

International Journal of Chemical Kinetics, Volume 41, Issue 10 (p 613-622) Abstract | References | Full Text: <u>HTML</u>, PDF (174k) Save Article to My Profile

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A Comparative LSER Study of the Reactivity of 2-Substituted Cyclohex-1-eneacetic and 2-Substituted Phenylacetic Acids with Diazodiphenylmethane in Various Solvents

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ABSTRACT: The rate constants for the reaction of 2-substituted cyclohex-1-eneacetic and 2substituted phenylacetic acids with diazodiphenylmethane were determined in various aprotic solvents at 30°C. To explain the kinetic results through solvent effects, the second-order rate constants of the examined acids were correlated using the Kamlet–Taft solvatochromic equation. The correlations of the kinetic data were carried out by means of multiple linear regression analysis, and the solvent effects on the reaction rates were analyzed in terms of initial and transition state contributions. The opposite signs of the electrophilic and the nucleophilic parameters are in agreement with the well-known mechanism of the reaction of carboxylic acids with diazodiphenylmethane. The quantitative relationship between the molecular structure and the

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chemical reactivity is discussed, as well as the effect of the molecular geometry on the reactivity of the examined compounds. © 2009 Wiley Periodicals, Inc. Int J Chem Kinet 41: 613–622, 2009

INTRODUCTION

The reactivity of carboxylic acids with diazodiphenylmethane (DDM) is closely related to the acid molecular structure and the present solvent. The main advantage that makes this esterification convenient for examining the solvent and structure influence on the carboxylic acid reactivity, is that the catalyst is not necessary for this reaction. It may vary in rate but takes place without any additional support and in aprotic solvents it follows the second-order kinetics [1,2]. The mechanism of this reaction has been thoroughly examined [3-6], and it was established that the rate-determining step involves a proton transfer from the carboxylic acid to DDM to form a diphenylmethanediazonium-carboxylate ion pair, which rapidly reacts to give esters in the subsequent product-determining step (or ethers in the case of hydroxylic solvents):

$$Ph_2CN_2 + RCOOH \rightarrow Ph_2CHN_2^+ + O_2^-CR$$

Our previous investigations of the reactivity of various substituted and nonsubstituted unsaturated cyclic carboxylic acids with DDM in various solvents [7,8] and the earlier work of Chapman et al. [9] have established that the solvent effects are best interpreted in terms of initial and transition state contributions of specific and nonspecific solvent–solute interactions. The multiple linear regression analysis (MLRA) is very useful in separating and quantifying such interactions on the examined reactivity.

The first comprehensive application of the MLRA to the kinetic phenomena was that of Koppel and Palm [10], who listed regression constants for the simple Koppel–Palm equation [10] for various processes. Shorter and coworkers [11] have applied the correlation analysis to the solvent effects on the reaction between DDM and benzoic acid.

In our recent papers [12,13], we examined the effects of a set of 11 aprotic and 3 protic solvents on the reaction of various cycloalkenylcarboxylic acids and cycloalkenylacetic acids with DDM by means of the linear solvation energy relationship (LSER) concept developed by Kamlet and Taft [14]. The correlation equations obtained by stepwise regression for all the examined acids showed that the total solvatochromic equation can be used in its complete form, without separating of effects supporting the transition state (solvent polarity and hydrogen bond donating ability) and the ground state (hydrogen bond accepting ability).

In the present work, the second-order rate constants for the reaction of various 2-substituted cyclohex-1eneacetic and 2-substituted phenylacetic acids with DDM in 11 aprotic solvents at 30° C were determined. To explain the kinetic results through solvent effects, the second-order rate constants of the examined acids in aprotic solvents, together with the second-order rate constants for the same acids in three hydroxylic solvents determined previously [15,16], were correlated using the total solvatochromic equation [12], of the form

$$\log k = A_0 + s\pi^* + a\alpha + b\beta \tag{1}$$

where π^* is the measure of solvent dipolarity/polarizability, β represents the scale of solvent hydrogen bond acceptor basicities, α represents the scale of solvent hydrogen bond donor acidities, and A_0 is the regression value of the solute property in the reference solvent, cyclohexane [14]. The regression coefficients *s*, *a*, and *b* measure the relative susceptibilities of the solvent-dependent solute property (rate constants) to the corresponding solvent parameter.

