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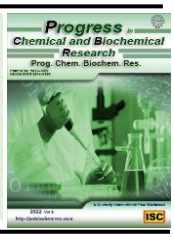

*Original Research Article*

# Effect of Temperature on Thermodynamic Properties of Glycine, Histidine, and Valine in Aqueous Solutions of Nortriptyline

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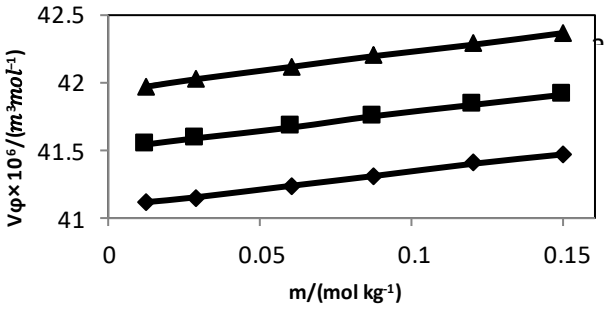
**ABSTRACT**

Thermodynamic properties such as apparent molar volume, $v\varphi$ and apparent molar isentropic compressibility, $k_{\varphi s}$ for aqueous solutions of glycine, histidine, and valine in nortriptyline corresponding measured their density as well as speed of sound at $T$ = (305.15, 310.15, and 315.15) K were computed. The obtained quantities were discussed in terms of interactions between drug-water and amino acids which was due to specification structural and upon the situation of nortriptyline molecules.

**GRAPHICAL ABSTRACT**

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## 1. INTRODUCTION

Physico-chemical quantities of glycine, histidine, and valine in aqueous solutions lead to understanding interactions between unlike molecules [1-4]. On the other hand, the behavior of amino acids in antidepressant drug recently is of high significance [5-9]. In this project, the drug nortriptyline was used to discuss the interactions with amino acids. For this purpose, first densities and speeds of sound were measured for pure components as well as for binary mixtures with different molalities at $T$ = (305.15, 310.15, and 315.15) K. Consequently, the apparent molar volume such as apparent molar volume, $\mathbf{v}\omega$, and apparent molar isentropic compressibility, $k_{\omega s}$ were also calculated. Compared to the other tricyclic anti-depressant, nortriptyline is less toxic and displays less drug interactions. It undergoes hepatic metabolism and hydroxylation followed by conjugation with glucuronic acid [10-12].

## 2. EXPERIMENTAL

The amino acids and nortriptyline with purities of >0.99 were used without further purification. The different molalities of solutions from (0.0006-0.004) $m$ of nortriptyline were made. Densities and sound velocities were measured by Anton Paar DSA 5000 M densitometer. Table 1 presents the purities outlines chemical specifications, purities, and supplier.

## 3. RESULTS AND DISCUSSION

The quantity $\mathbf{v}\omega$, of solutions were calculated as:

$$V_{\varphi} = \frac{1000(\rho_0-\rho)}{m\rho\rho_0} + \frac{M}{\rho} \quad (1)$$

Where, $M$ is molar mass and $m$ is molality. $\boldsymbol{\rho}_0$ is density of pure solvent and $\boldsymbol{\rho}$ is density of solution. The ontained $\mathbf{v}\omega$ values for various molality at $T$ = (305.15, 310.15 and 315.15) K are reported in Table 2. The $\mathbf{v}\omega$, values are positive and become more positive with enhancing molality of amino acid and temperatures in nortriptyline solutions. The sign of $\mathbf{v}\omega$ values is due to interactions between unlike molecules and increases with glycine to histidine at different temperatures. The $\mathbf{v}\omega$, values of histidine, valine, and glycine in water and in aqueous nortriptyline solutions at different molality and at $T$ = (305.15, 310.15, and 315.15) K are presented in Table 3, and displayed in Figures 1-3. The values apparent molar volume at dilute solutions $V_{\omega^\circ}$ and slope of plot $V_{\omega}$ *vs* molality as $S_v$, are obtained as:

$$\mathbf{v}\omega = V_{\varphi}^{0} + S_v m \quad (2)$$

The weaker interactions between solutes rather than solutions made positive lower values of $S_v$, relative to $V_{\omega^\circ}$ the computed values of $V_{\omega^\circ}$ and $S_v$, are listed in Table 4 [13-16].

To calculate isentropic compressibility, $\mathbf{k}_s$ the Newton-Laplace equation was used:

$$K_s = \frac{1}{\rho u^2} \quad (3)$$

$u$ and $\boldsymbol{\rho}$ are speed of sound and density, respectively. Apparent molar isentropic compressibility was calculated as follow:

$$K_{\varphi,s} = \frac{1000(K_s\rho_0 - K_s^0\rho)}{m\rho\rho_0} + \frac{MK_s}{\rho} \quad (4)$$

Where, $\boldsymbol{\rho}$ and $\boldsymbol{\rho}_0$ show densities of the solution and the solvent. The resultant $\mathbf{k}_{\omega s}$ is indicated in Table 3 and Figures 4-6. Results showed that $\mathbf{k}_{\omega s}$ were negative for all systems which indicate that water molecules around the solute are less compressible than those in the bulk. The limiting apparent molar isentropic compressibility $\mathbf{k}\mathring{\omega}s$ was calculated as follow:

$$K_{\varphi,S} = K_{\varphi,s}^{0} + S_k m \quad (5)$$

$S_k$, shows output solute-solute interactions and $\mathbf{k}\mathring{\omega}s$ , indicates solute-solvent interactions. The

computed values of $\mathbf{k}_{\mathring{\omega}s}$ and $S_k$ are presented in Table 4 [17–21].

The $V_{\omega^\circ}$ is transfer volume of amino acids from water to nortriptyline solutions and is given as follow:

$$V^0_{\varphi,tr} = V^0_{\varphi,\text{aqueous-nortriptyline}} - V^0_{\varphi,water} \quad (6)$$

The values $V_{\omega^\circ}$ is for histidine, valine, and glycine in water and transfer compressibility, $\mathbf{k}_{\mathring{\omega}s,tr}$ of amino acids from water to solutions was obtained as follow [22-24]:

$$K^0_{\varphi,s,tr} = K^0_{\varphi,s,\text{aqueous-nortriptyline}} - K^0_{\varphi,s,water} \quad (7)$$

The computed values of $\mathbf{k}_{\mathring{\omega}s,tr}$ and $V_{\mathring{\omega},tr}$ are reported in Table 5.

## 4. Conclusion

The density and speed of sound for amino acids in aqueous solutions of nortriptyline drug at $T$ = (305.15, 310.15, and 315.15) K were experimentally measured. From the experimental data, various parameters $\mathbf{v}\omega$, $V_{\omega^\circ}$, $\mathbf{k}_{\omega s}$, $\mathbf{k}\mathring{\omega}s$, $\mathbf{k}_{\mathring{\omega}s,tr}$, and $V_{\mathring{\omega},tr}$ were calculated. The different parameters showed that there are strong interactions between amino acids and drug molecules. This strength of solute-solvent interaction enhances with increase in molar mass of amino acids and molalities.

