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Transesterification of Esters of Carbocylic Acids by Titanium Alcoholates. I. Transesterification of n-Butyl Chloroacetate by sec.-Butylorthotitanate in Heptane

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Transesterification kinetics of n-butylchloroacetate by sec - butylorthotitanate in heptane over the temperature range from 0 to 55°C has been studied. Activation parameters of the reaction are determined. The reaction is kinetically second order (first in each reagent) and is not complicated by the side reactions.

Nucleophilic substitution reactions of esters are among the most quantitatively studied reactions in organic chemistry . Data on acidic and alkaline hydrolysis as well as on alkaline alcoholysis of esters has provided a basis for constructing a substantial part of quantitative theory of dependence of organic reactivity on structure. On the basis of the data on the esterification of carboxylic acids and hydrolysis of esters in non-polar solvent water mixtures. R.W. Taft[1] has suggested the scales of steric and induction substituent constants, E_s and σ^*.

However, solvent effects on nucleophilic substitution reaction rates of esters and especially combined effects of structure, medium, and temperature on these processes have received moderate attention. To elucidate and quantitatively describe these regularities such a reaction series

is desirable which mechanism does not vary within considerable changes in the reaction conditions. Alkaline alcoholysis, for example, does not fit for this purpose, as in alcohols and other organic solvents alongside with alcoxide ions ion pairs of alcoholate and their associates are present[2,3]. These species all possess various nucleophilicity to esters and their relative concentration depends on temperature and solvent[3,4].

The present work studies transesterification of n-butyl chloroacetate by sec - butylorthotitanate as an example of the transesterification reaction by titanium alcoholates.

This process may happen to be suitable for a multiparameter analysis of combined structure, medium, and temperature effects on the nucleophilic substitution reactions at the carbonyl group. The choice of titanium alcoholates as nucleophilic reagents is due to their physico-chemical properties: orthotitanates of secondary and tertiary alcohols are well soluble in organic solvents and monomeric in solutions[5].

In spite of the fact that titanium alcoholates are typical catalysts of the transesterification reaction[6] systematic kinetic data on their reactivity are absent in the literature.

Experimental

Reagents. Heptane and cyclohexane and cyclohexane were shaken with the mixture of concentrated sulphuric and nitric acids washed with water and redistilled over calcium hydride in the atmosphere of dry argon.

Purity of n-butyl chloroacetate was not less than 99% by the data of GLC. Sec.-butylorthotitanate was obtained from sec.-butyl alcohol distilled over calcium hydride and freshly distilled titanium tetrachloride in the flow of dry ammonia[7,8]. Before use it was distilled in the atmosphere of argon. The fraction of 108-110°C (1 mm) was collected.

Kinetic measurements. Kinetic measurements were carried out under pseudo-first-order conditions (not less than 20-

fold excess of orthotitanate) by the method of samples and their GLC analysis. The reaction was carried out in test--tubes. 2 ml of the reaction mixture was placed into the test-tube, corked hermetically with a fluoroplastic stopper provided with silicone septum to let initial solutions in and to take samples. The test-tubes were thermostated in 9U-10 thermostat to within 0.1°C.

1.5 ml of 0.02-0.10 M solution of sec-butylorthotitanate in heptane was transported into the cell with a hypodermic syringe. At the starting reaction moment 2-10 Ml of 10% solution of initial ester and internal standard (tridecane) in heptane was added into the reaction mixture.

Analysis of samples (1-3 μl) for the content of n-butyl chloroacetate or sec.-butylchloroacetate in the reaction mixture was done on a "Vôruchrom" chromatograph with a flame--ionization detector by the ratio of peak heights of ester and standard. The column (0.3x300 cm) was packed with fluorosilicone elastomer SKTFT-100 coated support Chromaton N Super. Carrier gas was nitrogen, temperature of the column was 115°C.

To determine the initial concentration of titanate in heptane 1-2 ml of samples was boiled with diluted sulphuric acid to decompose alcoholate and remove heptane. Then the excess of hydrogen peroxide and complexon III was added and the mixture was titrated back by standard solution of bismuth at pH=1-3 using the indicator xylene orange[9]. The concentration of alcoholate at 0° and 55°C was calculated from the results of titration at room temperature, using the coefficient of thermal expansion of heptane[10].

Determination of the molecular weight. Cryscopic measurements were done in dry cyclohexane. The difference of freezing temperatures of cyclohexane and 0.05-0.10 M solution of sec.-butylorthotitanate in cyclohexane was measured. The obtained molecular weights, 314 and 330 (m.w. for monomer is 340) indicate that the alcoholate in the solution is monomeric and some impurities in the alcoholate (probably, 1-2% addition of sec.-butyl alcohol) are present.

Results and Discussion.

Transesterification kinetics of n-butyl chloroacetate by sec.-butylorthotitanate in heptane over the temperature range from 0° to 55°C is studied. Kinetic measurements are carried out under pseudo-first-order conditions with large (not less than 20-fold) excess of orthotitanate. The first order rate constants are calculated from the relationship ln φ-t (φ is a ratio of peak heights of initial ester and standard; t is reaction time) by the least squares method. Linearity of this dependence within not less than two half--periods of the reaction (see Fig.1) indicates that the pseudo-first kinetic order is followed.

The reaction rate was measured at several concentrations of sec.-butylorthotitanate at intervals from 0.02 to 0.10 M. The results of determining the molecular weight in cyclohexane showed that at these concentrations orthotitanate is monomeric (see Experimental). The obtained values of k_1 depend linearly on the concentration of titanate (see Fig. 2). Second order transesterification rate constants, k_{II}, are calculated by the slope of this dependence. The Table lists these constants.

In the course of kinetic measurements no formation of the side product peaks was observed on the chromatograms. Coincidence within error limits of the transesterification rate constants calculated by the initial ester and reaction product also indicates that any side reactions are absent. The reaction studied is kinetically second order (first in each reagent). This speaks in favor of the fact that strong donor-accepting interaction between carbonyl oxygen and orthotitanate metal is absent.

Table

Rate Constants of the Reaction of n-Butyl Chloroacetate with sec.-Butylorthotitanate

t, °C	C, M	$10^4 k_1, s^{-1}$	$10^3 k_{II}, M^{-1}s^{-1}$	$10^3 k_{II}, M^{-1}s^{-1}$
1	2	3	4	5
0.0	0.0536	1.2721	2.37	
	0.0536	1.279	2.39	

1	2	3	4	5
	0.0536	1.335	2.49	2.34 ± 0.12
	0.1015	2.223	2.19	
	0.1015	2.294	2.26	
25.0	0.0240	2.04	8.48	
	0.0240	2.03	8.47	
	0.0520	4.51(4.00)*	8.68	
	0.0520	4.74(4.48)	9.12	8.59 ± 0.29
	0.0984	8.15(7.65)	8.29	
	0.0984	8.34(8.79)	8.48	
55.0	0.0501	14.99	29.92	
	0.0501	14.84	29.63	
	0.0501	16.23	32.40	30.85 ± 1.31
	0.0501	15.76	31.47	

* Rate constants calculated by the reaction product, sec.-Butyl chloroacetate are given in parentheses.

Activation parameters calculated by the data from the Table have the following values (at standard temperature,

$E = 8.36 \pm 0.08$ kcal/mol $\quad \Delta S^{\neq} = -42.0$ entr. un.

$\lg A = 4.05 \pm 0.06$ $\quad \Delta H^{\neq} = 7.8$ kcal/mol

$\Delta G^{\neq} = 20.3$ kcal/mol

The activation parameters obtained by us differ from those for alkaline alcoholysis and hydrolysis of esters by the $B_{Ac}2$ mechanism. In these reactions the value of entropy is within -20 - -30 entr. un. Ref. 11 suggests the following reaction menhanism for the tranesterification esters by titanium alcoholatee:

$$(RO)_4Ti \rightleftarrows (RO)_3Ti^{3+} + RO^-$$

$$RO^- + R^1C(=O)OR'' \rightleftarrows R^1C(=O)OR + R''O^-$$

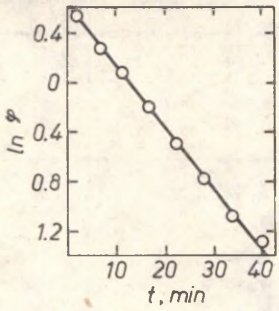

Fig. 1. Plot of ln φ (φ - ratio of the heights of the chromatographic peaks of butyl chloroacetate and tridecane) vs. time at 25.0°C

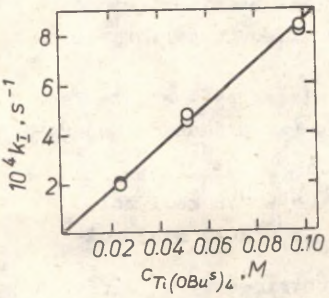

Fig. 2. Plot of the pseudo-first-order rate constants (k_I) vs. sec-butyl orthotitanate concentrations for the transesterification of butyl chloroacetate at 25.0°C.

Under our experimental conditions (low solvent polarity) such a mechanism where orthotitanate reacts in the non-dissociated form is more probable.

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A Note on Quantitative Analysis of Enzyme Specificity

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The principal complications connected with the "normalization" method sometimes used in the study of enzyme specificity are discussed. Besides the general considerations an example concerning acetylcholinesterase-catalyzed hydrolysis of acetic esters is analyzed.

A more complete understanding of the physico-chemical background of enzyme specificity requires separation and quantification of different specificity-determining factors. A relatively simple and easily available procedure to be applied for this purpose is the correlation analysis based on the linear-free-energy relationships. The principles of this extrathermodynamic approach have been elaborated in physical organic chemistry[1] and are also widely used in biochemistry[2]. In the present note a trend to oversimplification of this approach is discussed.

The factors determining the specificity of enzyme catalysis are often divided into two groups:

i - factors determining the "intrinsic" reactivity of the substrate in the catalytic steps, and

ii - intermolecular interactions responsible for the non-covalent complex formation in the binding step.

Unfortunately, sometimes it is not understood that the "intrinsic" reactivity of substrates also depends upon the properties of the reaction medium, i.e. on the specific and non-specific solvation of the reacting molecules (groups) in the initial and transition states. Therefore it is pointless to

use the method of "normalization" of the enzyme reaction rate constants for reactivity of the substrates in some"model" non-enzymic reaction in order to separate the binding and other typically enzymic effects. It should be noted that the procedure of "normalization" is valid only if the identity of both reaction mechanism can be proved. However, up to now there has not been found a single case to which this statement could have been applied with certainty. On the other hand, the differences between enzyme and non-enzymic reaction mechanism are widely discussed in elementary textbooks of biochemistry.

The complications connected with the "normalization" procedure can be obviously demonstrated by the following. If in an enzyme reaction the reactivity of congeneric substrates with a variable substituent R_i depends on n structural factors and in a non-enzymic "model" reaction reveals m different structural factors ($m < n$), the activation or reaction free-energy-related kinetic constants (log k or pK) can be represented:

$$\log k^i_{nonenz} = \log k^o_{nonenz} + \sum_{j=0}^{j=m} a^j_{nonenz} \cdot x_{ij} \qquad (1)$$

and

$$\log k^i_{enz} = \log k^o_{enz} + \sum_{j=0}^{j=n} a^j_{enz} \cdot x_{ij} \qquad (2)$$

where a^j_{nonenz} and a^j_{enz} denote the intensity factors of the appropriate structural effects, quantified by structural parameters x_{ij} ($j = 0,\ldots m,\ldots n$). According to the "normalization" procedure:

$$\log \frac{k^i_{enz}}{k^i_{nonenz}} = \log \frac{k^o_{enz}}{k^o_{nonenz}} + \sum_{j=0}^{j=m} (a^j_{enz} - a^j_{nonenz}) \cdot x_{ij} + \sum_{j=m+1}^{j=n} a^j_{enz} \cdot x_{ij} \cdot \qquad (3)$$

The above equation shows that the terms containing x_{ij} at $j=0...m$ cancel if $a^j_{enz} = a^j_{nonenz}$ for all factors at $j=0,...m$ and only in this case do the "normalized" rate constants depend upon "purely" enzymatic effects $j = m+1,...n$.

Here the reaction of acetylcholinesterase-catalyzed hydrolysis of acetic esters has been chosen to illustrate the above conclusions. For non-ionic acetic esters with a variable structure of alcohol part CH_3COOR_i, in the case of which the steric effect remains practically constant (but not negligible), the following two-parameter correlation equation is valid[3]:

$$\log k^i_{II} = \log k^o_{II} + \rho^*\sigma^* + \varphi\pi \,, \qquad (4)$$

where k_{II} is the second-order rate constant, σ^* and π account for the inductive and hydrophobic influences, ρ^* and φ are the appropriate intensity factors. For the above equation the following values of the intensity factors were found (0.15 M KCl, 25°C): $\rho^* = 2.80 \pm 0.33$ and $\varphi = 1.64 \pm 0.16$[3].

For the alkaline hydrolysis of the same series of acetic esters with permanent steric effect the single-parameter correlation equation holds[4]:

$$\log k^i_{OH} = \log k^o_{OH} + \rho^*\sigma^* \,, \qquad (5)$$

where $\rho^* = 1.91 \pm 0.08$ (H_2O, 25°C).

Comparison of the above data clearly demonstrates that the effect of hydrophobic interaction cannot be separated by means of the "normalization" procedure as $\rho^*_{enz} \neq \rho^*_{OH}$, although for certain limited sets of substrates with close σ^* values the approximate linearity between $\log(k_{II}/k_{OH})$ and π-constants can be observed owing to the small value of the increment $(\rho^*_{enz} - \rho^*_{OH})$ [5].

It can be noted that much more striking differences between the structural effects were observed in the case of butyrylcholinesterase-catalyzed and alkaline hydrolysis reac-

tions of butylcarboxylates $R_iCOOC_4H_9$ with non-ionic substituents R_i [6].

In the view of those results, which demonstrate remarkable differences in the reaction mechanism of cholinesterase-catalyzed and alkaline hydrolysis of carboxylic esters it is surprising that attempts are still made to use the normalization" procedure as a "more direct method" in the analysis of acetylcholinesterase specificity[5].

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INFLUENCE OF SOLVATATION EFFECTS ON THE SPECTRAL CHARACTERISTICS OF THE C=O VALENCE VIBRATIONS BAND IN α-CHLOROACETOPHENONE

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Quantitative relationships revealing the influence of various solvent properties (polarity, polarizability,nucleophilicity,etc.) on spectrum characteristics of the $\nu_{C=O}$ bands of α-chloroacetophenone (the frequency $\nu_{C=O}$ of individual conformers as well as their integral and peak intensities) have been established.

It was shown that the effect of nonspecific solvatation is well reflected in frequencies and the effect of specific solvatation in $\nu_{C=O}$ bands intensities.

Possible types of intramolecular interaction in the studied systems are considered.

When studying the influence of a solvent on the reactivity of compounds it is expedient to apply the spectroscopic characteristics of individual bands in the infrared spectra of reagents as the indicator of solvatation processes.Besides,if the solute is characterized by conformational isomerism,such information will prove to be of high value for describing the influence of the given factor on reactivity[1,2] and,above all,for establishing the conformational structure of the reagent[3].

With a view to conducting further research into the reactivity of α-acetophenone halides the present work studies

the regularities of the influence of solvents on the spectrum characteristics of the $\nu_{c=o}$ bands of α-chloroacetophenone.

The following solvents S were used: cyclohexane (I),benzene (2),toluene (3),chlorobenzene (4),I,2-dichlorobenzene (5),I,2,4-trichlorobenzene (6),benzonitrile (7), n-butyronitrile (8), nitrobenzene (9), I,2-dimethylbenzene (I0), I,4-dimethylbenzene (II), mesitylene (I2), I,4-dioxane (I3). In addition to that we used binary mixtures of cyclohexane with diethyl ether (I4), triethylamine (I5); pyridine (I6) as well as solvents 2 - 9 with different values of mole fractions of the latter (N_s).Thus, 78 systems have been studied under conditions where the solvent and concentration of its components were widely varied (Table I).

EXPERIMENTAL

The solvents were purified in accordance with the methods described in ref.4 ; α-chloroacetophenone by successive crystallization from ethanol and the mixture of benzene and hexane. The physico-cyemical properties of substances corresponded to reference values.The binary mixtures with prescribed mole composition were prepared gravimetrically. The concentration of α-chloroacetophenone was kept constant for all the cases and equalled 0.0400 M.

The spectra of the studied solutions were obtained on a UR-20.The scanning rate did not exceed I $cm^{-I} \cdot min^{-I}$,the range of the registered spectrum was I00 cm^{-I}/ I00 mm ,the spectral split width was $\sim$ 2.9 cm^{-I}.The spectrum in the gaseous phase was recorded in the cell of variable thickness using a spectrophotometer "Perkin-Elmer-I80",the length of a beam run being 876 cm.

The spectrum recorded in the solutions is in fact the superimposition of the noncompensated part of the absorption of the solvent and the absorption of α-chloroacetophenone. The distortion of the contour of the $\nu_{c=o}$ band,due to the different intensity of absorption of the solvent in the measurement cell and the compensation cell was eliminated by

introducing the relevant corrections on recording the "zero line"[5].

The integral intensities of bands were calculated by the Simpson method[6] in the frequency range I640 - I760 cm^{-I}. The integration step was 2 cm^{-I}. The calculations of molar coefficients of absorption ($\varepsilon_{c=o}$ M^{-I}. cm^{-I}) and integral intensities ($A_{c=o}$ M^{-I}. cm^{-2}) of bands were made on a "Mir-I" computer according to the formulae:

$$\varepsilon_{c=o} = \frac{I}{c.I} \lg \frac{T_o(\nu)}{T(\nu)} , \qquad (I)$$

$$A_{c=o} = \int \varepsilon_{c=o} d\nu , \qquad (2)$$

By $T_o(\nu)$ and $T(\nu)$ the optical transmissions at the frequency ν corresponding to the "zero line" and the contour of of the $\nu_{c=o}$ band are denoted, respectively.

The above methods of spectral measurements secured high reproducibility of spectral frequencies and intensities. In order to determine the standard deviations of frequencies, integral intensities and intensities in the peak of the $\nu_{c=o}$ bands we have carried out a number of independent measurements. Thus, on the basis of the four independent measurements in cyclohexane the general integral intensity of carbonyl absorption of α-chloroacetophenone, the wave numbers of the low- and high-frequency components of the $\nu_{c=o}$ band, corresponding to gauche and cis conformers of molecules[7,8] and the ratio of intensities in the peaks of the components of the $\nu_{c=o}$ bands were accordingly equal to: $(5.29 \pm 0.05).10^{3}$ M^{-I} $.10^{3} M^{-I}$. cm^{-2} ; $(I695.4 \pm 0.I)$ cm^{-I} ; $(I7I5.5 \pm 0.I)$ cm^{-I} ; 0.588 ± 0.008.

RESULTS AND DISCUSSION

The obtained data (Table I) reveal that the transition from cyclohexane to other solvents S leads to a change in the spectral characteristics of $\nu_{c=o}$ bands of α-chloroacetophenone. At the same time, as a rule; the frequencies of

Table 1

Spectrum characteristics of the $\nu_{c=o}$ band of α-chloroacetophenone in individual solvents S and their binary mixtures with cyclohexane at 30°C

No	N_S	$\nu^{gauche}_{c=o}$, cm^{-1}	$\nu^{cis}_{c=o}$, cm^{-1}	$\sum\varepsilon_{c=o}$, $M^{-1}\cdot cm^{-1}$	$A_{c=o}\cdot 10^{-3}$, $M^{-1}\cdot cm^{-2}$
1	2	3	4	5	6
		I. Cyclohexane			
1	0.0000	1695.4	1715.5	359	5.29
		2. Benzene			
2	0.1091	1694.7	1715.0	379	5.38
3	0.2244	1694.0	1714.4	392	5.57
4	0.3515	1693.3	1713.2	411	5.79
5	0.5029	1692.8	1712.1	415	5.63
6	0.6513	1692.3	1711.5	422	5.79
7	0.8025	1692.0	1710.9	429	5.88
8	1.0000	1691.3	1709.5	421	5.92
		3. Toluene			
9	0.1008	1694.4	1714.9	365	5.22
10	0.2226	1693.8	1714.2	382	5.32
11	0.3521	1693.2	1713.4	388	5.44
12	0.4971	1692.7	1712.5	414	5.56
13	0.6560	1692.4	1711.8	429	5.71
14	0.8013	1692.1	1711.2	407	5.64
15	1.0000	1691.6	1710.4	387	5.50
		4. Chlorobenzene			
16	0.04784	1694.9	1715.1	377	6.00
17	0.08861	1694.3	1714.7	369	5.63
18	0.2193	1693.4	1713.4	392	5.80
19	0.3523	1692.7	1712.4	407	6.03
20	0.5028	1692.1	1711.1	416	6.31

1	2	3	4	5	6
21	0.7529	1691.2	1709.9	388	5.78
22	1.0000	1690.7	1708.8	375	5.42
			5. 1,2-dichlorobenzene		
23	0.04496	1694.7	1714.8	382	6.07
24	0.07500	1694.0	1714.7	365	5.75
25	0.2188	1692.7	1712.4	390	5.81
26	0.3387	1692.3	1711.2	385	5.91
27	0.4931	1692.0	1710.3	361	5.68
28	0.7517	1691.5	1708.6	356	5.60
29	1.0000	1690.2	1707.7	377	5.63
			6. 1,2,4- trichlorobenzene		
30	0.05026	1694.6	1715.0	351	5.06
31	0.1004	1693.8	1714.4	349	5.09
32	0.2236	1693.0	1712.9	380	5.72
33	0.3502	1692.4	1712.0	390	5.90
34	0.5017	1691.9	1710.5	381	5.80
35	0.7510	1691.1	1709.5	360	5.49
36	1.0000	1690.2	1708.8	324	5.16
			7. Benzonitrile		
37	0.05037	1694.0	1713.8	363	5.74
38	0.09805	1693.0	1712.2	386	6.08
39	0.2254	1691.9	1709.8	390	6.21
40	0.3495	1691.7	1709.0	391	6.23
41	0.5028	1691.3	1707.5	385	6.08
42	0.7453	1690.9	1706.6	367	5.76
43	1.0000	1690.6	1706.2	343	5.02
			8. n-butyronitrile		
44	0.04932	1694.0	1713.5	362	5.70
45	0.1002	1693.3	1712.4	378	5.92
46	0.2253	1692.9	1711.0	392	6.17

Table 1 continued

1	2	3	4	5	6
47	0.3510	1692.2	1709.7	394	6.45
48	0.5002	1691.7	1708.9	400	6.20
49	0.7503	1691.3	1707.8	378	5.95
50	1.0000	1691.0	1707.4	377	5.85
		9.	Nitrobenzene		
51	0.02262	1694.8	1714.9	383	5.68
52	0.04960	1694.0	1714.0	387	5.84
53	0.1538	1692.6	1711.7	386	6.00
54	0.3353	1691.6	1709.1	404	6.30
55	0.6561	1690.5	1707.5	359	6.09
56	1.0000	1690.0	1706.0	368	5.62
		10.	1,2-dimethylbenzene		
57	1.0000	1691.7	1710.4	367	5.17
		11.	1,4-dimethylbenzene		
58	1.0000	1692.2	1711.0	424	5.36
		12.	Mesitylene		
59	1.0000	1692.4	1711.9	381	5.12
		13.	1,4-dioxane		
60	1.0000	1691.3	1709.9	394	5.56
		14.	Diethyl ether		
61	0.1008	1694.8	1715.2	351	5.44
62	0.2293	1694.4	1715.0	356	5.38
63	0.3421	1694.2	1714.6	367	5.48
64	0.5027	1694.0	1714.0	364	5.36
65	0.6518	1694.0	1713.6	376	5.63
66	0.8040	1693.9	1713.3	389	5.92
67	0.9017	1693.9	1713.0	389	5.46
68	1.0000	1693.5*)	1712.9*)	-	-

Table 1 continued

1	2	3	4	5	6
		15. Triethylamine			
69.	0.05005	1695.2	1715.4	343	5.32
70	0.09924	1695.1	1715.3	353	5.65
71	0.1996	1695.0	1715.2	350	5.45
72	0.3508	1694.8	1714.8	345	5.34
73	0.5017	1694.6	1714.3	353	5.52
74	0.7010	1694.2	1714.0	332	4.77
75	1.0000	1693.7*)	1713.7*)	-	-
		16. Pyridine			
76	0.03656	1695.1	1715.0	416	6.18
77	0.1752	1693.1	1712.3	390	5.91
78	0.2832	1692.5	1711.1	410	6.27
79	0.4192	1691.7	1709.4	397	6.24
80	0.6491	1691.2	1707.5	358	5.45
81	1.0000	1688.6*)	1702.9*)	-	-
		17. Gaseous phase			
82	-	1708.7	1730	-	-

*) The data have been obtained by extrapolation of the dependences $\nu_{C=O} = f(N_S)$ to $N_S = 1$.

the separate bands constituting the doublet $\nu_{C=O}$ drop but the total integral intensities of these bands ($A_{C=O}$) and the sum of their peak intensities ($\sum\varepsilon_{C=O}$) increase. For instance when passing from cyclohexane to chlorobenzene, and further to I,2-dichlorobenzene, the values of $A_{C=O}$ and $\sum\varepsilon_{C=O}$ increase by 2.6 and 4.5 per cent respectively. However, with a few solvents the intensities of $\nu_{C=O}$ bands prove to be remarkably lower than in cyclohexane (cf. the values of $A_{C=O}$, $\sum\varepsilon_{C=O}$ in Table I for Nos I, 36, 43 and Nos I, 57, 59). Hence, it would be of interest to follow the behavior of these values if the composition of medium were altered. As an example Fig.I indicates the dependence of $A_{C=O}$ (a) and $\sum\varepsilon_{C=O}$ (b) α-chloroacetophenone on the mole fraction of benzene and a number of its substitutes in the mixture with cyclohexane which shows very well that the dependence of intensity bands $\nu_{C=O}$ of α-chloroacetophenone on N_s is rather complicated[x]. Although the curves in Figures Ia and Ib resemble each other the peculiarities of their behavior are well marked for integral band intensities (Fig. Ia). This is primarily due to the fact that the $A_{C=O}$ values depend not only on the molar

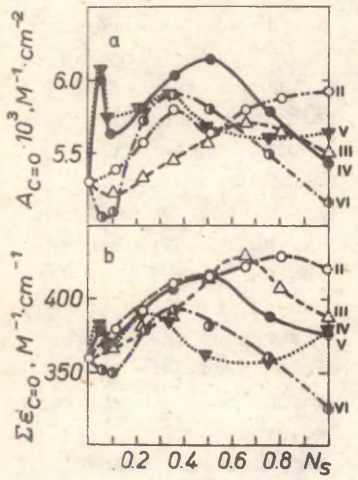

Fig.I. The dependence of $A_{C=O}$(a) and $\sum\varepsilon_{C=O}$(b) of α-chloro acetophenone on the composition of medium at 30°C. Curve numbers correspond to those of Table I.

x) It was for this reason why the above values, differently from $\nu^{gauche}_{C=O}$ and $\nu^{cis}_{C=O}$, were not obtained by extrapolation into the pure solvent for diethyl ether,

absorption coefficients of bands at peak frequencies but are at the same time also the result of changes in their contours.The last ones indicate versatility of intramolecular interactions in the systems of variable composition which is evidently accompanied by the appearance of new degenerated conformational states of α-chloroacetophenone. The well pronounced doublet nature of carbonyl absorption only shows that stereoforms with gauche and cis orientation of the C—Cl bond towards the C=O bond appear to be preferential[7,8]. The presence of other conformers besides the gauche and cis ones becomes apparent in the spectra of α-chloroacetophenone through the asymmetry and the half-width values of the $\nu_{c=o}$ band components which judging by the experiment depend on the composition and temperature of the solution,the nature of solvent,etc.As with a change in the composition of mixtures cyclohexane + + S the relative concentration of each conformer changes,it will certainly affect more the $A_{c=o}$ values than the $\sum\varepsilon_{c=o}$ values.The dependence of the frequencies of individual components of carbonyl absorption of α-chloroacetophenone on N_s diminishes monotonously for each system we studied (Fig. 2).At the same time

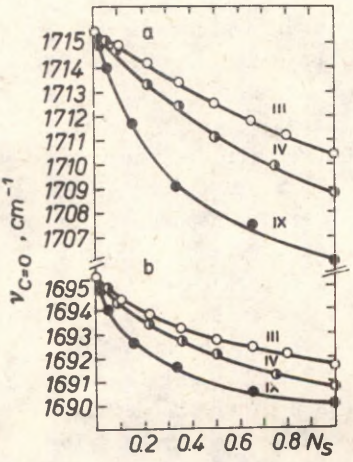

Fig. 2.The dependence of $\nu_{c=o}^{cis}$(a) and $\nu_{c=o}^{gauche}$(b) of α-chloroacetophenone on the composition of solvent at 30°C.Curve numbers correspond to those of Table I.

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triethylamine and pyridine (Nos 68 , 75 , 8I).

a change in the frequencies $\nu_{c=o}$ of the cis conformer (the high-frequency constituent) of α-chloroacetophenone in the full range of N_s concentrations exceeds similar changes for gauche conformer frequencies (the low-frequency constituent). This indicates nonidentity of solvatation of various rhotamers of α-chloroacetophenone.

In order to estimate quantitatively the influence of medium effects on various characteristics (including spectral) of dissolved substances a number of equations have been proposed (see for instance references 9 and 10). The total influence of nonspecific and specific solvatation is represented by eq.(3)[11]:

$$X = X_o + yY + pP + bB + eE \quad , \qquad (3)$$

where X and X_o are the values of the studied property in the given solvent and in the gaseous phase; $Y = \frac{\varepsilon - 1}{\varepsilon + 2}$ and $P = \frac{n^2 - 1}{n^2 + 2}$ stand for the functions of polarity and polarizability; B and E are the parameters of general basicity[12] and general acidity[13] of solvents. Coefficients y , p , b and e characterize the sensitivity of the value X to the change in each of the above medium parameters. The calculation of regression coefficientz was made on a "Mir-1" computer. The numerical values for eq.(3) were obtained for solvents Nos 1,8,15,22,29,43,56,60 (see Table 1) at $X = A_{c=o}$ and for solvents Nos 1,8,15,22,29,43,56,59,60,68, 75,81 at $X = \nu^{gauche}_{c=o}$ and $X = \nu^{cis}_{c=o}$. The results of the corresponding correlations are given below.

$$A_{c=o} = (5.27\pm0.18)\cdot10^{3}+(1.29\pm0.08)\cdot10^{3}Y-(1.23\pm0.69)\cdot10^{3}P- -(6.72\pm0.25)B+(4.37\pm0.14)\cdot10^{2}E \quad , \qquad (4)$$

$$S = 23.9\ (2.7\%),\ n = 9\ ,\ R = 0.998\ ;$$

$$\nu^{gauche}_{c=o} - 1700 = (5.29\pm2.78)-(4.14\pm1.37)Y-(37.0\pm10.6)P- -(3.04\pm 1.41)\cdot10^{-3}B-(6.96\pm2.14)\cdot10^{-1}E \quad , \qquad (5)$$

$$S = 0.776\ (11.4\%),\ n = 12,\ R = 0.994;$$

$$\nu^{cis}_{C=O} - 1700 = (33.0\pm4.8)-(9.65\pm2.35)Y-(58.7\pm18.5)P- \\ -(5.50\pm2.42)\cdot10^{-3}B-(1.07\pm0.37)E \ , \qquad (6)$$

$$S = 1.34 \ (10.6\%), \ n = 12, \ R = 0.955.$$

We have also obtained the IR-spectra of α-chloroacetophenone in the vapour phase at 30°C. The presence of the peak at $1708.7 cm^{-1}$ and a well marked shoulder in the range $1730 cm^{-1}$ in this spectra is in good agreement with the values of intercepts in equations (5) and (6). This fact together with satisfactory statistical values of relationships (4) - (6) give evidence of the validity of the above correlations.

