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SYNTHESIS AND CRYSTAL STRUCTURE OF SCHIFF BASES OBTAINED BY CONDENSATION OF 2-AMINOPYRIDINES WITH ACRYLIC ALDEHYDES

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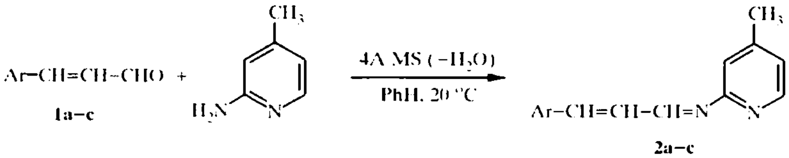
We synthesized a series of novel imines by reactions of 2-amino-4-methylpyridine with (hetero)aromatic derivatives of acrolein in the presence of molecular sieves (as a dehydrating and acid-catalyzing agent). We determined the molecular and crystal structure of two 2-pyridylazomethines containing the CH=CH–CH=N group by X-ray diffraction analysis.

Keywords: 2-pyridylazomethines, monoazabutadienes, X-ray diffraction analysis.

In our preceding study [1], by condensation of (hetero)aromatic acrylic aldehydes with 2-aminopyridine and its 2- and 6-methyl derivatives we obtained a series of Schiff bases. This was possible because we used zeolites, which in these processes exhibit both dehydrating and catalytic properties. In continuing this investigation using the method developed in [1], in this work we have synthesized aldimines **2a-c** by reaction of 2-amino-4-methylpyridine with fur-2-yl- and 5-methylfur-2-ylacroleins, and also their aromatic analog cinnamic aldehyde, in the presence of zeolite 4A.



Ar = 2-furyl (**1a**, **2a**); 5-methyl-2-furyl (**1b**, **2b**); Ph (**1c**, **2c**)

Reactions of aldehydes **1a-c** with amine used in equimolar amounts were carried out in dry benzene without heating (the products are thermally unstable), periodically withdrawing samples and analyzing them by GLC and GLC/MS. At the end of the reaction, the zeolite was filtered off, the benzene was driven off on a rotary evaporator, and the residues of the substrates were removed under vacuum. The solid products **2a,b** were recrystallized from hexane. Imine **2c** was an oily liquid. The ^{1}H NMR and mass spectra and elemental analysis of compounds **2a-c** corresponded to their structure. In Table 1, we present the characteristics of the reaction and the products obtained.

The structure of a rather large number of monoazadienes R–N=CH–CH=CH–R' is described in the literature. These basically represent the compounds obtained by condensation of aniline derivatives with derivatives of cinnamic aldehyde [2,3], and also their complexes with transition metals [4-8]. As a result of a search in the Cambridge crystallographic data bank, we found that structures of azomethines based on

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TABLE 1. Characteristics of Synthesized Compounds

Imine	Empirical formula	Reaction time, h	Found, % / Calculated, % C	H	N	mp, °C	Color	Yield, %
2a	$C_{13}H_{12}N_2O$	64	$\frac{73.46}{73.57}$	$\frac{5.57}{5.70}$	$\frac{13.20}{13.20}$	70-71	Yellow	51
2b	$C_{14}H_{14}N_2O$	132	$\frac{74.29}{74.31}$	$\frac{6.25}{6.24}$	$\frac{12.39}{12.38}$	91-92	Orange	57
2c	$C_{15}H_{14}N_2$	41	$\frac{-}{81.05}$	$\frac{}{6.35}$	$\frac{}{12.80}$	Oil	Dark red	81

aminopyridines are not known. We found only two structures of the above-indicated general formula based on furylacrolein derivatives: N-[3-(2,3-bismethoxycarbonylfur-5-yl)-2-propenylidene]aniline [9] and N'-[3-(5-nitrofur-2-yl)-2-propenylidene]benzhydrazide [10]. All these compounds and ligands in the complexes are conjugated systems, each including three practically planar moieties: R, N=CH–CH=CH, and R'.

With the objective of determining the structure of novel heterocyclic unsaturated Schiff bases and the nature of the conjugation in these imines, in this work by crystallization of compound **2b** and also the previously [1] synthesized 2-amino-N-(3-phenyl-2-propenylidene)pyridine (**2d**) from a hexane–ethylacetate mixture, we obtained single crystals and studied them by X-ray diffraction. In Figs. 1 and 2, we show the three-dimensional molecular models for compounds **2b,d**, and the numbering of the atoms.