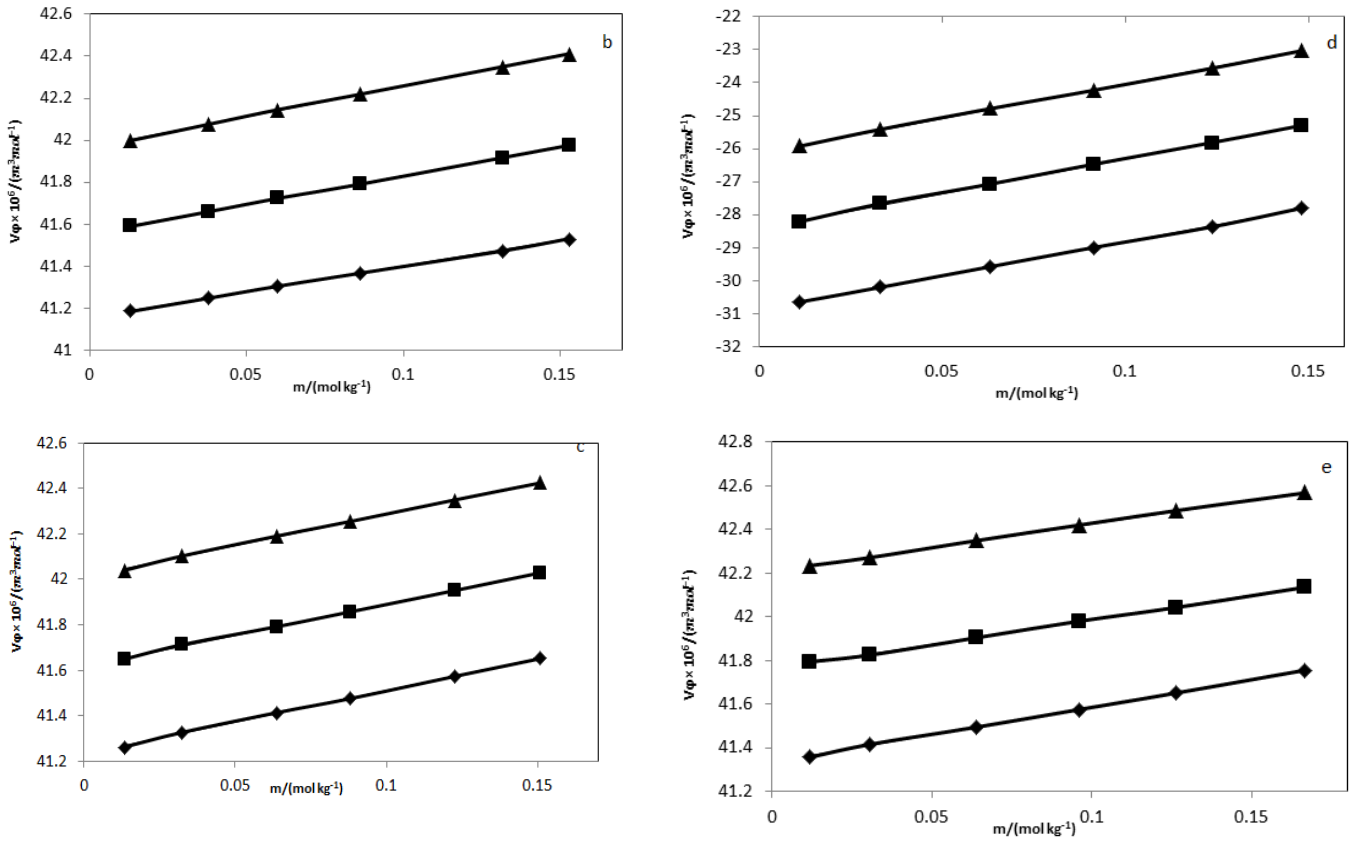



**Fig 1**.Plot of apparent molar volume $\mathbf{v}\omega$, *vs.* molality ,*m* of (a) glycine water, (b) glycine in 0.0006 m aqueous nortriptyline, (c) glycine in 0.001 *m* aqueous nortriptyline, (d) glycine in 0.002 m aqueous nortriptyline, and (e) glycine in 0.004 m aqueous nortriptyline at temperatures: 305.15 K(◊),310.15 K(□), and 315 .15 K(Δ)

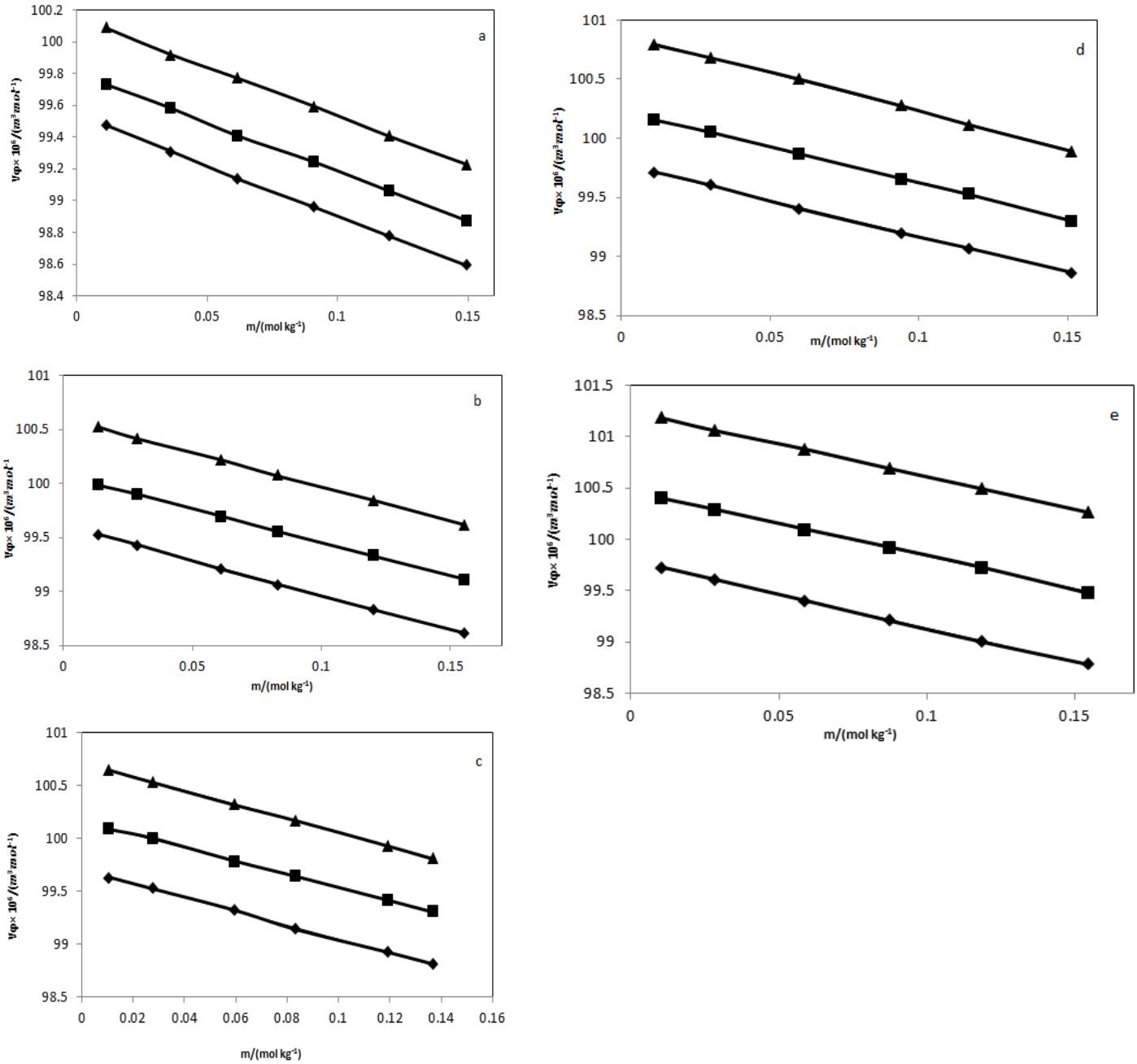



**Fig 2.**Plot of apparent molar volume $V_{\varphi}$, *vs.* molality, *m* of (a) histidine in water, (b) histidine in 0.0006 m aqueous nortriptyline, (c) histidine in 0.001 *m* aqueous nortriptyline, (d) histidine in 0.002 *m* aqueous nortriptyline, and (e) histidine in 0.004 *m* aqueous nortriptyline at temperatures: 305.15 K(◊), 310.15 K(□), and 315.15 K(Δ)

