

Synthesis of New Polydentate Acyclic Schiff Bases by Reaction of 2,3-Diaminomaleodinitrile with Dicarboxyl Compounds

N. E. Borisova, V. V. Roznyatovskii, M. D. Reshetova, and Yu. A. Ustynyuk

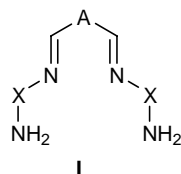
Faculty of Chemistry, Lomonosov Moscow State University, Vorob'evy gory, Moscow, 119899 Russia

e-mail: ustynyuk@nmr.chem.msu.su

Received August 11, 2004

Abstract—[1+2]-Condensation of 2,3-diaminomaleodinitrile with dialdehydes of the aromatic and heterocyclic series gave a number of new acyclic Schiff bases which attract interest as ligands for the synthesis of transition metal complexes and as building blocks for the synthesis of macrocyclic compounds.

Polydentate Schiff bases like **I**, which are obtained by [1+2]-condensation of aromatic and heterocyclic dialdehydes with diamines attract considerable interest as ligands for the synthesis of transition metal complexes, as well as building blocks for the preparation of macrocyclic compounds with a complex asymmetric structure. Reactions of aliphatic diamines with dialdehydes as a rule lead to formation of complex mixtures of oligomeric products; therefore, the yields of target compounds **I** in reactions performed under standard conditions are poor.

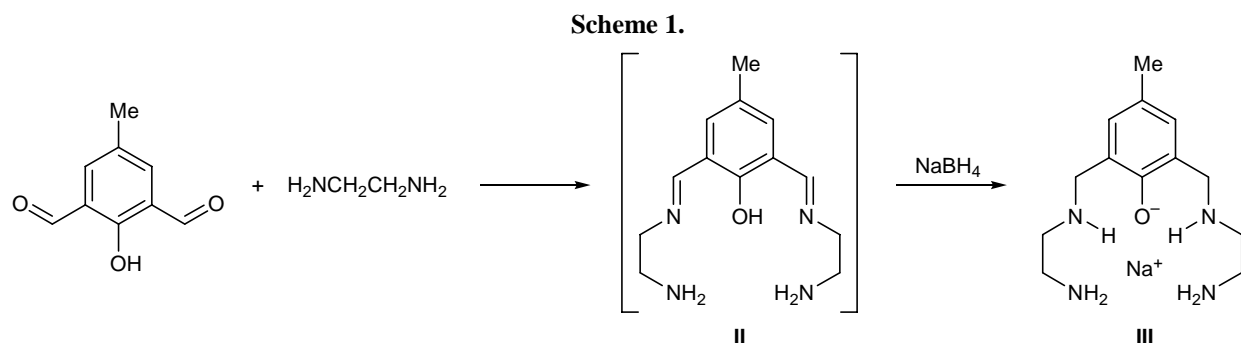


Schiff base **II** was formed only with the use of a large excess (50 equiv) of the corresponding diamine (Scheme 1), and it was subjected without isolation to reduction with NaBH₄ to obtain tetraamine **III** (the yield was not given) [1]. Nelson and Knox [2] devel-

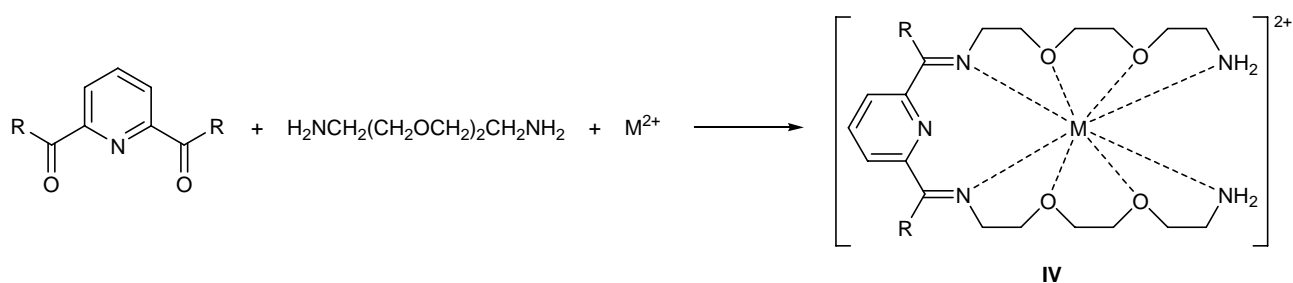
oped a more efficient template procedure for the synthesis of Schiff bases **IV** (Scheme 2) in the presence of alkaline-earth metal ions, and the yields of the target complexes attained 70–80% [2]. The yields of dinuclear complexes derived from Schiff bases **V** according to Scheme 3 [3] sharply fell down as the hydrophilicity of the initial dicarbonyl derivatives decreased; no expected product was formed when a *tert*-butyl group was introduced into initial 2-hydroxybenzene-1,3-dicarbaldehyde [4].

