A Low-cost Refractometer in an Undergraduate laboratory

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(*Submitted* 11-08-2015)

Abstract

The Undergraduate syllabus of Physics Honours course in Jamshedpur Women's College, Jamshedpur expects the students to carry out a project (30 marks) in the Fifth semester. A laser refractometer built out of a spectrometer (which has seen better days), a hollow glass prism(fabricated) and some other apparatus mandatorily available in the Undergraduate laboratory unfolds some interesting ideas to carry out projects on a shoestring budget.

1. Introduction

One of the most important optical properties of a medium is its refractive index. As it is a fundamental property of the substance it is often used to identify a particular substance, confirm its purity or measure its concentration.

The absolute refractive index of a medium is the ratio of the speed of electromagnetic radiation in free space to the speed of the radiation in the medium. The relative refractive index is the ratio of the speed of light in one medium to that in the adjacent medium. Refraction occurs with all types of electromagnetic waves but the refractive index of a medium differs with the frequency of the wave. For a given frequency the refractive index of a medium depends on the density of the medium, which is again a function of temperature.

Beside other methods, the refractive index of a substance can be measured using a refractometer. i.e. how much a light beam bends on passing through a medium.

Petrol is at times suspected to be adulterated with cheaper fuels like kerosene oil .An effort was made to determine the "purity" of petrol by calculating the refractive indices of petrol and that of a mixture of petrol and kerosene oil (in various proportions) and the values plotted to give a calibration curve to determine the degree of adulteration in any given sample. The usual method of determining the refractive index of a liquid with a hollow prism, a sodium lamp source and a spectrometer was found unsuitable as the image obtained was blurred making it difficult to take measurements.[1].

A make-shift refractometer was, therefore, made from a discarded spectrometer and a laser source replaced the conventional sodium lamp source.[2]

2.Fabrication

(a)Construction of a hollow glass prism

A transparent glass sheet 3mm thick was used from which a square 5cm x 5cm and three rectangular strips 2cm x 4 cm were cut out. Using a water-proof adhesive, the pieces were glued together and left to dry for 24 hours.(see Fig. 1)

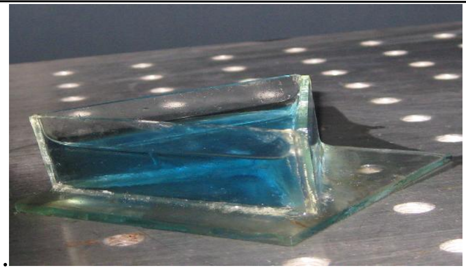


Fig.1 Hollow glass prism filled with kerosene

(b) Setting up a make-shift Refractometer.

A spectrometer was used to make a refactometer. The telescope tube was made open ended on both ends by removing the eye-piece and the lens and simply used as case for placing the pencil laser source.

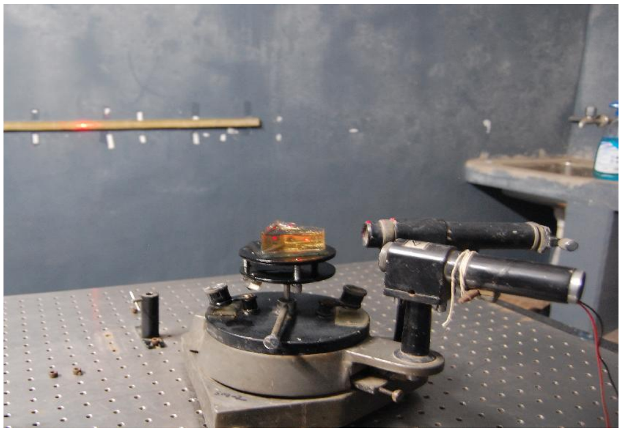


Fig.2

The prism table was used to keep the hollow prism filled with the desired liquid and also used to rotate it about a vertical axis passing through it. The collimator had no role to play and hence was rotated out of the way of the laser beam. A metre-rule was fixed on the wall to receive the incident laser beam after refraction through the liquid-filled prism as shown in Fig.2.

