*Russian Journal of Organic Chemistry, Vol. 37, No. 8, 2001, pp. 1117–1123. Translated from Zhurnal Organicheskoi Khimii, Vol. 37, No. 8, 2001, pp. 1176–1182.*


# Reactivity of Carboxamides toward Benzoyl Chloride in Acetonitrile

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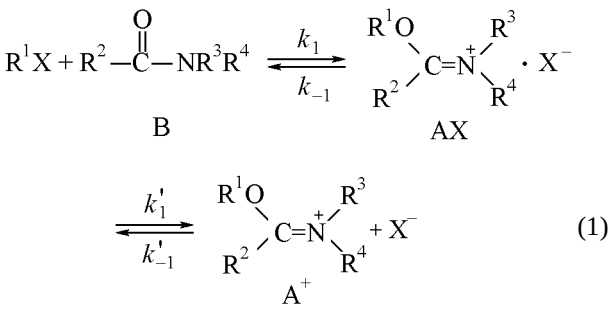
Received July 20, 2000

**Abstract**—Catalytic action of carboxamides at benzoyl chloride hydrolysis in acetonitrile at 25°C occurs by nucleophilic mechanism. Its first stage consists in reversible interaction between amides and substrate. The rate constants of the direct reaction were determined which characterized the oxygen-nucleophilic reactivity of amides toward benzoyl chloride. The assumption was confirmed that bimolecular addition of benzoyl chloride to the carbonyl oxygen of amides occurred in cyclic transition states.

The unfailing interest in the investigation of carboxamides properties is due to the versatility of their chemical transformations originating in its turn from the specific features of amide group structure [1]. Carboxamides are applied also as catalysts of organic reactions, in particular, of nucleophilic processes [2–5]. In the latter case two possible mechanisms are as a rule taken into consideration: nucleophilic (catalysis of acyl transfer [2, 3]), and general basic (catalysis of nucleophilic addition to a multiple heterobond [4]). As the nucleophilic (basic) center in the catalyst is presumed the oxygen and not nitrogen atom of the amide group.

The carboxamides are known as very weak organic bases, and the measurement of p$K_a$ thereof is a difficult experimental task. Therefore unlike the data on the other classes of organic compounds the information on their basicity is scarce and frequently ambiguous. As to the nucleophilic reactivity of amides, no such data existed before our first publication [3] concerning reactivity of carboxamides toward diphenyl chlorophosphate in acetonitrile.

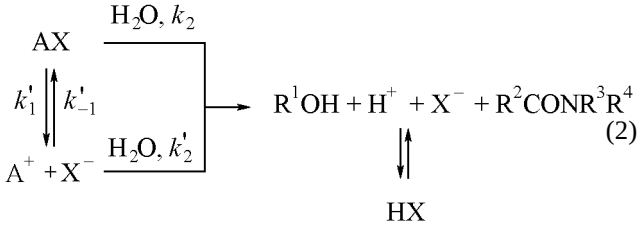
The difficulty in the experimental study of nucleophilic reactivity of amides [Scheme (1), stage $k_1$],



(1)

unlike the investigation of the catalytic activity, consists in the thermodynamic instability of the addition product (AX) [or ($A^+$)] that arises in reaction of amide (B) and electrophilic reagent $R^1X$. As a result, this product does not accumulate in the reaction system in sufficient amount to be detected by physicochemical methods.

In the absence of nucleophilic reagents (AX) [or ($A^+$)] species may undergo an intramolecular rearrangement, and in their presence (e.g., in the presence of water) nucleophilic substitution occurs affording stable compounds and recovering the amide [Scheme(2)].



(2)

Equations (1) and (2) correspond to a typical nucleophilic catalysis. We established [3] that in catalyzed by amides $R^2CONR^3R^4$ hydrolysis of diphenyl chlorophosphate ($R^1X$ = $Ph_2POCl$) in aqueous acetonitrile in the water concentration range 0.1–0.6 mol $l^{-1}$ the ratio of accumulation and consumption rates of the intermediate AX ($A^+$) permitted an evaluation of the $k_1$ value from the initial part of the kinetic curve.