As we have mentioned earlier a change in solvents will lead to the shift of the conformer equilibrium, whereas the experimentally measured $A_{C=O}$ values are in fact the sum of the contributions of integral intensities of individual conformers of α-chloroacetophenone. For a balanced system containing k conformers it could be expressed quantitatively in the form of succession of elementary developments:

$$A_{C=O} = \int \varepsilon(\nu)d\nu = \frac{I}{c \cdot l} \int \left[\sum_{i=1}^{k} D_i(\nu)\right] d\nu = \frac{I}{c \cdot l} \sum_{i=1}^{k} \int D_i(\nu)d\nu =$$

$$= \frac{I}{c \cdot l} \sum_{i=1}^{k} A_i c_i l = \frac{I}{c} \sum_{i=1}^{k} A_i c_i \ , \qquad (7)$$

i-th conformer and its concentration in the system; c is the analytical concentration of α-chloroacetophenone.

Similarly to the conclusions of reference 14 we have assumed that the A_i values of individual conformers of α-chloroacetophenone are equal to each other. Consequently, the $A_{C=O}$ value in eq.(7) does not depend on the state of conformer equilibrium and the dependence of $A_{C=O}$ values on the concentration of the S component in the mixture (Fig.1) reflects primarily the changes in intramolecular interactions in solutions. Let us consider dependence (4) within the framework of the given approximation.

The negative values of coefficients in the terms representing the contributions of polarizability and nucleophilicity to eq.(4) prove that together with an increase in

solvent properties under consideration the polarity of the C=O band of α-chloroacetophenone drops. The latter is in good agreement with the model of intramolecular interactions according to which the nucleophilic solvatation of a α-chloroacetophenone molecule is carried out at the carbonylic carbon atom. At this the compensation of the positive charge at the carbon atom by electrons donated by the nucleophile is accompanied by partial depolarization of the carbonyl bond. An increase in the two other characteristics of solvent (polarity and electrophilicity) will lead according to eq.(4) to an increase in the polarity of the C=O bond of α-chloroacetophenone. Indeed, an increase in solvent dielectric permittivity should favor the polarization of the carbonyl bond and an increase in dipolar momentum as a result of this. However, the interpretation of the influence of electrophilic solvatation in the studied system has encountered difficulties so far.

The comparison of absolute contributions of each of the considered solvatation effects to the change in the $A_{c=o}$ value when passing from the gaseous phase ($A_{c=o} = 5.27 \cdot 10^{3} \cdot M^{-1} \cdot cm^{-2}$, Y=P=B=E=0) to any of the studied solvents with a non-zero value of the parameter E indicates the predominant influence of specific effects and primarily electrphilic solvatation. So, for example when passing from the gaseous phase to toluene ($A_{c=o} = 5.50 \cdot 10^{3} M^{-1} \cdot cm^{-2}$, Y = 0.3149, P = 0.29257, B = 58 cm^{-1}, E = 1.3, $\Delta A_{c=o} = 230\ M^{-1} \cdot cm^{-2}$) the contribution of each solvatation effect is correspondingly equal to 410, -360, -390 and 570 $M^{-1} \cdot cm^{-2}$. A similar treatment of absolute contributions of various types of solvatation to the change in $\nu_{c=o}^{gauche}$ and $\nu_{c=o}^{cis}$ frequencies (see equations (5) and (6)) on the other hand points to the predominance of nonspecific effects and above all the polarizability of solvent.

Equations (5) and (6) show that an increase in any considered solvent property leads to a drop in the vibration frequencies of the carbonyl groups of conformers. At the same time the sensitivity of $\nu_{c=o}^{cis}$ to the change in medium polarity is approximately two times higher than that of

$\nu_{C=O}^{gauche}$. According to relatioships (5) and (6) the sensitivities of $\nu_{C=O}^{gauche}$ and $\nu_{C=O}^{cis}$ frequencies to the change in other solvent properties are statistically negligible.

Thus, the results of this work indicate that the nature of carbonyl absorption of α-chloroacetophenone are to a considerable extent dependent on the nature of solvent. At the same time an increase in the polarity and electrophilicity of medium leads to contrary effects in various spectroscopic characteristics of the c=o valent vibrations band. The conformers of α-chloroacetophenone are characterized by different sensibility to solvatation: the S-cis form is solvated more intensively.

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DETERMINATION OF BASICITY OF DIPIPERIDYLBENZAMINALS IN NITROMETHANE AND ACETONITRILE

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Nitromethane and acetonitrile media have been studied for the determination of pK_{BH^+} basicities of dipiperidylbenzaminals containing substituents in the aryl ring.

To measure the potentials of half-neutralization the method of potentiometric titration has been applied. This procedure allows to carry out separate determination of $kK_{BH_1^+}$ and $pK_{BH_2^+}$ by two jumps of the potential.

The values obtained show dipiperidylbenzaminals to be strong bases in the first step of protonation. In the second step they are more weak, $\Delta pK_{BH^+} = pK_{BH_1^+} - pK_{BH_2^+}$ constituting 6-7 units of pK_{BH^+}.

Such reduction of basicity at the second step is explained by statistic, electrostatic factors and the induction effect of the positively charged substituent - $\overset{+}{N}HR_2$. The effect of the substituents of the aryl ring can be estimated by correlation equations:

in nitromethane medium

$$pK_{BH_1^+} = 18,74 - 0,44 \cdot \bar{\sigma}^{\circ} \qquad (1)$$

$$pK_{BH_2^+} = 12,00 - 0,29 \cdot \bar{\sigma}^{\circ} \qquad (2)$$

in acetonitrile medium

$$pK_{BH_1^+} = 20,19 - 0,43 \cdot \bar{\sigma}^{\circ} \qquad (3)$$

$$pK_{BH_2^+} = 13,29 - 0,31 \cdot \bar{\sigma}^{\circ} \qquad (4)$$

where $\bar{\sigma}^{\circ}$ - is the induction constant[11].

Compounds with the structural link >N - C - N< (cyclic or with the open chain) have found wide application, particulary, in the production of biologically active compounds, polymeric materials, etc. [1,2]. When studying physicochemical properties of these compounds special attention is being paid to the estimation of their basicity (which, in particular, is connected with the biological activity of the compound). That is why such information is of obvious theoretical value[3].

In this connection dipiperidylbenzaminals present certain interest. These are compounds stable on storage which can be synthesized with quantitative yields (4) when piperidine reacts with aromatic aldehydes

$$RC_6H_4 - CHO + 2HNC_5H_{10} \rightarrow RC_6H_4 - CH-(NC_5H_{10})_2 + H_2O,$$

they also have two equal nitrogen-containing substituents at a single carbon atom.

The present paper deals with the investigation of basicity of dipiperidylbenzaminals in nitromethane and acetonitrile media.

Experimental

Nitromethane of "pure" quality was washed with water, dried over $CaCl_2$ and distilled. (the boiling point was 99-101°C).

Acetonitrile of "XI" quality was dried over P_2O_5, then purified according to the procedure[5]. The boiling temperature was 81,5°C.

Dioxane of "pure" quality was purified by 8-12 hour boiling over potassa and distillation over metallic sodium (the boiling point was 100,4 - 101,5°C).

The purity of solvents was checked by the gas-liquid-chromatography method using a "Chrom-4" device with a flame-ionization detector, column 3,2 m x 2 mm filled with a solid carrier "Tselit-504". The liquid phase of PEGS was

equal to 15%, the temperature range was from 100 to 200°C.

The object of the study was dipiperidylbenzaminals $RC_6H_4CH - (NC_5H_{10})_2$, obtained and purified by the previously described method [4].

$pK_{BH_1^+}$ and $pK_{BH_2^+}$ values of dipiperidylbenzaminals in nitromethane and acetonitrile were determined in accordance with the results of potentiometric titration in these solvents at 20°C, using a glass indicator electrode and a chlorine-silver comparison electrode. Initial concentration of titrated compounds was 0,01 M. 0,1 M dioxane solution of perchloric acid prepared from 72% water solution of $HClO_4$ was used as a titrant.

The calibration of the glass electrode was carried out in nitromethane and acetonitrile media, pyridine and piperidine being used as a standard. The pK_a of piredine and piperidine for nitromethane makes correspondingly 11,95[6] and 18.22[7] and for acetonitrile- 12.33[8] and 18.92[8].

$$paH = pK_{BH^+} + \log \frac{/B/}{/BH^+/} + \log f_{BH^+}$$

where pK_{BH^+} are the pK_a values of standard bases, /B/ and $/BH^+/$ are the concentrations of neutral and protonated bases; f_{BH^+} is the activity factor of a protonated base. The long $_{BH^+}$ values were calculated on the basis of the ionic strength (I) values of the solution according to the Debye equation: $\log f_{BH^+} = 1,5\sqrt{I}$, $I = \frac{1}{2}\sum_{i=1}^{n} CiZ_i^2$

Fig. 1. shows the relationship between the glass electrode potential (as regards the chlorine-silver comparison electrode) and p_aH values in non-aqueous solutions calculated from the titration data for pyridine and piperidine (Table 1,2). The determined value of hydrogen function of the glass electrode agreed with the theoretical one: - 58mB per unit of pK_a.

The curves of potantiometric titration of substituted dipiperidylbenzaminals are shown in Figures 2 and 3.

The $pK_{BH_1^+}$ and $pK_{BH_2^+}$ values of the studied dipiperidyl-

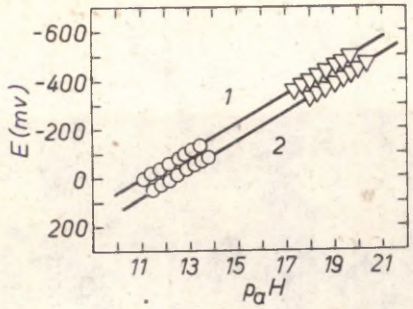

Fig. 1. Glass electrode calibration in nitromethane (1) and acetonitrile (2) media. Pyridine and piperidine (Δ) were used as standard bases (O)

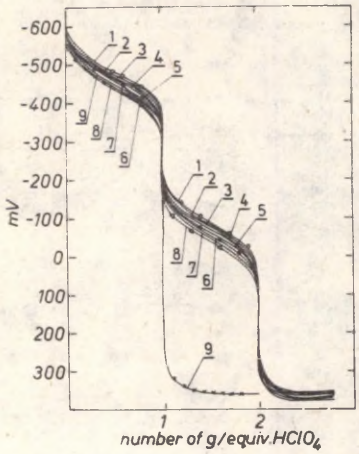

Fig. 2. Curves of potentiometric titration of substituted dipiperidylbenzaminals in nitromethane medium; titration was performed by 0.1 M dioxane solution of $HClO_4$: 1-p-$(C_2H_5)_2N$, 2-p-$(CH_3)_2N$, 3-p-CH_3O, 4-H, 5--p-F, 6--p-Cl, 7--p-NO_2, 8--m-NO_2, 9--$C_5H_{10}NH$ (standard).

Table 1

Potentiometric titration of 0.01 m piridine - and 0.1 m piperidine solutions by 0.1 m dioxane solution of $HClO_4$ in acetonitrile medium at 20°C (pK_a of piridine = 12.33, pK_a of piperidine = 18.92)

	Pyridine						Piperidine				
№№	V(ml $HClO_4$)	E (mv)	$\log \frac{[B]}{[BH^+]}$	$\log f_{BH^+}$	PaH	№№	V (ml $HClO_4$)	E (mV)	$\log \frac{[B]}{[BH^+]}$	$\log f_{BH^+}$	PaH
1.	0,0	-213	-	-	-	1	0,0	-480	-	-	-
2.	0,1	-88	1,27	0,14	13,74	2	0,1	-468	1,27	0,14	20,33
3.	0,2	-70	0,93	0,13	13,39	3	0,2	-445	0,93	0,13	19,98
4.	0,3	-55	0,66	0,12	13,11	4	0,3	-430	0,66	0,12	19,70
5.	0,4	-38	0,37	0,10	12,80	5	0,4	-415	0,37	0,10	19,39
6.	0,5	-10	0,00	0,07	12,40	6	0,5	-390	0,00	0,07	18,99
7.	0,6	+10	-0,31	0,03	12,08	7	0,6	-368	-0,31	0,03	18,64
8.	0,7	+25	-0,63	0,03	11,74	8	0,7	-352	-0,63	0,03	18,32
9.	0,9	+50	-0,91	0,03	11,45	9	0,9	-332	-0,73	0,03	18,04

Table 2

Potentiometric titration of 0.01M piridine - and piperidine solutions by 0.1M dioxane solution of $HClO_4$ in nitromethane medium at 20°C, pK_a of pyridine-11,95, pK_a of piperidine=18,22

Pyridine						Piperidine					
N№№	V(ml $HClO_4$)	E (mV)	$\log\frac{[B]}{[BH^+]}$	$\log f_{BH^+}$	PaH	N№№	V(ml $HClO_4$)	E (mV)	$\log\frac{[B]}{[BH^+]}$	$\log f_{BH^+}$	PaH
1	0,0	-256	-	-	-	1	0,0	-532	-	-	-
2	0,1	-131	1,27	0,14	13,36	2	0,1	-492	1,27	0,14	19,63
3	0,2	-112	0,93	0,13	13,01	3	0,2	-470	0,93	0,13	19,28
4	0,3	-100	0,66	0,12	12,73	4	0,3	-458	0,66	0,12	19,00
5	0,4	-80	0,37	0,10	12,42	5	0,4	-440	0,37	0.10	18,69
6	0,5	-58	0,00	0,07	12,02	6	0,5	-415	0,00	0,07	18,29
7	0,6	-35	-0,31	0,03	11,67	7	0,6	-393	-0,31	0,03	17,94
8	0,7	-17	-0,63	0,03	11,35	8	0,7	-375	-0,63	0,03	17,62
9	0,9	+5	-0,91	0,03	11,07	9	0,8	-359	-0,91	0,03	17,34

Table 3

The values of $pK_{BH_1^+}$ and $pK_{BH_2^+}$ for substituted dipiperidylbenzaminals, $RC_6H_4 - CH - (NC_5H_{10})_2$

	R	Solvent: Nitromethane		Solvent: Acetonitrile	
		$pK_{BH_1^+}$	$pK_{BH_2^+}$	$pK_{BH_1^+}$	$pK_{BH_2^+}$
1.	p-NO_2	18.32 ± 0.14	11.73 ± 0.16	19.77 ± 0.17	13.00 ± 0.18
2.	m-NO_2	18.40 ± 0.12	11.80 ± 0.14	19.84 ± 0.14	13.07 ± 0.16
3.	p-Cl	18.60 ± 0.13	11.85 ± 0.15	20.06 ± 0.16	13.12 ± 0.17
4.	p-F	18.67 ± 0.11	11.96 ± 0.13	20.15 ± 0.13	13.27 ± 0.15
5.	H	18.76 ± 0.08	12.02 ± 0.09	20.21 ± 0.10	13.30 ± 0.12
6.	p-CH_3O	18.84 ± 0.10	12.06 ± 0.12	20.28 ± 0.12	13.37 ± 0.14
7.	p-$(CH_3)_2N$	18.90 ± 0.16	12.13 ± 0.18	20.33 ± 0.17	13.42 ± 0.20
8.	p-$(C_2H_5)_2N$	18.98 ± 0.19	12.18 ± 0.21	20.38 ± 0.20	13.48 ± 0.22

benzaminals were calculated on the basis of titration curves and the results of glass electrode calibration:

$$pK_{BH_1^+} = p_aH - \log \frac{/B/}{/BH^+/} - \log f_{BH^+} \qquad (5)$$

$$pK_{BH_2^+} = p_aH - \log \frac{/BH^+/}{/BH_2^+/} - \log f_{BH_1^+} + \log f_{BH_2^+} \qquad (6)$$

For each dipiperidylbenzaminal titration was repeated three times. Mean values of individual measurements were taken to calculate the arithmetical mean values of $pK_{BH_1^+}$ and $pK_{BH_2^+}$. The values for substituted dipiperidylbenzaminals and their confidence intervals (when P = 0.95) are given in Table 3.

RESULTS AND DISCUSSION

The data obtained make it clear (Table 3 and Fig. 4) that $pK_{BH_1^+}$ and $pK_{BH_2^+}$ values conform to correlation equations $pK_{BH^+} - \rho\sigma^\circ$ which account for the induction effect of substituents of the aryl ring:

in nitromethane medium

$$pK_{BH_1^+} = (18.74 \pm 0.01C) - (0.44 \pm 0.024) \cdot \tilde{\sigma}^\circ \qquad (5)$$
$$r = 0.991, \; s^\circ = 0.030$$

$$pK_{BH_2^+} = (12.00 \pm 0.014) - (0.29 \pm 0.031) \cdot \tilde{\sigma}^\circ \qquad (6)$$
$$r = 0.970, \; s^\circ = 0.031$$

in acetonitrile medium

$$pK_{BH_1^+} = (20.19 \pm 0.014) - (0.43 \pm 0.028) \cdot \tilde{\sigma}^\circ \qquad (7)$$
$$r \pm 0,988, \; s^\circ = 0.031 \cdot$$

$$pK_{BH_1^+} = (13.29 \pm 0.020) - (0.31 \pm 0.031) \cdot \tilde{\sigma}^\circ, \qquad (8)$$
$$r = 0.962, \; s^\circ = 0.044$$

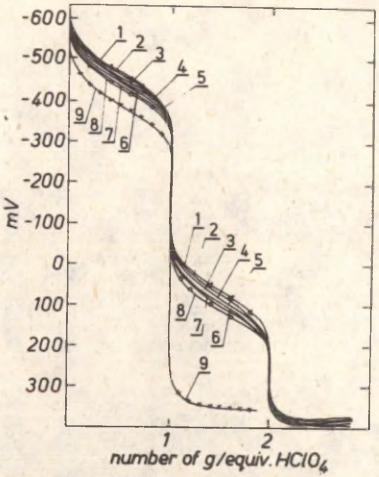

Fig. 3. Potentiometric titration curves for substituted dipiperidylbenzaminals in acetonitrile medium; 0.1 M dioxane solvent: $HClO_4$ was used for titration. 1--p-$(C_2H_5)_2$, 2--p-$(CH_3)_2B$, 3--p-OCH_3, 4--H, 5--p-F, 6--p-Cl, 7--p-NO_2, 8--m-NO_2, 9--$C_5H_{10}NH$ (standard)

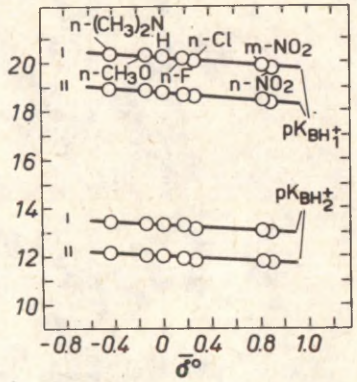

Fig.4. Correlation of $pK_{BH_1^+}$, and $pK_{BH_2^+}$ of substituted dipiperidylbenzaminals with $\bar{\sigma}°$ values in medium:
I - acetonitrile
II - nitromethane

The ρ°-values obtained for substituted dipiperidylbenzaminals in nitromethane and acetonitrile media exceed insignificantly the 0.40 - value[9] determined for toluene acids in ethanol medium. Low sensitivity of the reaction center to substituents is obviously due to the presence of the methylene CH-group which separates centres of basicity from the substituents of the benzene ring.

The basicity of substituted dipiperidylbenzaminals at the second step of protonation is considerably reduced and

$\Delta pK_{BH} = pK_{BH_1^+} - pK_{BH_2^+}$ makes 6-7 units of pK_{BH}.

This reduction in basicity can be explained by three reasons: the statistical factor, electrostatic and $+$induction effects of the positively charged substituent NHR_2.

As is known (10), when a base contains two or more functional groups, the observed pK_{a_1}, according to statistical reasons will be higher than the pK_a of the corresponding univalent base by lg2 = 0.3, whereas the observed pK_{a_2} will be by lg2 = 0.3 lower. Consequently, $\Delta pK_{BH^+} = pK_{BH_1^+} - pK_{BH_2^+}$ makes 0.6 of the pK_{BH^+} unit.

Electrostatic contribution to the $\Delta pK_{BH^+} = pK_{BH_1^+} - pK_{BH_2^+}$ value was calculated by means of a commonly adopted method (11)

$$\Delta pK_{BH} = -Ne^2/2.3\ RTEr$$

where r is the distance between two reaction centers assumed to be equal to $l_{NN} = 2.40$ Å *)

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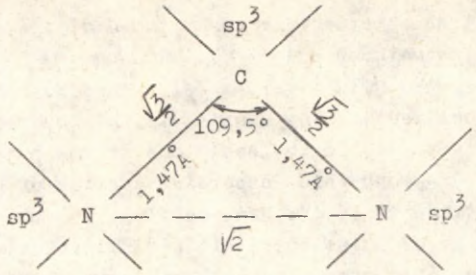
* The distance between positively charged nitrogen atoms was found on the basis of the following calculations:



$$l_{NN} = \frac{\sqrt{2}}{\frac{\sqrt{3}}{2}} \cdot 1,47 = \frac{2.\sqrt{2}}{\sqrt{3}} \cdot 1,47 = \frac{1,414.2.1,47}{1,732} = 2,40\ \text{Å}$$

These calculations show that the reduction of basicity of dipiperdylbenzaminals at the second step of protonation due to electrostatic effect makes 2.69 in nitromethane medium and 2.76 pK_{BH^+} units in acetonitrile medium.

The difference in $\Delta\ pK_{BH^+}$ can be estimated in terms of the influence produced by the induction effect of the positively charged substituent $\overset{+}{N}HR_2$. In this case the induction effect of the aliphatic series takes place. The ρ values for it were found to be equal to 4.16^{12}. The $\Delta\sigma^*$ was estimated by us proceeding from the following assumptions:

$\sigma^*_{\overset{+}{N}HR_2}$ for the charged substituent is equal to 3.06 and $\sigma^*_{NR_2}$ of the uncharged substituent is equal to 1.10^{11}. After taking into account the transmission factor ($\mathcal{E}$) of the C atom ($\mathcal{E} = 0.48^{9}$) the $\Delta\sigma^*$ value will be equal to:

$$\Delta\sigma^* = \sigma^*_{\overset{+}{N}HR_2} - \sigma^*_{NR_2} = (\sigma^*_{\overset{+}{N}HR_2} \cdot \mathcal{E}) - (\sigma^*_{NR_2} \cdot \mathcal{E}) =$$
$$= 3.06 : 0.48 - 1.10 \cdot 0.48 = 0.94$$

Consequently, the reduction of $\Delta\ pK_{BH^+}$ due to the induction effect of the positively charged constituent makes:

$$\Delta\ pK_{BH^+} = \rho^* \cdot \Delta\sigma^* = 4.16 \cdot 0.94 = 3.91\ pK_{BH^+}\ \text{units}$$

Thus, if we sum up the effect of all factors which reduce the basicity of dipiperidylbenzaminals at the second step of protonation, the experimentally observed reduction of $pK_{BH_2^+}$ will be explained as follows:

the contribution of the statistical factor to this reduction of basicity makes 0.6 of pK_{BH^+} units; that of electrostatistical one makes 2.69 and 2.76 for nitromethane and acetonitrile, correspondingly. And that of the induction effect of the positively charged substituent $\overset{+}{N}HR_2$ makes 3.91 pK_{BH^+} : the total for nitromethane makes 7.20 units of pK_{BH^+} and 7.27 units of pK_{BH^+} for acetonitrile, which agrees well enough with the experiment (6.74 and 6.91 for non-substituted dipiperidylbenzaminals).

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KINETICS OF INTERACTION OF ACRYLAMIDE WITH AMINO GROUPS OF SOME PROTEINS

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Kinetics of the reaction of acrylamide with amino groups of insulin, B-chain of insulin and α_1-casein has been studied in borate buffer, pH=10.3 at 25°. Acrylamide proved to be a suitable reagent for the modification of amino groups in proteins and for differentiation of them according to reactivity.

Previously we have studied the kinetics of addition of primary and secondary aliphatic amines to ethylenic bond of acrylamide[I]. Sufficiently high rates of these reactions made it possible to propose that acrylamide may be used for chemical modification of free amino groups in proteins and peptides. We report herein the results of investigation of kinetics of interaction between acrylamide and amino groups of some proteins (insulin, B-chain of insulin, α_1-casein). Amino groups are blocked by β-carbamidoethyl groups in the course of the reaction:

$$R\text{-}NH_2 \xrightarrow[(a)]{CH_2=CHCONH_2} \underset{I}{R\text{-}NH\text{-}CH_2CH_2CONH_2} \xrightarrow[(b)]{CH_2=CHCONH_2} \underset{II}{R\text{-}N(CH_2CH_2CONH_2)_2} \qquad (I)$$

where R represents the protein molecule.

There are two publications [2,3] where the blocking of sulfhydryl groups of proteins and peptides with acrylamide is described. But we have found in literature no system-

atic investigation on chemical modification of proteins by the aid of acrylamide.

Experimental

Reagents. N-methyl-2-carbamidoethylamine (I, R=CH_3) was prepared by addition of tenfold excess of 4M solution of methylamine in water to acrylamide. The product was distilled (b.p. 134-135°/7mm) and immediately converted into hydrochloride. Acrylamide was recrystallized from chloroform, m.p. 84° (lit.[4] 84-85°). The other reagents were used without purification. 2,4,6-trinitrobenzenesulfonic acid (TNBS) and sodium tetraborate were pure grade, α_1-casein was obtained from Merck, B-chain of insulin was obtained from Serva, insulin was obtained from the Kaunas plant of endocrinic preparations.

The amount of amino groups in proteins was checked by determining the content of lysine by amino acid analyser LKB-320I. The obtained number of lysines in α_1-casein was 15.1 for M W 23616 (lit.[5]-14), in insulin-0.93 for M W 5730 (lit.[6]-1).

All solutions for kinetic investigations were prepared gravimetrically. The proteins were dissolved in 0.1M borate buffer pH=10.3. TNBS was dissolved in distilled water. The water solution of N-methyl-2-carbamidoethylamine was prepared from hydrochloride adding the equivalent amount of titrated NaOH.

Kinetic measurements. The kinetics was studied in 0.1M borate buffer, pH=10.3 at 25°. Disappearance of primary amino groups was followed. Initial concentrations of protein amino groups in reaction mixture were $5.0\text{-}6.0 \cdot 10^{-4}$M and that of acrylamide was 0.5-0.75M. Samples of reaction mixture (2ml) were added to 20ml of 0.1M borate buffer, pH=9.18 and the concentration of amino groups was determined by the TNBS method[7]. From 2 to 4 runs were carried out for each protein. The rate constants are presented in the table

Results and discussion

In the course of the reaction between primary amino groups and TNBS coloured picramino derivatives III are produced:

$$\underset{\text{TNBS}}{(NO_2)_3C_6H_2SO_3^-} \longrightarrow \underset{\text{III}}{R\text{-}NH\text{-}C_6H_2(NO_2)_3} + SO_3^{2-} \quad (2).$$

It makes possible spectrophotometrical determination of amino groups.[5]

We have found that model compound I ($R=CH_3$) gives only a negligible absorbance in the conditions of amino groups determination with TNBS. Therefore our kinetic data represents the formation of protein derivatives I, i.e. the rate of reactions (Ia).

With the aim to compare the rates of reactions Ia and Ib we have studied kinetics of interaction of N-methyl-2-carbamidoethylamine (I, $R=CH_3$) with acrylamide. The rate constant at 25° in water solution was $(3.25 \pm 0.3I)\cdot10^{-3}$ l mol^{-I}sec^{-I}. For the addition of methylamine (Ia, $R=CH_3$) to acrylamide the rate constant[I] is $I.9\cdot10^{-3}$ l mol^{-I}sec^{-I}. So the rate of reaction Ib is higher than that of Ia. If excess of acrylamide is used the modification of amino groups ought to proceed to derivatives II.

The B-chain of insulin contains two amino groups: ε-NH_2 of lysine-29 and N-terminal α-NH_2. The reactivity of those amino groups differs considerably. The rate constant of reaction (I) for the more reactive amino group (probably ε-NH_2 of lysine was calculated according to the equation of the pseudo-first order kinetics, from the initial part of kinetic curve (Fig.I). The rate of the second amino group was found from the inclination of the linear part of the kinetic curve at a time $t > 20\ 000$sec.

Insulin contains two terminal α-NH_2 and one ε-NH_2 of lysine. Therefore the rate equation is:

$$V = -\frac{d[-NH_2]}{dt} = k_I c_I + k_2 c_2 + k_3 c_3 \qquad (3)$$

where c_I, c_2, c_3 are the concentrations of amino groups of three types,

k_I, k_2, k_3 - the corresponding reaction rate constants of their interaction with acrylamide.

Kinetic curve 2 (Fig.I) shows very low reactivity of one amino group in the insulin molecule.The rate constant for this amino group can be found from the linear part of the kinetic curve at $t > 30\,000$sec.,but only approximately, because inclination of the curve is comparable with experimental errors.

The rate constants k_I and k_2 were found from the experimental rate of reaction (curve 2, Fig. 2) by the method of iterations.As starting values were used: $k_I = V_o/(c_I)_o$, $k_2 = 0$.In the following iterations k_I was calculated at the time t=0 and k_2 at t=4860sec.,taking account of the contribution of the other reaction by using its rate constant from the previous iteration.Four iterations were necessary until the third figure of k_I and k_2 became constant.

The three-dimentional structure of insulin[6] allows to attribute the rate constant k_3 to the N-terminal α-NH_2 of the A-chain.This amino group is in the "pocket" of the globule in surroundings of relatively low polarity.The rate of nucleophilic addition to the activated double bound rapidly decreases if the solvating power of the medium diminishes.The most reactive (rate constant k_I) probably is ε-NH_2 of lysine.

The molecule of α_1-casein contains 14 ε-NH_2 of lysine and one N-terminal α-NH_2 of arginine[5].On the basis of the kinetic data we devided amino groups of α_1-casein into four classes of different reactivity: class I -9 amino groups , class II-3, class III-2 and class IV-I.The amino group of class IV do not react with acrylamide.The rate constants for more reactive amino groups (classes I,II,III) were found as in the case of insulin.

