Heat capacities of aqueous solutions of amino acid and dipeptide derivatives of fullerene

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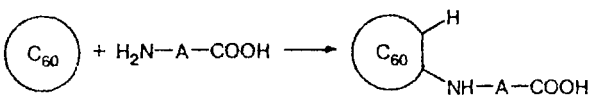
The concentration dependences of heat capacities of aqueous solutions of several amino acid and peptide derivatives of fullerene were measured by scanning differential calorimetry at 298 K. The heat capacities for the arginine, alanylalanine, and glycylvaline derivatives dissolved in water depend slightly on concentration. The concentration dependences of the heat capacities of aqueous solutions of the serine and alanine derivatives display extrema. The calculated contributions of hydration to the heat capacities of the dissolved fullerene derivatives have both positive and negative signs.

Key words: fullerene derivatives, amino acid, dipeptide, heat capacity, scanning differential calorimetry.

Recently *N*-(monohydrofullerenyl)amino acids and -dipeptides were synthesized *via* the addition of amino acid or dipeptide to fullerene.[1]



It is established that, unlike fullerenes, some amino acids and all dipeptide derivatives of fullerene are water-soluble. The fullerene derivatives were shown by the diffusion[2] and electron microscopy[3,4] methods to exist in aqueous solutions as both individual molecules and associates.

The influence of a biologically active substance introduced in cells on the mobility of water molecules is presently one of the most important problems in biology and medicine. It is known that the addition of some substances increases the mobility of water molecules, whereas the addition of other compounds decreases it. The data on the heat capacity of the dissolved compound make it possible to characterize the interaction of this compound with the solvent and the interaction of its molecules with each other.[5,6]

This work is aimed at the study of the heat capacity of aqueous solutions of several fullerene derivatives of amino acids and dipeptides and the influence of hydration of these compounds on the heat capacity and structure of the aqueous solutions in a wide concentration range.

Experimental

Fullerene derivatives of the following amino acids and dipeptides were chosen: DL-serine (**1**), L-alanine (**2**), L-arginine (**3**), DL-alanyl-DL-alanine (**4**), and glycyl-L-valine (**5**). These derivatives differ by solubility in water. Derivatives **1** and **2** are poorly soluble compounds: their solubility does not exceed 1.5 mg mL^{-1}. The solubilities of compounds **3**, **4**, and **5** are 15—20 mg mL^{-1}.

The excess heat capacities of solutions were measured in the 283—383 K temperature range on a DASM-4A differential scanning microcalorimeter (Institute of Biological Instrument Engineering, Russian Academy of Sciences) with a temperature scan rate of 2 deg min^{-1} and at an excess pressure of 2 atm. A platinum 0.46-cm^3 cell was used. The design of the instrument and cells was described in detail.[7] In each experiment, the heat capacity scale was calibrated against the Joule—Lenz effect. Reliability of the electric calibration was additionally checked using aqueous solutions of methanol as the calorimetric standard. The measured value of molar heat capacity of methanol in aqueous solutions (159 J (mol K)$^{-1}$) is close to that reported in Ref. 8 (158.3 J (mol K)$^{-1}$). The error of measurements was 5%.

The specific heat capacity of the dissolved compound ($C_{p,2}$) was calculated by the formula[7]

$$C_{p,2} = C_{p,1}\bar{V}_2/\bar{V}_1 - \Delta C_p^{app}/m,$$

where $C_{p,1}$ is the specific heat capacity of neat water, J (g K)$^{-1}$; $\bar{V}_2$ and $\bar{V}_1$ are the partial volumes of the dissolved compound and water, respectively; ΔC_p^{app} is the measured difference between the heat capacities of water and the solution studied; and m is the weight of the dissolved compound in the cell of the calorimeter.

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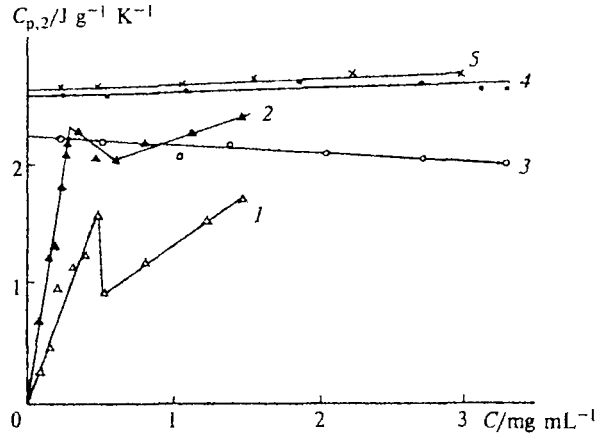

Fig. 1. Dependences of the specific heat capacities ($C_{p,2}$) of fullerene derivatives on the concentration (C) in aqueous solutions: *1*, DL-serine (**1**); *2*, L-alanine (**2**); *3*, L-arginine (**3**); *4*, DL-alanyl-DL-alanine (**4**); and *5*, glycyl-L-valine (**5**).

