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Theoretical Thermodynamic Study of Arginine and Lysine Amino Acids at different Solvents

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ABSTRACT

The thermodynamic functions such as enthalpy, H°, Gibbs free energy, G°, and entropy, S°, of Arginine and Lysine amino acids were theoretically studied at different polar solvents by using ″Gaussian o3″, software. First, the structural optimization of isolated Arginine and Lysine were done in the gas phase by applying the Density Functional Theory (B3LYP) level with 3-21G, 6-31G and 6-311G basis sets. Moreover, vibrational frequencies were calculated in gas phase on the optimized geometries at the same level of theory to obtain enthalpy, H°, Gibbs free energy, G°, and entropy, S°. Then, the calculation about the solvent effects on the thermodynamic functions of Arginine and lysine amino acids were performed for the various polar solvents (Water, Methanol and Ethanol) by using self-consistent Reaction-Field (SCRF=PCM) model at B3LYP/6-311G. Thermodynamically analysis shows the relative enthalpy changes, ΔH°, Gibbs free energy changes, ΔG°, are negative values but the entropy changes, ΔS°, are positive values for Arginine and Lysine molecules. Also, the results shows, with increasing dielectric constant of solvents the stability of considered molecules increases.

Keywords: Amino acids; Arginine; Lysine; B3LYP-calculations; Thermodynamic functions

INTRODUCTION

Arginine, 2-Amino-3-carbamoylpropanoic acid is an essential amino acid has a positive charge and is often found in the active centers of proteins and that plays important role in nitrogen metabolism. As a cation, Arginine, as well as Lysine, plays a role in maintaining the overall charge balance of a protein. Arginine has basic chemical properties, it is a chemical precursor to nitric oxide. Nitric oxide is a powerful neurotransmitter that helps blood vessels relax and also improves circulation.

Lysine is an essential amino acid, which means that the human body cannot synthesize it and must obtain it through food sources. Lysine aids in building muscle tissue, recovering from injury or surgery, and absorbing calcium effectively. It also helps the body produce antibodies, enzymes and hormones. Lysine is basically alanine with a propylamine substituent on the β carbon [1-3].

Theoretical study on the solvation thermodynamics properties of amino acids become very important in developing a molecular view of how different residues interact with each other and with solvent. In this study, the structural optimization of

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the two amino acids Arginine and Lysine were investigated.The optimization results of the isolated Arginine and Lysine molecules in the gas phase, at the Density Functional Theory (B3LYP) level with 3-21G, 6-31G and 6-311G basis sets have also been carried out. The calculation about solvent effects (Water, Methanol and Ethanol) on the thermodynamic functions such as enthalpy, H°, Gibbs free energy, G°, and enthropy, S°, with using PCM model and vibrational frequencies method at B3LYP/6-311G level of Arginine and Lysine molecules were performed and then the solvent effects of surrounding were analyzed.

COMPUTATIONAL METHODS

Geometries

Gaussian 03[21], suit of programs can be used in many field of science, engineering, statistics and mathematics in order to determine the structural and thermodynamics properties of molecules and complex systems at the atomic level. In other hands, all calculations were done with the Gaussian 03, ab initio packages at the Density Functional Theory (B3LYP) level. The geometry of Arginine and Lysine molecules were optimized at the B3LYP/3-21G, 6-31G and 6-311G levels in gas phase. The minimum energy were obtained by B3LYP/6-311G level of optimizations for Arginine and Lysine molecules in the gas phase. Then, vibrational frequencies were calculated in gas phase on the optimized geometries at the same level of theory to obtain enthalpy, H°, Gibbs free energy, G°, and entropy, S°, in STAP condition (t=25°C, P=1atm).

Solvent model

A Self Consistent Reaction-Field (SCRF=PCM) model with three solvents including: (Water, Methnol and Ethanol) were used in these calculations. First, molecular geometries were obtained by B3LYP/6-311G level of optimization in the gas phase, then each of them separately placed in three solvents and the results were compared with each and gaseous phase.

