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# DEHYDROCYANATION OF 2,5-DIARYL-3,3,4,4-TETRACYANOPYRROLIDINES

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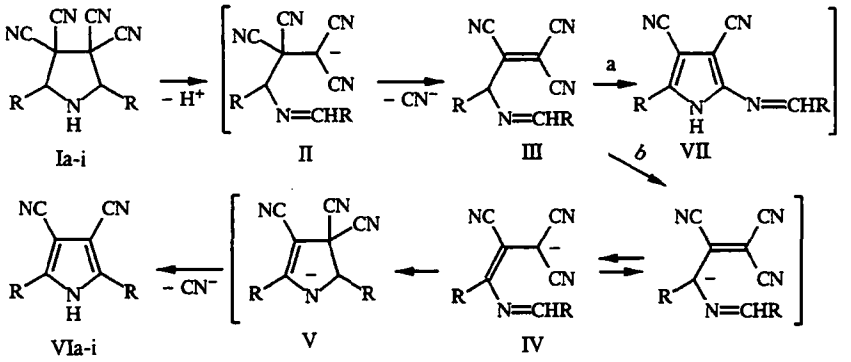
*A second direction has been found in the thermal conversions of 2,5-diaryl-3,3,4,4-tetracyanopyrrolidines. When they are refluxed in DMF or DMSO in the presence of a base, rearrangement does not take place, but rather elimination of two molecules of hydrogen cyanide and the formation of 2,5-diaryl-3,4-dicyanopyrroles. It was shown that 2,6-diphenyl-4,5-dicyanopyrrolo[2,3-d]pyrimidine is formed when the basicity of the medium is within certain limits.*

We had reported previously [1] that in the mass-spectrometric decomposition of 2,5-diaryl-3,3,4,4-tetracyanopyrrolidines, no molecular ions could be detected. The largest value in their mass spectra corresponds to that of the ion $[M - HCN]^+$. This fact, along with a single case of elimination of a hydrogen cyanide molecule in the process of acylation [1], suggested the possibility of thermal dehydrocyanation of 3,3,4,4-tetracyanopyrrolidines.

However, it was shown in [2] that 2,5-diaryl-3,3,4,4-tetracyanopyrrolidines (I), upon refluxing in DMF, undergo rearrangement to 2-(N-arylidenamino)-5-Ar-3,4-dicyanopyrroles, even though 2,5-diphenyl-3,4,4-tricyano-2-pyrrolidine under these conditions will split out a molecule of hydrogen cyanide to form 2,5-diphenyl-3,4-dicyanopyrrole. In contrast, we found that tetracyanopyrrolidines I that have electron-acceptor groups in the aromatic substituent are not rearranged when refluxed in DMF, but rather split out two molecule of hydrogen cyanide and are converted to the corresponding 2,5-diaryl-3,4-dicyanopyrroles VIc, d. On the basis of these facts, we have concluded tentatively that the elimination of hydrogen cyanide proceeds through the linear form II, the form to which the pyrrolidines I are converted in a polar solvent [3].



I—VII R = $R^1$—$C_6H_4$; $R^1$a = H; b = 4-$CH_3$; c = 3-$O_2N$; d = 4-$O_2N$; e = 2-Cl; f = 4-Br; g = 4-F; h = 2-$H_3CO$; i = 4-$H_3CO$

When the pyrrolidine Ia was heated in a higher-boiling solvent such as DMSO, which also has a more basic character, we recovered 2,5-diphenyl-3,4-dicyanopyrrole VIa, which was identical with a sample obtained by the method of [2]. However, the results obtained by use of the DMSO refluxing procedure proved to be poorly reproducible. Depending on the purity of the DMSO as the basic substance, in a number of cases we recovered the pyrrole VII, the formation of which is a competing process.

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TABLE 1. Properties of 2,5-Diaryl-3,4-dicyanopyrroles VIa-i and Pyrrolopyrimidine VIII

