



MEASUREMENT OF THE REFRACTIVE INDEX OF A LIQUID USING THE THICK LENS EQUATION AND LASER BEAMS

Janchai YINGPRAYOON*, Treewut WONGNIM¹ and Sarunyaphong WONGNIM²

* PSU Wittayanusorn Suratthani School, THAILAND

Corresponding Email: dr.janchai@gmail.com

¹ Thaksin University Demonstration Secondary School,
Phatthalung, THAILAND

² PSU Wittayanusorn Hatyai School, THAILAND

Communicated: 19.05.2026

Revision: 27.05.2026 & 28.06.2026

Published: 30.09.2026

Accepted: 29.06.2026

ABSTRACT:

The refractive index is an important optical property of transparent materials and is widely used for material characterization, concentration analysis, and optical measurements. Conventional refractive index measurement techniques generally require specialized optical components, precise alignment, and relatively expensive laboratory equipment, which limits their suitability for educational and low-cost applications. This study aimed to develop a simple and inexpensive laser-based method for determining the refractive indices of transparent liquids by applying the thick lens equation to experimentally measured focal lengths. A transparent cylindrical plastic container was used as a liquid lens and placed inside a transparent rectangular chamber. Two parallel red laser beams were directed through the liquid, while fog generated inside the chamber made the beam paths visible and allowed the focal length to be measured. The geometrical parameters of the cylindrical container were kept constant, with an inner diameter of 2.8 cm and radii of curvature of 1.4 cm for both surfaces. Experiments were performed at 25 °C using distilled water, glycerol, saturated saline solution, and edible vegetable oil. The measured refractive indices were 1.33, 1.46, 1.38, and 1.46, respectively. Comparison with accepted standard reference values showed deviations of less than 1% for all samples. The results demonstrate that the proposed method provides good accuracy while requiring only low-cost and readily available materials. The combination of a liquid-filled cylindrical container, laser beams, and the thick lens equation offers a practical and effective approach for refractive index measurements in physics laboratories, undergraduate education, and other resource-limited experimental settings.

Keywords : *refractive index; thick lens equation; laser beam; liquid lens; focal length measurement; optical measurement; transparent liquids; low-cost experimental apparatus; educational laboratory; geometric optics.*

INTRODUCTION:

The refractive index is one of the most important optical properties of transparent materials. It describes the ratio of the speed of light in a vacuum to its speed in a medium and determines the extent to which light is refracted when it passes from one medium to another. The refractive index depends on several factors, including the chemical composition, concentration, temperature, pressure, and wavelength of the incident light. Consequently, it serves as a fundamental physical parameter for characterizing liquids, solids, and gases.

Accurate measurement of the refractive index is essential in many scientific and industrial fields. Refractive index measurements have numerous practical applications across science and engineering.

Because the refractive index is sensitive to changes in composition and temperature, it is often used as a rapid, non-destructive analytical technique. Several standard techniques have been developed for measuring the refractive index of liquids. Although these methods provide excellent accuracy, they generally require specialized optical components, precision alignment, and relatively expensive

laboratory equipment. Despite their widespread use, conventional refractive index measurement techniques have several limitations.

These limitations reduce their suitability for classroom demonstrations, portable field measurements, and low-cost laboratory experiments. Consequently, there is increasing interest in developing alternative measurement techniques that are inexpensive, simple to construct, and sufficiently accurate for educational and research applications.

The thick lens equation incorporates the radii of curvature of both lens surfaces, the refractive index of the lens material, and the lens thickness, providing a more accurate relationship between these parameters and the effective focal length. When a thick lens is immersed in a liquid, the effective focal length changes according to the refractive index of the surrounding medium.

By accurately measuring the focal length of a thick lens using laser beams, the refractive index of the surrounding liquid can therefore be determined. This approach combines geometric optics with straightforward optical measurements and eliminates the need for specialized refractometers.

OBJECTIVES OF THE STUDY

The objectives of this study are:

1. To develop a simple laser-based method for measuring the refractive index of transparent liquids.
2. To apply the thick lens equation for determining the refractive index from experimentally measured focal lengths.
3. To design a low-cost experimental apparatus suitable for laboratory and educational use.
4. To evaluate the accuracy of the proposed method by comparing the measured refractive indices with standard reference values.

5. To investigate the feasibility of using ball lenses and laser beams for optical refractive index measurements.

3. Theory

3.1 Refractive Index

Definition

The refractive index is a dimensionless optical parameter that describes the propagation of light through a transparent medium. It is defined as the ratio of the speed of light in vacuum to the speed of light in the material:

$$n = \frac{c}{v} \dots\dots\dots (1)$$

Where,

n = refractive index of the medium,

c = speed of light in vacuum

v = speed of light in the medium.