We previously showed that aromatic diamines in which both amino groups are involved in direct polar conjugation react with dicarbonyl compounds in a different way. In particular, reactions of 5-alkyl-2-hydroxybenzene-1,3-dicarbaldehydes with *o*-phenylenediamine lead to formation of partially reduced [2+2]-macrorings having two C=N bonds and two CH₂NH fragments [5, 6]. The same phenol derivatives react with 2,3-diaminomaleodinitrile (**VI**) to afford only [1+2]-condensation products **VIIIa** and **VIIIb**, regardless of the reactant ratio (Scheme 4) [7].

In the present work we found that diamine **VI** also smoothly reacts with diformyl-substituted five-

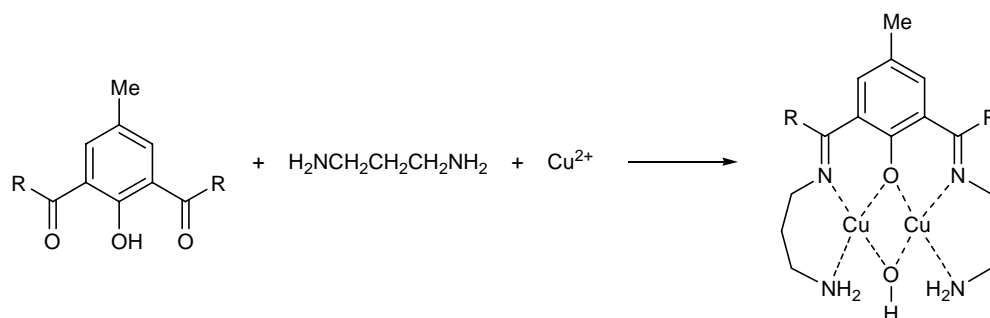


Scheme 2.



R = H, Me; M = Mg, Ca, Ba.

Scheme 3.



R = H (80%), Me (40%), Ph (40%).

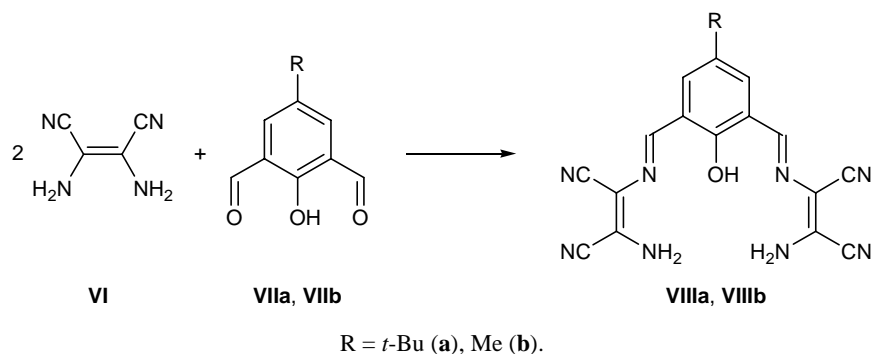
membered heterocycles and pyridine to afford acyclic products, Schiff bases **VIII**, as a result of [2+1]-condensation (Scheme 5) in good or satisfactory yields (Table 1). The solvent nature (alcohols, acetonitrile) does not affect the reaction direction, while the maximal yields of the target products were obtained in anhydrous ethanol. Compounds **VIII** are yellow to crimson amorphous substances. They are soluble in DMSO, DMF, and other polar organic solvents, poorly soluble in alcohols, and insoluble in nonpolar organic solvents and water. The products were characterized by the data of NMR and IR spectroscopy, mass spectrometry, and elemental analysis.

