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# Thermodynamics of solvation of DL-α-amino butyric acid in aqueous dimethyl sulfoxide at 298.15 K

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## ABSTRACT

The thermodynamics of interactions in terms of total transfer Gibbs free energy, $\Delta G_t^0(i)$ and entropy, $\Delta S_t^0(i)$ as well as by the terms of chemical transfer free energy ($\Delta G_{t,ch}^0(i)$) and entropy ($\mathrm{T}\Delta S_{t,ch}^0(i)$) of DL-á-amino butyric acid in aqueous mixture of dimethyl sulfoxide at 298.15 K, is discussed here in the paper. For the evaluation of these factors, solubilities of this amino acid have been measured by 'formol titrimetry' method at five equidistant temperatures i.e. from 288.15 to 308.15 K in different composition of the protophilic dipolar aprotic dimethylsulfoxide (DMSO). The various solvent parameters as well as thermodynamic parameters like molar volume, densities, dipole moment and solvent diameter of aqueous solution of aprotic dimethylsulfoxide have also been reported here. The chemical effects of the transfer Gibbs energies ($\mathbf{\Delta G_{t,ch}^0(i)}$) and entropies of transfer ($\mathbf{T\Delta S_{t,ch}^0(i)}$) have been obtained after elimination of cavity effect and dipole-dipole interaction effects from the total transfer energies. The chemical contribution of transfer energetics of DL-α-amino butyric acid is mainly guided by the composite effects of increased dispersion interaction, basicity effect and decreased acidity, hydrogen bonding effects, hydrophilic hydration and hydrophobic hydration of aqueous DMSO mixtures as compared to that of reference solvent, water.

## KEYWORDS

DL-α-amino butyric acid;
Dimethylsulfoxide;
Transfer energetic;
Dispersion interaction.

## INTRODUCTION

Amino acids are the biomolecules. These are building block of proteins and intermediates in metabolism. The amino acids are not only important in protein formation, but also important due to their applications in chemical, cosmetics, pharmaceutical and food industries. The solubility studies of these biomolecules in different solvent systems, such as aquo-organic, non-aqueous and aqueous electrolyte solutions are very important. This type of studies may help in the understanding of the solubility behaviour of other biomolecules.

The α-carbon atom of DL-α-amino butyric acid is bonded with an apolar aliphatic hydrophobic side chain (-$CH_2CH_3$). The group of this amino acid may impart hydrophobic hydration interaction for the stabilization of proteins and other biomolecules constituted by it. So the thermodynamic studies of such type of amino acid are very important.

Researchers have drawn their attention [1-12] to determine the various thermodynamic properties of amino acids in different aqua-organic mixed solvent systems.

These types of studies will help to gain the various aspects of protein folding-unfolding processes and protein stability in different aquo-organic solvent systems[13, 14]. In this regard researchers have reported solubilities, transfer free energies, enthalpies and entropies of some amino acids in different aquo-organic solvent systems[5-12, 32]. All these experiments leads to a concluding remark on the relative stabilization of amino acids and other biomolecules in aqua-organic media with respect to reference solvent (water) and the complex solute-solvent and solvent-solvent interactions therein.

Very recently solvation chemistry of glycine, DL-alanine, DL-α-amino butyric acid and DL-nor-valine are studied by our group in aqueous mixture of *N, N*-dimethylformamide[11,12,15]. Our main objective of such type of studies were to know about the nature of solubility in aqueous mixture of such protophilic dipolar aprotic organic solvent at various temperatures and to get new idea about the nature of solvation as well as interaction of. such amino acids having smaller or larger hydrophobic moieties

In continuation of these earlier works here aqueous mixture of dimethylsulfoxide is used to carry out such study. DMSO is also a protophilic dipolar aprotic solvent having two hydrophobic groups (i.e. –$CH_3$) as well as soft (>S=O) moiety. The particularity of this solvent may play important role in term of soft-soft, dispersion and hydrophobic interaction to influence solvation chemistry of DL-α-amino butyric acid. Therefore the estimated thermodynamic parameters from this work may be helpful to enrich chemical, biochemical, industrial and pharmaceutical sciences in future.

## EXPERIMENTAL SECTIONS

### Materials

DL-α-amino butyric acid [> 99.5 %, E Merck] was used after drying in desiccator[11,18]. Dimethylsulphoxide [> 99.8 %, Sigma Aldrich] rigorously dried over fused $CaCl_2$ for 3-5 days, decanted and then distilled under reduced pressure. The distilled solvent was preserved in a well stopper battle in desiccator[16,19]. For the titration, standardized NaOH [GR, Grade] solution and phenolphthalein indicator [GR, Grade] were used. Neutral formaldehyde [E Merck] was used to mask before titration. Triple distilled water was used for the preparation of solutions.

### Experimental procedures

Aqueous solutions of Dimethylsulfoxide that have been used were 0, 20, 40, 60, 80 and 100 wt %, prepared by triple distilled water. Solutions were prepared on the weight basis by using a Mettler balance having a precision of ±0.01 mg. These were taken in well fitted stoppered glass tubes. Glass tubes were incompletely filled to facilitate good mixing. The thermostat used for all measurements which is capable of registering temperatures having an accuracy of ±0.02 K. A known mass of filtered saturated solution was transferred to a dry conical flask. The solubility of DL-α-amino butyric acid is measured by formol titrimetry method[20, 21]. These measurements were taken at 288.15, 293.15, 298.15, 303.15 and 308.15 K temperatures. Five sets of measurements for all the co-solvent mixtures were made for all temperatures by equilibrating the solutions from both above and below (±0.02 K) the required temperatures and the solubilities were found to agree to within ±0.5 to 1.0 %.