This paper demonstrates how the LSER method can be applied to present and explain multiple interacting effects of the solvent on the reactivity of 2-substituted cyclohex-1-eneacetic and 2-substituted phenylacetic acids in their reaction with DDM, and the influence of the substituents of different nature at the C-2 position in the ring for the reactions in the given solvent set. The quantitative relationship between the molecular structure and the chemical reactivity has been discussed, as well as the effect of geometry on the reactivity of the examined molecules. The geometric data of the examined carboxylic acids, corresponding to the energy minima in the applied solvents, were obtained using semiempirical MNDO-PM3 energy calculations.

MATERIALS AND METHODS

Cyclohex-1-eneacetic acid was prepared by the method of Sugasawa and Saito [17] from cyclehexanone with cyanoacetic acid and ammonium acetate. The obtained nitrile was hydrolyzed with KOH to the acid: b.p. 138– 148°C/17 mmHg (lit. [18] 139°C/17 mmHg).

2-Substituted cyclohex-1-eneacetic acids were prepared by a Reformatsky reaction with ethylbromoacetate and the corresponding 2-subsituted cyclohexanone, followed by saponification and dehydration of the resulting hydroxy esters as reported previously [16]. The chemical structure and purity of the obtained acids were confirmed by boiling points, as well as ¹H NMR, FTIR, and UV spectroscopy.

Phenylacetic acid and the 2-subsituted phenylacetic acids were commercial products (Fluka, Deisenhofen, Germany).

Diazodiphenylmethane was prepared by the method of Smith and Howard [19], and stock solutions were stored in a refrigerator and diluted before use. Solvents were purified as described in previous papers [4,20]. All the solvents used in kinetic studies were analytical grade. Rate constants for the reaction of examined acids with DDM were determined as reported previously, by the spectroscopic method of Roberts and his coworkers [21] using a Shimatzu UV-1700 spectrophotometer. Absorbance measurements were performed at 525 nm with 1 cm cells at $30 \pm 0.05^{\circ}$ C. The secondorder rate constants for all acids were obtained by dividing the pseudo-first-order rate constants by the acid concentration (the concentration of acid was 0.06 mol dm^{-3} and that of DDM 0.006 mol dm^{-3}). Three to five rate determinations were made on each acid in every case, and the particular second-order rate constants agreed within 3% of the mean. The correlation analysis was carried out using Origin and Microsoft Excel computer software. The goodness of fit was discussed using the correlation coefficient (R), the standard deviation (SD), and the Fisher's value (F).

The reported conformations and the corresponding heats of formation of the examined molecules were obtained by the semiempirical MO PM6 method, using MOPAC 2007 program package [22]. The following keywords were used for optimization: EF GNORM = 0.100 MMOK GEO-OK PM6 EPS = xx PRECISE, where xx stands for the appropriate dielectric constant of a solvent (ethanol in this case).

RESULTS AND DISCUSSION

The values of second-order rate constants for the reaction of the examined 2-substituted cyclohex-1eneacetic and 2-substituted phenylacetic acids with DDM in 11 aprotic solvents and some of previously obtained rate constants [16] in hydroxylic solvents are given in Tables I and II. The results obtained show that the rate constants are increased in solvents with high polarity and proton-donating ability and decreased in solvents with high proton-accepting ability, which is in accordance with the supposed mechanism of the reaction [14]; solvent properties are given in Table III.

Solvent–Reactivity Relationship

To explain the obtained kinetic results through solvent dipolarity/polarizability and basicity or acidity, the rate constants were correlated with the solvatochromic parameters π^* , α , and β [14], using the total solvatochromic equation (1). The correlation of the kinetic data was carried out by means of the MLRA. It was found that the rate constants in 14 selected solvents show satisfactory correlation with π^* , α , and β solvent parameters. The obtained correlation results are given in Tables IV and V.

From the results presented in Tables IV and V, the general conclusion is that the solvent effects influence the carboxylic acid-DDM reaction by two reverse effects. The opposite signs of the electrophilic and the nucleophilic parameters are in accordance with the described reaction mechanism. The positive signs of the s and a coefficients prove that the classical solvation and HBD effects dominate the transition state and increase the reaction rate, and the negative sign of the b coefficient points out that HBA effects stabilize the initial state before the reaction starts and are responsible for a decrease in the reaction rate. The percentage contribution of each solvent effect for each acid is given in Table VI. The specific interactions, HBA and HBD effect, are dominant and have rather similar share for both acid types, but the classical solvation effects are somewhat higher for the phenylacetic acids, especially for its halogen- and nitro-substituted derivatives. To get a complete view of the solvent interaction with the molecules of the examined acids, the solvent effects are expressed quantitatively, for both carboxylic acid systems, and referring separately to the ground and the transition state.