In the present study we used this approach to he evaluation of the nucleophilic reactivity of carboxamides with respect to another electrophilic substrate,

**Table 1.** Pseudofirst-order rate constants $k_{\tau=0}$ of benzoyl chloride hydrolysis catalyzed with carboxamides (B) [acetonitrile, 25°C, $c(H_2O)$ 0.4 mol $l^{-1}$]

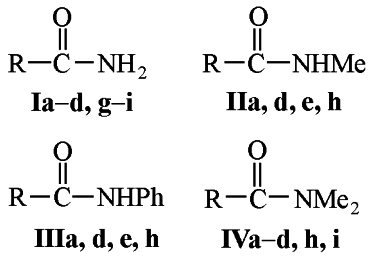
| $c(B)\times10^3$, mol $l^{-1}$ | $k_{\tau=0}\times10^3$, $s^{-1}$ | $c(B)\times10^3$, mol $l^{-1}$ | $k_{\tau=0}\times10^3$, $s^{-1}$ |
|---|---|---|---|
| 2-Methylpropionamide (**Ia**) | | *N*-Methyltrichloroacetamide (**IIi**) | |
| 0.257 | 2.44±0.15 | 9.96 | 0.526±0.037 |
| 0.449 | 4.36±0.23 | 13.6 | 0.821±0.077 |
| 0.674 | 5.57±0.13 | 22.7 | 1.08±0.02 |
| 0.962 | 9.33±0.26 | 31.8 | 1.45±0.03 |
| 1.28 | 11.0±0.06 | 39.8 | 1.87±0.13 |
| Acetamide (**Ic**) | | 2-Methylpropionanilide (**IIIa**) | |
| 0.0382 | 0.303±0.011 | 0.492 | 0.724±0.024 |
| 0.0764 | 0.474±0.037 | 0.983 | 1.58±0.07 |
| 0.314 | 2.58±0.05 | 0.983 | 1.58±0.07 |
| 0.314 | 2.58±0.05 | 1.97 | 2.20±0.16 |
| 0.397 | 3.54±0.41 | 2.95 | 3.18±0.17 |
| 0.597 | 5.49±0.83 | 3.93 | 4.35±0.10 |
| 0.764 | 5.87±0.64 | Acetanilide (**IIIb**) | |
| Formamide (**Ic**) | | 1.58 | 0.847±0.046 |
| 2.57 | 0.904±0.032 | 2.37 | 2.00±0.12 |
| 6.41 | 1.50±0.05 | 3.15 | 2.29±0.13 |
| 12.8 | 2.19±0.05 | 7.11 | 4.50±0.05 |
| 25.7 | 3.55±0.10 | Benzanilide (**IIId**) | |
| 38.5 | 6.38±0.37 | 2.58 | 1.01±0.03 |
| Benzamide (**Id**) | | 3.44 | 1.08±0.02 |
| 0.165 | 0.567±0.003 | 5.17 | 1.85±0.08 |
| 0.440 | 1.29±0.01 | 8.61 | 3.03±0.06 |
| 0.550 | 1.57±0.01 | 13.8 | 5.10±0.06 |
| 0.825 | 2.61±0.01 | Trichloroacetanilide (**IIIh**) | |
| 1.10 | 3.37±0.01 | 6.72 | 0.400±0.022 |
| α-Chloroacetamide (**If**) | | 17.9 | 0.967±0.074 |
| 0.266 | 0.489±0.003 | 31.4 | 1.73±0.02 |
| 1.06 | 2.21±0.01 | 35.8 | 2.13±0.15 |
| 1.33 | 2.39±0.02 | *N*,*N*-Dimethyl-2-methylpropionamide (**IVa**) | |
| 1.99 | 3.85±0.02 | 1.44 | 2.73±0.20 |
| 2.66 | 5.13±0.03 | 2.88 | 3.99±0.04 |
| 3-Nitrobenzamide (**Ig**) | | 4.31 | 5.31±0.16 |
| 0.574 | 0.625±0.030 | 4.60 | 6.29±0.21 |
| 0.862 | 0.962±0.030 | *N*,*N*-Dimethylacetamide (**IVb**) | |
| 1.15 | 1.12±0.03 | 1.26 | 0.787±0.042 |
| 1.72 | 1.61±0.10 | 1.88 | 1.76±0.07 |
| Trichloroacetamide (**Ih**) | | 2.52 | 2.00±0.13 |
| 5.40 | 2.51±0.08 | 5.04 | 4.60±0.05 |
| 6.75 | 4.72±0.13 | *N*,*N*-Dimethylformamide (**IVc**) | |
| 11.0 | 6.17±0.57 | 3.00 | 1.84±0.09 |
| 27.0 | 13.1±0.5 | 5.00 | 3.12±0.14 |
| 3,5-Dinitrobenzamide (**Ii**) | | 6.00 | 3.96±0.10 |
| 0.465 | 0.417±0.001 | 9.99 | 5.68±0.21 |
| 0.930 | 0.700±0.002 | | |
| 1.40 | 0.782±0.017 | | |
| 2.33 | 1.41±0.03 | | |

