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# Acoustic and refractometric study of binary mixtures of 1-Propanol + Benzonitrile at 313 K

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Ultrasonic speed ($U$), refractive index ($n$) and density (ρ) for binary mixtures of various concentrations of 1-Propanol (1-PrOH) with Benzonitrile (BN) have been measured at constant temperature 313 K. Various acoustic and optical parameters have been determined from the measured values of ultrasonic speed, refractive index and density of binary liquid mixtures. Excess of measured acoustic and optical parameters have been evaluated and fitted in R-K polynomial. The deviations in the sign and values of these parameters from the ideal mixing reveal inter-molecular interactions in the liquid mixture. Several theoretical mixing relations for ultrasonic speed and refractive index for the binary mixtures have been applied and verified for the same.

**Keywords**: Binary mixtures, Density, Mixing relations, Refractive index, Ultrasonic speed

## 1 Introduction

In recent past ultrasonic speed measurements emerge as a new probe for determining the molecular interaction in binary liquid mixtures[1-14]. Ultrasonic speed in a liquid mixture is fundamentally related with the binding forces acting between the atoms/molecules present in the liquid system. Refractive index and density measurements of binary liquid mixtures are also important and expected to throw some light on the molecular interactions and configuration of their mixtures. Such studies have revealed the structure and bonding of associated molecular complex in the binary mixtures[15-19]. There have been a number of reports on acoustic, dielectric, refractometric, volumetric, thermodynamic properties of binary liquid mixtures consisting of associated-associated, associated-non associated and non-associated-non associated compounds[1-27]. As a further contribution to this area and in continuation of our earlier work, in the present paper binary mixture (1-PrOH + BN) data of ultrasonic speed ($U$), refractive index ($n$) and density ρ at constant temperature 313 K are reported. Using this experimental data adiabatic compressibility β, specific acoustic impedance ($Z$), Rao's molar sound function ($R$), intermolecular free length ($L_f$), molar compressibility ($W$), degree of intermolecular interaction ($\alpha_i$), molar volume ($V_m$), molar refraction ($R_m$), molecular radii ($r$) and internal pressure ($P_{int}$) are evaluated. Several excess parameters related to acoustic and refractometric are determined and fitted with R-K Polynomial[26].

## 2 Experimental Details

1-Propanol (1-PrOH) and Benzonitrile (BN) of A R grade was procured from Loba Chemie (India). Binary mixtures of 1-PrOH and BN were prepared in volume fraction (0.0, 0.1, 0.2...1.0) at 313 K. Ultrasonic speed ($U$) of the binary mixtures are measured[13] using digital ultrasonic pulse echo velocity meter (Model - VCT-70A, VI Microsystems Pvt Ltd, Chennai, India) with an accuracy of ±2 m/s. Temperature of the binary liquid mixtures was maintained constant using electronically operated digital constant temperature bath. Refractive index of the binary mixtures was measured using Abbe's refractometer with a Sodium D-line source. Densities of the binary mixtures were measured using the specific gravity bottle. All measurements were carried out at constant temperature 313 K. The temperature was controlled by circulating water continuously around the sample. The experimental values of ultrasonic speed, refractive index and density of pure liquids along with literature values are presented in Table 1.

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## 3 Results and Discussion

From Table 1, it is clear that the experimental values of ultrasonic speed ($U$), density (ρ) and refractive index $n$ of individual component namely 1-PrOH and BN found in the present investigation are in good agreement with the literature values. Various acoustic parameters, adiabatic compressibility (β), intermolecular free length ($L_f$), specific acoustic impedance ($Z$), Rao's molar sound function ($R$), Molar compressibility ($w$), and degree of intermolecular interaction ($\alpha_i$) are obtained using the standard formulae[3-7]. The acoustic parameters of pure components and their binary mixtures are presented in Table 2. A close perusal of Table 2 indicates that as the concentration of 1-PrOH increase in the mixture, adiabatic compressibility (β), inter-molecular free length ($L_f$) increase while specific acoustic impedance ($Z$), Rao's molar sound function ($R$) and molar compressibility $w$ decreases. The variation in ultrasonic speed in a solution depends upon the inter-molecular free length on mixing. According to sound propagation model of Erying and Kincaid, ultrasonic speed decreases with increase in intermolecular free length and vice-versa[8]. Here, in this case intermolecular forces are decreasing on increasing the concentration of 1-PrOH resulting in an increase in intermolecular free length and hence a decrease in ultrasonic velocity is expected. The increase in the value of inter-molecular free length with a decrease in ultrasonic speed supports the molecular interaction taking place between solute molecules in the system[4-5].The increasing trend in adiabatic compressibility β indicates that the medium is more and more easily compressed with increasing concentration of 1-PrOH. The degree of inter-molecular attraction parameter ($\alpha_i$) has also been evaluated to study the structural variation and the nature of interaction occurring in the system. The positive values of $\alpha_i$ over the entire concentration range (0.0 to 1.0) suggest strong molecular interaction between the participating molecules in the binary system[6]. From the measured values of refractive index ($n$) and density (ρ), molar volume ($V_m$), molar refraction ($R_m$), molecular radii $r$ and internal pressure ($P_{int}$) are determined from the standard formulae[9-15]. A close perusal of Table 3 indicates that refractive index $n$ and density ρ of each binary mixture decreases as the concentration of 1-PrOH increases, this trend is expected because of low packing density and open structure of 1 - PrOH in which the molecules are