2-substituted cyclohex-1-eneacetic acids:

Reactants	\Rightarrow	Transition state	\Rightarrow	Products
HBA solvation (\sim 57%)		HBD and solvation by the		
		nonspecific interactions ($\sim 43\%$)		

2-substituted phenylacetic acids:

Reactants	\Rightarrow	Transition state	\Rightarrow	Products
UDA solution (a. 58%)		HBD and solvation by the		
		nonspecific interactions (\sim 42%)		

phenylmethane at 30°C in a Set of	
nex-1-eneacetic Acids with Diazod	
Reaction of 2-Subsituted Cycloh	
s $(dm^3 mol^{-1} min^{-1})$ for the F	
Second-Order Rate Constants	olvents
Table I	Various S

				$k (dm^3 mol^{-1} min^{-1})$	(
Solvent	Cyclohex-1- eneacetic Acid	2-Methylcyclohex-1- eneacetic Acid	2-Ethylcyclohex-1- eneacetic Acid	2-Chlorocyclohex-1- eneacetic Acid	2-Bromocyclohex-1- eneacetic Acid	2-Iodocyclohex-1- eneacetic Acid	2-Nitrocyclohex-1- eneacetic Acid
Methyl acetate	0.144	0.087	0.092	0.285	0.290	0.331	1.461
Cyclohexanone	0.149	0.092	0.097	0.286	0.289	0.329	1.357
Diethyl ketone	0.214	0.133	0.141	0.406	0.411	0.467	1.880
Carbon tetrachloride	1.759	1.117	1.178	3.251	3.251	3.716	14.13
Ethyl acetate	0.128	0.078	0.083	0.249	0.251	0.288	1.230
Cyclopentanone	0.110	0.066	0.071	0.216	0.217	0.251	1.096
Dioxane	0.225	0.077	0.081	0.229	0.229	0.262	1.020
Acetonitrile	1.294	0.803	0.849	2.469	2.472	2.841	11.57
Acetone	0.194	0.118	0.125	0.380	0.385	0.440	1.898
Methanol	1.652	0.890	0.942	2.479	2.669	3.212	9.682
Ethanol	0.659	0.350	0.362	0.963	1.080	1.269	4.230
Ethylene glycol	3.020	1.550	1.607	3.775	4.197	4.932	12.36
Dimethyl sulfoxide	0.024	0.018	0.019	0.038	0.042	0.067	0.242
Tetrahvdrofiiran	0.056	0.034	0.036	0,111	0.117	0.129	0.578

Table II Second-Order Rate Constants ($dm^3 mol^{-1} min^{-1}$) for the Reaction of 2-Subsituted Phenylacetic Acids with Diazodiphenylmethane at 30° C in a Set of Various Solvents

				$k (\mathrm{dm}^3 \mathrm{mol}^{-1} \mathrm{mir}$	1 ⁻¹)		
Solvent	Phenylacetic Acid	2-Methylphenyl- acetic Acid	2-Ethylphenyl- acetic Acid	2-Chloro- phenylacetic Acid	2-Bromo- phenylacetic Acid	2-Iodo- phenylacetic Acid	2-Nitro- phenylacetic Acid
Methyl acetate	0.132	0.063	0.066	0.169	0.182	0.198	0.290
Cyclohexanone	0.153	0.089	0.096	0.232	0.240	0.252	0.316
Diethyl ketone	0.279	0.165	0.168	0.358	0.364	0.376	0.560
Carbon tetrachloride	6.628	4.041	5.153	7.816	7.880	8.126	12.86
Ethyl acetate	0.210	0.109	0.124	0.273	0.286	0.294	0.462
Cyclopentanone	0.117	0.058	0.061	0.157	0.184	0.199	0.264
Dioxane	0.169	0.102	0.140	0.239	0.248	0.259	0.342
Acetonitrile	8.920	3.802	3.955	10.57	11.03	11.16	16.28
Acetone	0.233	0.101	0.113	0.348	0.360	0.384	0.486
Methanol	2.539	2.420	2.460	3.329	3.500	3.790	5.110
Ethanol	1.139	1.010	1.020	1.440	1.559	1.670	2.470
Ethylene glycol	5.050	5.333	5.457	6.761	7.261	8.035	8.750
Dimethyl sulfoxide	0.014	0.008	0.007	0.021	0.034	0.040	0.164
Tetrahydrofuran	0.057	0.033	0.033	0.092	0.098	0.134	0.198