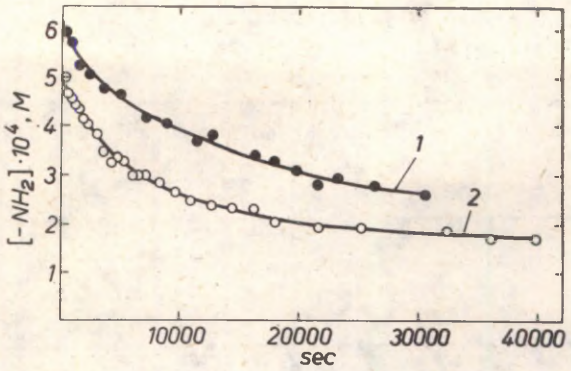

Fig.I.Kinetics of modification of amino groups of insulin(∘) and B-chain of insulin(•).

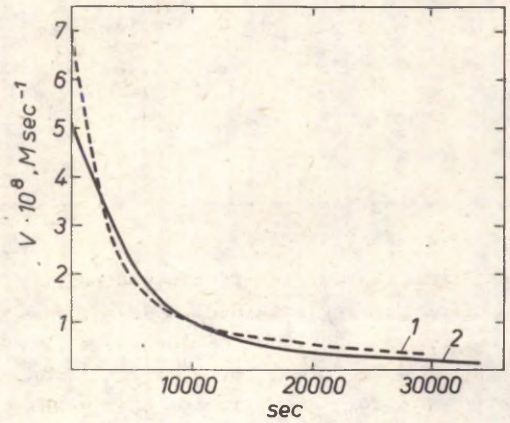

Fig.2.The rates of modification of amino groups of insulin(2) and B-chain of insulin(1) obtained by the method of approximation of kinetic curves by analytical functions[8].

Table.

Rates constants of interaction of acrylamide with amino groups of some proteins at 25° in 0.IM borate buffer, pH=I0.3

Protein	Number of amino groups	$k \cdot I0^{-4}$ $l\ mol^{-I} sec^{-I}$	
B-chain of insulin	I	3.4I	0.I6[x]
	I	0.07	0.02
Insulin	I	k_1=2.73	0.I5
	I	k_2=I.72	0.57
	I	k_3<0.03	
α_1-casein	9	2.9I	0.42
	3	I.70	0.02
	2	0.3	
	I	0	

[x]Standart deviations are presented.

The rate constants of addition of protein amino groups to ethylenic bond of acrylamide obtained in the present investigation are lower as in the case of the same reaction for n-butylamine[I] ($k=9.4\ I0^{-4} l\ mol^{-I} sec^{-I}$). The inductive constants of substituents for n-butylamine and ε-NH_2 of lysine do not differ. The decrease of reactivity is the result of steric and solvation factors. This study demonstrates clear differentation in reactivity of protein amino groups.

We have used chemical modification with acrylamide (in water solution at 50° and pH=10.3) as a method to obtain proteins with blocked amino groups suitable as substrates for proteases[9].The conditions for substrate synthesis were optimized with casein according to Hammersten.About 80% of its amino groups are of similar activity (with rate constant around 2.5 10^{-4} mol^{-1} sec^{-1}).10% of amino groups are by 1-2 orders less reactive.The remaining 10% of amino groups practically do not react with acrylamide.Varying of temperature (25-90°) and of medium pH (9.1-10.9) do not change the amount of inactive amino groups.

We followed modification of amino groups with TNBS(reaction 2).It was necessary to check that the observed optical density was the result of the only reaction between free amino groups and TNBS.For this reason we have studied interaction of TNBS with nucleophilic side chains of proteins using model compounds: α-N-acetyl-L-histidine, α-N-acetyl-D,L-tryptophan, α-N-acetyl-L-arginine, N-acetyl-L-tyrosine.No absorbance was observed in the conditions used for determination of amino groyps.It is in agreement with the results of R.B. Freedmann and G.K.Radda[10].The model compounds mentioned above did not change the absorbtion spectrum of methylpicramide,i.e. they did not form coloured complexes with the trinitrophenyl group.

We are grateful to D.Iljasevičienė for carrying out the amino acid analyses.

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KINETICS OF FORMATION OF n-BUTYLMAGNESIUM HALIDES IN MIXTURES OF TOLUENE WITH ORGANIC BASES.

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The rate constants, yields, and heats for the reaction of n-butyl halides with magnesium were determined in mixtures of toluene with tetrahydrofurane, ethyl ether, butyl ether, and dimethyl aniline. Under the conditions used in this work organic bases reveal catalytic properties only at low concentration. At higher concentrations the base influences the reaction rate only by altering viscosity of the medium. The main part of heat of reaction is produced by solvation of the Grignard reagent formed in the reaction.

Preparation of the Grignard reagent has turned to be a common and in most cases easily feasible laboratory procedure. Nevertheless, the mechanism of the Grignard reagent formation remained obscure for a long time. Also the role of a solvent in this process was not revealed. Only during the last decades works concerned with the investigation of nature and mechanism of the Grignard reaction began to appear. In some of them[1-5] also the medium effects have been investigated. However, at this time the mechanism of the reaction, and the role of the solvent in formation of the Grignard reagent are not yet clear.

Accomplishment of big-scale organomagnesium synthesis in industry requires the replacement of flammable solvents (ethers) by more safe hydrocarbons of high boiling points. In this connection the knowledge of medium effects in the

Grignard reaction is needed urgently.

This work is a continuation of an earlier investigation undertaken by one of us[2,3], We set our mind on specifying the role of organic bases in formation of the Grignard reagent. For doing this we investigated the kinetics of the reaction of n-butyl halides with magnesium in various mixtures of different organic bases with toluene. The reaction conditions (temperature, stirring, shape and quantity of magnesium etc.) were kept constant. The induction period[2,3] was eliminated carrying out the reaction with a small portion of the relevant halide in the reaction mixture before the measurements. The kinetics of the reaction with n-butyl bromide and iodide was followed by heat evolution during the process. That with n-butyl chlorides was followed by taking aliquots and titration of the Grignard reagent formed. For bromide and iodide the kinetic measurements were accompanied with determination of the yield of the Grignard reagent and with estimation of heat of the reaction.

EXPERIMENTAL SECTION

Reagents and Solvents

Toluene was treated with conc. sulfuric acid, dried over heated calcium chloride and distilled over sodium.

Ethyl and n-Butyl Ethers were purified from peroxides with potassium hydroxide, dried over heated calcium chloride, distilled over sodium and, before use, over the Grignard reagent.

Tetrahydrofuran was treated with copper (I) chloride and potassium hydroxide, distilled over calcium hydride.

N,N- Dimethylaniline was treated with potassium hydroxide and distilled over sodium.

N-Butylhalides were dried over heated calcium chloride and rectified.

Magnesium metal was used in the form of granules from 1.0 to 1.6 mm in diameter.

EXPERIMENTAL METHODS

Kinetic Measurements by the Thermographic Method

An earlier described thermographic method was used[6,7].

The reaction flask (35-ml Erlenmeyer flask) was capped with a teflon stopper which was equipped with a silicon rubber disk. Through the disk was placed a thermister MT-54 which was connected into a Wheatstone bridge-system of direct current. The thermograms were recorded by a potentiometer E_Z-8.

The reaction flask was placed into a glass vessel, whose temperature was kept at 30±0.1°C by means of a thermostat U-10. The reaction mixture was stirred by a magnetic stirring bar.

Before the kinetic runs 1.500 g of magnesium (granules) was placed into the flask. Solvents (20.0 ml in each run) were introduced into the flask by calibrated pipets. After reaching the system of a constant temperature (30°C), 0.5 mL of n-butyl bromide or iodide was introduced through the silicon rubber disk by a hypodermic syringe.

Kinetic measurements were carried out in the reaction mixture where the first portion of butyl halide had reacted to completion. This method eliminates any induction period. Subsequently a second and then a third portion of butyl halide (á 0.5 mL) were added and the corresponding thermograms were recorded .

The thermograms were transfered into kinetical curves by numerical integration from the plot of ΔT vs. t in accordance with the formula[7]

$$\Delta T_o = \Delta T + \rho \int_o^t \Delta T(t)dt,$$

where ΔT is the temperature difference between the reaction flask and the thermostat at any time t; ΔT_o is the integral temperature difference; ρ is the cooling coefficient.

The coefficient ρ was determined experimentally as follows. After the halide had reacted to completion, 0.2 mL

of acetone was added to the reaction mixture. A very fast exothermic reaction lead to a temperature jump after which a cooling curve was recorded by the potentiometer E_Z8; the value of the coefficient ρ was calculated from the equation

$$\rho = \frac{1}{t_2 - t_1} \ln \frac{\Delta T_1}{\Delta T_2}$$

The first order rate constants of formation of the Grignard reagent were calculated from the slope of a plot of $\ln (\Delta T_o^{\infty} - \Delta T_o)$ vs time. The calculations were carried out by means of a ECM "Nairi-2". Accuracy of determining the rate constant averages from ± 1 to $\pm 4\%$.

Analysis of Reaction Mixture

After the halide portion had reacted completely (after the heat liberation had ceased), aliquots were withdrawn by removing 1.0 mL of the reaction mixture by syringe, and analyzed. The amount of basic magnesium was determined by acid titration and that of the halide by the Volhard method.

Kinetic Measurements by the Method of Aliquots

The reaction conditions and reaction flask used for the slow reaction of magnesium with n-butyl chloride were similar to those for the thermographic method, only the reaction kinetics was followed using the method of samples. Aliquots were withdrawn at appropriate times by removing 1.0 mL of the reaction mixture by syringe, and the amount of basic magnesium was determined.

The reaction was initiated with 0.4 mL of dibromoethane. The induction period was eliminated by addition of 1.0 mL n-butyl chloride to the reaction mixture and after the latter had reacted completely, a new portion of butyl chloride was introduced and kinetic measurements were carried out.

The first order rate constant was determined by the differential method[8] from the slope of plot $\ln (\Delta C/\Delta t)$ vs τ, where ΔC is the change of concentration of basic magnesium

at the time-interval Δt; τ is the time corresponding to the intermediate of this time-interval Δt. Accuracy of determening the rate constant averages from ± 10 to $\pm 15\%$.

Assessment of Heat of Reaction

The heat of the reaction between n-butyl bromide or iodide and metallic magnesium were approximately calculated according to the formula

$$Q = cm \Delta T_o^{\infty}$$

where ΔT_o^{∞} is the integral temperature difference between the reaction flask and the thermostat at the end of the reaction; m is the weight of reaction mixture and c is the heat capacity of reaction mixture. The latter was calculated proceeding from the assumption about additivity of component molar fractions. Heat capacity of the Grignard reagent was neglected.

Table 1

Rate Constants, Yields and Heats of the Reaction Between n-Butyl Bromide and Magnesium in Toluene-Organic Base Mixtures

Volume % of Base	The amount of Base in moles per mole of bromide	k, sec^{-1}	Yield %		Q K cal / mole
			Mg	Br	
1	2	3	4	5	6
		Tetrahydrofuran			
100	52.3	-	100	100	-
	48.8	0.0295	97	93	55
	45.4	0.0249	100	73	58
50	26.2	-	91	73	-
	23.7	0.0245	94	97	34
	21.8	0.0227	91	72	34
50	26.2	-	92	70	-
	23.7	0.0202	94	99	38
	21.3	0.0254	91	72	41
25	13.1	-	90	78	-

Table 1 continued

1	2	3	4	5	6
	11.2	0.0253	93	95	51
	10.2	0.0234	95	76	50
25	13.1	-	90	78	-
	11.2	0.0244	94	98	38
	10.2	0.0232	94	75	45
10	5.20	-	99	94	-
	4.00	0.0300	95	97	28
	2.84	0.0305	94	73	29
10	5.20	-	99	90	-
	4.00	0.0293	97	99	28
	2.84	0.0298	96	61	27
5	2.60	-	105	99	-
	1.52	0.0240	90	84	29
	0.49	-	68	77	17
5	2.60	-	100	99	-
	1.52	0.0323	89	92	29
	0.49	-	85	75	13
3.85	2.00	-	100	108	-
	0.95	0.0049	54	77	-
	0	0.0050	98	79	14
3.85	2.00	-	100	112	-
	0.95	0.0073	60	57	-
	0	0.0040	79	94	26
		Diethyl Ether			
100	41.5	-	94	80	-
	39.7	0.0340	97	100	30
	38.7	0.0307	100	98	32
100	41.5	-	100	89	-
	40.5	0.0358	91	96	39
	39.6	0.0406	100	99	38
75	31.1	-	93	81	-
	30.2	0.0355	94	100	30
	29.2	0.0352	100	100	29

Table 1 continued

1	2	3	4	5	6
75	31.1	-	96	85	-
	30.1	0.0333	94	100	34
	29.2	0.0333	100	99	32
50	20.7	-	100	97	-
	19.3	-	95	98	30
	18.4	0.0363	99	97	30
50	20.7	-	100	87	-
	19.8	0.289	94	100	39
	18.8	0.294	100	90	36
25	10.4	-	83	81	-
	9.37	0.0257	87	94	37
	8.39	0.0267	72	95	36
25	10.4	-	100	84	-
	9.37	0.0281	98	100	-
	8.39	0.0277	100	99	-
10	4.15	-	98	88	-
	3.08	0.0258	91	100	30
	2.17	-	94	97	33
10	4.15	-	100	89	-
	3.15	0.0268	92	99	40
	2.23	0.0270	93	98	38
7.5	3.11	-	98	82	-
	2.13	0.0267	90	99	42
	1.23	-	79	94	-
7.5	3.11	-	96	87	-
	2.09	0.0232	87	94	37
	1.22	-	85	100	-
5	2.07	-	92	95	-
	1.16	0.0098	97	100	30
	0.19	-	84	93	-
5	2.07	-	94	83	-
	1.09	0.0103	90	97	41
	0.19	-	83	92	-

Table 1 continued

1	2	3	4	5	6
		Dibutyl Ether			
100	24.9	-	100	96	
	22.9	0.0229	95	100	
	20.8	0.0195	96	100	
100	24.9	-	100	96	
	22.9	0.0204	96	100	
	20.8	0.0198	97	95	
100	24.9	-	90	92	
	22.9	0.0216	86	100	
	20.8	0.0213	94	100	
87.5	21.9	-	97	93	
	19.9	0.0192	95	100	
	17.8	0.0208	93	100	
87.5	21.9	-	94	98	
	19.9	0.0250	93	100	
	17.8	0.0200	94	100	
87.5	21.9	-	91	100	
	19.9	0.0215	95	100	
	17.8	0.0218	95	98	
75	18.7	-	100	96	
	16.8	0.0263	92	99	
	15.0	0.0250	98	100	
75	18.7	-	100	94	
	16.8	0.0223	96	100	
	15.0	0.0221	93	100	
75	18.7	-	94	100	
	16.8	0.0227	89	100	
	15.0	0.0223	97	100	
62.5	15.5	-	96	100	
	13.8	0.0192	96	99	
	12.2	0.0179	100	100	
62.5	15.5	-	96	100	
	13.8	0.0199	89	98	

Table 1 continued

1	2	3	4	5	6
	12.2	0.0171	100	100	
62.5	15.5	-	91	100	
	13.8	0.0224	94	100	
	12.2	0.0200	95	100	
50	12.4	-	100	90	
	10.9	0.0277	96	100	
	9.4	0.0231	93	100	
50	12.4	-	100	92	
	10.9	0.0267	96	100	
	9.4	0.0225	92	100	
50	12.4	-	84	100	
	10.9	0.0190	96	100	
	9.4	0.0202	92	100	
37.5	9.33	-	94	100	
	7.91	0.0224	91	100	
	6.57	0.0247	91	100	
37.5	9.33	-	84	100	
	7.91	0.0208	91	98	
	6.57	0.0194	96	100	
37.5	9.33	-	87	100	
	7.91	0.0209	93	100	
	6.57	0.0208	91	95	
25	6.22	-	97	95	
	4.96	0.0175	94	100	
	3.76	0.0219	90	100	
25	6.22	-	92	92	
	4.96	0.0257	94	100	
	3.76	0.0253	88	100	
15.	3.73	-	88	95	
	2.59	-	89	82	
	1.51	0.0258	86	100	
15	3.73	-	88	95	
	2.59	0.0203	90	99	
	1.51	0.0210	85	100	

Table 1 continued

1	2	3	4	5	6
15	3.73	-	86	98	
	2.59	0.0238	84	100	
	1.51	0.0244	89	100	
10	2.49	-	85	100	
	1.41	0.0226	89	99	
	0.39	-	65	76	
10	2.49	-	83	97	
	1.41	0.0197	88	100	
	0.39	-	65	73	
10	2.49	-	80	100	
	1.41	0.0235	83	100	
	0.39	-	63	73	
7.5	1.87	-	88	96	
	0.82	-	87	97	
	0	-	60	66	
7.5	1.87	-	69	99	
	0.82	-	93	99	
	0	-	63	71	
7.5	1.87	-	74	100	
	0.82	-	94	95	
	0	-	61	100	
5	1.24	The reaction does not initiate			
5	1.24	The reaction does not initiate			

Table 2

Rate Constants, Yields and Heats of the Reaction Between n-Butyliodide and Magnesium in Toluene--Organic Base Mixtures

Volume % of Base	The amount of Base in moles per mole of iodide	k, sec^{-1}	Yield		Q $\frac{kcal}{mole}$
			Mg	I	
1	2	3	4	5	6
		Diethyl Ether			
100	44.1	-	91	85	-
	43.2	0.0490	100	95	30
	42.1	0.0346	94	100	35
100	44.1	-	91	82	-
	43.1	0.0405	96	90	29
	42.2	0.0496	92	100	30
100	44.1	-	80	87	-
	43.4	0.0435	100	88	28
	42.4	0.0421	100	100	28
75	33.0	-	83	88	-
	32.3	0.0371	99	83	33
	31.3	0.0341	100	97	35
50	22.0	-	94	81	-
	21.1	0.0234	100	86	47
	20.1	0.0300	99	97	42
25	11.0	-	86	74	-
	10.2	0.0319	100	84	42
	9.16	0.0278	100	90	47
15	6.61	-	87	73	-
	5.74	0.0266	100	82	45
	4.74	0.0262	100	89	45
5	2.20	-	84	73	-
	1.36	0.0218	86	87	48
	0.51	0.0149	95	94	-

Table 2 continued

1	2	3	4	5	6
		Dimethylaniline			
100	36.1	-	89	94	-
	35.7	0.0132	88	95	58
	34.8	0.0130	97	100	51
100	36.1	-	81	93	-
	35.3	0.0149	89	99	55
	34.4	0.0139	91	96	51
75	27.1	-	83	79	-
	26.7	0.0166	98	96	50
	25.7	0.0160	93	87	51
75	27.1	-		92	-
	26.1	0.0171	92	95	48
	25.1	0.0162	85	85	54
50	18.1	-	77	100	-
	17.3	0.0247	91	95	50
	16.4	0.0249	83	88	52
50	18.1	-	81	88	-
	17.2	0.0191	86	90	53
	16.4	0.0191	92	94	48
25	9.02	-	67	91	-
	8.36	0.0205	83	95	59
	7.53	0.0210	91	98	50
25	9.02	-	77	89	-
	8.25	0.0209	80	92	55
	7.45	0.0189	75	100	60
10	3.61	-	60	95	-
	3.01	0.0286	69	91	60
	2.32	0.0290	78	98	53
10	3.61	-	57	86	-
	3.04	0.0268	73	93	45
	2.31	0.0279	76	98	42
5	1.80	-	46	94	-
	1.34	0.0209	57	94	66

Table 2 continued

1	2	3	4	5	6
	0.77	-	87	94	-
5	1.80	-	51	89	-
	1.30	0.0271	74	95	48
	0.56	-	58	76	-
5	1.80	-	50	91	-
	1.30	0.0271	59	92	60
	0.71	-	58	76	-
2.5	0.90	Reaction does not initiate			

Table 3

Reaction Rate Constants of n-Butylchloride with Magnesium in Toluene-Organic Base Mixtures

Volume % of Base	The amount of Base in moles per mole of chloride	10^3 k, sec^{-1}
	Tetrahydrofuran	
100	23.0	0.28
75	16.9	0.28
50	10.8	0.26
25	4.7	0.25
10	1.0	0.23
	Diethyl Ether	
100	18.6	0.44
75	13.6	0.45
50	8.6	0.44
25	3.5	0.43
12	1.0	0.40

* after elimination of induction period.

Table 4

Rate Constants and Heats of Reaction with n-butylhalides and Magnesium in Various Media

Halide	Solvent	$10^2.k, sec^{-1}$	Q^* kcal/mole
Cl	Diethyl Ether	0.044	-
	Tetrahydrofuran	0.028	-
Br	Diethyl Ether	3.49	34 ± 5
	Tetrahydrofuran	2.95	44 ± 8
	Dibutyl Ether	2.16	-
I	Diethyl Ether	4.47	38 ± 7
	Dimethylaniline	1.40	52 ± 6

* Average value from heat effects in toluene mixtures

RESULTS

In our kinetic experiments all the reaction conditions were strictly kept constant except the composition of reaction medium (ratio of organic base to toluene), Therefore the dependence of the obtained reaction rate constants on relative content of added organic base must reflect the influence of the medium in general and that of the base on the rate of the reaction in particular.

The rate constants obtained for the reaction of n-butyl halides with magnesium are collected in Tables 1-3. The volume part of the base is given for the initial reaction mixture of the experiment. Molar ratio of base to halide corresponds to the initial moment of the next run and is calculated with the assumption of the previous portion of halide being totally consumed. It was also assumed that only one molecule of organic base is bounded to each molecule of alkylmagnesium halide. At low amounts of organic base organomagnesium compound is probably in polymeric state and it is most logical to suppose such a composition of solvation complex.

At high content of base this is certainly not quite exact but involves insignificant error. However, it has to be taken into account that those ratios are formal even in the case of low values. As will be discussed further, alkylmagnesium halides are equilibrium solvated and certain part of a base always remains free.

The yields of basic magnesium and halide ion are calculated for total alkyl halide added before the determination. Because of heterogenity of the reaction mixture accuracy and reproducability of the data are not very high, nevertheless the data reflect sufficiently well the tendencies caused by altering the composition of reaction medium.

DISCUSSION

In Table 4 rate constants for the reactions in pure solvents are summarized. It appears that the constants weakly depend on the solvent. One can suppose that the reaction rate increase with decreasing viscosity of the solvent, for the sequence observed ethyl ether > tetrahydrofuran > butyl ether does not correspond to that of basicities, polarities nor polarisabilities of these bases. Reactivities of butyl bromide and iodide are very similar, but chloride reacts considerably slower. All these results coincide with the observations of Whitesides et al[4,5], and with that of the Amsterdam group[1].

Rate constants for the mixtures with toluene depend relatively little on the composition of the mixture. In the case of chlorides the latter practically does not affect the reaction rate but for bromide and iodide we obtained the dependences represented in Figures 1 and 2. The shapes of the curves are different for various bases, however, at high and moderate concentrations of bases the reaction rate obviously increases with decreasing viscosity of the medium*.

* In accordance with viscosity the solvents used in this work form the following sequence : dimethylaniline > butyl ether > toluene > tetrahydrofurane > ethyl ether[10].

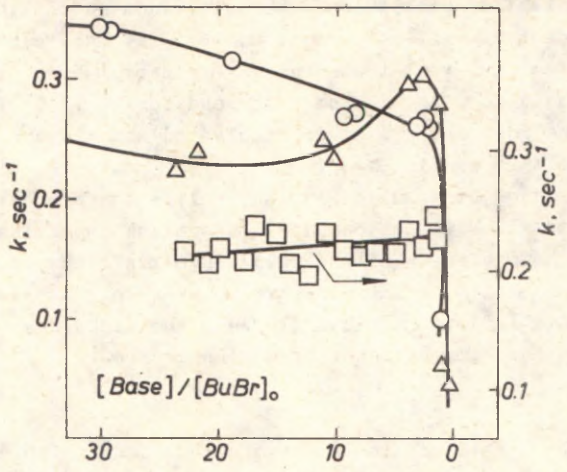

Fig. 1. Dependence of the rate constant of the reaction of butyl bromide with magnesium on the relative content of the base in the mixture base-toluene. ○ - ethyl ether, Δ - tetrahydrofurane, ● - butyl ether.

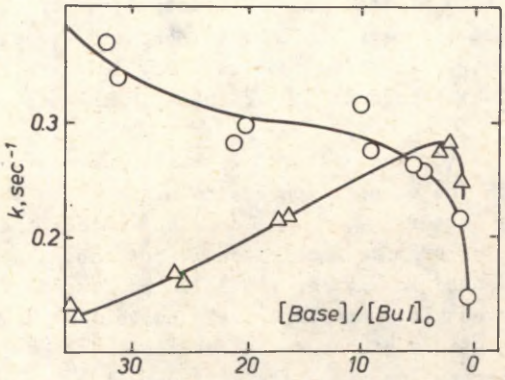

Fig. 2. Dependence of the rate constant of the reaction of butyl iodide with magnesium on the relative content of the base in the mixture base-toluene. ○ - ethyl ether, Δ - N,N - dimethyl aniline

Gradual replacement of dimethylaniline to toluene decreases the viscosity of the medium and increases the rate of the reaction. In the case of ethyl ether and tetrahydrofurane the addition of toluene increases the viscosity of the solution and causes a decrease in the reaction rate. The viscosities of butyl ether and toluene are very similar and the rate constant also does practically not depend on the ratio of these solvents in the mixture.

Beginning with a relatively low value of the ratio base to halide (about 2 mole to one mole), decrease of the ratio causes a dramatic decrease in the rate constant. In most cases this is accompanied, as seen from Tables 1 and 2, with decrease in the total yield of the reaction, increase in the Wurz reaction yield (increase of ratio of halide ion to basic magnesium), and decrease in heat of the reaction. Decrease of the latter caused in some cases difficulties in determination of rate constants. A further decrease of the content of the base in the reaction mixture makes it impossible to initiate the reaction under given conditions. The features described above are present also in the case of tetrahydrofurane. However, before decrease of the rate constant one can observe a slight maximum on the curve, and a gradual decrease in heat of reaction.

In Tables 1 and 2 rate constants are compared to values of the ratio of base to halide at the beginning of the next kinetic measurement. The ratio was calculated assuming the Grignard reagent being highly associated and therefore being solvated with one molecule of base per molecule of alkylmagnesium halide. As is seen from the yields, the reaction can proceed at low contents of the base (less than one mole per mole of halide) with some decrease in the yield and heat of reaction only, provided that the initial content of the base exceeds a certain limit (about 2 moles per mole of halide, under the conditions kept in this work). If the total amount of the halide is lower than the limit (about one mole per mole of halide, in this work) the reaction can not be initiated. The value of such a limit at fixed

initial concentration of halide apparently depends on the solvating power of the base. Consequently, alkylmagnesium halides are equilibrium-solvated and more of the free base can be invclved in the reaction than predicted by the formal calculation mentioned above.

As already stated above, the heat of reaction decreases at low content of the base. In more concentrated solutions it does not depend on the composition of the mixture. The mean values of the heat of reaction apparently are associated with solvating power of bases -- the higher effective basicity of the base[11] the higher the heat of the reaction (Table 4). There are particularly few data for the heat of the Grignard reaction in the literature. Carson and Skinner[12] determined for the formation of methylmagnesium iodide in ethyl ether ΔH=65.4 kcal/mole. Markov and Peschev[13] found for the reaction of butyl iodide with magnesium in toluene in presence of catalytic amounts of dimethylaniline ΔH=72.5 kcal/mole. Products of the reaction and their yields were not determined. Our estimated values are in relatively good agreement with data by Holm[21].

It is necessary to dwell briefly on the comparability of the results of different works dealing with the rates of formation of the Grignard reagent. The reaction conditions (shape of magnesium, stirring, temperature etc.) apparently exert strong influence on the results. For instance, in early works of our laboratory[2,3] the first kinetic order in respect of the solvent was found for mixtures of ethyl ether with benzene and n-hexane. In the same work[3] an evident dependence of the rate constant on the steric effect of the alkyl group in bromide was found for the reaction in ethyl and butyl ethers. This dependence disappeared in tetrahydrofuran. Whitesides et al.[14,15] report about an independence of the reaction rate from the organic group of bromides and iodides in ethyl ether. The values of activation energy published in various works[4,9,13,16] etc. differ to a large extent. If we accept

the view of the Whitesides group[4,14] that the reaction of alkyl bromides and iodides with magnesium will proceed on the borderline between the slow and diffusion-limited reactions, one can interpret some of the controversies mentioned above.

On the basis of the results described above one can draw some conclusions about the role of the solvent in formation of the Grignard reagent, valid at least for the mixtures with toluene. Organic bases reveal catalytic properties at low concentrations. Presence of a base is also needed for initiation of the reaction. The minimal amount of the base required apparently depends on the reaction conditions. At high concentrations the base influences the rate of the reaction by altering the viscosity and/or dielectric constant of the medium.

The heat of the reaction is mainly connected with solvation of the Grignard reagent formed. The equilibrium solvation may occur after the rate-limiting step of the reaction. The latter conclusion is based on our observation about considerable decrease of the heat of reaction at low amounts of base while the Grignard reagent still forms with good yield and with insignificant decrease in rate. Ascription of the main part of the heat of reaction to solvation energy may cause some objections in connection with the results of Tsechelinzeff[17,18] and Lifschnitz[19], who estimated the heat of solvation of various organo-magnesium halides with ethyl ether to be about 12 kcal per mole of the Grignard reagent. In these works ethyl ether was added to the Grignard reagent prepared in benzene and the amount of heat evolved was measured. The composition of the product of the Grignard synthesis was not investigated. In our opinion the real solvation energy must be essentially higher because under these conditions polymeric organomagnesium compounds form and considerable part of solvation energy is consumed for destruction of the polymers. Since strong association of organomagnesium compounds has been observed also in ether solutions[20], the

energies of solvation and association (polymerization) can not differ very much. Therefore, the result obtained by these authors must be an algebraic sum of energies of partial depolymerization and solvation of the organomagnesium compound.

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LFER CORRELATIONS AND COMPETITIVE REACTIONS. IMITATIVE MODELLING. CHIMERICAL CORRELATIONS

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The method of quantitative imitative modelling has enabled us, in principle, to observe good (statistical) linear correlations of Hammett, Taft, Grunwald-Winstein and Arrhenius equations for overall rate constants of competitive reactions described by equations (1) or (1a). Despite good statistical values such correlations appear to be, in fact, not true LFER correlations but chimerical ones which arise due to the superposition of a number of true correlation dependences in the case the linear approximation error of the function $\lg k_{obsd}$ being of the same order with experimental inaccuracy. To observe (in the above sense) good chimerical correlations it is necessary that similar correlations hold for each of the competitive reactions as well as only moderate differences in the influence of the given factor on the free energy change of individual reactions while the deviations from the regression hypersurface do not follow the normal statistical distribution but depend on the argument which is to be revealed by the analysis of the residua.

