TERNARY SOLUTIONS OF THE CARBANION MONOSUBSTITUTED PYRIDAZINIUM YLIDS IN BINARY PROTIC SOLVENTS*

Mihaela DULCESCU[1], Dana-Ortansa DOROHOI[2]

Piridazinium ilidele carbanion – monosubstituite sunt compuşi relativ stabili cu importanţă în farmacologie. Reacţiile lor cu solvenţii netoxici, cum ar fi apa şi etanolul, trebuie să fie cunoscute când sunt utilizaţi in situ. În amestec de apă şi etanol în diferite concentaţii, deplasările spectrale sunt datorate influenţei globale a solventului binar asupra complecşilor formaţi prin legătură de hidrogen de tipul apă – piridazinium ilidă şi etanol – piridazinium ilidă. Deplasările spectrale măsurate în solventul binar depind liniar de fracţia molară a etanolului în soluţie. Pentru fracţii molare mici ale etanolului în solventul binar apă + etanol predomină complecşi de tipul apă – piridazinium ilidă, în timp ce la concentraţii mari ale etanolului se formează numai complecşi de tipul etanol – piridazinium ilidă pentru că nu sunt suficiente molecule de apă..

Carbanion-mono-substituted pyridazinium ylids are relatively stable compounds with potential pharmacological importance. So, their interactions with non-toxic solvents such as water and ethanol must be known when they are used in situ. In water-ethanol mixtures of various concentrations, the spectral shifts are due to the global influence of the solvent mixture on the hydrogen bonded complexes of the type water-pyridazinium ylid or ethanol-pyridazinium ylid. The spectral shifts measured in binary solvent are linearly dependent on the ethanol molar fraction in solution. For the small ethanol molar fractions in binary solvent water+ethanol, the complexes of the type water-pyridazinium ylid are predominant, while for the high ethanol concentrations there are insufficient water molecules and only complexes of the type ethanol-pyridazinium ylid can be formed.

Keywords: carbanion mono-substituted pyridazinium ylids, water, ethanol, electronic absorption spectra, hydrogen bond complexes

1. Introduction

Mixed binary solvents offer the possibility to vary the solvent-solvent and solute-solvent interactions and as such, spectral study in these media is likely to throw light on the role of each type of interactions on the solvation process.

[1] PhD Faculty of Physics, "Al. I. Cuza" University, 11 Carol I Bvd., Iassy - RO-700056, Romania
[2] Prof., Faculty of Physics, "Al. I. Cuza" University, 11 Carol I Bvd., Iassy - RO-700056, Romania
[*] Paper presented at the Scientific Meeting on 2008, organized by The Department of Physics I, Faculty of Applied Science, UPB, on the occasion of the 70-th birthday of Prof. C.P. Cristescu

Moreover, there may be a difference in specificity of interactions of the solute [1] with two components of the binary solvent. These can lead to preferential solvation and also to differences between the binary solvent average composition and the statistical weights of the two solvents in the first solvation sphere of a solute molecule [2].

The electronic spectroscopic parameters such as wavenumber and intensity of the electronic absorption bands have been extensively utilized for obtaining information on solvation in pure and mixed solvents.

Water and ethanol are non-toxic liquids frequently used for biochemical and biophysical researches [3]. Water is a very good solvent, having a great importance for life, because it assures the nutrients' transport into human body and eliminates the toxic components from the organisms. The structure of the water mixtures with different polar, non-polar, protic or aprotic solvents was theoretically [4] described or studied by using various means, such as spectral techniques, namely NMR [5], or IR [6, 7].

Ethanol is soluble in water in various portions and in a wide range of temperature. The behavior of the binary solvent water + ethanol components was intensively studied [8, 9].

Water has hydroxy, polar and polarizable molecules and so, in liquid alcohol solutions its molecules can coexist into hydrogen bonded complexes (of the type water-water, water-alcohol; water-water-alcohol), or as free ones. When ionic or dipolar molecules are introduced in water or in their mixtures with the primary alcohols, a hydration process determines modifications in the local order and contributes to the appearance of some clarthrate shells around the ions or dipoles [10,11].