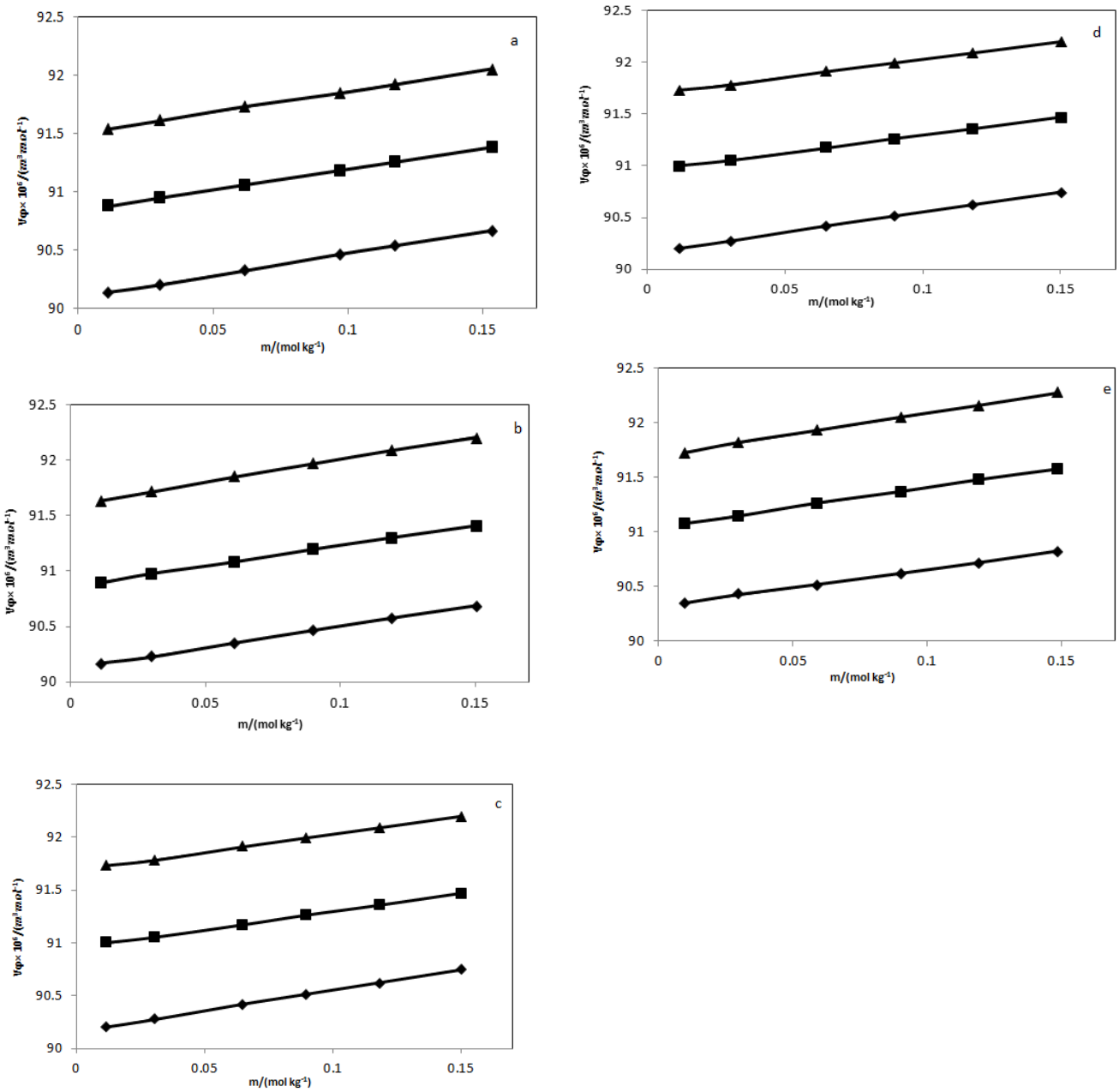



**Fig 3.**Plot of apparent molar volume $V_{\varphi}$, *vs.* molality, m of (a) valine in water, (b) valine in 0.0006 *m* aqueous nortriptyline, (c) valine in 0.001 *m* aqueous nortriptyline, (d) valine in 0.002 m aqueous nortriptyline, and (e) valine in 0.004 m aqueous nortriptyline at temperatures: 305.15 K(◊), 310.15 K(□), and 315 .15 K(Δ)

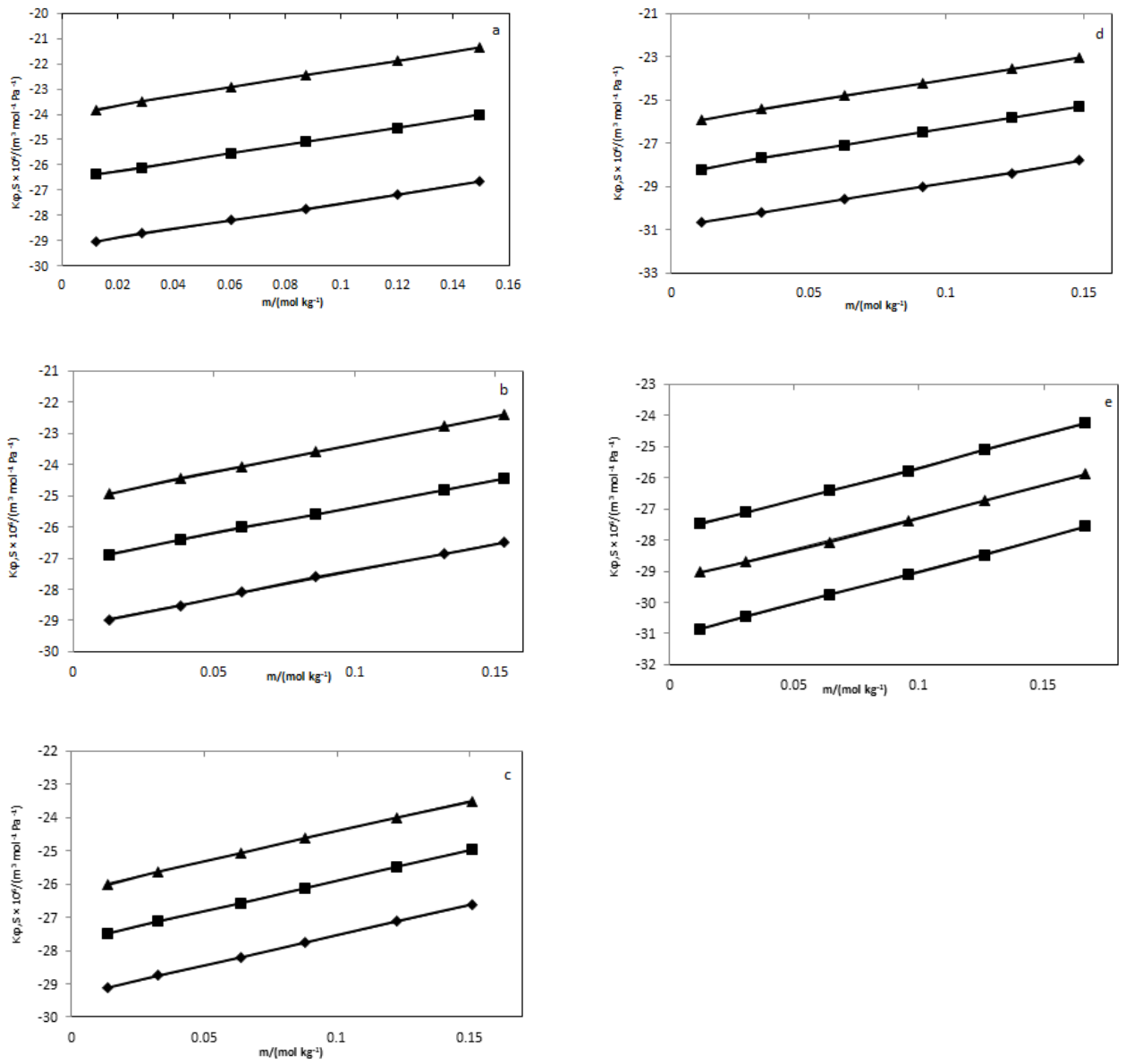



**Fig 4.**Plot of isentropic compressibility $\mathbf{k}_{\varphi,S}$, *vs.* molality, *m* of (a) glycine in water, (b) glycine in 0.0006 *m* aqueous nortriptyline, (c) glycine in 0.001 *m* aqueous nortriptyline, (d) glycine in 0.002 m aqueous nortriptyline, and (e) glycine in 0.004 m aqueous nortriptyline at temperatures: 305.15 K(◊), 310.15 K(□), and 315 .15 K(Δ)

