

DISSOCIATION ENERGIES IN WATER SOLUTION FOR SALINE BONDS IMPLIED IN INTERACTIONS MEDIATED BY PEPTIDOGLICANS. AB INITIO – PCM COMPUTATIONS

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Dissociation energies in water solution are computed for saline bonds mediated by Ca^{2+} and Mg^{2+} , and by acetate, methylsulphate, etandiol, as models for Lewis bases groups on peptidoglicans. The structures, energies, and geometries of the L_2M – type complexes, in which L = ligands and M = cations are computed for vacuum and water solutions using the *ab initio* method and 6-31G* basis set, and the PCM version for solvent interactions. Two sets of ionic radii are used for Ca^{2+} and Mg^{2+} cations for hydration energy computations. Hydration energy results are compared with experimental figures for the L – ligands, M-cations, and for a series of other molecules and ions. Computed dissociation energies for the L_2M complexes indicate Mg^{2+} - based saline bonds less stable than Ca^{2+} - based bonds.

INTRODUCTION

Intercellular interactions mediated by peptidoglycans imply saline bonds between two Lewis bases ($-\text{COO}^-$, $-\text{OSO}_3^-$, $-\text{OH}$, etheric $-\text{O}$ -groups) and Ca^{2+} ions, which cannot be substituted by Mg^{2+} ions.¹ Stabilities of saline bonds implied in interactions mediated by peptidoglycans,² are simulated using computed dissociation energies for ML_2 complexes (M: Ca^{2+} , Mg^{2+} ; L: CH_3COO^- , $\text{CH}_3\text{OSO}_3^-$, 1,2-ethanediol), in water solution. These are considered as models for the Lewis base groups from peptidoglycans. In a previous publication hydration energies of ML_2 in aqueous solutions were computed by a variety of mainly semiempirical methods.³ Here we compute these dissociation energies by the PCM method,^{4,5} employing 6-31G* *ab initio* computations. Hydration energies for the L – ligands, and other simple organic molecules and ions are also computed and compared with experimental results, in order to assess the reliability of our methods, and to select the best set of parameters (ionic radii, etc.) for the dissociation energy calculations.

METHODS

Optimized geometries and the corresponding energies of the L_2M – type complexes, L – ligands and M – cations, as well as of other molecules employed as a test were calculated in vacuum and in water solution, using the *ab initio* method and PCM (Polarizable Continuum Model) for water solution, for 6-31G* basis set (as implemented in Gamess 7.0 package).⁶ For the ionic species, hydration free energies, ΔG_h , were calculated with two sets of ionic radii, and compared with experimental values⁷⁻⁹. Finally, dissociation free energies, ΔG_d , were calculated as differences between energies, ΔG values, in water solution (for $\text{M}^{2+} + 2\text{L}$ minus for ML_2). Vibrational analysis (298°C) for the vacuum structures was performed within the *ab initio* computations and the zero point energy (ZPE) corrections are included in the computed ΔG_d values. The same ZPE values were considered in vacuum and in water solution.

RESULTS AND DISCUSSION

Ab initio 6-31G* hydration energies ($\Delta G_{h,calc}$) were calculated as differences between the total

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free energy in water solution, and the total energy in vacuum, for a set of $N = 21$ molecules and ions. For the neutral or polyatomic ionic species the default Gamess radii were employed. The results

are presented in Table 1. For the atomic ions the two sets of ionic radii tested are those of Wells¹⁰ and Sutton.¹¹ Table 2 lists the values obtained for these two types of radii.

