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Design a Simple Refractometer to Calculate the Refractive Index of a Transparency Liquid Using Beer's Lambert Law

Mohammed H.K. AL-Mamoori, Saif M. AL-Sharify, Mohammed J. Jader and Amer AL-Nafiey
College of Science for Woman, University of Babylon, Hilla, Babylon, Iraq

Abstract: This research aims to design a simple and low cost refractometer by applying Beer's Lambert Law. It contains two parts: part one, the refractive index of water was calculated by using a He-Ne laser, Diode-Pumped Solid-State Lasers (DPSSL) with different wavelengths and semiconductor laser operating at second harmonic generation were used to compute the refractive index of water. The refractometer (Type Zei 13743, Germany) was used to compute the refractive index directly, then the comparison between these measurements and find the percentage errors in measurements of refractive index. The second part, He-Ne laser was used to compute the refractive index of the following liquids: gas oil, benzene (C_6H_6) and kerosene, then refractometer was used, so as to calculate the refractive index of these liquids directly and comparison between these measurements, then the percentage errors were found. The relationship between absorbance, refractive index, reflectance, percentage error and transmittance as a function of wavelength and between refractive index and percentage error for pure water has been studied. The results shows the refractive index can be calculated by any type of laser (in visible and IR region) by applying Beer's Lambert Law. It is applied to calculate the refractive index for cold, hot, toxic and non-toxic liquids.

Key words: Beer's Lambert Law, refractive index calculation, laser light, different solutions, liquids directly, relationship

INTRODUCTION

The refractive index is an important optical parameter in many fields such as in pharmaceuticals, food production and other chemical-based industries to monitor the purity of the end product. The refractive index of an intermediate is the fraction of the vacuum velocity of an Electromagnetic Wave (E.W) to its phase velocity in the intermediate (El-Zaiat, 2007). Leupacher defines an experimental method to compute the refractive indices of solids and liquids did a varied frequency area (near UV to near IR) by reflection measurement on a slight angle of incidence and distinct absorption detection (Lewpacher and Penzkofer, 1984). Thormahlen was derived a new equation to determine the refractive index of water and the dependency of molar refraction on temperature, wavelength and density for (182 nm $\leq\lambda\leq$2770 nm) (-10°C $\leq$T$\leq$500°C) (0.0028 kg/m $\leq\rho\leq$1045 kg/m), respectively (Thormahlen *et al*., 1985). Gorand used a BP-2000-V differential refractometer at 25°C at the wavelength of 436, 546, 589 and 633 nm and they found that the particular refractive index increase (dn/dc) of insulin in water increase with decreasing wavelength (Nikolic *et al*., 2001). Aonis used Mach-Zehender interferometer to calculate the refractive index of air and water (Flores *et al*., 2002). Alexey was used Cauchy equation to determine the refractive index of water and its dependency on wavelength and temperature in the spectral range from 200-000 nm. Subedi *et al*. (2006) was used a hollow prism to conclude the refractive index of liquid and he was found a linear dependency of refractive index of some solution (common salt, sugar, propanol_1, sucrose, potassium chloride) with their concentration and the refractive index decreases with increasing the temperature of the range 30-70°C (Subedi *et al*., 2006). Gobi was using a simple fiber optic sensor to conclude the refractive index of liquids (Govindan *et al*., 2009). Indra Sapkota was used a minimum deviation method of a prism to calculate the refractive index of sugar solution and his study showed that a linear dependence of refractive index of the sugar solution with the concentration in the range 0-40%.