| Compound | Empirical formula | Found, %/Calculated, % | | | $R^1$, ($R = R^1$-$C_6H_4$) | mp, °C | Yield, % |
|---|---|---|---|---|---|---|---|
| | | C | H | N | | | |
| VIa | $C_{18}H_{11}N_3$ | 80,37<br>80,27 | 4,03<br>4,12 | 15,53<br>15,60 | H | 282...283 | 37 |
| VIb | $C_{20}H_{15}N_3$ | 80,69<br>80,87 | 4,95<br>5,08 | 14,22<br>14,13 | 4-$H_3C$ | 337...338 | 44 |
| VIc | $C_{18}H_9N_5O_4$ | 60,08<br>60,17 | 2,57<br>2,52 | 19,36<br>19,49 | 3-$O_2N$ | 259...260 | 42 |
| VId | $C_{18}H_9N_5O_4$ | 60,25<br>60,17 | 2,60<br>2,52 | 19,57<br>19,49 | 4-$O_2N$ | 313...314 | 36 |
| VIe | $C_{18}H_9Cl_2N_3$ | 63,81<br>63,93 | 2,77<br>2,68 | 10,73<br>10,82 | 2-Cl | 256...257 | 18 |
| VIf | $C_{18}H_9Br_2N_3$ | 50,69<br>50,62 | 2,19<br>2,12 | 9,71<br>9,84 | 4-Br | 360...361 | 44 |
| VIg | $C_{18}H_9F_2N_3$ | 70,75<br>70,82 | 2,88<br>2,97 | 13,83<br>13,76 | 4-F | 288...289 | 45 |
| VIh | $C_{20}H_{15}N_3O_2$ | 73,07<br>72,94 | 4,44<br>4,59 | 12,63<br>12,76 | 2-$H_3CO$ | 251...252 | 33 |
| VIi | $C_{20}H_{15}N_3O_2$ | 73,05<br>72,94 | 4,63<br>4,59 | 12,65<br>12,76 | 4-$H_3CO$ | 317...319 | 55 |
| VIII | $C_{20}H_{11}N_5$ | 74,82<br>74,76 | 3,54<br>3,45 | 21,68<br>21,79 | — | 306...307 | 38 |

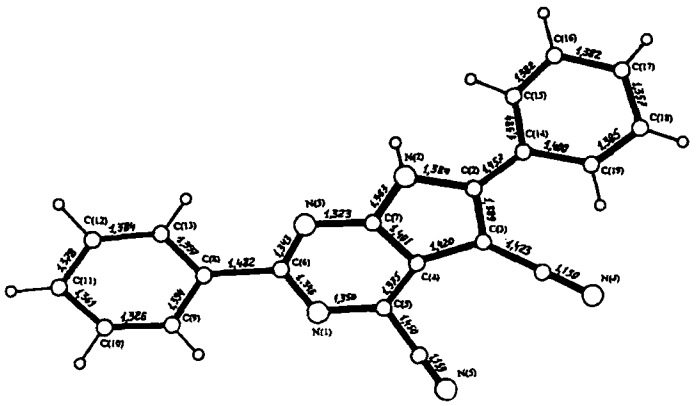
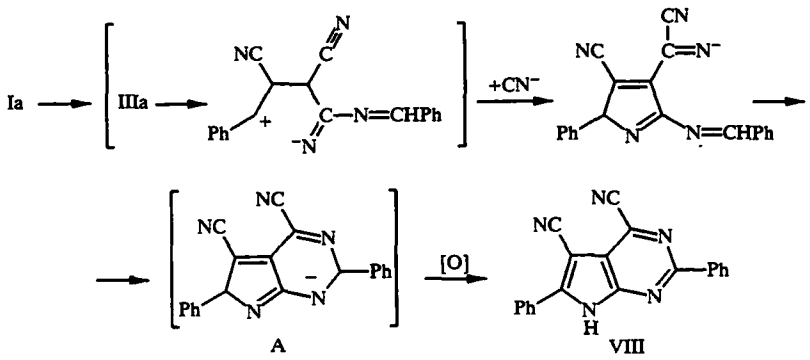


Fig. 1. Molecular structure of 2,6-diphenyl-4,5-dicyanopyrrolo[2,3-*d*]pyrimidine VIII (bond lengths are in Å).

In this connection, we believe that upon heating, by analogy with the rearrangement process [2], what takes place first is elimination of a hydrogen cyanide molecule to form an alkene III. Upon further heating in a more basic medium, the rearrangement process (*a*) is accompanied by a competitive process of splitting out a proton (*b*) to form the anion IV, which is cyclized intramolecularly by attachment at the imino C=N bond to form the ion V. This ion is stabilized by ejection of a cyanide anion to form 2,5-diaryl-3,4-dicyanopyrroles VIa-i.

According to the proposed scheme, the stability of the anions IV will be higher when electron-acceptor groups are present in the aromatic substituent. This is the probable reason why the nitro-substituted derivatives Ic, d in DMF do not undergo rearrangement, but form the corresponding pyrroles VIc, d.