## RESULTS

### Solubility data

The solubilities of DL-α-amino butyric acid are measured on molal scale ($mol\cdot kg^{-1}$) and listed in TABLE 1. Solubility is measured by using 'formol titrimetry' method at 0, 20, 40, 60, 80 and 100 wt %

**TABLE 1: Solubilities (*S*) in mol·kg$^{-1}$ of DL-α-amino butyric acid in aqueous mixtures of dimethylsulfoxide at different temperature (K)**

| Wt % DMSO | 288.15 K | 293.15 K | 298.15 K | 303.15 K | 308.15 K |
|---|---|---|---|---|---|
| 0 | 1.834<br>(1.856)[18]<br>(1.702)[12] | 1.980<br>(2.060)[18]<br>(1.952)[12] | 2.134<br>(2.130)[18]<br>(2.205)[12] | 2.408<br>(2.360)[18]<br>(2.534)[12] | 2.920<br>(2.920)[18]<br>(2.874)[12] |
| 20 | 0.831±0.005 | 0.984±0.003 | 1.156±0.002 | 1.234±0.005 | 1.329±0.003 |
| 40 | 0.464±0.006 | 0.530±0.004 | 0.612±0.003 | 0.643±0.003 | 0.684±0.002 |
| 60 | 0.318±0.002 | 0.330±0.006 | 0.344± 0.003 | 0.368±0.001 | 0.437±0.003 |
| 80 | 0.221±0.004 | 0.232±0.006 | 0.246±0.003 | 0.259±0.001 | 0.271±0.006 |
| 100 | 0.048±0.002 | 0.054±0.003 | 0.062±0.006 | 0.068±0.001 | 0.072±0.003 |

**(±) Values are standard deviation;**

DMSO. These measurements were taken at 288.15 to 308.15 K temperatures. The standard deviations, ($s_f$) are also estimated for all solubility values to know about the precision and are shown in parentheses (TABLE 1) for 20, 40, 60, 80 and 100 wt % for the aqueous mixture of DMSO at all temperatures.

## Determination of transfer Gibbs free energy and entropy

The important relevant parameters of the DL-α-amino butyric acid and aqueous mixture of DMSO are presented in the TABLE 2.

Like in the previous studies by Bates and coworkers[22], Kundu and coworkers[23, 24] and Dolui *et al.*[6, 9-12, 15-19, 21] for various types of biomolecules, the standard Gibbs energies of solutions of the amino acid ($\Delta G_s^0$) on molal scale were calculated for each solvent using equation (I) and presented in TABLE 3.

$$\Delta G_s^0(i) = -RT\ln C\gamma = -RT\ln m \qquad (1)$$

Where γ is the molar activity coefficient of the solutes but taken tentatively to be unity in each solvent[20, 25], '*C*' is the concentration of the solute in solvent and 'm' is the molal solubility (mol·kg$^{-1}$) of the solutes in solvent. Here it is important to note that the involved activity coefficient factor -RTlnγ in $\Delta G_s^0$ arising from interactions of dipolar solute with large dipole moment may not be so small. But as there is neither the required experimental data nor any appropriate theoretical correlations for computing the same, these have been tacitly taken to be negligibly small, as is usually done for the non-electrolytes[26].

The free energies, $\Delta G_s^0$ at different temperatures are fitted by the method of least squares to an equation of the form (Equation 2)[27],

$$\Delta G_s^0 = a + bT + cT\ln T \qquad (2)$$

where T is the temperature in Kelvin scale. The values of the coefficients a, b, c are presented in TABLE 4. These are found to reproduce the experimental data within ±0.04 (kJ·mol$^{-1}$/ (kJ·mol$^{-1}$·K$^{-1}$) respectively.

Transfer Gibbs energies $\Delta G_t^0$ and entropies $\Delta S_t^0$ of the amino acids from water to aqueous dimethylsulfoxide mixtures were calculated at 298.15 K on mole fraction scale by using the following equations (3) & (4):

$$\Delta G_t^0(i) = {}_s\Delta G_{sol}^0(i) - {}_R\Delta G_{sol}^0(i)$$

i.e. $$\Delta G_t^0(i) = (a_s - a_R) + (b_s - b_R)T + (c_s - c_R)T\ln T - RT\ln(M_s/M_R) \qquad (3)$$

and, $$\Delta S_t^0(i) = (b_R - b_s) + (c_R - c_S)(1 + \ln T) + R\ln(M_s/M_R) \qquad (4)$$

here the subscript 's' and 'R' refer to the aqueous dimethylsulfoxide mixtures and reference solvent ($H_2O$) respectively and $M_R$ and $M_s$ are the molar mass of the pure and mixed solvent respectively. $\Delta G_t^0(i)$ and values $T\Delta S_t^0(i)$ of α-amino acids thus obtained and presented in the TABLE 4. The involved uncertainties in $\Delta G_t^0(i)$ and $\Delta S_t^0(i)$ are about ±0.05 kJ·mol$^{-1}$and 2J·K$^{-1}$ mol$^{-1}$, respectively.

## Determination of cavity, transfer dipole-dipole interactions, enthalpy due to cavity formation, chemical parts of transfer Gibbs energy and entropy

The term $\Delta P_t^0(i)$ (where P=G or S) can be partitioned into cavity, dipole-dipole and chemical contributions assuming dipole induced dipole force negligible[20, 21].

i.e. $\Delta P_t^0(i) = \Delta P_{t,cav}^0(i) + \Delta P_{t,d-d}^0(i) + \Delta P_{t,ch}^0(i)$ **(5)**

Here, $\Delta P_{t,cav}^0(i)$ indicates the transfer energy contribution of the cavity effect which is involved due to creation of cavities for the species, DL-α-amino butyric acid in $H_2O$ and aqueous dimethylsulfoxide mixtures and $\Delta P_{t,d-d}^0(i)$ stands for the dipole-dipole interaction effect involving interaction between dipolar-zwitter-ionic amino acid and the solvent molecules.

