CHAPTER 1
INTRODUCTION

Refractive index is one of the most important optical properties of a medium. Refractive index, also called index of refraction, is the measure of the bending of a ray of light when passing from one medium into another. If i is the angle of incidence of a ray in vacuum (angle between the incoming ray and the perpendicular to the surface of a medium, called the normal), and r is the angle of refraction (angle between the ray in the medium and the normal), the refractive index (n) is defined as the ratio of the sine of the angle of incidence to the sine of the angle of refraction.

$$n = \sin i / \sin r$$

Refractive index is also equal to the velocity c of light of a given wavelength in empty space divided by its velocity v in a substance.

$$n = c/v.$$

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 provide more detailed discussion on the concentration mapping by the measurement of refractive index of liquids [1-3]. Temperature coefficient of refractive index can also be used to calculate thermal expansion coefficient [4]. Several techniques are reported in literature for the measurement of concentration and temperature dependence of refractive index of liquids [5-7].

Some typical refractive indices for yellow light (wavelength equal to 589 nanometers) are the following: air, 1.0002; crown glass, 1.517; dense flint glass, 1.655; and diamond. 2.417. These values show that the refractive index of the medium increases with the increasing density of the medium. In this project we determine the refractive indices of different liquids. Then we try to see how the refractive indices of liquids vary with respect to densities of liquid. The phenomenon of dispersion of light through a prism is used to determine the refractive index.

1.1 THEORETICAL FRAMEWORK

In Fig. (1), ABC is a principal section of a prism of refracting angle A. AB and AC are faces of the prism and BC is the base. A ray PQ incident on the face AB at an angle i_1, is refracted along QR at an angle r_1 , such that the refractive index n of the material is given by

$$n = \sin i_1 / \sin r_1 \qquad \ldots (1)$$

The ray QR is incident on the face AC at an angle r_2 and emerges out at an angle i_2 such that

$$n = \sin i_2 / \sin r_2$$

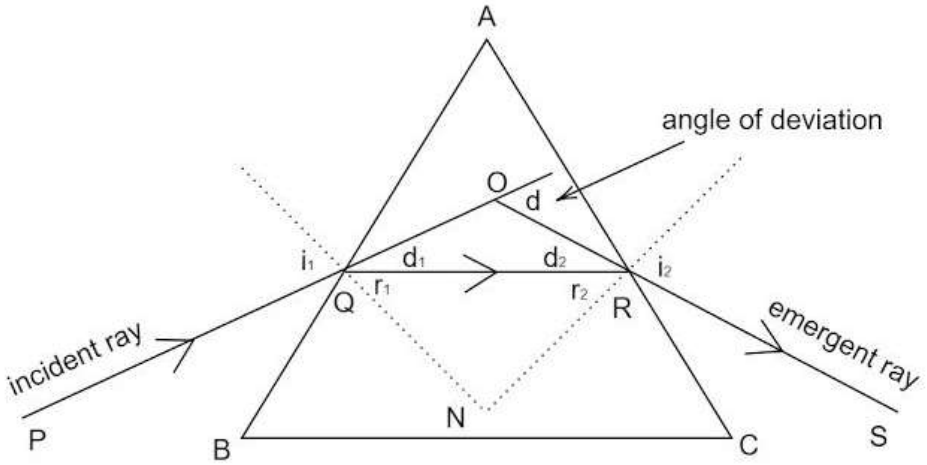

Fig. 1: Ray diagram showing refraction through a prism

The angle between the direction of the incident ray and the emergent ray is called angle of minimum deviation (d). Let the two normals at Q and R meet at N.

In the quadrilateral, $AQNR$, $\angle AQN = \angle ARN = 90°$

$$\therefore \angle A + \angle N = 180° \qquad \ldots (2)$$

In the triangle QNR, $r_1 + r_2 + \angle N = 180°$

$$\therefore A = r_1 + r_2 \qquad \ldots (3)$$

Considering the triangle QMR the deviation,

$$d = \angle OQR + \angle ORQ$$

$$d = i_1 - r_1 + i_2 - r_2 = i_1 + i_2 - (r_1 + r_2)$$

$$d = i_1 + i_2 - A \qquad \ldots (4)$$

For a given prism and for a given colour of light the angle of deviation depends only on the angle of incidence. As the angle of incidence increases, the angle of deviation decreases. reaches a minimum value and then increases. The smallest value of deviation is called angle of minimum deviation (D). The ray undergoing minimum deviation passes symmetrically through the prism. Therefore, we can write.

