International Journal of Physics and Applications.
ISSN 0974-3103 Volume 9, Number 1 (2017), pp. 11-18

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Refractive Index of Copper Sulfate Pentahydrate from Aqueous Solution

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Abstract

There are different methods to determine the refractive index of salts, solids (crystalline) and liquids. These methods are quite tedious. A simple and reliable method is developed by developing mathematical equation for aqueous solutions. The technique was employed to study refractive index of salt and water by varying concentrations. A hollow prism is used along with optical spectrometer at room temperature to determine refractive index of aqueous solution of copper sulfate pentahydrate ($CuSo_4.5H_2O$). The results were compared with the results obtained from commercial refractometers and it was found that this technique is quite reliable and can be safely used in the study of the optical properties of any crystal clear liquids and solids.

1. **INTRODUCTION** :-

Refractive index is one of the most important optical properties of a medium. It plays an important role in many areas of material science with special reference to thin film technology and fiber optics. Similarly, measurement of refractive index is widely used in analytical chemistry to determine the concentration of solutions. Recent studies [Schwartz 1999, Olesberg 2000, Shlichta 1986] provide more detailed discussion on the concentration mapping by the measurement of refractive index of liquids. Temperature coefficient of refractive index can also be used to calculate thermal expansion coefficient [Miller 1975]. Several techniques are reported in literature for the measurement of concentration dependence of refractive index of liquids [McPherson 1999, Garcia 1999, Otalora 1999, Miyashita 1994]. The present project reports a relatively simple and effective technique, which can be used to measure the refractive index of the liquid at different concentrations. M.T. Teli developed the equation for volume shrinkage of salt when added to water which is taken into account for this experiment [1997 Radiation physics and chemistry].Recently U V Biradar etal. Measured the refractive index of KCl in IJCMS Vol 6, issue 2.

A prism divides white light into its constituent spectral colours. For a given colour, the refractive index of a medium depends on the density of the medium.

In 1928, C.V. Raman discovered another (much weaker) type of light scattering in which the frequency changes when the light is scattered. The frequency shift $\Delta\nu$ occurs when some of the energy of the scattered photon is taken up by a molecule, which is excited into vibration motion. Most of the molecules are initially in the ground state but because of thermal agitation some molecules will be in an excited state. 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 that 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 waves but is most familiar with light waves. The refractive index of a medium differs with frequency. The scattering process can be thought of as the incoming photon raising the molecule to a virtual (i.e. non-existent) excited state.

2. EQUIPMENT USED FOR THE STUDY :-

It is a compact apparatus for obtaining a pure spectrum. It is used for the study of spectra and for finding the refractive index of a material in the form of a prism. In its simplest form it has following main parts.

(Fig 1. Optical Spectrometer Hollow Prism)

2.1 Collimator :-

Its purpose is to produce a parallel beam of light. It consists of a tube mounted horizontally on the arm of the spectrometer. The tube has a converging achromatic lens at one end and a sliding tube having and adjustable vertical slit at the other end. The focal length of the lens is almost equal to the length of collimator tube. The distance between the slit and the lens can be changed by a rack and pinion arrangement or by sliding the inner tube to obtain parallel rays. The tube rests on two screws by which it can be slightly tilted up or down if necessary as shown in figure1.

2.2 Slit :-

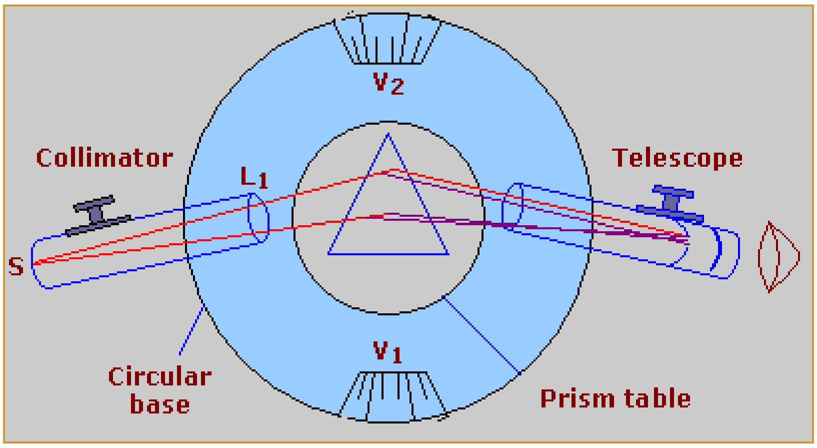
It consists of two sharp edges. One of the edges is fixed while the other can be moved parallel to it by working the screw provided at its side as shown in figure 1.

