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Exploration of Diverse Interactions of Some Vitamins in Aqueous Mixtures of Cysteine

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Abstract. The apparent molar volume (ϕ_V), viscosity *B*-coefficient, molal refraction (R) and adiabatic compressibility (ϕ_K) of Nicotinic Acid, Ascorbic Acid, and Folic Acid have been determined in 0.01, 0.03, 0.05 mol·dm^{-3} aqueous Cysteine solutions at 298.15 K from density (ρ), viscosity (η), refractive index (n_D) and speed of sound (u) respectively. The limiting apparent molar volumes (ϕ_V^0) and experimental slopes (S_V^*), derived from the Masson equation, have been interpreted in terms of solute-solvent and solute-solute interactions respectively. The viscosity data were analyzed using the Jones-Dole equation and the derived parameters A and B have also been interpreted in terms of solute-solute and solute-solvent interactions respectively in the solutions. Using the Lorentz-Lorenz equation, molal refractions (R) have been calculated. At infinite dilution, limiting apparent molar adiabatic compressibilities (ϕ_K^0) of these vitamins were evaluated and discussed.
Key words: Apparent molar volume, solute-solvent interaction, solute-solute Interaction, cysteine, nicotinic acid, ascorbic acid, folic acid.

Resumen. Fueron determinados el volumen molar aparente (ϕ_V), el coeficiente B de viscosidad, la refracción molar (R) y la compresibilidad adiabática (ϕ_K) de los ácidos nicotínico, ascórbico y fólico en soluciones acuosas de 0.01, 0.03, 0.05 mol·dm^{-3} cisteína (298.15 K) a partir de los valores experimentales de densidad (ρ), viscosidad (η), índice de refracción (n_D) y (u), respectivamente. Los volúmenes molares aparentes límites (ϕ_V^0) y las pendientes experimentales (S_V^*), obtenidas con la ecuación de Masson, han sido asociados a las interacciones soluto-solvente y solvente-solvente, respectivamente. Los datos de viscosidad fueron analizados utilizando la ecuación de Jones-Dole y los parámetros A y B obtenidos de este análisis fueron también asociados con las interacciones soluto-solvente y solvente-solvente, respectivamente. Por otra parte, las refracciones molales (R) fueron calculadas con la ecuación de Lorentz-Lorenz. Los valores de compresibilidad molar límite aparente (ϕ_K^0) de estas vitaminas fueron obtenidos y discutidos.
Palabras clave: Apparent molar volume, solute-solvent interaction, solute-solute Interaction, cysteine, nicotinic acid, ascorbic acid, folic acid.

Introduction

A vitamin is an organic compound required by an organism as a vital nutrient in limited amounts. Vitamins are essential precursors for various coenzymes. These coenzymes are therefore required in almost all metabolic pathways [1]. Nicotinic Acid, commonly known as vitamin B3 [2], is a water-soluble vitamin, an essential micronutrient and a reactive moiety of the coenzyme nicotinamide adenine dinucleotide (NAD). Ascorbic acid, known as vitamin C is water soluble vitamin, required for the synthesis of collagen, the intercellular "cement" which gives the structure of muscles, vascular tissues, bones, and tendon. Vitamin C plays an important role for the synthesis of several important peptide hormones neurotransmitters and creatinine. It also enhances the eye's ability and delay the progression of advanced age related muscular degeneration [3]. Folic acid is water-soluble vitamin, known as vitamin B9 (folate). It is an essential vitamin that is yellow-orange in color, is reported to be present in photosensitive organs, various mammalian metabolic pathways, and possibly involved in photosynthesis [4]. Humans cannot synthesize folate inside body; therefore, folate has to be supplied through the diet to meet their daily requirements. Children and adults both require folic acid to produce healthy red blood cells and prevent anemia [5].

Cysteine is a semi-essential amino acid, which means that it can be bio-synthesized in human body [6] under normal physiological conditions if a sufficient quantity of methionine is available. Although classified as a non-essential amino acid, in rare cases, cysteine may be essential for infants, the elderly, and individuals with certain metabolic disease.

