Refractive Index of a Liquid Measured with a He-Ne Laser

Snell's law is usually used in the determination of the refractive index of a substance. This determination involves measurements of the incident and refraction angles of a light beam. When possible, the refraction angle is set at 90° to simplify the angle measurement. The incident angle that gives rise to a refraction angle of 90° is called the critical angle. Consequently, a measurement of the critical angle yields the refractive index. To achieve a refraction angle of 90°, however, it is necessary to have the light beam travel from the denser medium to the rarer medium. We have constructed a simple refractometer that allows a He-Ne laser beam to travel from a liquid to air. By adjusting the incident angle of the laser beam at the liquid-air interface, we can easily set the refraction angle to 90° and obtain the critical angle. With the value of the critical angle, we obtain the refractive index of the liquid using Snell's law.

![Wall of Chamber](image)

**Fig. 2. Diagram of the shaft holder.** The left end of the shaft is inside the chamber. The cap presses the rubber O-ring against the shaft so that liquid cannot leak out of the chamber along the shaft. Although the rubber ring is pressed hard against the shaft, the shaft can still be rotated easily if a small amount of silicone lubricant is put on the rubber ring. A simpler but less reliable method is to drill a small hole (~0.3 cm) in a wall of the chamber so that a shaft can pass tightly through this hole. A small amount of silicone lubricant placed on the contact surface between the shaft and the chamber would prevent any liquid leakage.

![Air Laser Liquid Mirror](image)

**Fig. 1. Schematic of the refractometer.** The incident light beam is first reflected by the mirror. The reflected beam is then reflected and refracted at the liquid-air interface.

Our refractometer, which can provide a quick measurement of the refractive index to within one percent accuracy, is shown schematically in Fig. 1. A He-Ne laser is used as the light source, with its beam aligned to be horizontal. This horizontal beam first passes through a wall of a plastic chamber filled with a liquid, and then illuminates a small mirror submerged in the liquid. The mirror is glued to one end of a shaft. The shaft, which is horizontal but perpendicular to the laser beam, passes through a hole in the wall of the chamber so that the free end is outside of the chamber. A shaft holder is necessary to prevent any liquid leaking out of the chamber through the cracks between the shaft and the wall of the chamber. The construction of such a shaft holder is shown in Fig. 2. After the shaft system has been constructed, including the mirror, a protractor is glued on the wall of the chamber (Fig. 3).

By turning the free end of the shaft, we can rotate the mirror submerged in the liquid. The amount of rotation of the mirror is monitored by the protractor. The mirror is first rotated to a position where its surface is at 45° from the horizontal. At this position, light reflected by the mirror is incident on the liquid-air interface at a right angle, and consequently the incident and reflected beams overlap each other. Under the overlapping condition the incident angle of the laser beam at the liquid-air interface is zero, and the protractor is adjusted to read zero. To find the critical angle associated with the liquid, the mirror is rotated toward the horizontal axis. As the mirror is rotated, the angle between the refracted beam and the liq-
Fig. 3. A protractor is glued on the wall of the refractometer chamber. Any rotation of the shaft turns the needle. The amount of rotation is determined by the settings of the needle.

The liquid-air interface becomes smaller. Eventually the refracted beam lies on the interface. It is then scattered by the meniscus of the liquid at the wall of the chamber. This indicates that the refracted beam is on the liquid-air interface and the refraction angle is 90°. The relationship between the critical angle (θ_c) and rotation angle (θ_m) of the mirror is shown in Fig. 4. The mirror is initially at EF, which is at 45° to the horizontal. Then it is rotated by angle θ_m to the position CD. At this mirror position the laser beam reflected from the mirror is incident on the liquid-air interface at the critical angle. According to Fig. 4, the angle LOC + 90° + θ_c + BOD = 180°.

The reflection angles are equal or LOC = BOD. Then, 2LOC + θ_c = 90°. LOE = θ_m = 45° - θ_m = LOC. Then, 2 (45° - θ_m) + θ_c = 90° and θ_c = 2θ_m. Therefore, the critical angle is equal to twice the angle of rotation of the mirror. The refractive index, n, of the liquid is determined by

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n = \frac{1}{\sin \theta_c} - \frac{1}{\sin (2\theta_m)}
\]

To facilitate further refractive index measurements, the angular graduations of the protractor are converted to readings of refractive index value according to Eq. (1). In other words, the amount of the mirror’s rotation, which gives rise to the critical refraction, is expressed in terms of refractive index values.

We have used this simple refractometer as a classroom demonstration to measure the refractive index of water and anisole (C_6H_5OCH_3). The index values of these liquids were determined to be 1.32 and 1.51, respectively. Anisole can corrode a plastic chamber and therefore any measurement should be made as quickly as possible.

References
2. First-surface mirror (9.4 x 26 x 3.2 mm) purchased from Edmund Scientific for $4.15.

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