

## ACID-BASE PROPERTIES OF SUBSTITUTED NAPHTHOIC ACIDS IN NONAQUEOUS MEDIA

Patrik PARIK<sup>1</sup> and Miroslav LUDWIG<sup>2</sup>

*Department of Organic Chemistry, Faculty of Chemical Technology, University of Pardubice, 532 10 Pardubice, Czech Republic; e-mail: <sup>1</sup> parik@hbl.upce.cz, <sup>2</sup> ludwig@hbl.upce.cz*

Received May 14, 1997

Accepted July 21, 1997

Thirteen substituted 1-naphthoic acids have been prepared and their dissociation constants, along with those of twenty-five substituted 2-naphthoic acids, have been measured potentiometrically in methanol, *N,N*-dimethylformamide, pyridine, and acetonitrile. The  $pK_{HA}$  values obtained have been treated by linear regression using four sets of substituent constants. The experimental data have also been interpreted by statistical methods using latent variables. The first latent variable calculated by these methods can be used as a new set of substituent constants for describing substituent effects in naphthalene skeleton.

**Key words:** Naphthoic acids; Dissociation; Substituent effects; Solvent effect; Chemometrics.

Hammett<sup>1</sup> adopted the dissociation of substituted benzoic acids in water for a model process in study of substituent effects. A replacement of benzene ring by another hydrocarbon skeleton, *e.g.* naphthalene, results in a different basic model. As compared with benzene ring, naphthalene skeleton provides room for studies of a more extensive set of substituent effects. The present communication is focused on the dissociation of monosubstituted naphthoic acids.

Many papers have been published dealing with the dissociation of both unsubstituted and substituted naphthoic acids in water or in mixed aqueous–organic solvents. The reports on the acid-base properties of major sets of substituted naphthoic acids involve the potentiometric determination of dissociation constants of five substituted 1-naphthoic acids in 78% aqueous ethanol<sup>2</sup>, thirteen nitronaphthoic acids in 50% aqueous 2-butoxyethanol<sup>3</sup>, and the dissociation constants of 1- and 3-halo-2-naphthoic acids in 71% aqueous ethanol determined by conductometry<sup>4</sup>. Spectrophotometry was adopted to study the dissociation of a series of four methylnaphthoic acids in 20% aqueous dioxane<sup>5</sup>, conductometry was applied to a series of five methylnaphthoic acids in 50% aqueous ethanol<sup>6</sup>, and again spectrophotometry was used to study a series of 6-substituted-2-naphthoic acids in 50% aqueous ethanol<sup>7</sup>. (Methylsulfonyl)naphthoic acids were investigated potentiometrically in 50% aqueous ethanol<sup>8</sup>, 50% aqueous 2-butoxyethanol<sup>9</sup>, and 80% aqueous 2-methoxyethanol<sup>9</sup>. The dissociation constants of five chloro-1-naphthoic acids were determined in 50% aqueous ethanol<sup>10</sup>. Aminonaphthoic

acids undergo zwitterionic equilibrium reactions in aqueous methanolic media. These reactions were studied potentiometrically and spectrophotometrically<sup>11</sup>. Considerable attention was given to 8-substituted-1-naphthoic acids in 50% aqueous ethanol<sup>12</sup>, 80% aqueous 2-methoxyethanol<sup>13,14</sup>, and in 80% aqueous 2-butoxyethanol<sup>15</sup>. The most extensive and comprehensive works concern the dissociation of thirty four substituted 1-naphthoic acids in 50% aqueous ethanol<sup>16</sup> and of six substituted 1-naphthoic acids and forty five substituted 2-naphthoic acids in the same medium<sup>17</sup>. Dewar and Grisdale<sup>16</sup> suggested an expression for a quantitative description of substituent effects in naphthalene and pointed out possible different behaviour in various solvents. They also stressed the necessity of more experimental work on the systems different from benzene. Wells and Adcock<sup>17</sup> described further factors affecting the behaviour of the system: substituent–naphthalene skeleton–reaction centre. An overall analysis of substituent effects in naphthalene based on treatment of experimental data obtained by measurements in aqueous and aqueous–organic media was presented by Wells, Ehrenson and Taft<sup>18</sup>.

The dissociation of naphthoic acids in organic solvents is dealt with in a polarographic study of 1- and 2-naphthoic acids in methanol and *N,N*-dimethylformamide<sup>19</sup>, in a spectrophotometric study of 1-naphthoic acid in *N,N*-dimethylformamide<sup>20</sup>, and in a spectral study of 1- and 2-naphthoic acids in ethanol<sup>21</sup>.

