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A Study of the Dependence of Refractive Index of an Aqueous Solution on Concentration and Density Using a Novel Set-Up

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ABSTRACT

The objective of the present study is to determine the nature of variation of refractive index of an aqueous solution as a function of its concentration and density. In this study, we have used aqueous solution of sodium chloride of different concentrations at the room temperature. We have constructed a novel experimental set-up for this purpose, which can be regarded as a makeshift spectrometer, using which, the angle of deviation of light by a prism can be measured with an accuracy of one degree. We have prepared sodium chloride solutions of different concentrations and put each solution in a hollow prism. The angle of minimum deviation was then measured using our setup. Refractive index has been calculated based on this angle. We also calculated the density of the solution from its concentration. The variation of refractive index as functions of percentage concentration and density has been depicted graphically. Here, the light source is a LASER pointer emitting light of wavelength 532 nm. We have devised a Python program that enables the user to get the refractive index based on inputs of the percentage concentration and density of the solution.

Keywords: Refractive index, Aqueous solution, Percentage concentration, Density, Angle of minimum deviation, LASER, Hollow prism.

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1. INTRODUCTION

In various previous studies, the dependence of refractive index on concentration and density has been extensively investigated [1-5]. The refractive index for polar and non-polar solvents have also been studied previously [2, 6-14]. In this study, we aim to further extend our understanding and analyze the relationship of refractive index with percentage concentration and density for an aqueous solution of Sodium Chloride, also known as common salt. We have devised a make shift spectrometer for this study which is affordable and easier to work with. Similar studies on sugar solutions have been performed using sophisticated instruments like a Spectrometer [4].

2. EXPERIMENTAL METHOD

We have constructed a novel setup (a makeshift spectrometer) for the purpose of the present study, which is described below.

- We have a laser pointer acting as the source of light. In front of the laser source, we have a rotating table on which a hollow prism filled with a particular fluid is kept. The rotating table is fixed with the protractor to record the minimum angle of deviation. In front of the prism we have a screen. We have two scales fixed perpendicularly with respect to one another to move and slide on the screen and find the angle from the protractor.
- For different angles of incidence, obtained by rotating the prism in different directions, we will be measuring the angle of minimum deviation. This procedure will be repeated for different liquids.
- We can observe that, as we rotate the prism and increase the angle of incidence, the angle of deviation decreases, then reaches a minimum value and then again start increasing.
- First, in the absence of prism, we take the initial reading on the protractor to be 0^o.
- After rotating the prism, we arrive at the position of minimum angle of deviation. We then record the angle of minimum deviation by sliding the scale to that position and note the corresponding reading from the protractor.

Based on the minimum angle of deviation, the refractive index can be calculated, using the following formula:

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} \qquad (1)$$

A - Angle of the prism (60^o)
δ_m -Angle of minimum deviation
μ - Refractive index of the fluid inside the hollow prism

Figure 1. Undeviated Laser Beam in the absence of prism.

Figure 2. Deviated Laser Beam in the presence of prism.

Figures 1 & 2 show the deviation of the laser beam due the prism (filled with water) in our setup. For a video demonstration, please visit the following link, which shows the procedure of measurement of the angle of minimum deviation for water using our experimental setup:
https://www.youtube.com/watch?v=4PfSyT6PCHY&t=35s

3. EXPERIMENTAL FINDINGS

3.1. Relation between Refractive Index and Percentage Concentration

The amount of salt taken in 100gm of water has been defined as the percentage concentration of the solution. We have prepared salt solutions of different concentrations and put each solution in a hollow prism. Using the set-up that we have made, we then find the angle of minimum deviation, followed by the calculation of the refractive index. The percentage concentration versus refractive index data for aqueous sodium chloride solution has been shown in Table-1.

Table 1. Percentage Concentration vs Refractive Index for Aqueous Sodium Chloride Solution

PERCENTAGE CONCENTRATION (%)	REFRACTIVE INDEX
0	1.338261213
10	1.351180415
20	1.36399672
30	1.376709151
40	1.389316741
50	1.401818529
60	1.414213562
70	1.426500898
80	1.438679601
90	1.450748742
100	1.462707403

Figure 3 depicts the variation of refractive index as a function of the percentage concentration of solution. It has been plotted using MATLAB.