In order to verify the proposed scheme, we made an attempt to synthesize the pyrroles VI by refluxing the pyrrolidines I in DMF in the presence of a equimolar quantity of triethylamine, which was used to increase the basicity of the medium and to obtain a more nearly complete conversion of the tetracyanopyrrolidines to the linear form II. And indeed, this change proved to be sufficient to shift the direction of the reaction toward formation of the pyrroles VI. However, when the reaction was performed with 2,5-diphenyl-3,3,4,4-tetracyanopyrrolidine Ia under analogous conditions, we unexpectedly recovered 2,6-diphenyl-4,5-dicyanopyrrolo[2,3-*d*]pyrimidine (VIII).




In this conversion, apparently, the basicity of the medium is inadequate for formation of the pyrrole VIa; and the rearrangement process, after migration of the imine fragment, is accompanied by the addition of a hydrogen cyanide molecule at the other nitrile group. The fragment is bound by the triethylamine and does not leave the reaction mixture. This is followed by synchronous cyclization to compound A, which, under the particular reaction conditions, is oxidized to the pyrrolopyrimidine VIII. The probability of primary addition of hydrogen cyanide with subsequent cyclization to form the pyrrolopyrimidine VIII is supported indirectly by experiment. An attempt to synthesize compound VIII by the interaction of HCN with 2-(N-benzylidenamino)-5-phenyl-3,4-dicyanopyrrole (the product of rearrangement of the pyrrolidine Ia [2]) in DMF in the presence of triethylamine did not give any favorable results. The original substance was completely decomposed upon refluxing. On this basis, we have postulated that the addition of HCN takes place before the formation of the pyrrole ring, or that this process goes forward almost simultaneously.

The structure of compound VIII was determined unambiguously by x-ray structure analysis of a single crystal (Fig. 1).

Dehydrocyanation of compound Ia in the presence of triethylamine, with DMSO as the solvent, gives the pyrrole VIa and the pyrrolopyrimidine VIII simultaneously. The use of sodium hydroxide in DMSO, in accordance with the scheme proposed previously in this article, makes it possible to obtain the pyrrole VIa alone.

Thus, the thermal dehydrocyanation of the tetracyanopyrrolidines Ia-i, forming the 2,5-diaryl-3,4-dicyanopyrroles VIa-i, is effected through a linear form; and whether this direction of the process will be realized depends on the basicity of the reaction medium.

The symmetry of the structure of the dicyanopyrroles VIa-i is confirmed by the $^{13}C$ NMR spectra of compounds VIa-c. In these spectra, apart from the carbon atoms of the aromatic substituents, the only signals observed are two signals of carbon atoms of the heterocycle [$C_{(2)}C_{(5)}$ 141.43 ppm and $C_{(3)}C_{(4)}$ 92.66 ppm] and one signal of the cyano-group carbon atom at 114.78 ppm.

The IR spectra of compounds VIa-h are characterized by the presence of absorption bands from stretching vibrations of conjugated nitrile groups in the 2245-2230 $cm^{-1}$ region, and usually the presence of broad bands from absorption by NH bonds in the 3530-3220 $cm^{-1}$ region (Table 2).

The mass spectra of the dicyanopyrroles VIa-h are characterized by the presence of very intense molecular ions (Tables 2 and 3), the decomposition of which goes forward with splitting of the heterocycle and ejection of the corresponding benzonitrile or its protonated analog (ions $\Phi_5$ and $\Phi_7$, Fig. 2), with subsequent splitting out of HCN or a CN radical (ion $\Phi_6$). The second direction of fragmentation is related to losses of substituent in the benzene ring (ion $\Phi_1$) with subsequent ejection of a hydrogen cyanide molecule or of the second substituent (ions $\Phi_3$ and $\Phi_2$). The overall fraction of ions in the total ion current is generally in the 20-65% interval (Table 3), indicating a high selectivity of decomposition of these compounds under electron impact.