We have shown that the monotone non-linear nature of correlations, deviations from the latter by individual points, the break of a correlation and even the inversion of the sign of the angular coefficient might be caused not by competition between the processes of formation and breaking the bond in the transition state, not by the appearance of additional types of interaction between the substituent and the reaction center and even not by the passing of a parameter through its isoparametrical value but by the composite nature of rate constants, i.e. by the fact that the studied reaction proceeds simultaneously by a number of competitive routes.

It is a well-established fact in physical organic chemistry that the constancy of mechanism of a process in the limits of the studied reaction series is required to observe any good (in statistical sense) LFER correlation in this series[1-8*] . It is believed that the opposite point of view is also valid, i.e. the observance of Hammett-Taft, Grunwald-Winstein and other similar equations as well as the Arrhenius equation**

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* This point of view has been formulated[6] more accurately in relation to the Hammett equation, "Constancy of mechanism throughout the reaction series is a basic requirement for conformity to the Hammett equation in any of its forms".

** The Arrhenius as well as the van't Hoff equations may be treated[9] as special cases of LFER correlations, for the linear nature of the dependences $\lg k_A$ and $\lg k_B$ on $1/T$ for any two representatives A and B of the reaction series equal the linear dependence between $\lg k_A$ and $\lg k_B$ at the given temperature interval.

for any reaction series in which structure, solvent or temperature is varied is treated as the criterion of constancy of reaction mechanism in the given reaction series. The fact that individual points fall out from the linear correlation, the non-linear nature of the correlation in general or break of the correlation dependence are usually ascribed to the change of transformation mechanism[1-7] or to the change of the rate-determining step at consecutive reactions[5,10]. The break of the Arrhenius dependence is treated similarly, see e.g. ref. 11. At present it is hard to overrate the vast positive role that the given criterion has played in the study of the mechanisms of organic reactions. At the same time a number of heterolytical reactions, e.g. the substitution at saturated or carbonyl carbonic atoms, proceed simultaneously by a number of parallel reaction routes[12], which leads to identical or different products due to the fact that the reacting particles in the reaction system may appear to be in states that are different both qualitatively and for reactivity[12-14] which in its turn is caused by the presence of reagents of different nature [14,15] in the reaction system or by the ambident nature of reacting particles[16]. Simultaneous routes of transformation are likely also for many solvolytic processes in aqueous-organic and particularly in aqueous-alcoholic mixtures, see e.g. references 17 and 18.

When studying kinetically similar processes the observed rate constant k_{obsd} appears to be the composite value and has the form of equation (1) or (1a)

$$k_{obsd} = \sum_i k_i \qquad (1)$$

$$k_{obsd} \sum_i \alpha_i k'_i \qquad (1a)$$

where k_i - is the rate constant for the i-th simultaneous reaction, α_i - the portion of particles (e.g. ions or their various associates of a definite type, k'_i - the rate constant of these particles.

Let us assume, that the common LFER correlation of type (2) is strictly observed for every $k_i(k_i')$ represented in the right-hand part of equation (1) and (1a):

$$\lg k_i(k_i') = \alpha_i + \beta_i X \qquad (2)$$

Here α_i and β_i denote the intercept and the slope X - the substituent or medium or the numerical value of I/T, then the dependence of lg k_{obsd} on X at any $k_i(k_i')$ remains non--linear. In this case the numerical value of RT lgk_{obsd} does not have the meaning of the activation free energy. It might be assumed that LFER correlations of those values k_{obsd} should not be observed at all, with the exception of the case when all the $k_i(k_i')$ values are proportional to each other (see the appendix). However, the substituent effects on the overall k_{obsd} of many reactions, and especially on various solvolytic processes in ethanol-water media may be described rather adequately[19] by the simple Hammett equation.

In water-ethanol solutions of alkalis the following equilibrium occurs[20]

$$HO^- + ROH \rightleftharpoons RO^- + H_2O \qquad (3)$$

Therefore in such media the anions HO^- and RO^- interact competitively with various electrophiles[17]. Thus, under these conditions the carboxylic esters interacting with HO^- undergo alkaline hydrolysis and those with the anion RO^- undergo reesterification[21], i.e. k_{obsd} of this process appears to be a composite value. Kinetic studies of bimolecular alkaline decomposition of m,p - substituted phenyl esters of acetic[22] and phenylacetic[23] acids have indicated good observance of LFER correlations not only for the substituent effects but also for the composition of the water--ethanol mixture and the observed rate constants k_{obsd} of this process has been described by eq.(1a). Reference 22 explains these experimental data by the assumption that the change of free activation energies in carboxylic esters with ions HO^- and RO^- are proportional and are determined

by the same factors. This hypothesis is in fact based on the assumption stating that the substitution of the carboxylic carbon atom is independent of substituent effects for the substrate and the nucleophile. This fact has been confirmed by a number of studies, see e.g. references 22, 24 and 25. Similar "LFE correlations" work well also for the influence of the structure of the leaving and acyle groups, medium and temperature in bimolecular decomposition reactions of (thion) phosphinates in water-ethanol alkaline solutions[26]. Under these conditions phosphonic esters as well as their carboxyl analogues are to undergo competitive processes of alkaline hydrolysis and reesterification due to the high reactivity of alkoxyle ions in reactions of nucleophilic substitution at the phosphoric atom in various phosphates, phosphonates and phosphinates[27,28]. At the same time, in substitution reactions at the quadricoordinated phosphorus the structural effects of the organophosphorus substrate and O- nucleophile may be to a large extent non-additive[27] *. Consequently, the argument of ref. 22 cannot in the general case be extended to explaining the reasons for good observance of linear correlation relationships for overall rate constants k_{obsd} of alkaline decomposition of organophosphorus esters in water-ethanol mixtures.

The above circumstances prompted us to consider the quantitative imitative modelling with the aim to test the possibilities for observing various correlation relationships for the observed rate constants of compasite reactions. In order to facilitate our task we treated only linear correlations similar to the Hammett and Arrhenius equations and started from the fact that "experimental" rate constants k_{obsd} can be described by eq.(1). In our view, the results of this modelling might be of interest to many researchers

* In contrast to ref. 27 there are experimental data referring to the possible independence of the structural effect of the substrate and O-nucleophile for the substitution at the quadricoordinated phosphorus.

dealing with the quantitative description of organic reactivity and pursuing the physical sense of correlation relationships. These results make us introduce the concept of "synthetic" correlations or chimerical correlations which arise as a result of superposition of several true correlation dependences. It is likely that at least some of the correlation relationships up to now are namely chimerical correlations of this kind. Besides, the results of modelling indicate that such facts as the deviation of some points (especially the extreme ones) the non-linear (U-shaped) nature of the correlation or its steep break passing through the minimum (maximum) may be the result of comparity nature of the value correlated.

Imitations of Hammett correlations

Let us assume that in a reaction system of the compounds XØZ, where X is the substituent, Z - the reaction center and Ø the phenylene bridge, undergo a number of simultaneous transformations with rate constants $k_i = k_A, k_B, k_C, k_D, k_E, k_F, k_G$ and k_H. For each reaction the Hammett-Taft equation is strictly observed.*

$$\lg k_i = a_i + \rho_i \bar{\sigma}^{\circ}_i \qquad (4)$$

---

* We have chosen an equation of this type because it describes excellently kinetic data for bimolecular alkaline decomposition of phenyl esters of carboxylic and (thion) phosphinate acids[22,23,26] although the choice of equation type in this case is insignificant. The two first equations in Table 1 are true correlations for alkaline hydrolysis of phenylacetates in water and 70% dioxane[31]. The rest of the equations have been chosen at random with the aim to achieve a possibly wider range of the values a_i and ρ_i, different variants of changing the numerical values of k_i as well as various combinations of the signs a_i and ρ_i.

The adopted values for coefficients a_i and ρ_i; for various k_i are displayed in Table 1, but substituents X have been limited to the following representative set : m, p-NO_2, m, p-Cl, m, p-MeO, H, m, p-Me, m, p-NH_2 (11 substituents altogether). The values for $\bar{\sigma}^o$ have been taken from ref. 30. Also, let us suppose that we can measure k_{obsd} which represent various combinations of k_i (Table 2) described by eq. (1). Consequently, our task will be reduced to the following: can these values of k_{obsd} be described by analoguous (4) equations

$$\lg k_{obsd} = a_{obsd} + \rho_{obsd}\bar{\sigma}^o \qquad (5)$$

and if so, with what precision?

On the basis of the a_i and ρ_i values from Table 1 and constants $\bar{\sigma}^o$ we have calculated the k_i values for various X. From these values we have in its turn constructed various combinations k_{obsd} (Table 2). The results of describing in this way "synthesized" constants k_{obsd} within the framework of eq. (5) are given in Table 2 and are illustrated in figures 1-7.

Table 1

The adopted values of the coefficients a_i and ρ_i of eq.(4) for rate constants k_i

k_i	a_i	ρ_i	k_i	a_i	ρ_i
k_A	0.151[a]	0.947[a]	k_E	1.151	0.253
k_B	-0.210[b]	1.628[b]	k_F	-1.151	0.253
k_C	1.151	2.011	k_G	-0.210	-1.628
k_D	-1.151	2.011	k_H	1.151	-1.628

[a] The correlation[31] for alkaline hydrolysis of phenylacetates in water at 25°C. [b] The same in 70% dioxane[30].

Table 2

Statistics of describing by eq.(5) "synthetic" constants k_{obsd}, determined by eq.(1)

k_{obsd} [a]	Reg.	a_{obsd}	ρ_{obsd}	n	r	s_o	s%
$k_A + k_B (k_A \approx k_B)$	1	0.318∓ ∓0.006	1.229∓ ∓0.014	11	0.9997	0.018	1.16
$k_A + k_C (k_A < k_C)$	2	1.200∓ ∓0.004	1.949∓ ∓0.009	11	0.9999	0.011	0.45
$k_A + k_D$ ($k_A \approx k_D$ at $\bar{\sigma}_x^o > 0$; $k_A > k_D$ at $\bar{\sigma}_x^o \leq 0$)	3	0.179∓ ∓0.005	1.069∓ ∓0.013	11	0.9993	0.017	1.26
$k_A + k_E (k_A < k_E)$	4	1.197∓ ∓0.003	0.357∓ ∓0.008	11	0.9979	0.010	2.26
$k_A + k_F (k_A > k_F)$	5	0.174∓ ∓0.001	0.924∓ ∓0.002	11	0.9999	0.003	0.26
$k_D + k_F$ ($k_D > k_F$ at $\bar{\sigma}_x^o > 0$; $k_D < k_F$ at $\bar{\sigma}_x^o < 0$)	6a	-0.788∓ ∓0.031	1.506∓ ∓0.074	11	0.9894	0.095	6.90
	6b	-0.874∓ ∓0.029	1.670∓ ∓0.059	7[b]	0.9968	0.056	3.52
$k_A + k_B + k_C +$	7a	1.543∓ ∓0.029	1.494∓ ∓0.071	11	0.9900	0.091	5.04
$+ k_D + k_E + k_F$	7b	1.510∓ ∓0.023	1.569∓ ∓0.054	10[c]	0.9954	0.063	3.85
$k_A + k_G$ ($k_A > k_G$ at $\bar{\sigma}_x^o > 0$; $k_A \leq k_G$ at $\bar{\sigma}_x^o < 0$)	8a	0.224∓ ∓0.016	0.858∓ ∓0.028	5[d]	0.9984	0.019	2.21
	8b	0.233∓ ∓0.013	-0.684∓ ∓0.064	5[e]	0.9869	0.015	8.02
$k_A + k_H$ ($k_A > k_H$ at $\bar{\sigma}_x^o > 0$; $k_A \ll k_H$ at $\bar{\sigma}_x^o \leq 0$)	9a	0.678∓ ∓0.046	0.365∓ ∓0.063	3[f]	0.9855	0.024	18.2
	9b	1.214∓ ∓0.010	-1.371∓ ∓0.052	8[g]	0.9957	0.026	2.77
$k_B + k_H$ ($k_B \gg k_H$ at $\bar{\sigma}_x^o > 0$; $k_B < k_H$ at $\bar{\sigma}_x^o \leq 0$)	10a	0.419∓ ∓0.063	0.915∓ ∓0.036	3[f]	0.9956	0.034	8.08
	10b	1.189∓ ∓0.008	-1.447∓ ∓0.045	8[g]	0.9971	0.023	2.34

*a in parentheses are given the correlations of constants k_i,
[b] Without taking into account p-NH_2m, m-NH_2, p-Me and p-MeO.
[c] Without taking into account p-NH_2. [d] For p-NO_2, m-NO_2, p-Cl, m-Cl and m-MeO. [e] For p-MeO, m-Me, p-Me, p-NH_2 and m-NH_2.
[f] For p-NO_2, m-NO_2 and p-Cl. [g] For the remaining 8 substituents X.

In Table 2 in order to describe regression equations more precisely we have in addition to the values of r and s_o given also the S% values[9]. Let us consider the obtained results.

Regressions 1-5 (Figures 1-3).* We have considered the cases when all the points are described by one regression equation and the correlation between lg k_{obsd} and $\bar{\sigma}^{\circ}$ holds well (Table 2). It is only the analysis of residua that indicates the non-linearity of the lg k_{obsd} function. The residua which are determined as differences Δ_j = lg k^j_{obsd} - lg k^j_{calcd} (where k^j_{obsd} is the value of the synthesized constant at the substituent j, k^j_{calcd} - the value of the constant which has been calculated in accordance with the regression equation for the same substituent j), depend on the argument which should not take place if the model is adequate to experimental data. The dependence of residua Δ_j on $\bar{\sigma}^{\circ}$ (is illustrated by Figures 1-3). In the cases under consideration the initial constants k_i differed from each other by numeric values as well as by parameters a_i and ρ_i. It should be noted that the obtained values of a_{obsd} and ρ_{obsd} stand nearer to the corresponding parameters a_i and ρ_i for the constant which possesses a higher numerical value.

Regressions 6,7 (Figures 4 and 5). This case is of special interest from the point of view of the methodology of correlation analysis. Between lg k_{obsd} and $\bar{\sigma}^{\circ}$ for all substituents X only a satisfactory correlation is observed (regressions 6a and 7a). The precision of description will improve

* An experimental case of good observation of correlations 1 and 2 for overall rate constants has been described recently in ref. 33. The authors have shown that not only the values of elementary constants k_2 and k_3 for the methylation with MeJ or the dimethylsulphate of anions of 2-aryle-iminothiazolidin-4-ones for each of the two reaction centers but also experimentally measured overall rate constants $k_1=k_2+k_3$ can be well described by the Hammett and Brønsted equations.

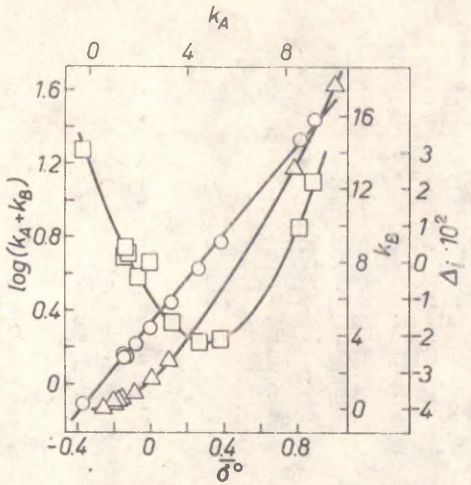

Fig.1. The correlation between the logarithm values of $k_{obsd}=k_A + k_B$ and constants $\bar{\sigma}^o$ of substituents X (O). The dependence of k_A on k_B(Δ). The dependence of residua Δ_i on constants $\bar{\sigma}^o$ ($\square$).

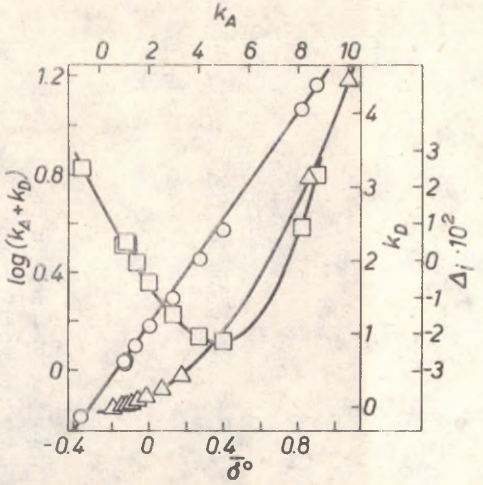

Fig.2. The correlation between the logarithm values of k_{obsd} = = $k_A + k_D$ and constants $\bar{\sigma}^o$ of substituents X (O). The dependence of k_A on k_D (Δ). The dependence of residua Δ_i on constants $\bar{\sigma}^o$ ($\square$).

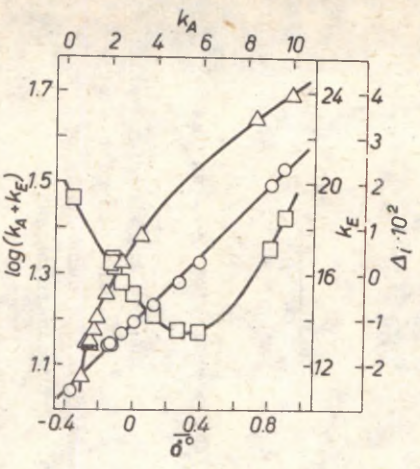

Fig.3. The correlation between the logarithm values of $k_{obsd}=k_A+k_E$ and constants $\bar{\sigma}^\circ$ of substituents X (○). The dependence of k_A on k_E (△) The dependence of residua Δ_i on constants $\bar{\sigma}^\circ$(□).

considerably, if one eliminates the points for X=p-NH_2, p-MeO and p-Me (Reg. 6b) or the point p-NH_2 (Reg. 7b). It can easily be seen that each of the eliminated substituents is in principle able for polar resonance with the electron-deficient reaction center*. The precision of describing "experimental" values of $k_{obsd}=k_D + k_F$ (Reg.6) will naturally improve if the biparameters equation is applied** and it will lead to a considerable contribution of the polar resonance with the reaction center. Alternative ways of interpreting the deviations could be noted as well: a) the necessity to specify the $\bar{\sigma}^\circ$ values for deviated substituents; b) the conclusion that the reaction mechanism has been violated, especially in the case of the compound with X=p-NH_2 if it is considered that the reaction proceeds despite reality by one route only.

* Somehow it takes place in the solvolysis of cunyl chlorides or in the alkaline hydrolysis of ethylbenzoates [34] and in a large number of other series, see e.g. ref. 3.

** For example the equation $\lg k = \lg k_o + \rho^\circ\bar{\sigma}^\circ + \rho_R^+ \bar{\sigma}_R^+$ applied in ref. 34 for description of experimental data for alkaline hydrolysis m, p-XC_6H_4COOEt in aqueous solution, see also ref. 9.

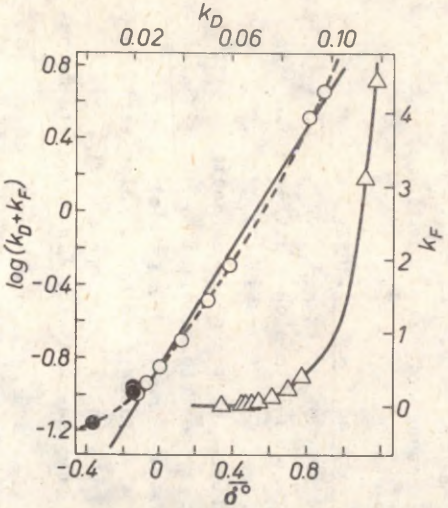

Fig.4. The correlation between the logarithm values $k_{obsd}=k_D + k_F$ and $\bar{\sigma}^o$ (○●) the dependence of k_D on k_F (△). The points ● correspond to substituents X = p-NH_2 p-MeO and p-Me. The dotted line indicates the actual dependence of the logarithm of the sum $k_D + k_F$ on $\bar{\sigma}^o$.

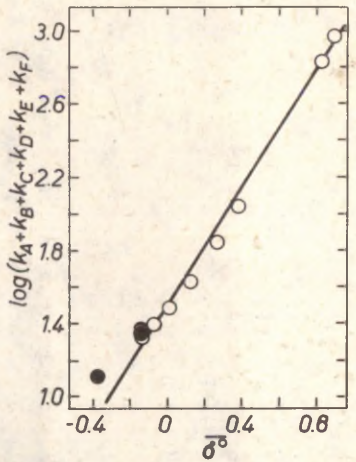

Fig. 5. The correlation between the logarithm values of $k_{obsd} = k_A + k_B + k_C + k_D + k_E + k_F$ and $\bar{\sigma}^o$.
The points correspond to substituents X = p-NH_2, p-MeO, p-Me.

It is evident that in case the dependence of individual rate constants k_i on the structure of reagents is described e.g. by constants σ^*, the occurrence of similar deviations correlations of overall k_{obsd} values from σ^* may be explained by the evidence of steric interactions or hyperconjugation of a special type, the "rabbit's ears" effect, anchimeric effect, etc. When describing the dependence of k_{obsd} on medium there are even wider possibilities for interpretation of deviated points within the framework of content chemical concepts.

Figure 4 indicates that the true dependence of $lgk_{obsd} = lg(k_D + k_F)$ on $\bar{\sigma}^o$ is nonlinear. This nonlinearity is evidently caused (cf. Figures 1-3) by the fact that ρ_D and ρ_F are remarkably different: $\rho_D/\rho_F \cong 8$. Therefore it is expected that the nonlinearity of the correlation k_{obsd} due to a certain parameter will jump with an increase in sensitivity differences for the given effect on individual constants k_i. The nonlinearity of monotone dependence of experimental constants on the structural factor in correlation analysis is usually not ascribed to the competition of two mechanisms of transformation of compounds (two reaction routes), but to the processes of bond formation and breaking in the transition state.

Regressions 8-10 (Figures 6 and 7). Here we have treated the cases where the dependence of $lg\ k_{obsd}$ on $\bar{\sigma}^o$ splits into two separate linear branches with slopes different in sign which well represents the case of "notable change of process mechanism within the limits of the studied reaction series" (see references 1-10). A specific peculiarity of this situation is the difference of signs ρ_i for initial constants*. For separate branches the linearity of plot holds well. In the case of Reg. 8 the unsubstituted compound (Fig. 6) apparently represents the case with the "intermediate mecha-

* It may be suggested that a more simple example of such a situation is the reversible first order reaction, when $k_{obsd} = k_1 + k_{-1}$ and the signs ρ_1 and ρ_{-1} are different due to the principle of microscopic reversibility[10b].

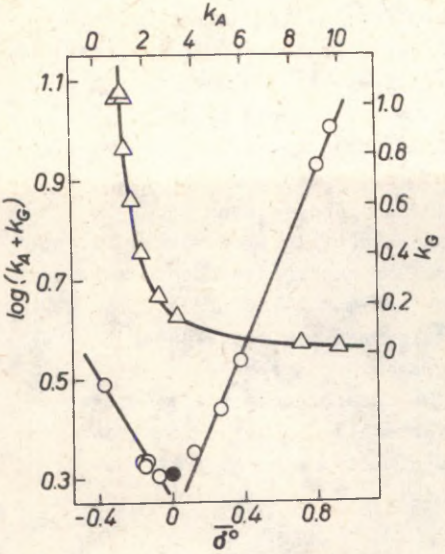

Fig. 6. The correlation between the logarithms of $k_{obsd}=(k_A+k_G)$ and $\bar{\sigma}^o(0)$ and the dependence of k_A on k_G(Δ). The point ● corresponds to X=H.

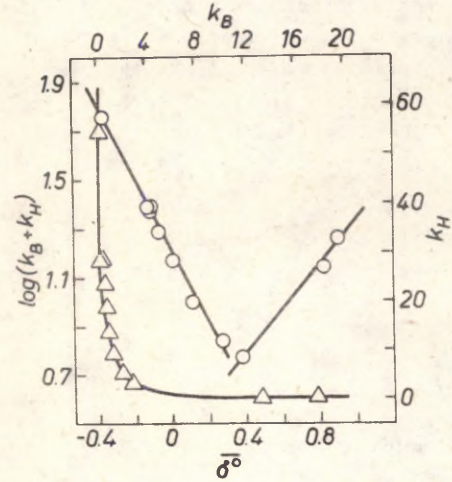

Fig. 7. The correlation between the logarithms of $k_{obsd}=(k_B+k_H)$ and $\bar{\sigma}^o(0)$ and the dependence of k_B on k_H (Δ).

nism" and for this reason does not belong to any of the branches of the correlation plot. In the case of regressions 9 and 10 the overlapping of different branches takes place already in the vicinity of the substituent m-Cl (Fig.7).

It should be noted that in the three treated cases of abrupt break of correlations the dependence of k_{obsd} on $\bar{\sigma}^{o}$ proceeds through the minimum. The reasons for the appearance of "curved" dependence of lg k on structural parameters and the abrupt break of such a dependence together with the passing through the maximum value of lg k have been treated in the literature, see e.g. references 3 and 5 as well as the quoted sources. Such dependence of k_{obsd} on $\bar{\sigma}^{o}$ takes place e.g. in the case of competitive stages of decomposition of the intermediate into the final and initial products . Formally, a similar dependence may be observed e.g. in coordinates lg k_{obsd} $\div \bar{\sigma}^{o}$, where $k_{obsd} = I/(k_A + k_G)$.

Imitations of Arrhenius correlations

The situation with the temperature dependence of total rate constants of competitive reactions described by equations (1) and (1a) is similar to the one described above for Hammett correlations. As a matter of fact, if the temperature dependence of rate constants $k_i(k_i')$ of each of the competitive reactions obeys the Arrhenius equation, then the apparent activation energy of the overall process is the following:

$$E_{obsd} = R \frac{\partial \ln k_{obsd}}{\partial (I/T)} = R(\sum_i k_i)^{-1} \sum_i \frac{\partial k_i}{\partial (I/T)} = (\sum_i k_i)^{-1} \sum_i k_i E_i \quad (6)$$

and similarly

$$E_{obsd} = (\sum_i \alpha_i k_i')^{-1} \sum_i \alpha_i k_i' E_i \quad (6a)$$

where E_i is the activation energy of an i-th competitive reaction. The Arrhenius equation

$$\lg k_{obsd} = \lg A_{obsd} - E_{obsd}/2.303\ RT \qquad (7)$$

for overall rate constants will be obeyed strictly only in the special case of the activation energies of all the competitive reactions being equal to each other: E_i = const for only in this case, according to (6) and (6a) the value of E_{obsd} does not depend on k_i and k_i. The equality of activation energies is mathematically equivalent to the independence of temperature of the ratio of rate constants k_i for any two competitive reaction routes.

Table 3

The adopted values for parameters $\lg A_i$ and E_i of the Arrhenius equation (8) for individual rate constants k_i[a]

k_i	$\lg A_i$	$E_{a/i}$ kcal/mole
k_L	5.7	6.5
k_M	16.1	21.7
k_N	8.3	11.2

[a] The adopted values of activation energies E_{ai} lie at intervals which are characteristic of alkaline hydrolysis reactions of carboxylic and organophosphorous esters.

Applying the parameters $\lg A_i$ and E_i from Table 3 for hypothetical competitive reactions we have calculated the numerical values for rate constants k_L, k_M and k_N at 15,0, 15, 25, 35, 55 and 75°C in accordance with the equation

$$\lg k_i = \lg A_i - E_i/2.303\ RT \qquad (8)$$

Then, from these values k_i by eq.(1) we have "synthesized" the overall rate constants $k_{obsd} = (k_L + k_M)$, $(k_L + k_N)$ and $(k_M + k_N)$ at the same temperatures. Table 4 presents the results of correlations of these values k_{obsd} within the framework of eq.(7) with the aim to determine the precision of maintaining such correlations and to compare its parame-

ters i.e. "experimental" values of the " frequence factor" lg A_{obsd} and "activation energy" E_{obsd} with such k_i for rate constants as applied for the "synthesis" of k_{obsd}.

Imitative modelling shows that the Arrhenius correlation (7) for overall constants k_{obsd} may in many cases have fully acceptable precision from the point of view of the experimentator if the following conditions are held: i. the difference in activation energies of competitive reactions must be insignificant (e.g. 5-7 kcal/mole, see Reg. 11 in Fig.8), ii. the experimental temperature range must be rather narrow (e.g. 30-40°). At the same time the precision of the correlation will rise together with a decrease in the temperature range (see regressions 12a - 12d, Fig.8, i.e. at a relatively narrow temperature range a good (statistically)Arrhenius correlation for the overall constant k_{obsd} may be obtained even if the difference in activation energies of competitive reactions amounts up to 15-20 kcal/mole (see Reg. 13b),

Thus together with an increase in the difference between

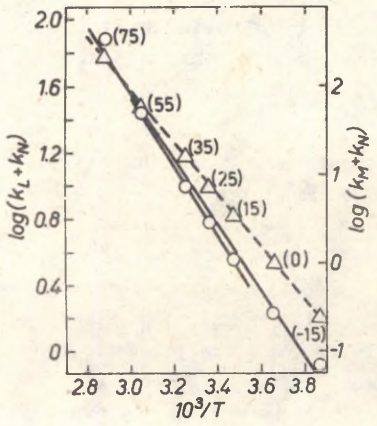

Fig. 8. The correlation between the logarithm values $k_{obsd}=k_L + k_N$ (Δ); $k_{obsd}=k_M + k_N(0)$ and $10^3/T$. The figures in parentheses correspond to T°C values.

Table 4

Statistics of correlation (7) of temperature of "synthetic" rate constants k_{obsd} [a]

k_{obsd}	Reg.	lgA_{obsd}	$E_{a,obsd}$	n	r	s_o	s%
k_L+k_N	11	6.237∓ ∓0.063	7.155∓ ∓0.086	7[b]	0.9996	0.016	1.0
k_M+k_N	12a	12.962∓ ∓0.622	16.889∓ ∓0.842	7[b]	0.9938	0.156	4.2
	12b	12.046∓ ∓0.567	15.715∓ ∓0.751	6[c]	0.9954	0.109	3.8
	12c	12.935∓ ∓0.538	16.958∓ ∓0.732	5[d]	0.9971	0.074	3.2
	12d	13.829∓ ∓0.387	18.229∓ ∓0.539	4[e]	0.9991	0.037	2.2
k_L+k_M	13a	8.751∓ ∓0.771	10.335∓ ∓1.044	7[b]	0.9754	0.193	8.3
	13b	6.495∓ ∓0.244	7.465∓ ∓0.317	5[f]	0.9973	0.035	3.4
	13c	9.247∓ ∓0.709	11.237∓ ∓0.988	4[e]	0.9924	0.067	6.5
$k_M+k_N/(k_L+k_N)$	14	18.164∓ ∓0.073	25.770∓ ∓0.099	7[b]	0.9999	0.018	0.3
$k_L k_M/(k_L+k_N)$	15	15.560∓ ∓0.071	21.064∓ ∓0.096	7[b]	0.9999	0.018	0.4
$k_L\ k_M/(k_M+k_N)$	16a	11.638∓ ∓0.314	14.890∓ ∓0.391	3[g]	0.9996	0.024	2.6
	16b	7.030∓ ∓0.272	8.629∓ ∓0.397	4[h]	0.9979	0.032	2.4
$k_L\ k_N/(k_M+k_N)$	17a	3.781∓ ∓0.418	-4.259∓ ∓0.521	3[g]	0.9924	0.032	16.8
	17b	-1.056∓	2.313∓	3[i]	0.9996	0.024	6.4

[a] When calculating the parameters of eq.(7) the value $-1000/2.303RT$ has been used as the argument

[b] For the temperature range from -15 to 75°C.