Since light travels more slowly in a material than in vacuum, the refractive index of transparent materials is always greater than unity. The refractive index depends on wavelength (dispersion), temperature, pressure, and chemical composition.

Snell's Law

Snell's law describes the refraction of light when a light beam passes from one medium to another. It relates the angles of incidence and refraction to the refractive indices of the two media.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \dots\dots\dots (2)$$

In Figure 1, we have

n_1 = refractive index of the first medium,

n_2 = refractive index of the second medium,

θ_1 = angle of incidence measured from the normal,

θ_2 = angle of refraction measured from the normal.

Notes

If $n_2 > n_1$, the ray bends toward the normal ($\theta_2 < \theta_1$).

If $n_2 < n_1$, the ray bends away from the normal ($\theta_2 > \theta_1$).

Angles are measured from the normal to the surface.

When light travels from air into a liquid, the refractive index of air is approximately. Therefore, the refractive index of the liquid can be expressed as

$$n = \sin \theta_1 / \sin \theta_2 \dots\dots\dots (3)$$

This equation shows that the refractive index can be determined by measuring the incident angle and the refracted angle of a light beam passing through the liquid.

In the present experiment, laser beams were refracted by the curved surfaces of a cylindrical liquid container. The refraction of the beams follows Snell's law, and the resulting convergence of the beams was used to determine the focal length and subsequently the refractive index of the liquid.

Thick Lens Equation

Unlike the thin lens approximation, the thick lens equation accounts for the finite thickness of the lens.

$$\frac{1}{f} = (n-1) \left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2} \right] \dots\dots\dots (4)$$

where:

f = effective focal length (EFL),

n = refractive index of the lens,

R_1 and R_2 = radii of curvature of the first and second surfaces,

d = center thickness of the lens.

By knowing all parameters in the equation, if we use transparent cylindrical container for a measuring liquid as a liquid lens we can measure refractive index of the liquid.

MATERIALS AND METHOD**MATERIALS:**

The materials and equipment used for the refractive index measurement experiment were as follows:

- A transparent cylindrical plastic container used to hold the liquid under investigation. The tested liquid must not dissolve or chemically react with the plastic container. The inner diameter of the container was 2.8 cm.
- A transparent rectangular plastic container capable of accommodating the cylindrical plastic container described in Item 1.
- A ruler used to measure the focal distance obtained from the experiment.
- Two red laser pointers.
- A fog generator used to introduce mist into the transparent rectangular plastic container, allowing the laser beams to become visible during the experiment.
- The liquids used for refractive index determination were distilled water, glycerol, standard saline solution, and vegetable oil.

METHOD:

The measurement of the refractive index of liquids in this study was performed by an indirect method. The refractive index was not determined directly from its definition given in Equation (3); instead, it was obtained from optical measurements based on a liquid lens configuration. The liquid to be measured was placed in a transparent cylindrical plastic container, which, when viewed from above, behaved similarly to a thick spherical liquid lens formed by the liquid itself.

The transparent cylindrical container was positioned inside a transparent rectangular plastic container with a cover. A fog generator

was used to introduce mist into the rectangular container. Two parallel laser beams were then directed through both containers. The fog made the laser beams clearly visible, thereby facilitating the measurement of the focal length f used in Equation (4).

The relevant experimental parameters were measured as follows. The inner diameter of the transparent cylindrical plastic container was $d = 2.8$ cm. The radii of curvature of the cylindrical container were $R_1 = R_2 = 1.8$ cm. During the experiment, the paths of the laser beams could be observed clearly, as shown in Figure 2, allowing the focal lengths produced by the different liquids to be measured. Four types of liquids were used in this experiment at 25 °C: distilled water, glycerol, a saturated saline solution, and edible vegetable oil.

Using the measured parameters, the refractive indices of the tested liquids were calculated from Equation (4). The experimentally determined refractive indices were then compared with accepted standard reference values.

EXPERIMENTAL RESULTS

The refractive indices of the liquids were calculated using Equation (4). Throughout the experiment, the geometrical parameters of the transparent cylindrical plastic container remained constant. Specifically, the container had an inner diameter of $d = 2.8$ cm, while the radii of curvature of its two surfaces were $R_1 = R_2 = 1.4$ cm. Consequently, the primary variable parameters in the experiment were the focal length, f , of the liquid-filled container and the corresponding refractive index, n , calculated from Equation (4).

Four types of liquids were used in this experiment at 25 °C: distilled water, glycerol, a saturated saline solution, and edible vegetable oil. For each liquid sample, the focal length was experimentally determined from the position of the laser beam focus. The corresponding

refractive index was then calculated using the measured focal length together with the constant geometrical parameters of the container. The resulting values of the focal length and refractive index for the different liquid samples are summarized in Table 1.