**Table 1.** (Contd.)

| $c(B)\times10^3$, mol $l^{-1}$ | $k_{\tau=0}\times10^3$, $s^{-1}$ | $c(B)\times10^3$, mol $l^{-1}$ | $k_{\tau=0}\times10^3$, $s^{-1}$ |
|---|---|---|---|
| *N*-Methyl-2-methylpropionamide (**IIa**) | | *N*,*N*-Dimethylbenzamide (**IVd**) | |
| | | 4.99 | 4.91±0.12 |
| 8.29 | 1.87±0.05 | 9.98 | 7.79±0.36 |
| 16.6 | 3.43±0.03 | 15.0 | 9.35±0.33 |
| 22.1 | 4.69±0.04 | 24.9 | 13.8±0.05 |
| 33.2 | 7.30±0.47 | *N*,*N*-Dimethyltrichloroacetamide (**IVe**) | |
| *N*-Methylbenzamide (**IId**) | | | |
| 7.78 | 0.788±0.006 | 3.46 | 0.958±0.025 |
| 10.4 | 1.09±0.02 | 6.91 | 1.22±0.03 |
| 15.6 | 1.75±0.02 | 14.6 | 2.62±0.25 |
| 26.0 | 3.26±0.16 | 24.2 | 3.44±0.28 |
| 41.5 | 5.26±0.23 | *N*,*N*-Dimethyl-3,5-dinitrobenzamide (**IVi**) | |
| *N*-Methyl-4-chlorobenzamide (**IIe**) | | | |
| | | 0.920 | 0.433±0.015 |
| 3.81 | 0.651±0.054 | 1.84 | 0.479±0.054 |
| 9.52 | 1.10±0.08 | 2.76 | 0.534±0.031 |
| 11.4 | 1.32±0.03 | 4.60 | 0.716±0.014 |
| 15.2 | 1.94±0.09 | | |

benzoyl chloride ($R^1X$ = PhCOCl). This substrate is widely used in the studies of catalytic activity of various organic bases, in particular, of amides of carboxylic and phosphoric acids [2, 5], in the aminolysis processes in aprotic media.

The hydrolysis of benzoyl chloride was studied in the presence of 22 amides that belonged to the following reaction series (**I–IV**).



**Ia–d, g–i** **IIa, d, e, h**

**IIIa, d, e, h** **IVa–d, h, i**

R (in the order of increasing $\sigma^*$-constant of the substituent): *i* - Pr (**a**), Me (**b**), H (**c**), Ph (**d**), 4-$ClC_6H_4$ (**e**), $CH_2Cl$ (**f**), $NO_2C_6H_4$ (**g**), $CCl_3$ (**h**), 3,5-$(NO_2)_2C_6H_3$ (**i**).

The study was carried out under the conditions previously used in the hydrolysis of diphenyl chlorophosphate [3]: 25°C, acetonitrile containing as a rule 0.4 mol $l^{-1}$ of water, the ratio of concentrations of reagents and catalyst $c(RX) << c(B) < c(H_2O)$ [$c(RX) \approx 10^{-6}\times10^{-5}$ mol $l^{-1}$]. Under these conditions the benzoyl chloride was quantitatively hydrolyzed to benzoic acid. The reaction rate was monitored con-

ductometrically by decrease in the electric resistance of solutions due to accumulation of ionic species in the system [equation (2)].

The apparent rate constants of pseudofirst order $k$ ($s^{-1}$) of the benzoyl chloride hydrolysis either decreased in the course of the process (usually at relatively low concentration of amide) or remained constant (Fig. 1). The decrease in constants $k$ is apparently due to the inhibition by the liberating chloride ion as confirms the significant reduction in the reaction rate at addition to the system of lithium chloride (Fig. 2). In this case we calculated the apparent rate constants $k_{\tau=0}$ ($s^{-1}$) at the initial moment by extrapolation of curvilinear relations $k = f(\tau)$ to the zero time with the use of a cubic polynomial [equation (3)], $a = k_{\tau=0}$.

$$k = a + b\tau + c\tau^2 + d\tau^3 \qquad (3)$$

When the value $k$ was constant in the course of the process we took as $k_{\tau=0}$ the average value of $k$.