$i_1 = i_2 = i$

$r_1 = r_2 = r$

$d = D$

From equation (3),

$A = 2r \qquad \therefore r = \frac{A}{2}$

From equation (4), $D = 2i - A, i = \frac{A+D}{2}$

From equation (1) we get refractive index, n = $\frac{\sin\frac{A+D}{2}}{\sin\frac{A}{2}}$ $\qquad \ldots (5)$

Equation (5) can be used for calculating the refractive index.

CHAPTER 2

EQUIPMENTS AND METHODOLOGY

In this project we make use of a simple spectrometer and Abbe's Refractometer for obtaining the refractive index.

2.1 SPECTROMETER

Spectrometers are mainly used for the measurements of wave length of spectral line using prisms or gratings. Using spectrometer, we can determine the refractive indices of transparent materials such as glass, water etc. It can also be used to find the dispersive power and other optical constants. All these involve angle measurements. Fig. (2) shows a simple spectrometer.

Fig 2: Spectrometer

In this project a sodium vapor lamp (589.3 nm) is used as the light source to perform the experiment. A prism of the liquids under investigation is formed by taking the liquids in a hollow glass prism. Our eyes have some inherent limits on the accuracy with which we can measure angles. But accuracy in the measurement of angles can be improved by using

telescopes having good angular magnification. In ordinary spectrometers, we have angle measuring devices that use telescopes. fine adjustment mechanisms and a pair of Vernier scales. In ordinary spectrometers the angles are marked in degrees with a main scale division equal to half degree (30 minutes). The Vernier typically has 30 divisions giving a least count of one minute.

Least count of the spectrometer = 1 main scale division / No. of divisions on vernier scale.

Care should be taken while finding difference between two readings to measure the angle. When the difference is above 180, we have to add 360 to lower angle and find the difference to get the correct angular separation. For example, the difference between 10^o and 340^o we may end up with a result equal to 330 which is absurd. The actual difference is $(10^o + 360^o) - 340 = 30^o$.

Main parts of a spectrometer are collimator, telescope, prism table and vernier table. The collimator is a tube with a slit at one end and a collimating lens at the other end which is used to produce parallel rays. The distance between the lens and slit can be changed by working the rack and pinion arrangement. The prism is placed in the space between collimator and telescope on a turntable known as prism table. The telescope is arranged with its axis in the same horizontal plane of the collimator axis. The telescope is attached with a circular scale graduated in half degrees (0 - 360). Two Vernier scales are provided diametrically opposite to each other for measuring the angles more accurately. The telescope along with the circular scale can be rotated about the vertical axis of the stand and can be fixed at any position using the radial screw. Fine adjustment in the position of the telescope can be made by using a tangent screw. Both the turntable and telescope can be locked at any position.

2.1.1 Preliminary adjustments for Spectrometer

i. **Eye -piece:** The telescope is turned to a whitewall. The eye - prese is pushed in or pulled out gently ul the cross wires are clearly are seen.

ii. **Telescope:** The telescope is turned towards a distant object. By means of the track and pinion arrangement, the length of the telescope is varied to get a clear image of the distant coinciding with the cross wires without parallax. Thus, the telescope is adjusted to receive parallel rays.

iii. **Collimator:** The slit of the collimator is illuminated with sodium light. The telescope is brought in a line with the collimator and the image of the slit is got in the telescope. The slit is made sufficiently wide. The rack and pinion arrangement of the collimator

is worked till the image of the slit is clearly seen coinciding with the cross wires without parallax. Now the collimator is ready to produce parallel rays.

iv. **Prism-table:** The prism - table is levelled by an optical method as follows. The prism ABC is placed on the prism - table with its base turned towards the clamp and one of the refracting faces AB, perpendicular to the line joining the two levelling screws P and Q. The table is rotated so that the edge A points towards the collimator. The reflected image of the slit from the face AB is observed through the telescope. P or Q (or both) is (are) worked till the image is symmetrical with respect to the horizontal cross wire. Then the reflected image from the other face AC is observed through the telescope. The image is made symmetrical as before by working the third screw R. The prism table is thus levelled.

v. The slit is made narrow.