Solvent	π^*	α	β
Methyl acetate	0.60	0.00	0.42
Cyclohexanone	0.76	0.00	0.53
Diethyl ketone	0.72	0.00	0.45
Carbon tetrachloride	0.28	0.00	0.00
Ethyl acetate	0.55	0.00	0.45
Cyclopentanone	0.76	0.00	0.52
Dioxane	0.55	0.00	0.37
Acetonitrile	0.85	0.19	0.31
Acetone	0.72	0.08	0.48
Methanol	0.60	0.93	0.62
Ethanol	0.54	0.83	0.77
Ethylene glycol	0.92	0.90	0.52
Dimethyl sulfoxide	1.00	0.00	0.76
Tetrahydrofuran	0.58	0.00	0.55

Table IIISolvent Parameters [14]

It can be noticed that the two examined carboxylic acid types behave similarly, as the distribution of solvent effects is practically the same. However, the more general conclusion from these results is that the substituents at the C-2 position in both carboxylic acid types have very weak influence on the solvation effects during the reaction with DDM.

Table VIPercentage Contributions of Kamlet–Taft'sSolvatochromic Parameters to the Reactivity

Acid	$P_{\pi*}(\%)$	P_{α} (%)	P_{β} (%)
Cyclohex-1-eneacetic acid	8	35	57
2-Methylcyclohex-1-eneacetic acid	10	33	57
2-Ethylcyclohex-1-eneacetic acid	10	33	57
2-Chlorocyclohex-1-eneacetic acid	8	33	59
2-Bromocyclohex-1-eneacetic acid	8	34	58
2-Iodocyclohex-1-eneacetic acid	10	34	56
2-Nitrocyclohex-1-eneacetic acid	8	36	56
Phenylacetic acid	10	31	59
2-Methylphenylacetic acid	8	35	57
2-Ethylphenylacetic acid	7	35	58
2-Chlorophenylacetic acid	10	31	59
2-Bromophenylacetic acid	12	31	57
2-Iodophenylacetic acid	12	31	57
2-Nitrophenylacetic acid	14	30	56

Structure–Reactivity Relationship

The relationship between the molecular structure and the chemical reactivity gives a much better insight into the reaction mechanism. The structures of the examined carboxylic acids with minimal energy contents,

Table IV	Results of the Correlations	of the Kinetic Data for	2-Substituted Cyclohex-	1-eneacetic Acids with Eq. (1)

Acid	s ^a	a^a	b^b	R^b	s ^c	F^d	n ^e
Cyclohex-1-eneacetic acid	0.40 ± 0.21	1.67 ± 0.10	2.73 ± 0.22	0.985	0.12	112	14
2-Methylcyclohex-1-eneacetic acid	0.50 ± 0.25	1.61 ± 0.12	2.71 ± 0.28	0.977	0.14	71	14
2-Ethylcyclohex-1-eneacetic acid	0.50 ± 0.25	1.60 ± 0.12	2.70 ± 0.27	0.977	0.14	70	14
2-Chlorocyclohex-1-eneacetic acid	0.38 ± 0.28	1.55 ± 0.13	2.72 ± 0.30	0.972	0.16	55	14
2-Bromocyclohex-1-eneacetic acid	0.39 ± 0.28	1.58 ± 0.13	2.67 ± 0.29	0.973	0.16	59	14
2-Iodocyclohex-1-eneacetic acid	0.46 ± 0.26	1.57 ± 0.12	2.60 ± 0.28	0.975	0.15	63	14
2-Nitrocyclohex-1-eneacetic acid	0.36 ± 0.30	1.58 ± 0.14	2.50 ± 0.32	0.962	0.17	41	14

^a Calculated solvatochromic coefficient.

^b Correlation coefficient.