In the ^1H NMR spectra of the products, signals from protons in the amino groups appear in a weak field ($\delta \sim 8$ ppm in $\text{DMSO}-d_6$ and ~ 7 ppm in acetone- d_6), indicating considerable deficit of electron density on the amino nitrogen atoms and increased acidity of the N–H bonds. The spectra of phenol derivatives contained sharp signals from the hydroxy protons at δ 11.35 (**VIIIa**) and 11.15 ppm (**VIIIb**). Protons of the NH groups in pyrrole derivatives **VIIIc** and **VIIIg** appeared at δ 11.24 and 10.26 ppm, respectively. In the IR spectra of Schiff bases **VIIIa**–**VIIIg** we observed two absorption bands with approximately equal intensities in the region 2204 – 2260 cm^{-1} , which

belong to stretching vibrations of the cyano groups. Absorption bands corresponding to stretching vibrations of the amino groups were located at 3170 – 3582 cm^{-1} ; they appeared as four (or three for compounds **VIIIc** and **VIIIg**) well defined relatively narrow peaks.

Theoretical study in terms of the density functional theory (PBE functional, TZ2p basis set [8]) showed that the potential energy surface (PES) of Schiff bases **VIII** possesses three minima corresponding to conformers formed due to restricted rotation about the $\text{C}_{\text{arom}}\text{--C}$ bonds. These conformers are characterized by *cis,cis*, *cis,trans*, and *trans,trans* arrangement of the maleodinitrile fragments with respect to the aromatic rings. The aromatic fragments in compounds **VIIIc** and **VIIIg** are linked through a flexible sulfide or dimethylmethylene bridge; therefore, their conformational behavior is more complex, as compared to the other compounds. The potential energy surfaces of **VIIIc** and **VIIIg** contain several local minima, among which the three deepest minima correspond to structures related to *cis,cis*, *cis,trans*, and *trans,trans* conformers. The results of calculations (Table 2) indicate that the *cis,cis* conformers of **VIIIc**, **VIIIc**, and **VIIIg** are the most favorable from the viewpoint of thermodynamics. Contrary to our expectations, these conformers lack

Scheme 4.



hydrogen bonds between N–H protons and nitrogen atoms at the C=N bonds, and the heterorings are not coplanar. The most thermodynamically favorable conformer of **VIIIa**, **VIIIb**, and **VIIIh** is *cis,trans*, and the global minimum on the PES corresponds to *trans,trans* conformer only for pyridine derivative **VIIIc**. The *cis,cis* conformers of **VIIIa**–**VIIIe** are characterized by the lowest dipole moments; therefore, these conformers are stabilized in weakly polar solvents. The energy difference between the above conformers of Schiff bases **VIII** is not large. This means that the

population of *cis,cis* conformers in solution may be considerable, which should favor condensation of diamines **VIII** with dicarbonyl compounds to produce macrocyclic ligands according to Scheme 6.

The charges on the amino nitrogen atoms in the *cis,cis* conformers of **VIIIa**–**VIIIg** are similar (–0.13

Table 1. Structures and yields of polydentate Schiff bases **VIIIa**–**VIIIg** obtained by condensation of aromatic and heterocyclic dialdehydes with diamine **VI**

Compound no.	A	Yield, %
VIIIa		75
VIIIb		79
VIIIc		78
VIIId		77
VIIIe		58
VIIIf		54
VIIIg		34 ^a

^a Compound **VIIIg** contained an impurity of the initial aldehyde which cannot be removed without appreciable loss in the yield.