2.1.2 To find the angle of the prism (A)

The least count of the Vernier is noted. The Vernier table is rotated so that the edge of the prism points towards the collimator. Now the parallel rays of light from the collimator fall almost equally on the faces AB and AC. Fig. (3) shows the ray diagram of the procedure. The Vernier table is clamped. The reflected image of the slit from the face AB is obtained through telescope. The telescope is clamped in this position. The tangent screw of the telescope is worked till the vertical cross - wire coincides with the centre of the image of the slit. (If the slit is not very narrow, adjust the vertical cross - wire to coincide with the fixed edge of the image of the slit). The readings of the circular scale and both the Verniers are noted. The telescope is unclamped. Then the reflected image of the slit from the other face AC is obtained in the telescope and the corresponding readings are taken. The difference between the readings of corresponding Verniers gives twice the angle of prism. Hence A is determined.

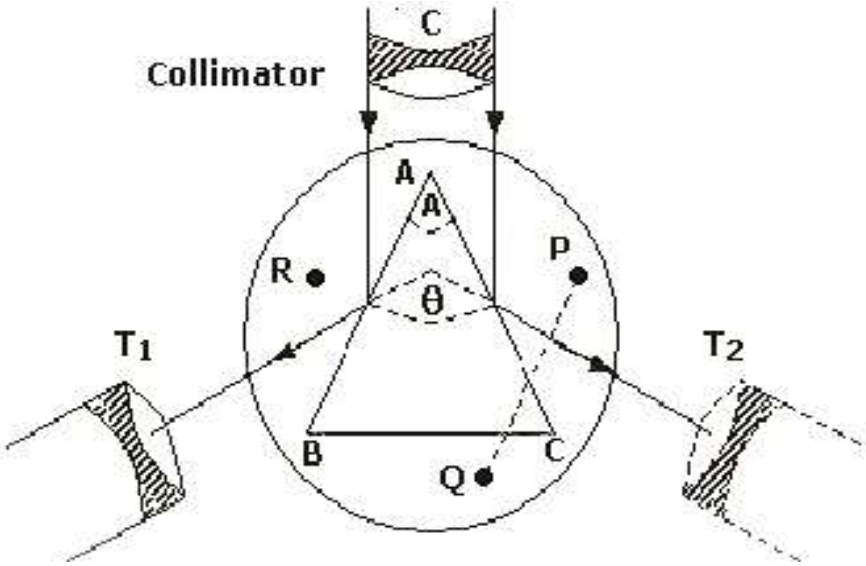

Fig. 3: Ray diagram showing the procedure to determine the angle of the prism

2.1.3 To find the angle of minimum deviation (D)

The Vernier table is unclamped and rotated so that light from the collimator falls obliquely on one face of the prism (Fig.2). The telescope is rotated so that the refracted image is seen through the other face. The Vernier table is slowly rotated in such a direction that the image moves towards the direct position (i.e. angle of deviation decreases). The telescope is also rotated in the same direction so that the image is always in the field view. The Vernier table is rotated until the image is found to remain stationery for a moment and then begins to retrace.

This is the minimum deviation position. The Vernier table and telescope are clamped. The tangent screw of the telescope is worked so that the vertical cross wire coincides with the centre of the image. The readings of the circular scale and Verniers are taken.

The prism is removed. The telescope is released and brought in a line with the collimator so that the direct image of the slit is seen. The direct reading is taken. Difference between the readings of corresponding Verniers gives the angle of minimum deviation. The mean angle of minimum deviation D is thus determined. The refractive index of the liquid in the hollow prism is hence calculated.