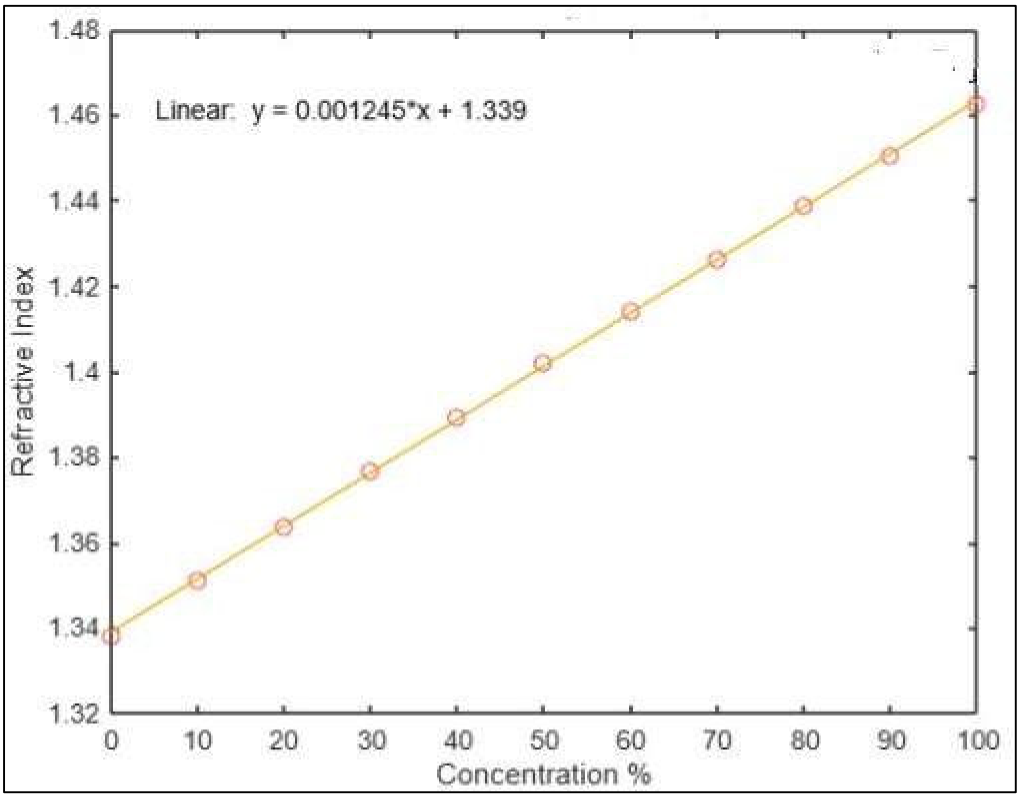

Figure 3. Refractive Index vs Percentage Concentration for aqueous Sodium Chloride Solution.

The relation between Refractive Index and Percentage Concentration below the saturation limit has been obtained as:

$$n = 0.001245\,C + 1.339 \qquad (2)$$

n - Refractive index of the Aqueous Salt Solution
C - Percentage concentration of the solution

3.2. Relation between Refractive Index and Density

We first calculated the molality of the solution from its percentage concentrations mentioned in Table 1 using the formula:

$$m = \frac{C}{5.85} \qquad (3)$$

C - Percentage concentration of the solution
m - Molality of the solution
Using the basic definition of molality and percentage concentration, we have derived equation (3).

The Density of Aqueous Sodium Chloride solution at constant temperature and pressure is given by:

$$d = \frac{1000d_0 + M_2 m d_0}{1000 + A_0 m d_0 + B_0 m^{\frac{3}{2}} d_0 + C_0 m^2 d_0} \quad (4)$$

d - Density of the aqueous sodium chloride solution

M_2-Molecular Weight of NaCl

m - Molality of the solution

d_0 - Density of pure water

A_o, B_o, C_o - Constants dependent on temperature

At 25°C, the constants take the following values:

A_0 = 16.62

B_0 = 1.773

C_0 = 0.098

d_0 = 0.997047

The relation mentioned in equation (4) has been obtained from the works of Potter, R. W., & DL, B. (1977) [1]. Table-2 contains the refractive index data for aqueous NaCl solutions with different molalities and densities.

Table 2. Molality, Density and Refractive Index for aqueous Sodium Chloride Solution

MOLALITY (mol/kg)	DENSITY (gm/cc)	REFRACTIVE INDEX
0	0.997047	1.338261213
1.709401709	1.062065684	1.351180415
3.418803419	1.119070192	1.36399672
5.128205128	1.16946139	1.376709151
6.837606838	1.213989067	1.389316741
8.547008547	1.253254361	1.401818529
10.25641026	1.28778076	1.414213562
11.96581197	1.3180642	1.426500898
13.67521368	1.344443888	1.438679601
15.38461538	1.367385274	1.450748742
17.09401709	1.387206242	1.462707403

Figure 4 shows a plot of refractive index as a function of the density of solution. It has been plotted using MATLAB.