On other hand, $\Delta P_{t,ch}^0(i)$ includes all other effects such as those arising from acid-base or short-range dispersion interaction, hydrophilic or hydrophobic hydration and structural effects, etc. Scaled particle theory (SPT)[21, 26] has been applied for computation of $\Delta P_{t,cav}^0(i)$ as earlier[18,26], assuming the solutes and solvent molecules as equivalent to hard-sphere models as are dictated by their respective diameters.(Vide TABLE 2).

The involved equations are given as follow:

$$\Delta G_{cav}^0(i) = G_C + RT\ln(RT/V_S) \qquad (6)$$

$$G_C = RT[-\ln(1-Z) + \{3X/(1-Z)\}\sigma_x$$
$$+\{3Y/(1-Z)\}\sigma_x{}^2 + \{9X^2/4(1-Z)^2\}\sigma_x{}^2]$$
$$Z = \pi N_A/6V_s(z_R\sigma_R{}^3 + z_s\sigma_s{}^3)$$
$$X = \pi N_A/6V_s(z_R\sigma_R{}^2 + z_s\sigma_s{}^2)$$

Where $Y = \pi N_A/6V_s(z_R\sigma_R + z_s\sigma_s)$

$$V_s = M_s/d_s$$

In this expression $N_A$ is Avogadro's number, $z_R$ and $z_s$ are the mole fraction of reference solvent water and co-solvent respectively. '$\sigma_x$, '$\sigma_R$, and '$\sigma_s$' are the hard sphere diameters of DL-α-amino butyric acid, reference solvent, water and aqueous dimethylsulfoxide mixtures respectively. Where the terms $M_s$, $d_s$ represent for molar mass and molar density of the solvent.

Therefore, the required $\Delta G_{t,cav}^0(i)$ represents the difference,

$$\Delta G_{t,cav}^0(i) = {}_s\Delta G^0{}_{cav}(i) - {}_R\Delta G^0{}_{cav}(i)$$
$$= {}_sG_C - {}_RG_C + RT\ln(V_R/V_s) \qquad (7)$$

Again $\Delta G_{t,d-d}^0(i) = ({}_s\Delta G_{d-d}^0(i) - {}_R\Delta G_{d-d}^0(i))$ **(8)**

and $\Delta S_{t,d-d}^0(i) = ({}_s\Delta S_{d-d}^0(i) - {}_R\Delta S_{d-d}^0(i))$ are calculated by means of the Keesom-orientation expression[12, 28], for ${}_s\Delta G_{d-d}^0(i)$ in a solvent S, as given below:

$${}_s\Delta G_{d-d}^0(i) = (8\Pi/9)N^2\mu_s^2\mu_x^2\sigma_{s-x}^{-3}(kT)^{-1}v_s^{-1} = A/T\text{-}V_S \qquad (9)$$

Where $A = -(8\Pi/9)N^2\mu_s^2\mu_x^2\sigma_{s-x}^{-3}(k)^{-1}$ and $V_s = M_s/d_s$ and that of $\Delta S_{d-d}^0(i)$ as follows-

$${}_s\Delta S_{d-d}^0(i) = -\{\delta_s\Delta G_{d-d}^0(i)/\delta T\}_p \qquad (10)$$

i.e. $T_s\Delta S_{d-d}^0(i) = {}_s\Delta G_{d-d}^0(i)[1 + T\alpha]$, where N stands for Avogadro's number, $\mu_s, \mu_x$ are the dipole moment of aqueous dimethylsulfoxide mixtures and amino acid respectively (TABLE 2).

$\sigma_{s-x}$ is the distance at which the attractive and repulsive interactions between the solvent and solute molecules are equal and is generally equal to ½($\sigma_s + \sigma_x$) where $\sigma_s$ and $\sigma_x$ are the hard sphere diameter of cosolvent and solute molecules respectively (TABLE 2) and á is the isobaric thermal expansibility constant of the solvent and given by the following equation-

$$\alpha = (\delta\ln V_s/\delta T)_P = -(\delta\ln d_s/\delta T)_P \qquad (11)$$

The enthalpy change due cavity forming interaction in water to aqueous dimethylsulfoxide (DMSO) mixtures is measured by the equation-

$$\Delta H_{t,cav}^0(i) = {}_s\Delta H_{cav}^0(i) - {}_R\Delta H_{cav}^0(i) \qquad (12)$$

$$\Delta H_{cav}^0(i) = (A + H + K + E) \times B \qquad (13)$$

where $A = (\Pi N_A/6V_s) \times (Z_R\sigma_R{}^3 + Z_S\sigma_S^3)$ ;

$B = \sigma_S RT^2/1 - A$ ; $H = \sigma_x \times 3Y/1 - A$ ; $K = \sigma_x \times 3X/1 - A$ ;

$E = 9\sigma_x{}^2 \times X^2/(1 - A)^2$ ;

$X = (\Pi N_A/6V_s) \times (Z_R\sigma_R{}^2 + Z_S\sigma_S^2)$ ;

and $Y = (\Pi N_A/6V_s) \times (Z_R\sigma_R + Z_S\sigma_S)$ .

Following Marcus[29] and Kim *et al.*,[28] in order to get this $\Delta P_{t,d-d}^0(i)$ term on mole fraction scale the quantity was again multiplied by the term $X_{s1}$.