Pyridazinium ylids (PY) [12, 13] are amphyonic compounds in which a positive, sp^3 hybridized nitrogen belonging to pyridazinium ring, is covalently bonded with a negative carbon (carbanion), whose hybridization between sp^2 and sp^3, strongly depends on the attached substitutes. When one from the carbanion substitutes is hydrogen, PY are named carbanion mono-substituted. The carbanion mono-substituted pyridaziniu ylids are relatively stable compounds. Their stability is assured by electrostatic interactions between the heterocycle and the carbanion [12]. They are more stable when the carbanion substituent is an electron withdrawing atomic group, as p-nitro-benzoyl in the studied by us compounds.

Recently some pyridazinium ylids [14] were tested from point of view of their antimicrobial and antifungal action. The carbanion mono-substituted pyridazinium ylids are moderate active compounds against Esch. Coli and Staph. Aureus.

These substances can be prepared and used in solutions. So, the interactions between these types of substances and the solvents such as water, ethanol, or their mixtures, must be known when solutions of these substances are used in pharmacological purposes.

2. Experimental

The carbanion mono-substituted pyridazinium ylids [12] with chemical structures from Fig.1 and Table 1 were prepared by known methods. They are of pharmaceutical interest, being potential pharmaceutical compounds [14, 15]. The study of the aqueous solutions of ylids is important because these compounds are prepared in situ and are used in solutions. The chemical structure of the studied spectrally active substances is illustrated in Fig.1.

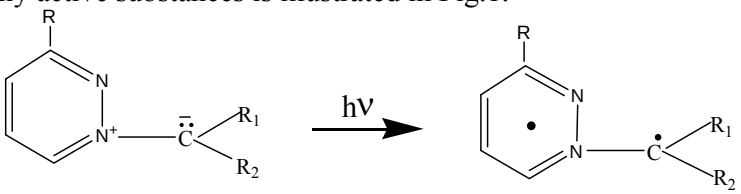

Fig.1. Structural features and ICT mechanism for the studied PY

The visible absorption band of PY appears after an electronic intramolecular transfer between the ylid carbanion and the heterocycle. The intramolecular charge transfer (ICT), responsible for the visible band appearance, determines an important decrease of the PY electric dipole moment.

Table 1

Substitutes of the studied pyridazinium ylids

PY	R	R_1	R_2
p-phenyl-pyridazinium -p-nitro-phenacylid (PPNiPY)	$-C_6H_5$	$-H$	$-CO-C_6H_5-(NO_2)_p$
p-cumyl-pyridazinium -p-nitro-phenacylid (CPNiPY)	$-C_6H_5-CH(CH_3)_2$	$-H$	$-CO-C_6H_5-(NO_2)_p$

Water was double distilled. Ethanol delivered by Merck Company was spectrally grade and used without supplementary purification. The used solvents were treated for water elimination by known methods [16].

Determination of ε at 25^0C was made using a Waine Kerr Autobalance Universal Bridge B-641 (300MHz) coupled with a Telmes TR-970 dielectric cell for liquids, thermostated with a U-10 Ultrathermostat ($\pm 0.2^0C$ accuracy).

Electronic spectra were recorded with a Specord UV VIS Carl Zeiss Jena spectrophotometer with data acquisition system.

Ternary solutions of the type water + ethanol + PY having a small concentration of PY (10^{-4} mol/L) and variable ethanol molar fractions were spectrally studied.

The substance weightings were made at a Mettler MDB-5 balance ($\pm 10^{-5}$ grams).

3. Results and Discussions

Table 2

Physical parameters of water + ethanol + PY solutions: x_e -ethanol molar fraction; $Z(kcal/mol)$ - solvent empirical polarity; $f(\varepsilon)$-solvent function for orientation interactions; $\bar{\nu}(cm^{-1})$-wavenumber in the ICT visible band of PY

x_e	$Z(kcal/mol)$	$f(\varepsilon)$	$\bar{\nu}(cm^{-1})$ PPNiPY	$\bar{\nu}(cm^{-1})$ CPNiPY
1	79.6	0.886	20790	20790
0.94	80.2	0.889	20820	20890
0.88	80.8	0.893	20890	20990
0.86	81.2	0.887	21000	21030
0.78	82	0.899	21030	21060
0.74	82.5	0.903	21030	21060
0.64	83.8	0.91	21100	21100
0.56	84.8	0.917	21100	21130
0.48	85.7	0.923	21130	21200
0.42	86.4	0.929	21200	21240
0.32	88.4	0.936	21300	21330
0.24	89.6	0.945	21320	21360
0.17	90.7	0.951	21370	21400
0.14	91.4	0.953	21380	21420
0.12	91.9	0.955	21400	21430
0.1	92.5	0.956	21410	21440
0.07	92.7	0.958	21420	21460
0.05	93.3	0.959	21440	21470
0.03	93.7	0.961	21450	21480
0.02	94.2	0.962	21470	21490
0.01	94.3	0.962	21480	21500
0.006	94.5	0.963	21490	21520
0	94.6	0.963	21500	21530