In all cases the constants $k_{\tau=0}$ are significantly larger than the rate constant of the noncatalyzed hydrolysis of benzoyl chloride {$k_h$ $3\times10^{-4}$ $s^{-1}$ at $c(H_2O)$ 0.4 mol $l^{-1}$ [6]} that evidences the catalytic action of amides on the hydrolysis (Table 1). The values $k_{\tau=0}$ obtained by extrapolation or averaging are proportional to catalyst (B) concentration (Fig. 3), and the differences $k_{\tau=0}-k_h$ are independent of water concentration in the range 0.1–0.5 mol $l^{-1}$ (Fig. 4). These data correspond to the first order of reaction in amide and zero order in water.

The kinetic laws obtained are identical to those found for diphenyl chlorophosphate hydrolysis catalyzed by carboxamides [3], and for benzoyl chloride hydrolysis catalyzed by substituted and unsubstituted pyridines and pyridine N-oxides [6]. The conformity of the latter to the schemes of nucleophilic catalysis (1, 2) was discussed in detail [1, 2].

Thus in the range of water concentrations studied the expression for $k_{\tau=0}$ looks like (4).

$$k_{\tau=0} = k_h + k_1\,[B] \qquad (4)$$

The rate constant $k_1$ [l $mol^{-1}$ $s^{-1}$] is a characteristic of the oxygen-nucleophilic reactivity of amide. The values of $k_1$ calculated from the data of Table 1 along equation (4) are given in Table 2.

The effect of substituents R in amides on the reaction rate for the reaction series **I–IV** follows

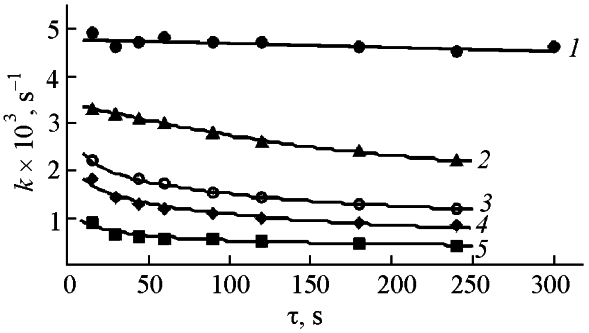



**Fig. 1.** Plot of apparent rate constants ($k$) as a function of time for benzoyl chloride hydrolysis in the presence of carboxamides (B) [acetonitrile, 25°C, $c$ ($H_2O$) 0.4 mol $l^{-1}$]. (*1*), (*2*) 2-Methylpropanoic acid N-methylamide, $c$ (B) $2.21\times10^{-2}$ mol $l^{-1}$ (*1*), $1.66\times10^{-2}$ mol $l^{-1}$ (*2*); (*3*) α-chloroacetamide, $c$ (B) $1.33\times10^{-3}$ mol $l^{-1}$; (*4*) *N*,*N*-dimethylformamide, $c$ (B) $3\times10^{-3}$ mol $l^{-1}$; (*5*) trichloroacetanilide, $c$ (B) $1.79\times10^{-2}$ mol $l^{-1}$.

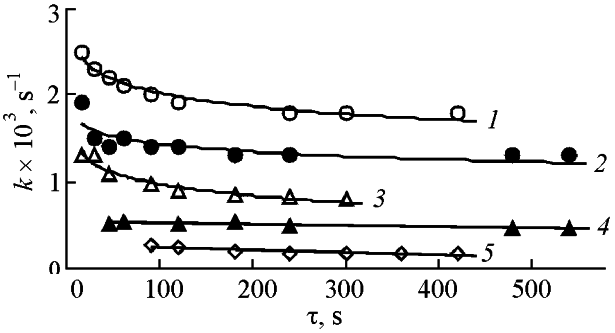



**Fig. 2.** Effect of lithium chloride on the hydrolysis rate of benzoyl chloride in the presence of acetamide (B) [acetonitrile, 25°C, $c$ ($H_2O$) 0.4 mol $l^{-1}$, $c$ (B) $3.14\times10^{-4}$ mol $l^{-1}$]; $c$ (LiCl), mol $l^{-1}$: (*1*) 0, (*2*) $3.18\times10^{-6}$, (*3*) $6.36\times10^{-6}$, (*4*) $1.27\times10^{-5}$, (*5*) $3.18\times10^{-5}$.