TABLE 2 : Values of solvent parameters (Mole % of DMSO solvent system, Mole fraction of DMSO ($z_s$), water (($z_R$), mean mol. Weight ($M_S$), density ($d_s$), hard sphere diameter of co-solvent ($\sigma_s$) (DMSO+$H_2O$) and $\sigma_{s-x}$ (= ½($\sigma_s + \sigma_x$)), Dipole moment of co-solvent ($\mu_s$) and isobaric thermal expansibility constant (α) of the $H_2O$+DMSO system at 298.15 K

| Wt % DMSO | Mole fraction of DMSO ($z_s$) | Mole fraction of water ($z_R$) | Molar mass ($M_S$) (kg· mol) | $10^3$ $d_s$ (kg· m$^{-3}$) | Molar Vol.($V_s$) (m$^{-3}$·mol) | $\sigma_s$ (nm) | $\sigma_{s-x}$ (nm) | Dipole Moment ($\mu_s$) | α (x $10^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.000 | 1.000 | 18.015 | 0.997 | 18.069 | 0.274 | 0.445 | 1.831 | 0.257* |
| 20 | 0.054 | 0.946 | 21.260 | 1.002 | 21.218 | 0.286 | 0.451 | 1.941 | 0.296 |
| 40 | 0.133 | 0.867 | 26.010 | 1.009 | 25.778 | 0.303 | 0.459 | 2.105 | 0.353 |
| 60 | 0.256 | 0.744 | 33.400 | 1.021 | 32.713 | 0.329 | 0.473 | 2.359 | 0.442 |
| 80 | 0.479 | 0.521 | 46.810 | 1.042 | 44.923 | 0.378 | 0.497 | 2.821 | 0.604 |
| 100 | 1.000 | 0.000 | 78.130 | 1.091 | 71.613 | 0.491 | 0.554 | 3.900 | 0.982# |

*, # values are taken from the references[29].

TABLE 3 : Gibbs energies of solutions ($\Delta G_s^0$) on molal scale in their respective solubilities of DL-α-amino butyric acid in aqueous mixtures of dimethylsulfoxide at different temperature (K)

| 288.15 K | | 293.15 K | | 298.15 K | | 303.15 K | | 303.18 K | |
|---|---|---|---|---|---|---|---|---|---|
| S (mol·kg$^{-1}$) | $\Delta G_s^0$ (kJ·mol$^{-1}$) | S (mol·kg-$^{1}$) | $\Delta G_s^0$ (kJ·mol$^{-1}$) | S (mol·kg$^{1}$) | $\Delta G_s^0$ (kJ·mol$^{-1}$) | S (mol·kg$^{-1}$) | $\Delta G_s^0$ (kJ·mol$^{-1}$) | S (mol·kg$^{-1}$) | $\Delta G_s^0$ (kJ·mol$^{-1}$) |
| 1.834 | -1.45298 | 1.980 | -1.66488 | 2.134 | -1.87894 | 2.408 | -2.21491 | 2.920 | -2.74535 |
| 0.831 | 0.44350 | 0.984 | 0.03931 | 1.156 | -0.35930 | 1.234 | -0.52990 | 1.329 | -0.72870 |
| 0.464 | 1.83957 | 0.530 | 1.54735 | 0.612 | 1.21715 | 0.643 | 1.11300 | 0.684 | 0.97302 |
| 0.318 | 2.74474 | 0.330 | 2.70208 | 0.344 | 2.64518 | 0.368 | 2.51956 | 0.437 | 2.12084 |
| 0.221 | 3.61650 | 0.232 | 3.56086 | 0.246 | 3.47636 | 0.259 | 3.40486 | 0.271 | 3.34498 |
| 0.048 | 7.27460 | 0.054 | 7.11377 | 0.062 | 6.89265 | 0.068 | 6.77543 | 0.072 | 6.74074 |

TABLE 4 : Coefficients a, b and c, Gibbs energies $\Delta G_t^0$ and entropies $T\Delta S_t^0$ of transfer of DL-α-amino butyric acid on mole fraction scale from $H_2O$ to $H_2O$-DMSO mixture at 298.15 K

| Wt % DMSO | a (kJ·mol$^{-1}$) | b (kJ·mol$^{-1}$·K$^{-1}$) | c (kJ·mol$^{-1}$·K$^{-1}$) | $\Delta G_t^0(i)$ (kJ·mol$^{-1}$) | $T\Delta S_t^0(i)$ (kJ·mol$^{-1}$) |
|---|---|---|---|---|---|
| 0 | -368.73 | 8.5979 | -1.29310 | 0 | 0 |
| 20 | 341.54 | -7.3475 | 1.08833 | 1.165 | -0.919 |
| 40 | 283.68 | -6.0971 | 0.90387 | 2.263 | -5.379 |
| 60 | -385.45 | 8.8814 | -1.33030 | 3.082 | -9.331 |
| 80 | 9.9444 | -0.0656 | 0.00770 | 3.513 | -12.999 |
| 100 | 196.22 | -4.0924 | 0.60683 | 5.184 | -14.298 |

$$X_{s1} = X_s(\mu_s/\sigma_s^3)/(\mu_R/\sigma_R^3) \qquad (14)$$

This is the real mole fraction contribution due to dipole-dipole interaction[29]. Subtraction of $\Delta P_{t,cav}^0(i)$ and $\Delta P_{t,d-d}^0(i)$ from the total, i.e. $\Delta P_t^0(i)$ we get $\Delta P_{t,ch}^0(i)$ of the solute amino acid. The values of $\Delta P_{t,cav}^0(i)$, $\Delta P_{t,d-d}^0(i)$ and $\Delta P_{t,ch}^0(i)$ are presented in TABLE 5.

The required diameter and other solvent parameters of $H_2O$ and DMSO mixtures are taken from Ref.[29] The required diameter of DL-α-amino butyric acid is 6.58 Å as given in Ref.[6,18] Dipole-moment value of DL-α-amino butyric acid is 16.0 D[20, 29].