The molar fraction, $x_{et.}$, of ethanol, the solvent empirical polarity, $Z(kcal/mol)$, defined by Kosower [17,18] (as a measure of the solvent intermolecular interactions with the standard substance 1-ethyl-4-carbo-ethoxy-pyridinium iodide), function, $f(\varepsilon)$, describing the orientation intermolecular interactions in simple liquids, all estimated for various alcohol molar fractions in ethanol + water solutions are listed in Table 2. This table also contains the wavenumbers, $\bar{\nu}$, in the maximum of the visible electronic absorption band of the ternary solutions water + ethanol + PY. The empirical polarities $Z(kcal/mol)$ of the binary solvent water + ethanol were measured by us, following the method proposed by Kosower and using as standard 1-ethyl 4-carboethoxy-pyridinium iodide.

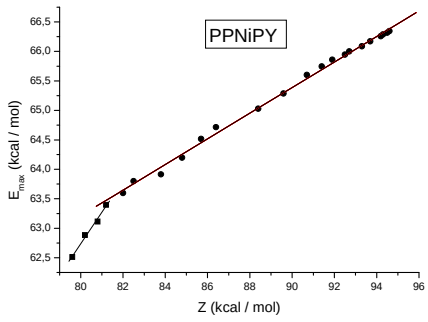

Fig.2. $E_{\max}(kcal/mol)$ vs. $Z(kcal/mol)$ for ternary solutions water + ethanol+ PPNiPY

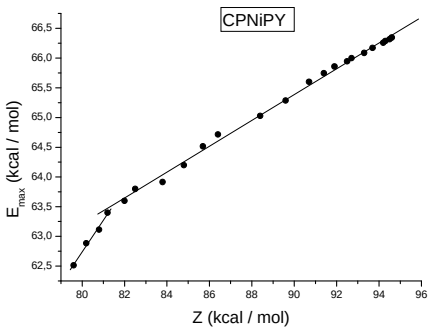

Fig.3. $E_{\max}(kcal/mol)$ vs. $Z(kcal/mol)$ for ternary solutions water + ethanol + CPNiPY

The dependences of the energy in the visible electronic absorption band $E_{\max.}(kcal/mol) = 2.8584 \cdot 10^{-3} \cdot \bar{\nu}(cm^{-1})$ for the studied PY in binary solvents on the empirical polarities [17, 18] of binary solvent are plotted in Figs 2 and 3. These dependences are quite linear. They are of the type

$$E_{\max}(kcal/mol) = E^0_{\max} + m \cdot Z(kcal/mol) \quad (1)$$

The slopes and the cuts at origin of the lines (1) are listed in Table 3. The following notations are made in Table 3: R-regression coefficient; SD standard deviation; N- number of experimental sets $(E_{\max}, Z)$; P-precision. For the small values of the ethanol molar fractions, the slopes of the lines (2) are smaller than for the high ethanol concentrations in binary solvent, showing us the bigger sensitivity of the PY' complexes formed by hydrogen bond, with ethanol, compared to water.

Table 3

Slopes and cuts at origin for the lines of the type (1)

PY	x_e	$E^0_{max} \pm \Delta E^0_{max}$ (kcal/mol)	$m \pm \Delta m$	R	SD	N	P
PPNiPY	$x_e > 0.74$	40.44 ± 4.41	0.238 ± 0.055	0.974	0.047	4	0.144
	$x_e < 0.74$	51.32 ± 0.20	0.107 ± 0.002	0.996	0.046	20	0.0001
CPNiPY	$x_e > 0.78$	24.61 ± 2.17	0.438 ± 0.027	0.996	0.033	5	0.003
	$x_e < 0.78$	51.41 ± 0.25	0.107 ± 0.003	0.994	0.051	19	0.0001

The change of the slope in Eqn. (1) could be induced by the changes in the composition of the solvation sphere of the complex formed by hydrogen bond between the studied molecules and the molecules of the protic solvents, or even by the substitution of the PY-water complex by PY-ethanol complex. From these graphs it results changes in intermolecular interaction nature. An example could be the replacing of the PY-water complex by the PY-ethanol complex, when the ethanol molar fraction increases in the solvent mixture.