The crystallographic data, the coordinates of the non-hydrogen atoms, and some parameters characterizing the structure of the studied compounds are presented in Tables 2-6. Molecules of both aldimines have an s-*trans-E* configuration; their conformation includes three approximately planar moieties: pyridine moiety A; furan (for **2b**) or phenyl (for **2d**) moiety B; and diene moiety C. In Table 6, we give the equations for the average planes for the moieties A, B, and C in a Cartesian coordinate system as well as the deviations of the atoms from these planes. The maximum deviation is observed for the $C_{(9)}$ atom of the **2b** molecule. The relative orientation of the moieties is determined by their rotations about the $N_{(2)}$–$C_{(2)}$ and $C_{(9)}$–$C_{(10)}$ bonds. The dihedral angles between the A and C planes are 9.1(3) and 8.7(2)° for molecules **2b** and **2d** respectively; between planes B and C, they are equal to 13.6(3) and 16.0(3)°. These deviations from a planar structure, even though slight, disrupt the conjugation in molecules **2b** and **2d**. Analysis of the bond lengths and bond angles indicates unevenness of the π-electron distribution in the molecules. Thus the bonds $C_{(2)}$–$N_{(2)}$, $C_{(7)}$–$C_{(8)}$, and $C_{(9)}$–$C_{(10)}$ are longer than a one-and-a-half bond, while the bonds $N_{(2)}$–$C_{(7)}$ and $C_{(8)}$–$C_{(9)}$ are close in length to a double bond. The bond angles in the side chain (Table 5) increase in the direction from the pyridine ring toward the furan (or benzene) ring. The presence of angles somewhat larger than the standard 120° value is consistent with the theory of electron pair repulsion in the valence level [11]. A decrease in the angles, based on that theory, is explained by the effect of the unshared pair of electrons of the $N_{(1)}$ and $N_{(2)}$ nitrogen atoms.

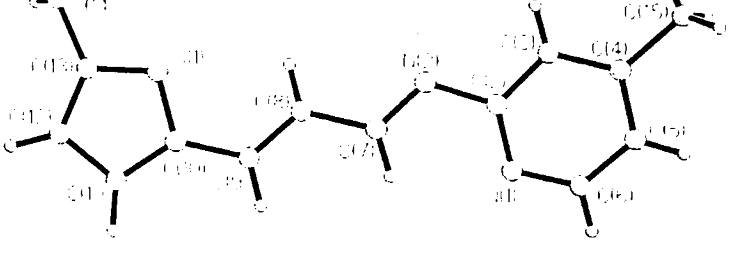

Fig. 1. Three-dimensional molecular model for compound **2b** with numbering of atoms.

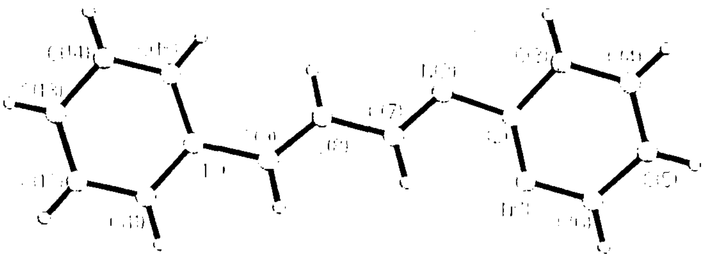

Fig. 2. Three-dimensional molecular model for the A moiety of compound **2d** with numbering of atoms.

Fig. 3 illustrates the packing of molecules of compound **2d** in the crystal, whose structure includes two crystallographically independent molecules (A and B). The B molecule is located in a special position and is disordered, and accordingly the standard deviations of the geometric parameters of this molecule are substantially higher than in the A molecule. So in discussing the results, we use the values calculated for the A molecule. Packing of the molecules in crystals of compounds **2b**,**d** is accomplished at distances no less than the sum of the van der Waals radii of the atoms in contact [12].

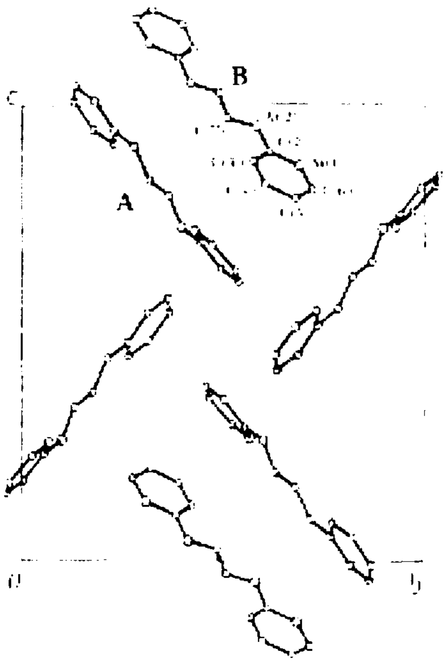

Fig. 3. Diagram showing the packing of molecules in the crystal of **2d** in a projection onto the y0z plane and the numbering of atoms for the B molecule.

