Study of intermolecular interaction of binary mixture of adrenaline and KOH

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Abstract

The Density and Ultrasonic Velocity of Adrenaline with KOH have been measured at different range of temperatures for different concentrations. Ultrasonic velocity and density values increases with increase in concentration. By using ultrasonic and volumetric data various parameters such as adiabatic compressibility, acoustic impedance, available volume, molar volume, intermolecular free length, Rao’s constant, Wada’s constant, Van Der Waal Constant, relative intensity and effective molecular weight have been calculated. With rise in temperature the interaction between the solute and solvent particles increases, which is confirmed by available volume and intermolecular free length. The non-linear variations in Rao’s constant, Wada’s constant, Van Der Waal Constant and other parameters suggest the presence of complex formation or charge transfer interaction or dipole-dipole interaction or dispersive forces or maybe all in the solution.

1. Introduction

Adrenaline, or epinephrine, is a stress hormone and a neurotransmitter secreted by the adrenal glands of the kidneys. It plays an important role in making the body prepared for a fight-or-flight reaction in case of a threat. Adrenaline binds to the receptors on heart, arteries, liver, pancreas
and muscle tissues. Adrenaline is used as a medication too. It is used to treat number of conditions like cardiac arrest, anaphylaxis, superficial bleeding, bringing the body out of shock, asthma and treatment of viral disease called croup disease. Direct study of Adrenaline is difficult, so ultrasonic study is carried out to study its nature. From past few decades many experiments and researches have been carried out to study interaction of molecules in their binary or tertiary mixtures with the help of Raman Effect, NMR (Nuclear Magnetic Resonance), Pulse Echo method, Ultrasonic method etc. These methods have been of great use as they have helped in investigating the interactions of molecules. With time they have seen many advancements and have revolutionized the development of the determining methods. Study on Ultrasonic parameters have become an incipient field in modern times. Aim of Ultrasonic study is to determine intermolecular interaction between solute and solvent. Various thermo-acoustic parameters are determined with the help of latter. Ultrasonic is a branch of Acoustics which deals with generation, propagation and use of inaudible ultrasound sound waves. Ultrasound waves are the sound waves with frequencies higher than 20 KHz. Ultrasound is same as normal audible sound waves in case of physical properties.

2. Material and Methods:

The aim of the paper is to understand the intermolecular interactions taking place in the binary mixture of Adrenaline (molecular weight 183.2 g/mol) dissolved in Potassium Hydroxide (KOH) (molecular weight 56.11 g/mol). Adrenaline used was of AR grade with 99.0% of purity of Loba Chemie. Experimental work is performed with different concentrations. Two stocks of Potassium hydroxide in distilled water, i.e. 1M and 3 M were prepared. In above two stocks Adrenaline was dissolved in different concentrations (0.05M, 0.06M, 0.07M, 0.08M, 0.09M, and 0.1M). These samples were subjected to experiment at four different temperatures (298.15, 303.15, 308.15, and 313.15 K) at constant frequency (2MHz) with the help of Ultrasonic Interferometer. Density was computed with help of 10ml specific gravity bottle. Various other thermo-acoustical parameters related to density and velocity of ultrasonic were calculated with help of experimental data. Distilled water has been the standard liquid for washing and other tasks throughout the experiment.
Binary mixture of Adrenaline and KOH was used for investigation of the intermolecular interactions. Adrenaline also known as Epinephrine having molecular weight 183.2 g/mol of AR grade with assay 99.0% and Potassium Hydroxide (KOH) having molecular weight 56.11 g/mol were used to prepare experimental samples.

For carrying out the experiment, Mittal Enterprises Ultrasonic Interferometer of frequency 2 MHz with 0.001mm least count, connected with water bath used. For carrying out density calculation specific bottle of 10ml.

3. Calculated parameters

3.1 Acoustics impedance:

The following equation is used to find the impedance in the liquid mixture

\[ Z = \rho \times c \]  \hspace{1cm} (1)

This is used for determining the acoustic reflection and transmission at the boundary of two materials having different acoustics impedances.

3.2 Adiabatic compressibility:

This is determined by density of medium and speed of sound using equations of Newton’s which were:

\[ \beta = \frac{1}{[\rho(c^2)]} \]  \hspace{1cm} (2)

3.3 Intermolecular free length:

The distances between surfaces of neighbouring molecules that is given by

\[ L_F = K_{\tau} \beta^{\frac{1}{2}} \]  \hspace{1cm} (3)

3.4 Wada’s constant:
It is the relation between adiabatic compressibility, effective mass and density of the mixture. Relation is as follow as follows

\[ W = \left( \beta \right)^{\frac{1}{3}} \left( \frac{M}{\rho} \right) \]  

(4)

3.5 Rao’s constant:
It is the simple relation between velocity of ultrasound and density of mixture and can be given as,

\[ R = \frac{\left[ \frac{c^3}{M} \right]}{\rho} \]  

(5)

Rao’s number gives an idea of how the nature of molecular interaction changes with concentration.

