Chemistry of Heterocyclic Compounds, Vol. 33, No. 11, 1997

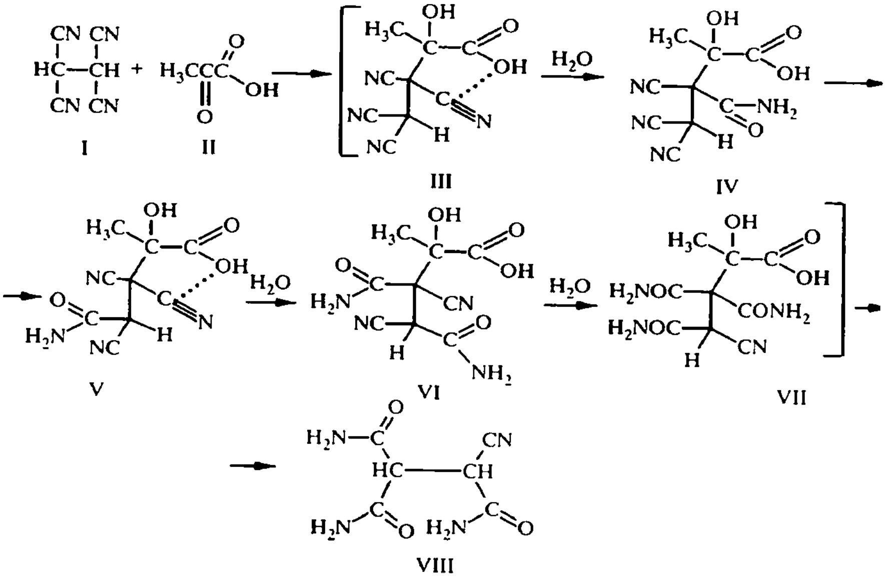
UNUSUALLY READY HYDROLYSIS OF NITRILE GROUPS IN 1,1,2,2-TETRACYANOETHANE BY PYRUVIC ACID

O. E. Nasakin, V. V. Pavlov, A. N. Lyshchikov,
P. M. Lukin, V. N. Khrustalev, and M. Yu. Antipin

A scheme for the unusually ready selective hydrolysis of three of the cyano groups in 1,1,2,2-tetracyanoethane to 2-cyanoethane-1,1,2-tricarboxamide by the action of pyruvic acid was proposed. Only one cyano group undergoes hydrolysis in the reaction with sodium pyruvate. In the course of this reaction, 2-amino-5-methyl-3,4-dicyano-4,5-dihydrofuran-4,5-dicarboximide, the structure of which was determined by x-ray diffraction investigation of the monocrystal, is formed.

Fairly drastic conditions are required for the hydrolysis of organic nitriles. We showed previously that 1,1,2,2-tetracyanoethane (I) is converted to 2-cyanoethane-1,1,2-tricarboxamide with a small exothermic effect in an aqueous solution of pyruvic or chloropyruvic acid [1]. We were interested in this unusual selective hydrolysis of three nitrile groups in sym-tetracyanoethane (I) and the resulting ethane (VIII), itself, being a new CH-acid with good possibilities for synthesis due to the carboxamide portions and the cyano group in its structure.

It was established as a result of work carried out that esters of these acids do not lead to the cyanoethane (VIII) under analogous conditions with tetracyanoethane. This fact indicates the decisive role of the carboxyl group in the process of hydrolysis. By using the comparison with other data, we proposed the following scheme for the formation of compound (VIII).



In the first stage, addition of tetracyanoethane occurs at the carbonyl group of pyruvic acid by analogy with other carbonyl compounds [2] with the formation of the adduct (III), in which the carboxyl group is coordinated to one of the neighboring cyano groups. This probably assists the ready addition of a molecule of water. Since the cyano group is a stronger

---

I. N. Ul'yanov Chuvashsk State University, Cheboksary 428015. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 11, pp. 1472-1476, November, 1997. Original article submitted February 3, 1997.