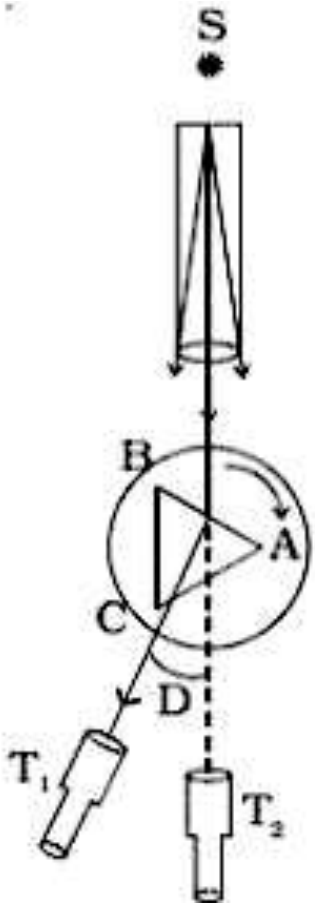

Fig. 4: Ray diagram showing the determination of the angle of minimum deviation

2.2 ABBE'S REFRACTOMETER

The Abbe instrument is the most convenient and widely used refractometer, Fig (5) shows a schematic diagram of its optical system. The sample is contained as a thin layer (~0.1mm) between two prisms. The upper prism is firmly mounted on a bearing that allows its rotation by means of the side arm shown in dotted lines. The lower prism is hinged to the upper to permit separation for cleaning and for introduction of the sample. The lower prism face is rough-ground: when light is reflected into the prism, this surface effectively becomes the source for an infinite number of rays that pass through the sample at all angels. The radiation is refracted at the interface of the sample and the smooth-ground face of the upper prism. After this it passes into the fixed telescope. Two Amici prisms that can be rotated with respect to another serve to collect the divergent critical angle rays of different colours into a single white beam, that corresponds in path to that of the sodium D ray. The eyepiece of the telescope is provided with crosshairs: in making a measurement, the prism angle is changed until the light-dark interface just coincides with the crosshairs. The position of the prism is then established from the fixed scale.

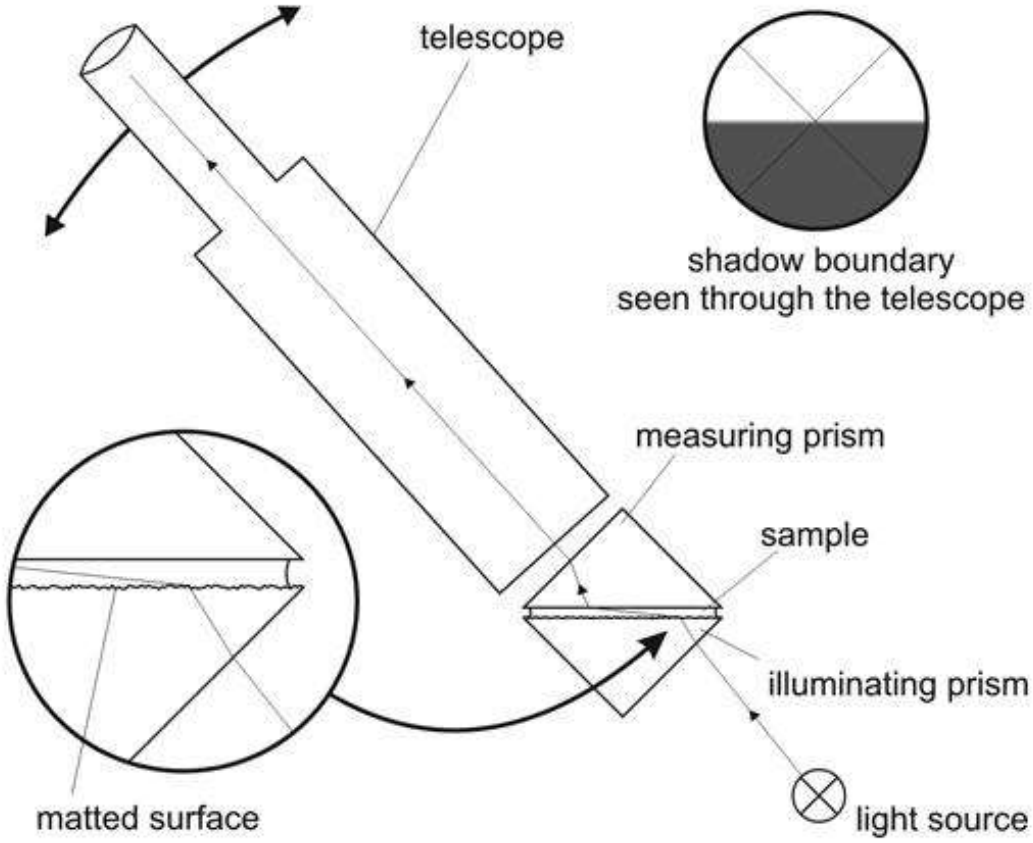

Fig. 5: Schematic diagram of optical system of Abbe's refractometer

From the Fig (6) we can see the Compensator Knob and Knob for adjusting boundary lines. Compensator knob allows to control the sharpness of the shadow back boundary. Knob for adjusting boundary lines helps to coincide the crosshairs with the boundary lines.