3.6 Vander Waal’s constant:
It is determined by using the relation

\[ b = \left( \frac{M}{\rho} \right) \left[ 1 - \frac{RT}{Mc^2} \right] \sqrt{1 + \frac{Mc^2}{3RT}} - 1 \]  

(6)

Where, \( R = \) Rao’s constant, \( M = \) Effective molecular weight, \( W = \) Wada’s constant (independent of temperature), \( \beta = \) Adiabatic compressibility, \( K_T = \) Temperature of dependent Jacobson’s constant, \( \rho = \) Density of mixture and \( c = \) Ultrasonic velocity in the medium

4. Results and discussion:
The binary mixture of Adrenaline and KOH is used to understand the intermolecular interactions. Experiment is done at four different temperatures (298.15, 303.15, 308.15, and 313.15K) at constant frequency of 2 MHz using twelve different concentrations of binary mixture. Two stocks of 1M and 3M KOH were prepared. In above two stocks Adrenaline was dissolved in different concentrations (0.05M, 0.06M, 0.07M, 0.08M, 0.09M, and 0.1M).

Values of different parameters namely ultrasonic velocity (U), density (\( \rho \)), acoustic impedance (Z), adiabatic compressibility (\( \beta \)), Intermolecular free length (L_f), effective molecular weight (Meff), Wada’s constant (W), Rao’s constant (R), molar volume(Vm), Van Der Waal constant (b), available volume (Va) and relative volume (Ri).
Table 1: Experimental values of Ultrasonic Velocity (U) and Density (ρ) at different Mole fraction of binary mixture of Adrenaline and 1M KOH

| Mole Fraction | 298.15K U (m/s) | 303.15K U (m/s) | 308.15K U (m/s) | 313.15K U (m/s) | 298.15K ρ (Kg/m³) | 303.15K ρ (Kg/m³) | 308.15K ρ (Kg/m³) | 313.15K ρ (Kg/m³) |
|---------------|----------------|----------------|----------------|----------------|------------------|------------------|------------------|------------------|
| X₁            | X₂             | 1575.00        | 1600.00        | 1635.00        | 1650.00          | 1002.93          | 1001.30          | 998.95           | 997.85           |
| 0.04762       | 0.95238        | 1550.00        | 1580.00        | 1615.00        | 1630.00          | 994.32           | 991.87           | 989.92           | 987.93           |
| 0.05660       | 0.94340        | 1568.00        | 1600.00        | 1630.00        | 1645.00          | 1022.44          | 1020.03          | 1017.00          | 1013.87          |
| 0.06542       | 0.93458        | 1590.00        | 1615.71        | 1645.00        | 1660.00          | 1044.07          | 1032.518         | 1024.46          | 1020.65          |
| 0.07407       | 0.92593        | 1569.00        | 1599.71        | 1625.00        | 1640.00          | 1020.36          | 1010.399         | 992.52           | 984.58           |
| 0.08256       | 0.91744        | 1575.00        | 1605.00        | 1630.00        | 1647.00          | 1029.46          | 1016.759         | 1006.29          | 1002.14          |
| 0.09090       | 0.90910        |                |                |                |                  |                  |                  |                  |                  |

Figure 1. Graph plotted between Ultrasonic Velocity and Mole Fraction for binary mixture of Adrenaline in 1M KOH. The graph obtained is nonlinear.

Figure 2. Graph plotted between Density and Mole Fraction for binary mixture of Adrenaline in 1M KOH. The graph obtained is nonlinear.

Ultrasonic velocity is the speed with which sound propagates in a material. Material density and elasticity effects the ultrasonic velocity. From Table 1 it is seen that there is change in ultrasonic velocity with concentration and moreover, ultrasonic velocity is increasing with temperature. From Table 1 and 2, it is also seen that Ultrasonic velocity in case of 1M KOH is lower than in case of 3M KOH. Figure 1 shows a nonlinear trend of ultrasonic velocity with increase in concentration of solute.
Density is an intensive property, as seen in Table 1, density is higher for 298.15 K and least for the 313.15 K. It can be noted that with increase in temperature bonds between the molecules of solute-solvent lengthens up and which results in overall decrease in density with increase in temperature. From Table 1 and 2 data, it is clear that for 1M KOH solvent density is lower than compared to 3M KOH which suggest that mass of the sample increases with increase in solvent concentration. The Non-linear trend as seen in Figure 2, suggest that there is some sort of interaction present between solute and solvent.

