Thermochimica Acta, 176 (1991) 141–148
Elsevier Science Publishers B.V., Amsterdam

THERMOCHEMISTRY OF AQUEOUS SOLUTIONS OF ALKYLATED NUCLEIC ACID BASES.

Part VII. Apparent molar heat capacities and volumes of aqueous solutions of alkylated derivatives of uracil at 298.15 K

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(Received 14 May 1990)

ABSTRACT

Densities and heat capacities of some alkylated derivatives of uracil (1,3,6-trimethyluracil, 1,3-dimethyl-6-ethyluracil, 1,3-dimethyl-6-propyluracil and 1,3-dimethyl-6-butyluracil) in dilute aqueous solutions are measured using flow calorimetry and flow densimetry at 298.15 K. Apparent molar volumes and heat capacities were derived and analyzed as a function of concentration.

INTRODUCTION

One of the thermodynamic functions reflecting hydrophobic hydration effects in water is the partial molar heat capacity at infinite dilution. Results of calorimetric investigations on uracil, thymine and their derivatives reported earlier [1–3] indicate a linear relationship between partial molar heat capacities and the number of hydrogen atoms covalently bound to the solute molecules. We have now undertaken to complete such data for other alkylated derivatives of uracil.

For this experimental work we used direct flow microcalorimetric measurements of heat capacities per unit volume c_p^v at constant pressure. To transform heat capacities per unit volume to specific and then molar apparent heat capacities, concomitant density measurements were carried out with the same solutions using flow vibrating tube densimetry.

EXPERIMENTAL

Materials and methods

All the solutions were prepared by weight using degassed and deionized distilled water. The alkylated compounds were supplied by the Military Academy of Medicine (Lodz). Their purity (99.41% for 1,3-dimethyl-6-ethyluracil, 99.98% for 1,3-dimethyl-6-propyluracil, 99.53% for 1,3-dimethyl-6-butyluracil and 99.41 for 1,3,6-trimethyluracil) was checked using a Du Pont differential scanning calorimeter 1090B.

The products were carefully dried for several days before use. The c_p^{v} values of the solutions were measured relative to water using the Picker microcalorimeter equipped with gold cells (Setaram).

The measurements were performed with very dilute solutions (in the concentration range 0.01–0.15 mol kg^{-1}) using the single reference method. The instrument and working procedure have been described elsewhere [4,5]. As the sample delivery device a Gilson Minipuls system was used, giving a flow rate of 0.5 cm^3 min^{-1}.

The differences in densities between the solutions and pure water were obtained with a digital flow densimeter [6] thermostatted at 298.15 K. The uncertainties in these differential density measurements were, respectively, 2×10^{-6} g cm^{-3} and 10^{-5} J K^{-1} cm^{-3} for c_p^{v}.

DATA REDUCTION

The apparent molar volumes V_ϕ and heat capacities $C_{p\phi}$ of the alkylated uracils were calculated from the differences between densities and specific heat capacities of solutions and water using standard expressions:

$$V_\phi = \frac{M_2}{d} - 1000\frac{(d-d_0)}{mdd_0} \tag{1}$$

$$C_{p\phi} = M_2 c_p + 1000\frac{(c_p - c_{p0})}{m} \tag{2}$$

Where M_2 is the molecular weight of the solute; m is the number of moles of the solute per kg of water; d, d_0 and c_p, c_{p0} are the density and specific heat capacity of the solution and water, respectively.

The difference $(c_p - c_{p0})$ was calculated from the difference in the heat capacities per unit volume:

$$c_p - c_{p0} = c_{p0}\left(\frac{c_p^{\mathrm{v}} - c_{p0}^{\mathrm{v}}}{c_{p0}^{\mathrm{v}}} + 1\right)\frac{d_0}{d - c_{p0}} \tag{3}$$

Where $c_p^{\mathrm{v}} = c_p d$ and $c_{p0}^{\mathrm{v}} = c_{p0} d$.