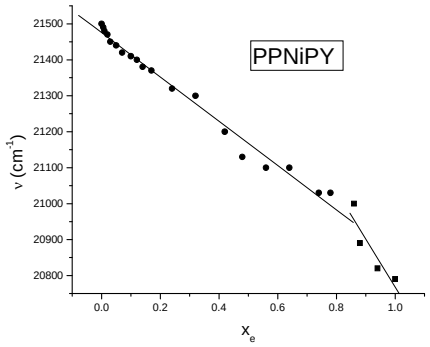

Fig.4 $\bar{\nu}\left(cm^{-1}\right)$ vs. x_e ethanol molar fraction in binary solvent water + ethanol for PPNiPY

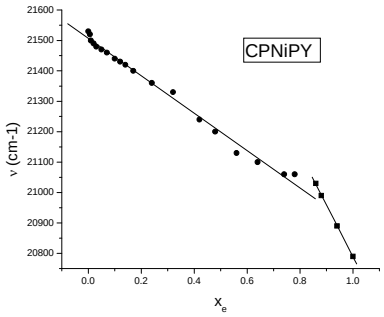

Fig.5 $\bar{\nu}\left(cm^{-1}\right)$ vs. x_e ethanol molar fraction in binary solvent water + ethanol for CPNiPY

Table 4

Slopes and cuts at origin for the lines of the type (2)

PY	x_e	$A \pm \Delta A$	$B \pm \Delta B$	R	SD	N	P
PPNiPY	$x_e > 0.74$	22101.67 ± 410.73	-1333.33 ± 445.6	0.904	48.82	4	0.096
	$x_e < 0.74$	21475.45 ± 6.73	-615.52 ± 18.44	0.992	20.76	19	0.0001
CPNiPY	$x_e > 0.74$	22489 ± 26.61	-1700 ± 28.87	0.999	3.16	4	0.003
	$x_e < 0.74$	21506.84 ± 4.97	-614.99 ± 13.61	0.996	15.32	19	0.0001

$$\bar{\nu}\left(cm^{-1}\right) = A + B \cdot x_e \tag{2}$$

These dependences offer information about the difference between the spectrally active complex (1-ethyl-4-carbomethoxy-pyridinium iodide), used as standard in Kosower' scale of the solvents [17, 18], and the solutes here studied.

When the spectral data are used in order to put in evidence the intermolecular interactions between a spectrally active molecule and the solvent molecules, beside empirical scales of the solvents, some theories regarding the intermolecular interactions in the simple liquids must be considered.

If one takes into consideration the Bakhshiev theory [19, 20] on the homogeneous solutions, considered as infinite continuous dielectric media, the dependence between the spectral shifts $\Delta\bar{\nu}$ and the solvent functions $f(\varepsilon)$ and $f(n)$ [21-23], defined by the relation (3), can be established.

$$\Delta\bar{\nu} = \bar{\nu}_s - \bar{\nu}_g = C_1 f(\varepsilon) + C_2 f(n) \tag{3}$$

The spectral shift $\Delta\bar{\nu}$ is measured when the spectrally active molecule passes from its gaseous state to solution. In relation (3) the following notations were made:

$$f(\varepsilon) = \frac{\varepsilon - 1}{\varepsilon + 2} \text{ and } f(n) = \frac{n^2 - 1}{n^2 + 2} \tag{4}$$

Relation (3) can be written as in (5).

$$\bar{\nu}_s = \bar{\nu}_g + C_1 f(\varepsilon) + C_2 f(n) \tag{5}$$

By using experimental data regarding the wavenumber in the maximum of the electronic ICT band, electric permittivity and refractive index, respectively $\left(\bar{\nu}\left(cm^{-1}\right), f(\varepsilon), f(n)\right)$, the determined regression coefficients have a physical significance and they offer information about the strength of the intermolecular interactions in respective solution. The coefficient $\bar{\nu}_g$ estimates wavenumber in the maximum of the ICT for the gaseous phase of PY and the terms $C_1 f(\varepsilon)$ and $C_2 f(n)$ are proportional to the strength of the induction-orientation interactions and dispersive interactions, respectively.