The above survey (which is not complete and neglects the dissociation of naphthoic acids in water) indicates the absence of studies dealing with the acid-base behaviour of substituted naphthoic acids in nonaqueous media.

The main aim of the present communication is to create a set of experimental data and, by their mathematical-statistical treatment, to contribute to the quantification of substituent effects in naphthalene skeleton in organic solvents and to discuss the effects observed.

## EXPERIMENTAL

The model substances, except for 4-cyano-1-naphthoic acid and 4-chloro-1-naphthoic acid, were prepared by reported procedures. Their structure was verified by <sup>1</sup>H NMR spectra (a Bruker AMX 360 spectrometer). The dissociation constants,  $pK_{HA}$ , at 25 °C in methanol (MeOH), acetonitrile (AN), *N,N*-dimethylformamide (DMF), and pyridine (Py) were determined by potentiometric titration using an automatic titrator TITRALAB3 (Radiometer) and the same experimental and electrode arrangement as in our previous communications<sup>22–24</sup>. The solvents used were purified by standard procedures.

### Synthesis of 4-Cyano-1-naphthoic Acid

4-Bromo-1-naphthoic acid<sup>25</sup> was esterified with dimethyl sulfate in basic medium, using the method of Short and Wang<sup>26</sup>. The methyl 4-bromo-1-naphthoate obtained was transformed into methyl 4-cyano-1-naphthoate by a modified procedure of Dewar and Grisdale<sup>27</sup>: a mixture of methyl 4-bromo-1-naphthoate (2.6 g), cuprous cyanide (0.9 g), *N,N*-dimethylformamide (20 ml), and pyridine (3 drops) was heated at 180 °C for 5.5 h. The hot solution was poured in an ammonia solution (52 ml concentrated ammonia and 52 g ice), and the resulting suspension was extracted with chloro-

form (2 × 70 ml); the organic layer was washed with dilute hydrochloric acid and water and dried (Na<sub>2</sub>SO<sub>4</sub>). The solvent was evaporated to leave 2.4 g of crude product which was recrystallized from 50% aqueous ethanol with charcoal to give 1 g of methyl 4-cyano-1-naphthoate, m.p. 105–107 °C.

A mixture of methyl 4-cyano-1-naphthoate (1 g), acetic acid (20 ml), hydrochloric acid (15 ml), and water (20 ml) was refluxed for 4.5 h. After cooling, the separated crystals were collected by filtration and washed with water. The yield was 0.6 g of the crude product; recrystallization from ethanol with charcoal afforded 0.3 g of 4-cyano-1-naphthoic acid, m.p. 237–240 °C (ref.<sup>27</sup> gives m.p. 236–237 °C).

#### Synthesis of 4-Chloro-1-naphthoic Acid

A mixture of 4-acetylamino-1-naphthonitrile<sup>28</sup> (5 g), acetic acid (85 ml), and hydrochloric acid (85 ml) was refluxed for 3 h. After cooling, the separated solid was collected by filtration and washed with water, yield 2.8 g of 4-amino-1-naphthonitrile.

A suspension of 4-amino-1-naphthonitrile (2.8 g) in hydrochloric acid (10 ml) and water (85 ml) was diazotized by adding a solution of sodium nitrite (2.5 g) in water (20 ml) at 0 °C. The solution formed was poured into a stirred solution of cuprous chloride (6.7 g) in hydrochloric acid (60 ml) at 0 °C with stirring. Then the mixture was heated to 90 °C and cooled to give a yellow solid which was collected by filtration and washed with water. The yield was 2.7 g of the crude 4-chloro-1-naphthonitrile.

A mixture of the crude 4-chloro-1-naphthonitrile (2.7 g), acetic acid (30 ml), sulfuric acid (30 ml), and water (30 ml) was refluxed for 13 h. After cooling, the solution was poured onto crushed ice (*ca* 200 g). The separated solid was collected by filtration, washed with water, and redissolved in a solution of sodium carbonate (10 g) in water (100 ml). The alkaline solution was extracted with toluene (2 × 50 ml) and with ether (2 × 50 ml), and then it was acidified with hydrochloric acid. The precipitate was filtered off, washed with water, and recrystallized from an ethanol–water mixture (2 : 1) with charcoal to give 1.4 g of 4-chloro-1-naphthoic acid, m.p. 222–225 °C (ref.<sup>27</sup> gives m.p. 220–221 °C).