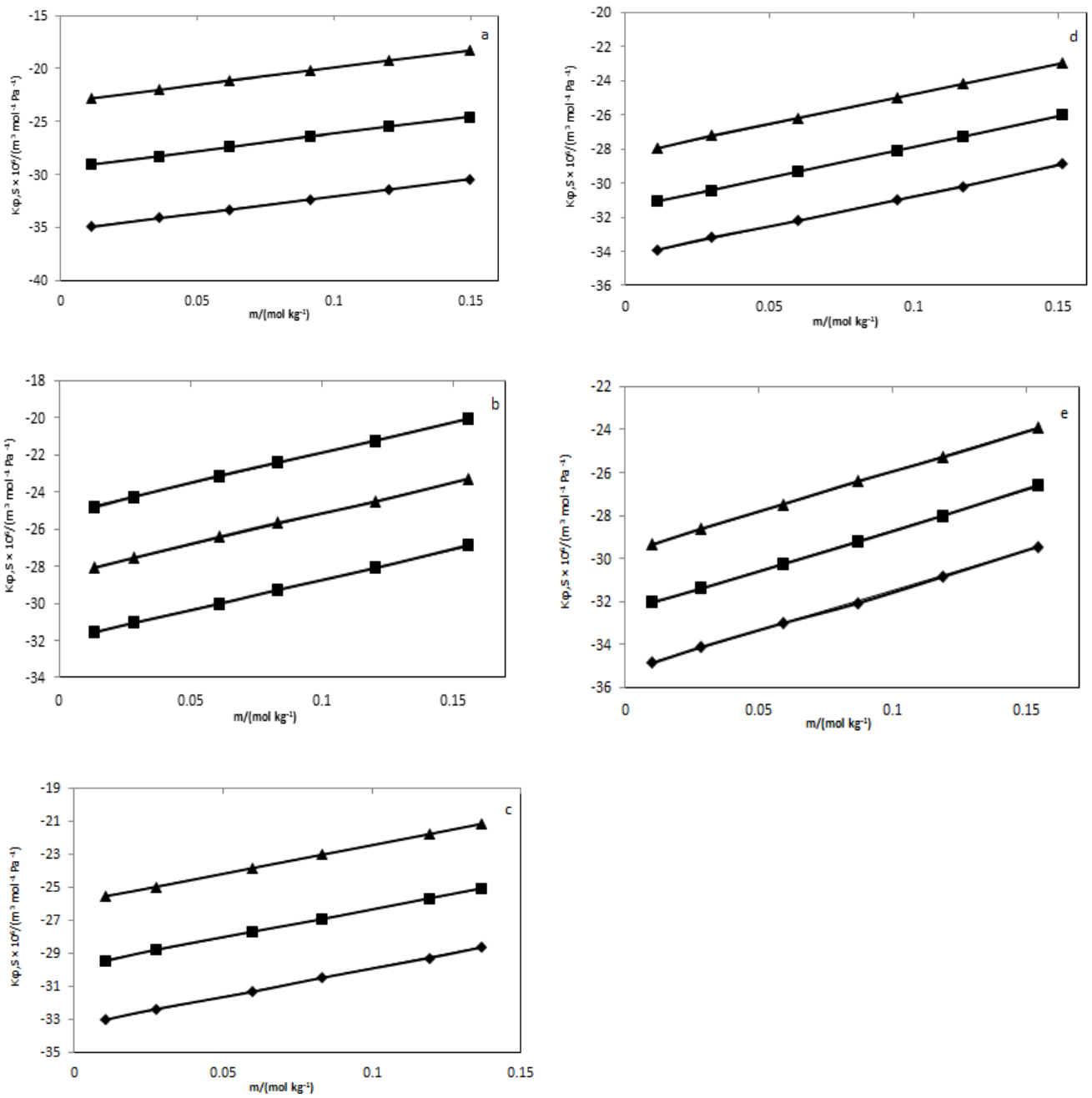



**Fig 5.**Plot of isentropic compressibility $\mathbf{k}_{\varphi s}$, *vs.* molality, *m* of (a) histidine in water, (b) histidine in 0.0006 *m* aqueous nortriptyline, (c) histidine in 0.001 *m* aqueous nortriptyline, (d) histidine in 0.002 *m* aqueous nortriptyline, and (e) histidine in 0.004 *m* aqueous nortriptyline at temperatures: 305.15 K(◊), 310.15 K(□), and 315.15 K(Δ)

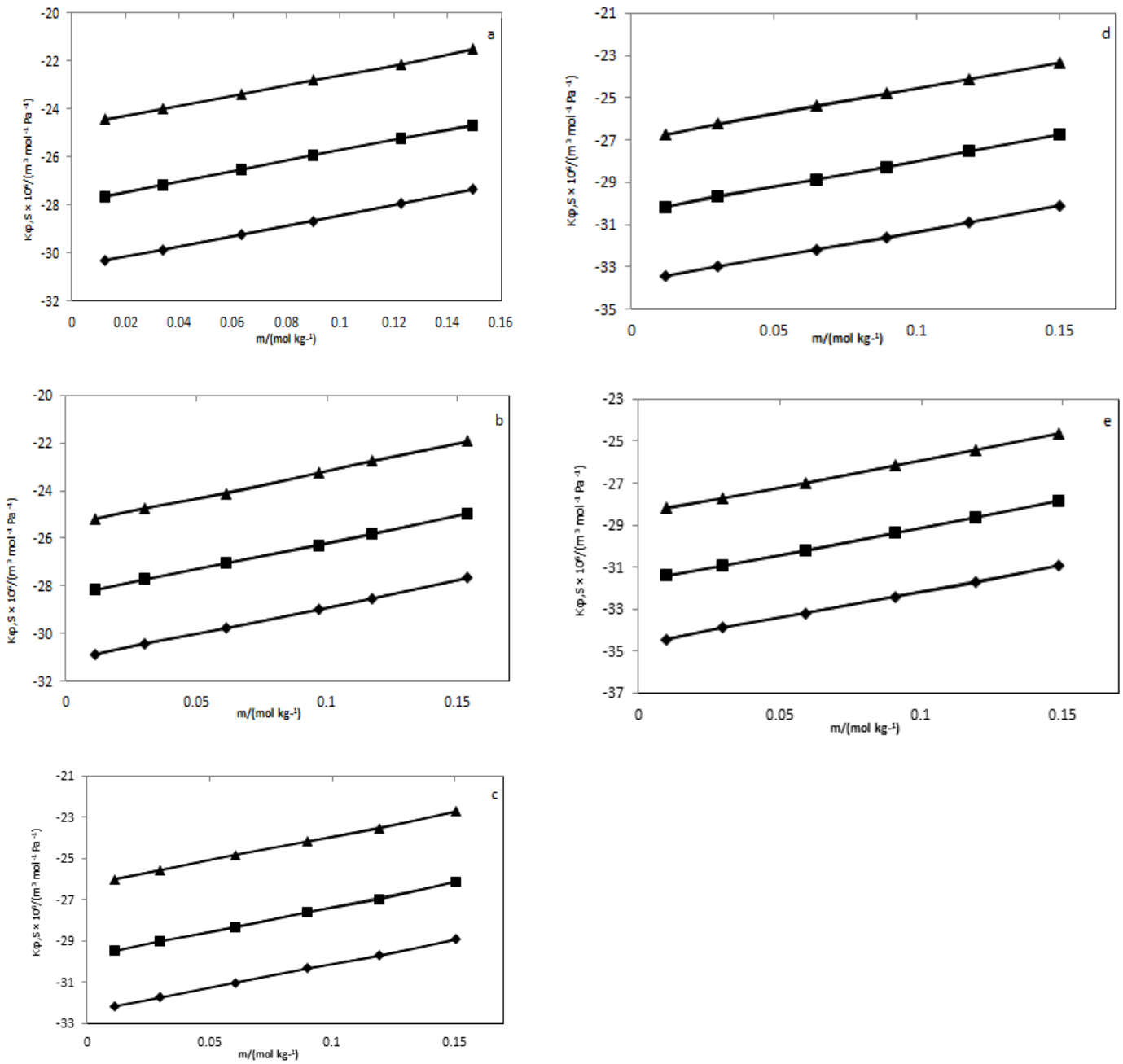



**Fig 6.**Plot of isentropic compressibility $\mathbf{k}_{\varphi,S}$, vs. molality, *m* of (a) valine in water, (b) valine in 0.0006 *m* aqueous amitriptyline, (c) valine in 0.001 m aqueous amitriptyline, (d) valine in 0.002 *m* aqueous amitriptyline, and (e) valine in 0.004 m aqueous amitriptyline at temperatures: 305.15 K(◊), 310.15 K(□), and 315.15 K(Δ)