Table 2: Experimental values of Ultrasonic Velocity (U) and Density (ρ) at different Mole fraction of binary mixture of Adrenaline and 3M KOH

| Mole Fraction | 298.15 K U (m/s) | 303.15 K U (m/s) | 308.15 K U (m/s) | 313.15 K U (m/s) | 298.15 K ρ (Kg/m³) | 303.15 K ρ (Kg/m³) | 308.15 K ρ (Kg/m³) | 313.15 K ρ (Kg/m³) |
|--------------|-----------------|-----------------|-----------------|-----------------|-------------------|-------------------|-------------------|-------------------|
| X₁           | X₂              | 1610            | 1620            | 1640            | 1655              | 1065.30           | 1063.62           | 1061.72           | 1061.72           |
| 0.01639      | 0.98361         | 1600            | 1610            | 1621            | 1635              | 1053.20           | 1050.42           | 1047.53           | 1045.10           |
| 0.01961      | 0.98039         | 1635            | 1650            | 1665            | 1680              | 1092.28           | 1086.46           | 1081.05           | 1076.03           |
| 0.02280      | 0.97720         | 1660            | 1676            | 1690            | 1705              | 1124.03           | 1114.30           | 1106.67           | 1096.53           |
| 0.02913      | 0.97087         | 1625            | 1635            | 1647            | 1660              | 1094.76           | 1089.07           | 1070.96           | 1058.59           |
| 0.03226      | 0.96774         | 1648            | 1660            | 1675            | 1683              | 1104.19           | 1099.72           | 1081.10           | 1071.26           |

Figure 3. Graph plotted between Ultrasonic Velocity and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is nonlinear.

Figure 4. Graph plotted between Density and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is nonlinear.
Table 3: Experimental values of **Acoustic Impedance (Z)** and **Adiabatic Compressibility (β)** at different **Mole fraction** of binary mixture of Adrenaline and 1M KOH

| Mole Fraction | 298.15K $Z \times 10^6$ (Kg m$^{-2}$s$^{-1}$) | 303.15K $Z \times 10^6$ (Kg m$^{-2}$s$^{-1}$) | 308.15K $Z \times 10^6$ (Kg m$^{-2}$s$^{-1}$) | 313.15K $Z \times 10^6$ (Kg m$^{-2}$s$^{-1}$) | 298.15K $β \times 10^{10}$ (N m$^{-2}$) | 303.15K $β \times 10^{10}$ (N m$^{-2}$) | 308.15K $β \times 10^{10}$ (N m$^{-2}$) | 313.15K $β \times 10^{10}$ (N m$^{-2}$) |
|---------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| $X_1$          | $X_2$                           | $X_1$                           | $X_2$                           | $X_1$                           | $X_2$                           | $X_1$                           | $X_2$                           | $X_1$                           | $X_2$                           |
| 0.04762        | 0.95238                         | 1.58                            | 1.60                            | 1.63                            | 1.65                            | 4.01944                         | 3.90118                         | 3.74472                         | 3.68101                         |
| 0.05660        | 0.94340                         | 1.54                            | 1.57                            | 1.60                            | 1.61                            | 4.18609                         | 4.03860                         | 3.87304                         | 3.80977                         |
| 0.06542        | 0.93458                         | 1.60                            | 1.63                            | 1.66                            | 1.67                            | 3.97805                         | 3.82954                         | 3.70085                         | 3.64488                         |
| 0.07407        | 0.92593                         | 1.66                            | 1.67                            | 1.69                            | 1.69                            | 3.78857                         | 3.71001                         | 3.60722                         | 3.55553                         |
| 0.08256        | 0.91744                         | 1.60                            | 1.62                            | 1.61                            | 1.61                            | 3.98105                         | 3.86745                         | 3.81552                         | 3.77625                         |
| 0.09090        | 0.90910                         | 1.62                            | 1.63                            | 1.64                            | 1.65                            | 3.91587                         | 3.81796                         | 3.74026                         | 3.67862                         |

**Figure 5.** Graph plotted between **Acoustic Impedance** and **Mole Fraction** for binary mixture of Adrenaline in 1M KOH. The graph obtained is nonlinear.

**Figure 6.** Graph plotted between **Adiabatic Compressibility** and **Mole Fraction** for binary mixture of Adrenaline in 1M KOH. The graph obtained is nonlinear.

Acoustic Impedance is the opposition to acoustic flow and is proportional to density and Ultrasonic velocity. From Table 3 and 1 values, it is clear that due to less density of 1M KOH and Adrenaline solution its acoustic impedance is lower than that of 3M KOH + Adrenaline solution. Figure 5, shows nonlinear trend which was expected due to nonlinear graphs obtained for density and ultrasonic velocity. Non-Linear trend may be due to presence of complex.

From Table 3, change in adiabatic compressibility with concentration suggests that there is existence of interaction between solute and solvent. Variation in adiabatic compressibility is
surely due to contraction of molecules with change in concentration. Non-linear graph for adiabatic compressibility as seen in Figure 6, may be due to charge-charge transfer or hydrogen bonding or dipole-dipole interaction or complex formation or may be all.

