REACTIVITIES OF HETEROCYCLIC COMPOUNDS DURING NITRATION

III.* NITRATION OF SOME PYRROLE DERIVATIVES

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The mechanism of nitration of 2-nitro-, 3-nitro-, 1-methyl-, and 2- and 1-methyl-3-nitropyrroles in a mixture of sulfuric and nitric acids is similar to the mechanism of nitration of benzene. A 1-methyl group activates the investigated compounds only slightly.

It is known that pyrrole is more reactive than benzene by a factor of 53,000 during nitration in acetic anhydride [2]. We were interested in the reactivities of pyrrole and its nitro and 1-methyl derivatives in sulfuric and nitric acid. We were unable to study the nitration of pyrrole, inasmuch as the substrate underwent resinification. In the case of 3-nitropyrrole it was shown that the rate constant (k_1) is directly proportional to the nitric acid concentration in the case of constant sulfuric acid concentration and under pseudo-first-order conditions. The relationship between the rate of nitration and the acidity of the medium (Table 1) was studied for 3-nitro (I), 2-nitro- (II), 1-methyl-3-nitro- (III), and 1-methyl-2-nitropyrroles (IV). Like benzene derivatives, which have a linear relationship between log k_2 and the acidity function of the medium [4], the investigated pyrrole derivatives also are subject to this relationship. The activation parameters for the nitration of 3-nitropyrrole (Table 2), which are close to those for benzene [4], indicate coincident mechanisms for the nitration of these compounds.

The reactivities with respect to benzene and the partial rate factors of pyrrole derivatives during their nitration with nitric acid in a 71.5% solution of sulfuric acid at 25°C are presented in Table 3. Using the data from [2] we calculated that the introduction of a nitro group into the 3 position lowers the reactivity of pyrrole by a factor of $2.6 \cdot 10^4$, whereas introduction of a nitro group into the 2 position lowers the reactivity by a factor that is 5.9 times greater. Thus although the deactivating effect of a nitro group in the pyrrole ring is considerable, it is less than in benzene derivatives, in which it amounts to $5.8 \cdot 10^8$ [5, 6]. A methyl group in the 1 position causes a slight increase in the reactivity. An increase in the fraction of the 2,4-dinitro isomer (V and VII, respectively) is observed for 2-nitropyrroles II and IV, and this is apparently due to steric hindrance, just as in iodination [7] or nitration in acetic anhydride [8].

EXPERIMENTAL METHOD

The UV spectra and the kinetic measurements were made with an SF-4 spectrophotometer.

A modified method [9] was used to obtain 2- and 3-nitropyrroles by nitration of pyrrole wtth nitric acid (70%) in acetic anhydride at 0-15°. The mixture of isomers was separated with a column filled with aluminum oxide with elution by petroleum ether–ether (3 : 1). The yield of 3-nitropyrrole was 15%. 1-Methyl-2- and 1-methyl-3-nitropyrroles were obtained by nitration of 1-methylpyrrole [9] and were separated by vacuum sublimation at 60°. Dinitropyrroles V-VIII were obtained by known methods [9] from mononitropyrroles. 2,5-Dinitropyrroles VI and VIII were recrystallized from HNO_3 (sp. gr. 1.3), whereas

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*See [1] for communication II.

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TABLE 1. Rate Constants for the Nitration of Pyrrole Derivatives with HNO_3 in H_2SO_4 Solution at 25 ± 2°C

Substrate	$C_{H_2SO_4}$, wt. %	$C_{HNO_3} \cdot 10^3$, M	$(H_R + \lg a_{H_2O})$*	$k_1 \cdot 10^3$, sec^{-1}	$k_2 \cdot 10$, liter $\cdot$ $mole^{-1} \cdot sec^{-1}$
I	68,25	4	12,27	0,451	1,13
	69,35	4	12,63	1,176	2,94
	69,35	10	12.63	2,95	2,95
	69,35	28,6	12,63	8,574	2,998
	69,8	29,7	12,77	15,35	5.17
	70,4	4	12,97	2.71	6.78
	70,4	50	12,97	32	6.40
	70.85	4	13,13	3,82	9,55
	71,6	4	13,37	6,923	17,35
	72.5	6	13,67	25,53	42,55
	74,5	1	14,34	33,13	331,3
II	69,8	29,7	12,77	2.429	0,818
	70,4	4	12,97	0.439	1,098
	71,6	4	13,37	1,193	2,98
	72,5	6	13,67	3,648	6,08
	74,5	1	14,34	4,64	46,4
III	69,8	29,7	12,77	20,55	6,92
	70.4	50	12,97	44,55	8,91
	71.6	4	13,37	12.08	30,2
	72,5	6	13,67	47,73	79,55
	74,5	1	14,34	39,79	397,9
IV	69.8	29.7	12,77	3,356	1.13
	70.4	50	12,97	6.30	1,26
	71.6	4	13,37	1,784	4,459
	72,5	6	13.67	4.803	8.005
	74.5	1	14.34	6.03	60,3

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*According to [3].