**Table 1.**Specification of chemical samples

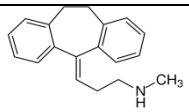
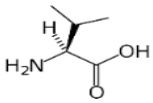
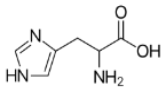
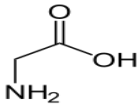
| Chemical name | Structure | Mass Fraction purity |
|---|---|---|
| Nortriptyline |  | >99% |
| Valine |  | >99% |
| Histidine |  | >99% |
| Glycine |  | >99% |

**Table 2.**Densities $\rho$ and speed of sounds $u$ of amino acids in water and aqueous nortriptyline solutions at different temperatures

| $m$/(mol Kg$^{-1}$) | $\rho$ x10$^{-3}$ / (kg m$^{-3}$) | | | $u$/(m S$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | $T$ = 305.15 k | $T$ = 310.15 k | $T$ = 315.15 k | $T$ = 305.15 k | $T$ = 310.15 k | $T$ = 315.15 k |
| Valine+water | | | | | | |
| 0 | 0.99504 | 0.99334 | 0.99145 | 1513.7 | 1523.7 | 1532.2 |
| 0.01 | 0.99538 | 0.99367 | 0.99177 | 1515.0 | 1524.9 | 1533.3 |
| 0.03 | 0.99596 | 0.99424 | 0.99233 | 1517.1 | 1526.9 | 1535.3 |
| 0.06 | 0.99674 | 0.99501 | 0.99307 | 1519.9 | 1529.7 | 1537.9 |
| 0.08 | 0.99745 | 0.99570 | 0.99375 | 1522.4 | 1532.1 | 1540.3 |
| 0.12 | 0.99831 | 0.99654 | 0.99457 | 1525.5 | 1535.1 | 1543.1 |
| 0.14 | 0.99901 | 0.99722 | 0.99523 | 1528.0 | 1537.5 | 1545.4 |
| Valine+0.0006 $m$ Nortriptylin | | | | | | |
| 0 | 0.99505 | 0.99335 | 0.99145 | 1513.79 | 1523.82 | 1532.27 |
| 0.01 | 0.99536 | 0.99365 | 0.99175 | 1514.92 | 1524.92 | 1533.33 |
| 0.03 | 0.99588 | 0.99416 | 0.99224 | 1516.8 | 1526.75 | 1535.09 |
| 0.06 | 0.99671 | 0.99497 | 0.99304 | 1519.86 | 1529.72 | 1537.95 |
| 0.09 | 0.99765 | 0.99589 | 0.99394 | 1523.26 | 1533.02 | 1541.1 |
| 0.11 | 0.99818 | 0.99641 | 0.99445 | 1525.2 | 1534.9 | 1542.89 |
| 0.15 | 0.99912 | 0.99733 | 0.99534 | 1528.54 | 1538.13 | 1545.99 |
| Valine+0.001 $m$ nortriptyline | | | | | | |
| 0 | 0.99506 | 0.99337 | 0.99146 | 1513.87 | 1523.88 | 1532.32 |
| 0.01 | 0.99538 | 0.99367 | 0.99176 | 1515.05 | 1525.03 | 1533.42 |
| 0.03 | 0.99588 | 0.99416 | 0.99224 | 1516.92 | 1526.85 | 1535.16 |
| 0.07 | 0.99669 | 0.99496 | 0.99302 | 1519.97 | 1529.82 | 1537.99 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.10 | 0.99747 | 0.99572 | 0.99376 | 1522.88 | 1532.64 | 1540.69 |
| 0.14 | 0.99823 | 0.99647 | 0.99449 | 1525.71 | 1535.38 | 1543.3 |
| 0.17 | 0.99904 | 0.99725 | 0.99525 | 1528.64 | 1538.2 | 1545.99 |
| Valine+0.002 *m* nortriptyline | | | | | | |
| 0 | 0.99509 | 0.99338 | 0.99147 | 1513.98 | 1523.99 | 1532.49 |
| 0.01 | 0.99541 | 0.99369 | 0.99178 | 1515.21 | 1525.18 | 1533.57 |
| 0.03 | 0.99592 | 0.99418 | 0.99226 | 1517.14 | 1527.04 | 1535.35 |
| 0.06 | 0.99684 | 0.99508 | 0.99314 | 1520.68 | 1530.45 | 1538.6 |
| 0.08 | 0.99748 | 0.99571 | 0.99375 | 1523.14 | 1532.81 | 1540.85 |
| 0.11 | 0.99823 | 0.99644 | 0.99446 | 1525.96 | 1535.51 | 1543.43 |
| 0.14 | 0.99905 | 0.99724 | 0.99525 | 1529.03 | 1538.45 | 1546.23 |
| Valine+0.004 *m* nortriptyline | | | | | | |
| 0 | 0.99517 | 0.99348 | 0.99151 | 1514.34 | 1524.32 | 1532.66 |
| 0.01 | 0.99543 | 0.99374 | 0.99176 | 1515.4 | 1525.34 | 1533.68 |
| 0.02 | 0.99597 | 0.99426 | 0.99228 | 1517.52 | 1527.4 | 1535.66 |
| 0.06 | 0.99675 | 0.99502 | 0.99302 | 1520.55 | 1530.34 | 1538.48 |
| 0.08 | 0.99758 | 0.99583 | 0.99382 | 1523.78 | 1533.46 | 1541.47 |
| 0.11 | 0.99832 | 0.99655 | 0.99452 | 1526.64 | 1536.21 | 1544.1 |
| 0.14 | 0.99907 | 0.99728 | 0.99524 | 1529.49 | 1538.96 | 1546.73 |
| Glycine+ water | | | | | | |
| 0 | 0.99504 | 0.99334 | 0.99145 | 1513.7 | 1523.7 | 1532.2 |
| 0.01 | 0.99545 | 0.99375 | 0.99185 | 1514.4 | 1524.3 | 1532.8 |
| 0.02 | 0.99601 | 0.99430 | 0.99239 | 1515.3 | 1525.2 | 1533.5 |
| 0.06 | 0.99708 | 0.99536 | 0.99344 | 1517.0 | 1526.8 | 1535.0 |
| 0.08 | 0.99797 | 0.99624 | 0.99431 | 1518.4 | 1528.1 | 1536.2 |
| 0.12 | 0.99907 | 0.99732 | 0.99537 | 1520.0 | 1529.6 | 1537.7 |
| 0.14 | 1.00004 | 0.99828 | 0.99632 | 1521.5 | 1531.0 | 1538.9 |
| Glycine+0.0006 *m* nortriptyline | | | | | | |
| 0 | 0.99505 | 0.99336 | 0.99146 | 1514.01 | 1523.8 | 1532.28 |
| 0.01 | 0.99548 | 0.99379 | 0.99189 | 1514.72 | 1524.48 | 1532.93 |
| 0.03 | 0.99633 | 0.99463 | 0.99272 | 1516.08 | 1525.78 | 1534.17 |
| 0.06 | 0.99707 | 0.99535 | 0.99344 | 1517.24 | 1526.89 | 1535.23 |
| 0.08 | 0.99795 | 0.99622 | 0.99429 | 1518.6 | 1528.2 | 1536.47 |
| 0.12 | 0.99945 | 0.99771 | 0.99576 | 1520.89 | 1530.38 | 1538.53 |
