HETEROCYCLIC NITRO COMPOUNDS

XV.* KINETICS OF THE REACTION OF 1-METHYL-3-NITRO-5-HALO-1,2,4-TRIAZOLES WITH HYDROXIDE IONS

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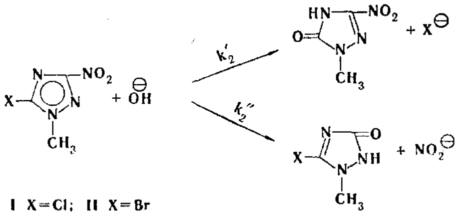
The kinetics of the reaction of 1-methyl-3-nitro-5-chloro-1,2,4-triazoles and 1-methyl-3-nitro-5-bromo-1,2,4-triazoles with hydroxide ions were studied. The reaction leads to replacement of the halogen or nitro group, and the ratio of the rates of substitution is 30 : 1. The mutual influence of the halogen and nitro group on the rate of substitution as a function of their position in the ring was examined.

In the reaction of 1-methyl-3-nitro-5-halo-1,2,4-triazoles with nucleophilic reagents, the halogen in the 5 position is replaced to give 1-methyl-3-nitro-5-substituted 1,2,4-triazoles [2]. However, one cannot exclude the possibility of replacement of the nitro group in the 3 position, although the corresponding reaction products have not been isolated [2]. To elucidate these problems and to evaluate and compare the substitution of halogen and the nitro group in the triazole ring, in the present research we have studied the kinetics of the reaction of 1-methyl-3-nitro-5-chloro-1,2,4-triazole (I) and 1-methyl-3-nitro-5-bromo-1,2,4-triazole (II) with hydroxide ions. The reactions of I and II with hydroxide ion were carried out in aqueous solutions in the presence of excess sodium hydroxide. The course of the reaction was monitored from the buildup of halide and nitrite anions.

Preliminary experiments demonstrated that substitution of both the halogen and the nitro group occurs during the reaction. The nitrite ion concentration during the reaction increases from zero to 2.7-2.9% of the initial I and II concentrations. Since, as demonstrated by special experiments, substitution of the nitro group does not occur in the product of the substitution of halogen by the hydroxyl group, the appearance of nitrite ion in the reaction mixture should be ascribed to the simultaneous substitution of the 3-nitro group in I and II.



I X=Cl; II X=Br

The effective rate constants for substitution of halogen (k'_1) and the nitro group (k''_1) in the presence of excess alkali were calculated by the methods used for calculations of the rates of parallel reactions [3]. The corresponding second-order reaction rate constants were obtained by division of k'_1 and k''_1 by the hydroxide ion concentration:

$$k'_2 = k'_1/[OH^{\ominus}];\ k''_2 = k''_1/[OH^{\ominus}].$$

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*See [1] for communication XIV.

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TABLE 1. Rate Constants for Substitution of Halogen (k') and the Nitro Group (k") by Hydroxide Ions in I and II

Compound	T, °C	$c_0 \cdot 10^3$, M	$[OH^-]$, M	$k'_1 \cdot 10^4$, sec⁻¹	$k'_1 \cdot 10^5$, sec⁻¹	$k'_2 \cdot 10^4$, liter/mole-sec	$k'_2 \cdot 10^5$, liter/mole-sec
I	26,6	21,55	0,8685	1,12	0,297	1,29	0,342
	38,6	10,84	0,1670	0,713	0,205	4,27	1,23
	38,6	19,97	0,3210	1,42	0,392	4,41	1,22
	48,8	20,06	0,3190	4,09	1,17	12,8	3,67
II	30,1	20,25	0,7250	0,916	0,304	1,26	0,419
	39,7	20,18	0,7920	2,78	0,949	3,51	1,20
	49,1	15,02	0,3200	2,66	1,03	8,32	3,23

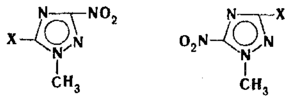
TABLE 2. Activation Parameters for Substitution of Halogen and the Nitro Group by Hydroxide Ions in I and II

Compound	Substitution	E_A, kcal/mole	lg A	ΔH_{25}, kcal/mole	ΔS_{25}, eu
I	Chlorine	19,8	10,6	19,2	−12,2
	Nitro group	20,5	9,5	19,9	−17,1
II	Bromine	19,3	10,0	18,7	−14,7
	Nitro group	20,9	9,7	20,3	−16,1

The rate constants for substitution of halogen and the nitro group by hydroxide ions in I and II and the activation parameters of the reactions are presented in Tables 1 and 2.