Table 1 – Comparison of experimental and literature values of pure compounds at 313 K

| Parameters | 1-Propanol | | Benzonitrile | |
|---|---|---|---|---|
| | Experimental | Literature* | Experimental | Literature* |
| $U$ (m/s) | 1155.4 | 1155.6 [12]<br>1159.0[2]<br>1157.0 [1]<br>1155.0 [14] | 1360.3 | 1376.4 [3]<br>1398.7 [9] |
| ρ (kg/m$^3$) | 791.6 | 787.7 [12]<br>787.4 [1]<br>788.3 [2]<br>786.2 [15]<br>797.7 [17] | 990.92 | 988.1 [9]<br>991.9 [25] |
| $n$ | 1.3780 | 1.378 [15]<br>1.3781 [27]<br>1.378 [14]<br>1.3785 [24] | 1.5212 | 1.5211[25] |

***** superscript shows related references

Table 2 – Ultrasonic velocity $U$, adiabatic compressibility β, specific acoustic impedance $Z$, Rao's molar sound function $R$, molar compressibility $W$, intermolecular free length $L_f$ and degree of intermolecular interaction $\alpha_i$ for mole fraction of 1-PrOH in binary mixture (1-PrOH+BN)

| $X$ | $U$ (m/s) | β ($10^{-10}$) (Pa$^{-1}$) | $L_f$ ($10^{-10}$) (m) | $Z$ ($10^{-6}$) (kg$^3$·m$^{-2}$·s$^{-1}$) | $R$ (s$^{1/3}$·mol$^{-1}$) | $W$ (m$^3$·Pa$^{1/7}$·mol$^{-1}$) | $\alpha_i$ |
|---|---|---|---|---|---|---|---|
| 0.0000 | 1360.3 | 5.4538 | 0.4933 | 1.35 | 1.15 | 2.19 | 0.00 |
| 0.1323 | 1345.7 | 5.7056 | 0.5046 | 1.30 | 1.11 | 2.11 | 0.09 |
| 0.2554 | 1331.8 | 5.9577 | 0.5156 | 1.26 | 1.07 | 2.02 | 0.16 |
| 0.3703 | 1315.2 | 6.2427 | 0.5278 | 1.22 | 1.03 | 1.94 | 0.19 |
| 0.4777 | 1295.0 | 6.5812 | 0.5419 | 1.17 | 0.99 | 1.87 | 0.20 |
| 0.5784 | 1272.6 | 6.9603 | 0.5573 | 1.13 | 0.96 | 1.79 | 0.19 |
| 0.6730 | 1251.4 | 7.3547 | 0.5729 | 1.09 | 0.92 | 1.72 | 0.17 |
| 0.7620 | 1230.1 | 7.7840 | 0.5894 | 1.05 | 0.89 | 1.66 | 0.14 |
| 0.8459 | 1209.1 | 8.2469 | 0.6067 | 1.00 | 0.86 | 1.60 | 0.11 |
| 0.9251 | 1187.2 | 8.7543 | 0.6250 | 0.96 | 0.83 | 1.54 | 0.06 |
| 1.0000 | 1155.4 | 9.4625 | 0.6498 | 0.91 | 0.80 | 1.48 | 0.00 |