To interpret various interactions occurring in solutions, the volumetric, viscometric and interferometric behavior of solutes has been proved to be very useful. To obtain information on solute-solute, solute-solvent, and solvent-solvent interactions, studies on the effect of concentration (molality), the apparent molar volumes of solutes have been extensively used.

In view of the above and in continuation of our studies, we have undertaken a systematic study on the density, viscosity, refractive index and ultrasonic speed of some vitamins in aqueous cysteine solutions at 298.15 K and we have attempted to report the limiting apparent molar volume (ϕ_V^0), experimental slopes (S_V^*), viscosity *B*-coefficients, molar refraction (R) and limiting apparent molar adiabatic compressibility (ϕ_K^0) for the cited vitamins in aqueous cysteine solution. The nature and mode of the cysteine, interacting with the additionally input vitamins has also been discussed.

Experimental section

Source and purity of samples

The studied salts (Nicotinic acid, Ascorbic acid and Folic acid) and cysteine, puriss grade was purchased from Sigma-Aldrich, Germany and was used as purchased. The mass purity of salts were ≥0.99. The salts were dried from moisture at 353 K for 24

h, and then they were cooled and store in a desiccator prior to use. Triply distilled water with a specific conductance $<10^{-6}$ S cm^{-1} was used for the preparation of different aqueous cysteine solutions. The physical properties of different mass fraction of aqueous cysteine mixture are listed in Table 1.

Apparatus and Procedure

Aqueous binary solution of cysteine was prepared by mass (Mettler Toledo AG-285 with uncertainty ± 0.0003 g), which are used as solvent. Stock solutions of the salts (vitamins) were also prepared by mass and the working solutions were obtained by mass dilution. The conversion of molarity into molality was accomplished using experimental density values. All solutions were prepared afresh before use. The experimental values of densities (ρ), viscosities (η), refractive indices (n_D) and ultrasonic speeds (u) of solutions are reported in Table 2 and the derived parameters are reported in Table 3 and Table 4.

The densities of the solutions (ρ) were measured by means of vibrating-u-tube Anton Paar digital density meter (DMA 4500M) with a precision of ± 0.00005 g cm^{-3} maintained at ± 0.01 K of the desired temperature. It was calibrated by triply-distilled water and passing dry air.

The viscosities were measured using a Brookfield DV-III Ultra Programmable Rheometer with fitted spindle size-42. The viscosities were obtained using the following equation

$$\eta = (100/\text{RPM}) \times \text{TK} \times \text{torque} \times \text{SMC} \quad (1)$$

where RPM, TK (0.09373) and SMC (0.327) are the speed, viscometer torque constant and spindle multiplier constant, respectively. The instrument was calibrated against the standard viscosity samples supplied with the instrument, water and aqueous $CaCl_2$ solutions [7]. Temperature of the solution was maintained within ± 0.01 °C using Brookfield Digital TC-500 temperature thermostat bath. The viscosities were measured with an accuracy of ± 1.0% [viscosity of 0.01 molar aqueous $CaCl_2$ solution is 0.896 mPa s (at 25 °C), water is 0.890 mPa s (at 25 °C)]. Each measurement reported herein is an average of triplicate reading with a precision of 0.3%.

Refractive index was measured with the help of a Digital Refractometer Mettler Toledo (Refracto 30 GS). The light source was LED, λ = 589.3 nm. The refractometer was calibrated twice using tripply distilled water, benzene and dry air and calibration was checked after every few measurements. The uncertainty of refractive index measurement was ± 0.0002 units.

The ultrasonic speed (u) was measured by multi frequency ultrasonic interferometer (Model M-81) from Mittal Enterprises, India. The interferometer working at 5 MHz is based on the same principle as was used by Freyer et al. [8] and Kiyoharo et al. [9]. The obtained speeds were corrected for diffraction errors as given by Subrahmayan et al. [10]. The uncertainty in the speed is ±0.2 m s^{-1}. The temperature was controlled within ±0.01 K using a Lauda thermostat during the measurement.

Table 1. The values of Density (ρ), Viscosity (η), Refractive index (n_D), and Speed of sound (u) in different mass fraction of Cysteine at 298.15 K.