## RESULTS AND DISCUSSION

Tables I and II summarize the average dissociation constants  $\bar{p}K_{\text{HA}}$  (along with the corresponding standard deviations) for individual substrates and respective solvents. Comparison of the results obtained in different media is difficult since it is impossible to define an absolute pH scale. For easier orientation at least, we give the dissociation constants of benzoic acid which was used as the standard. The solvents chosen cover the basic types usually adopted in potentiometric studies (the values in brackets are the dissociation constants of benzoic acid): amphiprotic methanol (9.41; ref.<sup>29</sup>), dipolar aprotic protophobic acetonitrile (20.70; ref.<sup>30</sup>), dipolar aprotic protophilic *N,N*-dimethylformamide (12.27; ref.<sup>30</sup>), and pyridine (9.80; ref.<sup>31</sup>). The substituents chosen involved those with predominant inductive effects (CH<sub>3</sub>, Cl, Br), those with distinct mesomeric effects (NO<sub>2</sub>, CN, OCH<sub>3</sub>, NH<sub>2</sub>), and, of course, the standard substituent – hydrogen.

The experimental data obtained were analyzed using mathematical-statistical methods. All the  $pK_{\text{HA}}$  values (each measurement was repeated three times) were subjected to both simple and multiple linear regressions. On the other hand, the methods

working with latent variables, in particular the principal component analysis<sup>32</sup> (PCA) and the conjugated deviations analysis<sup>33</sup> (CDA) treated the  $\overline{pK}_{\text{HA}}$  values. The calculations using simple linear regression and the classic Hammett relation ( $pK_{\text{HA}} = pK_{\text{HA}}^0 - \rho\sigma$ ) were carried out for all the four media studied with four sets of substituent constants:  $\sigma$  (the constants proposed by Exner<sup>34</sup>),  $\sigma_{\text{P6}}$  and  $\sigma_{\text{F6}}$  (the constants designed for non-aqueous media<sup>35</sup>), and  $\Delta_{\text{calc}}$  (the constants designed for description of substituent effects in naphthalene skeleton<sup>17</sup>). One can presume that for the alternating and nonalternating positions it will be more precise to adopt the  $\sigma_p$  and  $\sigma_m$  constants, respectively. Table III summarizes the results of calculations by simple linear regression using the  $\sigma$  values by Exner and  $\Delta_{\text{calc}}$  values. From the regression characteristics it follows that the presumption mentioned is not always satisfactorily fulfilled (*e.g.* for the position 7 $\beta$  in all the four solvents). In the case of 2-naphthoic acids it seems more appropriate to use the  $\sigma_m$  values for the substitution at 4 $\beta$  and 5 $\beta$  positions and  $\sigma_p$  values for 6 $\beta$ , 7 $\beta$ , and 8 $\beta$  positions. All the four sets of substituent constants give comparable results. Hence, only the application of  $\sigma$  (by Exner) and  $\Delta_{\text{calc}}$  will be discussed below.

TABLE I

The average dissociation constants ( $\overline{pK}_{\text{HA}}$ ) and their standard deviations ( $s$ ) of substituted 1-naphthoic acids in various solvents

X	$\overline{pK}_{\text{HA}}$ ( $s$ )			
	MeOH	DMF	Py	AN
H	8.98 (0.02)	12.00 (0.02)	9.49 (0.06)	20.13 (0.01)
3-NO <sub>2</sub>	8.05 (0.04)	10.35 (0.08)	8.10 (0.03)	18.74 (0.06)
4-OCH <sub>3</sub>	9.58 (0.01)	12.58 (0.05)	10.15 (0.05)	20.97 (0.06)
4-Cl	8.66 (0.04)	11.31 (0.03)	8.89 (0.02)	19.95 (0.06)
4-Br	8.68 (0.02)	11.28 (0.04)	8.88 (0.03)	19.91 (0.00)
4-CN	7.86 (0.03)	10.46 (0.02)	8.07 (0.04)	19.14 (0.02)
5-NH <sub>2</sub>	9.13 (0.01)	12.60 (0.02)	9.97 (0.03)	20.36 (0.08)
5-Cl	8.62 (0.02)	11.31 (0.03)	8.98 (0.04)	19.73 (0.07)
5-Br	8.58 (0.03)	11.19 (0.07)	8.96 (0.08)	19.80 (0.12)
5-CN	8.30 (0.01)	10.96 (0.02)	8.90 (0.01)	19.32 (0.02)
5-NO <sub>2</sub>	8.32 (0.04)	10.86 (0.07)	8.55 (0.06)	19.24 (0.08)
8-Cl	8.38 (0.02)	11.93 (0.06)	9.40 (0.04)	19.70 (0.06)
8-NO <sub>2</sub>	8.55 (0.05)	11.47 (0.03)	9.23 (0.03)	19.58 (0.07)