## EXPERIMENTAL

The course of the reaction and the purity of the synthesized compounds were monitored by TLC on Silufol UV-254 plates, with development by UV irradiation and iodine vapor. The IR spectra were taken in a UR-20 instrument in a thin layer (suspension in white mineral oil). The $^{13}C$ NMR spectra were obtained in a Bruker WH-90 spectrometer with a working frequency of 22.63 MHz, internal standard HMDS. The mass spectra were obtained in a Kratos MS 25PFA instrument with

TABLE 2. IR and Mass Spectra of Pyrroles VIa-i

| Compound | IR spectrum, $cm^{-1}$ | | Mass spectrum,* m/z (and relative intensity, %) |
|---|---|---|---|
| | $\nu_{NH}$ | $\nu_{C\equiv N}$ | |
| VIa | 3285 | 2235, 2245 | 269(100), 268(12), 267(6), 241(4), 166(5), 165(8), 139(13), 104(5), 77(9), 63(4), 51(6) |
| VIb | 3230 | 2235 | 297(100), 296(13), 281(3), 280(3), 269(3), 179(5), 153(3), 149(6), 118(2), 91(5), 65(4) |
| VIc | 3580 | 2240 | 359(100), 313(24), 267(37), 266(18), 265(11), 240(8), 239(11), 165(6), 164(8), 138(5), 63(5) |
| VId | 3530 | 2245 | 359(100), 358(8), 329(40), 313(16), 267(33), 266(16), 239(12), 207(18), 164(13), 73(12), 64(22) |
| VIe | 3420 | 2240 | 337(100), 302(12), 267(13), 239(5), 200(2), 199(5), 173(2), 165(17), 138(13), 102(9), 75(9) |
| VIf | 3230 | 2230, 2240 | 427(86), 347(18), 267(21), 226(15), 213(28), 212(50), 168(32), 165(28), 141(37), 131(18), 105(100) |
| VIg | 3245 | 2235 | 305(100), 183(13), 177(21), 157(16), 145(60), 118(22), 104(43), 103(73), 91(12), 76(27), 51(20) |
| VIh | 3360 | 2230 | 329(64), 314(18), 285(13), 226(13), 145(9), 136(10), 103(19), 91(7), 76(13), 69(38), 45(100) |
| VIi | 3225 | 2235 | — |

*Peak values are listed for the molecular ion and the ten most intense peaks of fragment ions.

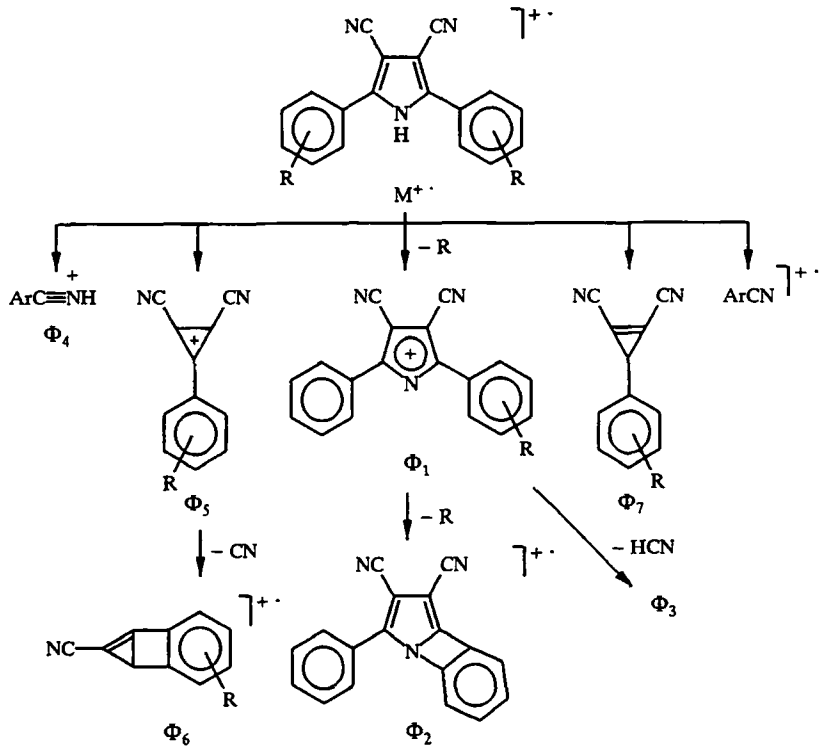



Fig. 2. Scheme of mass-spectrometric decomposition of 2,5-diaryl-3,4-dicyanopyrroles VI under electron impact.

direct introduction of the substance into the ion source, with an ionization energy of 50 eV. The x-ray structure analysis was performed in a CAD-4 four-circle automatic diffractometer manufactured by Enraf Nonius, MoK$\alpha$ radiation, $\omega$-scanning.