RESULTS AND DISCUSSION

At the first, the geometries optimization of Arginine and Lysine molecules were selected in the gase phase. These molecules were found to be stable in the optimized gas phase at B3LYP/3-21G, 6-31G and 6-311G level. The calculation results relative energy (kcal/mol) in gas phase are shown in Table1.

In accordance with the obtained results, the minimum energy were related to basis set 6-311G level. Therefore, here the basis set of 6-311G were selected for another calculations. Vibrational frequencies calculations were applied in the gas phase for the determining thermodynamics functions such as enthalpy, H°, Gibbs free energy, G°, and entropy, S°, of Arginine and Lysine molecules in STAP condition(t=25°C, P=1atm). The results are presented in Table2.

A Self Consistent Reaction-Field (SCRF=PCM) model were used for obtain an estimation of the solvent effects on the optimized geometreies gasous phase in various solvents such as (Water, Methanol and Ethanol). Then, calculations about vibrational frequencies for determining themodynamic parameters such as enthalpy, H°, Gibbs free energy, G°, and entropy, S°, were applied of considered solvents. The enthalpy changes are identified by: $\Delta H^{\circ} = H^{\circ}_{solut} - H^{\circ}_{gas\ phase}$ Gibbs free energy changes are identified by: $\Delta G^{\circ} = G^{\circ}_{solut} - G^{\circ}_{gas\ phase}$ and entropy changes are identified by: $\Delta S^{\circ} = S^{\circ}_{solut} - S^{\circ}_{gas\ phase}$. The thermodynamic parameters such as, enthalpy changes,ΔH°, Gibbs free energy changes, ΔG° and entropy changes,

ΔS°, in kcal/mol for Arginine and Lysine as a function of dielectric constant,ε, of considered solvents are shows in Table3. The results shows the stability of these molecules reduces with decreasing polarisibility of solvents. The most stabilities is observed for Water with ε=78.39 and the lowest stabilities is for Ethanol with ε=24.55.

Regular alterations were observed concerning thermodynamic functions *versus* dielectric constant. with increasing of dielectric constant of the solvents the enthalpy changes, ΔH°, and Gibbs free energy changes, ΔG°, were decreased and entropy changes, ΔS°, were increased (Fig1a-c). The Fig.1a shows the plot of the enthalpy changes ΔH° (in kcal/mol) of Arginine and Lysine versus the dielectric constant, ε, of the three solvents. Obviously, the magnitude of ΔH° is decreased by increasing the dielectric constant, ε, of the solvents. The Fig.1b shows the plot of the Gibbs free energy changes ΔG° (in kcal/mol) of Arginine and Lysine versus the dielectric constant, ε, of the three solvents. The results in Fig.1b shows with increasing of dielectric constant, ε, of solvents the Gibbs free energy changes is decreases. The Fig.1c shows the plot of the enthropy changes ΔS° (in kcal/mol) of Arginine and Lysine versus the dielectric constant, ε, of the three solvents. The entropy changes values are positive and can be related to the structural stability in gas phase and solution phase. The results in Fig.1c shows, with increasing of dielectric constant, ε, of solvents the entropy changes is increases.

Thermodynamic analysis

Table 2 displays the calculated relative enthalpies, H°, Gibbs free energies, G° and entropies, S° in gas phase for Arginine and Lysine molecules. In addition, the calculated relative enthalpy changes, ΔH°, Gibbs free energy changes, ΔG° and entropy changes, ΔS° for Arginine and Lysine molecules as a function of dielectric constant, ε, of considered solvents are shown in Table 3. Since, the plots of calculated relative enthalpy changes, ΔH°, Gibbs free energy changes, ΔG° and entropy changes, ΔS° versus the dielectric constant,ε, are drown in Fig.1a-c respectively. From Table3 and Figs.1a-b it can be seen that Arginine and Lysine molecules have negative values of relative enthalpy changes, ΔH°, and Gibbs free energy changes, ΔG°, in considered solvents. Also, our results in Table 3 and Figs. 1c shows entropy changes, ΔS°, for Arginine and Lysine molecules have positive values. These observations can be related to the structural stability of Arginine and Lysine molecules in solution phase with high dielectric constant (Water, ε=78.39).