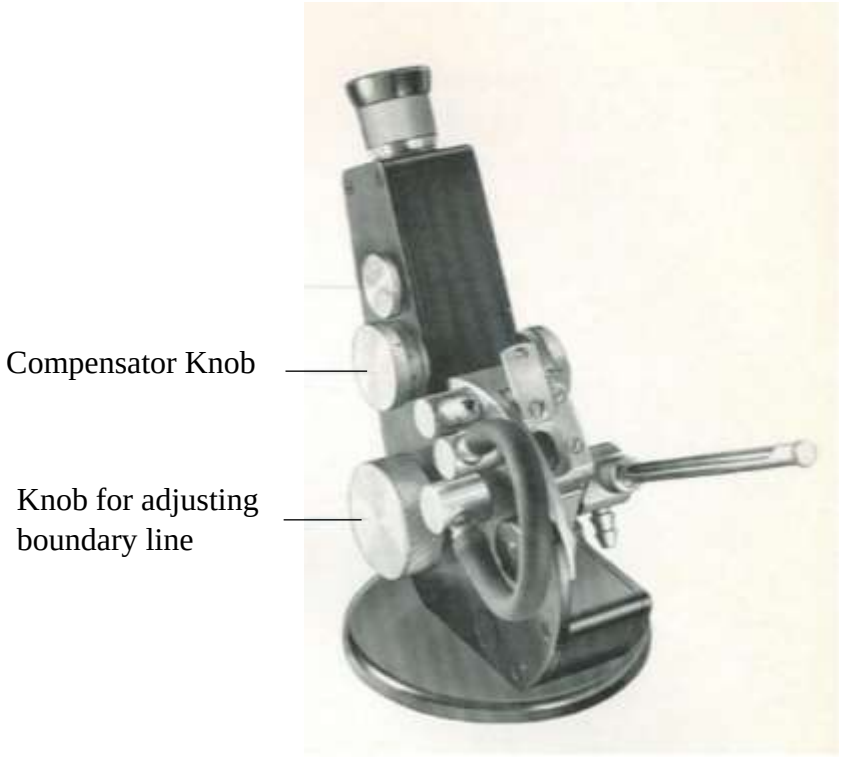

Fig. 6: Abbe's refractometer

2.2.1 Experimental Steps

i. Clean the surface of prism first with alcohol and then with acetone using cotton and allow it to dry.
ii. Using a dropper put 2-3 drops of given liquid b/w prisms and press them together
iii. Allow the light to fall on mirror.
iv. Adjust the mirror to reflect maximum light into the prism box
v. Rotate the prism box by moving lever until the boundary b/w shaded and bright parts appear in the field of view.
vi. If a band of colours appear in the light shade boundary make it sharp by rotating the compensator.
vii. Adjust the lever so that light shade boundary passes exactly through the centre of cross wire
viii. Read the refractive index directly on the scale

2.3 MOLAR CONCENTRATION AND DENSITY

For finding the molar concentration of the solution prepared, we used the equation

$$M = \frac{w \times 1000}{m \times v(ml)}$$

$M = molar\ cocentration\ of\ solution$

$m = molecular\ mass\ of\ the\ solute$

$w = weight\ of\ the\ solute$

$v = volume\ of\ the\ solvent$

In this project, KCl and NaCl are used as solute and the water is used as the solvent. The amount of salt to be added for 100 ml of solvent can be calculated and using that value the density of solution can be calculated.

CHAPTER 3

RESULTS AND CONCLUSION

In this project we make use of a simple spectrometer and Abbe's Refractometer for determining the refractive index. The average of refractive index obtained using spectrometer and value obtained using Abbe's refractometer for a concentration of the solutions it used for analysis. In order to study the variation of refractive index of liquid with same nature but different densities we considered salt solutions of different concentrations. Solutions of Sodium chloride (NaCl) and Potassium chloride (KCl) were used.

The variation (fig. 6) shows almost a linear behavior. The linear fit of the data has an R2 value of 0.999 which is an excellent fit. From the result of present study we see a linear relationship between refractive index and density if the liquids under consideration are of same nature. However, more elaborate and extensive study by considering more liquid samples must be conducted to draw a solid conclusion to the problem.

3.1 RESULTS

The refractive index values obtained for different concentrations KCl solution are tabulated in Table 1 and the refractive index values obtained in the case of NaCl solutions are tabulate in Table 2.