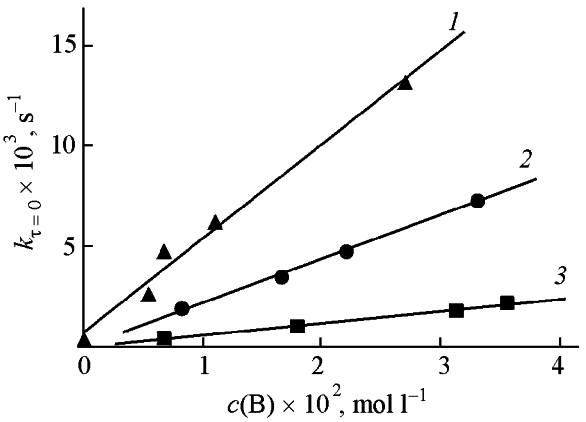



**Fig. 3.** Rate constants $k_{\tau=0}$ as a function of catalyst amide (B) concentration in benzoyl chloride hydrolysis [acetonitrile, 25°C, $c$ ($H_2O$) 0.4 mol $l^{-1}$]. (*1*) Trichloroacetamide, (*2*) *N*-methyl-2-methylpropionamide, (*3*) trichloroacetanilide.

**Table 2.** Second-order rate constants $k_1$ for reaction of carboxamides (B) with benzoyl chloride [acetonitrile, 25°C, $c$ ($H_2O$) 0.4 mol $l^{-1}$]

| Compd. no. | $k_1$, l $mol^{-1}$ $s^{-1}$ | $n$[a] | $r$[b] | Compd. no. | $k_1$, l $mol^{-1}$ $s^{-1}$ | $n$[a] | $r$[b] |
|---|---|---|---|---|---|---|---|
| **Ia** | 8.62±0.47 | 6 | 0.994 | **IIh** | 0.0395±0.0024 | 6 | 0.993 |
| **Ib** | 8.12±0.50 | 7 | 0.991 | **IIIa** | 1.00±0.05 | 6 | 0.996 |
| **Ic** | 0.144±0.013 | 6 | 0.983 | **IIIb** | 0.604±0.054 | 5 | 0.988 |
| **Id** | 2.88±0.15 | 6 | 0.994 | **IIId** | 0.354±0.016 | 6 | 0.996 |
| **If** | 1.85±0.07 | 6 | 0.997 | **IIIh** | 0.0518±0.0047 | 5 | 0.988 |
| **Ig** | 0.771±0.046 | 5 | 0.995 | **IVa** | 1.19±0.10 | 5 | 0.989 |
| **Ih** | 0.470±0.035 | 5 | 0.992 | **IVb** | 0.881±0.081 | 5 | 0.987 |
| **Ii** | 0.474±0.050 | 5 | 0.983 | **IVc** | 0.551±0.030 | 5 | 0.995 |
| **IIa** | 0.210±0.007 | 5 | 0.998 | **IVd** | 0.516±0.058 | 5 | 0.981 |
| **IId** | 0.125±0.007 | 6 | 0.994 | **IVh** | 0.131±0.011 | 5 | 0.990 |
| **IIe** | 0.102±0.010 | 5 | 0.986 | **IVi** | 0.0849±0.0074 | 5 | 0.989 |

[a] Number of points [including the point $c$ (B) 0 mol $l^{-1}$] used in calculation of $k_1$ constant according to equation (4).
[b] Coefficient of linear correlation according to equation (4).

Taft's equations (5–8) and it is presented graphically in Fig. 5.

In the series **I** (N-unsubstituted amines) was excluded from correlation a point of formamide (**Ic**) that strongly deviated downwards:

$$\log k_1 = (0.811\pm0.049)-(0.456\pm0.032)\sigma^* \quad (5)$$
$$r\ -0.988,\ s_0\ 0.087,\ n\ 7.$$

Series **II** (*N*-methylamides):

$$\log k_1 = -(0.733\pm0.006)-(0.270\pm0.004)\sigma \quad (6)$$
$$r\ -0.999,\ s_0\ 0.008,\ n\ 4.$$

Series **III** (*N*-phenylamides):

$$\log k_1 = -(0.152\pm0.040)-(0.461\pm0.031)\sigma \quad (7)$$
$$r\ -0.995,\ s_0\ 0.066,\ n\ 4.$$

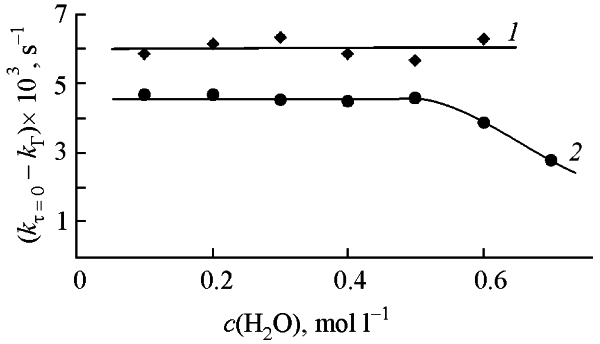



**Fig. 4.** Plot of values $k_{\tau=0}-k_h$ against water concentration for benzoyl chloride hydrolysis in amides (B) presence (acetonitrile, 25°C). (*1*) Acetamide, $c$ (B) $7.58\times10^4$ mol $l^{-1}$; (*2*) acetanilide, $c$ (B) $7.11\times10^3$ mol $l^{-1}$.