Table1. Absolute calculated results of the conformational energies (E (in kcal/mol)) of Arginine and Lysine obtained by geometry optimization at basis set 6-311G, 6-31G and 3-21G levels

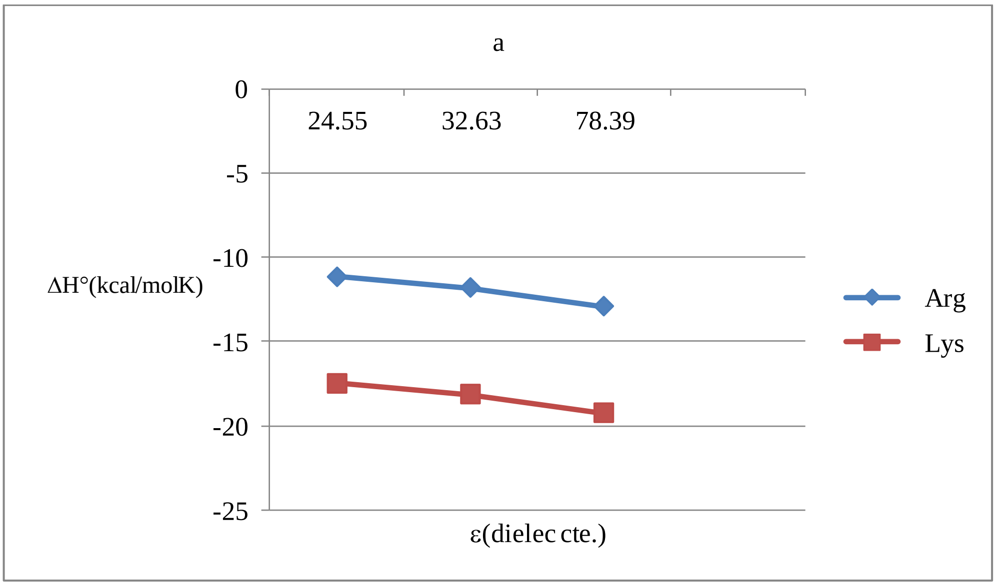
	E (kcal/mol)	
Basis set	**Arg**	**Lys**
3-21G	-340213.5261	-310098.7822
6-31G	-340278.1258	-310105.1475
6-311G	-340296.8337	-310118.2581

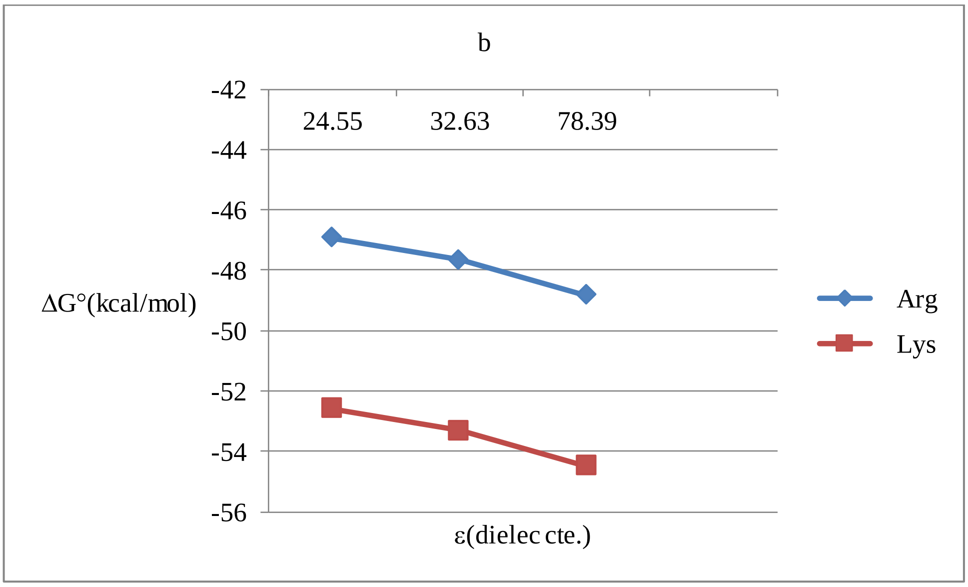
Table 2. The determining thermodynamic functions of Arginine and Lysine by using vibrational frequencies calculations with the B3LYP/6-311G method in the gas phase