Mass-fraction Cysteine	$\rho \times 10^{-3}$ (kg m^{-3})	η (mPa s)	n_D	u (ms^{-1})
$w_1 = 0.01$	0.99752	0.81	1.3319	1499.8
$w_1 = 0.03$	0.99854	0.83	1.3326	1503.2
$w_1 = 0.05$	0.99951	0.86	1.3334	1506.7

Uncertainty of density measurement: ± 0.00005g cm^{-3}
Uncertainty of viscosity measurement: ± 0.02 mPa s
Uncertainty of refractive index measurement: ± 0.0002
Uncertainty of ultrasonic speed measurement: ± 0.2 m s^{-1}

Results and Discussions

Density measurement

Apparent molar volumes (ϕ_V) were determined from the solution densities using the equation 2 [11].

$$\phi_V = \text{M}/\rho \;\; 1000(\rho - \rho_0)/m\rho\rho_0 \quad (2)$$

where M(g mol^{-1}) is the molar mass of the solute, m(mol kg^{-1}) is the molality of the solution, ρ_0 (kg m^{-3}) and ρ (kg m^{-3}) are the densities of the mixture and the solution respectively. The plots of ϕ_V against square root of molal concentration ($\sqrt{m}$) were found to be linear. Using a least-square treatment to the plots of ϕ_V versus $\sqrt{m}$ using the Masson equation, equation 3 [12], the limiting apparent molar volume ϕ_V^0 was calculated.

$$\phi_V = \phi_V^0 + S_V^* \sqrt{m} \quad (3)$$

where ϕ_V^0 is the limiting apparent molar volume at infinite dilution and S_V^* is the experimental slope. Values of ϕ_V^0 and S_V^* are reported in Table 4.

A glance of Table 4 shows that ϕ_V^0 values for vitamins are positive and increase with increasing concentrations in aqueous cysteine mixture, indicating the presence of strong solute-solvent interactions and these interactions are further strengthened as increases the mass fraction of cysteine in the mixture. A probable interaction pattern is shown in scheme 1.

Interaction of vitamins with cysteine increases with increasing interacting centre of vitamins. The trend in the solute-solvent interaction is

Nicotinic Acid (NA) < Ascorbic Acid (AA) < Folic Acid (FA)

The S_V^* values of the vitamin solution given in Table 4 decreases with increase in the interactive centres of the studied vitamins and with increase in the mass fraction of cysteine in the solvent mixture rendering minimum solute-solute interaction.

The magnitude of ϕ_V^0 (Fig. 1) values is much greater than those of S_V^* for all studies vitamins as well as mass fraction of

Table 2. Experimental values of Densities (ρ), Viscosities (η), Refractive Index (n_D) and Ultrasonic Speed (u) of Nicotinic Acid, Ascorbic Acid and Folic Acid in different mass fraction of Cysteine at 298.15 K.