TABLE II  
The average dissociation constants ( $\overline{pK_{HA}}$ ) and their standard deviations ( $s$ ) of substituted 2-naphthoic acids in various solvents

X	$\overline{pK_{HA}}$ ( $s$ )			
	MeOH	DMF	Py	AN
H	9.36 (0.03)	12.11 (0.05)	9.74 (0.04)	20.30 (0.05)
4-CH <sub>3</sub>	9.39 (0.03)	12.26 (0.05)	9.89 (0.04)	20.52 (0.02)
4-Cl	8.87 (0.04)	11.24 (0.02)	8.98 (0.07)	19.73 (0.05)
4-Br	8.85 (0.03)	11.20 (0.04)	8.98 (0.07)	19.76 (0.03)
5-Br	9.03 (0.02)	11.66 (0.06)	9.29 (0.04)	20.49 (0.06)
5-NO <sub>2</sub>	8.82 (0.03)	11.40 (0.03)	8.98 (0.06)	19.94 (0.10)
6-OCH <sub>3</sub>	9.54 (0.00)	12.47 (0.01)	9.95 (0.04)	20.77 (0.01)
6-CH <sub>3</sub>	9.44 (0.02)	12.31 (0.03)	9.87 (0.04)	20.47 (0.04)
6-Cl	9.13 (0.02)	11.99 (0.05)	9.39 (0.05)	20.73 (0.03)
6-Br	9.13 (0.04)	11.87 (0.00)	9.39 (0.05)	20.48 (0.01)
6-CN	8.77 (0.05)	11.49 (0.04)	8.99 (0.07)	19.79 (0.05)
6-NO <sub>2</sub>	8.73 (0.01)	11.37 (0.04)	8.86 (0.07)	19.91 (0.06)
7-NH <sub>2</sub>	9.59 (0.05)	12.79 (0.04)	10.32 (0.02)	20.60 (0.06)
7-OCH <sub>3</sub>	9.39 (0.03)	12.28 (0.07)	9.78 (0.03)	20.46 (0.10)
7-CH <sub>3</sub>	9.41 (0.02)	12.27 (0.02)	9.74 (0.02)	20.50 (0.07)
7-Cl	9.10 (0.01)	11.89 (0.05)	9.43 (0.07)	20.18 (0.04)
7-Br	9.10 (0.01)	11.85 (0.05)	9.33 (0.05)	20.02 (0.12)
7-CN	8.88 (0.04)	11.52 (0.03)	9.06 (0.07)	19.76 (0.04)
7-NO <sub>2</sub>	8.79 (0.02)	11.46 (0.05)	8.97 (0.06)	19.45 (0.14)
8-OCH <sub>3</sub>	9.49 (0.02)	12.41 (0.03)	9.70 (0.05)	20.47 (0.09)
8-CH <sub>3</sub>	9.32 (0.05)	12.15 (0.06)	9.63 (0.06)	20.46 (0.02)
8-Cl	9.11 (0.02)	11.72 (0.02)	9.33 (0.04)	20.32 (0.10)
8-Br	9.07 (0.03)	11.76 (0.05)	9.23 (0.04)	20.32 (0.06)
8-CN	8.86 (0.02)	11.39 (0.07)	8.98 (0.06)	20.05 (0.15)
8-NO <sub>2</sub>	8.85 (0.02)	11.33 (0.05)	8.99 (0.02)	20.01 (0.06)

TABLE III

Linear regressions of  $pK_{HA}$  vs  $\sigma_m$ ,  $pK_{HA}$  vs  $\sigma_p$ , and  $pK_{HA}$  vs  $\Delta_{calc}$  for 4- and 5-substituted 1-naphthoic acids and for 4-, 5-, 6-, 7-, and 8-substituted 2-naphthoic acids in various solvents