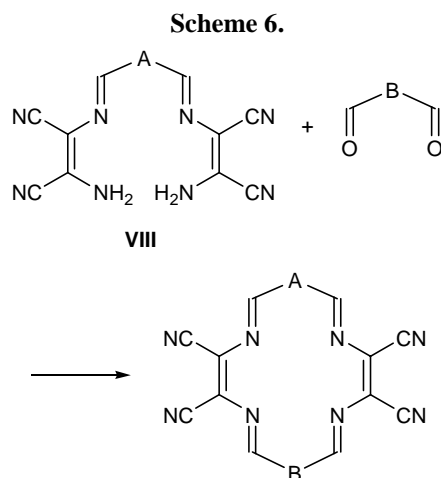
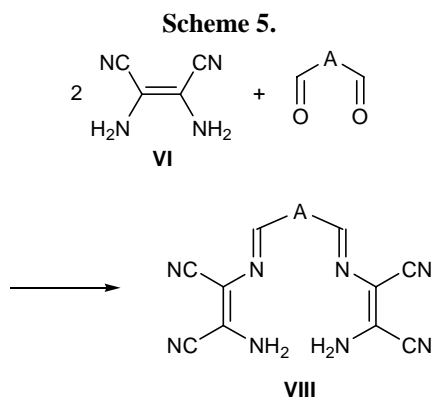
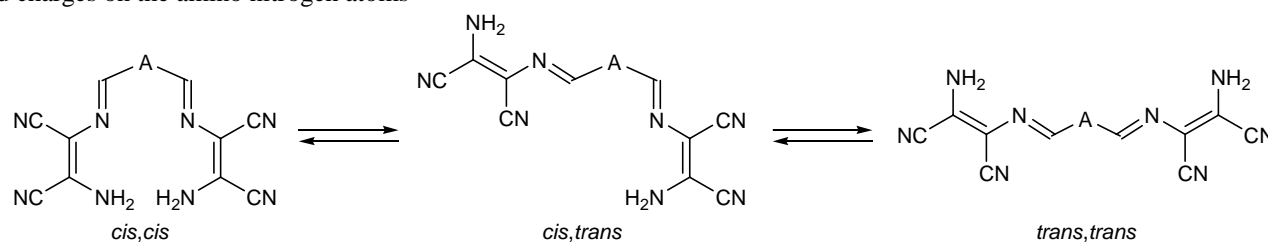


Table 2. Relative energies and dipole moments of *cis,cis*, *cis,trans*, and *trans,trans* conformers of Schiff bases **VIIIa–VIIIg** and charges on the amino nitrogen atoms

Compound no.	Relative energy E_{rel} , kcal/mol (dipole moment μ , D)			Hirshfeld charge on the amino nitrogen atom
	<i>cis,cis</i> conformer	<i>cis,trans</i> conformer	<i>trans,trans</i> conformer	
VIIIa	1.85 (2.70)	10.52 (7.98) ^a 0 (6.65) ^b	9.58 (12.55)	-0.13
VIIIb	1.87 (2.60)	10.48 (7.82) ^a 0 (6.32) ^b	9.59 (12.36)	-0.13
VIIIc	3.69 (1.76)	0.15 (8.65)	0 (14.32)	-0.13
VIII d	0 (2.57)	0.91 (4.81)	2.90 (9.90)	-0.14
VIIIe	0.68 (1.19)	0 (6.36)	1.02 (12.20)	-0.13
VIII f	0 (9.98)	0.45 (10.89)	0.63 (6.57)	-0.13
VIII g	0 (7.11)	1.86 (2.58)	3.61 (2.74)	-0.14
VIII h^d	1.94	0	9.84	-

^a Conformer with no intramolecular hydrogen bond OH...NH.

^c Conformer with intramolecular hydrogen bond OH...NH.

^d Model compound having no alkyl group in the *para* position with respect to the hydroxy group [7].

to -0.14 a.u.; cf. -0.16 a.u. in initial compound **VI**), and the difference in the charges between *cis,cis*, *cis,trans*, and *trans,trans* conformers does not exceed 0.05 a.u. Reduction of the negative charge on the amino nitrogen atom due to formation of C=N bond involving the neighboring carbon atom is responsible for the reduced reactivity of compounds **VIII** with respect to dicarbonyl compounds, and closure of macroring according to Scheme 6 requires additional activation of Schiff bases **VIII**. The use of Schiff bases **VIII** as ligands opens new prospects in obtaining various mono- and dinuclear complexes of transition metals.

EXPERIMENTAL

The NMR spectra were recorded at 24°C on a Bruker DPX-300 spectrometer. The IR spectra were measured on a Specord M80 spectrometer in KBr and on a UR-2 instrument in mineral oil. The mass spectra were obtained on a Finigan MAT-212 spectrometer.