Table 4: Experimental values of Acoustic Impedance (Z) and Adiabatic Compressibility (β) at different Mole fraction of binary mixture of Adrenaline and 3M KOH at four different temperatures (298.15, 303.15, 308.15 and 313.15K) at constant frequency of 2 MHz.

| Mole Fraction | 298.15 K Z*10^6 (Kg m^2 s^-1) | 303.15 K Z*10^6 (Kg m^2 s^-1) | 308.15 K Z*10^6 (Kg m^2 s^-1) | 313.15 K Z*10^6 (Kg m^2 s^-1) | 298.15 K β*10^-10 (N m^-2) | 303.15 K β*10^-10 (N m^-2) | 308.15 K β*10^-10 (N m^-2) | 313.15 K β*10^-10 (N m^-2) |
|---------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| X_1 | X_2 | 1.72 | 1.72 | 1.74 | 1.76 | 3.62138 | 3.58246 | 3.50189 | 3.44123 |
| 0.01639 | 0.98361 |
| 0.01961 | 0.98039 |
| 0.02280 | 0.97720 |
| 0.02597 | 0.97403 |
| 0.02913 | 0.97087 |
| 0.03226 | 0.96774 |

Figure 7. Graph plotted between Adiabatic Impedance and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is nonlinear.

Figure 8. Graph plotted between Adiabatic Compressibility and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is nonlinear.
As seen in Table 4, Acoustic Impedance is higher for this system (3M KOH + Adrenaline) due to higher experimental values of density and Ultrasonic velocity in this system. Figure 7. Shows similar graph as one in the Figure 5. Trend of acoustic impedance is similar for both the systems.

From Table 4, it is seen that values for adiabatic compressibility is lower in 3M KOH + Adrenaline system than that of 1M KOH + Adrenaline system (Table 3). Trend is similar for both the system as seen in Figure 6 & 8.

**Table 5:** Experimental values of Inter Molecular free length ($L_f$) and Effective molecular weight ($M_{eff}$) at different Mole fraction of binary mixture of Adrenaline and 1M KOH at four different temperatures (298.15, 303.15, 308.15 and 313.15K) at constant frequency of 2 MHz.

| Mole Fraction | 298.15K $L_f$ (m) | 303.15 K $L_f$ (m) | 308.15K $L_f$ (m) | 313.15 K $L_f$ (m) | 298.15K $M_{eff}$ (g/mol) | 303.15K $M_{eff}$ (g/mol) | 308.15K $M_{eff}$ (g/mol) | 313.15K $M_{eff}$ (g/mol) |
|---------------|------------------|------------------|------------------|------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| $X_1$         | $X_2$            | 3.96E-11         | 3.90E-11         | 3.82E-11         | 3.79E-11                  | 62.16                    | 62.16                    | 62.16                    |
| 0.04762       | 0.95238          | 4.04E-11         | 3.97E-11         | 3.88E-11         | 3.85E-11                  | 63.30                    | 63.30                    | 63.30                    |
| 0.05660       | 0.94340          | 3.94E-11         | 3.86E-11         | 3.80E-11         | 3.77E-11                  | 64.42                    | 64.42                    | 64.42                    |
| 0.06542       | 0.93458          | 3.84E-11         | 3.80E-11         | 3.75E-11         | 3.72E-11                  | 65.52                    | 65.52                    | 65.52                    |
| 0.07407       | 0.92593          | 3.94E-11         | 3.88E-11         | 3.85E-11         | 3.83E-11                  | 66.60                    | 66.60                    | 66.60                    |
| 0.08256       | 0.91744          | 3.91E-11         | 3.86E-11         | 3.82E-11         | 3.79E-11                  | 67.66                    | 67.66                    | 67.66                    |
| 0.09090       | 0.90910          | 3.84E-11         | 3.80E-11         | 3.75E-11         | 3.72E-11                  | 66.60                    | 66.60                    | 66.60                    |

From Table 5 values, it is clear that intermolecular free length is decreasing with increase in concentration. This clearly suggests that Adrenaline interacts strongly with KOH. Figure 9 shows graph is non-linear with a decreasing trend which tells that intermolecular free length is decreasing as the mole fraction of Adrenaline is increasing in the solution and molecules are closer. Moreover, intermolecular free length is highest at 298.15 K and lowest for 313.15 K suggesting decrease in free length at higher temperatures.