TABLE 1

Apparent molar volumes and heat capacities of aqueous alkylated derivatives of uracil at 298.15 K

m (mol kg^{-1})	d (g cm^{-3})	V_ϕ (cm^3 mol^{-1})	c_p (J g^{-1} K^{-1})	$C_{p\phi}$ (J mol^{-1} K^{-1})
1,3,6-trimethyluracil ($\mathrm{m}_3^{1,3,6}\mathrm{Ura}$)				
0.15725	1.001746	123.98	4.1347	353.89
0.11080	1.000362	124.11	4.1478	355.38
0.08046	0.999463	124.11	4.1565	357.34
0.04982	0.998547	124.15	4.1652	358.23
0.02448	0.997790	124.00	4.1724	361.29
0.01112	0.997382	124.31	4.1762	365.67
1,3-dimethyl-6-ethyluracil ($\mathrm{m}_2^{1,3}\mathrm{e}^6\mathrm{Ura}$)				
0.11075	1.000203	139.58	4.1509	442.22
0.08252	0.999410	139.55	4.1579	440.06
0.05351	0.998548	140.26	4.1659	450.42
0.05270	0.998563	139.54	4.1654	442.61
0.02870	0.997851	140.34	4.1720	448.09
0.01227	0.997395	140.13	4.1763	457.76
1,3-dimethyl-6-propyluracil ($\mathrm{m}_2^{1,3}\mathrm{p}^6\mathrm{Ura}$)				
0.08755	0.999303	156.48	4.1603	540.70
0.06789	0.998865	155.53	4.1641	534.62
0.04011	0.998103	156.11	4.1714	539.16
0.03205	0.997902	155.77	4.1721	537.07
0.01773	0.997515	156.23	4.1754	540.22
0.009674	0.997280	158.51	4.1774	565.22
1,3-dimethyl-6-butyluracil ($\mathrm{m}_2^{1,3}\mathrm{b}^6\mathrm{Ura}$)				
0.07674	0.998953	171.52	4.1643	621.31
0.05795	0.998493	171.48	4.1679	621.09
0.05443	0.998367	171.84	4.1689	627.33
0.03801	0.997984	171.87	4.1720	626.49
0.02881	0.997726	173.00	4.1738	629.91
0.02146	0.997586	171.48	4.1752	630.44

All experimental data are listed in Table 1. Figures 1 and 2 show the variations of V_ϕ and $C_{p\phi}$ of the alkylated uracils versus molarity of the solution.

The variations of V_ϕ and $C_{p\phi}$ as functions of m in the investigated concentration range were fitted by the least-squares method with first- and second-order polynomial equations.

$$C_{p\phi} = C_{p\phi}^0 + A_c m + B_c m^2 \tag{4}$$

$$V_\phi = V_\phi^0 + A_v m + B_v m^2 \tag{5}$$

In both cases the root mean square deviations (RMSD) were very similar; that is why we could assume that with alkylated uracils, V_ϕ and $C_{p\phi}$ varied

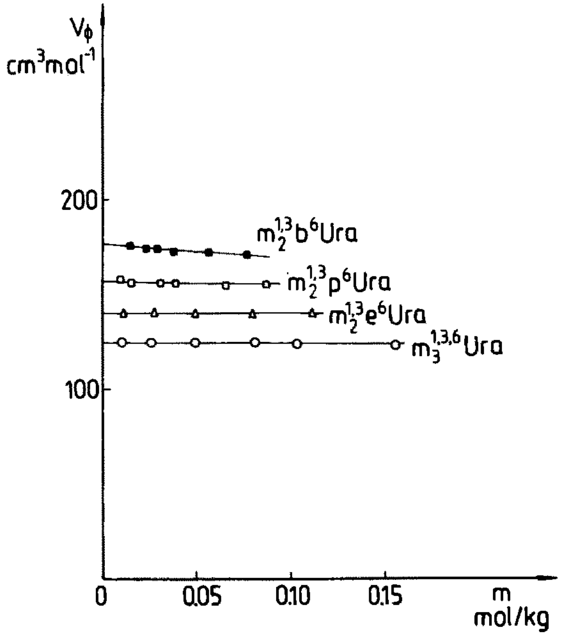

Fig. 1. Apparent molar volumes of aqueous alkylated derivatives of uracil at 298.15 K as a function of molarity.