Table 3 – Refractive index ($n$), density (ρ), molar volume ($V_m$), molar refraction ($R_m$), molecular radii ($r$) and internal pressure ($P_{int}$) of mole fraction of 1-PrOH in binary mixtures (1-PrOH+BN)

| $X$ | $n$ | $P$ (kg/m$^3$) | $V_m$ (cm$^3$/mol) | $R_m$ (cm$^3$/mol) | $R$ (Å) | $P_{int}$ (N/m$^2$) |
|---|---|---|---|---|---|---|
| 0.0000 | 1.5212 | 990.92 | 104.065 | 31.70 | 2.3253 | 97.63 |
| 0.1323 | 1.5125 | 967.90 | 100.661 | 30.23 | 2.2888 | 99.57 |
| 0.2554 | 1.4990 | 946.32 | 97.359 | 28.59 | 2.2466 | 100.79 |
| 0.3703 | 1.4862 | 926.08 | 94.151 | 27.04 | 2.2053 | 102.15 |
| 0.4777 | 1.4720 | 906.02 | 91.134 | 25.52 | 2.1632 | 103.19 |
| 0.5784 | 1.4570 | 887.10 | 88.194 | 24.02 | 2.1199 | 104.13 |
| 0.6730 | 1.4410 | 868.25 | 85.423 | 22.56 | 2.0760 | 104.79 |
| 0.7620 | 1.4262 | 849.00 | 82.850 | 21.24 | 2.0347 | 105.51 |
| 0.8459 | 1.4120 | 829.50 | 80.447 | 20.02 | 1.9950 | 106.19 |
| 0.9251 | 1.3940 | 810.40 | 78.138 | 18.69 | 1.9499 | 106.16 |
| 1.0000 | 1.3780 | 791.59 | 75.923 | 17.50 | 1.9077 | 106.42 |

interlaced by self-associated H-bonds. Molar refraction ($R_m$) is a measure of volume occupied with an atom or molecule and depends on the refractive index which gives information about the presence of specific inter-molecular interactions in the binary mixture. It is noticed that the molar refraction ($R_m$) of the studied binary mixtures decreases as the molar volume ($V_m$) and refractive index ($n$). Molecular radii $r$ and internal pressure ($P_{int}$) of binary mixtures show opposite trends as the concentration of 1-PrOH increases in the mixtures. Variation of ultrasonic speed ($U$), density (ρ) and refractive index ($n$) of binary mixtures against mole fraction of 1-PrOH are graphically shown in Fig. 1. As the concentration 1-PrOH increases in the mixture, ultrasonic speed ($U$), density (ρ) and refractive index ($n$) of binary mixture decreases non-rectilinear due to the change in packing of participating molecules in the mixtures. The non-rectilinear variation suggests inter molecular interaction between participating molecules. Excess values are important rather than actual values of measurements for elucidate nature of molecular interactions between components of the liquid mixtures. The excess values $U^E$, $\beta^E$, $R^E$, $Z^E$, $w^E$, $L_f^E$, $n^E$, $V_m^E$, $R_m^E$ and $P_{int}^E$ are fitted by the method of least squares with all points weighed equally to the Redlich-Kister polynomial equation. The values of coefficients $A_0$, $A_1$, $A_2$, $A_3$ with standard deviation δ are listed in Table 4. A detailed observation of the graphical representation shows non-linear variations of excess values with mole fraction of 1-PrOH. This shows deviation from ideal behaviour and is indicative of structural variations after mixing.The sign (positive/negative) and magnitude depend on the

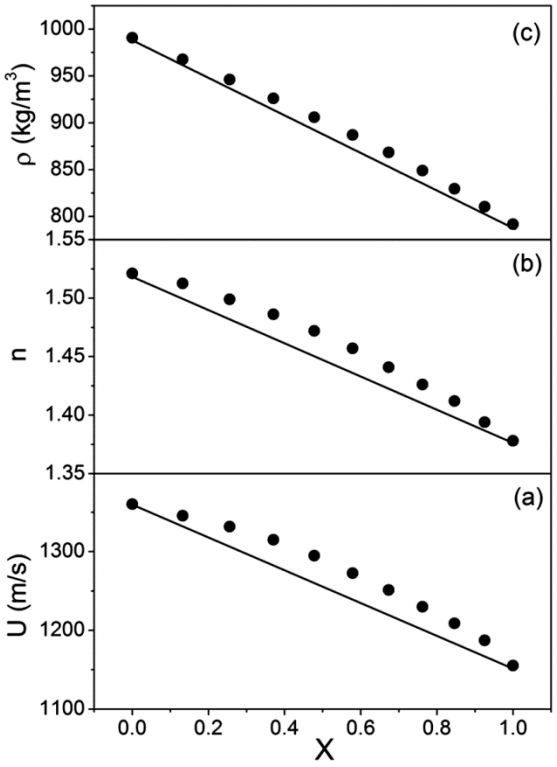


Fig. 1 – Variation of ultrasonic velocity ($U$), refractive index ($n$) and density (ρ) against mole fraction of 1-PrOH in binary mixtures. Solid geometrical shape (●) shows experimental points and solid line represents simple additive mixing behaviour, respectively