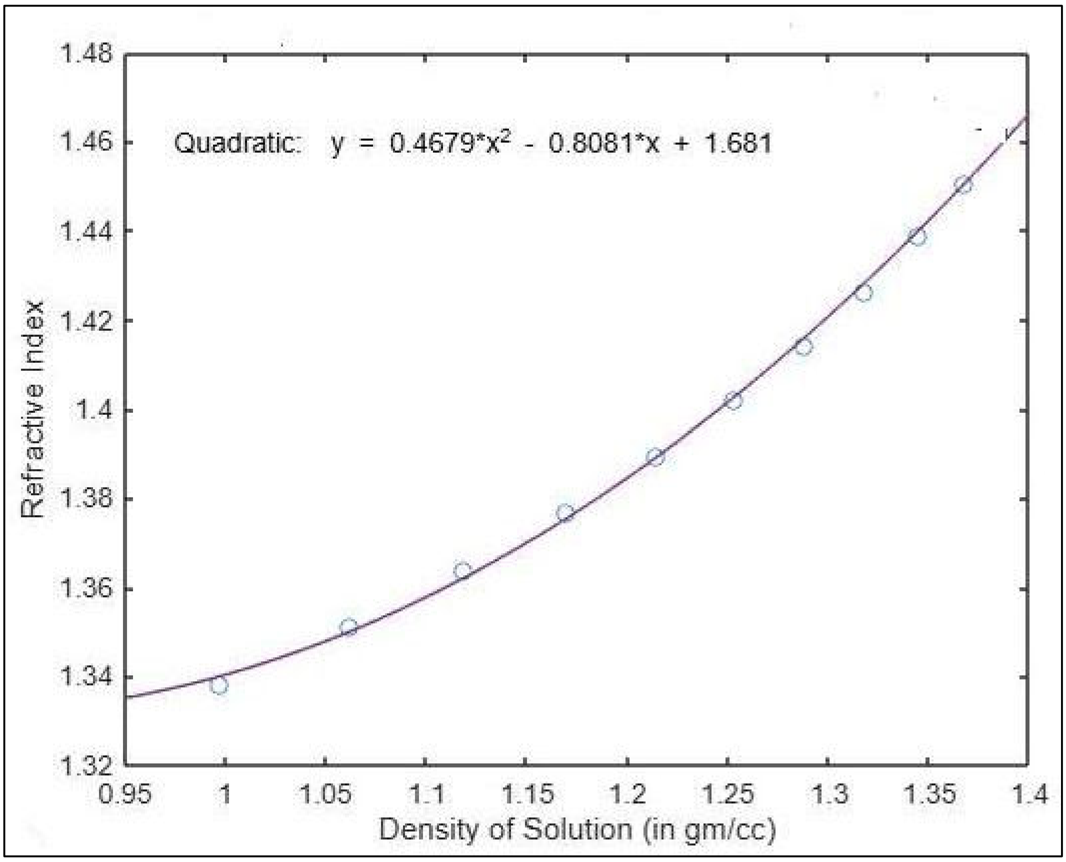

Figure 4. Refractive Index vs Density for Aqueous Sodium Chloride Solution.

The relation between Refractive Index and Density of the solution has been obtained as:

$$n = 0.4679d^2 - 0.8081d + 1.681 \qquad (5)$$

n - Refractive index of the Aqueous Salt Solution

d - Density of the solution (in gm/cc)

4. PYTHON PROGRAMMING

We have also devised a Python Programming that enables the user to put the percentage concentration or density as the input and provides refractive index as the output.

It helps in predicting the refractive indices of the aqueous Sodium Chloride solution when its concentration or density is provided.

```
choice=int(input("Enter your choice between 1 for concentration and 2 for density:"))
if choice==1:
    n1=int(input("Enter the percentage concentration of salt:"))
    if n1<0 or n1>100:
        print("Enter the percentage concentration within 0 to 100")
    else:
        ri1=0.001245*n1+1.339
        print("The refractive index is",ri1)
else:
    n2=float(input("Enter the density of salt solution in gm/cc:"))
    ri2=(0.4679*n2*n2)-(0.8081*n2)+1.681
    print("The refractive index is",ri2)
```

Figure 5. Code of Python programming.

```
= RESTART: C:\Users\PRERANA MANNA\AppData\Local\Programs\Python\Python312\ri.py
Enter your choice between 1 for concentration and 2 for density:1
Enter the percentage concentration of salt:37
The refractive index is 1.385065

===================================================== RESTART: C:\Users\PRERANA MANNA\
Enter your choice between 1 for concentration and 2 for density:2
Enter the density of salt solution in gm/cc:1.3
The refractive index is 1.4212209999999998
```

Figure 6. Output of the Python program shown in Figure 5.

The code for the Python programming and the corresponding output have been shown in Figures 5 and 6 respectively.

5. CONCLUSION

This is a study illustrating the dependence of refractive index on the concentration and density for aqueous Sodium Chloride solution. The entire experiment is performed at room temperature using a hollow prism [15]. We find the relation between the refractive index and percentage concentration is linear in nature but that between refractive index and density is quadratic in nature. Similar results have also been found in previous studies [2,16]. The novel setup used for the purpose of our study is affordable and easier to operate compared to other sophisticated instruments [17-19]. The Python programming allows us to quickly get the refractive index [20] for a particular concentration or density without performing the experiment repeatedly.

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