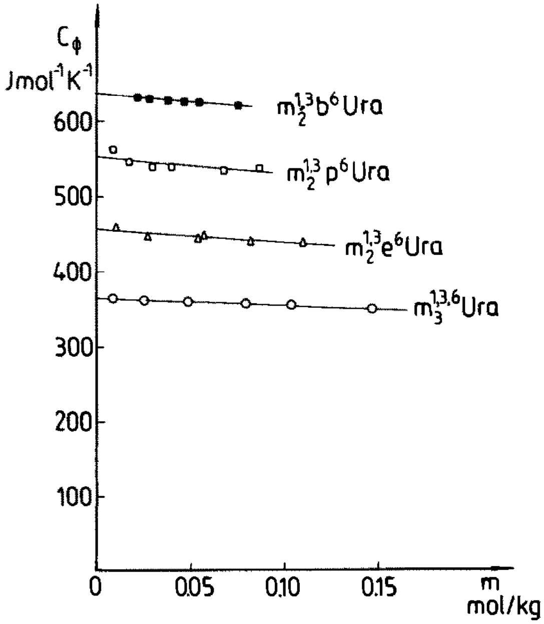

Fig. 2. Apparent molar heat capacities of aqueous alkylated derivatives of uracil at 298.15 K as a function of molarity.

TABLE 2

Apparent molar volumes and heat capacities at infinite dilution of alkylated uracils in water at 298.15 K

Compound	$C_{p\phi} = C_{p2}^0$ (J mol^{-1} K^{-1})	A_c (J kg K^{-1})	RMSD ($C_{p\phi}$) (J mol^{-1} K^{-1})	$V_\phi = V_2^0$ (cm^3 mol^{-1})	A_v (cm^3 kg)	RMSD (V_ϕ) (cm^3 mol^{-1})
$m_3^{1,3,6}$Ura	363.8	−71.1	1.9	124.20	−1.19	0.11
$m_2^{1,3}e^6$Ura	455.2	−147.4	4.5	140.34	−7.63	0.30
$m_2^{1,3}p^6$Ura [a]	541.8	−102.3	1.7	156.40	−12.40	0.22
$m_2^{1,3}b^6$Ura	634.2	−175.4	2.1	172.42	−12.04	0.60

[a] The first and the last value of the series have been omitted in the least-squares fitting for both V_ϕ and $C_{p\phi}$.

linearly with concentration m. The parameters V_ϕ^0, $C_{p\phi}^0$ and A_v, A_c are given with their RMSD uncertainties in Table 2.

At infinite dilution the limiting apparent molar quantities V_ϕ^0 and $C_{p\phi}^0$ are assumed to be identical to the partial molar quantities V_2^0 and C_{p2}^0 respectively. Our value of $C_{p2}^0 = 363.7 \pm 1.9$ J mol^{-1} K^{-1} obtained for 1,3,6-trimethyluracil closely resembles that found by Szeminska et al. [1] ($C_{p2}^0 = 357.2 \pm 3.7$ J mol^{-1} K^{-1}) at the same temperature. The latter value is in fact the mean value obtained on the concentration range 0.05–0.2 m and mean value on the same range would be 358.75 J mol^{-1} K^{-1}.

Figure 3 shows the values of C_{p2}^0 plotted against the number n of alkyl carbon atoms. It was shown previously that, for several homologous series, C_{p2}^0 values increase linearly with the number n of carbon groups [7–10]. The effect of branching of the alkyl chain was found to be small or insignificant.

$$C_{p2}^0 = a + bn \tag{6}$$

In most cases, the CH_2 increment was found to be around 90 J K^{-1} mol^{-1} (Nichols et al. [8]). With our C_{p2}^0 data (Table 2) fitted using the eqn. (6) we have obtained the following expression:

$$C_{p2}^0 = 94.47 + 89.80n \tag{7}$$

where n is the total number of methylene groups attached to the diketopyrimidine skeleton.

As for the influence of the total number of methylene groups on C_{p2}^0, we obtained the similar linear correlation in the case where n was the number of CH_2 groups attached only to the 6th atom in the skeleton.

$$C_{p2}^0 = 364.1 + 89.80n \tag{8}$$

In both cases, the CH_2 increments were equal to the value given by Nichols et al. [8]. These results indirectly confirm the credibility of our experimental data and prove how accurate the observed additivity relations are.