^c Standard deviation of the estimate.

^d Fisher's test.

^e Number of points used in the calculation.

Table V	Results of the Co	orrelations of the	Kinetic Data for	2-Substituted Pher	ylacetic Acids with	Eq. (1)
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Acid	s ^a	a^a	b^a	R^b	s ^c	F^d	n ^e
Phenylacetic acid	0.66 ± 0.52	2.08 ± 0.24	3.99 ± 0.55	0.952	0.29	32	14
2-Methylphenylacetic acid	0.55 ± 0.47	2.36 ± 0.22	3.93 ± 0.49	0.966	0.26	47	14
2-Ethylphenylacetic acid	0.45 ± 0.45	2.35 ± 0.21	4.04 ± 0.48	0.969	0.25	51	14
2-Chlorophenylacetic acid	0.67 ± 0.49	2.03 ± 0.23	3.85 ± 0.52	0.983	0.12	96	14
2-Bromophenylacetic acid	0.76 ± 0.47	1.98 ± 0.22	3.71 ± 0.50	0.954	0.28	34	14
2-Iodophenylacetic acid	0.75 ± 0.46	1.96 ± 0.21	3.61 ± 0.48	0.952	0.26	35	14
2-Nitrophenylacetic acid	0.82 ± 0.54	1.79 ± 0.25	3.31 ± 0.56	0.929	0.30	22	14

^a Calculated solvatochromic coefficient.

^b Correlation coefficient.

^c Standard deviation of the estimate.

^d Fisher's test.

^e Number of points used in the calculation.



Figure 1 Most stable conformation of cyclohex-1eneacetic acid. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

in ethanol as solvent, are given in Figs. 1–6, obtained by using the semiempirical MNDO-PM3 energy calculations [23,24]. These geometrical conformations are taken into consideration because they are the most stable forms in which molecules generally exist and react; their torsion angles $(C_2-C_3-C_4)$ and the heats of formation corresponding to those forms are given in Table VII. It can be noticed that the more stable compounds (phenylacetic acids) with lower heats of formation have higher values for the reaction rate constants than the cyclohex-1-eneacetic acid system.

It can be seen that for both acid types the compound with electron-accepting substituents (halogens and nitro group) in γ -position reacts faster than those with electron-donating substituents (alkyl groups), and the unsubstituted acid is always in the middle. It is quite logical as the carboxylic anion is present in the transition state and is stabilized by the inductive effects of electron acceptors. Furthermore, as can be seen represented in the example of 2-chlorosubstituted both acid types, Figs. 5 and 6, the relatively small halogen is far away from the reaction center and does not interfere with it.

Generally, the presence of the substituent affects the orientation of the carboxylic group (torsion an-



Figure 3 Most stable conformation of 2-methylcyclohex-1-eneacetic acid. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

gles), comparing to the unsubstituted molecules, and the secondary steric effect is of weaker significance in these systems. The electronic effect of substituents is dominant in both systems of the examined carboxylic acids in the reaction with DDM.

The additional evidence of the solvent effect on the structure–reactivity relationship in the reaction of 2-substituted cyclohex-1-eneacetic and 2-substituted phenylacetic acids with DDM was also obtained by correlating the log k of the examined acids with the Hammet equation (2) [25]:

$$\log k = \log k_0 + \rho \sigma \tag{2}$$

where ρ is the reaction constant, reflecting the sensitivity of log k to substituent effects. The substituent constant σ_p [26] is the measure of the electronic effect of a substituent. The results of the correlations are given in Tables VIII and IX, and have shown that



Figure 2 Most stable conformation of phenylacetic acid. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Figure 4 Most stable conformation of 2-methylphenylacetic acid. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

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Compound	Torsion Angle C ₂ –C ₃ –C ₄ ($^{\circ}$)	Heat of Formation (kcal mol^{-1})
Cyclohex-1-eneacetic acid	-96.30	-108
2-Methylcyclohex-1-eneacetic acid	-95.20	-120
2-Chlorocyclohex-1-eneacetic acid	-90.80	-122
Phenylacetic acid	-107.7	-82
2-Methylphenylacetic acid	-84.60	-91
2-Chlorophenylacetic acid	-68.20	-92

Table VII Data Calculated Using the Semiempirical MNDO-PM3 Method

Table VIII Hammet Correlation with σ_p Constants for the 2-Supstituted Cyclohex-1-eneacetic Acids