**Figure 9.** Graph plotted between Intermolecular free length and Mole Fraction for binary mixture of Adrenaline in 1M KOH. The graph obtained is nonlinear.
Table 6: Experimental values of Inter Molecular free length ($L_f$) and Effective molecular weight ($M_{eff}$) at different Mole fraction of binary mixture of Adrenaline and 3M KOH at four different temperatures (298.15, 303.15, 308.15 and 313.15K) at constant frequency of 2 MHz.

| Mole Fraction | 298.15 K $L_f$ (m) | 303.15 K $L_f$ (m) | 308.15 K $L_f$ (m) | 313.15 K $L_f$ (m) | 298.15 K $M_{eff}$ (g/mol) | 303.15 K $M_{eff}$ (g/mol) | 308.15 K $M_{eff}$ (g/mol) | 313.15 K $M_{eff}$ (g/mol) |
|---------------|--------------------|--------------------|--------------------|--------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| $X_1$ | $X_2$ | 3.76E-11 | 3.74E-11 | 3.69E-11 | 3.66E-11 | 58.19 | 58.19 | 58.19 | 58.19 |
| 0.01639 | 0.98361 | 3.80E-11 | 3.78E-11 | 3.76E-11 | 3.73E-11 | 58.60 | 58.60 | 58.60 | 58.60 |
| 0.01961 | 0.98039 | 3.65E-11 | 3.63E-11 | 3.60E-11 | 3.58E-11 | 59.00 | 59.00 | 59.00 | 59.00 |
| 0.02280 | 0.97720 | 3.55E-11 | 3.53E-11 | 3.51E-11 | 3.49E-11 | 59.41 | 59.41 | 59.41 | 59.41 |
| 0.02597 | 0.97403 | 3.67E-11 | 3.66E-11 | 3.66E-11 | 3.65E-11 | 59.71 | 59.81 | 59.81 | 59.81 |
| 0.02913 | 0.97087 | 3.60E-11 | 3.58E-11 | 3.58E-11 | 3.58E-11 | 60.21 | 60.21 | 60.21 | 60.21 |

Figure 10. Graph plotted between Inter molecular free length and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is nonlinear.

From Table 6, Intermolecular free length is lower in 3M KOH + Adrenaline system than as compared to the other system which suggests that as the mole fraction of KOH increases interaction of Adrenaline with it also increases. As intermolecular length is decreasing molecules are coming closer and forming stronger bond. Figure 11, shows similar nonlinear trend as seen in figure 9.
**Table 7:** Experimental values of **Molar Volume** \( (V_m) \) and **Wada’s Constant** \( (W) \) at different **Mole fraction** of binary mixture of Adrenaline and 1M KOH

| Mole Fraction | 298.15K \( V_m \) (m\(^3\)/mol) | 303.15K \( V_m \) (m\(^3\)/mol) | 308.15K \( V_m \) (m\(^3\)/mol) | 313.15K \( V_m \) (m\(^3\)/mol) | 298.15K \( W \) (m\(^3\)/mol) (Pa)\(^{1/7}\) | 303.15K \( W \) (m\(^3\)/mol) (Pa)\(^{1/7}\) | 308.15K \( W \) (m\(^3\)/mol) (Pa)\(^{1/7}\) | 313.15K \( W \) (m\(^3\)/mol) (Pa)\(^{1/7}\) |
|----------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| 0.04762        | 0.06198                       | 0.06208                       | 0.06222                       | 0.06229                       | 1.36306                     | 1.37112                     | 1.38240                     | 1.38733                     |
| 0.05660        | 0.06366                       | 0.06382                       | 0.06395                       | 0.06408                       | 1.39200                     | 1.40261                     | 1.41379                     | 1.41999                     |
| 0.06542        | 0.06301                       | 0.06316                       | 0.06335                       | 0.06354                       | 1.38777                     | 1.39863                     | 1.40965                     | 1.41709                     |
| 0.07407        | 0.06275                       | 0.06346                       | 0.06396                       | 0.06419                       | 1.39187                     | 1.41167                     | 1.42849                     | 1.43678                     |
| 0.08256        | 0.06527                       | 0.06591                       | 0.06710                       | 0.06765                       | 1.43745                     | 1.45764                     | 1.48677                     | 1.50098                     |
| 0.09090        | 0.06572                       | 0.06654                       | 0.06724                       | 0.06752                       | 1.45084                     | 1.47429                     | 1.49401                     | 1.50376                     |

Molar volume is the volume occupied by one mole of substance. From data of Table 7 it is clear that as the mole fraction of Adrenaline is increasing, the molar volume is increasing suggesting high interaction as concentration of Adrenaline increases. Molar volume is lowest at 298.15 K and highest for 303.15 K suggesting lengthening of bonds at higher temperatures. Non-linearity as seen in Figure 13 suggest hydrogen bonding or charge transfer or dipole-dipole interactions or dispersive forces or all of above.