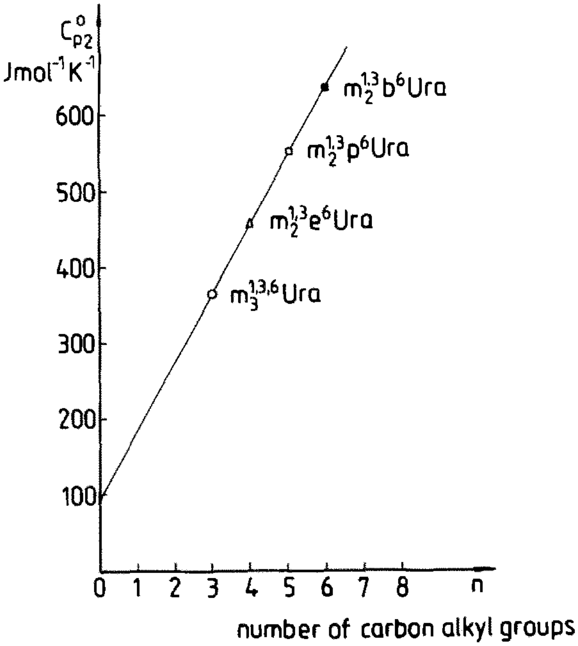

Fig. 3. Partial molar heat capacities of aqueous alkylated derivatives of uracil plotted against the number n of alkyl carbons.

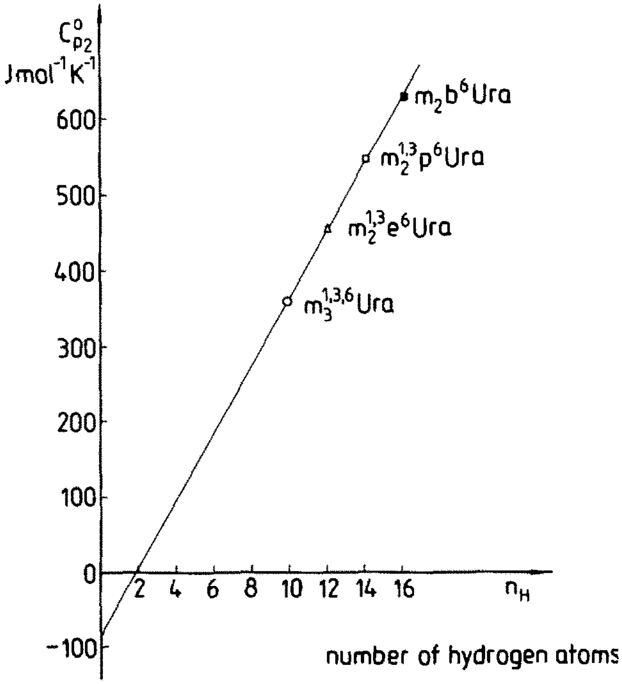

Fig. 4. Partial molar heat capacities of aqueous alkylated derivatives of uracil plotted against the number n_H of hydrogen atoms bound covalently.

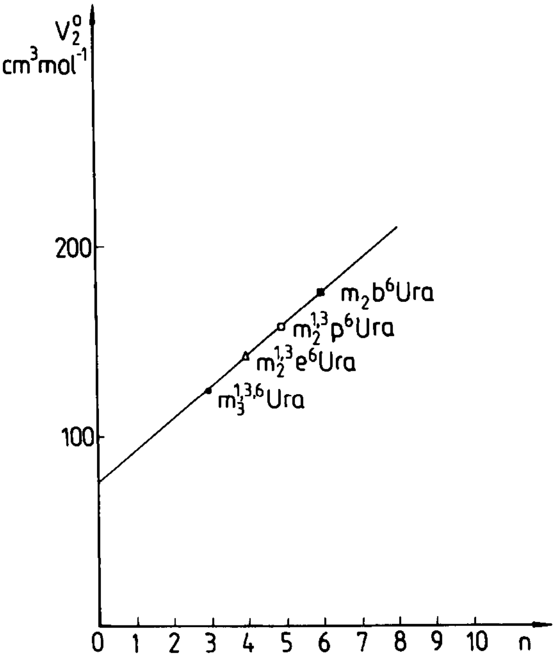

Fig. 5. Partial molar volumes of aqueous alkylated derivatives of uracil plotted against the number n of alkyl carbons.