**2,5-Diaryl-3,4-dicyanopyrroles (VIb-h).** To a suspension of 10 mmoles of 2,5-diaryl-3,3,4,4-tetracyanopyrrolidine Ib-h in 5-6 ml of DMF, 1.11 g (11 mmoles) of triethylamine was added, and the mixture was stirred until the compound was

TABLE 3. Intensities of Peaks of Characteristic Ions in Mass Spectra of Compounds VIa-h (% $\Sigma_{50}$)

| Compound | $w_m$ | $\Phi_1$ | $\Phi_2$ | $\Phi_3$ | $\Phi_4$ | $\Phi_5$ | $\Phi_6$ | $\Phi_7$ |
|---|---|---|---|---|---|---|---|---|
| VIa | 43,47 | 5,15 | 2,6 | 1,57 | 2,1 | 3,34 | 5,45 | 2,22 |
| VIb | 51,38 | 6,55 | 1,78 | 1,51 | 1,04 | 2,2 | 1,55 | 1,35 |
| VIc | 26,31 | 6,42 | 9,82 | 2,98 | — | — | — | — |
| VId | 12,98 | 2,14 | 4,28 | 1,11 | — | 0,63 | 0,4 | 0,48 |
| VIe | 22,44 | — | 2,62 | — | 2,99 | 1,16 | 0,54 | 0,48 |
| VIf | 6,46 | 1,37 | 1,59 | 0,13 | 0,32 | 0,23 | 0,15 | 0,15 |
| VIg | 14,19 | 0,11 | 0,10 | 0,69 | 0,77 | 1,89 | 2,24 | 0,86 |
| VIh | 9,54 | — | — | 1,17 | 1,44 | 0,45 | 0,45 | 0,12 |

completely dissolved. The resulting solution was heated to boiling and refluxed for 1 min. After cooling, the precipitate was filtered off, washed with isopropyl alcohol, and recrystallized from methyl Cellosolve or acetonitrile (Table 1).

**2,5-Diaryl-3,4-dicyanopyrroles (Vc, d).** A suspension of 10 mmoles of the tetracyanopyrrolidine Ic, d in 5-6 ml of DMF was heated to boiling while stirring, and then refluxed for 1 min. After cooling, the precipitate was filtered off, washed with isopropyl alcohol, and recrystallized (VIc from methyl Cellosolve, VId from acetonitrile) (Table 1).

**2,6-Diphenyl-3,4-dicyanopyrrole (VIa).** To a solution of 0.56 g (10 mmoles) of sodium hydroxide in 5-6 ml of DMSO, 3.23 g (10 mmoles) of 2,5-diphenyl-3,3,4,4-tetracyanopyrrolidine Ia was added in a single batch; this mixture was stirred until the compound was dissolved and then heated to boiling. After refluxing for 1 min, the darkened solution was cooled, and 1.2 g (20 mmoles) of glacial acetic acid was added. The resulting precipitate was filtered off, washed with isopropyl alcohol, and recrystallized from methyl Cellosolve or acetonitrile (Table 1).

**2,6-Diphenyl-4,5-dicyanopyrrolo[2,3-d]pyrimidine (VIII).** A 5-g quantity (16 mmoles) of 2,5-diphenyl-3,3,4,4-tetracyanopyrrolidine Ia was dissolved at room temperature in a mixture of 8 ml of DMF and 1.6 ml (16 mmoles) of triethylamine. The resulting solution was heated to boiling and refluxed for 1 min. After cooling the reaction mass with water, an abundant precipitate was formed; this was diluted with 10 ml of isopropyl alcohol, filtered off, washed with isopropyl alcohol, and recrystallized from a 2:1 mixture of acetonitrile and methyl Cellosolve. After drying, obtained 1.9 g of compound VIII (Table 1). $C_{20}H_{11}N_5$. IR spectrum: 3220 ($\nu_{NH}$), 2240 ($\nu_{C\equiv N}$), 1605 $cm^{-1}$ ($\nu_{C=N}$).

**X-Ray Structure Analysis of VIII.** Basic crystallographic data: $a$ = 9.021(2), $b$ = 7.375(2), $c$ = 27.966(2) Å; $\beta$ = 97.2(2)°, $V$ = 1846.1 $Å^3$; sp.gp. P21/c, $Z$ = 4. Used 1775 reflections with $I > 3\sigma(I)$ for refinement of the positional and thermal parameters of the molecule, the motif of which was found by means of direct methods realized in the MULTAN program of the SDP program set. The positional and thermal parameters of the nonhydrogen atoms were refined in the anisotropic full-matrix approximation. The hydrogen atoms were localized from Fourier syntheses and were refined in the isotropic approximation. Final $R_f$ = 4.0%. The molecule is depicted in Fig. 1.

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