The data on partial specific volumes of fullerene derivatives were taken from Ref. 2 ($\bar{V}_2$ = 0.752 cm^3 g^{-1}).

Results and Discussion

The concentration dependences of the specific heat capacities of fullerene derivatives **1**—**5** at 298 K are presented in Fig. 1. In the first approximation, the heat capacities of compounds **3**—**5** depend slightly on the concentration. As shown by the diffusion method, in the 0.75—1.5 mg mL^{-1} concentration range, derivative **5** is present in the solution in the molecular-dispersed state, whereas derivatives **1**—**4** in this concentration range exist in the associated state.[2] The degree of association of derivatives **3** and **4** decreases rapidly with dilution. At concentrations <0.6 mg mL^{-1} for **1** and <0.4 mg mL^{-1} for **2**, an extreme concentration dependence of the heat capacity is observed, which can most likely be related to the formation of micelle-like structures of fullerene derivatives. It is known[9] that the process of micelle formation is usually accompanied by a jumpwise increase in the heat capacity. Most likely, derivatives **3**—**5** form no micelle-like structures, since no jumpwise change in the heat capacity is observed on the curves of the concentration dependence of the heat capacity. Thus, it can be assumed that the mechanism of dissolution of compounds **1** and **2** differs from that of compounds **3**—**5**.

It is noteworthy that fullerene derivatives **1** and **2** differ from classical surfactants in the sign of the difference in heat capacities during micelle formation. In the case of surfactants, the micelle formation is accompanied by a jumpwise increase in the heat capacity, *i.e.*, $\Delta C_p > 0$, whereas $\Delta C_p < 0$ for the fullerene derivatives **1** and **2** under discussion. It cannot be ruled out that the decrease in the heat capacity during micelle formation indicates a mechanism of micelle formation different from the standard one. It can be assumed that hydrophobic hydration of molecules **1** and **2** is weakened due to the van der Waals interactions between the fullerene fragments.[10] In these associates, the fullerene fragment of the molecules probably becomes less accessible for water molecules, and hydrophobic hydration should decrease. At the same time, it is known that hydrogen in the $C_{60}H$ fragments of fullerene derivatives possesses proton mobility[11] and favors the formation of hydrogen bonds with water. The fraction of hydrophilic hydration increases against the background of a decrease of hydrophobic hydration, and ΔC_p becomes negative. Most likely, in this case, the processes of hydrophilic hydration and hydrophobic interactions between the fullerene fragments compete. Preliminary data on potentiometric titration suggested that in compounds **3**—**5** the hydrogen atom attached directly to the fullerene fragment ($C_{60}H$) is more acidic than those in compounds **1** and **2**. In addition, compounds **3**—**5** contain many functional groups in the amino acid or dipeptide fragment, and they are capable of forming hydrogen bonds with water. Therefore, hydrophilic hydration of these compounds probably favors their higher solubility in water.

Table 1. Molar heat capacities ($C_{p,2}$) (J (mol K)$^{-1}$) of fullerene (F) derivatives of amino acids and dipeptides in aqueous solutions with infinite dilution ($C_{p,2}$) and in the gas phase (C_p^g) and contribution of hydration to the heat capacity ($\Delta_g^w C_p$) at 298 K

Substance	s/mg mL^{-1}	$C_{p,2}$	C_p^g	$\Delta_g^w C_p$
F-Ala (**2**)	1.5	0	412	−412
F-Ser (**1**)	1.6	0	428	−428
F-Arg (**3**)	20	2000	525	1475
F-AlaAla (**4**)	15	2100	497	1613
F-GlyVal (**5**)	20	2250	515	1735

Note: s is solubility in water at 298 K.

It has been shown[8,12—13] that the contribution of hydration to the heat capacity of the dissolved substance in water can be calculated from the difference of heat capacities of the substance in solution and in the gas phase. The heat capacity in the gas phase was calculated using the method of additivity of group increments.[14] The values of molar heat capacities of compounds **1**—**5** in the gas phase[14] and aqueous solution at infinite dilution are presented in Table 1. It is seen that the contribution of hydration to the heat capacity for derivatives **1** and **2** is negative, whereas it is positive for derivatives **3**—**5**. Obviously, hydrophilic hydration predominates in the case of negative contributions of hydration. These data are also evident for different mechanisms of hydration of the compounds studied.

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