0009-3122/97/3311-1272$18.00

TABLE 1. Coordinates of the Atoms in the Molecule of (XI) ($\times 10^4$)

Atom	*x*	*y*	*z*
$C_{(1)}$	5477(1)	3014(2)	6194(1)
$C_{(2)}$	4568(1)	4115(2)	6335(1)
$C_{(3)}$	5124(1)	1562(2)	5949(1)
$C_{(4)}$	6520(1)	3448(2)	6254(1)
$C_{(5)}$	4412(1)	4438(2)	7140(1)
$C_{(6)}$	4651(1)	5660(2)	5946(1)
$N_{(3)}$	5623(1)	236(2)	5755(1)
$N_{(4)}$	7376(1)	3817(3)	6281(1)
$N_{(5)}$	3587(1)	3504(2)	7357(1)
$N_{(6)}$	4765(2)	6836(2)	5641(1)
$C_{(1')}$	3097(1)	2658(2)	6830(1)
$C_{(2')}$	3639(1)	3024(2)	6117(1)
$C_{(3')}$	2900(2)	3639(3)	5556(1)
$O_{(1')}$	2368(1)	1766(2)	6900(1)
$O_{(2')}$	4085(1)	1505(1)	5870(1)
$O_{(3')}$	4937(1)	5302(2)	7501(1)
$H_{(3NA)}$	6274(18)	151(26)	5857(11)
$H_{(3NB)}$	5283(18)	-676(29)	5640(13)
$H_{(5N)}$	3359(16)	3476(25)	7792(11)
$H_{(3'A)}$	2359(17)	2811(27)	5439(11)
$H_{(3'B)}$	3284(17)	3850(26)	5096(12)
$H_{(3'C)}$	2567(20)	4576(30)	5723(12)

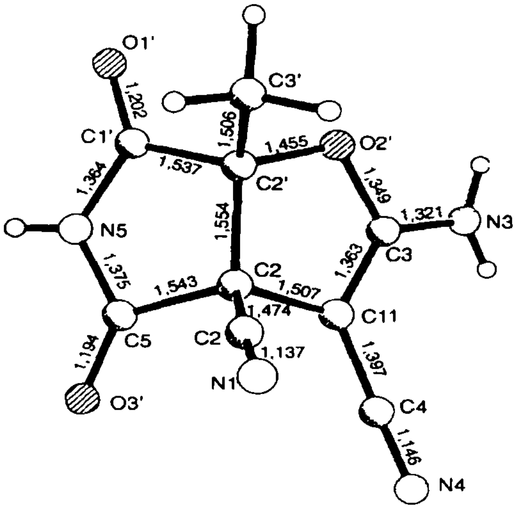


Fig. 1. Molecular structure of compound (XI) (bond lengths, Å).

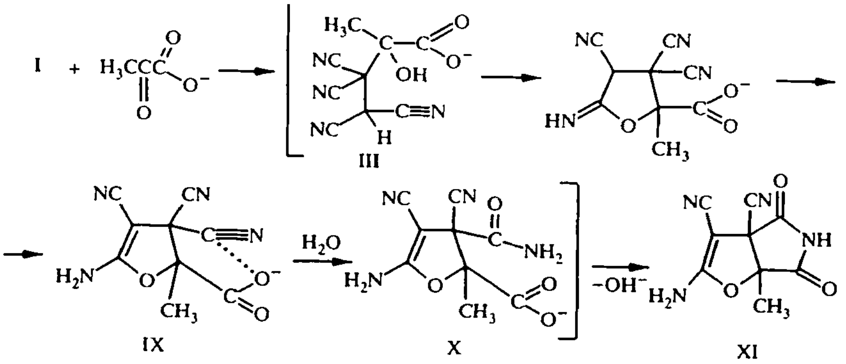
electron acceptor than the carbamoyl group, the adduct (VI) is converted to the adduct (V) by the retroaldol cleavage and the subsequent addition by the stronger CH-acid center at the carbonyl group, i.e., the stronger acid replaces weaker. It was shown experimentally that the substitution of the nitrile group by the carbamoyl group lowers the CH-acidity. Thus, 2-cyanoethane-1,1,2-tricarboxamide (VIII) is added to crotonaldehyde [3] and crotonaldehyde dimethylhydrazone [4] with the stronger acid center (the one associated with the cyano group), which was found by x-ray diffraction analysis of the structures of the corresponding compounds. In turn, the retroaldol decomposition of similar adducts was found in the investigation of the reaction of tetracyanoethane with carbonyl compounds [2].

