Chemistry of Natural Compounds and Bioorganic Chemistry

Hydrophobic hydration of aliphatic amino acids

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Indexes of hydrophobic hydration of aliphatic amino acids derived by millimeter spectroscopy (31.42 GHz) give a linear correlation with the accessible surface area of the side chains.

Key words: aliphatic amino acids, hydrophobic hydration, accessible surface area, absorption millimeter spectroscopy.

The interaction of amphiphilic compounds with water results in two interrelated phenomena, *viz.*, hydrophobic hydration (HH) and hydrophobic interactions (HI), which are of great importance for various chemical and biological systems.[1,2] The quantitative estimation of the corresponding effects is commonly made on the basis of indirect data, *e.g.*, the partition in the water—octanol system,[3] microcalorimetry of solutions,[2] *etc.*

Previously, the absorption millimeter spectroscopy (MMS) in the 3—10 cm^{-1} (300—100 GHz) range was proposed as a direct method for investigation of hydration effects in solutions of alcohols,[4] methylureas[5] and the other amphiphilic compounds.[6] It was possible to estimate the numbers of hydrophobic hydration of a series of hydrocarbon radicals using the MMS method. Recently, a new modification of the MMS method[7] in the 0.75—1.3 cm^{-1} (30—40 GHz) range based on the "wave-guide dielectric resonance" effect has been proposed. In the present work, this method is used to study HH-effects in diluted aqueous solutions of aliphatic α-amino acids (also of low solubility), which exist in the form of zwitterions ($H_3N^+CHRCOO^-$).

Experimental

The absorption measurements for aqueous solutions of glycine, *L*-alanine, *L*-valine, *L*-leucine, and *L*-isoleucine were performed at 31.42 GHz at 30 °C, with accuracy of at least ±4%. Absorptions (α/dB · mm^{-1}) were estimated using the formula $\alpha = -\lg I/I_0$, where I_0 is an intensity of the initial radiation, and I is the intensity of radiation after passing through the solution. The hydration effects of amino acids were calculated as the difference ($\delta\alpha$) between the absorption

Translated from *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 11, pp. 2031—2033, November, 1994.

of the solution (α_{exp}) and the theoretical contribution of an aqueous component ($\varkappa_1 C_1$) using the equation:

$$\delta\alpha = \alpha_{exp} - \varkappa_1 C_1,$$

where C_1 and $\varkappa_1$ are the concentration and the extinction coefficient of pure water, respectively.

Results and Discussion

The concentration dependences of attenuation of the electromagnetic radiation at 1.05 cm^{-1} by solutions of glycine and *L*-leucine are presented in Fig. 1. These two amino acids differ greatly in hydrophobicity of the side chains. As can be seen in Fig. 1, the linear dependence between the absorption and the concentration of glycine and leucine (C_2) in the 0.1—1.0 mass. % range holds. Previously, it has been shown that in the millimeter range the difference between the measured values α_{exp} and the expected contribution of the aqueous component to the absorption ($\varkappa_1 C_1$) is the result of a change in state of water molecules in the hydration shells of the solute molecule[6] (the absorption frequency range for amino acids is far beyond the millimeter wavelength range). The existence of linear functions $\alpha(C_2)$ (Fig. 1) allowed us to calculate the indexes of hydration $N = \delta\alpha/\varkappa_1 C_2$ (Table 1). The data obtained demonstrate that observed hydration effects increase with an increase in the hydrophobic radical R.

Table 1. Hydration indexes $N = \delta\alpha/\varkappa_1 C_2$ of the aliphatic amino acids $N^+H_3CHRCOO^-$

Amino acid	R	C_2 mol L^{-1}	$\delta\alpha$ dB mm^{-1}	N	ASA Å^2
Glycine	H	0.134	0.036	3.8	73.4
L-Alanine	Me	0.112	0.123	15.1	104.0
L-Valine	$CHMe_2$	0.0854	0.177	30.2	143.9
L-Leucine	$CHMeCH_2Me$	0.0762	0.177	33.7	161.4
L-Isoleucine	CH_2CHMe_2	0.0762	0.201	37.4	171.5

The dependence of N on the molecular weight of the amino acid M_2 (Fig. 2) is not linear and tends toward saturation. This fact might indicate a decrease in the contribution of volumes of the $—CH_2—$ and $CH_3—$ groups to the hydration as the total volume of the side chain R is increased. The dependence of N on the accessible surface area (ASA) of the amino acid residues[8] is of another type. In Fig. 3 a good linear correlation between the hydration effects and the surface of the hydrated side group R is clearly seen. By definition, the hydration is the effect of interaction of the water molecule with the surface atomic groups of the molecules. Therefore, one can assume N as a quantitative measure (index) of hydration of the solute.