TABLE 2. Crystallographic Data for Compounds **2b**,**d**

Characteristic	Compound	
	2b	**2d**
Formula	$C_{14}H_{14}N_2O$	$C_{14}H_{12}N_2$
Molecular weight	226.28	208.26
Color	Orange	Orange
Size (mm)	0.70 × 0.36 × 0.20	0.50 × 0.50 × 0.30
Crystal syngony	Monoclinic	Monoclinic
Space group	$C2/c$	$P2_1/c$
Cell parameters		
a (Å)	27.018(8)	6.649(1)
b (Å)	6.748(2)	17.422(3)
c (Å)	23.424(5)	15.164(3)
β (°)	143.78(1)	100.49(3)
Volume of unit cell, V (Å^3)	2523.3(9)	1727.2(5)
Number of molecules in unit cell, Z	8	6
Density, d (g/cm^3)	1.191(1)	1.201(1)
Absorption coefficient, μ (mm^{-1})	0.077	0.072
Number of independent reflections	2214	2259
Number of reflections with $I > 2\sigma(I)$	1107	1001
Number of refined parameters	210	217
R factor	0.0595	0.0821

EXPERIMENTAL

The ^1H NMR spectra were studied on a Varian Mercury spectrometer (200 MHz) for solutions in $CDCl_3$, internal standard TMS. The mass spectra were obtained on an HP 6890 GC/MS chromatograph/mass spectrometer equipped with an HP-5 MS capillary column (30.0 m × 250 mm × 0.25 mm), with temperature programming from 70°C to 260°C (10°C/min). The reaction mixtures were analyzed on a Chrom-4 chromatograph equipped with a flame ionization detector and a glass column (1.2 m × 3 mm) packed with the phase 5% OV-17 on Chromosorb W-AW (60-80 mesh), column temperature 120-250°C, carrier gas nitrogen (60 ml/min).

TABLE 3. Coordinates of Non-hydrogen Atoms in the Structure of **2b**

Atom	x	y	z
O(1)	0.12005(14)	0.4562(3)	0.74584(16)
N(1)	0.3584(2)	-0.4043(5)	0.9427(2)
N(2)	0.2803(2)	-0.1782(4)	0.9266(2)
C(2)	0.3240(2)	-0.3587(5)	0.9606(2)
C(3)	0.3310(2)	-0.4784(6)	1.0150(3)
C(4)	0.3738(2)	-0.6549(6)	1.0517(3)
C(5)	0.4096(3)	-0.7025(7)	1.0333(3)
C(6)	0.4010(3)	-0.5755(7)	0.9808(4)
C(7)	0.2521(2)	-0.0929(6)	0.8558(3)
C(8)	0.2087(2)	0.0928(5)	0.8188(3)
C(9)	0.1765(2)	0.1876(6)	0.7437(3)
C(10)	0.1328(2)	0.3705(5)	0.7050(2)
C(11)	0.0961(3)	0.4854(7)	0.6310(3)
C(12)	0.0602(3)	0.6470(7)	0.6255(3)
C(13)	0.0754(2)	0.6263(6)	0.6957(3)
C(14)	0.0546(4)	0.7418(8)	0.7273(5)
C(15)	0.3796(6)	-0.7943(11)	1.1073(6)

TABLE 4. Coordinates of Non-hydrogen Atoms in the Structure of **2d**

Atom*	x	y	
N(1)	0.7689(10)	0.4304(3)	0.7670(4)
N(2)	0.4175(8)	0.3971(3)	0.7460(4)
C(2)	0.5820(11)	0.4423(4)	0.7267(5)
C(3)	0.5290(11)	0.4962(4)	0.6581(5)
C(4)	0.6791(15)	0.5407(4)	0.6382(6)
C(5)	0.8733(14)	0.5325(4)	0.6814(6)
C(6)	0.9156(11)	0.4759(4)	0.7466(5)
C(7)	0.4364(9)	0.3663(3)	0.8244(4)
C(8)	0.2795(10)	0.3195(4)	0.8479(4)
C(9)	0.2898(9)	0.2835(3)	0.9253(4)
C(10)	0.1372(10)	0.2332(3)	0.9521(4)
C(11)	0.1867(10)	0.1858(4)	1.0259(4)
C(12)	0.0448(12)	0.1362(4)	1.0501(4)
C(13)	-0.1484(12)	0.1333(4)	1.0010(5)
C(14)	-0.2040(11)	0.1818(4)	0.9283(5)
C(15)	-0.0622(11)	0.2305(4)	0.9058(4)
At(1)	0.2016(11)	0.6907(4)	0.8721(5)
At(2)	0.0844(11)	0.5859(4)	0.9545(5)
C(2')	0.2387(12)	0.6171(5)	0.9077(4)
C(3')	0.4041(12)	0.5784(4)	0.8997(4)
C(4')	0.5403(13)	0.6074(5)	0.8560(6)
C(5')	0.5111(14)	0.6806(6)	0.8189(5)
C(6')	0.3445(15)	0.7202(4)	0.8290(5)
C(7')	0.0788(11)	0.5137(5)	0.9769(5)