MATERIALS AND METHODS

Calculation the refractive index from optical properties Beer's Lambert Law and Absorbance (A): Beer's Lambert Law affirming that the portion of light absorbed by a thin layer of solution is proportionate to the number of absorbing molecules experimentally, the

Corresponding Author: Mohammed H.K. AL-Mamoori, College of Science for Woman, University of Babylon, Hilla, Babylon, Iraq

efficiency of the light absorbing at a wavelength (λ) by an absorbing medium is considered by the absorbance A (λ) or transmittance T (λ). Beer-Lamberts Law clear as (Prasad, 2003; Abebe, 2007):

$$I = I_0 \exp(-\alpha(\lambda)C_m\lambda) \quad (1)$$

Where:

- (I_o) and (I) = The light intensities of the beam incoming and leave-taking the absorbing medium correspondingly
- $\alpha(\lambda)$ = The molar absorption coefficient, usually stated in (L/mol. cm)
- C_m = The concentration in (mol/L) of the absorbing classes
- (l) = Absorbing path length (thickness of absorption medium (cm)

The absorbance of a medium is definite as the part of absorbed and instance intensities from Eq. 1. The absorbance is (Valeur, 2002):

$$A = \log\frac{I_0}{I} = \alpha(\lambda)C_m\lambda \quad (2)$$

Transmittance (T): Is definite as the part transmitted and incident intensities. The transmittance is given by Kaur *et al*. (2009):

$$T = \frac{I_0}{I} = \exp(-\alpha(\lambda)C_m\lambda) \quad (3)$$

Equation 3 refers to transmittance is proportional exponentially with concentration and optical path length.

Reflectance (R): It's defined as the part of reflected incident intensities (Bashkatov and Genina, 2003; Prasad, 2003). The reflectivity defined as the part of reflected and incident electric field amplitudes. The reflectivity and reflectance depend on the incidence angle, the Fresnel equation for normal incidence is given by Niemz (2007):

$$R = \left[\frac{\eta-1}{\eta+1}\right]^2 \quad (4)$$

η = Index of refraction. The equations that combinations absorbance, transmittance and reflectance is given by Kadhim and Kzar (2016):

$$A+T+R = 1 \quad (5)$$

Table 1: The laser types were used to calculate the refractive index of liquids

Lasers types	λ (nm)	Power	Manufactured by
He-Ne	632.8	5 mW	USA
Diode Pumped Solid State Laser (DPSSL)	810	1 W	Phywe company-Germany
DPSSL	404	10 mW	Phywe company-Germany
DPSSL	430	20 mW	Phywe company-Germany
Semiconductor laser (operate at the second harmonic generation)	532	42 mW	Phywe company-Germany

Fig. 1: The setup of experiment

Index of refraction (η): The index of refraction of a medium is the fraction of the vacuum velocity of the electromagnetic wave (c) to its phase velocity in the medium (υ) and it's given by Read (1679):

$$\eta = \frac{c}{\upsilon} \quad (6)$$

Experimental set-up

Laser sources: In this study, Table 1 was illustrated the laser types were used to calculate the refractive index of liquids.

Laser detector: Silicon detector (Phywe-Germany) was used to detect the laser light, it has high photosensitivity and suitability and it converts incident light directly into electrical energy can be measured by the digital multimeter (Phywe-Germany).

Quartz cell: Quartz cell was used to put the samples inside it, the incident intensity was measured when the quartz cell was empty but the transmitted intensity was measured when the quartz cell filled with liquids.

Standard refractometer: Refractometer (type Zei 13743, Germany) was used to calculate the refractive index of solutions. It measures the refractive index at range from 1.3-1.7.

Sample preparation: Water (H_2O), Gasoline (C_6H_6) and Kerosene were used as samples placed inside the quartz cell to calculate their refractive index using standard refractometer and laser beam and then comparing both measurements. Figure 1 shows the set-up experiment.

RESULTS AND DISCUSSION

The refractive index of water that was measured by standard refractometer and laser for different wavelengths is listed in Table 2. When the wavelength (in free space) increases, the refractive index increases as shown in Figure 2a but the wavelength (inside matter) decreases and this is consistent with the Cauchy equation (Aristizabal and Mikan, 2016). The variation of absorbance as a function of wavelength as illustrated in Figure 2b. it's clear that when the wavelength (in free space) increases, the absorbance of water increases because that absorbing a photon of visible light promotes one of the atom's or molecule's valence electrons to a higher-energy level. But when a molecule absorbs infrared radiation on the other hand, one of its chemical bonds