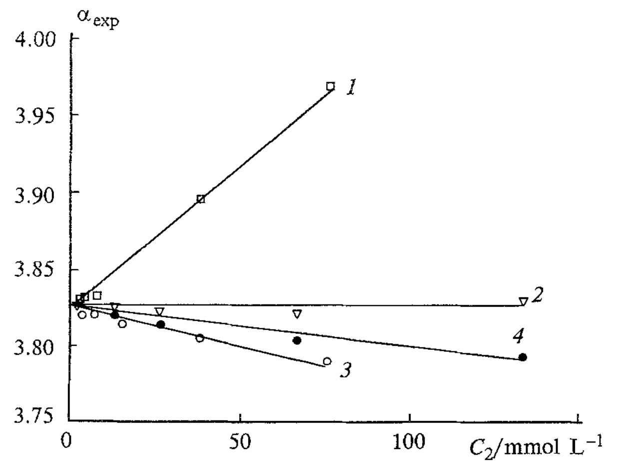

Fig. 1. Dependence of absorption on concentration (C_2 /mmol · L^{-1}) for *L*-leucine (*1*) and glycine (*2*). The theoretical contribution of the aqueous component for *L*-leucine (*3*) and glycine (*4*) solutions.

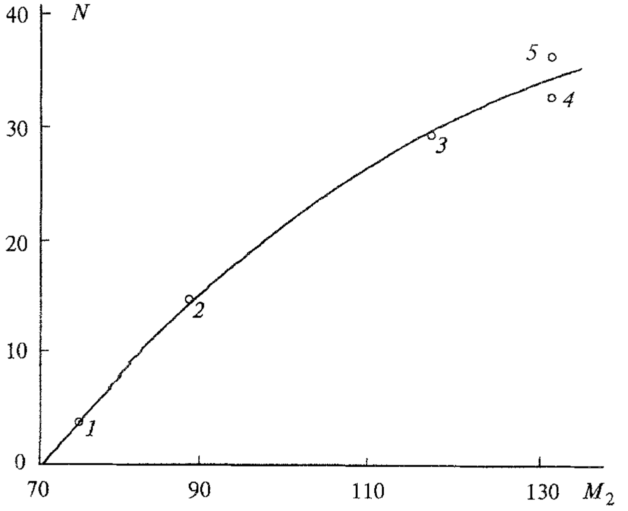

Fig. 2. Dependence of the hydration index of the aliphatic amino acids on the molecular weight. (*1*) glycine, (*2*) *L*-alanine, (*3*) *L*-valine, (*4*) *L*-leucine, (*5*) *L*-isoleucine.

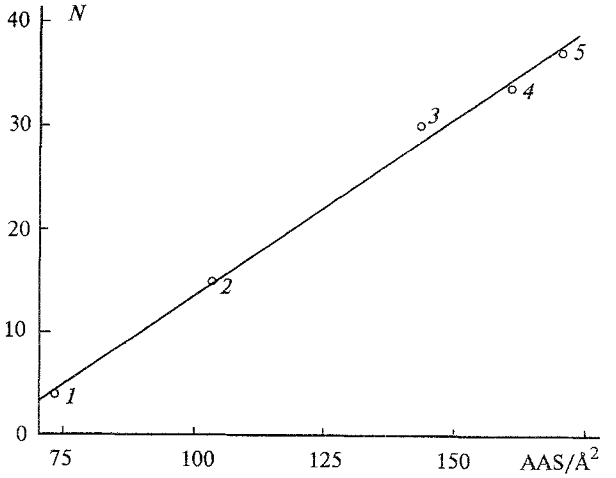

Fig. 3. Dependence of the hydration index on the accessible surface area (ASA) for the aliphatic amino acids. The designations of the amino acids see in Fig. 2.

The index obtained by MMS includes at least two components,[6] *viz.*, the contributions of hydrophilic (N_P) and hydrophobic (N_R) hydrations: $N = N_P+N_R$. Since the contribution of the zwitterion fragment ($H_3N^+CHCOO^-$) to hydration must be constant, the increase in N proceeds parallel with the increase in ASA (Table 1). This effect is clearly demonstrated by the magnitude of the N/ASA values: N/ASA is 0.052 for glycine, 0.145 for alanine, 0.210 for valine, 0.210 for leucine, and 0.218 for isoleucine. Hence, the HH-effects give the main contribution to non-additivity of absorption measured by MMS. If the hydrophilic contributions of all the amino acids are equal, therefore N_R depends upon HH of the hydrophobic radical, *i.e.*,. ASA (Fig. 3). The slope of the straight line in Fig. 3 is in accordance with the increase in hydration index $\Delta N_R = 0.345\pm0.015$ per 1 Å^2 ($r = 0.997$). This indicates high sensitivity of the method used for estimation of the effects of the hydrophobic hydration.

The numbers of hydrophobic hydration ($N_\theta{}^R$) in a series of aliphatic alcohols[4] containing all the hydrophobic groups R, for which the indexes of hydration (N) are determined in the present work, were measured previously by the MMS in the frequency range of 100—300 GHz at 25°C. The linear correlation between $N_\theta{}^R$ and the N values with the slope of 2.8 holds. This additionally indicates the possibility of using the N values as the hydrophobic hydration indexes. The procedure of measurements at 30—40 GHz[7] is rather simple and more sensitive in contrast to the one reported previously, in which the range 100—300 GHz was used.[4] This allows one to estimate experimentally the hydrophobic hydration numbers ($N_\theta{}^R$) both for the wide set of hydrophobic groups R and for other homologous series on the basis of $\delta\alpha/\varkappa_1 C_1$ data in diluted solutions, using the corresponding correlation equations between MMS data obtained in the different frequency ranges and at different temperatures.

We believe that application of MMS in the 30—40 GHz range is a promising method for studies of interactions of different substances with water.

The present work was supported by the Russian Foundation for Basic Research (Project No. 93-03-18459).

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Received September 14, 1994