strength of hetero interaction between the molecular species in the mixtures. It is difficult to identify specifically which types of molecular interactions exist. A close perusal of Fig. 2(a, c, d, f) ($U^E$, $Z^E$, $R^E$ and $w^E$) shows positive deviation against mole fraction of 1-PrOH. Which indicate strong hetero

Table 4 – Values of coefficients ($A_0$, $A_1$, $A_2$, $A_3$) of Redlich-Kister polynomials with standard deviation (σ)

| | $A_0$ | $A_1$ | $A_2$ | $A_3$ | σ |
|---|---|---|---|---|---|
| $U^E$ | 127.78754 | -20.11653 | 31.05608 | 139.85925 | 0.718695 |
| $\beta^E$ | -3.16435 | -0.74420 | -0.84838 | -1.83969 | 0.012966 |
| $Z^E$ | 0.12976 | -0.00325 | 0.01879 | 0.10361 | 0.000542 |
| $R^E$ | 0.03931 | -0.02546 | 0.01016 | 0.04604 | 0.000261 |
| $W^E$ | 0.06685 | -0.04109 | 0.01573 | 0.07364 | 0.000412 |
| $L_f^E$ | -0.10459 | -0.01709 | -0.02417 | -0.06497 | 0.000416 |
| $n^E$ | 0.07513 | -0.00054 | 0.01714 | -0.00096 | 0.000719 |
| $R_m^E$ | 2.25447 | -0.92034 | 0.89033 | 0.14588 | 0.03465 |
| $V_m^E$ | 1.87004 | -1.53504 | 0.30214 | 1.17067 | 0.017082 |
| $P_{int}^E$ | 5.38679 | 1.49996 | 2.61903 | -1.36855 | 0.111048 |

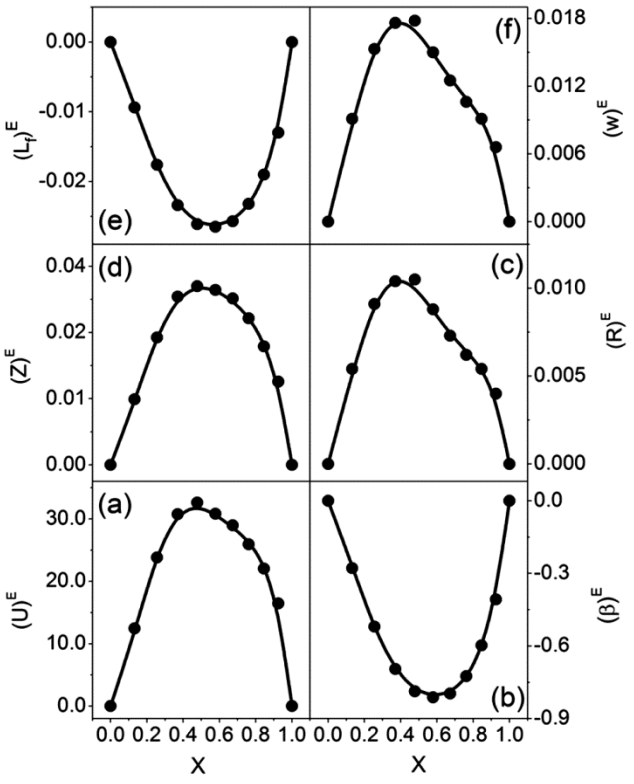


Fig. 2 – Variation of excess function $U^E$, $\beta^E$, $R^E$, $Z^E$, $L_f^E$ and $w^E$ against mole fraction of 1-PrOH in binary mixtures. Solid geometrical shape (●) shows excess experimental data points and solid lines represent Redlich- Kister fit