**TABLE 5 : Gibbs energies of transfer $\Delta G_t^0(i)$, $\Delta G_{t,cav}^0(i)$, $\Delta G_{t,dd}^0(i)$, $\Delta G_{t,ch}^0(i)$ and enthalpy of transfer, $\Delta H_{t,cav}^0(i)$ and entropies of transfer $T\Delta S_t^0(i)$, $T\Delta S_{t,cav}^0(i)$, $T\Delta S_{t,dd}^0(i)$ and $T\Delta S_{t,ch}^0(i)$ of DL-α-amino butyric acid from $H_2O$ to $H_2O$-DMSO at 298.15 K (on mole fraction scale) in $kJ \cdot mol^{-1}$**

| Wt % DMSO | $\Delta G_t^0(i)$ ($kJ \cdot mol^{-1}$) | $\Delta G_{t,cav}^0(i)$ ($kJ \cdot mol^{-1}$) | $\Delta G_{t,dd}^0(i)$ ($kJ \cdot mol^{1}$) | $\Delta G_{t,ch}^0(i)$ ($kJ \cdot mol^{1}$) | $T\Delta S_t^0(i)$ ($kJ \cdot mol^{1}$) | $\Delta H_{t,cav}^0(i)$ ($kJ \cdot mol^{1}$) | $T\Delta S_{t,cav}^0(i)$ ($kJ \cdot mol^{-1}$) | $T\Delta S_{t,dd}^0(i)$ ($kJ \cdot mol^{-1}$) | $T\Delta S_{t,ch}^0(i)$ ($kJ \cdot mol^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 1.165 | -1.580 | 0.460 | 2.285 | -0.919 | -1.080 | 0.500 | 0.433 | -1.852 |
| 40 | 2.263 | -3.190 | 2.060 | 3.390 | -5.379 | -1.810 | 1.380 | 1.900 | -8.659 |
| 60 | 3.082 | -4.860 | 5.080 | 2.862 | -9.331 | -2.070 | 2.790 | 4.530 | -16.651 |
| 80 | 3.513 | -6.660 | 9.910 | 0.323 | -12.999 | -1.080 | 5.580 | 8.330 | -26.909 |
| 100 | 5.184 | -7.830 | 16.70 | -3.686 | -14.298 | 16.80 | 24.630 | 12.400 | -51.328 |

## DISCUSSION

### Analysis of solubility data

The solubility values of DL-α-amino butyric acid increases with increasing temperature in a particular composition of aqua-organic mixed solvent system but with the increased concentration of DMSO the same show reverse nature at a particular temperature.

### Gibbs transfer free energy involved between DL-α-amino butyric acid and solvent mixtures

The present work represents different types of interactions involved between solute-solvent and solvent-solvent interactions and is shown in TABLES 3 and 5. The data are explained graphically for better understanding.

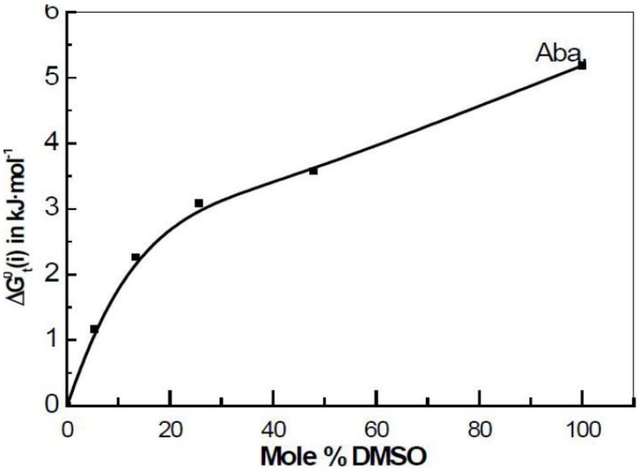

Figure 1 : Variation of $\Delta G_t^0(i)$ in $kJ \cdot mol^{-1}$ of DL-α-amino butyric acid in aqueous mixtures of DMSO at 298.15 K

Figure 1 represents the variation of $\Delta G_t^0(i)$ for amino acid DL-α-amino butyric acid against the mole % of DMSO at 298.15 K.

There occurs a positive increment of $\Delta G_t^0(i)$ values with the increased concentration of DMSO. Actually $\Delta G_t^0(i)$ is composed of $\Delta G_{t,cav}^0(i)$, $\Delta G_{t,d-d}^0(i)$ and $\Delta G_{t,ch}^0(i)$. [$\Delta G_{t,d-id}^0(i)$ i.e. free energy change due to dipole-induced dipole interaction, it is considered negligible].

The $\Delta G_{t,cav}^0(i)$, values are showing gradual negative increment with DMSO concentration (TABLE 5) which indicates that DL-α-amino butyric acid should easily be accommodated in DMSO than $H_2O$ with release of concerned energy due to the greater

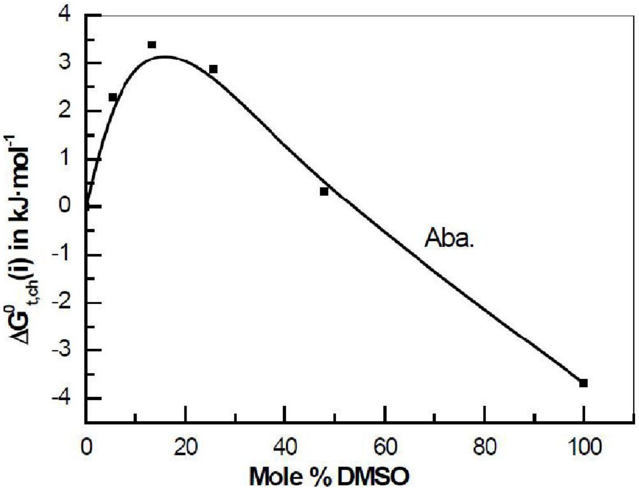

Figure 2 : Variation of $\Delta G_{t,ch}^0(i)$ in $kJ \cdot mol^{-1}$ of DL-α-amino butyric acid in aqueous mixtures of DMSO at 298.15 K

size of DMSO (4.91Å) than $H_2O$ (2.74 Å)[29].

