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Ultrasonic Analysis of Sodium Thiosulfate in Water-Tetrahydrofuran Mixture Across Varying Temperatures

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Abstract

The research investigates the ultrasonic properties of sodium thiosulfate in a mixed solvent of water and tetrahydrofuran (10% w/w) across various temperatures (293 K, 298 K, 303 K, 308 K, and 313 K). Ultrasonic velocity measurements were performed to examine molecular interactions and the structural dynamics of the solution. Acoustic parameters, including adiabatic compressibility, acoustic impedance, and intermolecular free length, were extracted from the experimental data to elucidate the physicochemical properties of the system. Temperature fluctuations markedly affected ultrasonic velocity and resultant acoustic properties, indicating alterations in solute-solvent and solvent-solvent interactions. At reduced temperatures, the system exhibited an increased level of intermolecular association, due to hydrogen bonding and solvent structuring. With the rise in temperature, a gradual disruption in these interactions was noted, resulting in alterations in acoustic impedance and compressibility. The research emphasizes the function of tetrahydrofuran as a co-solvent in altering the characteristics of the water-solvent system. The findings indicate that the incorporation of tetrahydrofuran diminishes the rigidity of the solvent structure, thereby improving molecular dynamics. This analysis is essential for comprehending the solvation behavior of ionic compounds in mixed solvents, especially for use in industrial and pharmaceutical formulations. The results emphasize the significance of ultrasonic methods in elucidating molecular interactions and their temperature dependence, facilitating further investigation of intricate solvent systems and their prospective applications.

1. Introduction

Ultrasonic techniques have become effective instruments for examining the physicochemical properties of liquid systems, providing significant insights into molecular interactions, structural organization, and thermodynamic behavior. The examination of solute-solvent interactions in mixed solvent systems is essential for comprehending the behavior of electrolytes in various industrial and pharmaceutical applications. Sodium thiosulfate, a commonly utilized inorganic compound, demonstrates distinctive solvation properties in diverse solvent environments. Its applications encompass medical treatments, photography, water purification, and industrial processes, rendering it a significant topic for physicochemical analysis[1-8]. Water serves as a universal solvent due to its remarkable hydrogen bonding properties, whereas tetrahydrofuran (THF), a cyclic ether, is recognized for its capacity to dissolve both polar and non-polar substances. The amalgamation of these solvents offers a flexible medium for examining the dissolution and interaction of solutes like sodium thiosulfate. The presence of THF in water can modify the solvent structure and affect the overall molecular dynamics of the system. Examining the ultrasonic properties of sodium thiosulfate in a water-tetrahydrofuran (10% w/w) mixture at different temperatures (293 K, 298 K, 303 K, 308 K, and 313 K) can enhance comprehension of solute-solvent interactions, thermodynamic stability, and structural alterations [9-18]. Ultrasonic velocity measurements provide a non-destructive and highly sensitive method for analyzing molecular interaction mechanisms. Acoustic parameters such as adiabatic compressibility, acoustic impedance, and intermolecular free length provide critical insights into the strength and characteristics of molecular interactions within the solution. This study seeks to investigate the influence of temperature on the ultrasonic characteristics of sodium thiosulfate within the water-THF system, enhancing comprehension of solvation effects, alterations in solvent structure, and prospective applications across diverse scientific and industrial domains [19-27].

2. Method

Analytical-grade sodium thiosulfate was obtained and utilized without additional purification to maintain consistency in experimental outcomes. The solvents utilized in this study were high-purity distilled water and tetrahydrofuran (THF) (≥99%), procured from a HI Media chemical supplier. A binary solvent system was created by combining water and THF in a 10% (w/w) ratio. All solutions were meticulously prepared utilizing a precision digital balance to reduce experimental errors.

2.1. Solution Preparation

Aqueous solutions of sodium thiosulfate were formulated at varying concentrations by dissolving precisely measured quantities of the salt in a water-THF mixture. The solutions were agitated thoroughly at ambient temperature to attain complete dissolution and uniformity.