Substitution	Subst. constant	MeOH			DMF			Py			AN		
		$pK^0$ (s)	$\rho$ (s)	$s$ (R)	$pK^0$ (s)	$\rho$ (s)	$s$ (R)	$pK^0$ (s)	$\rho$ (s)	$s$ (R)	$pK^0$ (s)	$\rho$ (s)	$s$ (R)
4 $\alpha$	$\sigma_m$	9.39 (0.12)	2.19 (0.35)	0.298 (0.867)	12.40 (0.13)	3.00 (0.36)	0.306 (0.918)	9.92 (0.14)	2.84 (0.39)	0.329 (0.898)	20.64 (0.16)	2.13 (0.44)	0.373 (0.803)
	$\sigma_p$	9.05 (0.02)	1.71 (0.04)	0.052 (0.996)	11.91 (0.03)	2.19 (0.09)	0.118 (0.988)	9.46 (0.03)	2.12 (0.09)	0.109 (0.989)	20.33 (0.04)	1.76 (0.10)	0.129 (0.979)
	$\Delta_{calc}$	8.99 (0.01)	0.98 (0.02)	0.040 (0.998)	11.83 (0.03)	1.25 (0.05)	0.105 (0.991)	9.39 (0.02)	1.21 (0.04)	0.079 (0.995)	20.27 (0.02)	1.02 (0.04)	0.085 (0.991)
5 $\alpha$	$\sigma_m$	9.00 (0.02)	1.02 (0.04)	0.055 (0.985)	12.15 (0.07)	2.02 (0.15)	0.184 (0.960)	9.63 (0.06)	1.49 (0.13)	0.160 (0.945)	20.21 (0.03)	1.35 (0.07)	0.086 (0.980)
	$\sigma_p$	8.80 (0.03)	0.63 (0.05)	0.098 (0.952)	11.78 (0.05)	1.28 (0.10)	0.201 (0.952)	9.36 (0.04)	0.95 (0.09)	0.166 (0.941)	19.96 (0.03)	0.87 (0.06)	0.113 (0.965)
	$\Delta_{calc}$	8.94 (0.03)	0.86 (0.06)	0.063 (0.970)	11.88 (0.06)	1.41 (0.11)	0.120 (0.960)	9.42 (0.06)	1.03 (0.11)	0.120 (0.930)	20.16 (0.04)	1.18 (0.07)	0.078 (0.976)
4 $\beta$	$\sigma_m$	9.34 (0.01)	1.28 (0.05)	0.034 (0.993)	12.12 (0.02)	2.41 (0.06)	0.040 (0.997)	9.76 (0.02)	2.10 (0.07)	0.052 (0.994)	20.37 (0.02)	1.69 (0.09)	0.060 (0.987)
	$\sigma_p$	9.24 (0.03)	1.61 (0.16)	0.085 (0.954)	11.94 (0.04)	3.09 (0.23)	0.123 (0.973)	9.60 (0.03)	2.70 (0.19)	0.103 (0.975)	20.24 (0.02)	2.23 (0.10)	0.052 (0.990)
	$\Delta_{calc}$	9.33 (0.01)	0.79 (0.03)	0.033 (0.993)	12.11 (0.01)	1.50 (0.03)	0.038 (0.997)	9.75 (0.02)	1.30 (0.05)	0.054 (0.993)	20.36 (0.02)	1.05 (0.06)	0.062 (0.986)

TABLE III  
(Continued)