On the other hand, $\Delta G^0_{t,d-d}(i)$ (TABLE 5) values are increasingly positive in nature with increased mole % of DMSO. The dipole moment of DMSO (3.90D)[29] is greater than $H_2O$ (1.83D)[29] but the involved hard sphere diameter difference of DMSO and $H_2O$ supports such variation. The Gibbs free energy due chemical interactions i.e. $\Delta G^0_{t,ch}(i)$ values for the solute, DL-α-amino butyric acid have been computed after subtraction of $\Delta G^0_{t,cav}(i)$ and $\Delta G^0_{t,d-d}(i)$ from $\Delta G^0_t(i)$. The chemical interaction such as H-bonding, acid-base, hard-soft, dispersion, hydrophilic hydration and hydrophobic hydration, etc. are involved in $\Delta G^0_{t,ch}(i)$ for the solute and solvent molecules in this system.

Figure 2 represents the variation of $\Delta G^0_{t,ch}(i)$ with DMSO concentration. The $\Delta G^0_{t,ch}(i)$ value shows maxima at about 15 mole % of DMSO in the $H_2O$-DMSO solvent system. This type of nature indicates the destabilization of DL-α-amino butyric acid and may be due to the breaking of extensive hydrogen bond between protic water and hydrophilic head of the zwitterionic amino acid with the introduction of larger protophobic dipolar aprotic DMSO in water. After that the gradual stabilization of DL-α-amino butyric acid occurs with the sharp decrement of $\Delta G^0_{t,ch}(i)$ values with DMSO concentration. Here hydrogen bonding capacity of the reference solvent, water is higher than the larger protophobic dipolar aprotic DMSO. This factor will destabilize DL-α-amino butyric acid with the increased concentration of DMSO. But the greater size of DMSO (4.91 Å) introduces strong soft-soft as well as dispersion interaction among the DMSO and larger size amino acid, DL-α-amino butyric acid [i.e. $CH_3$-$CH_2CH$ ($NH_3^+$) ($COO^-$) ] [6.58 Å]. Here it is important to note that in higher concentration of DMSO in aqueous co-solvent system the association of the solvents molecules (i.e. between water and DMSO molecules in 1:2 ratios)[30, 31, 34] [Diagram B) and the self association of DMSO [Diagram C] occurs extensively which may also take part in dispersion interaction with larger amino acid molecules.

The hydrophilic as well as hydrophobic hydration interactions are gradually reduced with increased concentration of DMSO. This factor may destabilize DL-α-amino butyric acid in aqueous DMSO system. But the overall increased dispersion interaction may play more dominating role over the reduced acid-base, H-bonding, hydrophilic and hydrophobic interaction involved between amino acid and DMSO in aqueous DMSO mixtures compared to the reference solvent, $H_2O$.

Figure 3 represents a comparative study of $\Delta G^0_{t,ch}(i)$ values of glycine[17], DL-alanine[34] and DL-α-amino butyric acid in water-DMSO solvent system. The α-amino acid, glycine having smaller size (5.64 Å)[11] will be more stabilized with increased concentration of DMSO by dispersion interaction and hydrophilic interaction than DL-alanine (6.16 Å) and DL-α-amino butyric acid [6.58 Å]. Though the dispersion interaction is more effective for larger amino acid than smaller one but the higher charge density on smaller amino acid is more efficient for hydrophilic interaction. Hence the combined effect of dispersion and hydrophilic interactions in smaller amino acid is more than larger one which is responsible for such type of observed stability order of these amino acids.

## Role of DL-α-amino butyric acid for controlling solvent-solvent interactions

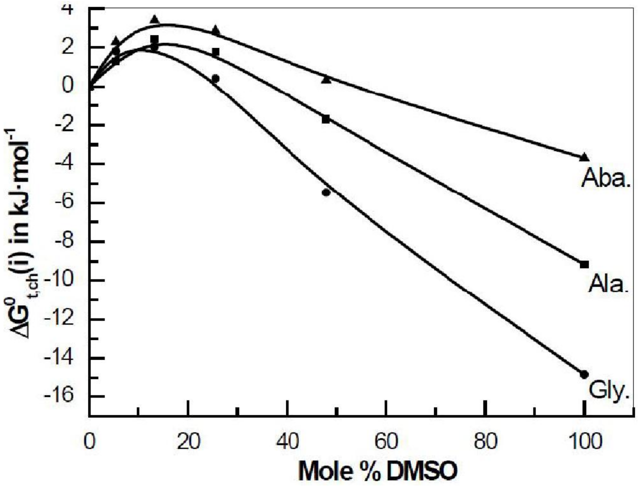

**Figure 3 : Variation of $\Delta G^0_{t,ch}(i)$ in kJ·mol$^{-1}$ of DL-α-amino butyric acid, DL-alanine and glycine in aqueous mixtures of DMSO at 298.15 K**

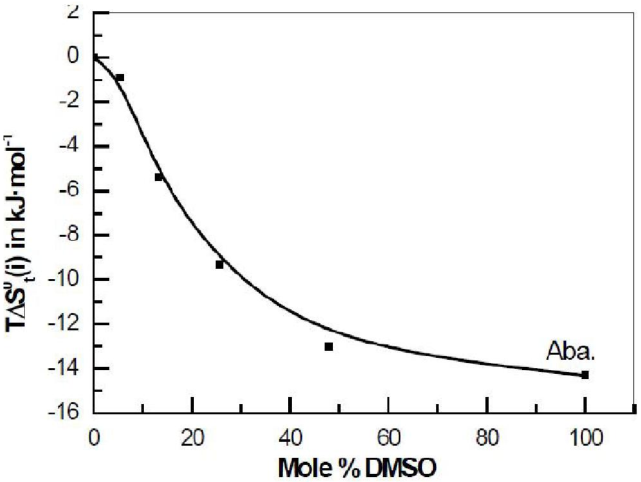

**Figure 4 : Variation of $T\Delta S_t^0(i)$ in kJ·mol$^{-1}$ of DL-α-amino butyric acid in aqueous mixtures of DMSO at 298.15 K**