In the resulting adduct (V), the addition of water initially at one nitrile group, and then at a second nitrile group, becomes possible with the formation of the compound (VII), the decomposition of which leads to 2-cyanoethane-1,1,2-tricarboxamide (VIII). Its further addition to pyruvic acid does not occur, probably owing to the lower nucleophilicity and steric hindrance caused by the bulkier carbamoyl portion.

It was previously shown that reaction of 4-oxoalkane-1,1,2,2-tetracarbonitriles with pyruvic acid leads to hydrolysis of one of the terminal nitrile groups. Hydrolysis of a second cyano group does not occur due to the retroaldol cleavage, since intramolecular cyclization with the amide portion occurs in the resulting monocarbamoyl derivative with the formation of pyridones [5]. This fact, also, is not at variance with our proposition.

Therefore, the reaction of tetracyanoethane with pyruvic acid, leading to the selective hydrolysis of three nitrile groups, bears a specific character. Pyruvic acid itself was not isolated after the synthesis of compound (VIII), and the mother liquor was utilized again in the synthesis without the addition of the acid (II). The yield of the highly impure substance (VIII) was, however, thereby halved.

According to results of the investigation, the reaction under consideration is general for α-ketoacids. Nevertheless, only pyruvic acid is appropriate for the synthesis of the tricarboxamidoethane (VIII). When other α-oxoacids, such as oxalacetic acid and α-ketoglutaric acid, were utilized in this process, compound (VIII) could not be synthesized. The reaction proceeds very slowly with these acids with the formation of a large amount of decomposition products, and the substance (VIII) is only detected in the reaction mixture using thin layer chromatography.



An unexpected result, confirming the possible assistance of the carboxyl group in the ready addition of water at the neighboring cyano group, was obtained in the reaction of tetracyanoethane with the aqueous solution of sodium pyruvate in the presence of acetic acid. Instead of the expected 2-cyanoethane-1,1,2-tricarboxamide (VIII), 2-amino-5-methyl-3,4-dicyano-4,5-dihydrofuran-4,5-dicarboximide (XI) was isolated as a result of this reaction. Its structure was determined by the x-ray diffraction investigation of the monocrystal.

It is known that bases catalyze cyclization of the Thorpe type. In performing the reaction with the pyruvate salt, the increased basicity of the medium probably leads to the initial intramolecular cyclization of the hydroxyl group at one of the terminal nitrile groups in the adduct (III) with the formation of the dihydrofuran (IX). This is then converted to the 4-carbamoyldihydrofuran (X) by the addition of a molecule of water at the cyano group the closest to the carboxyl portion. The ease of such an addition is probably determined by the assistance of the carboxyl group. Such an effect was also observed in the reaction of tetracyanoethane with α-dicarbonyl compounds, where the similar addition of water was facilitated due to the influence of the carbonyl group [6]. Intramolecular cyclization by the carbamoyl portion occurs in the dihydrofuran (X) at the carboxyl group situated in the same plane with the formation of the dicarboximide (XI). Replacement of acetic acid by hydrochloric acid in this reaction leads to the formation of the ethane (VIII). That indicates the fine dependence of the direction of the process on small changes in the basicity of the medium.

EXPERIMENTAL

Monitoring of the course of reactions and the purity of substances synthesized was accomplished by the method of TLC on plates of the Silufol UV-254 type; the developer was iodine vapor, and UV exposure was used. The IR spectra were taken on the UR-20 instrument in a thin layer using the suspension in mineral oil. The mass spectrum was obtained on the MX-1321A instrument with the ionization energy of 70 eV. The x-ray diffraction investigation was carried out on the Siemens P3/PC automatic four-circle diffractometer (153 K, λMoKα, graphite monochromator, $\theta/2\theta$-scanning, and $\theta_{max} = 27°$).