KCl Solution		**Refractive Index**		
Molar Concentration	**Density (*kg/l*)**	**Spectrometer**	**Refractometer**	**Average**
0.2	1014.7	1.3375	1.332	1.332
0.4	1029.4	1.3353	1.334	1.334
0.6	1044.1	1.3393	1.335	1.336
0.8	1058.8	1.3394	1.337	1.339
1.0	1073.5	1.3480	1.3405	1.342
1.2	1088.2	1.3569	1.3425	1.344

Table 1: Values of refractive index obtained for different concentrations of KCl solution

NaCl Solution		Refractive Index		
Molar Concentration	**Density (*kg/l*)**	**Spectrometer**	**Refractometer**	**Average**
0.2	1005.85	1.329	1.333	1.331
0.4	1011.70	1.331	1.334	1.333
0.6	1017.55	1.337	1.336	1.337
0.8	1023.4	1.338	1.3385	1.338
1.0	1029.25	1.340	1.3405	1.340
1.2	1035.10	1.329	1.333	1.342

Table 2: Values of refractive index obtained for different concentrations of NaCl solution

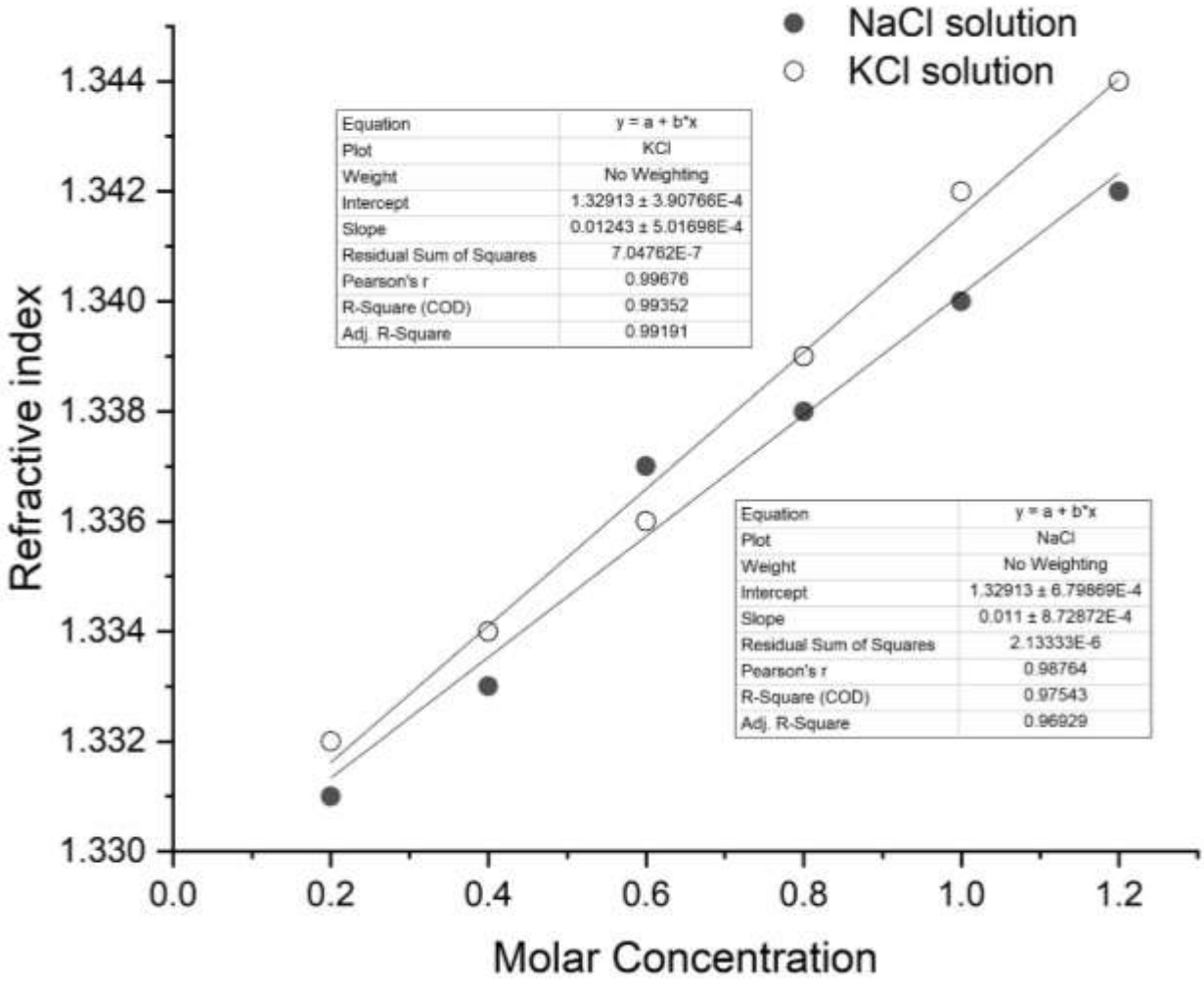

Figure 7: Graph showing the variation of refractive index with concentration.