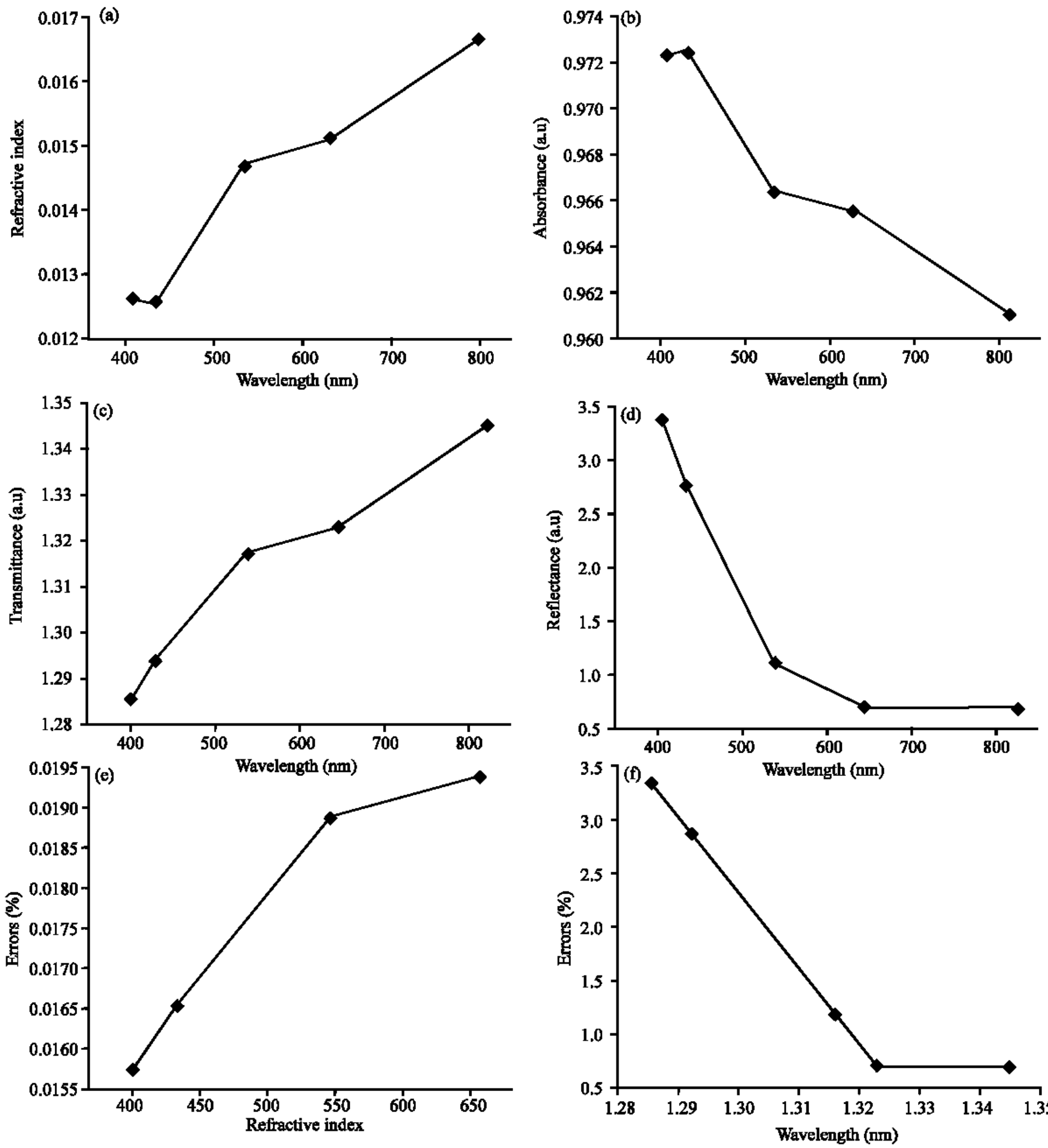

Fig. 2: The relation between wavelength and a) Refractive index; b) Absorbance; c) Transmittance; d) Reflectance; f) percentage errors and e) Between refractive index and percentage errors

Table 2: The refractive index of water that was measured by standard refractometer and laser for different wavelengths

