INFLUENCE OF SUBSTITUENTS ON NUCLEOPHILIC REACTIVITY OF ANILINES DURING REACTION WITH CYANUR CHLORIDE

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The basic kinetic data of the reactions of cyanur chloride, 2-anilino-4,6-dichloro-1,3,5-triazine and 2,4-dianilino-6-chloro-1,3,5-triazine with a series of *m*- and *p*-substituted anilines have been measured in methanol. The rate constants found have been correlated with the Hammett σ constants and the ϱ constants calculated have been discussed.

Nucleophilic substitution of the chlorine atoms in the symmetrical triazine nucleus has a considerable technological importance in dyestuff and pesticide production[1-3], and a great deal of research work is focused on it[4,5]. The halogen substituents in the triazine nucleus can be gradually substituted by the same or different nucleophilic atoms, because their reactivities in subsequent substitutions differ to such an extent that an appropriate change of reaction conditions can result in substitution of one, two, or all three halogen atoms. For the correct choice of the reaction conditions the knowledge of the rate constants of the individual reaction steps is necessary. The kinetic studies published so far deal with the reaction of cyanur chloride with hydroxyl groups of cellulose fibers or its decomposition by water[6]. The reaction of cyanur chloride with aniline was followed in benzene solution[4].

The aim of the present work is to ascertain the quantitative differences in reactivities of the individual chlorine atoms in symmetrical 1,3,5-triazine during substitution with substituted anilines in methanolic medium (reactions $(A)-(C)$).

$$ (A) $$
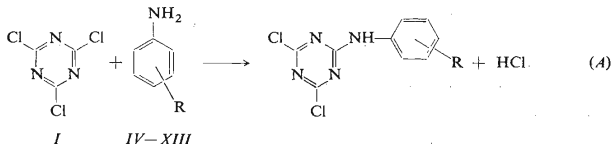
$$ I \qquad IV-XIII \qquad $$

EXPERIMENTAL

Reagents

The cyanur chloride (*I*) made in VCHZ-Synthesia was purified by crystallization from light petroleum, m.p. 142—143°C. The substituted anilines *IV—XIII* were commercial products and

$$C_6H_5-NH \quad N \quad NH-C_6H_5 \quad + \quad NH_2 \quad \longrightarrow \quad C_6H_5-NH \quad N \quad NH-C_6H_5 \quad + \quad HCl$$
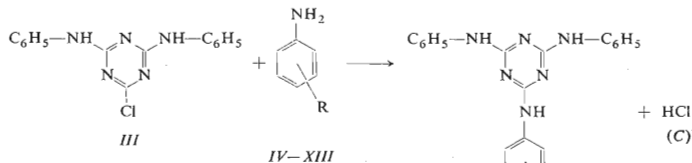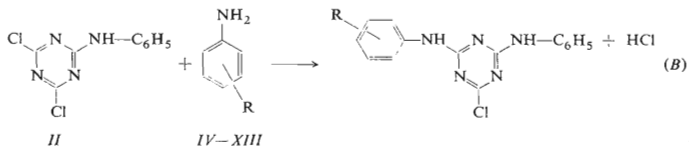
IV, R = H   *VII, R = 4-Cl*   *XI, R = 4-Br*

V, R = 4-CH₃   *VIII, R = 3-Cl*   *XII, R = 3-CO₂CH₃*

VI, R = 3-CH₃   *IX, R = 3-NO₂*   *XIII, R = 3-COCH₃*

                  X, R = 4-OCH₃

were purified through distillation or crystallization. 2-Anilino-4,6-dichloro-1,3,5-triazine (*II*), m.p. 134—135°C (ref.[6] 136°C), 2-chloro-4,6-dianilino-1,3,5-triazine (*III*), m.p. 199—201°C (ref.[7] 200—201°C), and 2,4,6-trianilino-1,3,5-triazine (*XIV*, R = H), m.p. 229—231°C (ref.[8] 229 to 231°C) were prepared by known methods[6–8]. Methanol p.a. (Lachema, Brno) was distilled before use. 4-Dimethylaminobenzaldehyde p.a. (Lachema, Brno) melted at 73—74°C.

Kinetic Measurements

In all the cases of reactions (*A*)—(*C*) the decrease of aniline was followed analytically but the method of the proper procedure was different for the individual reactions with respect to the different reactivity of the various chlorine atoms. The reaction course according to the scheme (*A*)—(*C*) was proved by isolating the reaction products *II*, *III* and *XIV* (R = H) under the conditions of kinetic experiments; the products were identified by their melting points.