Table 1

Hydration energy values (kcal/mol) for neutral and ionic polyatomic species

Compound	Total free energy vacuum	ZPE correction	Total free energy in water solution	$\Delta G_{h,calc}$	$\Delta G_{h,exp}$
MeOH	-72151.10	34.72	-72150.97	+0.13	-5.10
EtOH	-96630.02	53.98	-96627.55	+2.47	-5.01
<i>n</i> -PrOH	-121105.51	73.18	-121100.94	+4.57	-4.80
<i>i</i> -PrOH	-121108.99	72.78	-121104.15	+4.84	-4.74
EtGl	-143535.60	57.70	-143593.77	-58.19	-
Ac ⁻	-142553.18	32.72	-142620.73	-67.55	-79.9
CH ₃ OSO ₃ ⁻	-462155.84	38.00	-462217.18	-137.35	-
D (baie)	-191817.32	83.11	-191815.35	+1.97	-
D (chair)	-191823.85	83.31	-191821.30	+2.55	-

Total free energy in vacuum contains zero point energy (ZPE) correction. MeOH – methanol; EtOH – ethanol; *n*-PrOH, *i*-PrOH – normal and isopropanol; EtGl – 1,2 etandiol; D – 1,4-dioxan; $\Delta G_{h,calc}$, $\Delta G_{h,exp}$ – calculated and experimental hydration free enthalpies.

Table 2

Hydration energy values (kcal/mol) for atomic ions and ML₂ complexes

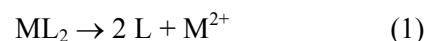
Compound	Total free energy vacuum	ZPE correction	Hydration free energy		$\Delta G_{h,exp}$
			Wells	Sutton	
			$\Delta G_{h,calc}$	$\Delta G_{h,calc}$	
Ca ²⁺	-424261.72	-	-552.48	-481.87	-381.2
Mg ²⁺	-124756.46	-	-761.50	-634.83	-455.5
Cl ⁻	-288356.95	-	-69.38	-73.94	-77.0
K ⁺	-375860.59	-	-100.64	-90.5	-81.0
Na ⁺	-101442.75	-	-132.56	-116.05	-98.0
Ac ₂ Ca	-709872.54	68.86	+1.66	-74.81	-
Ac ₂ Mg	-410469.94	69.76	-5.91	-6.11	-
(EtGl) ₂ Ca	-711679.57	118.1	-303.22	-210.72	-
(EtGl) ₂ Mg	-412212.44	119.86	-169.51	-169.77	-
(CH ₃ OSO ₃) ₂ Ca	-1349020.92	78.48	-109.5	-84.83	-
(CH ₃ OSO ₃) ₂ Mg	-1049606.02	79.20	-12.52	-12.72	-
D ₂ Mg	-508619.51	169.76	-149.85	-150.09	-

Ac – acetate; for other significances – see legend Tab. 1; Wells¹⁰ results calculated with $r_{Ca^{2+}} = 1.00$ Å, $r_{Mg^{2+}} = 0.72$ Å; Sutton¹¹ results calculated with $r_{Ca^{2+}} = 1.14$ Å, with $r_{Mg^{2+}} = 0.86$ Å. Hydration free energy values are calculated as differences between total free energies (ZPE corrections included) in water solution (values not indicated in Tab. 2) and respectively vacuum.

The values of $\Delta G_{h,calc}$ and $\Delta G_{h,exp}$ (the experimental hydration energies from the literature)⁷⁻⁹ from Table 1, demonstrate the fact that small values are hardly modeled by the differences between large calculated numbers (energies). Nevertheless, the general trend of the experimental values is in an acceptable manner reproduced. Comparing the experimental and calculated ΔG_h values presented in Table 2, one can conclude that the Sutton type radii perform better than the Wells values.

Dissociation free energies (ΔG_d) of six L₂M complexes (corresponding to eq. 1), calculated also with the two sets of ionic radii by PCM, are given

in Table 3.



The values from Table 3 show that the ZPE corrections do not change essentially the conclusions from reference:³ Ca²⁺ ions are required for cell adhesion mediated by peptidoglycans, and they cannot be substituted by Mg²⁺ ions. The ZPE corrected ΔG_d dissociation free energies demonstrate that the Mg²⁺ complexes are more instable than the Ca²⁺ complexes. This conclusion is in discordance with the Irving-Williams series order of stability of the complexes.