2.2. Ultrasonic Velocity Measurements

Ultrasonic velocity measurements were conducted utilizing an ultrasonic interferometer (frequency: 1 MHz), which offers high precision and accuracy in ascertaining sound velocity in liquid media. The device was calibrated with standard liquids prior to measurements [28-34]. The experimental apparatus included a thermostatically regulated water bath, sustaining the specified temperatures with an accuracy of ±0.1 K. Measurements were conducted at five distinct temperatures: 293 K, 298 K, 303 K, 308 K, and 313 K.

2.3. Density and Viscosity Measurements

The density was determined using a specific gravity bottle with about 25 ml capacity using a relative measurement method with an accuracy of + 0.01 gm-3. The densities of the solution at different concentrations and temperatures were also measured. The same readings were taken at least five times, and the difference between the two readings did not exceed + 0.02%.

$$\frac{d_1}{d_2} = \frac{W_3 - W_1}{W_2 - W_1}$$

Where, d1 = Density of required solution ,d2 = Density of conductivity water at a given temperature W3 = Weight of empty bottle + solvent of required wt%, W2 = Weight of empty bottle + conductivity water ,W1 = Weight of empty bottle

Ostwald's viscometer, which had a capacity of 10 ml, carried out a viscosity measurement. The viscometer is calibrated with fresh conductivity water in a water bath at the experimental temperature. The flow of time was measured by using a digital clock. The mixture's viscosity can be calculated by knowing the time of flow of the reference liquid.

$$\eta_2 = \eta_1 \left(\frac{t_2}{t_1}\right)\left(\frac{\rho_2}{\rho_1}\right)$$

Where η1 and η2 are the viscosity of water and solution, respectively, and t1 and t2 are the time of flow of water and solution, respectively.

3. Theory

Based on the measured ultrasonic velocity, density, and viscosity values, several acoustic parameters were calculated, including [35-46],

3.1. Adiabatic Compressibility (β)

When there is no heat transfer into or out of the liquid, it is the fractional drop in volume per unit increase in pressure. This can be calculated from the speed of sound and density of the medium y using the equation:

$$\beta = \frac{1}{U^2 d}$$

where β = Adiabatic compressibility of solution, d= Density of solution, U = Ultrasonic velocity of solution

3.2. Intermolecular Free Length (Lf)

Intermolecular free length refers to the separation between the surfaces of adjacent molecules. Ultrasonic velocities rise, and intermolecular free lengths fall as concentration increases. It is given as:

$$L_f = K_T \sqrt{\beta}$$

where K_T= Temp. dependent cont.

3.3. Acoustic Impedance (Z)

Acoustic impedance is a measure of the opposition that a material presents to the propagation of sound waves through it.

$$Z = U\ d$$

3.4. Experimental Uncertainty

All measurements were performed in triplicate to guarantee reproducibility, and the experimental uncertainties remained within acceptable parameters.This systematic method facilitates a thorough assessment of the ultrasonic characteristics of sodium thiosulfate in the mixed solvent system across different thermal conditions. Table 1 shows Density (d), viscosity (□) and velocity(U) of Sodium Thiosulfate in Water-Tetrahydrofuran. Table 2 shows Values of Adiabatic Compressibility (β), Free Length (Lf), Acoustic Impedance (Z) of Sodium Thiosulfate in Water-Tetrahydrofuran

Table 1 **Density (d), viscosity (η) and velocity(U) of Sodium Thiosulfate in Water-Tetrahydrofuran**