Materials	λ(nm) (space)	I_o (mV)	I (mV)	A = log I_o/I	T = I/I_o	R = 1-(A+T)	n (measured by laser $n = \frac{1+\sqrt{R}}{1-\sqrt{R}}$	n (measured by standard refractometer)	Percentage errors	Errors
Water	402	0.432	0.420	0.0122344	0.972222222	0.01554332	1.2848	1.3323	3.5	0.0294
Water	430	0.508	0.494	0.0121367	0.972440944	0.01634538	1.2931	1.3323	2.9	0.0081
Water	532	0.540	0.522	0.0147232	0.966666666	0.01861007	1.3159	1.3323	1.2	0.0356
Water	632.8	0.262	0.253	0.0151807	0.965648855	0.01917770	1.3214	1.3323	0.8	0.0123
Water	810	0.519	0.499	0.0170668	0.961464336	0.04468834	1.3433	1.3323	0.8	o.0113

Table 3: The refractive index of gas oil, benzene and Kerosene liquid was calculated using He-Ne laser (λ = 632.8 nm) and standard refractometer

Materials	I_o (mV)	I (mV)	A = log I_o/I	T = I/I_o	R = 1-(A+T)	n(measured by laser) $n = \frac{1+\sqrt{R}}{1-\sqrt{R}}$	n (measured by refractometer)	Percentage errors
Gas oil	0.296	0.280	0.0241336	0.945945945	0.02992037	1.4183	1.4596	2.8
Benzene	0.341	0.323	0.0235518	0.947214076	0.02923406	1.4124 [21]	1.4160	0.2
Kerosene	0.621	0.582	0.0281686	0.937198667	0.03463331	1.4573	1.4342	1.6

experiences a change in vibrational energy. Also, the absorption coefficient above 600 nm is relatively large and easier to measure and in part because pure water scattering is small compared with absorption at these wavelengths (Sogandares and Fry, 1997). Figure 2c was showed that the transmittance decreases when the wavelength increases because that any increase in absorbance is offset by a decrease in transmittance because of the exponential relationship between them {T = exp(-A)} (Triloki *et al*., 2013). Figure 2d was showed that the reflectance increases when the wavelength increasing because that the refractive index when it increases with the wavelength gives a sign of increasing the reflectance at that wavelength as the relationship between them in the Fresnel equation, note the Eq. 4. Figure 2e was showed that the percentage error decreases when the wavelength increases. This means that the use of the longest wavelength in the infrared region (λ = 810 nm) is better in measuring the refractive index because it gave the least percentage error in measuring the refractive index compared to the previous wavelengths. Figure 2f was showed that the percentage error decreases when the refractive index increases. This is another indication that the use of wavelengths in the infrared region (λ = 810 nm) is better because it suffers less refraction and therefore, the accuracy of refractive index measurement is greater. The measurement of the refractive index of water using the Beer's Lambert Law equation showed a significant correlation with 4-wavelength laser micro-refractometer and Michelson interferometer (Vlaeva *et al*., 2008; Abbas and Khalil, 2016; Jassim and Khudhair, 2014).

Also, the refractive index of gas oil, benzene and Kerosene liquid was calculated using He-Ne laser (λ = 632.8 nm) and standard refractometer as shown in the Table 3. It is clear that, the refractive index changes due to the change in density of the material and this is consistent with the results in the source (Al-Barwani and Al-Jahwari, 2017). The measurement of refractive index of benzene using Beer's Lambert Law is approximated to measure the refractive index of the same liquid using Michelson interferometer (Abbas and Khalil, 2016).

CONCLUSION

This refractometer (using Beer's Lambert Law) is characterized by the simplicity and low cost to manufacture and is used for transparent materials (liquids). It is applied to calculate the refractive index for cold, hot, toxic and non-toxic liquids. Any laser type (in visible and IR region) can be used to calculate the refractive index of liquids. The absorbance, refractive index and reflectance increases with increasing the wavelength while the transmittance and the percentage error decreases with the increasing the wavelength. The refractive index decreases with increasing percentage error. The value of refractive index measured by used the Beer's Lambert is a good agreement with their stander values (standard refractometer) and with Michelson Interferometer.

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