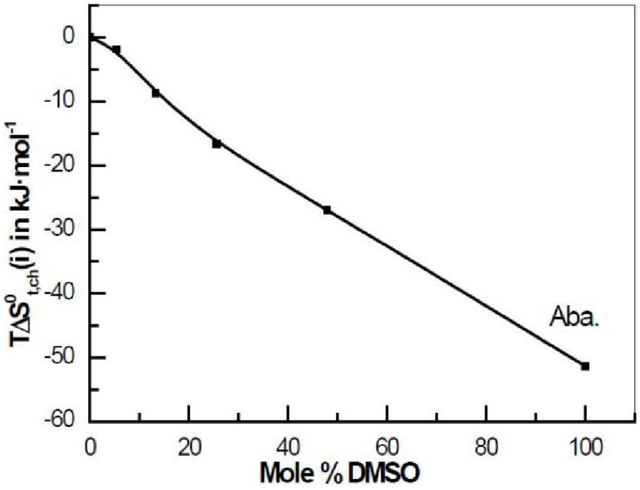

**Figure 5 : Variation of $T\Delta S_{t,ch}^0(i)$ in kJ·mol$^{-1}$ of DL-α-amino butyric acid in aqueous mixtures of DMSO at 298.15 K**

Figure 4 represents the variation of $T\Delta S_t^0(i)$, of DL-α-amino butyric acid against mole % of DMSO in aqueous DMSO. Like $\Delta G_t^0(i)$, $\mathbf{T\Delta S_t^0(i)}$ is composed of cavity, dipole-dipole and chemical interaction effects i.e. $\mathbf{T\Delta S_t^0(i) = T\Delta S_{t,cav}^0(i)} + T\Delta S_{t,d-d}^0(i) + \mathbf{T\Delta S_{t,ch}^0(i)}$

The combined effect in $\mathbf{T\Delta S_t^0(i)}$ value may represent such behavior as shown in Figure 4.

$T\Delta S_{t,cav}^0(i)$ values (TABLE 4) are gradually increased with the mole % DMSO. With the increased DMSO concentrations the water molecule becomes free from amino acid to allow it to be accommodated by the former. With the increased DMSO concentrations the water molecule becomes free from amino acid to allow it to be accommodated by DMSO. $T\Delta S_{t,d-d}^0(i)$ values (TABLE 4) are also gradually increased with the DMSO concentration. Here with the increased concentration of DMSO the dipolar amino acid, DL-α-amino butyric acid become less associated with dipolar co-solvent due to the larger size of DMSO (4.91 Å)[29] and therefore DL-α-amino butyric acid allow water as well as DMSO molecules to be more free as the concentrations of DMSO gradually increased.

$T\Delta S_{t,ch}^0(i)$ values are determined after subtraction of $T\Delta S_{t,cav}^0(i)$ and $T\Delta S_{t,d-d}^0(i)$ from $T\Delta S_t^0(i)$.

Figure 5 represents the variation of $T\Delta S_{t,ch}^0(i)$ of DL-á-amino butyric acid with increased DMSO concentration in aqueous DMSO mixture at 298.15 K. The nature of the curve with mole % DMSO indicates that water molecules adopt 3-D structure due to its extensive intermolecular hydrogen bonding (Diagram A in Figure 7) at lower concentration of DMSO.

On the other hand, the negative trend of the curve with increased mole % DMSO indicates that the large sized amino acid, DL-α-amino butyric acid induces the solvent molecules to be associated (i.e. between water and DMSO molecules) (Diagram B in Figure 7.)[31, 33] and to be dimerised [i.e. between the

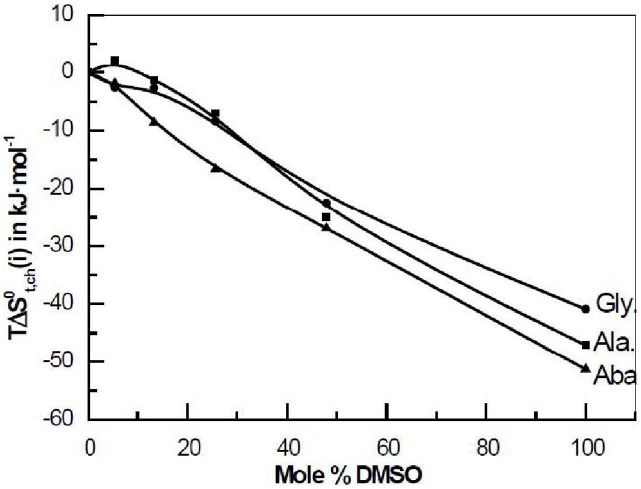

**Figure 6 : Variation of $\Delta H_{t,cav}^0(i)$ in kJ·mol$^{-1}$ of DL-α-amino butyric acid in aqueous mixtures of DMSO at 298.15 K**