Series **IV** (*N*,*N*-dimethylamides):

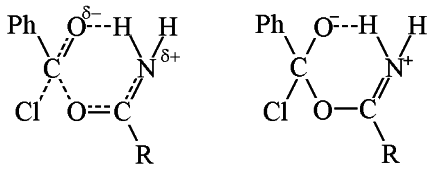
$$\log k_1 = -(0.041\pm0.027)-(0.365\pm0.018)\sigma \quad (8)$$
$$r\ -0.995,\ s_0\ 0.05,\ n\ 6.$$

Immediately apparent is a good fit to the Taft plots of points from aryl substituents R: unsubstituted phenyl (series **I–IV**), 4-chloro[series (**II**), 3-nitro (series **I**), and 3,5-dinitrophenyl (series **I** and **IV**). It means presumably that the conjugation between the π-electrons of the benzene ring and the π-system of the amide group is rather weak [3].

The fact that all the four reaction series fit to Taft's equation even when into the correlation are included such bulky substituents as *i*-Pr and $CCl_3$ indicates that the steric influence of R substituents in amides is insignificant. This is in agreement with assumption that the substrate RX attacks the sterically unhindered oxygen of the carbonyl group of the amide and not the nitrogen. The above reasoning suggests that the steric effect of the $NR^2R^3$ group also should be small.

From the analysis of the correlations (5, 6, 8) (see also Fig. 5) at equal values of σ for R substituents of amides may be constructed the following series of amides reactivity (the figures in parentheses mean the relative $k_1$ value for acetamides at $\sigma^* = 0$): $RCONH_2$ (~7) > $RCONMe_2$ (1) > RCONHMe (~0.2). This series does not coincide with the basicity series of the corresponding amides: $RCONH_2 < RCONMe_2 \approx$ RCONHMe [1]. The higher reactivity of N-unsubstituted amides **I** as compared to N,N-disubstituted

amides was also observed in reaction with diphenyl chlorophosphate [3].* This is due to stabilization of the transition state at the stage of attack of the electrophilic reagent by the formation of an intramolecular hydrogen bond. In the case of RX = PhCOCl it is represented by structure (B) (for the transition state) or (D) (for tetrahedral intermediate).

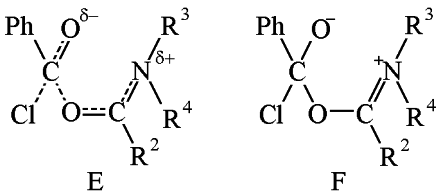


B D

This stabilization with N,N-disubstituted amines is impossible.Therefore it is presumably the reason of their lower (approximately 4–7 times) reactivity despite their higher basicity. With N-substituted amides **II** the stabilization of (B) or (D) type is possible only at a cis-configuration where the oxygen of the carbonyl group and the hydrogen atom of the NHMe group are located at the same side of the partially double bond C–N. It is known [1] however that *trans*-configuration of N-alkylamides is thermodynamically more stable. As we believe, this fact combined with lower basicity of N-substituted amides **II** with respect to N,N-disubstituted amides **IV** results in the lowest reactivity of amides **II**.

It is also interesting to compare the reactivity of two series of N-substituted amides: N-methyl- and *N*-phenylamides.The correlations (6, 7), Fig. 5 show that at similar $\sigma^*$ values of the R-substituents *N*-phenylamides **III** are more reactive than *N*-methylamides **II**, although the former are less basic [1]. In keeping with the above reasoning it should indicate that the contribution of cis-configuration is higher in N-phenyl- than in N-methylamides [9].

Thus it is possible to conclude that the reactions of N-unsubstituted amides **I** and *N*-phenylamides **III** proceed through transition states of B type [or intermediates of D type], and the reactions of *N*-methyl- **II** and *N*,*N*-dimethylamides **IV** go via acyclic states E or F.



E F

* Regretfully, the data on series **II** and **III** are lacking in [3].