Reaction (A): 1 ml of methanolic aniline solution of a suitable concentration was added from a pipette into a 10 ml calibrated flask. The flask was placed in a thermostat, and, after adjusting the required temperature with the accuracy of $\pm 0.3°C$, 0.1 ml cyanur chloride (*I*) solution in tetrahydrofuran was injected into the flask by means of a calibrated syringe. After a definite time interval about 4 ml p-dimethylaminobenzaldehyde solution was added into the flask (see Analytical Method), the flask was removed from the thermostat, and, after attaining the temperature of 20°C, the volume was completed with the solution of the same reagent. The resulting mixture was submitted to photometrical analysis.

Reaction (B): 10 ml methanolic solution of the triazine *II* of suitable concentration was placed in a 50 ml flask equipped with a reflux condenser, the flask was immersed in the thermostat bath, and, after attaining the required temperature, 0.5 ml methanolic aniline solution was added. At definite time intervals samples were withdrawn, wherefrom, after cooling at 20°C, 1 ml amount was measured with a pipette and added into 10 ml calibrated flask which was, immediately afterwards, filled up to the mark with the reagent solution. Then the photometric analysis was carried out.
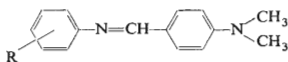
Reaction (C): 10 ml of methanolic solution of the chloro derivative *III* of a suitable concentration and 2 ml methanolic aniline solution were mixed in a flask. 1 ml portions of this mixture were placed in test tubes which were then sealed and immersed in the thermostate bath. At definite time intervals the individual test tubes were gradually removed from the bath, rapidly cooled at 20°C, and the content was transferred quantitatively in 10 ml calibrated flasks. After adjusting the volume with the reagent solution the photometric analysis was carried out. In this way also the reaction (*B*) was followed at 90°C.

Analytical Method

The Schiff's bases formed have their absorption maxima at such wavelengths (Table I) at which the remaining substances present in the reaction mixture absorb to a negligible extent only and

TABLE I

Photometric Characteristic of Solutions of Schiff's Bases under the Experimental Conditions Used

R	λ_{anal} nm	$\varepsilon_{anal} \cdot 10^{-4}$ 1/mol cm	R	λ_{anal} nm	$\varepsilon_{anal} \cdot 10^{-4}$ 1/mol cm
H	432	0·360	4-OCH$_3$	434	0·680
4-CH$_3$	438	0·505	4-Br	442	0·845
4-Cl	434	0·385	3-COOCH$_3$	436	0·700
3-Cl	435	0·283	3-COCH$_3$	438	0·333
3-NO$_2$	440	1·230			

TABLE II

The Rate Constants Values of Reaction (*A*) at 0°C Calculated according to Eq. (*1*)

$[I] \cdot 10^5$ mol/l	Aniline (Start. conc. $\cdot 10^5$ mol/l)		k 1/mol h	$[I] \cdot 10^5$ mol/l	Aniline (Start. conc. $\cdot 10^5$ mol/l)		k 1/mol h
5	*IV*	(3·0)	50·4 . 10^5	5	*VI*	(5·0)	92·0 . 10^5
5	*IV*	(6·0)	51·0 . 10^5	5	*VII*	(6·5)	15·2 . 10^5
3	*IV*	(9·0)	48·0 . 10^5	8	*VIII*	(5·0)	48·0 . 10^4
3	*IV*	(5·0)	52·0 . 10^5	7	*IX*	(5·0)	10·7 . 10^4
5	*IV*	(5·9)	61·7 . 10^{5a}	6	*X*	(5·0)	17·5 . 10^6
5	*IV*	(5·6)	31·6 . 10^{5b}	5	*XI*	(5·0)	16·3 . 10^5
5	*IV*	(5·9)	19·4 . 10^{5c}	5	*XII*	(5·0)	72·0 . 10^4
6	*V*	(5·0)	12·9 . 10^6	6	*XIII*	(5·0)	53·7 . 10^4

[a] Measured at 5°C; [b] at —5°C; [c] at —10°C.

do not interfere. The validity of the Lambert–Beer law was verified at these wavelengths for the experimental conditions chosen (Tables II, III and IV), and, at the same time, the calibration straight lines were constructred for individual substances. The value of the extinction coefficient depends on the amount of hydrochloric acid in the reagent used. The data of the Table I were obtained with the use of a reagent prepared as follows: 0·4 g p-dimethylaminobenzaldehyde was dissolved in 10 ml methanol, 5 ml conc. hydrochloric acid was added, and the volume was adjusted at 250 ml with methanol. The experimental error of the analysis of mixtures of a known content of components did not exceed 4%.