[c] Without taking into account k_{obsd} at 75°C.

[d] For the temperature range 0÷55°C.

[e] For temperatures 15,25,35, and 55°C.

[f] For the temperature range from -15 to 35°C.

[g] For the temperature range from -15 to 15°C.
[h] For temperatures 25, 35, 55 and 75°C.
[i] For temperatures 35, 55 and 75°C.

the numerical values of activation energies of competitive processes the dependence between the total rate constant and temperature in the coordinates of the Arrhenius equation become increasingly nonlinear (see Fig. 9).

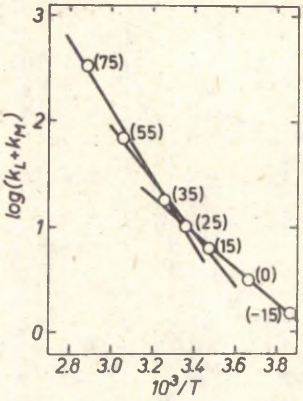

Fig. 9. The correlation between the logarithm values $k_{obsd} = k_L + k_M$ and $10^3/T$. The figures in parentheses correspond to temperature values in T°C.

However, the range of temperature change applied in our modelling is unbelievably wide (90°C!). Its reduction to ranges commonly used in the study of processes in liquid phase will lead to a situation when even in the case of very large differences in the activation energies of competitive reactions* the temperature dependence of overall rate constants may be described by Arrhenius equations (see regressions 13a ÷ 13g Fig. 9) leading to physically senseless values of "frequency factor" and "activation energy" or "activation parameters" $\Delta S^{\#}_{obsd}$ and $\Delta H^{\#}_{obsd}$ when using the Eyring equation. The nonlinear dependence of lg k_{obsd} on 1/T presented in Fig. 9 may be divided at least into two linear (from -15 to 25°C and from 35 to 75°C) with different

* Which may proceed at comparable rates due to the corresponding differences in entropy factors.

slopes. The obtained break may be interpreted in accordance with the methodology of correlation analysis as a reflection of reaction mechanism change with the change in temperature, see e.g. ref. 11.

Since we take a special interest in processes that proceed according to the scheme

$$A + B \rightleftarrows I \longrightarrow P \qquad (9)$$

through formation of the intermediate I, able for competitive decomposition into reaction products or reagents we have calculated by using the values of activation parameters presented in Table 3 also the values of $k_{obsd} = k_M k_N/(k_L + k_N)$, $k_L k_N/(k_L+k_N)$, $k_L k_M/(k_M+k_N)$ and $k_L k_N/(k_M + k_N)$ at the same temperatures.* Further we considered the possibility of describing the temperature dependence of "synthesized" in this way constants k_{obsd} within the framework of eq.(7). The obtained results are also presented in Table 4. In the case of regressions 14 and 15 at the wide temperature range from -15 to 75°C between lgk_{obsd} and 1/T good linear plots are maintained (see Fig.10) in a wide range of changing "reactivity" (~5 orders of k_{obsd}). Intercepts and slopes of the corresponding linear regressions in Fig. 10 lack a meaning which could be ascribed to them if we proceed from the adopted interpretation of eq.(7). In the case of regressions 16 and 17 for the values of $k_{obsd} = k_L k_N/(k_M + k_N)$ a break can be observed in the range of 20°C in the Arrhenius plot (see Fig.11). Higher and lower than this temperature good linear correlations take place between lg k_{obsd} and 1/T.
Breaks of this kind are usually ascribed to the change in reaction mechanism when the temperature is changed [11]. Even a more dramatic situation may be observed for k_{obsd} =

* If we admit the stationary concentration of the intermediate I the observed rate constant of process (9) is represented as follows $k_{obsd} = k_1 k_2/(k_{-1} + k_2)$, where k_1, k_{-1} and k_2 are the rate constants of formation reverse and forward decomposition stages of intermediate I into initial and final products respectively.

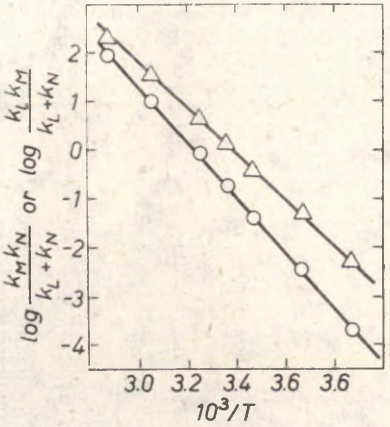

Fig. 10. The correlation between the logarithms of $k_{obsd}=k_M\ k_N/(k_L+k_N)$ (O) as well as $k_{obsd}=k_L\ k_M/(k_L+k_N)$ (Δ) and $10^3/T$.

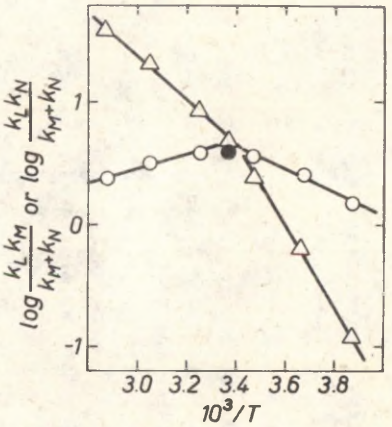

Fig. 11. The correlation between the logarithms of $k_{obsd}=k_L k_M/(k_M+k_N)$(Δ); $k_{obsd}=k_L k_N/(k_M+k_N)$ (O) and $10^3/T$.

$= k_L k_N/(k_M + k_N)$. In this case the dependence of $\lg k_{obsd}$ on $1/T$ decomposes in three sections: "normal dependence in the range from -15 to 15°C, "reversed dependence" in the range 35-75°C (negative "activation energy") and the point for 25°C which deviates at these correlations represented by good statistical characteristics. It should be noted that in the section of "reversed dependence" k_M is higher than k_N by 2.2, 6.4 and 16 times at 35, 55 and 75°C (respectively, i.e. at 35 and 55° one can not observe the situation corresponding to restrictions $k_M \gg k_N$ and $k_{obsd} \simeq k_L k_N/k_M$. In the latter case the reversed Arrhenius dependence is to be observed, if only $E_M > (E_L + E_N)$.

Conclusion

The results of this study indicate that meaningful observance of linear plots relating the reactivity of the studied compounds to their structure, medium properties, temperature etc., does not account for the fact that the transformation of these compounds in the given reaction is carried out by a single possible route. Good correlations may be observed even if the reaction mechanism is really complicated, i.e. the transformation of reacting products occurs at comparable rates simultaneously with the participation of different reagents or different forms of one and the same reagent (or substrate), and observed rate constants have some effective value . The conditions for observing such correlations for effective rate constants are the applicability of the corresponding correlations to all corresponding elementary rate constants for different routes of the complex reaction and comparatively small differences in the intensities of influence of the given factor on various routes. (see the appendix). Consequently, the observance of any sufficiently well-defined correlation relationship cannot be regarded as a well-grounded criterion for constancy of the reaction mechanism in the given reaction series, if by "constancy of mechanism" only a single possible effective route of this reaction is meant.

The results of this study prove also that deviations from linear correlations of individual points, especially those located in the section of minimum or maximum values of the influencing factors, must be treated with special care. These deviations may be not connected with the influence of additional factors and the necessity to introduce new parameters into the correlation equation, not with the precision of numerical values of substituent or solvent constants (e.g. the constant σ^{o} of deviated substituents) and not with the change in the reaction mechanism, but with the fact that the reaction considered proceeds by a number of parallel routes.

The correlations similar to these examined in this study, despite their good statistical characteristics, appear not to be true LFER correlations but chimerical correlations, for their parameters do not possess a meaning which could be assigned to the parameters of true LFER correlations, For this reason such correlations cannot be used in the general case for various theoretical concepts, qualitative and quantitative comparisons and interpretation of the reaction mechanism. Therefore, when constructing any correlation equation which relates reactivity to various factors it is first of all necessary to consider the problem whether the given correlation is a true LFER correlation or a chimerical one.

Appendix

Let us suppose that at $x \in X$

$$\lg k_i = \alpha_i + \beta_i x \qquad (A.1)$$

and

$$k_{obsd} = \sum_i a_i k_i \qquad (A.2)$$

where $a_i \neq 0$. It can be shown that under certain conditions the function

$$\lg k_{obsd} = \lg \sum_i a_i k_i = \lg \sum_i a_i 10^{\alpha_i + \beta_i x} \qquad (A.3)$$

may have a good linear approximation of the type

$$\lg k_{obsd} = \alpha + \beta x + R(x) \qquad (A.4)$$

where $R(x)$ is the residue of the linear approximation, comparable with the experimental uncertainty of the values $\lg k_{obsd}$. The equality $k_{obsd} = \alpha + \beta x$ should strictly be obeyed only in the case of proportionality of k_i values. In fact, if $k_{obsd} = \sum_i a_i k_i$ and all k_i are proportional, then $\sum_i a_i k_i = a k_j$, where k_j is one of the considered k_i values and $\lg k_{obsd} = \lg a + \lg k_j$. Since $\lg k_j = \alpha_j + \beta_j x$, then $\lg k$ $\lg k_{obsd} = (\lg a + \alpha_j) + \beta_j x$, where $\lg a + \alpha_j = \alpha$, $\beta_j = \beta$
Let us consider in detail a simpler case. Let

$$\lg k_1 = \alpha_1 + \beta_1 x \qquad (A.5)$$

$$\lg k_2 = \alpha_2 + \beta_2 x \qquad (A.6)$$

and

$$k_{obsd} = k_1 + k_2 \qquad (A.7)$$

for $x \in X$.

In that case

$$\lg k_{obsd} = \lg (10^{\alpha_1 + \beta_1 x} + 10^{\alpha_2 + \beta_2 x}) = f(x) \qquad (A.8)$$

is a function which is definite and has non-zero derivatives in the vicinity of a certain point $x_o \in X$. Let us consider the linear approximation of the function (A.8) in the

point x_0:

$$\lg k_{obsd} = f(x_0) + f'(x_0)\Delta x$$

where $\Delta x = x - x_0$. The error $R(x)$ of this approximation is equal to

$$R(x) = 0.5f''(\xi)(x)^2 \qquad (A.10)$$

where ξ belongs to the vicinity of the point x_0.

Let us now denote by k_1^o and k_2^o the values k_1 and k_2 in the point $x = x_0$ and by k_1^ξ and k_2^ξ - the values k_1 and k_2 in the point $x = \xi$.

Then

$$\lg k_{obsd} = \lg(k_1^o + k_2^o) - (k_1^o + k_2^o)^{-1}(k_1^o\beta_1 + k_2^o\beta_2)x_0 + (k_1^o + k_2^o)^{-1}(k_1^o\beta_1 + k_2^o\beta_2)x + R(x) \qquad (A.11)$$

and in accordance with (A.9) and (A.10)

$$R(x) = \frac{(\ln 10)k_1^\xi k_2^\xi(\beta_2 - \beta_1)^2}{2(k_1^\xi + k_2^\xi)^2}(\Delta x)^2 \quad \frac{(\ln 10)(\beta_2 - \beta_1)^2}{4}(\Delta x)^2 \qquad (A.12)$$

The above estimated error of the linear approximation will increase with an increase in the numerical values of k_i in the section X. Nevertheless the estimate indicates that in the vicinity of the point X_o the error $R(x)$ will decrease with a decrease in the difference of $(\beta_2 - \beta_1)$* and may be negligible enough at some values of β_2 and β_1.

Consequently, by negligible differences in the coefficients β_1 and β_2 and a relatively narrow interval of change are a requirement for a good linear approximation for eg. (A. 4). If $\beta_2 = \beta_1 = \beta$, then $\lg k_{obsd} = \alpha + \beta x$.

Let us compare the linear approximation (A.4) for $\lg k_{obsd}$ with the description of sample point values

* In the case of the Arrhenius or van't Hoff equations the value $(\beta_2 - \beta_1)$ is the difference of activation energies, if $x = -(2.3\ RT)^{-1}$ and in the case of the Hammett equation it is the difference of parameters ρ for parallel reactions.

($\lg k_{obsd}$, x) of this function in the vicinity of the point x_o by the least-squares method in the form of a linear regression (with parameters s_o and r).

$$\lg k_{obsd} = \alpha_{obsd} + \beta_{obsd} X \qquad (A.13)$$

The least-squares method levels experimental data, therefore parameters α_{obsd} and β_{obsd} of this description are to differ from the corresponding coefficients of the linear approximation (A.4), but at comparable R(x) and s_o such differences should be statistically negligible. Therefore it can be considered that the standard deviation s_o of regression (A.13) and the coefficient of the correlation r will be the better the smaller is the difference of β_2 and β_1 in equations (A.5) and (A.6) at the some interval of changing $x \in X$.

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STUDY OF SOLVENT DEPENDENCE OF ρ^0
3. INFLUENCE OF SOLVENT PARAMETERS

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In order to investigate the dependence of ρ^0 on different solvent parameters the values of $\Delta pK^x_{js} = pK^x_{js} - pK^o_{js}$ for acedic dissociation of of benzoic acids, phenols, anilinium ions, pyridinium ions; the values of $\Delta \log k^x_{js} = \log k^x_{js} - \log k^o_{js}$ for alkaline hydrolysis of ethyl benzoates, phenyl acetates, phenyl tosylates, phenyldimethyl thiophosphinates and for solvolysis of benzyl chlorides (altogether 648 values) as well as the values of $\Delta\rho^o_{js} = \rho^o_{js} - \rho^o_{j(H_2O)}$ for different reaction series in the case of individual solvents in binary mixtures have been statistically treated by using a specially prepared computer programme of multiple regression analysis (x, j and s denote the substituent, reaction series and medium, respectively).

The following solvents, besides water, were embraced: methanol, ethanol, 1- and 2- propanol, methyl-2-propanol, butanol, nitromethane, acetonitrile, DMFA, DMSO and binary mixtures of water with methanol, ethanol, dioxane, acetone, and DMSO.

In the case of dependence of the substituent effects on medium solvent electrophilicity was found to be the main influencing factor. The influence of polarity was found to be considerably less important. The influence of solvent

electrophilicity on the ρ^o values was found to be independent of the nine reaction series studied.

In our previous communication[1] on the basis of 190 values of ρ^o belonging to 14 reaction series the observance of the relationship

$$\rho^o_{js} - \rho^o_{jo} = \text{const} \qquad (1)$$

was checked for indidual solvents and binary mixtures as well as for concentrated aqueous solutions of different salts (j and s denote the reaction series and medium, respectively).

The main purpose of the present work was to check the significance of different solvent parameters to the substituent effects when the individual and binary solvents are embraced. On the other hand, it is of interest to verify whether the observance of relationship (1) is due to the constant influence of only one or a number of solvent parameters.

In the investigation of Koppel and Karelson[2] the dependence of ρ values on the solvent parameters have been studied for acidic dissociation of benzoic acids and phenols including the ρ values for individual solvents and the gaseous phase, according to the special variant

$$A = A^o + yY + eE \qquad (2)$$

of the following equation

$$A = A^o + yY + pP + eE + bB \qquad (3)$$

where $Y = (\varepsilon - 1)/(\varepsilon + 2)$ and $P = (n^2 - 1)/(n^2 + 2)$ are polarity and polarizibility of solvent, E[3,4] and B[4,5] are electrophilicity and nucleophilicity parameters of solvent. A and A^o are the ρ values for a considered and standard medium. ε denotes dielectric permittivity of solvent.

In the work considered[2] solvent polarity was found to be the main influencing factor. Influence of electro-

philicity was found to be somewhat less important, whereas the influence of polarizability and basicity were found to be negligible. But it should be mentioned that the correlation of ρ^o values according to equation (2) is quite crude and the calculated susceptibility parameters relative to the solvent electrophilicity for acidic dissociation of benzoic acids and phenols were found to be quite different (for benzoic acids e=0.164±0.061 and for phenols e=0.237±0.099).

If we assume that a single parameter dependence on both the substituent and solvent takes place for a given reaction series at constant temperature the equation could be written as follows:

$$\log k^x_{js} = \log k^o_{jo} + \rho_{jo}\sigma^x + s_{js}S + C_{xs}\sigma^x S \qquad (4)$$

$$(j = \text{const}, s \neq \text{const}, x \neq \text{const})$$

where $\log k^x_{js} - \log k^o_{js} = \rho_{jo}\sigma^x + C_{xs}\sigma^x S \qquad (5)$

$$\log k^o_{js} = \log k^o_{jo} + s_{js}S \qquad (6)$$

$$\rho_{js} = \rho_{jo} + C_{xs}S \qquad (7)$$

or

$$\rho_{js} - \rho_{jo} = C_{xs}S \qquad (8)$$

where S denotes the solvent parameter.

For standard medium s = o can be written

$$\log k^x_{jo} - \log k^o_{jo} = \rho_{jo}\sigma^x \qquad (9)$$

The solvent influence on the substituent effect can be represented as a difference:

$$\Delta\log k^x_{js} = \log k^x_{js} - \log k^x_{jo} = (\log k^o_{js} - \log k^o_{jo}) + C_{xs}\sigma^x S \qquad (10)$$

$$(j = \text{const}, s \neq \text{const}, x \neq \text{const})$$

or

$$\Delta\Delta\log k^x_{js} = (\log k^x_{js} - \log k^x_{jo}) - (\log k^o_{js} - \log k^o_{jo}) = C_{xs}\sigma^x S \qquad (11)$$

$$j \neq \text{const}, s \neq \text{const}, x \neq \text{const}$$

Relationship like (11), characterizing the dependence of substituent effects on medium could embrace all the data of reaction series for which relation (1) is applicable.

Consequently, the investigation of substituent effects (or the ρ^{o} values) depending on the solvent parameters consists in determination of C_{xs} constants (or $C_{xs_1s_2}$ constants when the cross terms like $C_{xs_1s_2}\sigma^{x}_{s_1s_2}$ are considered).

In principle, the C_{xs} values could be estimated from equations like (4), (5), (7) or (8), (10) or (11). Relationships (4) - (11) can be rather complicated depending on the number of medium and substituent parameters involved.

Thus, the estimation of the C_{xs} constants from the relationship of type (4) is quite hopeless due to the possible great number of terms in the right side of the correlation equation. On the other hand the error of the pK^{o}_{js} values (especially in the case of nonaqueous mediums) could exceed considerably the contributions of cross terms.

For investigation of the solvent parameters influence on substituent effects (or on ρ values) differential equations (5), (10) and (11) could have more prospects. When the data of different authors are quite contradictory, then the values of the substituent effects ($logk^{x}_{js} - logk^{o}_{js}$) are in better harmony with each other.

In order to check the contribution of different solvent parameters to the inductive effect of substituted phenyls, in the present work the values of

$$\Delta logk^{x}_{js}(\Delta pK^{x}_{js}) = logk^{x}_{js}(pK^{x}_{js}) - logk^{o}_{js}(pK^{o}_{js})$$

or

$$\Delta\rho^{o}_{js} = \rho^{o}_{js} - \rho^{o}_{jo}$$

were treated in accordance with the following equations:

$$\Delta pK^{x}_{js} = \rho^{o}_{jo}\sigma^{o}_{x} + C_{xE}\sigma^{o}_{x}E_{s} + C_{xB}\sigma^{o}_{x}B_{s} \qquad (14)$$

$$\Delta \log k^{X}_{js} (\Delta pK^{X}_{js}) = (\text{const}) + \rho^{o}_{j} \sigma^{o}_{X} + C_{XE} \sigma^{o}_{X} E_s + C_{XY} \sigma^{o}_{X} \Delta Y_s \qquad (15)$$

$$\Delta \log k^{X}_{js} (\Delta pK^{X}_{js}) = (\text{const}) + \rho^{o}_{j} \sigma^{o}_{X} + C_{XE} \sigma^{o}_{X} E_s + C_{XY} \sigma^{o}_{X} \Delta Y_s + \\ + C_{XEY} \sigma^{o}_{X} E_s \Delta Y_s \qquad (16)$$

$$\Delta \rho^{o}_{js} = (\text{const}) + C_{XE} (E_s - E_{H_2O}) + C_{XY} \Delta Y_s \qquad (17)$$

$$\Delta \rho^{o}_{js} = (\text{const}) + C_{XE} (E_s - E_{H_2O}) + C_{XY} \Delta Y_s + C_{XEY} (E_s - E_{H_2O}) \Delta Y_s \qquad (18)$$

where

$\log k^{o}_{js}$ or pK^{o}_{js} is the logk or pK_a value for an unsubstituted derivative ($X=C_6H_5$) in a solvent s;

$\Delta Y_s = \left(\frac{1}{\varepsilon_s} - \frac{1}{\varepsilon_{H_2O}} \right)$, where ε denotes dielectric permittivity of solvent[6];

E_s and B_s denote electrophilicity [3,4,7] (or general acidity) and nucleophilicity[4,5] (or general basicity) parameters of solvent, respectively.

As is seen, for the polarity parameters the inverse figure of dielectric permittivity of solvent was used. In the case of pK_a values treatment such a choice is quite natural. It should be added that the data processing by using the Kirkwood function did not lead to statistically more reliable results.

The contribution of solvent polarizability was found to be statistically insignificant in the case of all reactions studied. For this reason the term polarizability in all relationships considered was omitted.

In order to guarantee the investigation of substituted phenyl inductive effects depending on the solvent parameters only the $\Delta \log k^{X}_{js}$ or ΔpK^{X}_{js} values for meta-substituted derivatives as well as para-substituted derivatives with substituents not able for direct resonance conjugation with the reacting center were subjected to multilinear regression analysis following relationships (14), (15) and

(16).

According to equation (14) were treated the ΔpK_a values for acidic dissociation of benzoic acids, phenols, anilinium ions and pyridinium ions; according to equations (15) and (16) were treated the ΔpK_a values for acidic dissociation of benzoic acids, phenols, anilinium ions as well as the $\Delta \log k$ values for alkaline hydrolysis of ethyl benzoates, phenyl acetates, phenyl tosylates, phenyldimethyl thiophosphinates and for solvalysis of benzyl chlorides.

According to equations (17) and (18) the $\Delta\rho^{\circ}_{js}$ values were treated in two different ways. Common data treatment involved both the $\Delta\rho^{\circ}_{js}$ values for various reaction series separately (see Ref. 1) and the mean values of $\Delta\bar{\rho}^{\circ}_{s}$ (i.e. $\sum_{j=1}^{n} \Delta\rho^{\circ}_{js}/n$ *).

Water was chosen as standard medium (s=o) (i.e. $\rho^{\circ}_{jo} = \rho^{\circ}_{j(H_2O)}$).

In correlations of the $\Delta\rho^{\circ}$ values 58 different solvents were embraced.

The following solvents, besides water, were embraced: methanol, ethanol, 1- and 2- propanol, methyl-2-propanol, butanol, nitromethane, acetonitrile, dimethyl sulfoxide (DMSO), N,N-dimethylformanide (DMFA) and binary mixtures of water with methanol, ethanol, dioxane and acetone.

In the ΔpK^{x}_{js} values treatment according to equation (14) the data set did not include the ΔpK_a values either for methyl-2-propanol or binary mixtures of water with methanol and ethanol containing alcohol more than 60 mole per cent.

When the $\Delta \log k^{x}_{js}$ values for alkaline hydrolysis of ethyl benzoates and solvolysis of benzyl chlorides were treated according to equations (15) and (16) the data set included also the $\Delta \lg k^{x}_{js}$ values for binary mixtures of water with DMSO.

The lists of solvents used in the case of concrete

* n denotes the number of averaged values

reaction series, are given in Appendix.
References to the source of data are given in paper[8].

If the disagreements between the data sets of different authors were significant, the multiple regression analysis involved the data sets for which the relationship $\rho^{o}_{js} - \rho^{o}_{jo} = \text{const}$ (see Refs. 1,8) holds better. References to the source of the concrete data set are given in Appendix.

As $\log k^{o}_{js}$ or pK^{o}_{js} values, principally the experimental values of logk or pK for the unsubstituted derivative ($X=C_6H_5$) were used. The calculated $\log k^{o}$(pK^{o}) values were used: a) if the corresponding $\log k^{o}$ or pK^{o} value is lacking; b) if the difference between the experimental and calculated $\log k^{o}$ (or pK^{o}) values exceeds 0.15 log units. The numerical values of the corresponding calculated values are given in Appendix.

The statistical data processing was carried out on a "Nairi-2" computer using specially prepared program of multiple regression analysis, composed by V. Palm*.
The data treatment was carried out in two different ways:

1) exclusion of insignificant argument scales was carried out before excluding (according to Student) considerably deviating points;

2) exclusion of significantly deviating points was carried out before excluding insignificant argument scales.

In order to check the stability of the obtained statistical results, the calculations were performed consecutively on three different confidence levels (0.99, 0.97 and 0.95) for excluding the significantly deviating points.

The exclusion of argument scales according to Fischer's test on the confidence level of 0.95 was performed.

When calculating, the "recommended" values of σ^{o} and the values of E and B from publications[3-5,9] were used.

The values of electrophilicity parameters E for binary mixtures of water with DMSO were calculated using the $\Delta\rho^{o}_{s}$

* Detailed description of the algorithm of this program will be published elsewhere.

values for acidic dissociation of benzoic acids in H_2O-DMSO mixtures according to the equation

$$\Delta\rho_s^o = \rho_s^o - \rho_{H_2O}^o = -0.0842\,(E_s - E_{H_2O}),$$

where as $\Delta\rho_s^o$ we used the mean values of $\Delta\rho_s^o$ for all reaction series considered:

$$(\Delta\bar{\rho}_s^o = \sum_{j=1}^{n}\Delta\rho_{js}^o/n\ )\quad (\text{see Table 5}).$$

When calculating, the values of dielectric permittivity ε at 25°C from the I. Timmermans Tables[6] were used.

The results of the statistical ΔpK or Δlogk values treatment for various reaction series according to relationships (14), (15) and (16) are listed in Tables 1-4, as well as the characteristics of the $\Delta\rho_{js}^o$ values processing according to relations (17) and (18) are listed in Tables 5 and 6.

Tables 1, 3 and 5 lists the values of $\Delta\rho_{jo}^o$, C_{XE}, C_{XY} and C_{XEY} and the corresponding standard errors.

In column n/n_o the denominator reflects the total number of various substituent-solvent combinations involved in multiregression data processing, and the numerator equals the number of remaining points after excluding significantly deviating points on the confidence level (t).

In column n^s/n_o^s the denominator and the numerator reflects the same values for solvents embraced.

In the column "Notes" the characteristics of solvents embraced as well as numbers corresponding to solvent sets listed in Appendix, are given. Appendix also presents solvents excluded from the corresponding solvent set as a result of data processing.

The abbreviations given in Tables[10] stand for the solvents used.

Tables 2, 4 and 6 columns $(\rho_{jo}^o)_o$, $(C_{XE})_o$, $(C_{XY})_o$ and $(C_{XEY})_o$ list the corresponding values,

normalised in units of square root from dispersion.*

By s_o and s the standard erros in normalized and natural scales are denoted.**

The results of the $\Delta \log k^x_{js}$ (ΔpK^x_{js}) and $\Delta\rho^o_{js}$ values treatment according to equations (15)-(18) show, that the main factor responsible for dependence of substituent effects on medium is electrophilicity (general acidity) of solvent.

The influence of the solvent basicity (nucleophilicity) on the ΔpK values was found to be statistically insignificant. Such a consclusion was made on the basis of processing data only for individual solvents as much as the B values for binary mixtures with water in literature are missing.

When treating the ΔpKa values for acidic dissociation of benzoic acids and phenols as well as the $\Delta\rho^o_{js}$ values the coefficient C_{XY} responsible for the influence of the solvent polarity $\left(\frac{1}{\varepsilon_s} - \frac{1}{\varepsilon_{H_2O}}\right)$ was found to be significant, too.

However, in comparison with electrophilicity the reltive contribution of this factor does not exceed 25% (see the $(C_{XE})_o$ and $(C_{XY})_o$ values in Tables 4 and 6). Significance of this factor could be dependent on a solvent set considered. The contribution of polarity exceeds the level of "noises", if the diapason of variation of $\frac{1}{\varepsilon_s}$ values for a solvent set considered is great enough . In the case of dipolar aprotic solvents and binary mixtures with not high composition of organic component such a diapason is negligible, involving insignificance of polarity contribution.

The C_{XE} value, reflecting the susceptibility of substituent effect to solvent electrophilicity, varies in the

* For example, $(\rho^o_{jo})_o = \frac{\delta(\Delta pK^x_{js})}{\delta(\delta^o_x)}$ where δ denotes the square root from dispersion of quantity , shown in brackets i.e. mean square halfdiapasons of this quantity.

** $s_o = s/\delta$ where δ^2 denote dispersion of the correlated quantity.

range 0.05-0.1 depending to some extent on the solvent set considered as well as on the relationship according to which the data treatment was carried out. However, as is seen, in the data processing according to the same relationship, the numerical value for C_{XE} in the case of different reaction series varies in relatively narrow limits (the average value of C_{XE} = 0.07-0.08). A lower value C_{XE} (0.05 - 0.07) is characteristic of acidic dissociation of anilinium ions.

The value of C_{XY} for acidic dissociation of benzoic acids, phenols and anilinium ions is equal to 11.00 ± 0.44, 15.1 ± 2.2 and 5.65 ± 1.41 (on the confidence level t=0.95) and for the correlation of $\Delta\rho^{o}_{js}$ values is $C_{XY} \approx 7$ (see Table 5). This value could be considered as the averaged value of C_{XY} for various reaction series.

Proceeding from the above the observance of the relationship[1] $\rho^{o}_{js} - \rho^{o}_{jo}$ = const for the various reaction series is mainly caused by the constant influence of solvent electrophlicity on the substituent effect. The constant influence of solvent polarity is considerably less important.

It should be emphasized that the reaction series for which $\rho^{o}_{js} - \rho^{o}_{jo}$ = const or C_{XE} = const is observed also includes the solvolysis of benzyl (cumyl) chlorides for which the influence of substituents is opposite in sign by comparison with the other reaction series embraced ($\rho^{o} < 0$, e.i. the electronegative substituents retard the rate of reaction).

If in the case of all other reaction series when passing from water to any other solvent which has low electrophilicity, the ρ^{o} values will increase, then in the case of solvolysis of benzyl chlorides (and cumyl chlorides) the absolute ρ^{o} value decreases. Thus, when passing to medium having E = 0, the ρ^{o} value for solvolysis of benzyl chlorides becomes equal to zero, but at the same time the influence of medium on the ρ^{o} values was found to be the same (C_{XE} = -0.0781) as in the case of all other reactions considered.

From the significance and sign of the C_{XY} parameter it could be concluded that for inert nonpolar solvents having electrophilicity E = 0 and low dielectric permittivity, the ρ^o value would be considerably less than in the case of water and sometimes does not differ from zero.