molality (mol kg^{-1})	ρ × 10^{-3} (kg m^{-3})	η (mPas)	n_D	u (m s^{-1})	molality (mol kg^{-1})	ρ × 10^{-3} (kg m^{-3})	η (mPas)	n_D	u (m s^{-1})
		w_1 = 0.01					w_1 = 0.03		
		Nicotinic Acid					Nicotinic Acid		
0.0100	0.99761	0.83	1.3322	1502.2	0.0100	0.99861	0.85	1.3329	1506.1
0.0251	0.99776	0.85	1.3327	1508.5	0.0251	0.99873	0.88	1.3334	1514.0
0.0403	0.99792	0.87	1.3331	1516.8	0.0402	0.99887	0.91	1.3338	1524.9
0.0555	0.99809	0.89	1.3335	1526.9	0.0554	0.99902	0.94	1.3342	1538.3
0.0707	0.99827	0.91	1.3338	1538.7	0.0707	0.99918	0.97	1.3345	1554.3
0.0860	0.99845	0.93	1.3341	1552.3	0.0860	0.99935	1.00	1.3348	1572.4
		Ascorbic Acid					Ascorbic Acid		
0.0100	0.99767	0.84	1.3322	1503.2	0.0100	0.99867	0.86	1.3331	1507.0
0.0252	0.99792	0.88	1.3328	1512.7	0.0251	0.9989	0.91	1.3338	1518.2
0.0404	0.99819	0.92	1.3333	1525.5	0.0403	0.99915	0.96	1.3344	1533.4
0.0556	0.99847	0.96	1.3337	1541.2	0.0556	0.99943	1.01	1.3349	1551.6
0.0710	0.99876	1.00	1.3341	1559.2	0.0709	0.99972	1.06	1.3354	1573.1
0.0864	0.99907	1.03	1.3344	1579.4	0.0863	1.00002	1.11	1.3358	1598.8
Folic Acid					Folic Acid				
0.0101	0.99773	0.86	1.3325	1504.2	0.0101	0.99873	0.87	1.3331	1507.7
0.0253	0.99808	0.92	1.3332	1516.5	0.0253	0.99906	0.93	1.3338	1520.6
0.0408	0.99846	0.98	1.3338	1533.4	0.0407	0.99942	0.99	1.3344	1539.2
0.0564	0.99887	1.04	1.3343	1554.4	0.0564	0.99981	1.05	1.3349	1561.9
0.0723	0.99929	1.10	1.3348	1578.8	0.0722	1.00022	1.12	1.3354	1590.7
0.0883	0.99973	1.16	1.3352	1607.3	0.0883	1.00066	1.18	1.3359	1622.4
w_1 = 0.05									
		Nicotinic Acid							
0.0100	0.99956	0.88	1.3337	1509.8					
0.0251	0.99966	0.92	1.3343	1518.9					
0.0402	0.99979	0.96	1.3347	1532.0					
0.0554	0.99994	1.00	1.3351	1547.8					
0.0706	1.0001	1.04	1.3355	1566.4					
0.0859	1.00028	1.08	1.3358	1588.5					
		Ascorbic Acid							
0.0100	0.99962	0.88	1.3338	1510.6					
0.0251	0.99983	0.93	1.3346	1522.3					
0.0403	1.00007	0.98	1.3352	1539.4					
0.0555	1.00033	1.03	1.3358	1561.0					
0.0708	1.00062	1.09	1.3363	1586.4					
0.0862	1.00093	1.14	1.3368	1614.7					
Folic Acid									
0.0100	0.99966	0.89	1.334	1511.4					
0.0253	0.99994	0.95	1.3349	1526.5					
0.0407	1.00027	1.02	1.3357	1547.8					
0.0563	1.00063	1.08	1.3363	1574.5					
0.0722	1.00103	1.15	1.3369	1605.3					
0.0882	1.00143	1.21	1.3375	1642.9					

Uncertainty of density measurement: ± 0.00005g cm^{-3}
Uncertainty of viscosity measurement: ± 0.02 mPa s
Uncertainty of refractive index measurement: ± 0.0002
Uncertainty of ultrasonic speed measurement: ± 0.2 m s^{-1}

Table 3. Molality, apparent molar volume (ϕ_V), $(\eta/\eta_0 - 1)/m^{1/2}$, molar refraction ($R$), adiabatic compressibility (β) and apparent molal adiabatic compressibility (ϕ_K) of Nicotinic Acid, Ascorbic Acid and Folic Acid in Cysteine at 298.15 K.