Linear fitting is performed on the refractive index vs. concentration data and the values obtained are tabulated in Table 3.

Solution of	NaCl	KCl
Intercept (Refractive index of solvent)	1.32913	1.32913
Slope (Rate of change of refractive index w.r.t. concentration)	0.011	0.01243
R^2	0.97543	0.99352

Table 3: Parameters obtained after linear fitting of refractive index vs. concentration data

A plot of refractive index versus relative density of salt solution is also drawn to analyse the variation of refractive index with respect to the density of liquids (Figure 8)

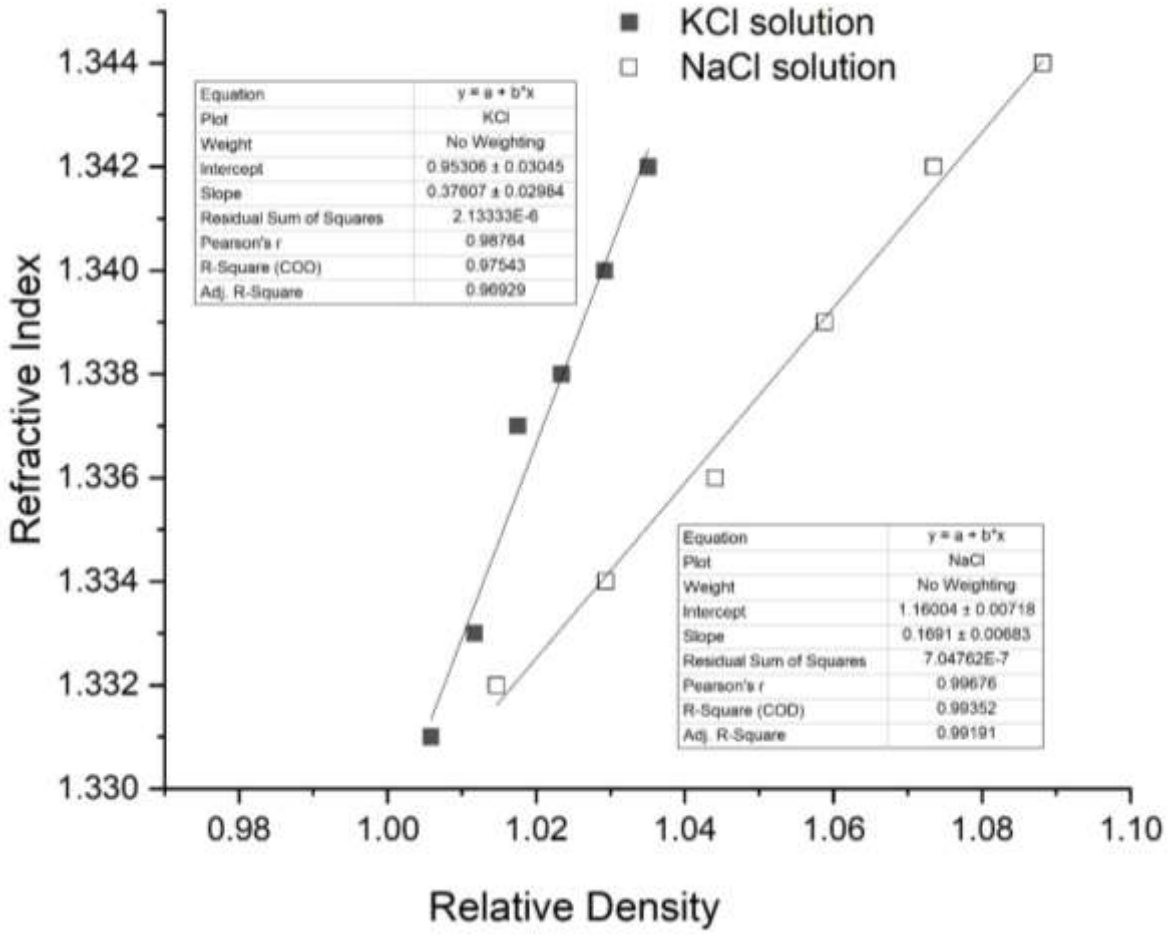

Figure 8: Graph showing the variation of refractive index with density.

Linear fitting is performed on the refractive index vs. relative density data and the values obtained are tabulated in Table 4.