2.3 Telescope :-

It is an astronomical telescope having an achromatic objective and a Ramsden's eye-piece. It is mounted on another arm fixed rigidly to the circular scale in half degrees. The telescope along with scale can be turned round a vertical axis passing through the centre of the spectrometer. It can be fixed in any position by screw and then can be given a slow rotation or fine adjustment by a tangent screw. The position of the telescope can be read by the two vernier V_1 and V_2,180^0 apart fixed to the prism table. The telescope rests on the screws by which it can be slightly tilted up or down, for adjustment of its axis if necessary. A rack and pinion arrangement is provided on the side of the telescope for focusing.

2.4 Prism table: -

It consists of an upper plate and a lower plate separated by three spring through which passes the leveling screws. A set of parallel equidistant lines are engraved on the upper plate. These lines are parallel to the line joining any two of the screws. The prism is always placed with one of its reflecting faces perpendicular to these lines. A series of circles concentric with the axis of rotation of the prism are also ruled on this plate. This help in placing the prism correctly. The height of prism table can be adjusted by camping screw, which is used to fix the prism table to the vernier V_1 and V_2 . The table can rotate about vertical axes and may be fixed in any desired position by means of the screw. When fixed by the screw, it can be turned very slowly by a tangent screw placed at a base of the spectrometer. The position of table can be accurately read by vernier moving on the circular scale.



(Fig 2.: Prism Table)

3. THEORY DEVELOPED FOR THE DETERMINATION OF R.I.OF SALT :-

Spectroscopy is the study of interaction between matter and radiated energy. Historically, spectroscopy originated through the study of visible light dispersed according to its wavelength by a prism. Latter the concept was expanded greatly to comprise any interaction with radiant energy as a function of its wavelength or frequency. Electromagnetic radiation was the first source of energy used for spectroscopic studies, There are different types of spectroscopy such as microwave spectroscopy, UV spectroscopy, IR spectroscopy, Gamma ray spectroscopy, acoustic spectroscopy….etc. Spectrometers are used as spectral measurement devices.

A convenient formula for refractive index is obtained in the minimum deviation case when a ray of light suffers deviation while passing through a prism. The deviation produced by the prism depends on the angle of incidence. For a certain value of the angle of incidence, the angle of deviation is minimum. If δ_m denotes the angle of minimum deviation for a given prism of refractive angle A, then the refractive index of the material of the prism η is given by

$$\eta = \sin(A+\delta_m)/2 \div \sin(A/2) \qquad \text{…………(i)}$$

Equation (i) is used to calculate the refractive index of the liquids (water). where A is angle of hollow prism and δ_m is angle of minimum deviation. If we consider V_w as the volume of water taken in the hollow prism and V_s is the volume of copper sulfate pentahydrate ($CuSo_4.5H_2O$) added to the water. Then total volume (V_s+V_w) in the hollow prism is

$$V' = V_s + V_w$$

When the copper sulfate pentahydrate ($CuSo_4.5H_2O$) is added to the water then there will be shrinkage of volume(δ) in the copper sulfate pentahydrate($CuSo_4.5H_2O$) which is to be considered by Teli's equation not by the above equation

$\delta = V' - V$ i.e. $V = V' - \delta = V'(1 - \delta/V') = V'(1 - \varepsilon)$

Where $\varepsilon = \delta/V' = V' - V/V$ = Degree of shrinkage

If we consider this equation for the solution for determining refractive index combining together [copper sulfate pentahydrate($CuSo_4.5H_2O$) and water] for different concentrations we get an equation of straight line in the following form.

$$\eta' = \eta_w + (\eta_s - \eta_w) Vs/V \qquad \ldots\ldots\ldots\text{(ii)}$$

Where η' is the refractive index of solution, η_w is the refractive index of the water and η_s is the refractive index of the copper sulfate pentahydrate($CuSo_4.5H_2O$). The equation (ii) can be used for any concentration of solution. These values are given in table 1.

Experimental arrangement used in our study is shown in Fig 1.Specially constructed hollow prism is used to measure the refractive index of liquid with the help of an optical spectrometer. A mercury lamp is used as a source of light and a collimated beam is allowed to fall on one reflecting face of the liquid prism and the angle of minimum deviation is determined for sodium light(at 589.3 nm). Mean of two values are taken for each angle of minimum deviation (δ_m). To study the variation of refractive index of copper sulfate pentahydrate ($CuSo_4.5H_2O$) solution as a function of concentration, an electronic balance is used to measure the mass of copper sulfate pentahydrate ($CuSo_4.5H_2O$) and solutions of required concentration are prepared by dissolving the copper sulfate pentahydrate($CuSo_4.5H_2O$) in 8 ml of water. Thus, prepared solutions are filtered before pouring into the hollow prism. The hollow prism was rinsed carefully after every measurement. Solutions of lower concentrations are made by adding the water of different volume with proper weight of salt. Accordingly the concentration is converted to volume as required in formula. The values of different concentrations are given in table(1).