Table 3

Dissociation free energies (ΔG_d) for saline bonds (kcal/mol)

Dissociation process	ΔG_d - Wells	ΔG_d - Sutton	ZPE correction
$\text{Ac}_2\text{Ca} \rightarrow 2 \text{Ac}^- + \text{Ca}^{2+}$	-84.99	-37.70	-3.30
$\text{Ac}_2\text{Mg} \rightarrow 2 \text{Ac}^- + \text{Mg}^{2+}$	-283.57	-156.70	-4.30
$(\text{CH}_3\text{OSO}_3)_2\text{Ca} \rightarrow 2 \text{CH}_3\text{OSO}_3^- + \text{Ca}^{2+}$	-118.14	-72.30	-2.50
$(\text{CH}_3\text{OSO}_3)_2\text{Mg} \rightarrow 2 \text{CH}_3\text{OSO}_3^- + \text{Mg}^{2+}$	-333.78	-206.91	-3.20
$(\text{EtGl})_2\text{Ca} \rightarrow 2 \text{EtGl} + \text{Ca}^{2+}$	-18.14	-40.03	-2.70
$(\text{EtGl})_2\text{Mg} \rightarrow 2 \text{EtGl} + \text{Mg}^{2+}$	-323.55	-196.62	-4.40
$\text{D}_2\text{Mg} \rightarrow 2 \text{D} + \text{Mg}^{2+}$	-379.3	-252.39	-3.54

ΔG_d – calculated as differences of total free energies in water solution listed in Table 1 and Table 2; ΔG_d – values contain ZPE corrections. For other significances, see legend of Table 1 and Table 2.

In an attempt to explain the above facts, the data from Table 4 are presented, with (Mulliken and Löwdin) charges on the M^{2+} cations, calculated by our *ab initio* methods. As can be seen, systematically greater positive charges on the Ca

atoms from the complexes result than for those carried by the Mg atoms, although the charges on the coordinated oxygen atoms (not presented here) do not differ dramatically.

Table 4

Atomic charges for the Ca^{2+} and Mg^{2+} ions from ML_2 complexes

L	Mulliken			Löwdin		
	vacuum	PCM		vacuum	PCM	
		Wells	Sutton		Wells	Sutton
Ca^{2+}						
Ac^-	1.4282	1.6495	1.6242	1.0853	1.2399	1.2216
EtGl	1.6288	1.9038	1.8937	1.1488	1.7996	1.7898
MeSO_4^-	1.4588	1.6777	1.6534	1.1045	1.2638	1.2462
Mg^{2+}						
Ac^-	1.0603	1.1565	1.1565	0.3666	0.4173	0.4173
EtGl	1.4612	1.5340	1.5340	0.3805	0.4309	0.4309
MeSO_4^-	1.0426	1.1612	1.1613	0.3080	0.3820	0.3820

If the stability is largely determined by electrostatic effects, then the Mg compounds will decompose more easily. An explanation for the smaller charges on the Mg atom can be found in reference,¹² a great capacity for a significant charge transfer from the ligands for this atom. Probably Ca presents a weaker tendency for this charge transfer.

As to experimental values for such dissociation ΔG_d 's, Hermais et al.¹³ indicate 6.5 and 8.5 kcal/mol from dissociation – binding studies between oligomeric carbohydrates coating monolayer in neutral water solutions containing 150 mM NaCl and 10 mM CaCl_2 . This binding process is highly cooperational and homotypic, but 5 -10 kcal/mol binding strength is suggested also by common knowledge on intermolecular forces.¹⁴ Our *ab initio* computations for dissociation energies (as a small difference between large numbers) certainly do not have the required 1 kcal/mol precision (at total energies in the range 10^5 - 10^6 kcal/mol); nevertheless they may correctly indicate relative stabilities between different saline bonds.

CONCLUSIONS

The present work confirms our earlier conclusions that the intercellular interactions mediated by peptidoglycans imply saline bonds mediated by Ca^{2+} ions, and not by Mg^{2+} .

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