Molality	**Temp.**	**d**	**η /10^3**	**U**
(mol/kg)	**(K)**	**(kg.m^{-3})**	**(N.s.m^{-2})**	**(ms^{-1})**
1.5	293	1000.9	1.299476	1530.09
	298	1000.3	1.141442	1542.44
	303	999.5	1.098762	1550.9
	308	998.8	0.975761	1561.95
	313	998.3	0.905402	1567.23
3.5	293	1001.5	1.344311	1546.33
	298	1000.8	1.189383	1560.35
	303	1000.3	1.138243	1566.25
	308	999.8	1.019002	1578.52
	313	999.5	0.946719	1585.84
5.5	293	1001.9	1.389346	1562.14
	298	1001.5	1.237504	1574.89
	303	1001.1	1.177544	1580.77
	308	1000.7	1.055157	1591.76
	313	1000.2	0.981457	1601.14
7.5	293	1002.5	1.434735	1577.89
	298	1002.1	1.261777	1589.67
	303	1001.6	1.224512	1596.88
	308	1001.1	1.098916	1606.32
	313	1000.8	1.022961	1614.31

Table 2 Values of Adiabatic Compressibility (β), Free Length (L_f), Acoustic Impedance (Z) of Sodium Thiosulfate in Water-Tetrahydrofuran

Molality	Temp.	$\beta \times 10^{-10}$	$L_f \times 10^{-11}$	$Z \times 10^{6}$
(mol/kg)	(K)	(m^2N^{-1})	(m)	($Kg\ m^{-2}s^{-1}$)
1.5	293	4.280	4.034	15.269
	298	4.213	4.037	15.387
	303	4.170	4.051	15.464
	308	4.115	4.060	15.560
	313	4.090	4.082	15.600
3.5	293	4.178	8.245	15.477
	298	4.115	8.189	15.575
	303	4.085	8.189	15.630
	308	4.025	8.144	15.739
	313	3.990	8.155	15.803
5.5	293	4.091	16.676	15.648
	298	4.036	16.453	15.732
	303	4.008	16.394	15.782
	308	3.956	16.200	15.879
	313	3.912	16.129	15.967
7.5	293	4.008	33.384	15.814
	298	3.959	32.736	15.890
	303	3.925	32.478	15.956
	308	3.882	31.917	16.037
	313	3.845	31.625	16.112

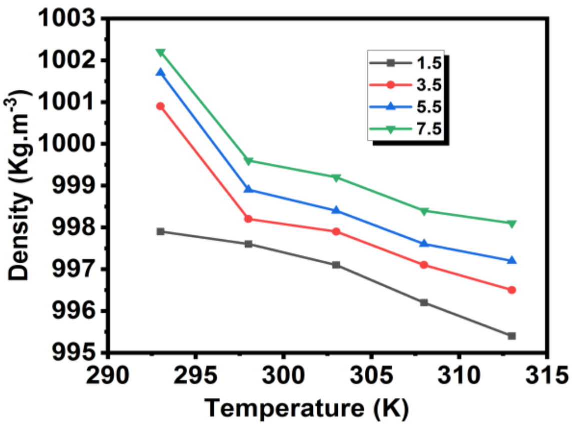

Figure 1 Variation of Density with Temperature

As the temperature rises, a progressive drop in density is seen (fig.1), demonstrating how temperature affects molecular packing. Because THF is less dense than water, its presence causes a non-linear trend in the density change. Higher temperatures may weaken hydrogen bonding or ion-dipole interactions, reducing structural organization and increasing molecular mobility, thereby decreasing density [47-55]. Figure 1 shows Variation of Density with Temperature.