The dependence of the type (5), expressing the spectral shift versus the solvent macroscopic parameters is given in Figs.6 and 7 for the PY molecules studied in this paper.

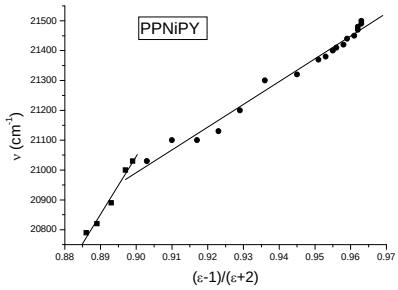

Fig.6 $\bar{\nu}\left(cm^{-1}\right)$vs. $f(\varepsilon)$ in binary solvent water + ethanol for PPNiPY

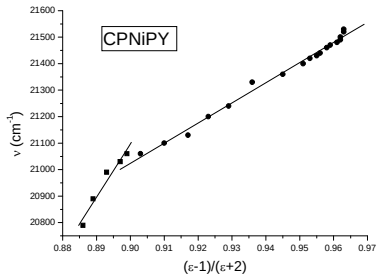

Fig.7 $\bar{\nu}\left(cm^{-1}\right)$vs. $f(\varepsilon)$ in binary solvent water + ethanol for CPNiPY

Table 5

Parameters of the dependences resulting from Bakhshiev theory for the ternary solutions of the studied PY ($C_2 = 0$)

PY	x_e	$\nu_g \pm \Delta\nu_g\left(cm^{-1}\right)$	$C_1 \pm \Delta C_1\left(cm^{-1}\right)$	R	SD	N	P
PPNiPY	$x_e > 0.78$	3508.63 ± 1484.84	19486.3 ± 1663.11	0.989	17.974	5	0.0013
	$x_e < 0.78$	14126.38 ± 236.87	7627.61 ± 250.66	0.991	20.61	18	0.0001
CPNiPY	$x_e > 0.78$	3050.14 ± 2297.17	20051.37 ± 2572.96	0.976	27.81	5	0.0044
	$x_e < 0.78$	14173.89 ± 167.71	7610.85 ± 177.47	0.996	14.59	18	0.0001

In relation (5) the coefficient C_2 is null, showing that in the ternary solutions of the studied PY the dispersive interactions could be neglected, while the induction-orientation interactions are predominant. From the values of C_1 coefficient we can estimate the gradual influence of the binary solvent on the PY hydrogen bonded complexes in protic solvents.

Because in our study all spectra were recorded into protic solvents or in their mixtures, the specific interactions take place in all solutions and all spectra will be shifted in the wavenumber scale compared with those obtained in aprotic solvents.

PY are dipolar molecules and they have the ability to form molecular complexes by hydrogen bonds with the protic solvents as water and ethanol. Such complexes are realized in all studied by us solutions. At low ethanol molar fractions, the complexes of the type PY-water are predominant. The hydrogen bonded complexes are realized by a proton transfer between a water molecule and the ylid carbanion [22, 23]. This complex is surrounded by solvation spheres containing smaller or bigger quantities of ethanol, depending on its molar fraction into binary solvent.

The probability of PY-ethanol complexes appearance has great values when ethanol becomes predominant (for concentrations $x_e > 0.74$). The energy of interactions between these complexes and solution is reflected in their electronic absorption spectra.

The solvation sphere of the water-PY complex contains only water molecules in binary solutions of PY in water. When the ethanol molar fraction increases in the ternary solutions, the alcohol molecules penetrate the first solvation sphere, modifying the strength of the interactions between the formed by hydrogen bond complex and its first solvation sphere.

At small molar fractions of ethanol in the binary solvent, complexes of type PY-water are predominant. If the ethanol molar fraction is higher than $x_e > 0.74$, the PY-ethanol complexes could be considered as being predominant.

4. Conclusions

As empirical characteristic of the solvent, the Z-parameter defined by Kosower informs about the global action of the binary solvent on the valence electronic cloud of the solute molecule, but does not permit to appreciate the contribution of each type of interaction to the total spectral shift of the electronic absorption band in a given solvent, comparatively to its position in gaseous phase.