Plot of refractive index of copper sulfate pentahydrate ($CuSo_4.5H_2O$) solution as a function of concentration is shown in fig(3). For 0.0988 concentrated solution, refractive index is as high as 1.348, which reduces to 1.338 when the solution is diluted to a concentration of 0.0465. With the decrease in concentration, the density of the solution also decreases and also refractive index decreases. The results showed that the refractive index of the solution of concentration less than 0.05 measures nearly the same as that of the pure water. The result indicates that the effect of concentration on refractive index is dominant upto the concentration of 0.05 M. By using above mathematical equations we can calculate refractive index of water (η_w) and Copper Sulfate Pentahydrate($CuSo_4.5H_2O$) by using graph as shown in fig.(3).

A graph between R.I. and concentration of copper sulfate pentahydrate($CuSo_4.5H_2O$) solution gives the slope of R.I.of solution [Copper Sulfate Pentahydrate($CuSo_4.5H_2O$)and water]and intercept gives the R.I.of water. By subtracting intercept from slope we get R.I.of copper sulfate pentahydrate($CuSo_4.5H_2O$). For this purpose, we made the calculations mentioned in table (1). It requires to be converted in V_s and V_w form. For this we have considered least square method. The refractive index of copper sulfate pentahydrate($CuSo_4.5H_2O$)is 1.514 and water is 1.333.Both these values are within the acceptable limit, which satisfies our experimental and theoretical results.

4. CONCLUSION :-

We have been able to use a hollow prism suitable for the measurement of refractive index of crystal clear aqueous solutions. Experimental results calculated by using formula considered by Dongarge S.M. is employed and the technique is easier than the other methods mentioned here. Our results are in good agreement with other methods employed. Here the study of dependence of concentration on refractive index of solutions is not only carried out but also the refractive index of salts which are dissolved in water are also calculated. This is an alternate method to determine the R.I. of crystalline material without taking them into prism form.

5. ACKNOWLEDGEMENT :-

We are thankful to Prof. Dr. J S Dargad, Principal, Dayanand Science College, Latur for giving the permission to work in their research laboratory.

Table (1) :Theoretical and experimental values of refractive index of copper sulfate pentahydrate as a function of concentration

Sr. No.	Concentration V_s/V_s+V_w	Ver - I	Ver – II	Refractive Index (Experimental)	Refractive Index (Theoretical)
1	0.0988	20.45	200.45	1.35	1.348
2	0.0888	20.58	200.58	1.348	1.346
3	0.0806	20.71	200.71	1.346	1.345
4	0.0739	20.91	200.91	1.344	1.343
5	0.0681	21.08	201.08	1.342	1.342
6	0.0632	21.16	201.16	1.34	1.341
7	0.0590	21.2	201.2	1.34	1.341
8	0.0552	21.28	201.28	1.339	1.34
9	0.0520	21.38	201.38	1.338	1.339
10	0.0491	21.4	202.4	1.337	1.339
11	0.0465	21.45	202.45	1.337	1.338

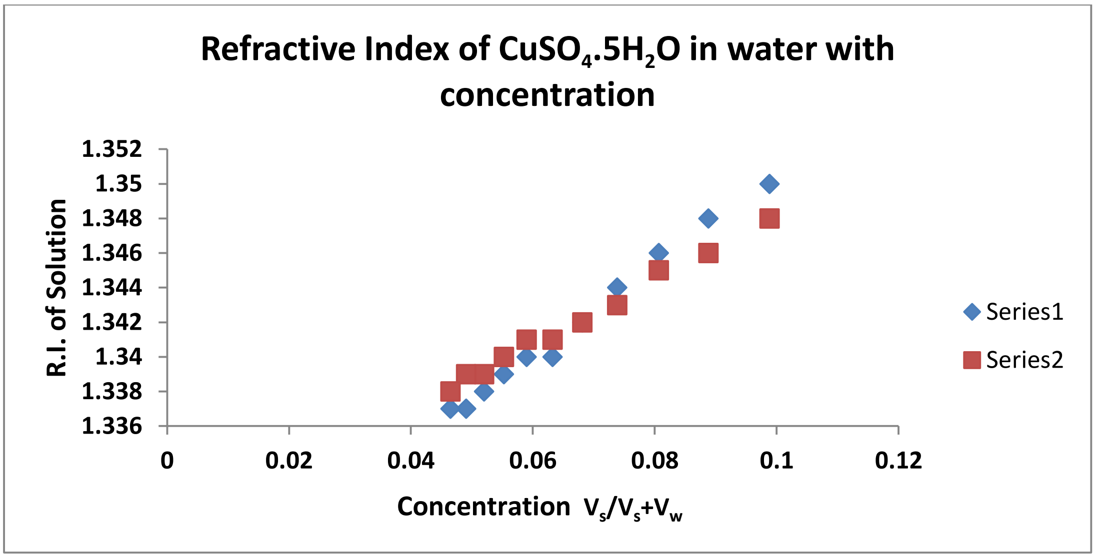


Fig.(3): Theoretical and experimental values of refractive index as a function of concentration

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