Molality (mol kg^{-1})	$\phi_V \times 10^6$ (m^3 mol^{-1})	$(\eta/\eta_0 - 1)/m^{1/2}$ (kg$^{1/2}$ mol$^{-1/2}$)	R (cm^3 mol^{-1})	$\beta \times 10^{10}$ (Pa^{-1})	$\phi_K \times 10^{10}$ (m^3 mol^{-1} Pa^{-1})
		$w_1 = 0.01$			
		Nicotinic Acid			
0.0100	114.39	0.25	25.33	4.44	−0.95
0.0251	113.79	0.31	25.36	4.40	−1.59
0.0403	113.39	0.37	25.38	4.35	−2.03
0.0555	113.02	0.42	25.41	4.30	−2.40
0.0707	112.67	0.46	25.42	4.23	−2.74
0.0860	112.45	0.51	25.44	4.16	−3.05
		Ascorbic Acid			
0.0100	161.52	0.37	36.23	4.43	−1.36
0.0252	160.52	0.54	36.28	4.38	−2.39
0.0404	159.77	0.68	36.32	4.30	−3.10
0.0556	159.24	0.79	36.35	4.21	−3.68
0.0710	158.80	0.88	36.38	4.12	−4.16
0.0864	158.28	0.93	36.40	4.01	−4.56
		Folic Acid			
0.0101	421.44	0.62	90.88	4.43	−0.83
0.0253	420.04	0.86	91.02	4.36	−2.16
0.0408	418.94	1.05	91.13	4.26	−3.13
0.0564	417.89	1.21	91.22	4.14	−3.94
0.0723	417.15	1.35	91.30	4.01	−4.60
0.0883	416.43	1.47	91.36	3.87	−5.22
		$w_1 = 0.03$			
		Nicotinic Acid			
0.0100	116.28	0.19	25.35	4.41	−1.22
0.0251	115.68	0.34	25.38	4.37	−2.05
0.0402	115.03	0.45	25.41	4.30	−2.67
0.0554	114.55	0.54	25.43	4.23	−3.18
0.0707	114.13	0.61	25.45	4.14	−3.65
0.0860	113.75	0.68	25.46	4.05	−4.05
		Ascorbic Acid			
0.0100	163.36	0.32	36.28	4.41	−1.57
0.0251	161.96	0.57	36.35	4.34	−2.84
0.0403	161.10	0.75	36.40	4.26	−3.69
0.0556	160.17	0.89	36.43	4.16	−4.33
0.0709	159.49	1.02	36.47	4.04	−4.90
0.0863	158.94	1.13	36.50	3.91	−5.46
		Folic Acid			
0.0101	423.02	0.42	90.93	4.40	−0.86
0.0253	421.21	0.72	91.08	4.33	−2.29
0.0407	420.01	0.93	91.19	4.22	−3.42
0.0564	418.92	1.10	91.28	4.10	−4.29
0.0722	418.01	1.29	91.37	3.95	−5.18
0.0883	417.07	1.41	91.45	3.80	−5.84

Table 3. Continúa.

Molality (mol kg^{-1})	$\phi_V \times 10^6$ (m^3 mol^{-1})	$(\eta/\eta_0 - 1)/m^{1/2}$ (kg$^{1/2}$ mol$^{-1/2}$)	R (cm^3 mol^{-1})	$\beta \times 10^{10}$ (Pa^{-1})	$\phi_K \times 10^{10}$ (m^3 mol^{-1} Pa^{-1})
		$w_1 = 0.05$			
		Nicotinic Acid			
0.0100	118.17	0.23	25.38	4.39	−1.31
0.0251	117.17	0.44	25.42	4.34	−2.34
0.0402	116.17	0.58	25.44	4.26	−3.14
0.0554	115.35	0.69	25.47	4.17	−3.74
0.0706	114.74	0.79	25.49	4.07	−4.26
0.0859	114.11	0.87	25.51	3.96	−4.77
		Ascorbic Acid			
0.0100	165.20	0.23	36.32	4.38	−1.60
0.0251	163.40	0.51	36.39	4.32	−2.94
0.0403	162.20	0.70	36.44	4.22	−4.00
0.0555	161.29	0.84	36.49	4.10	−4.86
0.0708	160.34	1.01	36.53	3.97	−5.57
0.0862	159.49	1.11	36.57	3.83	−6.12
		Folic Acid			
0.0100	426.61	0.35	91.07	4.38	−0.93
0.0253	424.41	0.66	91.27	4.29	−2.79
0.0407	422.61	0.93	91.44	4.17	−4.07
0.0563	421.24	1.09	91.55	4.03	−5.10
0.0722	419.89	1.27	91.66	3.88	−5.91
0.0882	419.02	1.39	91.77	3.70	−6.71