Potential energy surfaces of compounds **VIII** were analyzed in terms of the density functional theory using PRIRODA software which was developed by

D.N. Laikov [8]. The calculations were performed with the use of PBE functional including electron density gradient [9]. The Kohn–Sham equations were solved using TZ2p atomic basis sets consisting of grouped Gauss type functions. The orbital basis sets were characterized by the following contracted samples: (5s1p)/[3s1p] for hydrogen atoms and (11s6p2d)/[6s3p2d] for carbon, nitrogen, and oxygen atoms. Matrix elements of the Coulomb and exchange–correlation potentials were calculated by expansion of electron density over auxiliary basis set consisting of atom-centered ungrouped Gauss type functions, (4s1p) for H atoms and (3s2d1f) for C, N, and O atoms [8]. The geometric parameters were optimized without symmetry restrictions. Stationary points on the potential energy surface were identified by analysis of second derivatives with respect to energy.

2,6-Bis(2-amino-1,2-dicyanovinyliminomethyl)-4-tert-butylphenol (VIIIa). Diamine **VI**, 183 mg (1.68 mmol), and 5-*tert*-butyl-2-hydroxybenzene-1,3-dicarbaldehyde (**VIIa**), 175 mg (0.84 mmol), were dissolved in 25 ml of hot anhydrous ethanol. The solution was heated for 3 h under reflux, cooled, and left overnight. The precipitate was filtered off, washed with

cold ethanol, and dried in air. Yield 244 mg (75%), yellow–orange amorphous powder, mp 282–284°C (from aqueous ethanol). IR spectrum, ν , cm^{-1} : 1620 (C=N); 1585 (CH); 2216, 2245 (C≡N); 3200, 3330, 3470, 3630 (NH, OH). UV spectrum (EtOH), λ_{max} , nm (ϵ): 202 (7369), 241 (7127), 268 (4470), 276 (4651), 352 (10510), 368 (10389), 410 (8939). ^1H NMR spectrum (DMSO- d_6), δ , ppm: 1.30 s (9H, CH₃), 8.06 s (4H, NH₂), 8.08 s (2H, CH), 8.65 s (2H, CH=N), 11.35 s (1H, OH). ^{13}C NMR spectrum (DMSO- d_6), δ_{C} , ppm: 31.06, 34.22, 102.81, 113.92, 114.45, 120.85, 126.41, 130.69, 142.57, 154.32, 156.37. Mass spectrum, m/z (I_{rel} , %): 386 (100) $[M]^+$. Found, %: C 61.92; H 4.52; N 28.72. C₂₀H₁₈N₈O. Calculated, %: C 62.17; H 4.69; N 28.99.

2,6-Bis(2-amino-1,2-dicyanovinyliminomethyl)-4-methylphenol (VIIIb) was synthesized in a similar way from 183 mg (1.68 mmol) of diamine VI and 138 mg (0.84 mmol) of 2-hydroxy-5-methylbenzene-1,3-dicarbaldehyde. Yield 225 mg (78%), yellow amorphous powder, decomposition point >290°C (from ethanol). IR spectrum, ν , cm^{-1} : 1620 (C=N, CH); 2220, 2250 (C≡N); 3230, 3350, 3430 (NH, OH). ^1H NMR spectrum (DMSO- d_6), δ , ppm: 2.27 s (3H, CH₃), 7.86 s (2H, CH), 7.96 s (4H, NH₂), 8.44 s (2H, CH=N), 11.15 s (1H, OH). ^{13}C NMR spectrum (DMSO- d_6), δ_{C} , ppm: 19.92, 102.81, 113.79, 114.46, 121.22, 126.45, 128.83, 133.96, 153.49, 156.32. Mass spectrum, m/z (I_{rel} , %): 344 (13) $[M]^+$, 237 (20), $[M - 107]^+$, 53 (100) $[\text{NCCNH}]^+$. Found, %: C 58.88; H 3.41; N 32.26. C₁₇H₁₂N₈O. Calculated, %: C 59.30; H 3.51; N 32.54.