| 0.15 | 1.00015 | 0.99839 | 0.99644 | 1521.92 | 1531.36 | 1539.45 |
| Glycine+0.001 *m* nortriptyline | | | | | | |
| 0 | 0.99507 | 0.99337 | 0.99147 | 1514.11 | 1523.89 | 1532.3 |
| 0.01 | 0.99553 | 0.99382 | 0.99192 | 1514.86 | 1524.62 | 1533.01 |
| 0.03 | 0.99617 | 0.99445 | 0.99254 | 1515.9 | 1525.63 | 1533.99 |
| 0.06 | 0.99721 | 0.99549 | 0.99357 | 1517.57 | 1527.25 | 1535.56 |
| 0.09 | 0.99802 | 0.99628 | 0.99435 | 1518.83 | 1528.47 | 1536.74 |
| 0.13 | 0.99916 | 0.99741 | 0.99547 | 1520.58 | 1530.16 | 1538.38 |
| 0.16 | 1.00008 | 0.99832 | 0.99637 | 1521.96 | 1531.49 | 1539.67 |
| Glycine+0.002 *m* | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| nortriptyline | | | | | | |
| 0 | 0.99510 | 0.99340 | 0.99150 | 1514.09 | 1524.04 | 1532.49 |
| 0.01 | 0.99546 | 0.99377 | 0.99186 | 1514.72 | 1524.64 | 1533.06 |
| 0.03 | 0.99620 | 0.99450 | 0.99258 | 1515.98 | 1525.83 | 1534.19 |
| 0.06 | 0.99721 | 0.99550 | 0.99357 | 1517.66 | 1527.42 | 1535.69 |
| 0.09 | 0.99816 | 0.99643 | 0.99449 | 1519.2 | 1528.87 | 1537.06 |
| 0.11 | 0.99922 | 0.99748 | 0.99553 | 1520.9 | 1530.46 | 1538.55 |
| 0.15 | 1.00002 | 0.99827 | 0.99631 | 1522.13 | 1531.62 | 1539.63 |
| Glycine+0.004 *m* nortriptyline | | | | | | |
| 0 | 0.99515 | 0.99342 | 0.99156 | 1514.41 | 1524.35 | 1532.75 |
| 0.01 | 0.99555 | 0.99382 | 0.99195 | 1515.11 | 1525.03 | 1533.41 |
| 0.03 | 0.99618 | 0.99444 | 0.99257 | 1516.19 | 1526.08 | 1534.43 |
| 0.06 | 0.99729 | 0.99554 | 0.99365 | 1518.06 | 1527.9 | 1536.19 |
| 0.09 | 0.99835 | 0.99658 | 0.99469 | 1519.8 | 1529.58 | 1537.82 |
| 0.12 | 0.99935 | 0.99757 | 0.99566 | 1521.39 | 1531.11 | 1539.29 |
| 0.16 | 1.00067 | 0.99888 | 0.99695 | 1523.41 | 1533.07 | 1541.17 |
| Histidine+ water | | | | | | |
| 0 | 0.99504 | 0.99334 | 0.99145 | 1513.7 | 1523.7 | 1532.2 |
| 0.01 | 0.99566 | 0.99396 | 0.99206 | 1514.8 | 1524.6 | 1533.5 |
| 0.03 | 0.99704 | 0.99534 | 0.99344 | 1517.0 | 1526.7 | 1535.2 |
| 0.06 | 0.99848 | 0.99677 | 0.99486 | 1519.2 | 1528.7 | 1537.0 |
| 0.09 | 1.00013 | 0.99841 | 0.99649 | 1521.7 | 1530.9 | 1538.9 |
| 0.11 | 1.00174 | 1.00002 | 0.99809 | 1524.0 | 1532.9 | 1540.6 |
| 0.14 | 1.00340 | 1.00168 | 0.99974 | 1526.3 | 1534.9 | 1542.3 |
| Histidine+0.0006 *m* nortriptyline | | | | | | |
| 0 | 0.99506 | 0.99335 | 0.99146 | 1513.9 | 1523.88 | 1532.3 |
| 0.01 | 0.99580 | 0.99410 | 0.99219 | 1515.06 | 1524.98 | 1533.34 |
| 0.02 | 0.99664 | 0.99493 | 0.99302 | 1516.34 | 1526.19 | 1534.48 |
| 0.05 | 0.99845 | 0.99672 | 0.99480 | 1519 | 1528.69 | 1536.83 |
| 0.08 | 0.99969 | 0.99796 | 0.99602 | 1520.75 | 1530.33 | 1538.37 |
| 0.11 | 1.00177 | 1.00002 | 0.99807 | 1523.55 | 1532.95 | 1540.81 |
| 0.14 | 1.00375 | 1.00198 | 1.00002 | 1526.04 | 1535.26 | 1542.96 |
| Histidine+0.001 *m* nortriptyline | | | | | | |
| 0 | 0.99507 | 0.99338 | 0.99147 | 1513.92 | 1523.9 | 1532.34 |
| 0.01 | 0.99567 | 0.99397 | 0.99206 | 1514.88 | 1524.81 | 1533.27 |
| 0.02 | 0.99661 | 0.99491 | 0.99299 | 1516.36 | 1526.21 | 1534.58 |
| 0.05 | 0.99839 | 0.99668 | 0.99474 | 1519.07 | 1528.76 | 1536.95 |
| 0.08 | 0.99970 | 0.99797 | 0.99603 | 1520.96 | 1530.55 | 1538.6 |
| 0.12 | 1.00171 | 0.99997 | 0.99801 | 1523.75 | 1533.15 | 1540.99 |
| 0.15 | 1.00269 | 1.00094 | 0.99898 | 1525.03 | 1534.35 | 1542.08 |
| Histidine+0.002 *m* nortriptyline | | | | | | |
| 0 | 0.995083 | 0.993402 | 0.991499 | 1513.99 | 1524.02 | 1532.47 |
| 0.01 | 0.995699 | 0.994014 | 0.992105 | 1515 | 1525 | 1533.4 |
| 0.02 | 0.996742 | 0.99505 | 0.993131 | 1516.67 | 1526.61 | 1534.93 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.05 | 0.998395 | 0.996691 | 0.994756 | 1519.23 | 1529.06 | 1537.26 |
| 0.08 | 1.000318 | 0.998601 | 0.996649 | 1522.06 | 1531.76 | 1539.82 |
| 0.11 | 1.001589 | 0.999864 | 0.997903 | 1523.85 | 1533.46 | 1541.42 |
| 0.15 | 1.003509 | 1.001774 | 0.999796 | 1526.39 | 1535.88 | 1543.7 |
| Histidine+0.004 *m* nortriptyline | | | | | | |
| 0 | 0.99516 | 0.99345 | 0.99155 | 1514.45 | 1524.4 | 1532.8 |
| 0.009 | 0.99575 | 0.99401 | 0.99211 | 1515.37 | 1525.32 | 1533.69 |
| 0.02 | 0.99676 | 0.99501 | 0.99309 | 1517.02 | 1526.92 | 1535.23 |
| 0.05 | 0.99846 | 0.99669 | 0.99475 | 1519.69 | 1529.5 | 1537.71 |
| 0.08 | 1.00003 | 0.99824 | 0.99628 | 1522.06 | 1531.77 | 1539.88 |
| 0.12 | 1.0018 | 0.99999 | 0.99801 | 1524.57 | 1534.18 | 1542.2 |
| 0.14 | 1.00379 | 1.00196 | 0.99995 | 1527.22 | 1536.7 | 1544.62 |