Uncertainty in molality: ± 0.0002 mol kg^{-1}

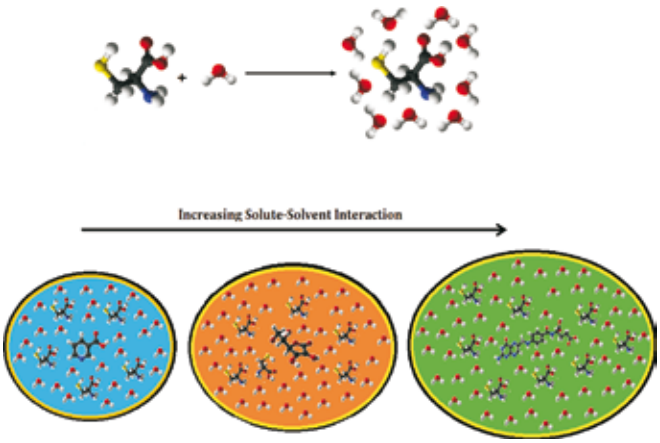
cysteine in the mixture suggests that solute-solvent interactions dominate over solute-solute interactions.

Viscosity measurement

The viscosity data has been analyzed using Jones-Dole equation, equation 4 [13].

$$(\eta/\eta_0 - 1)/m^{1/2} = A + Bm^{1/2} \quad (4)$$

where η_0 (mPa s) and η (mPa s) are the viscosities of the solvent and solution respectively, m(mol kg^{-1}) is the molality of the solution. A(kg mol^{-1}) and B(kg$^{1/2}$ mol$^{-1/2}$) are the viscos-



Scheme 1.

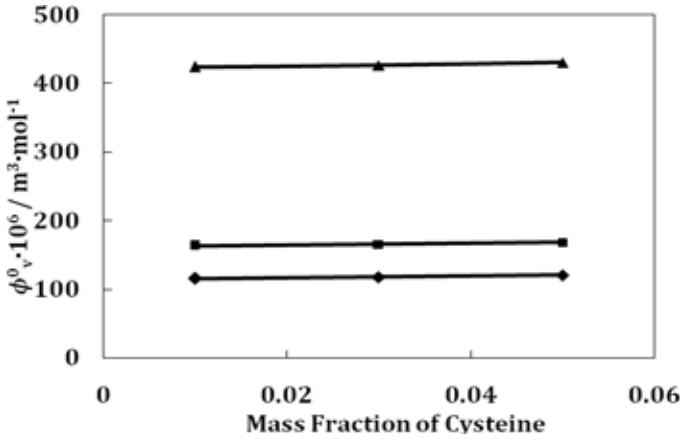


Fig. 1. The plots of limiting apparent molar volumes (ϕ_V^0) for Nicotinic Acid (—♦—), Ascorbic Acid (—■—), Folic Acid (—▲—) in different mass fractions (w_1) of Cysteine in aqueous mixture at 298.15 K.

Table 4. Limiting apparent molar volumes (ϕ_V^0), experimental slopes (S_V^*), A, B coefficients, limiting partial adiabatic compressibility (ϕ_K^0), and experimental slope (S_K^*) of Nicotinic Acid, Ascorbic Acid, and Folic Acid in aqueous Cysteine at 298.15 K.