Comparison of the reactivity of the nitro group in the 5 position in 1-methyl-3,5-dinitro-1,2,4-triazole [1, 4] with the rates of substitution of halogen in I and II obtained in this research gives the sequence $NO_2 \gg Cl \sim Br$, which is in agreement with the regularities usually observed in nucleophilic substitution [5, 6]. However, while the ratio of the rates of substitution of the nitro group and chlorine (bromine) in previously described cases was 200-1000 : 1, the value for the triazoles is ~300,000 : 1. The reason for this difference in the reactivities, in our opinion, consists in partial conjugation of the p electrons of chlorine with the π-electron system of the ring and the increase in the multiplicity of the C−Cl bond. The possibility of this sort of interaction is confirmed by quantum-chemical calculations of the molecules of 3-chloro- and 3-bromo-1,2,4-triazoles [12], which demonstrated that halogens act as electron donors with respect to the triazole ring.

Interesting data were obtained during a quantitative comparison of the mutual effect of chlorine and the nitro group as a function of their position in the triazole ring in 1-methyl-3-chloro-5-nitro-1,2,4-triazole (III) and the corresponding 1-methylnitrotriazoles that do not contain halogens (IV, V):



I X=Cl; IV X=H; III X=Cl; V X=H

While substitution of the chlorine in I proceeds 30 times faster than substitution of the nitro group, the chlorine in III undergoes practically no substitution (analytically determinable amounts of Cl^- ions cannot be detected in solution) [1]. The ratio of the substitution rate constants for the nitro groups in III and V is 117,* compared with 50 in I and IV.* The introduction of a chlorine atom into the 5 position of IV leads to a smaller increase in the reaction rate than the introduction of a chlorine atom into the 3 position of V.

Thus we here encounter different types of transmission of the effect of the substituents to the reaction center as their sites are changed. This phenomenon may be due to the different contributions of the mesomeric effect (+M) of chlorine in the 5 and 3 positions. In I, the +M effect of chlorine and the overall direction of polarization of the ring act in coordination, which also leads to a relatively lesser increase in the rate of substitution of the nitro group in the 3 position. On the other hand, the +M effect of chlorine in 1-methyl-3-chloro-5-nitro-1,2,4-triazole (III) does not coincide with the overall shift of the π-electron cloud of the ring, and its action on the reaction center is partially "extinguished" (although it cannot be completely

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* The rate constants for substitution of the nitro groups in III, IV, and V were taken from [1].

excluded [1]). The difference in the transmission of the +M effect of halogen from the 3 and 5 positions of the ring can be explained by the different possibilities of delocalization of the p electrons in the corresponding systems.

EXPERIMENTAL

Compounds I and II were synthesized by the method in [2] and were additionally crystallized twice.

The method used to perform the kinetic experiments was similar to the method previously described in [1]. The reagents were mixed by pouring together the alkali solution with a solution (200-250 ml) of the halo derivative in the reaction apparatus. The nitrite ion concentration was determined by photocolorimetry [4]. To determine the halide ion concentrations, a 10-ml sample was selected from the reaction apparatus and poured into 0.5 N sulfuric acid solution (10-20 ml) to stop the reaction. The solution was titrated with 0.5 N sodium hydroxide with phenolphthalein as the indicator, and the small excess of alkali was back-titrated with 0.5 N acetic acid until the phenolphthalein coloration vanished, after which the solution was pure green in color. The solution was then diluted to 35-40 ml with distilled water and titrated with 0.05 N mercuric nitrate in the presence of diphenylcarbazide (0.5% solution in ethanol) [13] to give a violet color with the Hg^{2+} ion. The indicator was added prior to the end of the titration as the green color vanished. The chief product of the reaction – 1-methyl-3-nitro-1,2,4-triazol-5-one – also gives a slightly dissociated and slightly soluble salt with divalent mercury. When both the halide ion and the triazolone are simultaneously present, the halide ion is titrated initially followed by titration of the triazolone. The end of the titration was readily established from the disappearance of the green color of the triazolone anion and the subsequent rapid appearance of the violet color of the product of the oxidation of diphenylcarbazide with excess divalent mercury. The presence of nitrite ions in neutral media (pH 6-7) did not affect the results of the titration. The error in the determination of the rate constants, which was calculated by the methods of mathematical statistics, was ±5%.

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