3.Theory and Method

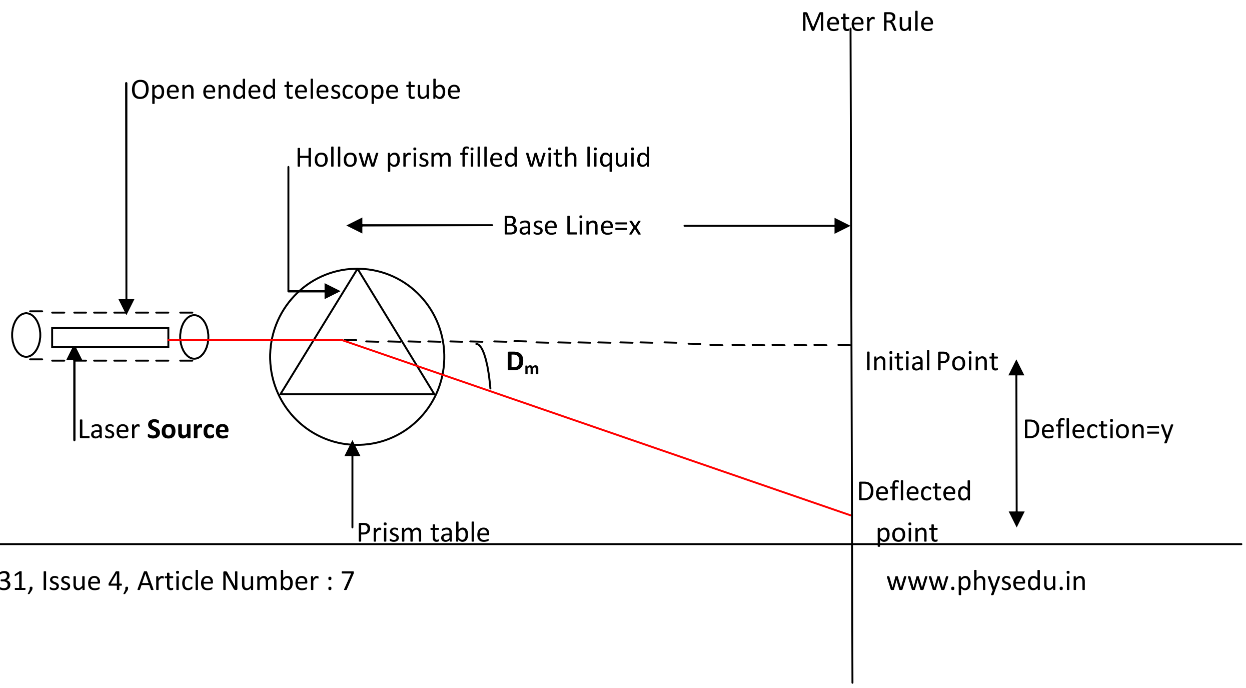


Fig.3

The above figure 3 shows the layout of the make-shift refractometer and the path of a laser beam(red) undergoing minimum deviation. D_m refers to the angle of minimum deviation. The point on the ruler where the laser light falls in the absence of the prism is called the "Initial point" and the distance between the centre of the prism and the Initial point is called the base line..

The refracting angle A and the angle of minimum deviation D_m give the refractive index μ of the medium by the following well known formula,

$$\mu = \sin\{(A + D_m)/2\}/\sin(A/2) \text{ ----------(1)}$$

From fig.3 we have

$$D_m = \tan^{-1}(y/x) = \tan^{-1}(\text{deflection/baseline}) \text{----(2)}$$

Using equations (1) and (2) we get

$$\mu \sin(A/2) = \sin\{(A + \tan^{-1}(y/x))/2\} \text{-------(3)}$$

Which finally gives an expression for the angle of the prism as

$$A = [2 \tan^{-1} \{\sin(D_m/2)\}] / \{\mu - \cos(D_m/2)\} \text{-------(4)}$$

Calibration of prism In theory, each angle of an equilateral prism is 60˚ but for a self-fabricated prism, this may not be true. Hence the prism needs to be be calibrated which in effect means that the angle between a pair of refracting sides of the prism must be determined.

To calibrate, first a pencil laser source was placed in the hollow open-ended telescope tube so that the laser beam travelled to the mounted ruler. The prism should not be on the prism table at this point. The reading on the ruler where the laser spot fell denoted the "Initial point". Next a hollow prism, filled with water, was placed on the prism table. The laser spot on the ruler shifted. The prism table was rotated about the vertical axis passing through it so that the shift or deflection was a minimum. The reading on the meter-rule now represents the "deflected point".

The actual deflection is given by

Deflection = (Deflected point) – (Initial point)

= y--------- (5)

The distance between the "initial point" and the centre of the prism was measured and denoted as baseline (= x). Assuming μ= 1.33 (water) and using Equations (2) and (4), the angle of the prism "A" was calculated. This value was written on a sticker and stuck on the side of the prism opposite to the angle measured .This would keep the value of "A" handy and also ensure that in the rest of the experiment too, the laser beam passed through the calibrated sides.