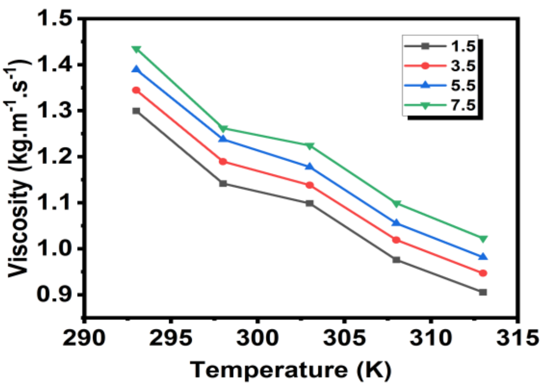

Figure 2 Variation of Viscosity with Temperature

A nonlinear decrease in viscosity is observed with increasing temperature (fig.2) due to the combined effects of solvent composition and molecular interactions. The reduction in viscosity is more pronounced at higher temperatures due to the disruption of structured solvent-solute networks. At a lower temperature Higher viscosity is the result of strong intermolecular interactions between sodium thiosulphate and water molecules. In contrast to pure aqueous solutions, the viscosity is decreased by the inclusion of THF, a less polar solvent. At a greater temperature Viscosity decreases as a result of increased fluidity and diminished molecular connections brought on by increased thermal motion. Temperature affects the overall viscosity behaviour by improving the solvent system's capacity to dissolve the solute. As temperature increases, molecular kinetic energy rises, reducing intermolecular forces such as hydrogen bonding and van der Waals interactions. This increased molecular motion facilitates easier flow, leading to a lower viscosity. At lower temperatures, solvent molecules interact more strongly with solute ions, leading to higher viscosity [56-63]. Figure 2 shows Variation of Viscosity with Temperature.

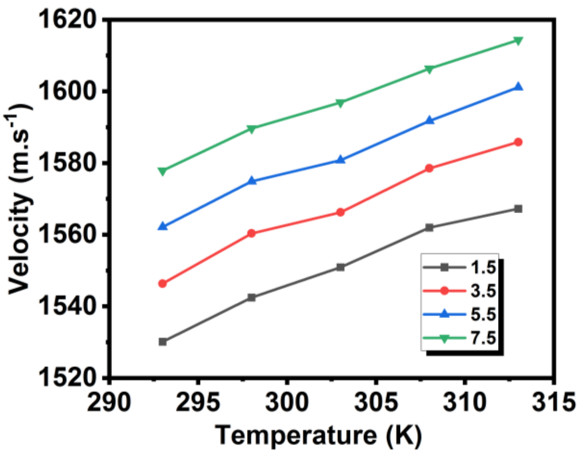

Figure 3 Variation of Ultrasonic Velocity with Temperature

Ultrasonic velocity measurements of sodium thiosulfate in a water-tetrahydrofuran (10% w/w) mixture at various temperatures (293 K, 298 K, 303 K, 308 K, and 313 K) demonstrated considerable fluctuations with temperature(fig.3). An elevation in ultrasonic velocity with increasing temperature indicates a reduction in molecular association and improved molecular mobility within the solvent system. This behavior results from the diminished hydrogen bonding interactions between water molecules and sodium thiosulfate ions, causing a decrease in structural rigidity [64-72]. Figure 3 shows Variation of Ultrasonic Velocity with Temperature.

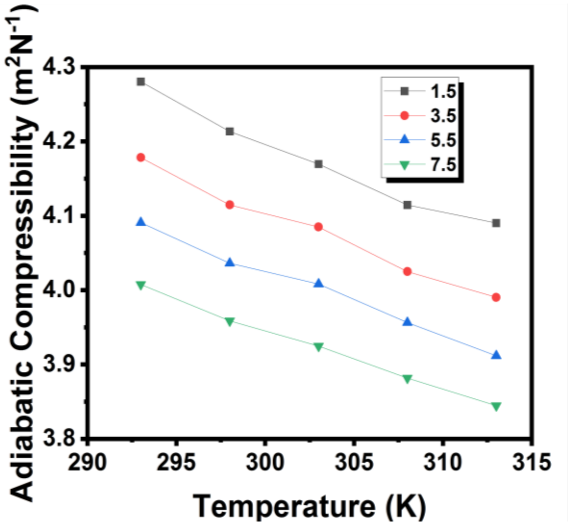

Figure 4 Variation of Adiabatic Compressibility with Temperature

The adiabatic compressibility values diminished with rising temperature(fig.4), signifying a more compact arrangement of molecules at higher temperatures. This reduction indicates that solvent molecules are tightly bound at lower temperatures; however, as temperature rises, the disintegration of the organized solvent network results in a more fluid state. The inclusion of tetrahydrofuran in the solvent mixture induces hydrophobic interactions, thereby influencing the compressibility values[72-79]. Figure 4 shows Variation of Adiabatic Compressibility with Temperature. Figure 5 shows Variation of Intermolecular Free with Temperature