Consequently, the dependence of the substituent effect on solvent polarity found in the present work is by its sign opposite to the one represented in a publication[2] found when the data for individual solvents and the gaseous phase were embraced.

It follows that the parameters characterizing the influence of medium on the substituent effect found only on the basis of data for the liquid phase, are qualitatively inapplicable to extrapolation with the view of describing the substituent effects in the gaseous phase.

Equations (15) and (17) are inapplicable in the case of data for t-BuOH. In the data treatment of the pK values for benzoic acids and phenols according to equation (15), as well as the ρ^o values according to equation (17), all points for t-BuOH were excluded.

The ΔpK or ρ^o values could be described by equations (16) and (18) as well. In such data treatment the ΔpK values for t-BuOH were not excluded.

It should be noted that despite the fact that all the points for t-BuOH were excluded in data processing by equations (15 and (17), the relationship $\rho^o_{js} - \rho^o_{jo} = const$[1] was found applicable to t-BuOH as well.

The results of the $\Delta\rho^o_{js}$ treatment according to equation (17)(Table 5) could be used for the evaluation of the medium electrophilicity values (E), if such parameters in literature are missing. For example, it follows from these results, that additions to water salts like NaCl and $NaClO_4$ increase medium electrophilicity since the ρ^o values were found lower than in water[1,19]. At the same time, when passing from water to aqueous 7.75 m tetra-n--butylammonium bromide solution the ρ^o value increases about a unit[1,20]. Consequently, by effective electro -

Table 1

Correlation of ΔpK Values According to Equation (14):

$$\Delta pK^{x}_{js} = pK^{x}_{js} - pK^{o}_{js} = \rho^{o}_{jo}\delta^{o}_{x} + C_{XE}\delta^{o}_{x}E_{s} + C_{XB}\delta^{o}_{x}B_{s}$$ *

No	t	ρ^{o}_{jo}	$C_{XE}.10^{2}$	n/n_o	n^s/n^s_o	Notes **
		Acidic dissociation of m- and p- substituted benzoic acids, 25°C				
1.	0.99	-2.68±0.08	8.26±0.30	68/69	10/10	Individual solvents,
2.	0.97	-2.69±0.04	8.25±0.30	56/69	10/10	see set 1
3.	0.99	-2.09±0.03	5.13±0.21	184/213	29/30	Individual solvents and binary
4.	0.97	-2.10±0.03	5.25±0.18	169/213	28/30	mixtures, see set 2. $MeNO_2$ and DMSO were excluded
5.	0.99	-2.28±0.03	6.06±0.22	118/146	21/23	Individual solvents and binary mixtures, except binary mixtures of H_2O with dioxane. $MeNO_2$ and DMSO were excluded.
		Acidic dissociation of m- and p- substituted phenols, 25°C				
6.	0.99	-4.23±0.11	9.11±0.71	57/60	7/7	Individual solvents, see set 3
7.	0.97	-4.27±0.10	9.14±0.67	53/60	7/7	
8.	0.95	-4.19±0.09	8.55±0.54	46/60	7/7	
9.	0.99	-4.16±0.09	9.11±0.60	124/129	15/15	Individual solvents and binary
10.	0.97	-4.12±0.09	8.76±0.54	114/129	15/15	mixtures, see set 4
11.	0.95	-3.95±0.09	7.79±0.51	102/129	15/15	

Table 1 continued

No	r	ρ^{o}_{jo}	$C_{XE}.10^{2}$	n/n_o	n^s/n^s_o	Notes
		Acidic dissociation of m- substituted anilinium ions, 25°C				
12.	0.99	-4.10 ± 0.08	5.24 ± 0.41	34/36	6/6	Individual solvents, see set 5.
13.	0.97	-4.21 ± 0.07	5.56 ± 0.44	32/36	6/6	
14.	0.99	-4.11 ± 0.08	5.21 ± 0.51	49/51	13/13	Individual and binary mixtures, see set 6
15.	0.97	-4.19 ± 0.07	5.56 ± 0.44	46/51	13/13	
		Acidic dissociation of 3- substituted pyridinium ions, 25°C				
16.	0.99	-7.64 ± 0.25	8.70 ± 1.61	9/10	2/2	H_2O, $MeNO_2$

* In the case of all correlations considered the $C_{XB}\delta^{o}_{x}B_{s}$ term was excluded i.e. $C_{XB}=0$.

Table 2

Correlation of ΔpK Values According to Equation (14)*

$$\Delta pK^{X}_{js} = pK^{X}_{jn} - pK^{o}_{js} = (\rho^{o}_{jo})_o(\delta^{o}_{x})_o + (C_{XE})_o(\delta^{o}_{x}E_s)_o + (C_{XB})_o(\delta^{o}_{x}B_s)_o \quad **$$

No	t	$(\rho^{o}_{jo})_o$	$(C_{XE})_o$	s_o	s	Notes
			Acidic dissociation of m- and p- substituted benzoic acids, 25°C			
1.	0.99	-1.26 ± 0.03	0.662 ± 0.036	0.227	0.181	Individual solvents
2.	0.97	-1.31 ± 0.02	0.698 ± 0.025	0.139	0.110	Individual solvents
3.	0.99	-1.48 ± 0.02	0.605 ± 0.024	0.156	0.067	Individual solvents and binary mixtures
4.	0.97	-1.50 ± 0.02	0.633 ± 0.021	0.130	0.055	Individual solvents and binary mixtures
5.	0.99	-1.60 ± 0.02	0.759 ± 0.027	0.138	0.063	Individual solvents and binary mixtures except binary mixtures of H_2O with dioxane
			Acidic dissociation of m- and p- substituted phenols, 25°C			
6.	0.99	-1.34 ± 0.04	0.506 ± 0.042	0.212	0.242	Individual solvents
7.	0.97	-1.34 ± 0.03	0.504 ± 0.036	0.182	0.207	Individual solvents
8.	0.95	-1.34 ± 0.03	0.490 ± 0.032	0.143	0.161	Individual solvents
9.	0.99	-1.39 ± 0.03	0.510 ± 0.034	0.211	0.203	Individual solvents and binary mixtures
10.	0.97	-1.37 ± 0.03	0.494 ± 0.031	0.181	0.171	Individual solvents and binary mixtures
11.	0.95	-1.42 ± 0.03	0.510 ± 0.036	0.168	0.141	Individual solvents and binary mixtures

Table 2 continued

No	t	$(\rho^{o}_{jo})_o$	$(C_{XE})_o$	s_o	s	Notes
			Acidic dissociation of m- substituted anilinium ions, 25°C			
12.	0.99	-1.22±0.02	0.313±0.027	0.109	0.100	Individual solvents
13.	0.97	-1.26±0.02	0.353±0.023	0.086	0.080	
14.	0.99	-1.19±0.02	0.268±0.026	0.107	0.116	Individual solvents and binary mixtures
15.	0.97	-1.23±0.02	0.295±0.023	0.090	0.096	
			Acidic dissociation of 3-substituted pyridinium ions, 25°C			
16.	0.99	-1.15±0.04	0.224±0.041	0.074	0,152	H_2O, $MeNO_2$

* $(\rho^{o}_{jo})_o$, $(\sigma^{o}_{x})_o$, $(C_{XE})_o$, $(E_s)_o$, $(C_{XB})_o$ and $(B_s)_o$ - the normalised values for the corresponding constants.

** In the case of all correlations considered the $C_{XB}\sigma^{o}_{x} B_s$ term was included, i.e. $C_{XB}=0$

Table 3

Correlation of $\Delta lgk(\Delta pk)$ According to Equations (15) and (16)[x] :

$$\Delta lgk^{x}_{js}(\Delta pK^{x}_{js}) = lgk^{x}_{js}(pK^{x}_{js}) - lgk^{o}_{js}(pK^{o}_{js}) = (const) + \rho^{o}_{jo}\delta^{o}_{x} + C_{XE}\delta^{o}_{x}E_{s} + C_{XY}\delta^{o}_{x}\Delta Y_{s}$$

$$\Delta lgk^{x}_{js}(\Delta pK^{x}_{js}) = (const) + \rho^{o}_{jo}\delta^{o}_{x} + C_{XE}\delta^{o}_{x}E_{s} + C_{XY}\delta^{o}_{x}\Delta Y_{s} + C_{XEY}\delta^{o}_{x}E_{s}\Delta Y_{s}$$

No	Eq[xx]	t[xxx]	ρ^{o}_{jo}	$C_{XE}\cdot 10^{2}$	C_{XY}	C_{XEY}	n/n_{o}	n^{s}/n^{s}_{o}	Notes[xxxx]
			Acidic dissociation of m- and p-substituted benzoic acids, 25°C						
1.	15	0.99	−2.15 ±0.04	5.43 ±0.24	0	-	209/245	35/39	Individual solvents and binary mixtures, see set 7
2.		0.97	−2.10 ±0.03	5.22 ±0.22	0	-	191/245	33/39	
3.		0.95	−2.09 ±0.02	5.21 ±0.15	0	-	151/245	31/39	
4.	15A	0.99	−2.84 ±0.05	9.00 ±0.27	8.70 ±0.85	-	224/245	38/39	
5.		0.97	−2.86 ±0.04	9.11 ±0.21	9.41 ±0.67	-	199/245	36/39	
6.		0.95	−2.91 ±0.02	9.32 ±0.14	10.00 ±0.44	-	150/245	34/39	
7.	16	0.99	−2.64 ±0.05	7.58 ±0.30	−23.3 ±1.9	2.63 ±0.19	216/233	37/37	
8.		0.97	−2.70 ±0.04	8.04 ±0.22	−25.9 ±1.3	2.90 ±0.13	183/233	36/37	
9.	16A	0.99	−2.64 ±0.05	7.58 ±0.30	−23.3 ±1.9	2.63 ±0.19	216/233	37/37	

Table 3 continued:

No	Eq.**	t***	ρ^{o}_{jo}	$C_{XE} \cdot 10^2$	C_{XY}	C_{XEY}	n/n_o	n^s/n^s_o	Notes****
			Acidic dissociation of m- and p-substituted phenols, 25°C						
10.	15	0.99	−3.62 ±0.10	6.69 ±0.64	0	-	164/178	21/22	Individual solvents and binary mixtures, see set 8
11.		0.97	−3.64 ±0.10	6.87 ±0.60	0	-	158/178	21/22	
12.		0.95	−3.54 ±0.08	6.87 ±0.46	0	-	131/178	21/22	
13.	15A	0.99	−4.42 ±0.12	10.4 ±0.64	14.2 ±2.5	-	165/178	21/22	
14.		0.97	−4.45 ±0.10	10.5 ±0.61	15.9 ±2.5	-	161/178	21/22	
15.		0.95	−4.53 ±0.10	10.6 ±0.53	15.1 ±2.2	-	144/178	21/22	
16.	16	0.99	−4.20 ±0.10	8.82 ±0.60	−44.4 ±3.2	5.28 ±0.44	169/178	22/22	
17.		0.97	−4.02 ±0.09	8.00 ±0.48	−46.4 ±2.4	5.35 ±0.34	145/178	22/22	
18.		0.95	−4.00 ±0.09	8.01 ±0.40	−44.7 ±1.9	4.90 ±0.28	124/178	22/22	
19.	16A	0.99	−4.20 ±0.10	8.82 ±0.61	−44.4 ±3.2	5.28 ±0.44	169/178	22/22	
			Acidic dissociation of m-substituted anilinium ions, 25°C						
20.	15	0.99	−4.14 ±0.10	5.10 ±0.60	0	-	59/62	14/14	Individual solvents and binary mixtures, see set 9
21.		0.97	−4.21 ±0.07	5.87 ±0.48	0	-	50/62	13/14	
22.		0.95	−4.23 ±0.07	5.97 ±0.34	0	-	44/62	12/14	

Table 3 continued

No	Eq.**	t***	ρ^{o}_{jo}	$C_{XE} \cdot 10^2$	C_{XY}	C_{XEY}	n/n_o	n^s/n^s_o	Notes****
23.	15A	0.99	−4.15 ±0.10	5.15 ±0.62	0	-	60/62	14/14	
24	15A	0.99	−4.40 ±0.15	6.71 ±0.83	32.6 ±12.6	−2.72 ±1.02	58/62	14/14	
25.		0.95	−4.30 ±0.08	6.24 ±0.40	3.58 ±1.85	0	45/62	13/14	
26.	15	0.99	−4.31 ±0.07	6.04 ±0.46	0	-	76/83	24/24	Individual solvents and binary mixtures,
27.		0.97	−4.32 ±0.06	6.16 ±0.38	0	-	70/83	23/24	including binary mixtures H_2O-DMSO,
28.		0.95	−4.32 ±0.05	6.25 ±0.31	0	-	62/83	23/24	see set 10[2]
29.	15A	0.99	−4.37 ±0.09	6.17 ±0.51	4.14 ±2.41	-	77/83	24/24	
30.		0.97	−4.40 ±0.07	6.51 ±0.41	5.40 ±1.91	-	71/83	24/24	
31.		0.95	−4.39 ±0.05	6.50 ±0.31	5.65 ±0.31	- ±1.43	61/83	23/24	
32.	16	0.99	−4.31 ±0.07	6.04 ±0.46	0	0	76/83	24/24	
			Alkaline hydrolysis of m- and p-substituted ethyl benzoates, 25°C						
33.	15	0.99	3.52 ±0.16	−9.19 ±1.09	0	-	40/40	14/14	H_2O and binary mixtures, see set 11
34.		0.97	3.62 ±0.14	−9.71 ±0.93	0	-	38/40	14/14	
35.		0.95	3.58 ±0.13	−9.52 ±0.87	0	-	37/40	14/14	

Table 3 continued

No	Eq**	t***	ρ^{o}_{jo}	$C_{XE}.10^{2}$	C_{XY}	C_{XEY}	n/n_o	n^s/n^s_o	Notes****
36.	15A	0.99	3.52 ±0.16	-9.19 ±1.09	0	-	40/40	14/14	
37.	16	0.99	3.52 ±0.16	-9.19 ±1.09	0	0	40/40	14/14	
38.	16A	0.99	3.52 ±0.16	-9.19 ±1.09	0	0	40/40	14/14	
			Alkaline hydrolysis of m- and p-substituted phenyl acetates, 25°C						
39.	15	0.99	2.52 ±0.13	-7.22 ±0.85	0	-	31/32	7/7	H_2O and binary mixtures, see
40.		0.97	2.46 ±0.10	-6.83 ±0.64	0	-	29/32	7/7	set 12
41.	15A	0.99	2.52 ±0.13	-7.22 ±0.85	0	-	31/32	7/7	
			Alkaline hydrolysis of m- and p-substituted phenyl tosylates, 60°C						
42.	15	0.99	3.39 ±0.14	-7.32 ±0.79	0	-	25/25	4/4	H_2O and binary mixtures, see
43.	15A	0.99	3.39 ±0.14	-7.32 ±0.79	0	-	25/25	4/4	set 13.
			Alkaline hydrolysis of m- and p-substituted phenyldimethylthiophosphinates, 25°C						
44.	15	0.99	3.17 ±0.30	-8.51 ±1.81	0	-	9/9	3/3	H_2O, H_2O-EtOH(23.6), H_2O-EtOH(73.8).

Table 3 continued

No	Eq*	t**	ρ^{o}_{ij}	$C_{XE} \cdot 10^2$	C_{XY}	C_{XEY}	n/n_o	n^s/n^s_o	Notes***
				Solvolysis of m- and p-substituted benzyl chlorides, 60°C					
45.	15	0.99	0	-7.81 ± 0.57	0	-	26/27	7/7	H_2O and binary mixtures, see set 14
46.	15A	0.99	0	-7.81 ± 0.57	0	-	26/27	7/7	
47.	16	0.99	0	-7.81 ± 0.57	0	0	26/27	7/7	
48.	16A	0.99	0	-7.81 ± 0.57	0	0	26/27	7/7	

* In the case of all correlations the term (const) in equations (15) and (16) does not differ from zero.

** Letter "A" added to the number of the equation (for example 15A) means that the exclusion of significantly deviating points occurs before the exclusion of insignificant argument scales. In all other cases the data treatment procedure is carried out in the opposite way.

*** If with a decrease in the confidence level the correlation parameters are equal to the above-listed, then such parameters were not repeated in Tables

**** The corresponding solvent sets are listed in Appendix.

Table 4

Correlation of $\Delta lgk(\Delta pK)$ Values According to Equation (15) and (16)*

$$\Delta lgk^{X}_{js}(\Delta pK^{X}_{js}) = lgk^{X}_{js}(pK^{X}_{js}) - lgk^{o}_{js}(pK^{o}_{js}) = (const) + (\rho^{o}_{jo})_o(\delta^{o}_{x})_o + (C_{XE})_o(\delta^{o}_{x}E_s)_o + (C_{XY})_o(\delta^{o}_{x}\Delta Y_s)_o$$

$$\Delta lgk^{X}_{js}(\Delta pK^{X}_{js}) = (const) + (\rho^{o}_{jo})_o(\delta^{o}_{x})_o + (X_{XE})_o(\delta^{o}_{x}E_s)_o + (C_{XY})_o(\delta^{o}_{x}\Delta Y_s)_o + (C_{XEY})_o(\delta^{o}_{x})(E_s\Delta Y_s)_o$$

No	Eq.	t	$(\rho^{o}_{jo})_o$	$(C_{XE})_o$	$(C_{XY})_o$	$(C_{XEY})_o$	s^o	s	Notes
			Acidic dissociation of m- and p-substituted benzoic acids, 25°C						
1.	15	0.99	-1.45 ± 0.02	$+0.583 \pm 0.026$	0	-	0.176	0.081	
2.		0.97	-1.47 ± 0.02	$+0.600 \pm 0.023$	0	-	0.147	0.064	
3.		0.95	-1.54 ± 0.02	$+0.667 \pm 0.019$	0	-	0.106	0.043	
4.	15A	0.99	-1.63 ± 0.03	$+0.787 \pm 0.023$	$+0.162 \pm 0.016$	-	0.169	0.095	
5.		0.97	-1.67 ± 0.02	$+0.832 \pm 0.019$	$+0.177 \pm 0.012$	-	0.130	0.071	
6.		0.95	-1.62 ± 0.01	$+0.783 \pm 0.011$	$+0.185 \pm 0.008$	-	0.076	0.044	
7.	16	0.99	-1.34 ± 0.02	$+0.569 \pm 0.023$	-0.400 ± 0.032	$+0.407 \pm 0.029$	0.165	0.109	
8.		0.97	-1.41 ± 0.02	$+0.647 \pm 0.018$	-0.455 ± 0.022	$+0.446 \pm 0.021$	0.113	0.072	
9.	16A	0.99	-1.34 ± 0.02	$+0.569 \pm 0.023$	-0.400 ± 0.032	$+0.407 \pm 0.029$	0.165	0.109	

Table 4 continued

No	Eq.	t	$(\rho^{o}_{jo})_o$	$(C_{XE})_o$	$(C_{XY})_o$	$(C_{XEY})_o$	s^o	s	Notes
			Acidic dissociation of m- and p-substituted phenols, 25°C						
10.	15	0.99	-1.31 ±0.04	0.394 ±0.038	0	-	0.226	0.194	
11.		0.97	-1.32 ±0.04	0.406 ±0.035	0	-	0.208	0.179	
12.		0.95	-1.31 ±0.03	0.385 ±0.029	0	-	0.154	0.127	
13.	15A	0.99	-1.49 ±0.04	0.548 ±0.034	0.127 ±0.022	-	0.199	0.190	
14.		0.97	-1.50 ±0.04	0.560 ±0.033	0.136 ±0.021				
15.		0.95	-1.49 ±0.03	0.558 ±0.028	0.125 ±0.018	-	0.154	0.149	
16.	16	0.99	-1.20 ±0.03	0.380 ±0.026	-0.485 ±0.034	0.403 ±0.033	0.164	0.187	
17.		0.97	-1.17 ±0.03	0.365 ±0.022	-0.562 ±0.029	0.440 ±0.028	0.124	0.135	
18.		0.95	-1.15 ±0.02	0.370 ±0.019	-0.555 ±0.023	0.395 ±0.022	0.092	0.101	
19.	16A	0.99	-1.20 ±0.03	0.380 ±0.026	-0.485 ±0.034	0.403 ±0.033	0.164	0.187	
			Acidic dissociation of m-substituted anilinium ions, 25°C						
20.	15	0.99	-1.21 ±0.03	0.274 ±0.032	0	-	0.150	0.139	
21.		0.97	-1.26 ±0.02	0.325 ±0.023	0	-	0.098	0.089	
22.		0.95	-1.26 ±0.02	0.337 ±0.019	0	-	0.075	0.071	

Table 4 continued

No	Eq.	t	$(\rho^{o}_{jo})_o$	$(C_{XE})_o$	$(C_{XY})_o$	$(C_{XEY})_o$	s^o	s	Notes
23.	15A	0.99	-1.19 ±0.03	0.270 ±0.033	0	-	0.153	0.145	
24.	16A	0.99	-1.28 ±0.04	0.356 ±0.044	0.250 ±0.097	-0.230 ±0.086	0.138	0.128	
25.		0.95	-1.28 ±0.04	0.348 ±0.022	0.029 ±0.015	0	0.077	0.073	
26.	15	0.99	-1.24 ±0.02	0.303 ±0.023	0	-	0.122	0.113	The data for binary mixtures of H_2O with DMSO were included as well
27.		0.97	-1.25 ±0.02	0.318 ±0.020	0	-	0.100	0.092	
28.		0.95	-1.24 ±0.01	0.322 ±0.016	0	-	0.076	0.072	
29.	15A	0.99	-1.25 ±0.03	0.314 ±0.030	0.029 ±0.017	-	0.126	0.116	
30.		0.97	-1.28 ±0.02	0.333 ±0.021	0.039 ±0.014	-	0.099	0.091	
31.		0.95	-1.27 ±0.02	0.331 ±0.016	0.040 ±0.010	-	0.069	0.067	
32.	16	0.99	-1.24 ±0.02	0.303 ±0.023	0	0	0.122	0.113	
			Alkaline hydrolysis of m- and p-substituted ethyl benzoates, 25°C						
33.	15	0.99	1.56 ±0.07	-0.623 ±0.074	0	-	0.139	0.109	
34.		0.97	1.59 ±0.06	-0.659 ±0.063	0	-	0.115	0.091	
35.		0.95	1.59 ±0.06	-0.651 ±0.060	0	-	0.109	0.087	
36.	15A	0.99	1.56	-0.623	0	-	0.139	0.109	

Table 4 continued

No	Eq.	t	$(\rho^{o}_{jo})_o$	$(C_{XE})_o$	$(C_{XY})_o$	$(C_{XEY})_o$	s^o	s	Notes
37.	16	0.99	1.56 ±0.07	−0.623 ±0.074	0	0	0.139	0.109	
38.	16A	0.99	1.56 ±0.07	−0.623 ±9.074	0	0	0.139	0.109	
			Alkaline hydrolysis of m- and p-substituted phenyl acetates, 25°C						
39.	15	0.99	1.64 ±0.09	−0.719 ±0.085	0	-	0.159	0.094	
40.		0.97	1.63 ±0.07	−0.707 ±0.067	0	-	0.122	0.070	
41.	15A	0.99	1.64 ±0.09	−0.719 ±0.085	0	-	0.159	0.094	
			Alkaline hydrolysis of m- and p-substituted phenyl tosylates, 60°C						
42.	15	0.99	1.59 ±0.06	−0.611 ±0.063	0	-	0.079	0.069	
43.	15A	0.99	1.59 ±0.06	−0.611 ±0.063	0	-	0.079	0.069	
			Alkaline hydrolysis of m- and p-substituted phenyldimethylthiophosphinates, 25°C						
44.	15	0.99	1.68 ±0.17	−0.756 ±0.170	0	-	0.155	0.119	
			Solvolysis of m- and p-substituted benzyl chlorides, 60°C						
45.	15	0.99	0	−0.941 ±0.069	0	-	0.351	0.161	

Table 4 continued

No	Eq.	t	$(\rho^{o}_{jo})_o$	$(C_{XE})_o$	$(C_{XY})_o$	$(C_{XEY})_o$	s^o	s	Notes
46.	15A	0.99	0	$\frac{-0.941}{+0.069}$	0	-	0.351	0.161	
47.	16	0.99	0	$\frac{-0.941}{+0.069}$	0	0	0.351	0.161	
48.	16A	0.99	0	$\frac{-0.941}{+0.069}$	0	0	0.351	0.161	

* See explanations of Table 3.

$(\rho^{o}_{jo})_o$, $(C_{XE})_o$, $(C_{XY})_o$, $(C_{XEY})_o$, $(\delta^{o}_{x})_o$, $(E_s)_o$ and $(\Delta Y_s)_o$ the normalized values of the corresponding constants.

Table 5

Correlation of $\Delta\rho^{o}$ Values According to Equations (17) and (18)[*]

$$\Delta\rho^{o}_{js} = \rho^{o}_{js} - \rho^{o}_{j(H_2O)} = (\text{const}) + C_{XE}(E_s - E_{H_2O}) + C_{XY}\Delta Y_s$$

$$\Delta\rho^{o}_{js} = (\text{const}) + C_{XE}(E_s - E_{H_2O}) + C_{XY}\Delta Y_s + C_{XEY}(E_s - E_{H_2O})\Delta Y_s$$

No	Eq.	t	$C_{XE} \cdot 10^2$	C_{XY}	C_{XEY}	n/no	Notes[**]
1.	17	0.99	-8.09 ± 0.50	0	-	128/132	The $\Delta\rho^{o}_{js}$ values of various reaction series were used separately. Individual solvents and binary mixtures, see set 15
2.		0.97	-8.56 ± 0.47	0	-	123/132	
3.		0.95	-8.56 ± 0.43	0	-	115/132	
4.	17A	0.99	-9.51 ± 0.51	-7.42 ± 1.62	-	128/132	
5.		0.97	-9.63 ± 0.52	-7.85 ± 1.56	-	124/132	
6.		0.95	-9.68 ± 0.47	-6.53 ± 1.47		116/132	
7.	18	0.99	-6.09 ± 0.73	-36.6 ± 5.75	-3.11 ± 0.39	132/132	
8.		0.97	-10.7 ± 0.58	0	0.812 ± 0.142	126/132	
9.		0.95	-10.5 ± 0.53	0	0.728 ± 0.127	117/132	
10.	18A	0.99	-6.09 ± 0.73	-36.6 ± 5.45	-3.11 ± 0.39	132/132	
11.	17	0.99	-8.06 ± 0.59	0	-	57/58	$\Delta\bar{\rho}^{o}_{s} = \sum_{j=1}^{n} \Delta\rho^{o}_{js}/n$

Table 5 continued

No	Eq.	t	$C_{XE} \cdot 10^2$	C_{XY}	C_{XEY}	n/n_o	Notes
12.		0.97	-8.25 ± 0.58	0	-	56/58	
13.		0.95	-8.42 ± 0.56	0	-	55/58	
14.	17A	0.99	-9.36 ± 0.64	-7.15 ± 1.92	-	57/58	
15.		0.97	-9.38 ± 0.61	-7.54 ± 1.84	-	56/58	
16.		0.95	-8.72 ± 0.34	-7.17 ± 0.94	-	38/58	
17.	18	0.99	-10.0 ± 0.70	0	0.706 ± 0.170	57/58	
18.		0.97	-10.0 ± 0.67	0	0.725 ± 0.163	56/58	
19.		0.95					
20.	18A	0.99	-10.0 ± 0.69	0	0.706 ± 0.170	57/58	

* In the case of all correlations considered the term "const" in equations (17) and (18) does not differ from zero. See explanations of Table 3.

* The corresponding solvent set is listed in Appendix.

Table 6

Correlation of $\Delta\rho^{o}$ Values According to Equations (17) and (18)[x]:

$$\Delta\rho^{o}_{js} = \rho^{o}_{js} - \rho^{o}_{j(H_2O)} = (\text{const}) + (C_{XE})_o\,(E_s - E_{H_2O})_o + (C_{XY})_o\,(\Delta Y_s)_o$$

$$\Delta\rho^{o}_{js} = (\text{const}) + (C_{XE})_o (E_s - E_{H_2O})_o + (C_{XY})_o\,(\Delta Y_s)_o + (C_{XEY})_o \left[(E_s - E_{H_2O})\,\Delta Y_s\right]_o$$

No	Eq.	t	$(C_{XE})_o$	$(C_{XY})_o$	$(C_{XEY})_o$	s_o	s	Notes
1.	17	0.99	-0.823±0.051	0	-	0.573	0.206	The $\Delta\rho^{o}_{js}$ values of various reaction series separately were used.
2.		0.97	-0.855±0.047	0	-	0.522	0.190	
3.		0.95	-0.881±0.044	0	-	0.477	0.170	
4.	17A	0.99	-0.930±0.050	-0.231±0.050	-	0.517	0.193	
5.		0.97	-0.954±0.051	-0.259±0.051	-	0.508	0.181	
6.		0.95	-0.970±0.047	-0.210±0.047	-	0.453	0.164	
7.	18	0.99	-0.481±0.058	-1.11 ±0.16	-1.43±0.18	0.496	0.241	
8.		0.97	-1.04 ±0.056	0	0.323±0.056	0.495	0.183	
9.		0.95	-1.06 ±0.053	0	0.305±0.053	0.448	0.162	
10.	18A	0.99	-0.481±0.058	-1.11 ±0.16	-1.43 ±0.18	0.496	0.241	$\Delta\bar{\rho}^{o}_{s} = \sum_{j=1}^{n} \Delta\rho^{o}_{js}/n$
11.	17	0.99	-0.878±0.064	0	-	0.487	0.163	
12.		0.97	-0.890±0.062	0	-	0.465	0.157	
13.		0.95	-0.899±0.060	0	-	0.446	0.152	
14.	17A	0.99	-1.02 ±0.069	-0.259±0.069	-	0.438	0.147	

Table 6 continued

No	Eq.	t	$(C_{XE})_o$	$(C_{XY})_o$	$(C_{XEY})_o$	s_o	s	Notes
15.		0.97	-1.03 ± 0.067	-0.275 ± 0.067	-	0.421	0.141	
16.		0.95	-1.15 ± 0.045	-0.344 ± 0.045	-	0.220	0.064	
17.	18	0.99	-1.09 ± 0.076	0	0.317 ± 0.076	0.427	0.143	
18.		0.97	-1.10 ± 0.074	0	0.329 ± 0.074	0.412	0.138	
19.		0.95	-1.13 ± 0.069	0	0.352 ± 0.069	0.373	0.125	
20.	18A	0.99	-1.09 ± 0.076	0	0.317 ± 0.076	0.427	0.143	

* See explanations of Tables 3, 4 and 5.

philicity such a medium is comparable with the binary mixture H_2O-DMSO(50 %)[1].

The difference between the ρ^o values for 7.75 m tetra--n-butylammonium bromide solution and the concentrated $NaClO_4$ solution is about 1.5 units. Similar, a positive deviation of the ρ^o value from relation (17) was found for t-BuOH. Evidently the significant decrease in the effective electrophilicity observed in the case of concentrated tetra--n-butylammonium bromide solution and t-BuOH as well, could be caused by one and the same factor - by the high structurization degree of both mediums considered.