From Table 7 it is clear that Wada constant is increasing with mole fraction of Adrenaline and is increasing with increase in temperature. Wada Constant is also known as molar compressibility and hence from data it can be confirmed that interaction between KOH and Adrenaline increases with increase in mole fraction of KOH + Adrenaline and temperature. Non-Linearity as seen in Figure 14 maybe due to complex formation or dispersive forces etc.
Table 8: Experimental values of Molar Volume ($V_m$) and Wada’s Constant ($W$) at different Mole fraction of binary mixture of Adrenaline and 3M KOH

| Mole Fraction | 298.15K $V_m$ (m$^3$/mol) | 303.15K $V_m$ (m$^3$/mol) | 308.15K $V_m$ (m$^3$/mol) | 313.15K $V_m$ (m$^3$/mol) | 298.15K $W$ (m$^3$/mol) (Pa)$^{1/7}$ | 303.15K $W$ (m$^3$/mol) (Pa)$^{1/7}$ | 308.15K $W$ (m$^3$/mol) (Pa)$^{1/7}$ | 313.15K $W$ (m$^3$/mol) (Pa)$^{1/7}$ |
|---------------|--------------------------|--------------------------|--------------------------|--------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| $X_1$         | $X_2$                    | $X_1$                    | $X_2$                    | $X_1$                    | $X_2$                         | $X_1$                         | $X_2$                         | $X_1$                         | $X_2$                         |
| 0.01639       | 0.98361                  | 0.05463                  | 0.05471                  | 0.05481                  | 0.05485                       | 1.21935                       | 1.22317                       | 1.22935                       | 1.23333                       |
| 0.01961       | 0.98039                  | 0.05564                  | 0.05579                  | 0.05594                  | 0.05607                       | 1.23780                       | 1.24281                       | 1.24818                       | 1.25374                       |
| 0.02280       | 0.97720                  | 0.05402                  | 0.05431                  | 0.05458                  | 0.05484                       | 1.21554                       | 1.22431                       | 1.23274                       | 1.24084                       |
| 0.02597       | 0.97403                  | 0.05285                  | 0.05332                  | 0.05368                  | 0.05418                       | 1.19933                       | 1.21162                       | 1.22168                       | 1.23447                       |
| 0.02913       | 0.97087                  | 0.05463                  | 0.05492                  | 0.05585                  | 0.05650                       | 1.22756                       | 1.23523                       | 1.25573                       | 1.27115                       |
| 0.03226       | 0.96774                  | 0.05453                  | 0.05475                  | 0.05569                  | 0.05621                       | 1.23162                       | 1.23847                       | 1.25996                       | 1.27161                       |

Figure 11. Graph plotted between Molar Volume and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is nonlinear.

Figure 12. Graph plotted between Wada Constant and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is linear.

From Table 8 it is seen that Molar Volume is lower for 3M KOH + Adrenaline system as compared to other (Table 7) which indicates that at higher mole fraction of KOH and Adrenaline, interaction is higher between Adrenaline and KOH. Temperature plays a role in deciding the interaction between KOH and Adrenaline. Figure 15 shows non-linear trend.

From Table 8, Wada constant is lower for 3M KOH and Adrenaline system than that of other system (Table 7) which indicates that increase in mole fraction of Adrenaline increases strong
interaction between solute and solvent. From Figure 16 it is seen that data follows a non-linear trend same as the previous system.

**Table 9:** Experimental values of Rao’s Constant (R) and Van Der Waal’s Constant (b) at different Mole fraction of binary mixture of Adrenaline and 1M KOH

| Mole Fraction | 298.15 K R (m³/mol) (m/s)¹/³ | 303.15 K R (m³/mol) (m/s)¹/³ | 308.15 K R (m³/mol) (m/s)¹/³ | 313.15 K R (m³/mol) (m/s)¹/³ | 298.15 K b (m³/mol) | 303.15 K b (m³/mol) | 308.15 K b (m³/mol) | 313.15 K b (m³/mol) |
|---------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------|-------------------|-------------------|-------------------|
| X₁ X₂         |                               |                               |                               |                               |                   |                   |                   |                   |
| 0.04762       | 0.95238                       | 0.72113                       | 0.72611                       | 0.73308                       | 0.73613           | 0.05165           | 0.05173           | 0.05186           | 0.05191           |
| 0.05660       | 0.94340                       | 0.73679                       | 0.74334                       | 0.75026                       | 0.75410           | 0.05305           | 0.05319           | 0.05329           | 0.05340           |
| 0.06542       | 0.93458                       | 0.73203                       | 0.73871                       | 0.74551                       | 0.75010           | 0.05251           | 0.05263           | 0.05279           | 0.05295           |
| 0.07407       | 0.92593                       | 0.73249                       | 0.74465                       | 0.75502                       | 0.76013           | 0.05230           | 0.05288           | 0.05330           | 0.05350           |
| 0.08256       | 0.91744                       | 0.75848                       | 0.77092                       | 0.78893                       | 0.79773           | 0.05439           | 0.05493           | 0.05592           | 0.05637           |
| 0.09090       | 0.90910                       | 0.76471                       | 0.77915                       | 0.79132                       | 0.79735           | 0.05477           | 0.05546           | 0.05603           | 0.05627           |

**Figure 13.** Graph plotted between Rao’s Constant and Mole Fraction for binary mixture of Adrenaline in 1M KOH. The graph obtained is nonlinear.