Substitution	Subst. constant	MeOH			DMF			Py			AN		
		$pK^0$ (s)	$\rho$ (s)	$s$ (R)	$pK^0$ (s)	$\rho$ (s)	$s$ (R)	$pK^0$ (s)	$\rho$ (s)	$s$ (R)	$pK^0$ (s)	$\rho$ (s)	$s$ (R)
5 $\beta$	$\sigma_m$	9.35 (0.02)	0.77 (0.04)	0.035 (0.991)	12.09 (0.03)	1.00 (0.07)	0.062 (0.983)	9.72 (0.03)	1.07 (0.06)	0.050 (0.990)	20.42 (0.11)	0.49 (0.24)	0.211 (0.608)
	$\sigma_p$	9.28 (0.05)	0.61 (0.09)	0.097 (0.925)	12.00 (0.07)	0.79 (0.14)	0.140 (0.909)	9.63 (0.06)	0.85 (0.13)	0.131 (0.930)	20.43 (0.08)	0.54 (0.16)	0.162 (0.793)
	$\Delta_{\text{calc}}$	9.34 (0.02)	0.88 (0.05)	0.039 (0.988)	12.08 (0.04)	1.15 (0.09)	0.067 (0.980)	9.71 (0.03)	1.23 (0.07)	0.055 (0.988)	20.42 (0.11)	0.58 (0.27)	0.208 (0.626)
6 $\beta$	$\sigma_m$	9.46 (0.03)	1.00 (0.08)	0.099 (0.946)	12.32 (0.05)	1.23 (0.13)	0.155 (0.919)	9.87 (0.04)	1.36 (0.09)	0.117 (0.959)	20.69 (0.09)	1.02 (0.22)	0.276 (0.743)
	$\sigma_p$	9.33 (0.01)	0.76 (0.02)	0.034 (0.994)	12.16 (0.13)	0.97 (0.03)	0.053 (0.991)	9.68 (0.02)	1.02 (0.04)	0.066 (0.987)	20.58 (0.05)	0.87 (0.12)	0.202 (0.872)
	$\Delta_{\text{calc}}$	9.38 (0.01)	1.08 (0.04)	0.044 (0.990)	12.23 (0.02)	1.36 (0.06)	0.076 (0.981)	9.76 (0.01)	1.46 (0.04)	0.048 (0.993)	20.63 (0.07)	1.17 (0.19)	0.234 (0.823)
7 $\beta$	$\sigma_m$	9.43 (0.02)	0.90 (0.04)	0.057 (0.979)	12.35 (0.04)	1.31 (0.12)	0.165 (0.924)	9.88 (0.04)	1.32 (0.11)	0.162 (0.927)	20.47 (0.04)	1.22 (0.09)	0.134 (0.940)
	$\sigma_p$	9.27 (0.01)	0.60 (0.03)	0.060 (0.976)	12.13 (0.02)	0.91 (0.04)	0.088 (0.979)	9.65 (0.02)	0.91 (0.05)	0.105 (0.970)	20.26 (0.03)	0.81 (0.06)	0.123 (0.949)
	$\Delta_{\text{calc}}$	9.39 (0.01)	1.05 (0.04)	0.044 (0.984)	12.23 (0.03)	1.36 (0.09)	0.090 (0.962)	9.75 (0.03)	1.37 (0.08)	0.082 (0.968)	20.45 (0.04)	1.52 (0.14)	0.138 (0.931)
8 $\beta$	$\sigma_m$	9.38 (0.03)	0.76 (0.07)	0.092 (0.925)	12.22 (0.05)	1.25 (0.12)	0.154 (0.921)	9.69 (0.03)	1.05 (0.07)	0.091 (0.959)	20.43 (0.04)	0.52 (0.09)	0.113 (0.792)
	$\sigma_p$	9.28 (0.02)	0.58 (0.04)	0.062 (0.967)	12.05 (0.02)	0.96 (0.05)	0.088 (0.975)	9.54 (0.03)	0.75 (0.06)	0.112 (0.937)	20.37 (0.02)	0.43 (0.05)	0.084 (0.889)
	$\Delta_{\text{calc}}$	9.34 (0.02)	0.64 (0.04)	0.064 (0.964)	12.14 (0.03)	1.06 (0.06)	0.102 (0.966)	9.62 (0.02)	0.85 (0.05)	0.082 (0.966)	20.41 (0.03)	0.45 (0.07)	0.097 (0.850)

For the 2-naphthoic acids we also carried out the calculations by fivefold linear regression of  $pK_{\text{HA}}$  vs  $\sigma$  ( $\sigma_m$  for 4 $\beta$ , 5 $\beta$ , and  $\sigma_p$  for 6 $\beta$ , 7 $\beta$ , 8 $\beta$ ) and  $pK$  vs  $\Delta_{\text{calc}}$ , the results of which are summarized in Table V. There are no substantial differences between the applications of the two sets of substituent constants. Due to the nonexistence of universal pH scale, comparisons of  $pK^0$  values in the individual media are difficult. However, the order of  $pK^0$  values agrees with that of  $pK_{\text{HA}}$  values of benzoic acids in all the media studied, increasing in the series: MeOH, Py, DMF, AN.