The energy in the maximum of the visible electronic absorption band of the studied ylids linearly depends on the empirical polarities Z. The slope of this dependence changes for ethanol molar fraction bigger than 0.74 for PPNiPY and 0.78 for CPNiPY, respectively.

The total spectral shift caused by the protic solvent mixtures linearly depends on the theoretically established solvent functions from Bakhshiev theory. This theory offers information about the gradual influence of the binary solvent with a variable content in ethanol on the hydrogen bonded complexes of PY in protic solvents. The lines giving the dependence of the wavenumber in the maximum of the visible absorption band of the studied pyridazinium ylids change their slopes for $x_e > 0.74$.

A spectral study of these substances in binary solutions in different protic and aprotic solvents could offer information about the energy used for hydrogen complex formation.

R E F E R E N C E S

[1] *C. Reichart*, Solvents and Solvent Effects in Organic Chemistry, 3, Wiley-VCH, Verlag GmbA & Co. KGaA, Weinheim, 2003, p.329.
[2] *A. Maitra, S. Bagchi*, J. Mol. Liquids., **137**, 131, 2008.
[3] *D. Marsh*, Biomembranes in Supramolecular Structure and Functions, (Pifat, G., Herak, J.N., Eds.), Plenum Press, New York, 1983, p.127.
[4] *A.A. Atamas, N.A. Atamas, L.A. Bulavin*, Ukr. J. Phys., **49 (6),** p.552, 2004.
[5] *K. Mizuno, Y. Miyashita, Y. Shindo, H. Ogawa*, J. Chem. Phys., **99**, p. 3225, 1995.
[6] *K.R. Harris, P.J. Newitt, Z.J Derlacki*, J. Chem. Phys. Faraday Trans., **94**, p.1963, 1998.
[7] G. *Onori, A. Santuci*, J. Mol. Liquids, **69**, p.1661, 1996.
[8] *P. Taboada, M. Gutierrez-Pichel, S. Barbarosa, D. Attwood, V. Mosquera*, Physical Chemistry Chemical Physics, **5**, 4, p. 703, 2003.
[9] *S. Oancea, D.O. Dorohoi*, Rev. Chim. Bucureşti 56 (4), p. 371, 2005.
[10] *D. Buzatu, E. Petrescu, C. Popa, F. Buzatu, J.G. Bright*, Rev. Chim. Bucureşti, **55(6)**, p.435, 2004.
[11] *G. Onori*, J. Chem. Phys., 87, p.1251, 1987.
[12] *I. Zugrăvescu, M. Petrovanu*, N-Ylid Chemistry, Acad. Press, London, New York, 1976.
[13] *S. Dima, R. Crețu, M.M. Dima*, Rev. Chim, Bucureşti, **58**, 11, p.1016. 2007.
[14] I. *Mangalagiu, G. Mangalagiu, M. Roman, M. Caprosu, M. Petrovanu*, Ann. Pharm. Fr., **58**, 000, 2000.
[15] *I. Olariu, M. Caprosu, G. Grosu, M. Ungureanu, M. Petrovanu*, Roum. Biotechnol. Lett., **4(5)**, 365, 1999.
[16] *A.I. Vogel*, A Text Book of Practical Organic Chemistry, Longmans, New York, 1978.
[17] *E.M. Kosower*, J. Am. Chem. Soc., **80**, 13, p. 3253, 1958; Introduction to Physical Organic Chemistry, Wiley, New York, Sidney, 1986.
[18] *E.M. Kosower, B.G. Ramsey*, J. Am. Chem. Soc., **81**, p. 856, 1959.
[19] *N.G. Bakhshiev*, Opt. i. Spectrosk., **16**, p.821, 1964.
[20] *N.G. Bakhshiev*, Spectroscopia Mejmoleculiarn'h Vzaimodeistvii, Izd. Nauka, Leningrad, 1972.
[21] *C. Gheorghieş, L.V. Gheorghieş, D.O. Dorohoi*, J. Mol. Struct. (2008), doi: 10.1016/J.molstruc.2008.02.038
[22] *D.O. Dorohoi*, J. Mol. Struct., **704**, 1.3, p.31, 2004.
[23] *D.O. Dorohoi*, J. Mol. Struct., **792-794**, 86, 2006.