As the reactions (A), (B) resp. (C) are followed by rapid neutralization of the hydrochloric acid formed by the amine, the reaction rate is given by Eq. (1).

$$dx/dt = k(a - x)(b - 2x) \qquad (1)$$

TABLE III

The Rate Constant Values of Reaction (B) Calculated according to Eq. (1)

$[II] \cdot 10^3$ mol/l	Substituted aniline (starting concentration $\cdot 10^3$ mol/l)		t °C	k l/mol h	E kcal/mol
0·66	IV	(0·8)	20	$1·8 \cdot 10^2$	
0·72	IV	(1·6)	20	$1·6 \cdot 10^2$	
0·86	IV	(2·9)	20	$1·8 \cdot 10^2$	
0·86	IV	(1·1)	30	$4·3 \cdot 10^2$	
0·80	IV	(0·8)	40	$6·8 \cdot 10^2$	15·5
0·86	IV	(1·1)	50	$2·4 \cdot 10^3$	
$3·3 \cdot 10^{-2}$	IV	($3·5 \cdot 10^{-2}$)	90	$3·8 \cdot 10^4$	
0·86	V	(1·3)	30	$1·9 \cdot 10^3$	
0·86	V	(1·0)	50	$5·8 \cdot 10^3$	12·8
$3·3 \cdot 10^{-2}$	V	($3·5 \cdot 10^{-2}$)	90	$6·1 \cdot 10^4$	
0·86	VI	(1·1)	30	$1·0 \cdot 10^3$	
0·86	VII	(1·1)	30	$1·2 \cdot 10^2$	
$6·0 \cdot 10^{-1}$	VII	($3·1 \cdot 10^{-1}$)	90	$1·0 \cdot 10^4$	16·1
0·86	VII	(1·1)	50	$7·0 \cdot 10^2$	
0·86	$VIII$	(1·1)	50	$2·5 \cdot 10^2$	
$6·7 \cdot 10^{-1}$	$VIII$	($3·3 \cdot 10^{-1}$)	90	$3·5 \cdot 10^3$	15·2
0·86	$VIII$	(1·1)	30	$5·6 \cdot 10$	
0·86	IX	(1·1)	30	$1·0 \cdot 10$	
0·86	IX	(1·1)	50	$5·9 \cdot 10$	
$6·7 \cdot 10^{-1}$	IX	($3·7 \cdot 10^{-1}$)	90	$1·2 \cdot 10^3$	16·6
0·86	X	(0·88)	30	$3·9 \cdot 10^3$	
0·86	X	(0·77)	50	$15·7 \cdot 10^3$	
$3·3 \cdot 10^{-2}$	X	($3·3 \cdot 10^{-2}$)	90	$8·4 \cdot 10^4$	10·7
0·86	XI	(1·0)	30	$8·8 \cdot 10$	
0·86	XII	(1·1)	30	$7·0 \cdot 10$	

TABLE IV

The Rate Constant Values of Reaction (C) Calculated according to Eq. (1)

[III] . 10³ mol/l	Substituted aniline (starting conc. . 10³ mol/l)	t °C	k . 10⁻² l/mol h
0·86	IV (2·8)	90	1·4
0·63	IV (0·97)	90	1·5
0·63	IV (0·97)	85	1·1
0·80	IV (0·72)	95	1·9
0·63	IV (0·97)	100	2·4
0·63	IV (0·97)	105	3·2
0·86	V (2·7)	90	2·0
0·86	VII (2·9)	90	0·89
0·86	VIII (3·5)	90	0·78
2·8	IX (2·8)	90	0·55
2·8	X (3·2)	90	2·2
1·1	XI (3·1)	90	0·95
2·8	XII (2·8)	90	0·90
1·1	XIII (3·1)	90	0·80

The rate constant values were calculated from the integrated form of Eq. (1), viz.

$$kt = \frac{2 \cdot 303}{b - 2a} \log \left(\frac{a}{b} \cdot \frac{b - 2x}{a - x} \right),$$

where k is the rate constant to be calculated, a and b stand for the concentrations of the chloro derivative I, II or III and aniline at the beginning of the reaction respectivaly, and x is the amount of product at a time t.