The PCA and CDA calculations were carried out for the series of substituted 2-naphthoic acids. The average values of dissociation constants were arranged in the form of a matrix with 25 lines (substituents) and 4 columns (solvents). The matrix was completely filled. Both the methods lead to the same results. The first latent variable,  $t1$ , (see Table IV) describes 92.6% variability of the data matrix and represents a new set of substituent constants describing the substituent effects in naphthalene skeleton. This fact is confirmed by the results of fivefold linear regression of  $pK_{\text{HA}}$  vs  $t1$  summarized in Table V. As the score vector  $t1$  is standardized (the values within the interval from 0 to 1), Table V does not give the  $pK^0$  and  $\rho$  values. The correlations are closer than those using the sets of  $\sigma$  and  $\Delta_{\text{calc}}$  constants. The second latent variable,  $t2$ , stands at the limit of statistical significance and describes 6.1% variability of the data matrix. Its existence can be ascribed to the lower accuracy of the measurements in acetonitrile and, hence, greater variability of data describing the dissociation in this solvent.

In conclusion it should be stated that the experimental data need extension with respect to the number of both model compounds (further substrates) and media (further organic solvents).

TABLE IV

The score vector  $t1$  from PCA calculation for substituted 2-naphthoic acids

X	$t1$	X	$t1$	X	$t1$
H	0.624	6-Br	0.475	7-NO <sub>2</sub>	0.000
4-CH <sub>3</sub>	0.737	6-CN	0.073	8-OCH <sub>3</sub>	0.745
4-Cl	0.042	6-NO <sub>2</sub>	0.036	8-CH <sub>3</sub>	0.629
4-Br	0.035	7-NH <sub>2</sub>	1.000	8-Cl	0.396
5-Br	0.387	7-OCH <sub>3</sub>	0.705	8-Br	0.371
5-NO <sub>2</sub>	0.100	7-CH <sub>3</sub>	0.710	8-CN	0.132
6-OCH <sub>3</sub>	0.884	7-Cl	0.417	8-NO <sub>2</sub>	0.112
6-CH <sub>3</sub>	0.810	7-Br	0.356		
6-Cl	0.548	7-CN	0.120		



TABLE V

Fivefold linear regressions of  $pK_{HA}$  vs  $\sigma$  ( $\sigma_m$  for 4 $\beta$ , 5 $\beta$ , and  $\sigma_p$  for 6 $\beta$ , 7 $\beta$ , 8 $\beta$ ),  $pK_{HA}$  vs  $\Delta_{calc}$ , and  $pK_{HA}$  vs  $tI$  for substituted 2-naphthoic acids in various solvents

Solvent	Subst. const.	$pK^0$ (s)	$\rho_{4\beta}$ (s)	$\rho_{5\beta}$ (s)	$\rho_{6\beta}$ (s)	$\rho_{7\beta}$ (s)	$\rho_{8\beta}$ (s)	s (R)
MeOH	$\sigma$	9.28 (0.01)	1.15 (0.05)	0.67 (0.04)	0.72 (0.03)	0.59 (0.02)	0.59 (0.03)	0.049 (0.984)
	$\Delta_{calc}$	9.36 (0.01)	0.83 (0.04)	0.92 (0.05)	1.05 (0.04)	0.98 (0.04)	0.68 (0.03)	0.054 (0.980)
	$tI$	–	–	–	–	–	–	0.043 (0.988)
DMF	$\sigma$	12.11 (0.01)	2.41 (0.10)	1.05 (0.06)	0.92 (0.04)	0.90 (0.38)	1.03 (0.04)	0.084 (0.982)
	$\Delta_{calc}$	12.20 (0.02)	1.62 (0.07)	1.37 (0.08)	1.31 (0.07)	1.30 (0.07)	1.13 (0.05)	0.092 (0.975)
	$tI$	–	–	–	–	–	–	0.074 (0.987)
Py	$\sigma$	9.63 (0.01)	1.78 (0.12)	0.91 (0.08)	0.96 (0.06)	0.89 (0.05)	0.85 (0.06)	0.107 (0.965)
	$\Delta_{calc}$	9.71 (0.01)	1.23 (0.06)	1.21 (0.08)	1.38 (0.06)	1.26 (0.07)	0.98 (0.05)	0.087 (0.972)
	$tI$	–	–	–	–	–	–	0.088 (0.977)
AN	$\sigma$	20.40 (0.03)	1.79 (0.22)	0.46 (0.14)	0.68 (0.10)	0.89 (0.09)	0.46 (0.10)	0.189 (0.871)
	$\Delta_{calc}$	20.53 (0.03)	1.31 (0.12)	0.80 (0.15)	1.01 (0.12)	1.71 (0.13)	0.64 (0.10)	0.169 (0.899)
	$tI$	–	–	–	–	–	–	0.154 (0.916)

The authors are indebted to Prof. W. Adcock (The Flinders University of South Australia, Adelaide, Australia) who kindly supplied the series of substituted 2-naphthoic acids.