Reactions of tetracyanoethane with pyruvic acid and its esters were performed by analogy with the method of [1].

2-Amino-5-methyl-3,4-dicyano-4,5-dihydrofuran-4,5-dicarboximide (XI). To the solution of 10 g (0.09 mole) of sodium pyruvate in 20 ml of water are added 9 g (0.15 mole) of glacial acetic acid and then, with stirring, 10.4 g (0.08 mole) of 1,1,2,2-tetracyanoethane in small portions. The resulting solution is left at room temperature. After 15-18 days, the residue which formed is filtered off, washed with water, and recrystallized from water. After drying, the yield of 3.5 g (20%) of the substance, which decomposes above 275°C, is obtained. The IR spectrum is as follows: 3390 cm^{-1}, 3350 cm^{-1}, 3290 cm^{-1}, 3230 cm^{-1}, 3110 cm^{-1} (ν_{NH}), 2265 cm^{-1}, 2200 cm^{-1} ($\nu C \equiv N$), 1780 cm^{-1}, 1725 cm^{-1} ($\nu_{C=O}$), 1645 cm^{-1} (δ_{NH}), and 1580 cm^{-1} ($\nu_{C=C}$). The mass spectrum, given as the *m/z* (relative intensity, %), is as follows: M^+ 218 (84), 175 (80), 148 (55), 147 (100), 105 (55), 103 (37), 92 (57), 77 (82), 76 (84), 44 (68), and 43 (73).

X-Ray Diffraction Investigation of the Monocrystal of (XI). The basic crystallographic data are as follows: orthorhombic crystals, a = 12.893(3) Å, b = 8.260(2) Å, c = 18.729(4) Å, V = 1994.6(10) Å^3, d_{calc} = 1.453 g/cm^3, space group Pbca, and Z = 4. The structure was interpreted by the direct method and specified by the full-matrix MLS using the anisotropic approximation for nonhydrogen atoms. The hydrogen atoms, localized objectively by the difference Fourier synthesis, were specified using the isotropic approximation. Final factors of divergence were R = 0.041 for 2160 independent reflections with the $I > 3\sigma(I)$, and R_W = 0.038 for all 3752 independent reflections. All calculations were carried out using the SHELXTL PLUS programs. Coordinates of the atoms are presented in Table 1 (the molecule is represented in Fig. 1).

The work was performed with the financial support of the GK of the Russian Federation (RF) for Higher Education, the NTP "Fine Organic Synthesis" (Grant FT-22).

REFERENCES

1. O. E. Nasakin, P. M. Lukin, P. B. Terent'ev, A. Kh. Bulai, B. A. Khaskin, and V. Ya. Zakharov, Zh. Org. Khim., **21**, 662 (1985).
2. O. E. Nasakin, V. V. Alekseev, V. K. Promonenkov, A. Kh. Bulai, and S. Yu. Sil'vestrova, Khim. Geterotsikl. Soedin., No. 6, 744 (1981).
3. O. E. Nasakin, V. V. Pavlov, A. N. Lyshchikov, P. M. Lukin, V. N. Khrustalev, and Yu. T. Struchkov, Mendeleev Commun., No. 6, 236 (1995).
4. O. E. Nasakin, V. P. Sheverdov, P. M. Lukin, V. A. Tafeenko, and A. Kh. Bulai, Zh. Org. Khim., **28**, 1841 (1992).
5. A. S. 1168554 USSR. O. E. Nasakin, E. G. Nikolaev, L. S. Shevnitsyn, P. B. Terent'ev, A. Kh. Bulai, V. D. Sheludyakov, A. N. Polivanov, and S. D. Danilov, Byull. Izobret., No. 27, 90 (1985).
6. O. E. Nasakin, P. M. Lukin, V. P. Sheverdov, A. N. Lyshchikov, A. Kh. Bulai, P. B. Terent'ev, and A. B. Zolotoi, Khim. Geterotsikl. Soedin., No. 6, 821 (1990).