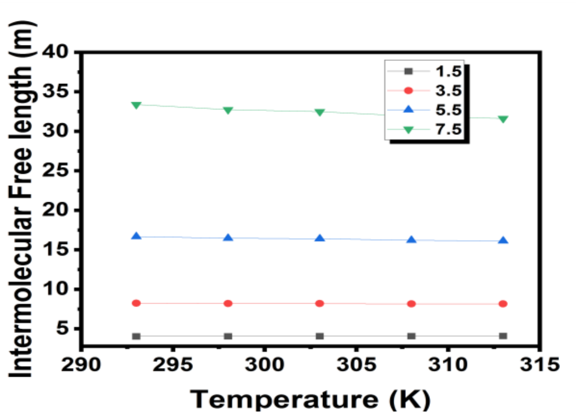

Figure 5 Variation of Intermolecular Free with Temperature

The intermolecular free length, a crucial measure of molecular spacing, exhibited a direct correlation with compressibility. As the temperature rose, a reduction in free length was noted, signifying increased molecular proximity at elevated temperatures. This can be ascribed to thermal expansion and decreased viscosity of the system, enhancing molecular accommodation [80-88]. Figure 6 shows Variation of Acoustic Impedance with Temperature.

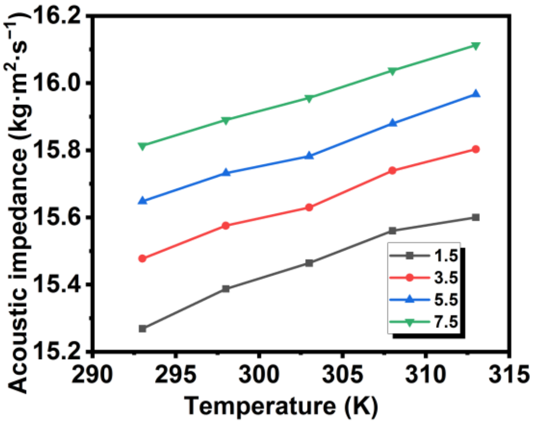

Figure 6 Variation of Acoustic Impedance with Temperature

The computed acoustic impedance values demonstrated a temperature-dependent rise(fig.6), correlating with the increase in ultrasonic velocity and density. This trend indicates increased resistance to sound propagation at elevated temperatures, suggesting enhanced molecular interactions despite diminished solvent structuring. The impedance values underscore the influence of temperature on the modulation of intermolecular forces within the solution [89-98].

Conclusion

This study examines the ultrasonic characteristics of sodium thiosulfate in a water-tetrahydrofuran (10% w/w) mixed solvent system at different temperatures (293 K, 298 K, 303 K, 308 K, and 313 K). The findings indicate that temperature significantly affects the molecular interactions and structural dynamics of the solution. The elevation of ultrasonic velocity with temperature indicates a diminishment in molecular association, resulting in improved solute-solvent interactions and diminished solvent structuring. The noted reduction in adiabatic compressibility and intermolecular free length with increasing temperature signifies denser molecular arrangement and diminished solvent rigidity. The rise in acoustic impedance indicates greater resistance to sound propagation at higher temperatures, denoting enhanced solute-solvent interactions in the mixed solvent milieu. Tetrahydrofuran's presence in the solvent mixture is pivotal in altering the solvent structure by diminishing hydrogen bonding in water, thus affecting the solvation behavior of sodium thiosulfate. The results offer significant insights into the influence of mixed solvents on electrolyte solutions, crucial for numerous industrial applications, such as pharmaceuticals, chemical processing, and materials science. In summary, ultrasonic methods have demonstrated efficacy in examining solute-solvent interactions and their temperature dependence. This study enhances the comprehension of the physicochemical properties of sodium thiosulfate in intricate solvent systems, facilitating future investigations into solvation dynamics across varying environmental conditions.

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