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Appendix

Sequence of Solvent Sets

If references to the source of data set are not shown these were given in publication[8].

1. H_2O, MeOH, EtOH, i-PrOH[11](pK^o_{calc} = 10.88), BuOH[12], $(CH_2OH)_2$, $MeNO_2$[13], MeCN, DMSO, DMFA.
2. H_2O, MeOH, EtOH, PrOH, i-PrOH[11](pK^o_{calc} = 10.88), BuOH[12], $(CH_2OH)_2$, $MeNO_2$[13], MeCN, DMSO, DMFA, H_2O-MeOH(30.9), H_2O-MeOH(47.6), H_2O-MeOH(51.0), H_2O-MeOH(57.3), H_2O-EtOH(16.3), H_2O-EtOH(17.1), H_2O-EtOH(23.6), H_2O-EtOH(27.3), H_2O-EtOH(29.8), H_2O-EtOH(51.9), H_2O-An(2.66), H_2O-An(7.57), H_2O-D(6.87), H_2O-D(12.7), H_2O-D(13.6), H_2O-D(20.0), H_2O-D(33.9), H_2O-D(36.2), H_2O-D(50.0)
3. H_2O, MeOH, EtOH, i-PrOH[11](pK^o_{calc} = 15.05), MeCN, DMSO[14], DMFA

4. H_2O, MeOH, EtOH, i-PrOH[11] (pK^o_{calc}=15.05), MeCN, DMSO[14], DMFA, H_2O-MeOH(30.9), H_2O-EtOH(7.18), H_2O-EtOH(11.7), H_2O-EtOH(16.3)(pK^o_{calc}=10.70), H_2O-EtOH(22.8), H_2O-EtOH(23.6), H_2O-EtOH(29.8)(pK^o_{calc}=11.20), H_2O-D(1.81).

5. H_2O, MeOH[15], EtOH[15], $MeNO_2$, MeCN, DMSO(pK^o_{calc}=4.00).

6. H_2O, MeOH[15], EtOH[15], $MeNO_2$, MeCN, DMSO(pK^o_{calc}=4.00), H_2O-MeOH(30.9), H_2O-EtOH(17.1), H_2O-EtOH(23.6), H_2O-D(4.86), H_2O-D(14.3), H_2O-D(32.3), H_2O-D(48.2).

7. The same solvents as in set 2 as well as t-BuOH, H_2O-MeOH(64.1), H_2O-MeOH(80.1), H_2O-MeOH(89.5), H_2O-EtOH(48.1), H_2O-EtOH(55.3), H_2O-EtOH(69.6), H_2O-EtOH(73.6), H_2O-EtOH(84.4).
   As a result of data processing all points for following solvents were excluded:
   eq.(15): t-BuOH, $MeNO_2$, MeCN, DMSO, H_2O-EtOH(73.6), H_2O-EtOH(55.3), H_2O-MeOH(80.1), H_2O-EtOH(84.4).
   eq.(15A): t-BuOH, MeCN, H_2O-EtOH(55.3), H_2O-MeOH(64.1), H_2O-EtOH(73.6).
   eq.(16A): H_2O-EtOH(55.3).

8. The same solvents as in set 4 as well as t-BuOH(pK^o_{calc}=20.84), H_2O-EtOH(69.6), H_2O-EtOH(85.5), H_2O-D(5.03), H_2O-D(12.4), H_2O-D(24.1), H_2O-D(45.9).

9. The same solvents as in set 6 as well as MeOH[16], EtOH[17], H_2O-EtOH(14.4).
   As a result of data processing all points for following solvents were excluded:
   H_2O-EtOH(23.6), H_2O-D(48.2).

10. The same solvents as in set 9 as well as H_2O-DMSO(5.88), H_2O-DMSO(9.67), H_2O-DMSO(14.0), H_2O-DMSO(19.5), H_2O-DMSO(26.7), H_2O-DMSO(35.0), H_2O-DMSO(35.5), H_2O-DMSO(48.6), H_2O-DMSO(59.4), H_2O-DMSO(70.0). As a result of data processing all points for H_2O-EtOH(23.6) were excluded.

11. H_2O, H_2O-EtOH(23.6), H_2O-EtOH(48.6), H_2O-EtOH(55.3), H_2O-EtOH(68.9), H_2O-D(8.31), H_2O-D(12.4), H_2O-D(17.5), H_2O-D(24.1), H_2O-An(10.3), H_2O-An(15.1), H_2O-An(20.9), H_2O-An(28.3), H_2O-DMSO(32.0).

12. H_2O, H_2O-EtOH(23.6), H_2O-EtOH(73.8), H_2O-D(17.5), H_2O-D(33.1), H_2O-D(45.9), H_2O-An(28.3).

13. H_2O, H_2O-EtOH(11.7), H_2O-EtOH(31.7), H_2O-EtOH(55.3).

14. H_2O, H_2O-EtOH(23.6), H_2O-An(19.7), H_2O-An(28.3), H_2O-An(63.2), H_2O-DMSO(21.0), H_2O-DMSO(32.0)

15. H_2O, H_2O-MeOH(19.1), H_2O-MeOH(27.3), H_2O-MeOH(30.9), H_2O-MeOH(43.9), H_2O-MeOH(47.6), H_2O-MeOH(51.0), H_2O-MeOH(57.3), H_2O-MeOH(62.3), H_2O-MeOH(64.1), H_2O-MeOH(80.1), MeOH, H_2O-EtOH(7.18), H_2O-EtOH(11.7), H_2O-EtOH(14.4), H_2O-EtOH(16.3), H_2O-EtOH(17.1), H_2O-EtOH(22.8), H_2O-EtOH(23.6), H_2O-EtOH(27.3), H_2O-EtOH(29.8), H_2O-EtOH(31.7), H_2O-EtOH(33.0), H_2O-EtOH(41.9), H_2O-EtOH(48.1), H_2O-EtOH(51.9), H_2O-EtOH(55.3), H_2O-EtOH(68.9), H_2O-EtOH(69.6), H_2O-EtOH(73.6), H_2O-EtOH(85.5), PrOH, i-PrOH, t-BuOH, $(HOCH_2)_2$, $MeNO_2$, MeCN, DMSO, DMFA, H_2O-D(5.03), H_2O-D(6.87), H_2O-D(12.4), H_2O-D(12.7), H_2O-D(13.6), H_2O-D(17.4), H_2O-D(20.0), H_2O-D(24.1), H_2O-D(33.9), H_2O-D(36.2), H_2O-D(45.9), H_2O-D(50.0), H_2O-An(2.66), H_2O-An(7.57), H_2O-An(10.3), H_2O-An(15.1), H_2O-An(20.9), H_2O-An(28.3)

In the case of all correlations all $\Delta\int\rho_s^o$ values for t-BuOH were excluded first of all.

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ON QUANTITATIVE INTERPRETATION OF SUBSTITUENT EFFECT ON ACID-BASE EQUILIBRIUM CONSTANTS OF BASES OF TRIARYLCARBINOL TYPE

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Analysis of the acid-base equilibrium constants for derivatives of 18 reaction series of bases of triarylcarbinol type has shown functional dependence of substitutent [p,m-CH_3, p,m-CH_3O, p,m-Cl, p,m-Br, p-NO_2, p-$(CH_3)_2N$] effects in aryl on the state of the reaction center. Measure of alteration in the substituent effects during transition from one reaction series to another has been estimated quantitatively.

Numerous studies deal with the question of quantitative estimation of effect of immediately bound to the reaction center meta- and para-substituted phenyls on position of acid-base equilibrium of bases of triarylcarbinol type ($\equiv C\text{-}OH + H^+ \rightleftharpoons \equiv C^+ + H_2O$). Papers [1,2] on acid-base transformations involving cations of 3,3-dialkyl(phenyl)-1-arylphthalylium (Alk=CH_3, C_2H_5) and their sulfide analogs (Alk=CH_3) have shown that effect of meta- and para-substituents in 1-aryl on pK_{R^+} value is described by the Brown and Okamoto electrophilic σ^+-constants within a one-parameter equation. Yet it should be noted that transition from 3,3-diphenyl-1-arylphthalylium to 3,3-dimethyl-1-arylthiophthalylium ions induces, insignificant though they are, impairment of correlation and increase in standard deviations (r 0.997 and 0.992, S 0.24 and 0.32, respectively). Subsequent increase in stability of cations (3,3-diisopropyl-1-aryl-

phthalylium [3]) results in that none of the series of the substituent constants reflects completely the effect of these substituents on pK_{R^+} (when σ^+: r 0.760; when σ : r 0.885; n 5). The limited number of experimental data for meta-substituents does not enable to apply the Yukawa and Tsuno two-parameter equation in this case.

During transition from phthalylium ions to their nitrogen analogs, 3,3-dimethyl-2-phenyl-1-arylisoindolynium ions[4], (with non-substituted aryl pK_{R^+} being increased by ~ 12 log units compared with 3,3-dimethyl-1-phenylphthalylium), the values for the acid-base equilibrium constants correlate with Hammett σ-constants (r 0.998, S 0.08, n 8). Finally, in studying hydrolysis of triarylmethane dyes with one antipyrine nucleus [5] (for non-substituted p-dimethylaminodiphenyl-antipyrilecarbonium pK_h 7.63) it was established that the effect of meta- and para-substituents in phenyl on pK_h is described by the Yukawa and Tsuno two-parameter equation (r 0.998, R 0.70, S 0.06, n 13).

All aforesaid indicates non-additivity of the substituent effect for different reaction series of carbonium ions with the similar mechanism of molarization reaction.

To establish a functional dependence between the substituent constants and the state of the reaction center, we have analysed lgK_R values for meta- and para-substituted and non-substituted cations of 18 reaction series involving both derivatives of triarylcarbonium series and those of monocyclic and condenced five-member hetero carbonium ions with one hetero atom, which are similar in stabilization nature to the latter (scheme).

Since they have a wider range of experimental data for comparison (Table 1), the following substituents have been chosen for analysis: R^1 = p,m-CH_3, p,m-CH_3O, p,m-Cl, p,m-Br, p-NO_2, p-$(CH_3)_2N$. The values of lgK_R for derivatives with non-substituted phenyl (R^1=H) reflecting to some extent $+\delta$-charge on the central carbon atom were taken as a criterion of the state of the reaction center.

The lgK_R values show an excellent correlation with lgK_H

Table 1

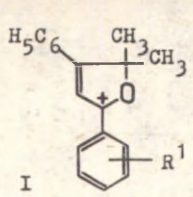
VALUES FOR ACID-BASE EQUILIBRIUM CONSTANTS FOR DERIVATIVES OF SERIES (I-XVIII)

Serial No	R^1, lgK_R										
	H	p-CH_3	m-CH_3	p-CH_3O	m-CH_3O	p-$(CH_3)_2N$	p-Cl	m-Cl	p-Br	m-Br	p-NO_2
1	2	3	4	5	6	7	8	9	10	11	12
I	-2.97 [6]	-3.73 [6]	-	-4.47 [6]	-	-	-	-	-	-	-
II	+1.77 [7]	+0.83 [7]	+1.48 [8]	-0.56 [7]	+2.12 [9]	-4.94 [2]	+2.18 [10]	+2.96 [11]	+2.37 [12]	+2.98 [12]	-
III	+0.94 [13]	-0.05 [13]	+0.79 [13]	-1.38 [14]	+1.45 [14]	-5.66 [15]	+1.59 [14]	+2.30 [14]	+1.76 [14]	+2.41 [14]	-
IV	-0.71 [3]	-1.64 [3]	-0.96 [3]	-	-	-	-	-	-	-	-
V	+3.74 [16]	+2.74 [1]	+3.21 [1]	+1.06 [1]	-	-2.98 [15]	+4.12 [1]	-	-	-	-
VI	+0.72 [17]	-0.22 [18]	+0.41 [18]	-1.22 [18]	+0.74 [2]	-5.42 [2]	+1.24 [18]	+1.63 [2]	+1.34 [18]	+1.81 [2]	-
VII	-10.35 [4]	-10.83 [4]	-10.53 [4]	-11.30 [4]	-10.01 [4]	-12.70 [4]	-9.60 [4]	-9.24 [4]	-	-	-
VIII	-7.30 [19]	-7.66 [19]	-7.48 [20]	-8.20 [19]	-6.72 [20]	-	-	-	-	-	-
IX	-10.85 [21]	-11.15 [21]	-	-	-	-	-	-	-	-	-
X	-8.06 [22]	-8.27 [22]	-	-	-	-	-	-	-	-	-
XI[a]	+6.63 [23]	+5.41 [23]	-	+3.40 [23]	-	-3.56 [24]	-	-	-	-	+9.15 [23]
XI[b]	+6.89 [23]	+5.67 [23]	-	+3.59 [23]	-	-	-	-	-	-	+9.76 [23]

Table 1 (continuation)

1	2	3	4	5	6	7	8	9	10	11	12
XII	-3.56[24]	-4.29[24]	-3.78[24]	-4.86[25]	-	-	-2.80[24]	-	-2.87[24]	-	-
XIII	-4.86[25]	-	-	-5.75[25]	-	-	-	-	-	-	-
XIV	-6.94[26]	-7.27[27]	-7.21[27]	-	-6.97[26]	-9.67[26]	-6.70[28]	-6.50[28]	-6.65[29]	-6.55[29]	-5.61[26]
XV	+3.40[23]	-	-	+1.24[23]	-	-4.86[25]	-	-	-	-	-
XVI	+1.24[23]	-	-	-0.82[23]	-	-5.75[25]	-	-	-	-	-
XVII[c]	-7.63 [5]	-7.87 [5]	-7.77 [5]	-8.56 [5]	-7.37 [5]	-10.36[5]	-7.27 [5]	-7.05 [5]	-7.29 [5]	-6.87 [5]	-6.11 [5]
XVII[d]	-7.46[30]	-7.75[30]	-	-	-7.22[30]	-	-	-	-	-6.69[30]	-6.05[30]
XVII[e]	-7.28[30]	-7.64[30]	-	-	-7.03[30]	-	-	-	-	-6.51[30]	-5.95[30]
XVII[f]	-7.14[30]	-7.46[30]	-	-	-6.88[30]	-	-	-	-	-6.35[30]	-6.86[30]
XVIII[g]	-6.60[31]	-7.00[32]	-6.80[32]	-7.48[32]	-6.57[33]	-10.52[34]	-6.13[31]	-5.82[35]	-6.00[32]	-5.76[35]	-4.78[31]
XVIII[h]	-6.47[36]	-6.84[36]	-	-	-	-	-	-	-5.88[36]	-	-4.77[36]
XVIII[i]	-6.41[36]	-6.78[36]	-	-	-	-	-	-	-5.85[36]	-	-4.77[36]

Note. [a] in H_2SO_4, [b] in $HClO_4$, [c] at 18 °C, [d] at 30 °C, [e] at 40 °C, [f] at 50 °C, [g] at 20°C, [h] at 40 °C, [i] at 50 °C.



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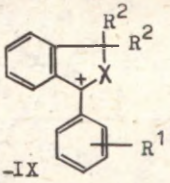
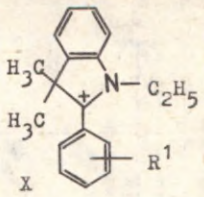


II-IX



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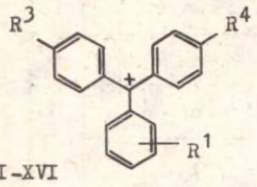
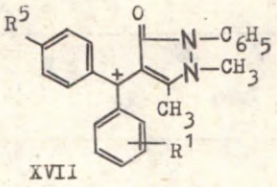
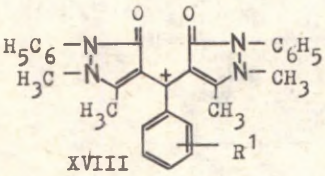


XI-XVI



XVII



XVIII

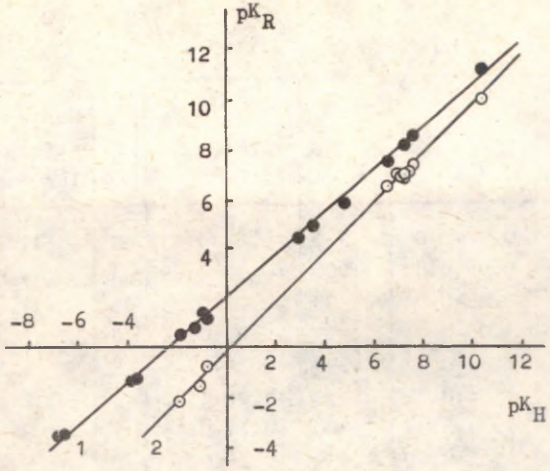
II R^2=CH_3, X=O,
III R^2=C_2H_5, X=O,
IV R^2=iso-C_3H_7, X=O,
V R^2=C_6H_5, X=O,
VI R^2=CH_3, X=S,
VII R^2=CH_3, X=N-C_6H_5,
VIII R^2=C_6H_5, X=N-C_6H_5,
IX R^2=C_6H_5, X=N-CH_3,
XI R^3=R^4=H,
XII R^3=H, R^4=p-$(CH_3)_2N$,
XIII R^3=p-CH_3O, R^4=p-$(CH_3)_2N$,
XIV R^3=R^4=p-$(CH_3)_2N$.
XV R^3=H, R^4=p-CH_3O,
XVI R^3=R^4=p-CH_3O,
XVII R^5=p-$(CH_3)_2N$.

for cations with non-substituted phenyl (s. Figure). The dependence $lgK_R = f(lgK_H)$ is of linear character and can be described by the following equation:

$$lgK_R = d \cdot lgK_H + lgK_R^o , \qquad (1)$$

where tangent of the angle of slope of the line d is a measure of change of the overall substituent effect depending on the degree of $+\delta$ -charge localization on C^1.

Parameters of Eq. (1) for different R^1 are listed in Table 2. With R^1=p-$(CH_3)_2N$, somewhat weaker correlation is accounted for by inadequacy of conditions during determina-



$pK_R = f(pK_H)$ dependence for
R^1=p-CH_3O (1) and R^1=m-CH_3O (2)

tion of pK_R. Thus, for non-substituted (R^1=H) triarylcarbonium (XI) and 1,3,3-triphenylphthalylium (V) pK_R values were determined in media with the H_R acidity function [16,23] while for substituted [R^1=p-$(CH_3)_2N$] cations aqueous [24] and organo-aqueous [15] buffer solutions were used.

As Table 2 shows, effect of such substituents as m-CH_3, m-CH_3O as well as substituents p-Cl and p-Br, which are incapable of pronounced mesomerism, does not change essentially (d≅1) during transition from one reaction series to another. Analysis of d values for substituents capable of mesomerism substantiates the hypothesis [38] that resonance effect of one or another substituent depends on not only the nature of the latter, but also on that of the reaction center. It is worth noting that the effect of electron-donating para-substituents of (+R)-type [CH_3, CH_3O and particularly $(CH_3)_2N$] depends on the value of positive charge on C^1 to a greater extent in comparison with (-R)-type substituents

Table 2

PARAMETERS OF EQUATION (1) [a]

R^1	$d \pm S_d$	r	$lgK_R^o \pm S$	n	Range of lgK_H alteration, log units
p-CH_3	0.94±0.01	1.000	-0.84±0.11	21	17.7
m-CH_3	0.99±0.01	1.000	-0.30±0.09	11	14.1
p-CH_3O	0.85±0.01	0.999	-2.01±0.25	15	17.2
m-CH_3O	1.00±0.01	0.999	+0.27±0.20	11	12.1
p-Cl	1.00±0.01	0.999	+0.49±0.19	9	14.1
m-Cl	1.04±0.02	0.999	+1.06±0.30	7	12.1
p-Br	1.03±0.01	1.000	+0.67±0.13	9	9.4
m-Br	1.06±0.02	0.999	+1.18±0.18	9	9.4
p-NO_2	1.09±0.01	1.000	+2.11±0.18	10	14.5
p-$(CH_3)_2N$	0.57±0.04	0.981	-6.27±0.67	11	17.0

Note. [a] The experimental data were processed by the least squares method.

(p-NO_2). As localized on the carbonium center $+\delta$ -charge diminishes, (+R)-effect for electron-donating and (-R)-effect for electron-accepting substituents decrease.

According to the modified Hammett equation

$$lgK_R - lgK_H = \rho \cdot \sigma^+ \qquad (2)$$

Since for standard reaction series (solvolysis of substituted cumylchlorides) $\rho \equiv 1$, after transposition of Eq.(1) in terms of Eq. (2) one obtains

$$\sigma^+ = (d-1) \cdot lgK_H + lgK_R^o \qquad (3)$$

When $lgK_H = 0$

$$\sigma^+ = lgK_R^o = \rho^o \cdot \sigma_o^+ \qquad (4)$$

The values for σ_0^+ calculated by Eq. (4) and reduced to the scale of σ^+-constants against substituents with d=1 (for hypothetical series with $lgK_H=0$ $\rho^0=4.4$) are listed in Table 3. The corresponding values for electrophilic σ^+-constants are also given in Table 3 for comparison. σ_0^+ lowered in the absolute value for some substituents as compared to σ^+ are due to unstability of (±R)-effects of these substituents during transition from the standard series of cumylchloride solvolysis to the hypothetical one ($lgK_H=0$).

Table 3

VALUES FOR σ_0^+ AND σ^+-CONSTANTS

R^1	σ_0^+	σ^+	R^1	σ_0^+	σ^+
p-CH_3	-0.19±0.02	-0.31	m-Cl	+0.24±0.07	+0.40
m-CH_3	-0.07±0.02	-0.07	p-Br	+0.15±0.03	+0.15
p-CH_3O	-0.46±0.06	-0.78	m-Br	+0.27±0.04	+0.41
m-CH_3O	+0.06±0.05	+0.05	p-NO_2	+0.48±0.04	+0.79
p-Cl	+0.11±0.04	+0.11	p-$(CH_3)_2N$	-1.43±0.15	-1.70

For bases of triarylcarbinol type, in terms of reduction of σ_d^+-constants to the scale of σ^+-constants ($1/\rho^0=0.227$) functional dependence of the substituent effect on the state of the reaction center may be represented by Eq. (5) derived from Eqs. (3) and (4):

$$\sigma_d^+ = 0.227\cdot(d-1)\cdot lgK_H + \sigma_0^+ \qquad (5)$$

As examples of use of σ_d^+ values for correlation of the acid-base equilibrium constants for bases of triarylcarbinol type, Table 4 represents thus obtained values of correlation r and standard deviation S coefficients for selective reaction series ($n \geqslant 6$). The respective parameters obtained by using the Brown and Okamoto electrophilic σ^+-constants are also given.

Table 4

PARAMETERS OF CORRELATION EQUATIONS

$$\lg K_R = \rho \cdot \sigma_d^+ (\sigma^+) + \lg K_H$$

Serial No	n	σ_d^+		σ^+	
		r	S	r	S
II	10	1.000	0.08	0.993	0.30
III	10	0.998	0.14	0.995	0.26
V	6	0.998	0.21	0.996	0.25
VI	10	0.999	0.09	0.988	0.34
VII	8	0.987	0.19	0.976	0.25
XII	6	0.985	0.15	0.945	0.29
XIV	10	0.993	0.13	0.992	0.14
XVII[c]	11	0.995	0.11	0.993	0.14
XVIII[g]	11	0.995	0.15	0.981	0.30

As Table 4 shows, in all the cases cited, when using σ_d^+-constants calculated for each reaction series according to Eq. (5), correlations with $\lg K_R$ improve.

Thus, quantitative estimation of alteration in the substituent effects during transition from one reaction series to another permits comparison of their effects on reactivity for different series of bases of triarylcarbinol type within the range of one scale of the substituent constants (in this instance σ^+-constants).

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STUDY OF S_N1 REACTIONS USING TRIPHENYLVERDAZYLS
IV. KINETICS AND MECHANISM OF Ph_2CHBr IONIZATION IN BENZONITRILE

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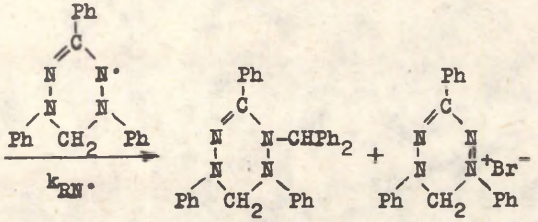
Ph_2CHBr ionization kinetics in PhCN has been studied spectrophotometrically in the presence of triphenylverdazyl (RN$^\bullet$) as an internal indicator; $v=k_1\cdot[Ph_2CHBr]$, $k_1^{25}=3.2\cdot10^{-8}$ sec^{-1}, $\Delta H^{\neq}=14.1$ kcal/mole, $\Delta S^{\neq}=-45.4$ e.u., $\Delta G^{\neq}=27.7$ kcal/mole. $Et_4NClO_4(LiClO_4)$ additions increase the rate (special salt effect), whereas those of Bu_4NNO_3 decrease it. Kinetic parameters of individual Ph_2CHBr ionization stages in CH_3CN and PhCN were estimated. The rate constant of $Ph_2CH^+Br^-$-formation was shown to be higher than the corresponding value for t-Bu^+Br^- by approx. one order of magnitude and lower by approx. 9 orders of magnitude as compared with the rate constant for $Ph_2CH^+|S|Br^-$ formation. The significance of dipole interaction is discussed.

The first works of this series[1,2] assume that at the rate-determining step of Ph_2CHBr ionization in CH_3CN the intimate ion pair is converted into the solvent-separated one (II⟶III)

$$\underset{\text{I}}{Ph_2CHBr} \underset{k'_{-1}}{\overset{k'_1}{\rightleftharpoons}} \underset{\text{II}}{Ph_2CH^+Br^-} \xrightarrow{k'_2} \underset{\text{III}}{Ph_2CH^+|S|Br^-} \longrightarrow \qquad (1)$$



As $Ph_2CH^+ \,|S|\, Br^-$ appears it reacts rapidly with the triphenylverdazyl radical (RN·) used as an internal indicator ($k_{RN\cdot} \gg k_2'$). The presence of RN· in the solution removes completely the external return of the ion pair (III → II reaction does not occur). This allows spectrophotometrically to measure the reaction rate at a very low substrate conversion degree against the RN· consumption and the formation of triphenylverdazylium salt (RN^+Br^-)

$$-d[RN\cdot]/2dt = d[RN^+Br^-]/dt = -d[Ph_2CHBr]/dt = k_1[Ph_2CHBr] \qquad (2)$$

This work gives the data for benzonitrile (ε =25.2, μ=4.05D, Z=65.0) whose polarity is much lower than that of CH_3CN (ε =37.5, μ=3.44D, Z=71.3).

RESULTS AND DISCUSSION

Kinetic runs were carried out at app. 500-fold excess of Ph_2CHBr relative to RN·. Substrate conversion degree in every individual run was about 0.05%. Under these conditions the reaction rate is described by the following zero order kinetic equation.

$$-d[RN\cdot]/2dt = d[RN^+Br^-]/dt = k_o \qquad (3)$$

This is illustrated by the kinetic curves in Fig.1, where the descending curves correspond to the RN· concentration change and the descending ones to that of RN^+Br^-.

The conditions and results of kinetic measurements are given in Table 1. The reaction rate is satisfactorily described by equation (2) ($k_1 = k_o/[Ph_2CHBr]$). The k_1 values in the tests with various initial concentrations of reagents and those calculated as from the RN· consumption and RN^+ formation (columns 5 and 6 of the Table) coincide satisfactorily with each other.

The reaction rate is independent of the RN· concentration which is in agreement with the conclusion[1-3] that triphenylverdazyl undergoes reaction after the rate-determining step.

Fig.2 and Table 2 show the effect of Bu_4NNO_3, Et_4NClO_4 and $LiClO_4$ additions on the reaction rate in PhCN. In both

Table 1

Kinetics of Ph_2CHBr Ionization in PhCN in the Presence of Triphenylverdazyl

Nos.	$[RN^{\bullet}] \cdot 10^4 M$	$[Ph_2CHBr] \cdot 10^2 M$	^oC	$10^8 \cdot k_1\ s^{-1}$		
				as $RN^{\bullet}$*)	as RN^+*)	mean
1	1.05	6.78	25.0	3.20±0.02	3.19±0.09	3.21±0.08
2	1.96	6.78		3.13±0.05	3.43±0.05	
3	1.61	7.20	30.5	5.02±0.04	5.4±0.02	5.22±0.18
4	0.800	7.20		5.07±0.05	5.4±0.01	
5	1.18	7.15	34.5	8.35±0.01	8.55±0.01	8.47±0.05
6	1.18	3.60		8.49±0.01	8.49±0.62	
7	0.980	3.60	40.2	10.3±0.2	10.0±0.1	10.4±0.2
8	0.980	7.20		10.7±0.6	10.5±0.1	
9	0.942	6.47	40.5	10.3±0.8	10.3±0.1	10.8±0.5
10	1.05	6.47		11.1±0.2	11.3±1.0	
14	0.967	6.73	43.5	13.6±0.7	14.7±0.2	14.1±0.4
15	1.40	6.73		13.0±0.1	14.9±0.2	

*) Mean of two runs

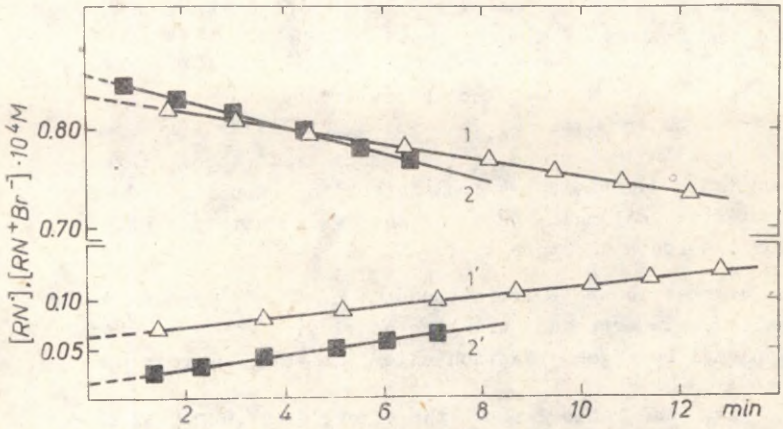


Fig.1. Kinetics of Ph_2CHBr ionization in PhCN.