**Figure 14.** Graph plotted between Van der Waal’s Constant and Mole Fraction for binary mixture of Adrenaline in 1M KOH. The graph obtained is linear.

Rao’s constant is also known as Molar sound velocity. From Table 9 data and Figure 17, it is clear that Rao’s constant is increasing non-linearly. Increase in Rao’s constant with concentration suggest high levels of interactions between solute and solvent. Interaction between solute and solvent may vary from Hydrogen Bonding to dispersive forces.
There is non-linear trend in Van Der Waal’s constant with increase in concentration of Adrenaline as seen in Figure 18, suggesting high interaction as bigger molecules have more electrons to polarize and hence increasing the strength of interaction in solution. There may be charge transfer or dipole-dipole interaction or complex formation between solute and solvent. The non-linear trend may be due to change in intermolecular geometry. Table 9 showcase the values for Van Der Waal Constant.

**Table 10**: Experimental values of **Rao’s Constant (R)** and **Van Der Waal’s Constant (b)** at different **Mole fraction** of binary mixture of Adrenaline and 3M KOH at four different temperatures (298.15, 303.15, 308.15 and 313.15K) at constant frequency of 2 MHz.

| Mole Fraction | 298.15K R (m³/mol) (m/s)¹/³ | 303.15 K R (m³/mol) (m/s)¹/³ | 308.15K R (m³/mol) (m/s)¹/³ | 313.15 K R (m³/mol) (m/s)¹/³ | 298.15K b (m³/mol) | 303.15K b (m³/mol) | 308.15K b (m³/mol) | 313.15K b (m³/mol) |
|---------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|----------------|----------------|----------------|----------------|
| X₁            | X₂                          |                             |                             |                             |                 |                 |                 |                 |
| 0.01639       | 0.98361                     | 0.64023                     | 0.64257                     | 0.64636                     | 0.64880         | 0.04552         | 0.04559         | 0.04568         | 0.04571         |
| 0.01961       | 0.98039                     | 0.65079                     | 0.65386                     | 0.65716                     | 0.66058         | 0.04637         | 0.04649         | 0.04662         | 0.04673         |
| 0.02280       | 0.97720                     | 0.63642                     | 0.64178                     | 0.64694                     | 0.65190         | 0.04502         | 0.04526         | 0.04549         | 0.04570         |
| 0.02597       | 0.97403                     | 0.62583                     | 0.63331                     | 0.63945                     | 0.64726         | 0.04405         | 0.04443         | 0.04474         | 0.04515         |
| 0.02913       | 0.97087                     | 0.64232                     | 0.64700                     | 0.65955                     | 0.66900         | 0.04553         | 0.04577         | 0.04654         | 0.04709         |
| 0.03226       | 0.96774                     | 0.64409                     | 0.64827                     | 0.66141                     | 0.66855         | 0.04544         | 0.04563         | 0.04641         | 0.04684         |

As seen in Table 18, for 3M KOH + Adrenaline system Rao’s constant is lower as compared to its counterpart which strongly suggests that interactions are higher when concentration of solute is higher. So, as the mole fraction of solute is higher, interaction is also higher. Interaction may be due to dipole-dipole moment or charge transfer or complex formation.

Van Der Waal Constant values are little lower for 3M KOH + Adrenaline system as seen in Table 20. This may be due to less moles of solute in the system as compared to previous one. Moreover, Van Der Waal is co-volume, and similar non-linear trend (Figure 20) same as before is obtained suggesting complex formation or charge transfer interaction or dispersion forces.
Figure 15. Graph plotted between Rao’s Constant and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is nonlinear.

Figure 16. Graph plotted between Van Der Waal’s Constant and Mole Fraction for binary mixture of Adrenaline in 3M KOH. The graph obtained is linear.

Table 11: Experimental values of Relative Intensity (R<sub>i</sub>) and Available Volume (V<sub>a</sub>) at different Mole fraction of binary mixture of Adrenaline and 1M KOH at four different temperatures (298.15, 303.15, 308.15 and 313.15K) at constant frequency of 2 MHz.