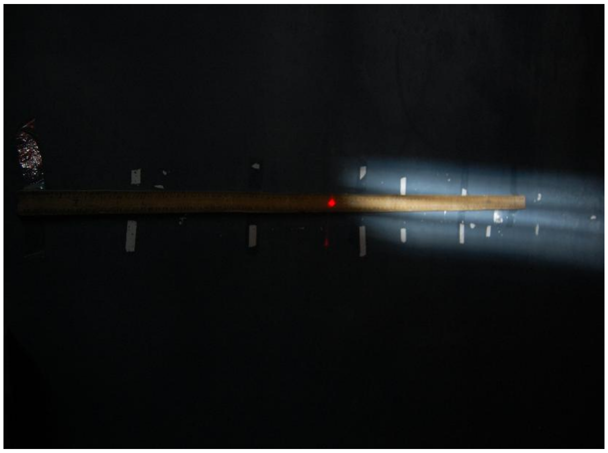


Fig.4 Laser spot on mounted ruler

Measurement of refractive index of the mixture

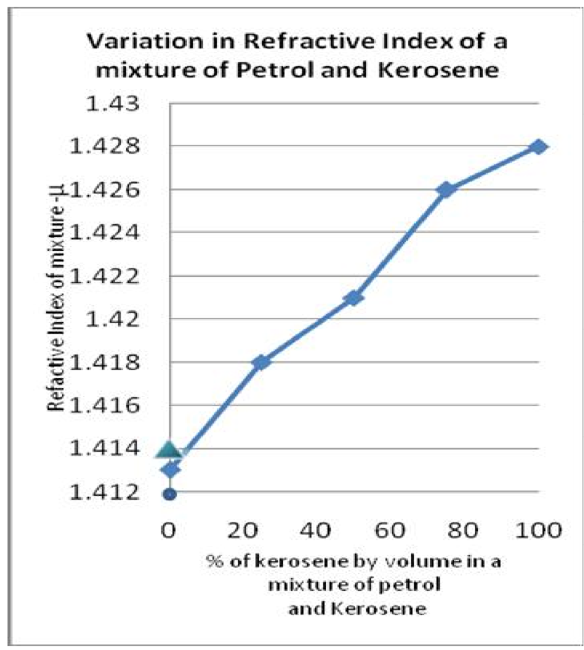
Without disturbing the laser source, the hollow prism now filled with petrol was placed on the prism table. Care was taken to align the prism so that the laser beam passed through the calibrated sides. As before, the prism was rotated about the vertical axis to obtain the minimum deflection. The deflected point was noted and the deflection and the angle of minimum deflection calculated using (5) and (2). Equation (1) was now used to calculate the refractive index of the petrol in the hollow prism. The value for "A" obtained in the previous section was used in Equation (1).

Next Kerosene was mixed with petrol such that the ratio by volume was 25: 75 and the above process was repeated. Several readings with increasing proportions of kerosene in the mixture were taken ending with 100% kerosene (no petrol). The refractive index of the mixture was calculated each time.

It was ascertained that the laser source did not undergo any motion (either rotational or translational) throughout the experiment. Its alignment with respect to the centre of the prism was kept constant and the prism was only rotated about the vertical axis through its centre. All these conditions were automatically satisfied in the above method by virtue of the construction of the spectrometer.

4.Results and Discussion

A graph was plotted between the refractive index of the mixture and the percentage of kerosene in it. It was observed that with an increase in the percentage of kerosene, the refractive index of the mixture increased. (Fig. 5).



The above triangle ▲ and ● dot show the refractive indices of petrol from two different petrol pump stations.

Fig.5

As petrol is made up of multi-components which can be broadly divided into alcohols, alkanes and aromatic compounds, the refractive index of petrol/gasoline varies from country to country and also from company to company. Moreover it is also dependent on the method of extraction, area of extraction and even the time of the year. As such comparison of our results with any standard result was not possible. The studies done in Sweden on gasoline gives its refractive index as 1.429 at 27°C using laser light (blue-green $\Delta\lambda$ = 488-514 nm) [3]. Our study was done with a source of He-Ne laser (λ= 668 nm) and for a particular brand of petrol, the value was 1.413. As it was diluted with kerosene (μ = 1.44)[4] its refractive index increased depending on the dilution.

5.Limitations of the method

Our result for refractive index of kerosene turned out to be 1.429, a little less than the standard value. Our set up could not be expected to yield very accurate results as a self-fabricated hollow glass prism was used. Moreover, in our deductions we have treated the thickness of glass as negligible which is not really true.

6. Learning

However, on performing the project, the student understands that refractive index can well be an index of adulteration in many liquids. The student also learns how to use an old instrument in a new and innovative way besides using the geometry of the set up and the concepts of Physics to deduce an expression for the refractive index. In a nutshell. the student is introduced to the flavor of research, something which she might savour and gravitate towards, later in her career.

7. Way forward

- A thin-walled and commercially manufactured hollow glass prism may give more accurate results.
- A calibration graph of y(= deflection) against % of dilution can be used as a quick way of indication of adulteration in petrol.
- The above set-up may be used to measure the refractive indicies of many transparent liquids and also to study the variation of the refractive index with change in temperature and also change in concentration in case of solutions.
- A fibre optic sensor for determining the refractive index of liquds is likely to give better results as was done by Roy in 1999 [5]

8. Expenses incurred on

- Waterproof adhesive
- Petrol and Kerosene
- Labour charge for cutting glass for making the prism.

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5. References

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