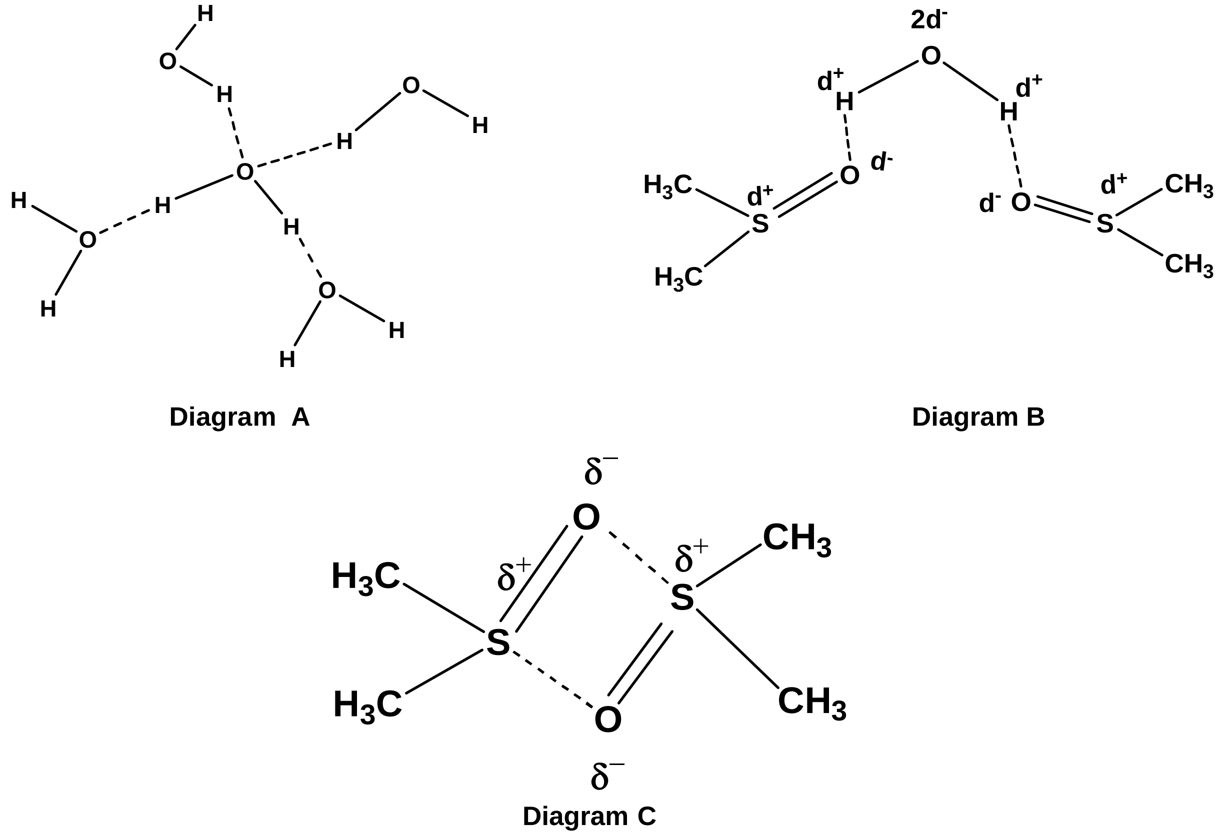

Diagram A

Diagram B

Diagram C

**Figure 7 : Diagram (A) for 3-D structure of water due to its extensive intermolecular hydrogen bonding, Diagram (B) for associated form between water and DMSO molecules, Diagram (C) for dimerised form between the dipolar aprotic DMSO molecules**

dipolar aprotic DMSO[30, 31] molecules (Diagram C in Figure 7.) Here the DL-α-amino butyric acid also induces the hydrophilic hydration and hydrophobic hydration to be decreased with the increased DMSO concentration.

Hence the solute induced dispersion interaction among large size DMSO molecules being the predominant factor over others, the overall decrement of $T\Delta S^0_{t,ch}$ (i) value occurs throughout the higher concentration of DMSO in this aqueous DMSO mixed solvent system.

Figure 6 represents a comparative study of variation of of α-amino acids, DL-α-amino butyric acid, glycine[11] and DL-alanine[34] in aqueous-DMSO mixed solvent system. Here we see that the amino acid glycine induce less dis-orderness to solvent mixtures in aqueous-DMSO than DL-alanine and upto the range of 30 mole % of DMSO and then upto 100 mole % glycine induces more dis-orderness to the solvent than DL-alanine and DL-α-amino butyric acid. At lower content of DMSO the hydrophobic/hydrophilic hydrations are more effective in case of glycine (i.e. smaller) than alanine due to higher charge density on glycine, as a result entropy of the system become less in the case of glycine + water + DMSO[11] system than the DL-alanine + water + DMSO system[34]. But in higher content of DMSO, comparatively larger solute, DL-alanine induces more strongly the solvent molecules to be associated (i.e. between water and DMSO molecules) (Diagram B in Figure 7) and to be dimerised between dipolar aprotic DMSO molecules (Diagram C in Figure 7)[30] which significantly reduces the number of free solvent molecules, resulting less dis-orderness in cash of DL-alanine than the glycine. But the amino acid, DL-α-amino butyric acid shows less dis-orderness throughout the whole region of water-DMSO concentration. Comparatively larger size DL-α-amino butyric acid [6.58 Å) induces the most strongly the solvent molecules to be associated (Diagram B in Figure 7.) and to be dimerised between dipolar aprotic DMSO molecules[30] which significantly reduces the number of free solvent molecules, resulting less dis-orderness in cash of DL-α-amino butyric acid than DL-alanine and glycine.

## CONCLUSIONS

Experimental results for solubility values of DL-α-amino butyric acid get decreased with the increased concentration of DMSO and increases with increasing temperature at a particular solvent composition. The observed stability of the amino acid, DL-α-amino butyric acid is due to chemical interactions in comparatively larger co-solvent, DMSO, with dipolar aprotic character. In addition, DL-α-amino butyric acid induces DMSO to be dimerized mainly through dispersion interaction in the DMSO rich region of this mixed aquo-organic solvent system.

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