H°(kcal/mol)	G°(kcal/mol)	S°(kcal/mol)
-340224.7148	Arg -340249.5814	0.083403
-310062.5249	Lys -310095.4179	0.110323

Table 3. The result relative thermodynamic functions changes (kcal/mol) of Arginine and Lysine by using solvent effect calculations with the B3LYP/6-311G method

Solvents	ΔH°(kcal/molK)	ΔG°(kcal/mol)	ΔS°(kcal/mol)
	Arg		
Water	-12.9423	-48.8349	0.12038
Methanol	-11.8312	-47.6571	0.12016
Ethanol	-11.1546	-46.9412	0.12003
	Lys		
Water	-19.2623	-54.4849	0.11814
Methanol	-18.1512	-53.3071	0.11791
Ethanol	-17.4746	-52.5912	0.11778





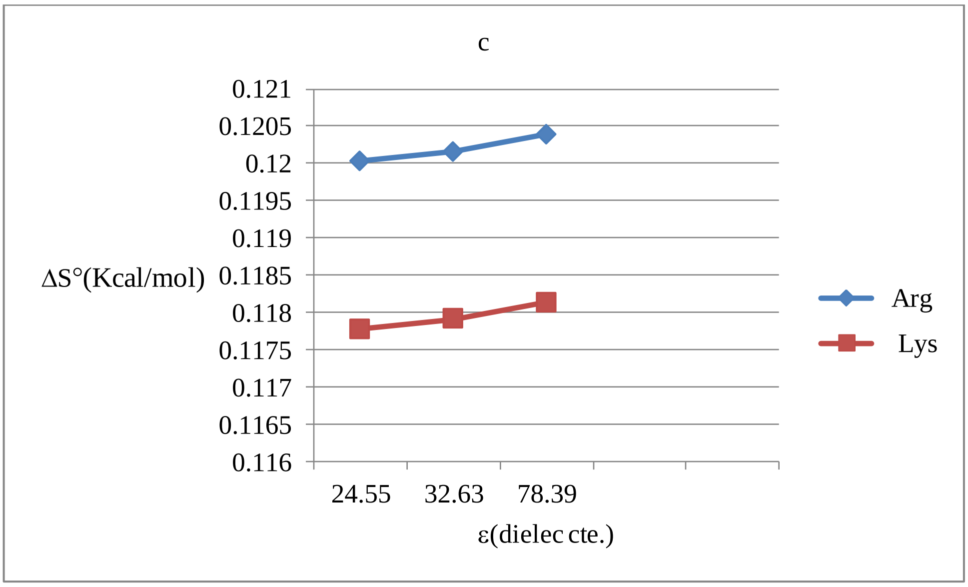


Fig. 1. Plots of the Enthalpy changes ΔH° (in kcal/mol) of versus dielectric constant,ε, (a), Gibbs free energy changes ΔG° (in kcal/mol) versus dielectric constant,ε, (b) and Entropy changes ΔS° (in kcal/mol) versus dielectric constant,ε, (c) of Arginine and Lysine in various solvents.

CONCLUSIONS

The thermodynamically analysis shows with increasing dielectric constant from gas phase to water, the enthalpy changes ΔH° (kcal/mol) and the Gibbs free energy changes ΔG° (kcal/mol) of Arginine and Lysine decreases and entropy changes ΔS° (kcal/mol) of Arginine and Lysine increases. This means with increasing dielectric constant from gas phase to water, the stability of Arginine and Lysine increases.

With this information, we can discuss the effect of variable solvent on Arginine and Lysine and whenever special reaction must be done.

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