molecular interaction between solute molecules[6-12]. The positive deviation suggests significant specific interaction between molecular species. The nature of $\beta^E$ and $L_f^E$ (Fig. 2(b, e)) plays vital role in assessing the compactness due to molecular rearrangement. The negative deviation ($\beta^E$, $L_f^E$) suggests chemical/specific interaction which include charge transfer, hydrogen bond formation and other complex forming interactions in the binary mixtures. As can be seen from the Fig. 2(a-d) shows positive deviation over entire mole fraction range (0.0 to 1.0). The positive deviation of $n^E$ and $R_m^E$ (Fig. 3(a, b)) suggests significant specific interaction mainly due to dispersive forces between the molecular species. The positive deviation of $n^E$ suggests that mixture has slight higher optical permittivity than the ideal case at sodium-D line wavelength. The $R_m^E$ gives the strength of interaction in the mixture and is a sensitive function of wavelength, temperature and mixture composition. The deviation of $R_m^E$ represents the electronic perturbation due to orbital mixing of two components. A plausible explanation for the positive deviation of $R_m^E$ can be given as, the dipole moment of BN (3.98 D) is comparatively higher than the dipole moment[16,17] of 1-PrOH (1.68 D). Hence, mixing of BN with 1-PrOH tends to breaks the self-associates H-bonds present in the 1-PrOH and forms hetero H-bond between ($CN^{\delta-}$ ....$^{\delta+}HO$) unlike molecules. According to Fort and Moore[18], the excess molar volumes ($V_m^E$) is the resultant contribution from several opposing effects, namely, chemical, structural and physical. The chemical or specific and structural interactions result in volume contractions, leading to negative deviation to ($V_m^E$), and these include charge transfer, complex-forming interactions, interstitial accommodation and the geometrical fitting of one component into another due to the differences in the free volume and molar volume between components. The positive deviation of ($V_m^E$) indicates disruption of dipolar association present in the liquid components[19]. In the present study excess molar volume ($V_m^E$) shows positive deviation over the entire concentration range (Fig. 3(c)) which indicates disruption of dipolar association of 1-PrOH in the binary system. This also

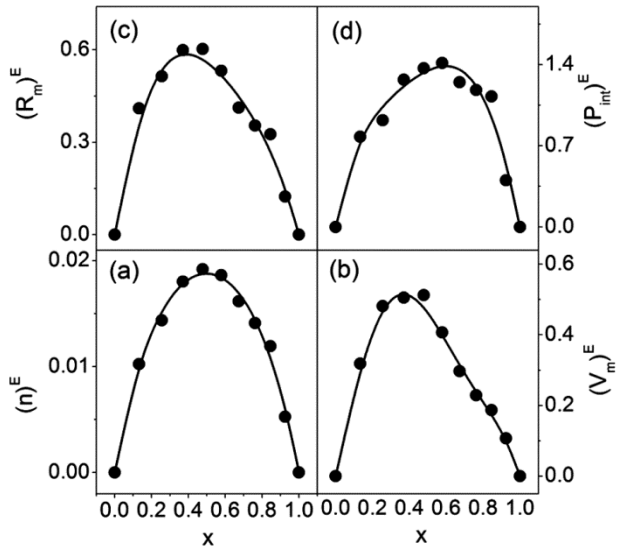


Fig. 3 – Variation of excess function $n^E$, $V_m^E$, $R_m^E$, $P_{int}^E$ against mole fraction of 1-PrOH in binary mixtures. Solid geometrical shape (●) shows excess experimental data points and solid lines represent Redlich-Kister fit

supports the explanation of positive deviation of $R_m^E$. From Fig. 3(d), the $(P_{int})^E$ values are positive over the entire concentration range which indicates that the attractive forces between the molecular species have predominant effect. Similar results have been also reported by Ali *et al*.[19] for binary mixtures of styrene with chlorobenzene, ethyl alcohol.

Since the binary mixtures are composed of constituents belonging to different classes of compounds, various molecular interactions are present. In that sense, the applicability of the most important mixing rules (suitable for predicting ultrasonic Speed and refractive index in various physical situations) to the binary mixtures under consideration has been tested.

The following relations are used for the prediction of ultrasonic speed (Eqs 1-5) and refractive index (Eqs 6-13) in the binary liquid mixtures[5,10-22,24,27]:

Nomoto's relation[5] ($U_N$):

$$U_N = \left[\frac{X_1R_1+X_2R_2}{X_1V_1+X_2V_2}\right]^3 \quad \ldots (1)$$

VanDael and Vangeel Ideal mixing relation[5] ($U_{V\text{-}V}$):

$$U_{V-V} = \left[\left(\frac{X_1}{M_1U_1^2}+\frac{X_2}{M_2U_2^2}\right)(X_1M_1+X_2M_2)\right]^{-\frac{1}{2}} \quad \ldots (2)$$