## REFERENCES

1. Hammett L. P.: *Physical Organic Chemistry*, 2nd ed. McGraw-Hill, New York 1970.
2. Price C. C., Mertz E. C., Wilson J.: *J. Am. Chem. Soc.* 76, 5131 (1954).
3. Berliner E., Winicov E. H.: *J. Am. Chem. Soc.* 81, 1630 (1959).
4. Hoop G. M., Tedder J. M.: *J. Chem. Soc.* 1962, 4853.

5. Fischer A., Mitchell W. J., Packer J., Topsom R. D., Vaughan J.: *J. Chem. Soc.* 1963, 2892.
6. Bonnier J. M., Rinaudo J.: *Bull. Soc. Chim. Fr.* 1966, 3901.
7. Baliah V., Nadar P. A.: *Indian J. Chem.* 1971, 671.
8. Koptyug V. A., Berezina R. N., Petrov V. P.: *Zh. Org. Khim.* 1966, 1696.
9. Berezina R. N., Kalfus K., Koptyug V. A.: *Izv. Sibir. Otd. Akad. Nauk SSSR, Ser. Khim. Nauk* 1970, 100; *Chem. Abstr.* 75, 5044 (1971).
10. Koptyug V. A., Komagorov A. M., Uzhu V. P., Petrov V. P.: *Zh. Org. Khim.* 1966, 465.
11. Mentre I.: *Ann. Chim. (Paris)* 1972, 333.
12. Hojo M., Katsurakawa K., Yoshida Z.: *Tetrahedron Lett.* 12, 1497 (1968).
13. Bowden K., Parkin D. C.: *J. Chem. Soc., Chem. Commun.* 1968, 75.
14. Bowden K., Last A. M.: *J. Chem. Soc., Perkin Trans.* 1973, 1144.
15. Bowden K., Parkin D. C.: *Can. J. Chem.* 47, 185 (1969).
16. Dewar M. J. S., Grisdale P. J.: *J. Am. Chem. Soc.* 84, 3546 (1962).
17. Wells P. R., Adcock W.: *Aust. J. Chem.* 18, 1365 (1965).
18. Wells P. R., Ehrenson S. R., Taft R. W.: *Prog. Phys. Org. Chem.* 6, 147 (1968).
19. Kheifets L. J., Przhivalgovskaya N. M., Dmitrievskaya L. I.: *Zh. Obshch. Khim.* 41, 510 (1971).
20. Berenjian N., Utley J. H. P.: *J. Chem. Soc., Chem. Commun.* 1979, 550.
21. Ballard R. E., Park C. H.: *Spectrochim. Acta, Part A* 26, 399 (1970).
22. Ludwig M., Pytela O., Kalfus K., Vecera M.: *Collect. Czech. Chem. Commun.* 49, 1182 (1984).
23. Ludwig M., Pytela O., Vecera M.: *Collect. Czech. Chem. Commun.* 49, 2593 (1984).
24. Ludwig M., Pytela O., Vecera M.: *Collect. Czech. Chem. Commun.* 51, 1948 (1986).
25. Gomberg M., Blicke F. F.: *J. Am. Chem. Soc.* 45, 1765 (1923).
26. Short W. F., Wang H.: *J. Chem. Soc.* 1950, 991.
27. Dewar M. J. S., Grisdale P. J.: *J. Am. Chem. Soc.* 84, 3541 (1962).
28. Vondracek M., Vecerek B.: *Chem. Listy* 49, 772 (1955).
29. Kolthoff I. M., Guss L. S.: *J. Am. Chem. Soc.* 60, 2516 (1938).
30. Kolthoff I. M., Chantooni M. K.: *J. Am. Chem. Soc.* 93, 3843 (1971).
31. Mukherjee L. M., Shultz R. S.: *Talanta* 19, 707 (1972).
32. Wold S., Esbensen K., Geladi P.: *Chemom. Intell. Lab. Syst.* 2, 37 (1987).
33. Pytela O.: *Collect. Czech. Chem. Commun.* 55, 42 (1990).
34. Exner O.: *Korelacni vztahy v organické chemii*. SNTL, Praha 1981.
35. Pytela O., Ludwig M., Vecera M.: *Collect. Czech. Chem. Commun.* 51, 2143 (1986).