**Table 3.**Apparent molar volumes $V_\varphi$ and isentropic compression $V_{\varphi,s}$ of amino acids in water and aqueous nortriptyline solutions at different temperatures

| $m$/(mol Kg$^{-1}$ ) | $V_\varphi$ x $10^{-6}$ /(m$^3$ mol$^{-1}$) | | | $K_{\varphi,s}$ x $10^6$/ (m$^3$ mol$^{-1}$ Pa$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | $T$ = 305.15 k | $T$ = 310.15 k | $T$ = 315.15 k | $T$ = 305.15 k | $T$ = 310.15 k | $T$ = 315.15 k |
| Valine+water | | | | | | |
| 0.01 | 90.04 | 90.80 | 91.57 | -30.28 | -27.65 | -24.43 |
| 0.03 | 90.13 | 90.86 | 91.64 | -29.85 | -27.15 | -24 |
| 0.06 | 90.22 | 90.97 | 91.76 | -29.23 | -26.52 | -23.39 |
| 0.08 | 90.32 | 91.07 | 91.86 | -28.66 | -25.92 | -22.81 |
| 0.12 | 90.45 | 91.20 | 91.98 | -27.94 | -25.23 | -22.16 |
| 0.14 | 90.53 | 91.30 | 92.07 | -27.34 | -24.69 | -21.50 |
| Valine+0.0006 *m* nortriptylin | | | | | | |
| 0.01 | 90.13 | 90.87 | 91.62 | -30.86 | -28.17 | -25.17 |
| 0.03 | 90.20 | 90.94 | 91.67 | -30.41 | -27.72 | -24.73 |
| 0.06 | 90.30 | 91.04 | 91.77 | -29.77 | -27.04 | -24.10 |
| 0.09 | 90.42 | 91.16 | 91.88 | -28.99 | -26.28 | -23.24 |
| 0.11 | 90.50 | 91.22 | 91.95 | -28.52 | -25.81 | -22.73 |
| 0.15 | 90.62 | 91.34 | 92.07 | -27.65 | -24.94 | -21.92 |
| Valine+0.001 *m* nortriptyline | | | | | | |
| 0.009 | 90.17 | 90.89 | 91.63 | -32.15 | -29.48 | -26.00 |
| 0.03 | 90.22 | 90.97 | 91.71 | -31.74 | -29.01 | -25.56 |
| 0.06 | 90.35 | 91.08 | 91.84 | -31.01 | -28.33 | -24.81 |
| 0.08 | 90.46 | 91.19 | 91.96 | -30.33 | -27.59 | -24.16 |
| 0.11 | 90.57 | 91.30 | 92.08 | -29.71 | -26.96 | -23.52 |
| 0.14 | 90.68 | 91.410 | 92.20 | -28.91 | -26.10 | -22.70 |
| Valine+0.002 *m* nortriptyline | | | | | | |
| 0.01 | 90.20 | 91.00 | 91.73 | -33.43 | -30.16 | -26.76 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.03 | 90.27 | 91.05 | 91.77 | -32.97 | -29.64 | -26.23 |
| 0.06 | 90.42 | 91.17 | 91.90 | -32.16 | -28.85 | -25.36 |
| 0.08 | 90.51 | 91.26 | 91.99 | -31.62 | -28.27 | -24.79 |
| 0.11 | 90.62 | 91.35 | 92.08 | -30.90 | -27.53 | -24.11 |
| 0.14 | 90.74 | 91.46 | 92.19 | -30.08 | -26.72 | -23.33 |
| Valine+0.004 m nortriptyline | | | | | | |
| 0.01 | 90.34 | 91.07 | 91.72 | -34.44 | -31.40 | -28.15 |
| 0.02 | 90.42 | 91.14 | 91.81 | -33.87 | -30.92 | -27.70 |
| 0.06 | 90.51 | 91.26 | 91.92 | -33.18 | -30.21 | -26.99 |
| 0.08 | 90.62 | 91.37 | 92.05 | -32.40 | -29.37 | -26.16 |
| 0.11 | 90.71 | 91.47 | 92.15 | -31.72 | -28.62 | -25.41 |
| 0.14 | 90.82 | 91.57 | 92.27 | -30.91 | -27.83 | -24.63 |
| Glycine+ water | | | | | | |
| 0.01 | 41.11 | 41.53 | 41.96 | -29.04 | -26.37 | -23.83 |
| 0.02 | 41.14 | 41.58 | 42.02 | -28.71 | -26.11 | -23.47 |
| 0.06 | 41.23 | 41.66 | 42.11 | -28.20 | -25.53 | -22.91 |
| 0.08 | 41.30 | 41.74 | 42.19 | -27.76 | -25.08 | -22.43 |
| 0.12 | 41.39 | 41.83 | 42.28 | -27.18 | -24.52 | -21.87 |
| 0.14 | 41.46 | 41.90 | 42.36 | -26.65 | -23.99 | -21.33 |
| Glycine+0.0006 *m* nortriptyline | | | | | | |
| 0.01 | 41.18 | 41.58 | 41.99 | -28.96 | -26.88 | -24.94 |
| 0.02 | 41.24 | 41.66 | 42.07 | -28.51 | -26.40 | -24.43 |
| 0.06 | 41.30 | 41.72 | 42.14 | -28.09 | -26.00 | -24.05 |
| 0.08 | 41.36 | 41.79 | 42.21 | -27.60 | -25.59 | -23.59 |
| 0.12 | 41.47 | 41.91 | 42.35 | -26.86 | -24.81 | -22.77 |
| 0.15 | 41.53 | 41.97 | 42.41 | -26.50 | -24.45 | -22.39 |
| Glycine+0.001 *m* nortriptyline | | | | | | |
| 0.01 | 41.26 | 41.65 | 42.04 | -29.11 | -27.48 | -26.02 |
| 0.02 | 41.32 | 41.71 | 42.10 | -28.75 | -27.11 | -25.62 |
| 0.06 | 41.41 | 41.79 | 42.19 | -28.19 | -26.56 | -25.06 |
| 0.09 | 41.47 | 41.85 | 42.25 | -27.75 | -26.11 | -24.60 |
| 0.13 | 41.57 | 41.95 | 42.34 | -27.11 | -25.47 | -23.99 |
| 0.16 | 41.65 | 42.02 | 42.42 | -26.60 | -24.96 | -23.51 |
| Glycine+0.002 *m* nortriptyline | | | | | | |
| 0.01 | 41.29 | 41.67 | 42.15 | -30.65 | -28.21 | -25.92 |
| 0.03 | 41.35 | 41.74 | 42.22 | -30.20 | -27.66 | -25.41 |
| 0.05 | 41.44 | 41.84 | 42.29 | -29.57 | -27.07 | -24.78 |
| 0.09 | 41.51 | 41.93 | 42.35 | -28.99 | -26.46 | -24.22 |
| 0.12 | 41.61 | 42.02 | 42.43 | -28.36 | -25.81 | -23.55 |
| 0.14 | 41.69 | 42.08 | 42.49 | -27.79 | -25.29 | -23.02 |
| Glycine+0.004 *m* nortriptyline | | | | | | |
| 0.01 | 41.35 | 41.79 | 42.23 | -30.85 | -29.03 | -27.46 |
| 0.03 | 41.41 | 41.82 | 42.27 | -30.44 | -28.69 | -27.10 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.06 | 41.49 | 41.90 | 42.34 | -29.74 | -28.05 | -26.41 |
| 0.09 | 41.57 | 41.97 | 42.42 | -29.10 | -27.38 | -25.78 |
| 0.12 | 41.65 | 42.04 | 42.48 | -28.46 | -26.72 | -25.09 |
| 0.16 | 41.75 | 42.13 | 42.56 | -27.56 | -25.88 | -24.24 |
| Histidine+ water | | | | | | |
| 0.01 | 99.47 | 99.73 | 100.08 | -34.95 | -29.06 | -22.81 |
| 0.03 | 99.31 | 99.58 | 99.92 | -34.11 | -28.28 | -22.02 |
| 0.06 | 99.13 | 99.40 | 99.77 | -33.33 | -27.41 | -21.12 |
| 0.09 | 98.95 | 99.24 | 99.59 | -32.35 | -26.38 | -20.18 |
| 0.11 | 98.77 | 99.05 | 99.40 | -31.42 | -25.46 | -19.24 |
| 0.14 | 98.59 | 98.87 | 99.22 | -30.42 | -24.55 | -18.31 |
| Histidine+0.0006 *m* nortriptyline | | | | | | |
| 0.01 | 99.53 | 99.98 | 100.52 | -31.55 | -28.07 | -24.81 |
| 0.02 | 99.43 | 99.90 | 100.41 | -31.04 | -27.53 | -24.24 |
| 0.05 | 99.20 | 99.70 | 100.21 | -30.02 | -26.41 | -23.12 |
| 0.08 | 99.06 | 99.55 | 100.06 | -29.27 | -25.66 | -22.40 |
| 0.11 | 98.83 | 99.32 | 99.84 | -28.09 | -24.51 | -21.22 |
| 0.14 | 98.61 | 99.11 | 99.61 | -26.86 | -23.27 | -20.04 |
| Histidine+0.001 *m* nortriptyline | | | | | | |
| 0.01 | 99.63 | 100.08 | 100.64 | -33.01 | -29.45 | -25.52 |
| 0.02 | 99.52 | 100.00 | 100.52 | -32.36 | -28.77 | -24.97 |
| 0.05 | 99.32 | 99.78 | 100.31 | -31.33 | -27.68 | -23.84 |
| 0.08 | 99.14 | 99.64 | 100.16 | -30.48 | -26.92 | -23.03 |
| 0.12 | 98.92 | 99.41 | 99.92 | -29.28 | -25.66 | -21.77 |
| 0.15 | 98.81 | 99.30 | 99.80 | -28.64 | -25.06 | -21.15 |
| Histidine+0.002 *m* nortriptyline | | | | | | |
| 0.01 | 99.71 | 100.15 | 100.79 | -33.90 | -31.05 | -27.95 |
| 0.02 | 99.60 | 100.05 | 100.68 | -33.18 | -30.40 | -27.21 |
| 0.05 | 99.40 | 99.87 | 100.50 | -32.21 | -29.32 | -26.18 |
| 0.08 | 99.19 | 99.65 | 100.27 | -30.98 | -28.07 | -24.98 |
| 0.11 | 99.06 | 99.52 | 100.11 | -30.18 | -27.26 | -24.17 |
| 0.15 | 98.86 | 99.30 | 99.88 | -28.86 | -26.01 | -22.96 |
| Histidine+0.004 *m* nortriptyline | | | | | | |
| 0.009 | 99.73 | 100.40 | 101.18 | -34.86 | -32.03 | -29.34 |
| 0.02 | 99.61 | 100.29 | 101.05 | -34.12 | -31.39 | -28.61 |
| 0.05 | 99.40 | 100.10 | 100.87 | -33.01 | -30.26 | -27.47 |
| 0.08 | 99.21 | 99.92 | 100.69 | -32.07 | -29.21 | -26.39 |
| 0.12 | 99.00 | 99.72 | 100.49 | -30.84 | -28.00 | -25.28 |
| 0.14 | 98.78 | 99.47 | 100.26 | -29.43 | -26.58 | -23.92 |

