Refractive Index of Salt (NaCl) from Aquous 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 NaCl. 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 transparent liquids and solids.

INTRODUCTION

Refractive index is one of the most important optical properties of a medium. It plays vital 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 in to account for this experiment[1997 Radiation physics and chemistry].

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. This effect, known as dispersion, lets a prism divide white light into its constituent spectral colors. For a given color, 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 scattering process can be thought of as the incoming photon raising the molecule to a virtual (i.e., non-existent) excited state.

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 Hallo Prism)

a) **The 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 the collimator tube. The distance between the slit and the lens and be alter by a rack and pinion arrangement or by sliding the inner tube to obtain parallel rays. The tube rests on two screws C1 and C2 by which it can be slightly tilted up or down if necessary.

ii) **The 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 S1 provided at its side.

iii) **The 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 C1 and then can be given a slow rotation or fine adjustment by a tangent screw C2. The position off the telescope can be read by the two verniers V1 and V2. 180° a part fixed to the prism table. The telescope rests on the screws C3 and C4 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.

(Analysis of white light by dispersing it with a prism is an example of spectroscopy)
iii) The prism table:

It consists of an upper plate A and a lower plate B separated by three springs through which pass the leveling screws P, Q, and R. 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, say P and Q. 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 A1. Which fixed the prism table to the vernier V1 and V2. The table can rotate about vertical axes and may be fixed in any desired position by means of the screw A2. When fixed by the screw A2 it can be turned very slowly by a tangent screw A2 placed at a base of the spectrometer. The position of table can be accurately read by vernier moving on the circular scale.

iv) Mercury vapour lamp:

The basic principal lamp of a mercury vapor lamp is the same as that of sodium vapor lamp. A high pressure lamp of the modern form essentially consists of an outer bulb A and an inner bulb B the space in between being highly evacuated. The inner bulb contains a small quantity of argon and mercury, two main electrodes E1 and E2 and a starting electrode S placed very close to E1. The auxiliary electrode S is connected to the other electrode E2 through a high resistance R of about 5000 ohms. Each of the main electrodes E1 and E2 consists of a tungsten wire spiral containing a rod of barium compound which when heated gives out a copious supply of electrons.
When the lamp is switched on the full mains voltage is applied across the electrodes E1 and S so that a discharge passes between the two, thereby starting the ionization of the gas. As the lamp warms up, the mercury gradually vaporizes and the pressure increases. The mercury discharge between E1 and E2 fills the whole tube. The argon discharge becomes ineffective because the resistance of the starting circuit is very high as compared to that of the parallel circuit.

Such lamps are available in 250-500 watts capacity. Special mercury vapour lamps are also being made in 80 and 125 watts. These operate at an extra high pressure of 5.10 atmospheres. The discharge tube is of quartz instead of glass so that it can withstand high pressure. The tube is about 5 cms long and is housed inside a pearl glass bulb similar to an ordinary 100 watt lamp as shown in figure. Such lamps are generally used in the laboratory.

The lamp is worked on A.O. main with the help of a choke which serves as a stabilizer. A Condenser is also placed across the mains to improve the efficiency of the lamp. If the lamp is switched off it cannot be started again at once because mercury must condense before the start. Electrodes can function. This requires about 10 minutes after which the lamp can be started as usual.

**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 type of spectroscopy such as microwave spectroscopy, UV spectroscopy, IR spectroscopy, Gamma ray spectroscopy NMR, MRI, acoustic spectroscopy….etc. Spectrometers are used as spectral measurement devices.

A convenient formula for refractive index, be 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 \( D_m \) denotes the angle of minimum deviation for a given prism of refractive angle \( \alpha \), then the refractive index of the material of the prism \( n \) is given by,

\[
n = \frac{\sin(A+D_m/2)}{\sin(A/2)}
\]

Equation has been employed to calculate the refractive index of the liquids (water) where \( A \) is angle of hallow prism and \( D_m \) is minimum deviation. If consider \( V_w \) as the volume of water taken in the hallow prism and \( V_s \) is the volume of salt (NaCl) added to the water. The total volume (\( V_s+V_w \)) in the hallow prism is,

\[
V = V_s + V_w
\]

When the salt (NaCl) is added to the water then there will be shrinkage of volume in the salt (salt) which is to be considered by Telis equation not by the above equation,

\[
\text{i.e. } V = V_w + V_s - d' = V'(1-\epsilon)
\]

where \( V' = V_s + V_w \) and \( \epsilon = d'/V' \)