Solution of	NaCl	KCl
Intercept	1.16004	0.95306
Slope (Rate of change of refractive index w.r.t. relative density)	0.1691	0.37607
R^2	0.97543	0.99352

Table 4: Parameters obtained after linear fitting of refractive index vs. relative density data

Molar Concentration	**Mass Percentage of Solute in Total Mass of Solution**		**Ratio (b)/(a)**	**Average of Ratio**
	NaCl (a)	**KCl (b)**		
0.2	0.581598	1.448704	2.491	2.440
0.4	1.156469	2.856033	2.470	
0.6	1.724731	4.223733	2.449	
0.8	2.286496	5.553457	2.429	
1	2.841875	6.846763	2.409	
1.2	3.390977	8.105128	2.390	

Table 5: Percentage of solute mass in total mass of solution and their ratios in NaCl to KCl solutions

3.2 CONCLUSION

In order to study the variation of refractive index of liquid with same nature but different densities, we considered solutions of NaCl and KCl with different concentrations. The graphs in fig. 7 and fig. 8 shows linear behaviour. The linear fit of the data has R^2 values above 0.97 (which is an indication of an excellent fit) for both solutions. The intercept values obtained for plots in fig. 7 is 1.32913 which is very close to the refractive index value of water. The rate of change of refractive index with respect to concentration (slope) are very close values for both salt solutions. From this observation we may infer that the rate of change of refractive index is proportional to the number of molecules of solute present in the solution. The value of intercept obtained by fitting plots in fig. 8 is very close to 1 which is refractive index of vacuum (a case relative where density can be zero). The ratio between slopes of refractive index vs. relative density plots (2.221) and the average value of ratio between the percentage mass of salt in the solutions with same molar concentration (2.440) is comparable and is within the limit of experimental errors. We can say that there is a linear relationship between refractive index and salt concentration Also, the relation between refractive index and relative density of solution with respect to solvent is linear. The values of various parameters obtained through fitting can be explained in terms of physically observable factors. However, more elaborate and extensive study by considering more liquid samples must be conducted to draw a solid conclusion to the problem.

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APPENDIX

OBSERVATIONS AND CALCULATIONS

Calculation of Least Count

Value of one main scale division ($1\ m.s.d$) = 0.5°

No. of divisions on Vernier scale, n = 30

Least Count = $\frac{1\ m.s.d}{n} = \frac{0.5}{30} = 0.01667°$

Measurements and Calculations to Determine Angle of the Prism (A)

Reading of	Vernier 1			Vernier 2		
	MSR	VSR	Total	MSR	VSR	Total
Reflected ray from face I (a)	48.0	0	48.0	228.0	5	228..084
Reflected ray from face II (b)	268.0	0	288.0	108.0	3	108.050
Difference between (a)&(b) (2A)			120.000			120.034

Mean value of 2A = 120.017^o

Therefore, Angle of the prism, A = 60.009^o

Measurements and Calculation of Experiment Conducted Using NaCl Solution

Molar Concentration	Vernier 1 (degree)			Vernier 2 (degree)			Minimum Deviation [(i)+(ii)]/2	Refractive index
	Refracted Ray	Direct Ray	Difference (i)	Refracted Ray	Direct Ray	Difference (ii)		
0.2	334.667	357.500	22.833	154.017	177.717	23.7	23.2665	1.329
0.4	332.500	356.000	23.500	152.667	176	23.333	23.4165	1.331
0.6	325.834	349.667	23.833	145.918	169.834	23.916	23.8745	1.337
0.8	330.667	354.667	24.000	150.751	174.751	24.000	24.0000	1.338
1.0	333.017	357.384	24.367	153.134	177.000	23.866	24.1165	1.340
1.2	338.918	363.468	24.550	158.918	183.067	24.149	24.3495	1.343

* Angle of minimum deviation (D)

Measurements and Calculation of Experiment Conducted Using KCl Solution

Molar Concentration	Vernier 1 (degree)			Vernier 2 (degree)			Minimum Deviation [(i)+(ii)]/2	Refractive index
	Refracted Ray	Direct Ray	Difference* (i)	Refracted Ray	Direct Ray	Difference* (ii)		
0.2	235.867	259.050	23.183	55.584	79.418	23.834	23.5085	1.332
0.4	232.000	255.918	23.918	52.134	75.500	23.366	23.642	1.334
0.6	233.600	257.401	23.801	53.667	77.468	23.801	23.801	1.336
0.8	229.167	253.334	24.167	49.167	73.418	24.251	24.209	1.341
1.0	233.834	258.251	24.417	53.902	78.334	24.432	24.4245	1.344
1.2	233.834	258.334	24.500	53.834	78.401	24.567	24.5335	1.345

* Angle of minimum deviation (D)