Solvent	$ ho^a$	r ^b	s ^c	n^d
Methyl acetate	1.29 ± 0.03	0.997	0.02	7
Cyclohexanone	1.23 ± 0.04	0.995	0.03	7
Diethyl ketone	1.21 ± 0.03	0.997	0.02	7
Carbon tetrachloride	1.16 ± 0.07	0.984	0.06	7
Ethyl acetate	1.26 ± 0.03	0.997	0.03	7
Cyclopentanone	1.28 ± 0.02	0.998	0.02	7
Dioxane	1.18 ± 0.01	0.999	0.01	7
Acetonitrile	1.22 ± 0.04	0.995	0.03	7
Acetone	1.27 ± 0.01	0.999	0.01	7
Methanol	1.08 ± 0.05	0.995	0.04	7
Ethanol	1.13 ± 0.04	0.995	0.04	7
Ethylene glycol	0.93 ± 0.07	0.987	0.05	7
Dimethyl sulfoxide	1.19 ± 0.09	0.984	0.07	7
Tetrahydrofuran	1.30 ± 0.04	0.996	0.03	7

^a Reaction constant.

^b Correlation coefficient.

^c Standard deviation of the estimate.

^{*d*} Number of points used in the calculation.

Solvent	$ ho^a$	r ^b	s ^c	n^d
Methyl acetate	0.70 ± 0.13	0.997	0.02	7
Cyclohexanone	0.60 ± 0.13	0.902	0.10	7
Diethyl ketone	0.56 ± 0.09	0.944	0.07	7
Carbon tetrachloride	0.47 ± 0.06	0.963	0.05	7
Ethyl acetate	0.64 ± 0.10	0.942	0.08	7
Cyclopentanone	0.71 ± 0.15	0.909	0.11	7
Dioxane	0.51 ± 0.09	0.921	0.08	7
Acetonitrile	0.65 ± 0.15	0.889	0.12	7
Acetone	0.72 ± 0.18	0.877	0.14	7
Methanol	0.36 ± 0.03	0.981	0.02	7
Ethanol	0.42 ± 0.02	0.991	0.02	7
Ethylene glycol	0.25 ± 0.05	0.897	0.04	7
Dimethyl sulfoxide	1.43 ± 0.10	0.987	0.08	7
Tetrahydrofuran	0.86 ± 0.12	0.949	0.10	7

^a Reaction constant.

^b Correlation coefficient.

^c Standard deviation of the estimate.

^{*d*} Number of points used in the calculation.



Figure 5 Most stable conformation of 2-chlorocyclohex-1-eneacetic acid. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

the ρ values decrease with the increase of the relative permittivity of the solvent. The higher values of the reaction constants for 2-substituted cyclohex-1eneacetic acids have shown that the susceptibility to the polar substituent effect is stronger in the case of 2substituted cyclohex-1-eneacetic than for 2-substituted phenylacetic acid system. The difference in the transmission of the substituent effects through the benzene ring and the double bond of the examined acids was ascribed to the different polarizability of the double bond of the examined compounds and to the different solvent effects on the transmission of the substituent proximity effect at the C-2 position of the ring.

The positive inductive effect of the alkyl group in vicinity can make the carboxylic anion less stable in both carboxylic acid systems. In a majority of examples, the phenylacetic acids are somewhat faster than the corresponding cyclohexenylacetic ones, which makes sense, as their structure is more approachable



Figure 6 Most stable conformation of 2-chlorophenylacetic acid. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

for the other reactant as well as for solvent, but it seems to be no great difference (Figs. 1 and 2). On the contrary, in the case of α , β -unsaturated cyclic carboxylic acids there is considerable difference between the reaction rate constants of benzoic and cyclohex-1-enecarboyxylic acids regardless of the presence of substituents [12,13]; in other words, the ring type determines the reactivity of a carboxylic acid. For β , γ unsaturated acids examined in this work, the ring is far away enough from the reaction center (carboxylic group) not to have much influence on it, and the steric and the electronic effects of substituents at γ position can be noticed more clearly. Regarding the geometric properties, 2-substituted cyclohex-1-eneacetic acids and 2-substituted phenylacetic acids have similar torsion angles, as well as the reactivity, but the α,β -unsaturated cyclic carboxylic acids (benzoic and cyclohex-1-enecarboxylic) have completely different geometry, and subsequently, behave differently in the same reaction. The torsion angle $(C_2-C_3-C_4)$ for benzoic acid is -16.60° and for cyclohex-1-enecarboxylic acid 142.0°. Their values are quite different, and the carboxylic groups are oriented in the opposite direction [13].