Rao's specific sound speed[5] ($U_R$):

$$U_R = \left[\left(\frac{X_1}{\rho_1}U_1^{\frac{1}{3}}+\frac{X_2}{\rho_2}U_2^{\frac{1}{3}}\right)\rho\right]^3 \quad \ldots (3)$$

Impedance dependent relation[5] ($U_{IM}$):

$$U_{IM} = \left[\frac{X_1Z_1+X_2Z_2}{X_1\rho_1+X_2\rho_2}\right] \quad \ldots (4)$$

Jungie's equation[14] ($U_J$):

$$U_J = \left[\frac{\frac{X_1M_1}{\rho_1}+\frac{X_2M_2}{\rho_2}}{\left(\frac{X_1M_1}{\rho_1^2U_1^2}+\frac{X_2M_2}{\rho_2^2U_2^2}\right)^{\frac{1}{2}}\left((X_1M_1+X_2M_2)^{\frac{1}{2}}\right)}\right] \quad \ldots (5)$$

Lorentz-Lorentz (L-L) equation[19]:

$$\frac{n^2-1}{n^2+2} = \left[\frac{n_1^2-1}{n_1^2+2}\right]\emptyset_1 + \left[\frac{n_2^2-1}{n_2^2+2}\right]\emptyset_2 \quad \ldots (6)$$

Weiner ($W$) relation[20]:

$$\frac{n^2-n_1^2}{n^2+2n_1^2} = \left[\frac{n_2^2-n_1^2}{n_2^2+2n_1^2}\right]\emptyset_2 \quad \ldots (7)$$

Gladstone – Dale (G-D) equation[21]:

$$n-1 = [n_1-1]\emptyset_1 + [n_2-1]\emptyset_2 \quad \ldots (8)$$

Arago – Biot (A-B) equation[22]:

$$n = n_1\emptyset_1 + n_2\emptyset_2 \quad \ldots (9)$$

Eykman (E) relation[24]:

$$\frac{n^2-1}{n+0.4} = \left[\frac{n_1^2-1}{n_1+0.4}\right]\emptyset_1 + \left[\frac{n_2^2-1}{n_2+0.4}\right]\emptyset_2 \quad \ldots (10)$$

Newton (N) relation[24]:

$$n^2-1 = [n_1^2-1]\emptyset_1 + [n_2^2-1]\emptyset_2 \quad \ldots (11)$$

Oster (Ost) relation[27]:

$$\frac{(n^2-1)(2n^2+1)}{n^2} = \left[\frac{(n_1^2-1)(2n_1^2+1)}{n_1^2}\right]\emptyset_1 + \left[\frac{(n_2^2-1)(2n_2^2+1)}{n_2^2}\right]\emptyset_2 \quad \ldots (12)$$

Eyring – John (E-J) relation[27]:

$$n = n_1\emptyset_1^2 + 2(n_1n_2)^{1/2}\emptyset_1\emptyset_2 + n_2\emptyset_2^2 \quad \ldots (13)$$

where $U$, $n$, ρ, $M$, $X$ and Φ are ultrasonic speed, refractive index, density, molecular weight, mole fraction and volume fraction respectively. Suffix 1 and 2 indicate 1-PrOH and BN, respectively. The root mean square deviation relative ($RMSD_r$) between an experimental and a theoretical values of the ultrasonic speed/refractive index was calculated using the relation:

$$RMSD_r = \left[\frac{1}{m}\sum\left(\frac{Q_{expt}-Q_{cal}}{Q_{expt}}\right)^2\right]^{1/2} \quad \ldots (14)$$

where $Q$ is the quantity and m is the number of data points.

The comparison between theoretical mixing relations and experimental values of ultrasonic speed and refractive index along with $RMSD_r$ are shown in Tables 5 and 6 respectively. The predictive abilities of various mixing relations for ultrasonic speed and refractive index depend upon the strength of interaction prevailing in a system. These relations generally fail to predict accurately when strong interactions are supposed to exist[13,19,23,24,27].

The experimental values of ultrasonic speed for the 1-PrOH + BN system along with theoretical values and root mean square deviation relative ($RMSD_r$) for Nomoto's Relation ($U_N$), Van Deal Vangeel ideal Mixing Relation ($U_{v\text{-}v}$), Rao's specific sound speed ($U_R$), impedance dependence relation ($U_{IM}$) and Junjie's relation ($U_J$) are shown in Table 5. The $RMSD_r$ values are in the sequence of $U_N<U_{IM}<U_J<U_R<U_{V\text{-}V}$.