| Mole Fraction | 298.15K | 303.15 K | 308.15K | 313.15 K | 298.15K | 303.15 K | 308.15K | 313.15K |
|---------------|---------|----------|---------|----------|---------|----------|---------|---------|
|               | R<sub>i</sub> | R<sub>i</sub> | R<sub>i</sub> | R<sub>i</sub> | V<sub>a</sub> (m<sup>3</sup>/mol) | V<sub>a</sub> (m<sup>3</sup>/mol) | V<sub>a</sub> (m<sup>3</sup>/mol) | V<sub>a</sub> (m<sup>3</sup>/mol) |
| X<sub>1</sub> | X<sub>2</sub> | 0.01563 | 0.00000 | -0.02188 | -0.03125 | 0.00097 | 0.00000 | -0.00136 | -0.00195 |
| 0.04762       | 0.95238  | 0.03125 | 0.01250 | -0.00938 | -0.01875 | 0.00199 | 0.00080 | -0.00060 | -0.00120 |
| 0.05660       | 0.94340  | 0.02000 | 0.00000 | -0.01875 | -0.03125 | 0.00126 | 0.00000 | -0.00119 | -0.00179 |
| 0.06542       | 0.93458  | 0.00625 | -0.00982 | -0.02817 | -0.03750 | 0.00039 | 0.00062 | -0.00180 | -0.00241 |
| 0.07407       | 0.92593  | 0.01938 | 0.00018 | -0.01563 | -0.02500 | 0.00126 | 0.00001 | -0.00105 | -0.00169 |
| 0.08256       | 0.91744  | 0.01563 | -0.00313 | -0.01875 | -0.02938 | 0.00103 | 0.00028 | -0.00126 | -0.00198 |
| 0.09090       | 0.90910  | 0.01563 | -0.00313 | -0.01875 | -0.02938 | 0.00103 | 0.00028 | -0.00126 | -0.00198 |
From Table 11 it is seen that Relative Intensity is decreasing with increase in temperature. It can be said that as the temperature rises the interaction of solute-solvent increase. A non-linear graph is obtained from experimental values (Figure 21) which may be due to complex formation in the molecules of the binary mixture.

Available Volume is free space for molecule to wander when it’s neighbour are fixed at their lattice positions. From Figure 22, it is seen that trend is non-linear which suggest very high level of interaction as many values obtained are negative (seen in Table 11), which strongly indicates that molecules of solute and solvent are very closely packed due to high level of interactions. Interactions are increasing with increase in temperature as available volume is decreasing with increase in temperature.

Table 12: Experimental values of Relative Intensity (Ri) and Available Volume (Va) at different Mole fraction of binary mixture of Adrenaline and 3M KOH

| Mole Fraction | 298.15K | 303.15 K | 308.15K | 313.15 K | 298.15K V$a$ (m$^3$/mol) | 303.15K V$a$ (m$^3$/mol) | 308.15K V$a$ (m$^3$/mol) | 313.15K V$a$ (m$^3$/mol) |
|---------------|---------|----------|---------|----------|------------------------|------------------------|------------------------|------------------------|
| $X_1$ | $X_2$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ |
| 0.01639 | 0.98361 | -0.00625 | -0.01250 | -0.02500 | -0.03438 | -0.00034 | -0.00068 | -0.00137 | -0.00189 |
| 0.01961 | 0.98039 | 0.00000 | -0.00625 | -0.01313 | -0.02188 | 0.00000 | -0.00035 | -0.00073 | -0.00123 |
| 0.02280 | 0.97720 | -0.02188 | -0.03125 | -0.04063 | -0.05000 | -0.00118 | -0.00170 | -0.00222 | -0.00274 |
| 0.02597 | 0.97403 | -0.03750 | -0.04750 | -0.05625 | -0.06563 | -0.00198 | -0.00253 | -0.00302 | -0.00356 |
| 0.02913 | 0.97087 | -0.01563 | -0.02188 | -0.02938 | -0.03750 | -0.00085 | -0.00120 | -0.00164 | -0.00212 |
| 0.03226 | 0.96774 | -0.03000 | -0.03750 | -0.04688 | -0.05188 | -0.00164 | -0.00205 | -0.00261 | -0.00292 |
Similar data as that of 1M KOH + Adrenaline system is seen in Table 12, as the temperature is rising, the relative intensity is also decreasing. This suggest that interactions are grow stronger with temperature. Trend of the graph (Figure 23) is similar to that of Figure 21 due to complex formation.

5. Conclusion:

Ultrasonic Investigation of binary mixture of KOH and Adrenaline suggest strong solute-solvent interactions among the molecules of solution. Data obtained from adiabatic compressibility, molar volume, available volume, intermolecular free length, Wada’s constant and Rao’s constant supports the fact that as the concentration of solute and solvent increased, interactions also increased. Temperature also played a crucial role in interaction of solute and solvent molecules. As the temperature increased the interaction between KOH and Adrenaline molecules also increased, which is backed by the data obtained for intermolecular free length. The non-linear graphs obtained for all parameters except for effective molecular mass suggest that there may be formation of complex or charge transfer interaction or dipole-dipole interactions or hydrogen bonding or dispersive forces of some sort or maybe all and intermolecular interactions don’t solely depend on geometrical structure of molecules.

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