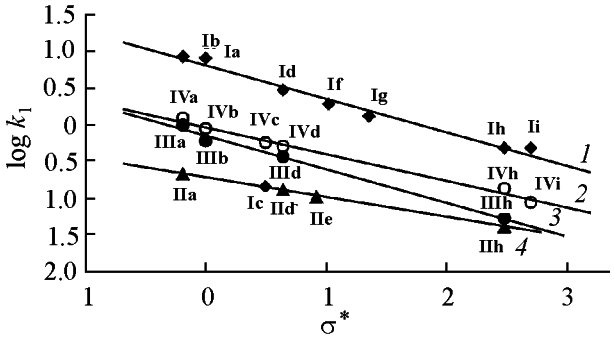
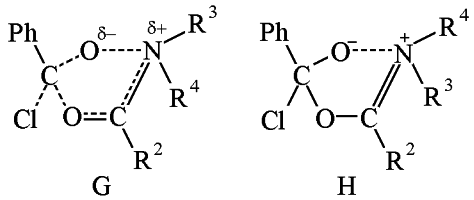



**Fig. 5.** Plot of rate constants $k_1$ [l mol$^{-1}$ s$^{-1}$] of reaction between amides and benzoyl chloride versus inductive constants $\sigma^*$ of substituent $R^2$ in amide $R^2CONR^3R^4$ [acetonitrile, 25°C, *c* ($H_2O$) 0.4 mol l$^1$], (*1*) N-Unsubstituted amides (**I**), (*2*) *N*,*N*-dimethylamides, (**IV**) (*3*) *N*-phenylamides (**III**) (*4*) *N*-methylamides (**II**) {$\sigma^*$ values for $R^2$ [$\sigma^0$ for $R^2$ = 3-$NO_2C_6H_4$ and 3,5-$(NO_2)_2C_6H_3$] from [7]; for nitro-substituted phenyls $\sigma^*$ values were calculated by a formula $\sigma^*$ ($XC_6H_4$) = $\sigma^*$ ($C_6H_5$) + $\sigma^0$($XC_6H_4$) [8]}.

This assumption is supported by the same values of $\rho^*$ constants in the Taft's equations for series **I** and **III** ($\rho^*$ –0.46) and close values for series **II** and **IV** ($\rho^*$ –0.27 and –0.36 respectively). Yet from the point of view of the assumed transition states the larger absolute value of $\rho^*$ for the cyclic transition state (B) as compared with acyclic transition state E seems unexpected. From the generally recognized position [10] the relation should be the opposite since the charge separation in the cyclic transition state is always less than in acyclic one. This controversity may be removed on assumption that amides **II** and **IV** react via cyclic transition states G [or tetrahedral intermediates (H)] where the cycle forms due to the interaction of charges on the oxygen atom in the acyl chloride and on the amide nitrogen.



G H

The cyclic character of the transition states B and G (or the respective intermediates) is also suggested by relatively small absolute values of $\rho^*$.

Interestingly enough is to find the place of amides as nucleophiles among the other oxygen bases. To this end are commonly compared Bronsted relations for different classes of nucleophilic reagents. We established that such oxygen bases as unsubstituted

and substituted pyridine N-oxides [6] and phosphin oxides [11] behave in the processes of acyl transfer as "supernucleophilic" reagents as compared to nitrogen bases (e.g., of pyridine series). To our regret we were unable to construct a proper correlation between the reactivity of amides in the reaction under study and their basicity in acetonitrile due to the lack of $pK_a^{MeCN}$ data for the most of amides. It was only possible to make a qualitative correlation between the reactivity of amides and the other base toward benzoyl chloride, and their basicity in water. Proceeding from Bronsted equation we obtained from the data of [6] the following correlations for the reactions with benzoyl chloride in acetonitrile of bases from the series of pyridine N-oxide [equation (9)] and of pyridine [equation (10)].

$$\log k_1 = (2.22 \pm 0.17) + (1.55 \pm 0.14)\, pK_a^{H_2O} \quad (9)$$
$$r\ 0.983,\ s_0\ 0.40,\ n\ 6.$$

$$\log k_1 = -(3.43 \pm 0.29) + (0.71 \pm 0.04)\, pK_a^{H_2O} \quad (10)$$
$$r\ 0.991,\ s_0\ 0.24,\ n\ 7.$$

As follows from equation (9) for pyridine N-oxide of basicity $pK_a^{H_2O}$ –0.35 (the same as by acetamide [1], one among the strongest of amides) the $\log k_1$ value is equal to 1.7. The experimental value of $\log k_1$ for acetamide is 0.9 (Table 2). The pyridine derivative of this basicity would have the value $\log k_1$ –3.7 as estimated along equation (10). With the less basic amide, N-methylbenzamide, ($pK_a^{H_2O}$ –1.5 [1]) the corresponding $\log k_1$ values are –0.10, –0.9 (Table 2, and –4.5. Thus we can conclude that by the reactivity the amides are close to such bases as pyridine N-oxide and its derivatives. According to the terms used in [2, 3, 6] amides may be regarded as "supernucleophilic" oxygen bases.