The results indicate that the Nomoto's relation and Impedance dependence relation provide best fit results with minimum $RMSD_r$ value, whereas Van Deal Vangeel ideal mixing relationcould not predict ultrasonic speed well due to larger $RMSD_r$ value. The experimental values of refractive indexfor the 1-PrOH + BN system along with theoretical values and root mean square deviation relative ($RMSD_r$) for eight mixingrelations are shown Table 6. It is clear that, minimum $RMSD_r$ value observed for Oster's relation. The applicability of mixing relation with the measured values of refractive index increases in the sequence of $n_{Ost}<n_{Nw}<(n_{A\text{-}B}= n_{G\text{-}D}) <(n_W) <(n_{Eyk}) <(n_{E\text{-}J}) <(n_{L\text{-}L})$.

## 4 Conclusions

In this paper ultrasonic speed, refractive index and density of binary mixtures of 1-PrOH with BN have

Table 5 – Comparison of experimental values of ultrasonic speed (m/s) with theoretically calculated values of different mixing rules with RMSDr

| $U$ | $U_N$ | $U$v-v | $U_R$ | $U_{IM}$ | $U_J$ |
|---|---|---|---|---|---|
| 1360.3 | 1360.3 | 1360.3 | 1360.3 | 1360.3 | 1360.3 |
| 1345.7 | 1338.8 | 1287.0 | 1363.3 | 1338.0 | 1326.3 |
| 1331.8 | 1317.5 | 1237.7 | 1361.3 | 1316.2 | 1296.4 |
| 1315.2 | 1296.4 | 1203.7 | 1355.3 | 1294.8 | 1270.2 |
| 1295.0 | 1275.6 | 1180.5 | 1341.4 | 1273.8 | 1247.0 |
| 1272.6 | 1255.0 | 1164.9 | 1325.1 | 1253.2 | 1226.5 |
| 1251.4 | 1234.7 | 1155.3 | 1302.4 | 1232.9 | 1208.4 |
| 1230.1 | 1214.5 | 1150.3 | 1272.1 | 1213.0 | 1192.4 |
| 1209.1 | 1194.6 | 1149.0 | 1235.6 | 1193.5 | 1178.4 |
| 1187.2 | 1174.9 | 1150.9 | 1196.7 | 1174.3 | 1166.1 |
| 1155.4 | 1155.4 | 1155.4 | 1155.4 | 1155.4 | 1155.4 |
| $RMSD_r$ | 0.0111 | 0.0622 | 0.0269 | 0.0121 | 0.0267 |

Table 6 – Comparison of experimental values of refractive index with theoretically calculated values of different mixing rules with RMSDr

| $n$ | $n_{L\text{-}L}$ | $n_{A\text{-}B}$ | $n_{G\text{-}D}$ | $n_W$ | $n_{Nw}$ | $n_{Eyk}$ | $n_{Ost}$ | $n_{E\text{-}J}$ |
|---|---|---|---|---|---|---|---|---|
| 1.5212 | 1.5212 | 1.5212 | 1.5212 | 1.5212 | 1.5212 | 1.5212 | 1.5212 | 1.5212 |
| 1.5125 | 1.5014 | 1.5023 | 1.5023 | 1.5020 | 1.5030 | 1.5020 | 1.5027 | 1.5019 |
| 1.4989 | 1.4832 | 1.4846 | 1.4846 | 1.4843 | 1.4859 | 1.4842 | 1.4854 | 1.4840 |
| 1.4840 | 1.4664 | 1.4682 | 1.4682 | 1.4678 | 1.4698 | 1.4677 | 1.4692 | 1.4674 |
| 1.4723 | 1.4509 | 1.4528 | 1.4528 | 1.4524 | 1.4546 | 1.4523 | 1.4538 | 1.4519 |
| 1.4569 | 1.4366 | 1.4384 | 1.4384 | 1.4380 | 1.4401 | 1.4378 | 1.4394 | 1.4375 |
| 1.4410 | 1.4232 | 1.4248 | 1.4248 | 1.4245 | 1.4264 | 1.4243 | 1.4258 | 1.4241 |
| 1.4262 | 1.4108 | 1.4121 | 1.4121 | 1.4118 | 1.4134 | 1.4117 | 1.4128 | 1.4114 |
| 1.4150 | 1.3991 | 1.4001 | 1.4001 | 1.3999 | 1.4010 | 1.3998 | 1.4006 | 1.3996 |
| 1.3937 | 1.3882 | 1.3887 | 1.3887 | 1.3886 | 1.3892 | 1.3886 | 1.3890 | 1.3885 |
| 1.3780 | 1.3780 | 1.3780 | 1.3780 | 1.3780 | 1.3780 | 1.3780 | 1.3780 | 1.3780 |
| RMSDr | 0.01009 | 0.00922 | 0.00922 | 0.00943 | 0.00839 | 0.00948 | 0.00873 | 0.00964 |