RESULTS AND DISCUSSION

An analytical method was developed for kinetic study of the reactions $(A)-(C)$ based on the rapid reaction of the anilines with 4-dimethylaminobenzaldehyde giving coloured Schiff's bases (Table I). The bases are formed in an acid medium preventing the reactions $(A)-(C)$ studied from going on. Our original attempts to follow the chloride ion concentration by potentiometric titration or to determine the dichloro-triazine residue colorimetrically with the use of pyridine solution[6] were not successful. The potentiometric titration has the disadvantage of halogen being split off from the triazine nucleus by the titration reagent $(AgNO_3)$ during the reaction (A) and, to some extent, also (B). The colorimetric method with pyridine cannot be used for all the three reaction steps, and, besides that, the colour intensity of the solutions changes with time.

From the kinetic experiments it follows that the reactions (A), (B) and (C) are of the first order with respect to each of the both reaction components (see data in Tables II, III and IV) in the case of the substitution with aniline (IV). In methanolic solution and in the concentration range used no autocatalysis was detected in contrast to the analogous reaction in benzene[4]. The Arrhenius activation energy value (for the same aniline IV) is the lowest in the case of the reaction (A) (11·5 kcal/mol) whereas, in the case of the reactions (B) and (C), the differences are within experimental errors $(E_B = 15·5$ kcal/mol; $E_C = 14·9$ kcal/mol). The difference between substitution of the first and second chlorine atoms is thus greater than that between the second and third ones. The rate constant values stand in accord to this fact too (e.g. at 90°C: $k_A = 8 . 10^7$ l/mol h, $k_B = 3·8 . 10^4$ l/mol h, $k_C = 1·4 . 10^2$ l/mol h). Neither the statistical factors affect the reactivity order substantially.
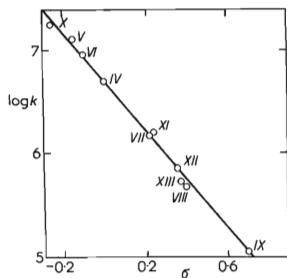

FIG. 1

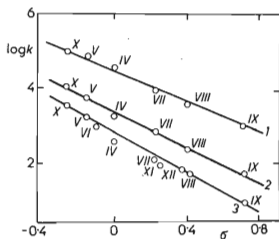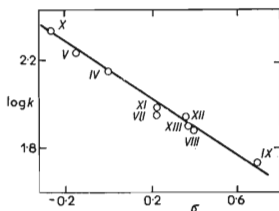Correlation of Rate Constants of Reaction (A) with σ Constants
Temperature 0°C; $\varrho = 2·6$.

FIG. 2

Correlation of Rate Constants of Reaction (B) with σ Constants
Temperature 90°C 1 $\varrho = 2·0$; 50°C, 2 $\varrho = 2·4$; 30°C, 3 $\varrho = 2·7$.

FIG. 3

Correlation of Rate Constants of Reaction (C) with σ Constants
Temperature 90°C; $\varrho = 0·7$.

The rate constant value of the reaction (A) was obtained by extrapolation from the linear dependence of the Arrhenius relation. The differences between the rate constant values show that the activating abilities of the chlorine atoms on the triazine nucleus are not additive. With respect to the differences in the reactivities of the chloro derivatives I, II and III found during the reactions with aniline (IV), the reaction sequence seemed to be a suitable model for solving a part of more general problems of selectivity and reactivity during organic reactions[9,10]. Therefore, after obtaining the kinetic data for the reaction of aniline IV, a series of analogous measurements were carried out with the respective m- and p-substituted derivatives. The reaction rate constants measured for a series of anilines $IV-XIII$ were correlated according to the Hammett equation[11,12] (see Figs 1—3). In the case of anilines $V-XIII$ such substituents were chosen that the mesomeric effect was not significant to the extent necessitating the use of the exalted σ^- values[11]. The ϱ values found for various reaction conditions are summarized in Figs 1—3. The value $\varrho_B = 3\cdot1$ (for 0°C) was obtained by extrapolation of the linear dependence of ϱ vs. $1/T$. These data of the reactions (A) and (B) stand in accord with the present views[10] that the selectivity of a reaction (which is expressed by the reaction constant ϱ of the Hammett equation) increases with decreasing reactivity. An anomaly was found in the case of the substitution of the last chlorine atom in the triazine nucleus (reaction (C); $\varrho = 0\cdot7$). The experimental material available does not, however, allow more than mere statement of this interesting fact.

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Translated by J. Panchartek.