2,6-Bis(2-amino-1,2-dicyanovinyliminomethyl)pyridine (VIIIc) was synthesized in a similar way from 183 mg (1.68 mmol) of diamine VI and 113 mg (0.84 mmol) of pyridine-2,6-dicarbaldehyde. An analytical sample was obtained by reprecipitation with water from a concentrated solution in DMSO. Yield 203 mg (78%), light yellow amorphous powder, decomposition point 248–250°C. IR spectrum, ν , cm^{-1} : 1610 (C–C, C=N); 2220, 2260 (C≡N); 3200, 3295, 3415, 3540 (NH₂). ^1H NMR spectrum (DMSO- d_6), δ , ppm: 8.01 t (1H, CH), 8.17 s (2H, CH), 8.32 s (4H, NH₂), 8.43 d (2H, CH). ^{13}C NMR spectrum (DMSO- d_6), δ_{C} , ppm: 101.82, 113.40, 114.09, 123.44, 128.59, 137.53, 153.86, 153.92. Mass spectrum, m/z (I_{rel} , %): 315 (17) $[M]^+$, 197 (100) $[M - \text{H}_2\text{NC}(\text{CN})\text{C}(\text{CN})\text{NCH}]^+$. Found, %: C 55.82; H 2.81; N 37.21. C₁₅H₉N₉·0.25DMSO. Calculated, %: C 55.60; H 3.16; N 37.64.

2,5-Bis(2-amino-1,2-dicyanovinyliminomethyl)pyrrole (VIIId) was synthesized in a similar way from 183 mg (1.68 mmol) of diamine VI and 103 mg (0.84 mmol) of pyrrole-2,5-dicarbaldehyde. Yield 195 mg (77%), bright red powder, decomposition point 196–198°C (from ethanol). IR spectrum, ν , cm^{-1} : 1660 (C=N); 2220, 2245 (C≡N); 3170, 3325, 3430 (NH₂, NH). ^1H NMR spectrum (acetone- d_6), δ , ppm: 6.96 s (4H, NH₂), 6.97 s (2H, CH), 8.17 s (2H, CH), 11.24 s (1H, NH). ^{13}C NMR spectrum (acetone- d_6), δ_{C} , ppm: 113.89, 115.34, 119.60, 126.67, 136.51, 146.39, 146.62. Mass spectrum, m/z (I_{rel} , %): 303 (70) $[M]^+$, 53 (100) $[\text{C}_2\text{N}_2\text{H}]^+$. Found, %: C 53.16; H 3.33; N 39.04. C₁₄H₈N₉·H₂O. Calculated, %: C 52.50; H 3.15; N 39.36.

2,5-Bis(2-amino-1,2-dicyanovinyliminomethyl)furan (VIIIe) was synthesized in a similar way from 0.2 g (1.6 mmol) of furan-2,5-dicarbaldehyde and 0.346 g (3.2 mmol) of diamine VI. Yield 0.282 g (58%), yellow powder, decomposition point 280–285°C. IR spectrum, ν , cm^{-1} : 1613 (C=C); 1633 (C=N); 2204, 2236 (C≡N); 2973 (C–H); 3180, 3314, 3414, 3582 (NH₂). ^1H NMR spectrum (DMSO- d_6), δ , ppm: 7.41 s (2H, CH), 8.00 s (4H, NH₂), 8.09 s (2H, CH). ^{13}C NMR spectrum (DMSO- d_6), δ_{C} , ppm: 113.39, 114.28, 117.70, 120.09, 140.61, 142.81, 153.99. Mass spectrum, m/z (I_{rel} , %): 304 (100) $[M]^+$, 197 (30) $[M - \text{HNC}(\text{CN})\text{C}(\text{CN})\text{C}]^+$, 185 (10) $[M - 119]^+$, 119 (25) $[\text{H}_2\text{NC}(\text{CN})\text{C}(\text{CN})\text{NCH}]^+$. Found, %: C 52.56; H 3.61; N 32.95. C₁₄H₈N₈O·H₂O·0.5EtOH. Calculated, %: C 52.17; H 3.79; N 32.45.