The experimental results revealed that the refractive indices of the four tested liquids were 1.33 for distilled water, 1.46 for glycerol, 1.38 for the saturated saline solution, and 1.46 for edible vegetable oil.

CONCLUSION

This study successfully developed a simple and low-cost laser-based method for measuring the refractive indices of transparent liquids. By applying the thick lens equation to experimentally measured focal lengths, the refractive indices of four liquid samples were determined. The measured values were 1.33 for distilled water, 1.46 for glycerol, 1.38 for saturated salt solution, and 1.46 for cooking vegetable oil.

Comparison with accepted standard reference values (1.33, 1.47, 1.39, and 1.47, respectively) showed that the deviations were within 1% for all samples. These results indicate that the proposed method provides good accuracy and reliability for refractive index measurements.

The experimental apparatus was constructed from inexpensive and readily available components, making it suitable for laboratory instruction and educational applications. Furthermore, the results demonstrate that the combination of a ball lens and a laser beam can be effectively used for optical refractive index measurements.

Overall, the proposed technique offers a practical, accurate, and economical alternative for determining the refractive indices of transparent liquids and has strong potential for use in physics education, undergraduate

laboratories, and other resource-limited experimental settings.

References

- Urone, P. P., & Hinrichs, R. (2016). University Physics Volume 3. OpenStax, Rice University.
- Urone, P. P., & Hinrichs, R. (2020). Physics. OpenStax, Rice University, Section 16.2: Refraction.
- Born, M., & Wolf, E. (2019). Principles of Optics (7th ed.). Cambridge University Press.
- Ito, A., & Goto, A. (1994). Measurements of refractive index for several liquids and its dependence on temperature. Transactions of the Japan Society of Mechanical Engineers, Series B, 60(576), 2875–2881. <https://doi.org/10.1299/kikaib.60.2875>.
- Harvey, A. H. (2024). Index of Refraction of Liquid Water. In CRC Handbook of Chemistry and Physics (105th ed.). CRC Press.
- Harvey, A. H., Gallagher, J. S., & Levelt Sengers, J. M. H. (1998). Revised formulation for the refractive index of water and steam as a function of wavelength, temperature, and density. Journal of Physical and Chemical Reference Data. The formulation was adopted by IAPWS.

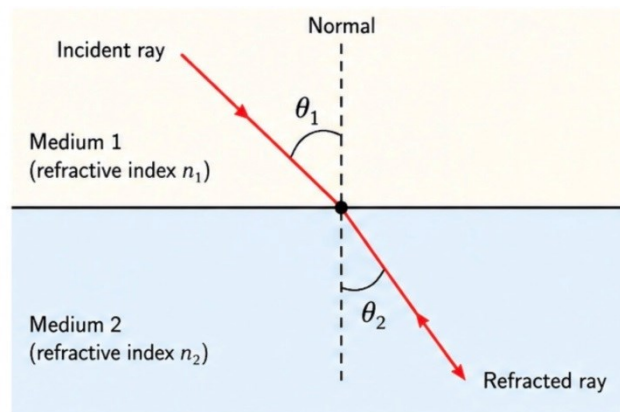


Figure 1. Refraction at a plane surface

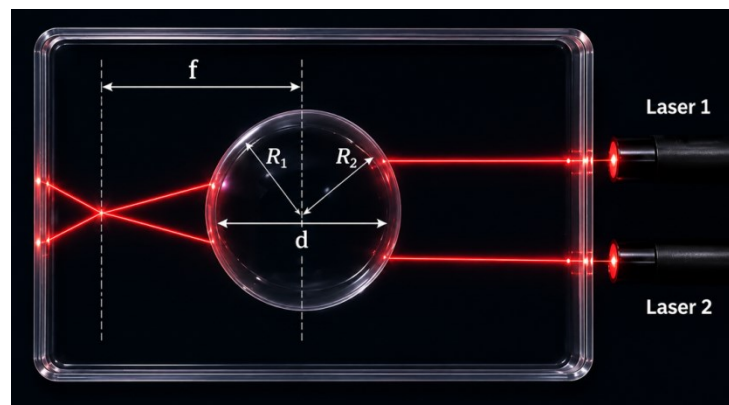


Figure 2 Showing an experimental setup

LIQUID	d (cm.)	R1 (cm.)	R2 (cm.)	f (cm.)	n (exp)	n (Ref)
Water	2.8	1.4	-1.4	2.84	1.33	1.33
Glycerol	2.8	1.4	-1.4	2.19	1.46	1.47
Sat. Salt Water	2.8	1.4	-1.4	2.55	1.38	1.39
Cooking Oil	2.8	1.4	-1.4	2.22	1.46	1.47

Table 1. Showing Experimental Results