As previously suggested [11–13], the hydrogen atoms are responsible for the large C_{p2}^0 values for hydrophobic compounds in aqueous solution. It was also found that the partial molar heat capacities correlated linearly with the number of hydrogen atoms [1]. Our results confirm this relation [see Fig. 4]. The slope of the plot C_{p2}^0 versus n_H gives an increment $C_{p2}^0 = 44.89$ J mol^{-1} K^{-1} per hydrogen atom. This value is very close to that found by Sköld at al. [7], $C_{p2}^0 = 44.35$ J mol^{-1} K^{-1}, as well as to that obtained by Szeminska et al. [1], $C_{p2}^0 = 42.8$ J mol^{-1} K^{-1}.

As for the apparent heat capacities, apparent molar volumes presented in Fig. 1 decrease slightly with increasing molarity. This behaviour is a general trend observed in very dilute solutions with polar compounds containing alkyl groups such as alcohols [9], amides and ketones [10], ethers [12], etc.

These variations reflect hydrophobic interactions of solute with increasing concentration, concomitantly A_v and A_c are more negative as the substituted chain length increases.

As for C_{p2}^0, V_2^0 values are correlated with the number of methylene groups (n) attached to the diketopyrimidine skeleton. Again the following linear relation was obtained, as illustrated in Fig. 5

$$V_2^0 = 76.0 + 16.1n \qquad (9)$$

The CH_2 increment, 16.1 cm^3 mol^{-1}, for alkylated uracils is also in excellent agreement with the recent value (16.0 cm^3 mol^{-1}) of Perron and

Desnoyers [13] as well as with other literature values [9,10,12]. This indicates that hydrophobic hydration is the main factor affecting the V_2^0 values.

ACKNOWLEDGMENTS

This work has been possible owing to cooperation between the Centre National de la Recherche Scientifique (France) and the Polish Academy of Science (RPBP 01.3). The authors are grateful to Dr. E. Utzig for the purity measurements and to Professor K. Wierzchowski for helpful discussions.

REFERENCES

1 J. Szeminska, W. Zielenkiewicz and K.L. Wierzchowski, Biophys. Chem., 10 (1979) 409.
2 A. Zielenkiewicz, E. Plesiewicz and K.L. Wierzchowski, Biophys. Chem., 10 (1979) 415.
3 A.B. Teplitsky, L.K. Yanson, O.T. Glukhova, A. Zielenkiewicz, W. Zielenkiewicz and K.L. Wierzchowski, Biophys. Chem., 11 (1980) 17.
4 P. Picker, P.A. Leduc, P.R. Philip and J.E. Desnoyers, J. Chem. Thermodyn., 3 (1971) 631.
5 J.L. Fortier and G.C. Benson, J. Chem. Thermodyn., 8 (1976) 411.
6 P. Picker, E. Tremblay and C. Jolicoeur, J. Solution Chem., 3 (1974) 377.
7 R. Sköld, J. Suurkuusk and I. Wadsö, J. Chem. Thermodyn., 8 (1976) 1075.
8 N. Nichols, R. Sköld, C. Spink, J. Suurkuusk and I. Wadsö, J. Chem. Thermodyn., 8 (1976) 1081.
9 C. Jolicoeur and G. Lacroix, Can. J. Chem., 54 (1976) 624.
10 G. Roux, G. Perron and J.E. Desnoyers, Can. J. Chem., 56 (1978) 2808.
11 S.J. Gill and I. Wadsö, Proc. Natl. Acad. Sci. (U.S.A.), 73 (1976) 2955.
12 G.I. Edward, P.G. Farrell and F. Shahidi, J. Chem. Soc., Faraday Trans. 1, 53 (1977) 705.
13 G. Perron and J.E. Desnoyers, Fluid Phase Equilibria, 2 (1979) 239.