thin parallel-sided gap between the prisms which is filled with an investigated liquid.

When working in passing light, rays from the light source pass through the side B_1C_1 of the illuminating prism and fall on the frosted surface of the side A_1B_1. The light is scattered and goes into the studied liquid at all possible angles, as shown at points a and b in Fig. 1. Thus the angles of incidence of the rays onto the interface AB between the liquid and glass has the values from 0° to 90°.

For a ray sliding along the interface, the angle of incidence is i_0 = 90° and, according to the Snell's law,

$n_1 = n_2 \cdot \sin r_0$,

where n_1 is the refraction index of the liquid and n_2 is the refraction index of the prism ($n_1 < n_2$); r_0 is the critical angle of total internal reflection.

If a telescope is placed on the pathway of the rays which have passed the refracting prism, then the bottom part of its field of vision will be illuminated while the upper part will be dark. The boundary between light and shade is defined by the ray corresponding to the critical angle.

When working in reflected light, light falls onto the frosted side BC of the refracting prism. Light is scattered and strikes the side AB at all possible angles. The rays which strike the AB surface at angles smaller than the critical angle, go into liquid and then to the prism $A_1B_1C_1$. But the rays whose angle of incidence is larger than the critical angle, undergo total internal reflection in the prism ABC and exit the system from the side AC. Two regions will be observed in the field of vision of the spotting scope: the bright upper part and the dark bottom part.

If one observes described phenomenon using white light, the boundary between light and shade will be blurred and coloured due to dispersion. To remove colouring and to get a well-defined image, a compensator is used made of two direct-vision prisms which can rotate in perpendicular directions.

A direct-vision prism (also called Amici prism) consists of three triangular prisms made of different sorts of glass (Fig. 2). Two outer prisms are made of crown-glass having the refraction index n_c, and the middle one is made of flint-glass and has the refraction index n_f ($n_f > n_c$). This prism does not decline yellow rays, but declines blue and violet rays towards the base of the middle prism and red and orange, towards its apex.

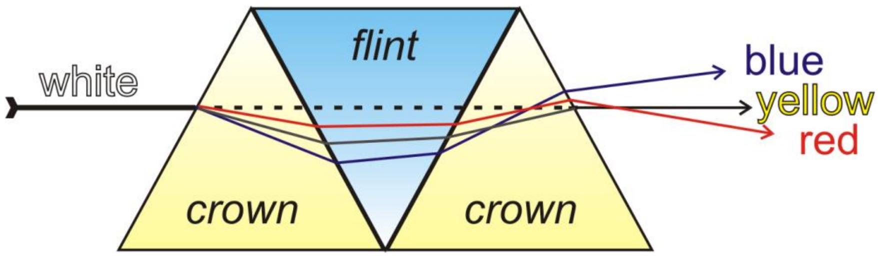

Fig. 2. Ray paths in an Amici prism.

If the Amici prism is put on the way of the light beam going from the refracting prism so that its dispersion is the same by the value but opposite in sign to the refracting prism's dispersion, then the summary dispersion will be zero and the beam of coloured rays will unite into a white beam. In practice it is convenient to use two direct-vision prisms, summary dispersion of which can be controlled by rotating them with respect to each other.

Operation of a compensator can be clarified as follows. Take two Amici prisms, set them along a single optical axis, and look at a brightly illuminated object. You will see that it has blurred coloured boundaries. Rotate the prisms around the optical axis and achieve disappearing of the rainbow colouring.

The refractometer unit consists of the upper and bottom parts. The bottom (fixed) part is the refracting prism, and the upper part is the illuminating prism.

When measuring refraction indices of liquids, put 2-3 droplets of the liquid onto the clean polished surface of the refracting prism by a glass rod or a pipette (**make it accurately, not touching the prism surface!**). Put down the illuminating prism. By rotating the handwheel, find the boundary between light and shade in the upper part of the ocular's field of vision, and take the reading of the refraction index from the gauge.

Exercise. Determination of the refraction index of glycerol solutions and finding an unknown concentration

1. Measure the refraction index of distilled water. Its tabulated value is n_w = 1.333. Find the correction to the refractometer's readings.
2. Measure the refraction indices of standard glycerol solutions and of the glycerol solution with an unknown concentration (allowing for the correction found in step 1). After each measurement, **remove thoroughly the liquid from the prism surface** with filter paper.
3. Build the calibration curve (dependency of n on the concentration c) and determine the unknown concentration using your graphic.

Questions

1. Reflection and refraction of light on the interface between two dielectrics.
2. Laws of reflection and refraction. Total internal refraction.
3. Correlation of refraction index and concentration. The Lorentz–Lorenz equation.
4. Scheme of a refractometer; function of its elements.
5. Ray paths in the refractometer's prisms in passing and reflected light.
6. The role of the telescope in the formation of the boundary between light and shade.
7. Formulate the purpose of the work, describe the experimental section, and explain your results.