2,2'-Bis[5-(2-amino-1,2-dicyanovinyliminomethyl)furyl] sulfide (VIIIf) was synthesized in a similar way from 50 mg (0.23 mmol) of 5,5'-thiodifuran-2,2'-dicarbaldehyde and 49 mg (0.46 mmol) of diamine VI. Yield 50 mg (54%), orange powder, decomposition point 228–230°C. IR spectrum, ν , cm^{-1} : 1620 (C=N, C=C); 2220, 2260 (C≡N); 3200, 3290, 3410 (NH₂). ^1H NMR spectrum (DMSO- d_6), δ , ppm: 7.04 d (2H, CH), 7.32 d (2H, CH), 7.91 s (4H, NH₂), 8.02 s (2H, CH). ^{13}C NMR spectrum (DMSO- d_6), δ_{C} , ppm: 102.92, 113.50, 114.32, 118.77, 119.98, 126.88, 142.21, 144.71, 154.31. Mass spectrum, m/z (I_{rel} , %): 402 (80) $[M]^+$, 284 (100) $[M - \text{HNC}(\text{CN})\text{C}(\text{CN})\text{C}]^+$, 119 (70) $[\text{H}_2\text{NC}(\text{CN})\text{C}(\text{CN})\text{NCH}]^+$. Found, %: C 51.43; H 2.88; N 26.65. C₁₈H₁₂N₈O₂S·H₂O. Calculated, %: C 51.18; H 3.34; N 26.53.

Dimethylbis[5-(2-amino-1,2-dicyanovinyliminomethyl)pyrrol-2-yl]methane (VIIIg). A solution of 366 mg (3.36 mmol) of diamine VI in 10 ml of anhydrous 1-butanol was added to a solution of 386 mg

(1.68 mmol) of 5,5'-dimethylmethylenedipyrrole-2,2'-dicarbaldehyde in 30 ml of anhydrous 1-butanol. The mixture was heated for 20 h under reflux, cooled, and evaporated to dryness. The residue was subjected first to column chromatography on silica gel and then to preparative thin-layer chromatography using petroleum ether–ethyl acetate (2:1) as eluent. Yield 230 mg (34%), crimson powder, decomposition point 158–162°C (from ethanol). ¹H NMR spectrum (acetone-*d*₆), δ, ppm: 1.77 s (3H, CH₃), 6.06 m (2H, CH, AA'BB' system), 6.47 s (4H, NH₂), 6.77 m (2H, CH, AA'BB' system), 8.04 s (2H, CH), 10.26 s (2H, NH). Found, %: C 56.79; H 4.41; N 31.24. C₂₁H₁₆N₁₀·2H₂O. Calculated, %: C 56.75; H 4.54; N 31.51.

This study was performed under financial support by the Russian Foundation for Basic Research (project no. 02-03-32101).

REFERENCES

- Dickson, I.E. and Robson, R., *Inorg. Chem.*, 1974, vol. 13, p. 1301.
- Nelson, S.M. and Knox, C.V., *J. Chem. Soc., Dalton Trans.*, 1983, p. 2525.
- Mandal, S.K. and Nag, K., *J. Chem. Soc., Dalton Trans.*, 1984, p. 2141.
- Roznyatovskii, V.V., Borisova, N.E., Reshetova, M.D., Ustynyuk, Yu.A., Aleksandrov, G.G., Eremenko, I.L., and Moiseev, I.I., *Izv. Ross. Akad. Nauk, Ser. Khim.*, 2004, p. 1161; *Russ. Chem. Bull., Int. Ed.*, 2004, vol. 53, p. 1208.
- Ustynyuk, Yu.A., Borisova, N.E., Nosova, V.M., Reshetova, M.D., Talismanov, S.S., Nefedov, S.E., Aleksandrov, G.G., Eremenko, I.L., and Moiseev, I.I., *Izv. Ross. Akad. Nauk, Ser. Khim.*, 2002, p. 454; *Russ. Chem. Bull., Int. Ed.*, 2002, vol. 51, p. 488.
- Borisova, N.E., Ustynyuk, Yu.A., and Reshetova, M.D., *Izv. Ross. Akad. Nauk, Ser. Khim.*, 2004, p. 174; *Russ. Chem. Bull., Int. Ed.*, 2004, vol. 53, p. 181.
- Borisova, N.E., Ustynyuk, Yu.A., Reshetova, M.D., Aleksandrov, G.G., Eremenko, I.L., and Moiseev, I.I., *Mendeleev Commun.*, 2003, p. 202.
- Laikov, D.N., *Chem. Phys. Lett.*, 1997, vol. 281, p. 151.
- Perdew, J.P., Burke, K., and Ernzerhof, M., *Phys. Rev. Lett.*, 1996, vol. 77, p. 3865.