been measured over the entire concentration range (0.0 to 1.0) at 313 K, and good accordance has been found between experimental and literature values. Various acoustic and refractometric parameters evaluated. Deviation of excess parameters indicates hetero molecular interaction through H-bond between hydroxyl group (OH) of 1-PrOH and cyanide group (CN) of BN. The applications of various mixing relations for ultrasonic speed and refractive index have been studied for binary mixtures of 1-PrOH with BN. It may be concluded that for the ultrasonic speed out of five theoretical mixing relations Nomoto's relation provides good results. Similarly, for the refractive index out of eight mixing relations Oster mixing relation provide best fit results with experimental values.

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**References**

1 Mehdi H, Hiray A P, Kadam U B, Shirude D F, Kurhe K J & Sawant A B, *J Sol Chem*, 40 (2011) 415.
2 Kadam U B, Hiray A P, Sawant A B & Mehdi H, *J Chem Eng Data*, 51 (2006) 60.
3 Madhuri N J, Naidu P S, Glory J & Prasad K R, *Eur J Chemistry*, 8 (2011) 457.
4 Nadh M L, Madhumohan T, Krishna T V & Kumar Ch R S, *Indian J Pure Appl Phys*, 51 (2013) 406.
5 Rama Rao G V, Sri S P B, Sharma A V & Rambabu C, *Indian J Pure Appl Phys*, 45 (2007) 135.
6 Dash A K & Paikaray R, *Phys Chem Liq*, 53 (2015) 230.
7 Sarangi A, Nath G & Swain S K, *Indian J Pure Appl Phys*, 52 (2012) 30.
8 Eyring H & Kincaid J F, *J Chem Phys*, 6 (1938) 620.
9 Palani R, Geetha A, Saravanan S & Durai T, *Mater Sci Res India*, 5 (2008) 403.
10 Elangovan S & Mullainathan S, *Indian J Phys*, 87 (2013) 659.
11 Elangovan S & Mullainathan S, *Russian J Phys Chem A*, 88 (2014) 2108.
12 Janardhanaiah M, Gangadhar S, Govinda V, Sreenivasulu K & Venkateswarlu P, *J Mol Liq*, 211 (2015) 169.
13 Rana V A & Chaube H A, *J Mol Liq*, 187 (2013) 66.
14 Misra A, Vibhu I, Singh R K, Gupta M & Shukla J P, *Phys Chem Liq*, 45 (2007) 93.
15 Gupta M, Vibhu I & Shukla J P, *Phys Chem of Liq*, 41 (2003) 575.
16 Prajapati A N, Rana V A & Vyas A D, *J Mol Liq*, 144 (2009) 1.
17 Prajapati A N, Rana V A, Vyas A D & Bhatanagar S P, *J Mol Liq*, 151 (2010) 12.
18 Fort A J & Moore W R, *Trans Faraday Soc*, 61(1965) 2102.
19 Ali A, Nabi F, Itoo F A & Tasneem S, *J Mol Liq*, 143 (2008) 141.
20 Sharma S, Bhalodia J, Ramani J & Patel R, *Phys Chem Liq*, 49 (2011) 765.
21 Mehra R, *Proc Indian Acad Sci (Chem Sci)*, 115 (2003) 147.
22 Prajapati A N, Rana V A, Vyas A D & Gadani D H, *J Int Acadm Phys Sci*, 16 (2012) 387.
23 Prajapati A N, Rana V A & Vyas A D, *Indian J Pure Appl Phys*, 51 (2013) 104.
24 Trivedi C M & Rana V A, *Indian J Pure Appl Phys*, 52 (2014) 183.
25 Shukla R K, Misra P, Sharma S, Tomar N & Jain P, *J Iran Chem Soc*, 9 (2012) 1033.
26 Redlich O & Kister T A, *Ind Eng Chem*, 40 (1984) 345.
27 Nain A K, *Phys Chem Liq*, 48 (2010) 41.