**Table 4.**Limiting apparent molar volume $V_{\omega^{\circ}}$, limiting apparent molar isentropic compression $\mathbf{k}^{0}{}_{\omega,s}$ , $S_{v}$, and $S_{k}$ aqueous nortriptyline solutions at different temperatures

| $m$/(mol $\mathbf{k}g^{-1}$ ) | $T$/(k) | $\mathbf{k}g^{-1}$ ($m_3mol^{-1}$ ) | $S_v$×10⁶ ($m^3$ $mol^{-1}$ $\mathbf{k}g^{-1}$) | $\mathbf{k}^{0}{}_{\omega,s}$ ×10⁶ ($m_3mol^{-1}$ $pa^{-1}$ ) | $S_k$×10⁶ ($m_3mol^{-1}$ $pa^{-1}$ $\mathbf{k}g^{-1}$ ) |
|---|---|---|---|---|---|
| Valine | | | | | |
| 0.0006 | 305.15 | 90.09 | 3.77 | -31.12 | 22.3 |
| | 310.15 | 90.83 | 3.55 | -28.42 | 22.39 |
| | 315.15 | 91.58 | 3.60 | -25.44 | 22.88 |
| 0.001 | 305.15 | 90.12 | 3.79 | -32.43 | 23.18 |
| | 310.15 | 90.86 | 3.69 | - 29.76 | 23.94 |
| | 315.15 | 91.59 | 4.11 | - 26.26 | 23.41 |
| 0.002 | 305.15 | 90.15 | 3.93 | - 33.72 | 24 |
| | 310.15 | 90.95 | 3.42 | - 30.43 | 24.59 |
| | 315.15 | 91.68 | 3.42 | - 27 | 24.54 |
| 0.004 | 305.15 | 90.37 | 3.85 | - 34.66 | 25.06 |
| | 310.15 | 91.06 | 3.63 | - 31.69 | 25.78 |
| | 315.15 | 91.80 | 3.75 | - 28.45 | 25.57 |
| Glycine | | | | | |
| 0.0006 | 305.15 | 41.15 | 2.44 | - 29.17 | 17.58 |
| | 310.15 | 41.55 | 2.75 | - 27.07 | 17.19 |
| | 315.15 | 41.96 | 2.93 | - 25.14 | 18.01 |
| 0.001 | 305.15 | 41.23 | 2.72 | - 29.35 | 18.29 |
| | 310.15 | 41.61 | 2.79 | - 27.72 | 18.35 |
| | 315.15 | 42.01 | 2.77 | - 26.23 | 18.24 |
| 0.002 | 305.15 | 41.26 | 2.89 | - 30.88 | 20.60 |
| | 310.15 | 41.64 | 3.04 | - 28.40 | 21.01 |
| | 315.15 | 42.13 | 2.39 | - 26.12 | 20.87 |
| 0.004 | 305.15 | 41.33 | 2.54 | - 31.10 | 21.11 |
| | 310.15 | 41.76 | 2.23 | - 29.32 | 20.48 |
| | 315.15 | 42.20 | 2.18 | - 27.74 | 20.88 |
| Histidine | | | | | |
| 0.0006 | 305.15 | 99.61 | -6.45 | - 31.99 | 32.79 |
| | 310.15 | 100.07 | -6.16 | - 28.49 | 33.48 |
| | 315.15 | 100.6 | -6.33 | - 25.2 | 33.25 |
| 0.001 | 305.15 | 99.7 | -6.54 | - 33.36 | 34.41 |
| | 310.15 | 100.16 | -6.26 | - 29.77 | 34.54 |
| | 315.15 | 100.71 | -6.60 | - 25.91 | 34.79 |
| 0.002 | 305.15 | 99.77 | -6.08 | - 34.29 | 35.52 |
| | 310.15 | 100.23 | -6.09 | - 31.46 | 35.98 |
| | 315.15 | 100.86 | -6.46 | - 28.30 | 35.36 |
| 0.004 | 305.15 | 99.79 | -6.61 | - 35.22 | 37.14 |
| | 310.15 | 100.48 | -6.36 | - 32.46 | 37.75 |
| | 315.15 | 101.25 | -6.35 | - 29.69 | 37.39 |

**Table 5.** Partial molar volume of transfer $V_{\phi,tr}$, and partial molar isentropic compression of transfer $\mathbf{k}_{\phi s,tr}$, of amino acids in water and in aqueous nortriptyline solutions at different temperatures

| $m$/(mol $\mathbf{k}g^{-1}$) | $V_{\phi,tr}$×**10⁶** /( $m_3mol^{-1}$ ) | | | $\mathbf{k}_{\phi s,tr}$×**10⁶** / ($m_3mol^{-1}$ $pa^{-1}$) | | |
|---|---|---|---|---|---|---|
| | $T$ = 305.15 k | $T$ = 310.15 k | $T$ = 315.15 k | $T$ = 305.15 k | $T$ = 310.15 k | $T$ = 315.15 k |
| Valine | | | | | | |
| 0.0006 | 0.08 | 0.09 | 0.06 | 0.54 | 0.62 | 0.65 |
| 0.001 | 0.11 | 0.11 | 0.07 | 1.85 | 1.86 | 1.54 |
| 0.002 | 0.15 | 0.20 | 0.16 | 3.14 | 2.64 | 2.28 |
| 0.004 | 0.31 | 0.29 | 0.16 | 4.09 | 3.80 | 3.74 |
| Histidine | | | | | | |
| 0.0006 | 0.07 | 0.27 | 0.45 | 0.37 | 1.12 | 2.02 |
| 0.001 | 0.16 | 0.36 | 0.56 | 1.74 | 2.41 | 2.74 |
| 0.002 | 0.23 | 0.43 | 0.72 | 2.67 | 4.09 | 5.13 |
| 0.004 | 0.25 | 0.67 | 1.10 | 3.60 | 5.09 | 6.52 |
| Glycine | | | | | | |
| 0.0006 | 0.08 | 0.04 | 0.02 | 0.39 | 0.47 | 1.13 |
| 0.001 | 0.15 | 0.11 | 0.06 | 0.58 | 1.13 | 2.22 |
| 0.002 | 0.18 | 0.13 | 0.19 | 2.10 | 1.80 | 2.11 |
| 0.004 | 0.25 | 0.25 | 0.26 | 2.32 | 2.72 | 2.72 |

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