Solute	$\phi_V^0 \times 10^6$ (m^3 mol^{-1})	$S_V^* \times 10^6$ (m^3 $mol^{-3/2}$ $kg^{1/2}$)	A (kg mol^{-1})	B ($kg^{1/2}$ $mol^{-1/2}$)	$\phi_K^0 \times 10^{10}$ (m^3 mol^{-1} Pa^{-1})	$S_K^* \times 10^4$ (m^3 $mol^{-3/2}$ Pa^{-1} $kg^{1/2}$)
			$w_1 = 0.01$			
Nicotinic Acid	115.40 ± 0.02	−10.16 ± 0.01	0.102 ± 0.02	1.363 ± 0.02	0.135 ± 0.01	−10.84 ± 0.02
Ascorbic Acid	163.1 ± 0.01	−16.54 ± 0.02	0.075 ± 0.03	2.984 ± 0.01	0.270 ± 0.01	−16.67 ± 0.02
Folic Acid	424 ± 0.03	−25.74 ± 0.02	0.158 ± 0.02	4.465 ± 0.02	1.444 ± 0.02	−22.77 ± 0.02
			$w_1 = 0.03$			
Nicotinic Acid	117.6 ± 0.03	−13.35 ± 0.02	−0.063 ± 0.02	2.552 ± 0.01	0.272 ± 0.02	−14.75 ± 0.02
Ascorbic Acid	165.6 ± 0.02	−22.95 ± 0.03	−0.098 ± 0.03	4.210 ± 0.02	0.379 ± 0.02	−20.04 ± 0.01
Folic Acid	426 ± 0.02	−29.97 ± 0.02	−0.093 ± 0.02	5.137 ± 0.02	1.778 ± 0.03	−25.99 ± 0.02
			$w_1 = 0.05$			
Nicotinic Acid	120.4 ± 0.01	−21.37 ± 0.02	−0.093 ± 0.02	3.331 ± 0.02	0.487 ± 0.01	−17.98 ± 0.02
Ascorbic Acid	168 ± 0.01	−29.15 ± 0.02	−0.220 ± 0.02	4.574 ± 0.03	0.789 ± 0.02	−23.83 ± 0.03
Folic Acid	430.5 ± 0.02	−39.25 ± 0.02	−0.192 ± 0.01	5.458 ± 0.02	1.980 ± 0.02	−29.87 ± 0.02

ity co-efficient estimated by a least-squares method and are reported in Table 4. The values of the A co-efficient are found to decrease with the increase in the mass fraction of cysteine in solvent mixture. The results indicate the presence of very weak solute-solute interactions. These results are in excellent agreement with those obtained from S_V^* values discussed earlier.

The effects of solute-solvent interactions on the solution viscosity can be inferred from the B-coefficient [14, 15]. The viscosity B-coefficient is a valuable tool to provide information concerning the solvation of the solutes and their effects on the structure of the solvent. From Table 4 and Fig. 2 it is evident that the values of the B-coefficient are positive, thereby suggesting the presence of strong solute-solvent interactions, and strengthened with increase of mass fraction of cysteine in the solvent mixture, are in agreement with the results obtained from ϕ_V^0 values discussed.

Refractive index measurement

The molar refraction, R can be evaluated from the Lorentz-Lorenz relation, equation 5 [16].

$$R = \{(n_D^2 - 1)/(n_D^2 + 2)\}(M/\rho) \quad (5)$$

where R (cm^3 mol^{-1}), n_D, M ($gm \cdot mol^{-1}$) and ρ (kg m^{-3}) are the molar refraction, the refractive index, the molar mass and the density of solution respectively. The refractive index of a substance is defined as the ratio c_0/c, where c is the speed of light in the medium and c_0 the speed of light in vacuum. Stated more simply, the refractive index of a compound describes its ability to refract light as it moves from one medium to another and thus, the higher the refractive index of a compound, the more the light is refracted [17], as stated by Deetlefs et al. [18].

The refractive index of a substance is higher when its molecules are more tightly packed or in general when the compound is denser and with the increase of mass fraction of cysteine in solvent mixture refractive index value also increases. Hence a perusal of Table 2 & Table 3 we found that the refractive index and the molar refraction values respectively are higher for Folic Acid than Ascorbic Acid and Nicotinic Acid, indicating the fact that the molecules are more tightly packed in the mixture. The interaction in the solution is basically solute-solvent interaction and a small amount of solute-solute interaction. This is also good agreement with the results obtained from density and viscosity parameters discussed above. The trend in the package of the studied vitamins in aqueous mixture of cysteine is

Nicotinic Acid < Ascorbic Acid < Folic Acid.

Ultrasonic speed measurement

The adiabatic compressibility (β) was evaluated from the following equation:

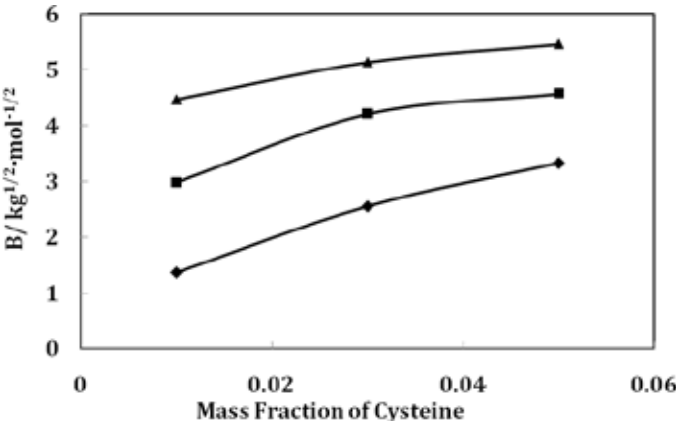


Fig. 2. The plots of viscosity B-coefficient for Nicotinic Acid (—♦—),Ascorbic Acid (—■—), Folic Acid (—▲—) in different mass fractions (w_1) of Cysteine in aqueous mixture at 298.15 K.

$$\beta = 1/u^2\rho \quad (6)$$

where ρ (kg m^{-3}) is the density of solution and $u(ms^{-1})$ is the speed of sound in the solution. The apparent molal adiabatic compressibility (ϕ_K) of the solutions was determined from the relation [19].

$$\phi_K = M\beta/\rho + 1000(\beta\rho_0 - \beta_0\rho)/m\rho\rho_0 \quad (7)$$

where β_0, β are the adiabatic compressibility of the solvent and solution respectively and m (mol kg^{-1}) is the molality of the solution. Limiting partial molal adiabatic compressibilities (ϕ_K^0) and experimental slopes (S_K^*) were obtained by fitting ϕ_K against the square root of molality of the electrolyte ($\sqrt{m}$) using the method of least squares.

$$\phi_K = \phi_K^0 + S_K^* \cdot \sqrt{m} \quad (8)$$

The values of β and ϕ_K are reported in Table 3. The values of ϕ_K^0 (m^3 mol^{-1} Pa^{-1}) and S_K^* (m^3 mol$^{-3/2}$ Pa^{-1} kg$^{1/2}$) are presented in Table 4. Since the values of ϕ_K^0 and S_K^* are measures of solute-solvent and solute-solute interactions respectively, a perusal of Table 4 and Figure 3 shows that the ϕ_K^0 values are in good agreement with those drawn from the values of ϕ_V^0 discussed earlier.

Conclusion

The positive effects of the derived parameters, as limiting apparent molar volume (ϕ_V^0), viscosity *B*-coefficients and limiting partial isentropic compressibility (ϕ_K^0) suggested the presence of strong solute(vitamins)-solvent(aq. mix. of Cystine) interactions; which increases with the increase in the interacting centres (groups) of vitamins and with increase of mass fraction of cysteine in the aqueous mixture. The refractive index and the molar refraction values imply that Folic Acid molecules are more tightly packed in the solution leading to higher solute-solvent interaction than the other vitamins. The conclusions from experimental and derived parameters also provides important working function of the cysteine with vitamins in biological systems; which demands the uniqueness of the work.

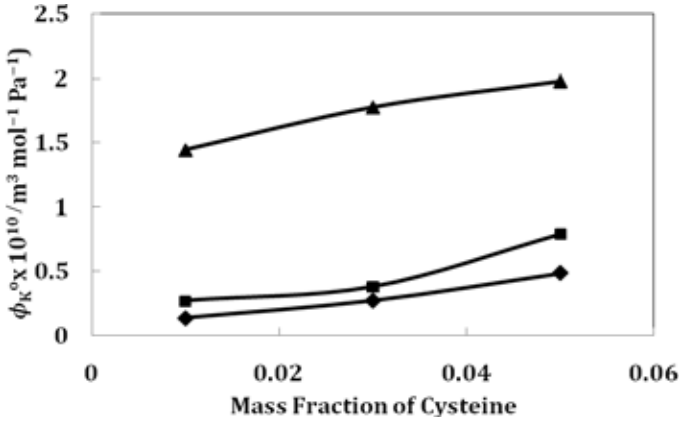


Fig. 3. The plots of limiting partial adiabatic compressibility (ϕ_K^0) for Nicotinic Acid (—♦—), Ascorbic Acid (—■—), Folic Acid (—▲—) in different mass fractions (w_1) of Cysteine in aqueous mixture at 298.15 K.

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