TABLE 2. Activation Parameters for the Nitration of 3-Nitropyrrole and Benzene in H_2SO_4

Compound	Temp., °C	k_2, liter $\cdot$ $mole^{-1}$ $\cdot$ sec^{-1}	ΔE, kcal $\cdot$ $mole^{-1}$	lg A	ΔS, kcal $\cdot$ $mole^{-1} \cdot {}^\circ K^{-1}$
I*	25	33,14	12.8	10.9	−10,6
	20	22,39			
	15	15,65			
	10	10,5			
Benzene†	2—25	—	13,9	9,5	−11‡

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*$C_{H_2SO_4}$ 74.5%, C_{HNO_3} 10^{-3} M, and $C_{substrate}$ 10^{-4}–10^{-5} M.

†$C_{H_2SO_4}$ 73.2%, C_{HNO_3} $5.9 \cdot 10^{-4}$ M, and $C_{substrate}$ 10^{-4}–10^{-5} M, according to the data in [4].

‡Calculated from the results in [4].

TABLE 3. Rate Constants (k_2) for the Nitration of Nitropyrroles in 71.5% Sulfuric Acid, Isomeric Composition of the Products, and Partial Rate Factors

Compound	k_2, liter $\cdot$ $mole^{-1}$ $\cdot$ sec^{-1}	K_{rel}†	K'_{rel}‡	Ratio of isomers with nitro group in ind. position		f	
				4	5	f_4	f_6
Benzene	0.8222	1	$1{,}89 \cdot 10^{-5}$	—	—	—	—
I	1.698	2,07	$3{,}90 \cdot 10^{-5}$	—	100	—	12,42
II	0,2884	0.35	$0{,}66 \cdot 10^{-5}$	60	40	1,26	0,84
III	2,692	3,27	$6{,}17 \cdot 10^{-5}$	—	100	—	19.6
IV	0.3631	0,44	$0{,}83 \cdot 10^{-5}$	77	23	2.04	0.6
Pyrrole*	—	53 000	1	20	80	30 000	13 000

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*According to the data in [2], in acetic anhydride.

†With respect to benzene.

‡With respect to pyrrole.

TABLE 4. Characteristics of the Nitropyrroles

Compound	mp, °C	λ_{max}, nm*	ε_{max}
I	64—65	359	13 000
II	101	290	6200
III	31—32	362,5	12 700
IV	64,5—65,5	305	6000
2,4-Dinitropyrrole (V)	150—151	332	12 800
2,5-Dinitropyrrole (VI)	174—175	348	16 000
1-Methyl-2,4-dinitropyrrole (VII)	95—95,5	336	11 600
1-Methyl-2,5-dinitropyrrole (VIII)	97—98	357,5	15 000

*In 68% H_2SO_4.

the remaining derivatives were recrystallized from H_2O. The melting points and UV spectra of the investigated pyrroles are presented in Table 4. An increase in the sulfuric acid concentration to 74% had no effect on the UV spectra.

The nitrating mixture was prepared by dissolving a weighed amount of potassium nitrate in sulfuric acid. The percentage composition of the sulfuric acid was determined from its density.

Method for the Kinetic Study. A nitrating mixture of the required concentration was placed in a thermostatted cuvette (±0.1°), after which a drop of a concentrated solution of the substrate (0.2-0.3 M) in CH_3COOH was added. Under these conditions the concentration of the substrate in the sulfuric acid–nitric acid mixture was 10^{-4}-10^{-5} M. Inasmuch as the spectra of the nitropyrroles are superimposed (Table 4), the change in the optical density with time was determined for both the starting materials and final products. The spectra of the solutions during the nitration of 3-nitro- and 1-methyl-3-nitropyrroles corresponded to the quantitative formation of the 2,4-dinitro product. In the case of 2-nitro- and 1-methyl-2-nitropyrroles, in the nitration of which two isomers are formed, the isomeric composition of the products was determined by the method in [10] (Table 3). The instantaneous concentrations of the starting materials and final products were calculated from the equations [11]

$$D\lambda_1 = \varepsilon_1\lambda_1 C_1 l + \varepsilon_2\lambda_1 C_2 l,$$

$$D\lambda_2 = \varepsilon_1\lambda_2 C_1 l + \varepsilon_2\lambda_2 C_2 l.$$

The reaction rate constants were determined graphically by the method in [12]. Inasmuch as the absorption of 3-nitropyrroles is very slight (Table 4), the rate constants for nitration were measured from the increase in the optical density of 2,4-dinitropyrrole at λ_{max} 332 nm and of 1-methyl-2,4-dinitropyrrole at λ_{max} 336 nm. The difference between the rate constants calculated from the concentrations and from the optical densities did not exceed 3%, and the measurements for 3-nitropyrroles were therefore made at the wavelength of absorption of the final 2,4-dinitro product, and the rate constant was calculated from the optical density. The averaged results of three parallel experiments are presented in Table 1.

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