CONCLUSION

On the basis of the results presented in this paper and the previously reported results for more than 50 carboxylic acids, it can be concluded that the solvatochromic concept of Kamlet and Taft is applicable to the kinetic data for the reaction of different carboxylic acids with DDM in various solvents. This means that the presented model gives a correct interpretation of the solvating effects on the carboxylic group in various solvents. The solvation models for 2-substituted cyclohex-1-eneacetic acids and 2-substituted phenylacetic acids are suggested. The results show that the substituents at the C-2 position of the ring have rather a weak influence on the solvation effects, during the reaction of carboxylic acids with DDM. The reactivity of the examined acids in the reaction with DDM is in agreement with the geometric characteristics obtained by the semiempirical MNDO-PM3 energy calculations.

BIBLIOGRAPHY

- Aslan, M. H.; Burden, A. G.; Chapman, N. B.; Shorter, J.; Charton, M. J Chem Soc, Perkin Trans 2 1981, 500.
- 2. Aslan, M. H.; Collier, G.; Shorter, J. J Chem Soc, Perkin Trans 2 1981, 1572.

- Bowden, K.; Buckley, A.; Chapman, N. B. Shorter, J. J Chem Soc 1964, 3380.
- Buckley, A.; Chapman, N. B.; Dack, M. R.; Shorter, J.; Wall, H. M. J Chem Soc B 1968, 631.
- More, R. A.; O'Ferral, R. M.; Kwok, W. K.; Miller, S. I. J Am Chem Soc 1964, 86, 5553.
- Chapman, N. B.; Dack, M. R.; Newman, D.; Shorter, J.; Willkinson, R. J Chem Soc, Perkin Trans 2 1974, 962.
- Ušćumlić, G., Nikolić, J., Krstić, V. J Serb Chem Soc 2002, 67, 77.
- Nikolić, J., Ušćumlić, G. J Serb Chem Soc 2007, 72, 1217.
- Chapman, N. B.; Newman, D.; Shorter, J. J Chem Soc B 1976, 847.
- Koppel, I. A.; Palm, V. A. In Advanced Linear Free Energy Relationships; Chapman, N. B.; Shorter, J. (Eds.); Plenum Press: London, 1972, Ch. 5.
- 11. Matter, D.; Shorter, J. J Chem Soc, Perkin Trans 2 1983, 1179.
- 12. Nikolić, J.; Ušćumlić, G.; Krstić, V. Int J Chem Kinet 2005, 37, 361.

- 13. Nikolić, J.; Ušćumlić, G.; Juranić, I. Int J Chem Kinet 2007, 39, 664.
- Kamlet, M.; Abboud, J.; Taft, R. W. Prog Phys Org Chem 1981, 13, 485.
- Ušćumlić, G. S.; Krstić, V. V.; Muškatirović, M. D. J Chem Soc, Perkin Trans 2 1993, 999.
- Ušćumlić, G. S.; Krstić, V. V.; Muškatirović, M. D. J Chem Soc, Perkin Trans 2 1994, 1799.
- 17. Sugasawa, S.; Saito, S. Pharm Bull (Tokyo) 1956, 237.
- 18. Linstead R. P. J Chem Soc 1927, 357.
- Smith, L. I.; Howard, K. L. Org Synth Colln 1955, III, 351.
- Chapman, N. B.; Dack, M. R. J.; Shorter, J. J Chem Soc B 1971, 834.
- 21. Roberts, J. D.; McElhill, E. A.; Armstrong, R. J Am Chem Soc 1949, 71, 2923.
- 22. Stewart, J. J. P. J Mol Mod 2007, 13, 1173–1213, Version 7.051W
- 23. Serena Software Box, Bloomington, IN.
- 24. Stewart, J. J. P. J Comp Chem 1989, 10, 221.
- 25. Hammett, L. P. J Am Chem Soc 1937, 59, 96.
- 26. Charton, M., Prog Phys Org Chem 1981, 13, 178.1111