If we consider this equation for the solution for determining refractive index combining together (slat and water) for different concentrations we get a equation of straight line in the fallowing form

\[
n' = n_w + (n_s - n_w) V_s/V' \]

where \( n' \) is the refractive index of solution, \( n_w \) is the refractive index of the water and \( n_s \) is the refractive index for the salt. The equation one can be use for any concentration of solution.
Experimental arrangement used in our study is depicted in Fig. 1. Specially constructed hollow prism was used to measure the refractive index of liquids with the help of an optical spectrometer. A mercury lamp is used source of light and a collimated beam was allowed to fall on one reflecting face of the liquid prism and the angle of minimum deviation is determined for green light (at 589 nm). Mean of two values were taken for each angle of minimum deviation. To study the variation of refractive index of salt solutions as a function of concentration, an electronic balance is weighed salts and solutions of required concentrations were prepared by dissolving the salts in 100 ml of water. Thus prepared solutions were filtered before pouring into the hollow prism. The hollow prism was rinsed carefully after every measurement. Solutions of lower concentrations (2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18%, 20%) were made by concentrating the solutions with equal weight of salt.

Refractive index of common salt solution as a function of concentration is depicted in Fig. 3. For 20% solution, refractive index is as high as 1.358, which reduces to 1.331 when the solution is diluted to a concentration of 1.25%. With the decrease in concentration, the density of the solution also decreases resulting a decrease in refractive index. The results showed that the refractive index of the solution of concentration less than 2.5% measures nearly the same as that of the pure water. The result indicated that the effect of concentration on refractive index is dominant up to the concentration of 5%.

After that there is weak dependence of concentration of refractive index the result of salt solution, the effect of concentration is strong up to 20% concentration. However, after this value the dependence becomes weak.

A plot between R.I. and conc. Of NaCl solution gives the slope as difference of R.I. of NaCl salt and water and intercept gives the R.I. for water. By subtracting intercept from slope we get R.i. of Nacl.

CONCLUSION

We have been able to use a hollow prism suitable for the measurement of refractive index of transparent aqueous solutions. Experimental results calculated by using formula developed by Dongarge et al. 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 refractive index of solutions is not only carried out but the salts which are dissolved in water their refractive index is also calculated. This is an alternate method to determine the R.I. of crystalline material without taking them in to prism form.
**OBSERVATION TABLE**

(Table for calculation of R.I of aqueous NaCl solution.)

Observation table for R.I. of aqueous solution of NaCl Solution

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Concentration</th>
<th>Ver-I</th>
<th>Ver-II</th>
<th>Refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>23.54°</td>
<td>203.54°</td>
<td>1.332</td>
</tr>
<tr>
<td>2</td>
<td>0.02</td>
<td>23.95°</td>
<td>203.95°</td>
<td>1.337</td>
</tr>
<tr>
<td>3</td>
<td>0.04</td>
<td>24.06°</td>
<td>204.06°</td>
<td>1.339</td>
</tr>
<tr>
<td>4</td>
<td>0.06</td>
<td>24.22°</td>
<td>204.22°</td>
<td>1.340</td>
</tr>
<tr>
<td>5</td>
<td>0.08</td>
<td>24.36°</td>
<td>204.36°</td>
<td>1.342</td>
</tr>
<tr>
<td>6</td>
<td>0.1</td>
<td>24.6°</td>
<td>204.6°</td>
<td>1.346</td>
</tr>
<tr>
<td>7</td>
<td>0.12</td>
<td>24.7°</td>
<td>204.7°</td>
<td>1.347</td>
</tr>
<tr>
<td>8</td>
<td>0.14</td>
<td>24.8°</td>
<td>204.8°</td>
<td>1.348</td>
</tr>
<tr>
<td>9</td>
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<td>24.9°</td>
<td>204.9°</td>
<td>1.351</td>
</tr>
<tr>
<td>10</td>
<td>0.18</td>
<td>25.1°</td>
<td>205.1°</td>
<td>1.358</td>
</tr>
<tr>
<td>11</td>
<td>0.20</td>
<td>25.6°</td>
<td>205.6°</td>
<td>1.361</td>
</tr>
</tbody>
</table>

**GRAPH**

(Refractive index of sodium chloride solution as a function of its concentration expressed in percentage.)
REFERENCES

15. M. T. Teli "on attenuation coefficient of X-ray and x-ray on aqueous solutions of salts”. Radiation physics and chemistry