Table 2

Salt Effects on the Ionization Rate of Ph_2CHBr in PhCN in the Presence of $RN^{\cdot}$, 40.5°C

$[RN^{\cdot}]$ 10^4M	$[Ph_2CHBr]$ M	MX addition		$10^7 \cdot k_1$ s^{-1}		
		nature	$[MX]$, 10^3M	as $RN^{\cdot}$*)	as RN^{+}*)	mean
0.904	0.072		0.23	0.518±0.010		0.518±0.010
1.110	0.072	Bu_4NNO_3	0.37	0.467±0.001	-	0.467±0.001
0.904	0.072		0.46	0.354±0.010	-	0.354±0.010
0.900	0.031		3.7	5.01±0.03	4.81±0.01	4.91±0.10
0.955	0.024		6.7	6.96±0.08	7.03±0.01	6.99±0.03
0.942	0.031		7.4	7.56±0.01	7.37±0.02	7.46±0.11
0.942	0.021	$LiClO_4$	9.9	9.86±0.25	10.1±0.1	9.98±0.12
0.942	0.065		14.8	11.1±0.2	11.3±0.1	11.2±0.2
0.955	0.024		20.0	12.1±0.4	12.0±0.3	12.1±0.1
0.955	0.020		29.4	14.6±0.3	14.6±0.1	14.6±0.1
0.930	0.067		2.7	1.95±0.06	2.06±0.01	2,05±0.10
0.930	0.067	Et_4NClO_4	5.5	2.44±0.13	2.44±0.11	2.44±0.01
0.930	0.031		14.2	2.71±0.01	2.79±0.16	2.73±0.02
0.900	0.031		29.0	3.48±0.14	3.54±0.09	3.51±0.03

*) Mean of two runs

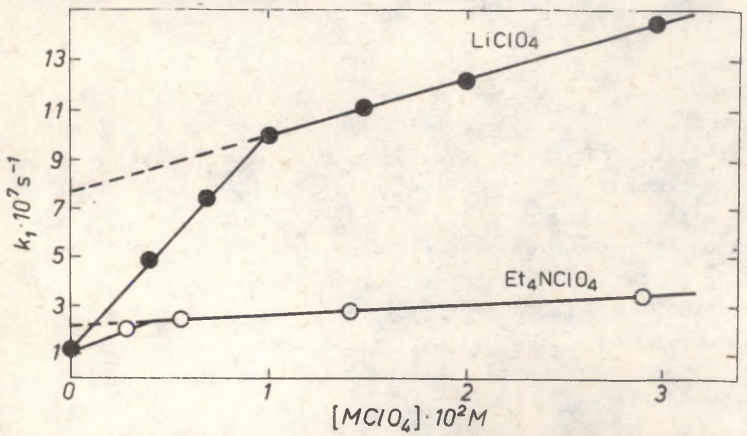


Fig.2. Influence of Et_4NClO_4 and $LiClO_4$ on the ionization rate of Ph_2CHBr in PhCN

cases, similarly to the reaction in the CH_3CN solution, the special salt effect of the perchloration is observed. The curve showing the enhancement in the reaction rate with the increasing salt concentration may be subdivided into two sections with different slopes. The b-values in equation (4) for the first sections of the curves are 230 and 810 for Et_4NClO_4 and $LiClO_4$, respectively, whereas for the second sections these are, accordingly, 46 and 210.

$$k_1^s = k_1(1+b[MClO_4]) \qquad (4)$$

The occurence of the special salt effect indicates the formation of a solvent-separated ion pair as intermediate[4]. According to our interpretation of this effect[2] the first sections of the curves refer to the equilibrium formation of either the ion triplet or the quadrupole between the intimate ion pair of the substrate and ClO_4^- (or $M^+ClO_4^-$), the triplet (or quadrupole) converting into the solvent-separated ion pair more readily than in II $\longrightarrow$ III reaction.

$$\underset{\text{II}}{Ph_2CH^+Br^-} + ClO_4^-(M^+ClO_4^-) \rightleftharpoons \underset{\text{IV}^-}{ClO_4^-|S|Ph_2CH^+Br^-}\left(\begin{matrix} Ph_2CH^+Br^- \\ |S| \\ ClO_4^-M^+ \end{matrix}\right) \longrightarrow$$

$$\xrightarrow{-Br^-(M^+Br^-)} \underset{\text{III}_y}{Ph_2CH^+|S|ClO_4^-} \qquad (5)$$

Ion pair III_y, similarly to III reacts rapidly with RN°. Curve bends (Fig. 2) show the intimate ion pair II to be entirely converted into the ion triplet (quadrupole) IV^-. Second sections of the curves reflect the action of the usual salt effect of the perchlorate on $IV^- \longrightarrow III_y$ reaction. Extrapolation of the curves to zero salt concentration gives the values of the rate constants of $2.1 \cdot 10^{-7}$ and $7.7 \cdot 10^{-7}$ s^{-1} for $EtNClO_4$ and $LiClO_4$, respectively. These represent the maximum values of the special salt effect, the usual salt effect being negligible. These values are then 2 and 7 times greater than those of k_1 without perchlorate additions.

Consequently, the formation of the solvent separated ion pair via the path of I → II → IV^{-} → III_y is two times (Et_4NClO_4) and seven times ($LiClO_4$) faster than that proceeding via the path of I → II → III.

Cation nature affects strongly the special salt effect (in the PhCN solution this is more pronounced, than in CH_3CN), both curve sections becoming steeper with the decrease in the cation size. This may be accounted for either by greater readiness of the formation of the cationoid triplet $Ph_2CH^+Br^-$ S M^+ with an increase in a cation size[2] or by the strengthening of dipole-dipole interaction when the cation is decreasing in size[4].

Earlier[2] the salts with such anions as Cl^-, Br^-, J^-, NO_3^- were shown to decrease the ionization rate of Ph_2CHBr in CH_3CN followed with RN° due to the formation of Y^- S $Ph_2CH^+Br^-$ triplet or $Ph_2CH^+Br^-$ quadrupole leading to anion exchange in Ph_2CHBr. In PhCN a similar effect is observed with Bu_4NNO_3 additions (Table 2, tests 13-15). As in CH_3CN the effect increases with an increase in salt concentration. We couldn't check the effect of hydrogen halide salts in PhCN solution as they react with RN^+Br^- to form RN°. It is also observed partially with $[Bu_4NNO_3] > 10^{-3}$M. Thus, with Ph_2CHBr ionization in PhCN the salt effect observed is the same as with Ph_2CHBr(Cl) ionization in CH_3CN[2,3], which indicates similar mechanisms for both solvents.

Table 3 shows kinetic parameters of monomolecular Ph_2CHBr heterolysis in CH_3CN and PhCN in comparison with t-BuX, PhMeCHBr, and p-$ClC_6H_4CMe_2Cl$ in these solvents and in CH_3NO_2 and $PhNO_2$. When passing from CH_3CN to PhCN the ionization rate of t-BuBr falls by a factor of due to 18 an increase in $\Delta H^{\neq}$ ($\Delta S^{\neq}$ values are essentially the same). With Ph_2CHBr the $\Delta H^{\neq}$ value decreases with passing from CH_3CN to PhCN, nevertheless the rate decreases by a factor of due to a sharp decrease in $\Delta S^{\neq}$. It is of some interest to note, that Ph_2CHBr and t-BuBr ionization rates both in

Table 3

Kinetic Parameters of Ph_2CHBr, t-BuX, PhMeCHBr, and p-$ClC_6H_4CMe_2Cl$ Ionization in RCN and RNO_2, 25°

Substrate	Solvent	*) $-\lg k_1^{25}$	$\Delta H^{\neq}$ kcal/mol	$-\Delta S^{\neq}$ e.u.	$\Delta G^{\neq}_{25}$ kcal/mol	References
Ph_2CHBr	CH_3CN	5.6	16.6	29.1	25.3	1
	PhCN	7.5	14.13± ±0.05	45.4± ±0.2	27.74± ±0.07	-
t-BuCl	CH_3CN	8.7	23.9	17.9	29.1	5
	CH_3NO_2	8.2	23.2	18	28.6	6
	$PhNO_2$	9.7	25.7	17.0	30.8	7
t-BuBr	CH_3CN	5.9	19.5	19.7	25.4	5
	CH_3NO_2	5.4	20.0	16.3	24.8	8
	PhCN	7.1	21.5	18.7	27.1	9
	$PhNO_2$	7.0	20.3	22.2	26.4	9
t-BuJ	CH_3CN	4.3	17.1	20.7	23.4	5
	PhCN	5.4	20.0	16.3	24.9	9
	$PhNO_2$	5.5	19.2	19.4	25.0	9
PhMeCHBr	CH_3CN	7.3	23.5	16	27.3	10
p-$ClC_6H_4CMe_2Cl$	CH_3CN	5.3	18.9	19.4	24.7	11
	CH_3NO_2	4.7	18.2	19.2	24.0	11

*) The constants in s^{-1}.

CH_3CN and PhCN, are close to one another, whereas $\Delta H^{\neq}$ and $\Delta S^{\neq}$ are greatly different. It is important to note that steric requirements to the formation of transition state increase with passing from t-BuBr to Ph_2CHBr

The substrate and solvent effects on the kinetic parameters could be explained by intimate ion pair formation at the rate-determining step of t-BuBr ionization whereas in the case of Ph_2CHBr the solvent-separated ion pair is formed[2].

The formation of an intimate ion pair from t-BuX in the solvents, whose molecules contain groups with large dipole moments (e.g. CN, NO_2) is caused by dipole interaction of the substrate with the solvent molecule[9]. If $Ph_2CH^+Br^-$ formation occurs in a similar way, then in the solution of nitriles for Ph_2CHBr one should expect the shift of the proton signal in the NMR-spectrum to the weak field as compared with the solution in CCl_4, where dipole interaction is absent[12]. Indeed, the values of δ methyne proton of Ph_2CHBr in CCl_4, CH_3CN and PhCN were found to be 6.12, 6.41 and 6.32 p.p.m., respectively. Dipole interaction results in the formation of a complex (quadrupole) having 1:1 composition[13]. Activation entropy value, determined by bimolecular interaction equals appr. -20 e.u.[14]. This conclusion is reinforced by the data of Table 3; $\Delta S^{\neq}$ values for t-BuCl, t-BuBr, t-BuJ, PhMeCHBr and $p\text{-}ClC_6H_4CMe_2Cl$ are -19 ± 2 e.u.

The $Ph_2CH^+ |S| Br^-$ formation rate is connected with three reactions (Equation 1). The measurable rate constant is determined from Equation (6)

$$k_1 = k_1/(1 + k_{-1}/k_2) \qquad (6)$$

Assuming $k_{-1}/k_2=20$*) and 100*) for CH_3CN and PhCN, respectively, the values of k_1 were calculated and kinetic parameters for the three reactions were roughly estimated (Table 4).

Table 4

Kinetic Parameters of $Ph_2CH^+Br^-$ and $Ph_2CH^+|S|Br^-$ Formation in CH_3CN and PhCN, 25°C

Solvent	$RBr \longrightarrow R^+Br^-$			$R^+Br^- \longrightarrow R^+\|S\|Br^-$			$R^+Br^- \longrightarrow RBr$		
	$\lg k_1'$	$\Delta H_1^{\neq}$	$\Delta S_1^{\neq}$	$\lg k_2'$	$\Delta H_2^{\neq}$	$\Delta S_2^{\neq}$	$\lg k_{-1}'$	$\Delta H_{-1}^{\neq}$	$\Delta S_{-1}^{\neq}$
MeCN	-4.4	15.1	-28	4.0	9.0	-10	5.3	7.4	-9
PhCN	-5.5	13.1	-36	3.6	6.5	-20	5.6	6.8	-10

*) For 4,4'-dimethylbenzhydryle thiocyanate in CH_3CN this ratio is approx. 19 (see[15]).

**) The ratio increases with a decrease in solvent polarity.

The rate of $Ph_2CH^+Br^-$ formation in CH_3CN has proved to be 1.1 order of magnitude higher than that in PhCN. The above is in agreement with the data on t-BuBr ionization in these solvents[5,9]. In addition it should be noted that the intimate ion pair $t\text{-}Bu^+Br^-$ is formed in both solvents approx. 1.5 order of magnitude slower than $Ph_2CH^+Br^-$. This result was to be expected.

$\Delta H_1^{\neq}$ values were estimated by the inequalities $\Delta H_1^{\neq} < 16.6$ (CH_3CN) and $\Delta H_1^{\neq} < 14.1$ kcal/mole (PhCN) (see Table 3) in such a way that maximum values of $\Delta S_1^{\neq}$ could be obtained. Nevertheless these appeared to be much lower than the level of -20 e.u. required for the formation of an intimate ion pair in dipole interaction with the solvent molecule. Table 3 shows that the substitution of one of two methyl groups by phenyl ones does not change the $\Delta S^{\neq}$ value. Therefore the explanation for low $\Delta S^{\neq}$ values in our case is to be looked for in relative positions of phenyl groups of Ph_2CHBr in the transition state. In the initial state the planes of phenyl groups are positioned relative to each other at an angle of approx. 35° (see[16]). Since $Ph_2CH^+Br^-$ formation is connected with $sp^3 \longrightarrow sp^2$ rehybridization of the central carbon atom having already partial sp^2-character[17] in the initial state and with charge delocalization onto phenyl rings, in the transition state phenyl groups may be expected to be located within one plane. The above should lead to an additional decrease in $\Delta S^{\neq}$ values and a considerable decrease in $\Delta H^{\neq}$ values, which is confirmed by the information in Table 3.

Kinetic parameters of II → III reactions were estimated on the basis of the following assumptions. With the introduction of a solvent into the intimate ion pairs of alkali metal fluorenyles the enthalpy value varies within 3-9 kcal/mole, whereas the entropy ranges from -10 to -30 e.u.[18]. For II → III reaction $\Delta H_2^{\neq}$ value was accepted to be 9.0 (6.5) kcal/mole and $\Delta S_2^{\neq}$ value was taken as -10(-20) e.u. in CH_3CN(PhCN). In this case we considered the fact that the

the coordination with one monodentate solvent molecule required -11 e.u.[19]. With decrease in solvent polarity the distance between ions in the ion pair increases greatly. In PhCN, where this distance is approx. 12 A° (See [4]), one may expect the introduction of two solvent molecules into the space between ions.

The $\lg k_{-1}$ value for II → I reactions was calculated from the ratio $\lg k'_{-1}/\lg k'_2 = 1.3$ (2.0) in CH_3CN(PhCN). $\Delta H^{\neq}_{-1}$ and $\Delta S^{\neq}_{-1}$ values were found using equation (6). It is of interest to note, that the intimate ion pair trapping in the covalent product is connected with a marked fall in $\Delta S^{\neq}$ values, though an increase in $\Delta S^{\neq}$ values by 10-30 e.u.[14] should be expected due to $Ph_2CH^+Br^-$ desolvatation. This confirms that quadrupole formation between $Ph_2CH^+Br^-$ and RCN (transition state in I ⇌ II reactions) is accompanied by a strong decrease in $\Delta S^{\neq}$ values.

Though the kinetic parameters in Table 3 are, in fact, only roughly estimated, they represent clearly individual steps of $Ph_2CH^+Br^-$ heterolysis. The constant of Ph_2CH^+ | S | Br^- formation rate is ~9 orders of magnitude higher than that of $Ph_2CH^+Br^-$. Nevertheless, the solvent-separated ion pair formation step determines the overall rate of the reaction, since the concentration of the intimate ion pair is very low (at [Ph_2CHBr] = 0.01M in CH_3CN [$Ph_2CH^+Br^-$] = $2 \cdot 10^{-12}$M, in PhCN [$Ph_2CH^+Br^-$] = $0.8 \cdot 10^{-14}$M).

EXPERIMENTAL

Benzonitrile was dried over potash and $CaCl_2$, decanted, distilled under vacuum over P_2O_5, kept overnight over CaH_2 and distilled twice again under vacuum. Other reagents were obtained and purified as elsewhere[1,2]. NMR spectra were taken with Tesla BS 487C (80 MHz). Kinetic runs were carried out according to[1].

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THE STUDY OF S_N1 REACTIONS USING TRIPHENYLVERDAZYL S
V. Ph_2CHBr IONIZATION KINETICS IN DICHLOROETHANE . SOLVENT INFLUENCE ON HETEROLYSIS RATES OF Ph_2CHBr and t-BuBr

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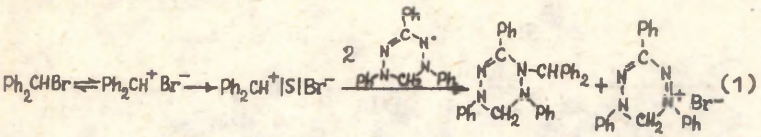
Ph_2CHBr ionization kinetics has been studied spectrophotometrically in dischloroethane using triphenylverdazyl ($RN^{\cdot}$) as the internal indicator, $v=k\ Ph_2CHBr$, $k^{25}= 1.49.10^{-8}\ s^{-1}$, $H^{\neq} = 14.7$ kcal/mol, $S^{\neq}_{25} = -45.0$ e.u. Et_4NClO_4 additions increase the reaction rate, the special salt effect is observed. At the rate-determining step the conversion of the intimate ion pair into the solvent-separated one with the further rapid reaction of the latter with $RN^{\cdot}$ is supposed. Heterolysis rates of Ph_2CHBr and t-BuBr in MeOH, EtOH, HOAc, MeCn, PhCn and dichloroethane were compared, it was concluded that benzhydryl derivatives were more convenient for solvatation effect correlation in heterolytic processes than tert-butyl ones.

Ph_2CHBr heterolysis kinetics has been studied in alcohols (MeOH, EtOH, n-PrOH, n-BuOH)[1-3], acetic acid[2], acetonitrile[4] and benzonitrile[5]. To further investigate the solvent effect on the kinetic parameters of this reaction, Ph_2CHBr ionization kinetics was studied in 1,2-dichloroethane. Kinetic experiments were conducted as before[4-6] in the presence of the stable triphenylverdazyl radical ($RN^{\cdot}$) used as the internal indicator. In works[5,6] $RN^{\cdot}$ was shown to react after the rate-determining step in the MeCN and PhCN solution (solvent-separated ion pair formation) which allowed to control the reaction rate spectrophotometrically agaist $RN^{\cdot}$ consumption and triphenylverdazylium bromide ($RN^{+}Br^{-}$) formation.



(1)

Fig. 1 shows typical kinetic experiments; $RN^{\cdot}$ (descending curves) and $RN^{+}Br^{-}$ (ascending curves) concentrations undergo linear changes with time. It is connected with the fact that our conditions ($[RN^{\cdot}] \ll [Ph_2CHBr]$) the substrate conversion is app. 0.01%, hence in each individual experiment $[Ph_2CHBr]$ = const. and the reaction rate is described by the zero order equation

$$-d[RN^{\cdot}]/2dt = d[RN^{+}Br^{-}]/dt = k_0 \qquad (2)$$

In general, the Ph_2CHBr ionization rate is satisfactorily described by the first order kinetic equation

$$v = k[Ph_2CHBr] \qquad (3)$$

being independent of $RN^{\cdot}$ concentration. This speaks for the fact that similar to its behaviour in other solvents in dichloroethane $RN^{\cdot}$ starts to react after the rate-determining step.

Table I presents the conditions and results of kinetic experiments. Rate constant values found using $RN^{\cdot}$ consumption and $RN^{+}Br^{-}$ formation satisfactorily coincide (columns 5 and 6 of Table I). Et_4NClO_4 *) additions increase the reaction rate (Table I, Exp. 10-15, Fig.2). The special salt effect[6,7] is observed - small salt additions give rise to a sharp reaction rate increase with further salt concentration growth bringing about a slower linear increase in the rate (Fig.2). According to our interpretation of this effect[6] the perchlorate catalyzes the intimate ion pair conversion into the solvent-separated one, resulting in the formation of either the ion triplet $ClO_4^{-}|S|Ph_2CH^{+}Br^{-}$ or the quadrupole $Ph_2CH^{+}Br^{-}$, $Et_4N^{+}ClO_4^{-}$. The first part of the curve in Fig.2 is connected with the formation of a new intermediate, whereas

*) Attempts to study the effects of other salts failed either because of their low solubility ($LiClO_4$) or because of their reaction with $RN^{+}Br^{-}$ (halogenides, nitrates).

Table I

Kinetics of Ph_2CHBr Ionization in Dichloroethane in the Presence of RN°

Nos	$[Ph_2CHBr] \cdot 10^2$ M	$[RN^\circ] \cdot 10^4$ M	°C	$10^8 \cdot k, s^{-1}$		
				as RN° *)	as RN^+ *)	average
1	6.50	1.28	24.5	1.40	-	1.40±0.04
2	8.60	1.27	30.5	2.32	-	2.34±0.07
3	8.60	0.630		2.30	2.51	
4	6.20	1.25	34.5	3.31	3.36	3.21±0.12
5	6.20	0.625		3.02	3.13	
6	3.88	1.25	40.5	5.73	5.37	5.48±0.11
7	7.83	1.43		5.32	5.41	
8	6.26	0.853		5.46	5.66	
9	6.18	1.43		5.39	5.50	
10[a]	3.40	0.853	40.5	10.2	11.3	10.8±0.5
11[b]	3.50	0.853		13.7	14.5	14.1±0.4
12[c]	3.40	0.853		14.5	14.5	14.5±0.1
13[d]	3.50	0.853		14.9	15.6	15.3±0.4
14[e]	3.40	0.853		15.4	17.0	16.2±0.8
15[f]	3.50	0.853		17.3	-	17.3±0.2
16	5.90	1.27	45.5	7.64	7.53	7.58±0.08
17	2.90	1.24		7.48	7.66	

*) Average from two runs

a) In the presence of $1.05 \cdot 10^{-3}$M Et_4NClO_4

b) In the presence of $2.10 \cdot 10^{-3}$M Et_4NClO_4

c) In the presence of $3.17 \cdot 10^{-3}$M Et_4NClO_4

d) In the presence of $6.40 \cdot 10^{-3}$M Et_4NClO_4

e) In the presence of $9.50 \cdot 10^{-3}$M Et_4NClO_4

f) In the presence of $14.3 \cdot 10^{-3}$M Et_4NClO_4

the second is related to the usual salt effect. Extrapolation of tne second part of the curve to zero Et_4NClO_4 content gives $k^{40.5} = 1.35 \cdot 10^{-7} s^{-1}$, i.e. the value being 2.5 times greater than that of the rate constant without the perchlo-

rate additions.It is the maximum reaction rate increase due to the special salt effect at zero value of the usual salt effect. Therefore, the intermediate (a triplet or a quadrupole) forming in dichloroethane with the participation of the perchlorate is converted into the solvent-separated ion pair $Ph_2CH^+|S|ClO_4^-$ 2.5 times faster, than in $Ph_2CH^+Br^- \longrightarrow Ph_2CH^+|S|Br^-$ reaction.

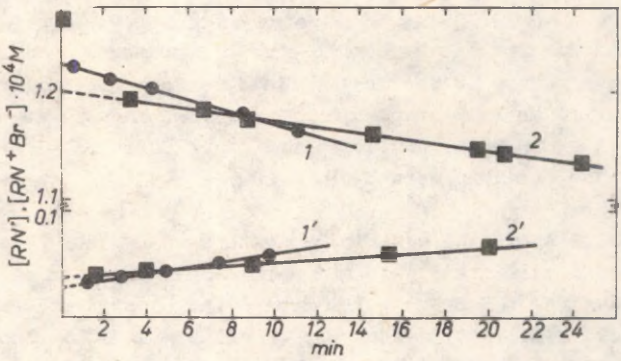


Fig.1. The kinetics of Ph_2CHBr ionization in dichloroethane in the presence of RN°; 45.5°C.
1 - $[Ph_2CHBr] = 0.0590$, $[RN^\cdot] = 1.27\cdot10^{-4}$M
2 - $[Ph_2CHBr] = 0.0290$, $[RN^\cdot] = 1.24\cdot10^{-4}$M

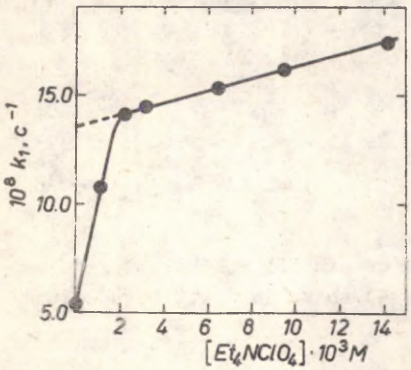


Fig.2. Et_4NClO_4 effect on the ionization rate of Ph_2CHBr in dichloroethane, 40,5°C.

Thus, at the rate-determining step of Ph_2CHBr heterolysis in dichloroethane similar to that in MeCN[6] and PhCN[5] the formation of the solvent-separated ion pair is observed.

It is interesting to note, that in the transition from such a polar solvent as benzonitrile (ε = 25.2) to dichloroethane having relatively low polarity (ε = 10.4) the Ph_2CHBr ionization rate decreases only app. 2 times. It seems to be connected with the fact, that dichloroethane is capable of forming H-complexes with the leaving group (electrophilic promotion of heterolysis). This being so, the PMR spectrum of Ph_2CHBr in dichloroethane should show a considerable shift of the methine proton to the weaker field, as compared with the CCl_4 solution where H-complexing is missing. Indeed, it was found that δ-methine proton values of Ph_2CHBr in CCl_4, dichloroethane and HOAc were 6.12, 6.28 and 6.32 ppm, respectively.

Table 2 shows the kinetic parameters of Ph_2CHBr heterolysis in six solvents[1,2,4,5] given in comparison with similar results for t-BuBr[8-11]. The Table also comprises Kosower's solvent polarity values (Z)[12]. Fig.3 gives the comparison of the log rate constants for the heterolysis of both substrates with Z-values in various solvents. The heterolysis rates of both substrates are close to each other in aprotic solvents, whereas in the protic ones t-BuBr reacts slower by 2-3 orders of magnitude (HOAc is the exception). A similar picture is observed for Ph_2CHCl and t-BuCl. The reaction of Ph_2CHCl is faster in protic solvents by appr. 3 orders of magnitude as compared with that of t-BuCl (in MeOH lg $k^{25}_{Ph_2CHCl}$= -3.1, lg $k^{25}_{t\text{-}BuCl}$=-6.1, in EtOH lg $k^{25}_{Ph_2CHCl}$=-4.3, lg $k^{25}_{t\text{-}BuCl}$= -7.1; in i-PrOH lg $k^{25}_{Ph_2CHCl}$=-5.2; lg $k^{25}_{t\text{-}BuCl}$=-7.8)[2,13-15]. In CH_3CN their rates are close to each other (lg $k^{25}_{Ph_2CHCl}$=-8.3, lg $k^{25}_{t\text{-}BuCl}$=-8.6)[9,16].

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*) Log values of alcoholysis constants for Ph_2CHBr at 25°C in n-PrOH (-3.4) and n-BuOH (-3.5) shown in Fig.3 were calculated using the data of ref. 3.

Table 2

Kinetic Parameters of Ph_2CHBr and t-BuBr Heterolysis in Different Solvents

Solvent	Z kcal/mol	Ph_2CHBr			t-BuBr		
		$-\lg k^{25}$ **)	$\Delta H^{\neq}$ kcal/mol	$\Delta S^{\neq}_{25}$ e.u.	$-\lg k^{25}$ **)	$\Delta H^{\neq}$ kcal/mol	$\Delta S^{\neq}_{25}$ e.u.
MeOH	83.6	1.80	19.2	-2.9	4.46	23.4	-0.5
EtOH	79.6	2.91	20.6	-2.6	5.36	24.6	-0.4
HOAc	79.2	4.78	22.0	-6.6	5.52	24.1	-1.9
MeCN	71.3	5.60	16.6	-29.1	5.90	19.5	-20.0
PhCN	65.0	7.49	14.1	-45.4	7.11	21.5	-18.7
CH_2ClCH_2Cl	63.4	7.83*)	14.7*)	-45.0*)	7.75	18.4	-32.2

*) Calculated from the data of Table I.

**) The rate constants in s^{-1}.

Fig. 3 shows that the Ph_2CHBr heterolysis rate changes linearly with the change in Z**), whereas the t-BuBr heterolysis rate sharply declines from this dependence pattern in the transition zone from aprotic to protic solvents. Indeed, in the transition from MeCN to EtOH Ph_2CHBr the heterolysis rate increases by 2.7 orders of magnitude, whereas the increase of the t-BuBr rate is only by 0.5 orders.

The observed differences in the behaviour of Ph_2CHBr and t-BuBr can be explained by the fact, that in the first case a solvent-separated ion pair is always formed at the rate-determining step, whereas in the second case it occurs only in protic solvents but in the aprotic ones the intimate ion pair

**) Extrapolation of this curve to Z_{H_2O} = 94.6 (see[12]) gives the value of rate constant hydrolysis of Ph_2CHBr in water, $\lg k^{25}$ = 1.4. The real value may be lower, since in the transition to water the nature of the transition state seems to change[7].

formation is the limiting factor. This conclusion agrees with the information available in the literature showing the influence of various salts on the rates of Ph_2CHX and t-BuX heterolysis[6,7]. It also agrees with the effect the solvent has on the anion exchange in t-BuX[7,17,18] as well as with the sharp increase in the polarity of t-BuCl transition state during the transition from aprotic to solvents[19]. Different nature of the transition state during t-BuX heterolysis in the two groups of solvents is also indicated by the fact, that in the correlation of t-BuX heterolysis rates with various solvent parameters different relationships are usually obtained for each group of solvents [12,19-21].

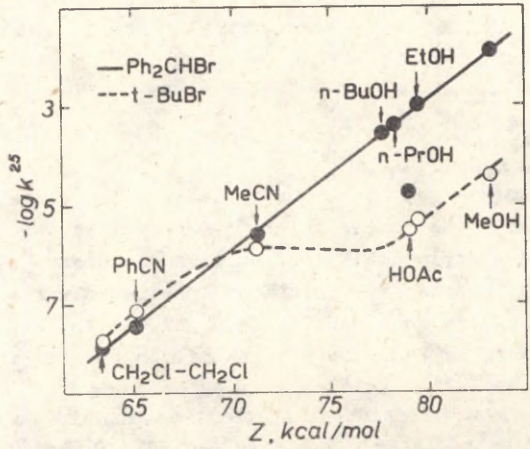

Fig.3. Dependence of log rate constants of the Ph_2CHBr and t-BuBr heterolysis on the solvent polarity values Z.

It is interesting to note, that in the transition from t-BuBr to Ph_2CHBr in protic solvents $\Delta S^{\neq}$ value undergoes only ly slight changes, whereas in the aprotic ones it decreases by 10-20 units (Table 2), which fact may be an additional confirmation of the solvent molecule coordination as a result of the solvent-separated ion pair formation.

The inflexion on the curve Z - lg $k_{t\text{-BuBr}}$ shows that solvent-separated ion pair formation is by 2-3 orders slower than that of the intimate one.

The comparison of Ph_2CHBr and t-BuBr heterolysis rates shows the benzhydryl derivatives to be more acceptable as standards for the correlation of solvation effects in heterolytic processes, than t-BuX, since the former substrates are more homogeneous from the mechanistic point of view and more sensitive to the solvent effect (during the transition from dichloroethane to MeOH Ph_2CHBr heterolysis rate changes by 6 orders of magnitude, whereas that of t-BuBr - only by 3.3 orders).

Experimental

The synthesis of reagents and methods of kinetic experiments have been reported previously[4-6,16]. Dichloroethane was washed with KOH water solution then dried overnight over $CaCl_2$, distilled over P_2O_5, boiled 2-3 hours with CaH_2 and again distilled. PMR spectra were recorded by Tesla BS 487 C (80 MHz) with HMDS.

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