The "supernucleophilicity" phenomenon (in particular, α-effect) that consists in positive deviation of reactivity from the Brønsted relationship for the so-called "normal" nucleophiles is rationalized as caused by additional interactions in the transition state which are lacking in the protonated base [12]. The structure of transition states B and G (or intermediates D and H) suggest that the high reactivity of carboxamides contrary to their low basicity is due to easy delocalization of the amide nitrogen electron pair to the carbonyl oxygen of substrate along the system $\overset{\delta+}{\curvearrowright}\!\!>\!N{=}C{=}O\cdots C{=}O^{\delta-}$, and with additional stabilization of these states by intramolecular hydrogen bond B or by electrostatic interactions G.

In the protonated form of amide ($>\!\overset{+}{N}{=}COH$) these interactions are obviously lacking.

In keeping with the notion of delocalization in the transition states (or intermediates) of the electron pair belonging to amide nitrogen we can consider the previously mentioned significant negative deviation of the formamide point in relation (5). It is known that in correlations according to Taft's equation for various organic reaction the deviation of the point corresponding to the unsubstituted compound is frequently observed. It is commonly rationalized as a "special" effect of a hydrogen atom with unclear nature. If we apply this explanation then would be incomprehensible the fact, that the reactivity of a related compound (*N*,*N*-dimethylformamide) is well described with equation (8). Also should be taken into account that similar pattern follow the correlations of amide reactivity with respect to diphenyl chlorophosphate [3]. Therefore it is reasonable to assume that the deviation of the formamide point from the corresponding correlation (Fig. 5, *1*) originates from certain specific features of its electron structure different from that of the other amides. In a review [1] are reported data that in contrast to the majority of amides possessing planar structure of the amide fragment due to the conjugation of the nitrogen electron pair with the C=O bond (limiting structure **I**, or intermediate **J**), in the formamide the respective fragment is not planar (The hydrogen atoms bonded to nitrogen are outside of the OCN plane). In the other words, the conjugation in formamide is virtually absent (limiting structure K).

Recent proofs of the planar structure of formamide [14] concern an isolated molecule or a molecule in the gas phase and apparently cannot characterize the spatial arrangement of a formamide molecule in so specific solvent as acetonitrile.

The delocalization of the nitrogen electron pair in the course of the nucleophilic attack virtually corresponds to transformation of the amide structure into the limiting form (I) where the amide conjugation is complete. This process is the easier the more planar is the structure of the original amide. Probably just the nonplanar structure of formamide results in its reduced reactivity. Therefore it is not excludes that the attack of the benzoyl chloride is directed on the nitrogen and not the oxygen of the formamide.

## EXPERIMENTAL

The reactions were carried out in a conductometric cell with platinum flat parallel electrodes at temperature control. Electric resistance of the solutions was measured with RLCG Bridge–Voltmeter BM-559.

The apparent rate constants $k$ ($s^{-1}$) were calculated as in [3].

Benzoyl chloride was subjected to vacuum distillation, acetonitrile was purified as described in [15]. 2-Methylpropionamide and *N*-methylbenzamide were recrystallized from benzene, trichloro and α-chloroacetamides, *N*-methyl-4-chlorobenzamide, *N*-methyltrichloroacetamide, and trichloroacetanilide from ethanol, 2-methylpropionanilide from 2-propanol, *N*,*N*-dimethylbenzamide, *N*-methyl-2-methylpropionamide, and *N*,*N*-dimethyltrichloroacetamide were distilled in a vacuum. The other amides were purified as described elsewhere [3].

The hydrolysis product of benzoyl chloride was isolated for the cases of catalysis with acetamide and formamide. To 604 mg of benzoyl chloride at stirring was added a solution of 1.181 g of acetamide in a mixture of 5 ml of acetonitrile and 3.6 ml of water. The reaction mixture was left standing at room temperature for 24 h. The benzoic acid formed was precipitated by adding a little cold water, filtered off, and dried at room temperature, yield 0.504 g (quantitative), mp 122°C (mp 122.5°C [16]). Similarly was demonstrated that at catalysis with formamide benzoyl chloride was hydrolyzed also to benzoic acid (quantitative yield).

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