* At = C (g = 0.5), N (g = 0.5).

The benzene was distilled over CaH_2 before use. Aldehydes **1a** and **1b** were synthesized according to the procedure in [13]. The cinnamic aldehyde (Reakhim) was purified by vacuum distillation and the 2-amino-4-methylpyridine (Fluka) was recrystallized from benzene, after which their properties corresponded to literature data. In this work, we used the molecular sieves 4A (VEB Laborchemie Apolda).

TABLE 5. Some Bond Lengths (*d*, Å) and Bond Angles (θ, degrees) in the Structures of **2b,d**

Characteristic	Compound	
	2b	**2d**
d		
C(2) N(2)	1.412(4)	1.421(8)
N(2) C(7)	1.275(5)	1.289(7)
C(7) C(8)	1.433(5)	1.420(8)
C(8) C(9)	1.338(5)	1.322(8)
C(9) C(10)	1.419(5)	1.453(8)
θ		
C(3) C(2) N(2)	116.9(3)	115.2(7)
C(2) N(2) C(7)	118.3(3)	118.1(6)
N(2) C(7) C(8)	121.4(4)	121.2(6)
C(7) C(8) C(9)	124.1(4)	125.0(6)
C(8) C(9) C(10)	125.3(4)	127.4(6)

TABLE 6. Normal Equations of the Planes for the Moieties and Deviations of Atoms From These Planes

Planar moiety	Coefficients of the equation for the plane *ax* + *by* + *cz* - *d* = 0				Deviations of the atoms from the plane of the moiety
	a	*b*	*c*	*d*	
			Molecule 2b		
A	-0.5824	-0.5032	-0.6385	-1.8022	ΔC2 = -0.018(5) ΔC9 =-0.004(5) ΔC3 = 0.009(6) ΔN1 = 0.004(4) ΔC4 = -0.014(6) ΔN2* = -0.419(5) ΔC6 = 0.003(9)
B	-0.2809	-0.5049	-0.8162	-6.9395	ΔO1 = -0.008(3) ΔC13 = 0.034(5) ΔC10 = -0.050(4) ΔC9* = 0.218(4) ΔC11 = -0.021(4) ΔC14* =-0.016(5) ΔC12 = 0.037(4)
C	-0.4508	-0.5863	-0.6731	-3.4906	ΔC7 = -0.005(5) ΔN2 = -0.027(4) ΔC8 = -0.072(5) ΔC2* = 0.034(5) ΔC9 = 0.105(5)
			Molecule 2d		
A	0.2851	-0.6611	-0.6940	-12.0540	ΔN1 = 0.014(5) ΔC5 = -0.011(8) ΔC2 = -0.029(7) ΔC6 = 0.005(8) ΔC3 = 0.014(6) ΔN2*= -0.036(5) ΔC4 = -0.006(8)
B	0.3897	-0.7050	-0.5926	-11.9582	ΔC10 = -0.013(6) ΔC14 = -0.004(8) ΔC11 = -0.008(7) ΔC15 = -0.011(7) ΔC12 = -0.007(7) ΔC9* = 0.056(6) ΔC13 = 0.016(8)
C	0.4834	-0.8023	-0.3506	-9.1094	ΔN2 = 0.009(5) ΔC9 = 0.013(6) ΔC7 = -0.013(6) ΔC2* = 0.034(7) ΔC8 = -0.016(6) ΔC10*= 0.049(6)

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* Atoms neglected in calculation of the plane.

X-ray Diffraction Studies. Orange single crystals of compounds **2b** and **2d** were obtained by slow crystallization from a 1:1 hexane–ethylacetate mixture. The investigations were conducted at 25°C on a Syntex $P2_1$ 4-circle automatic diffractometer (MoKα radiation, graphite monochromator, ω scanning, 2θmax = 50° for **2b** and 45° for **2d**). The structures were deciphered by the direct method and least-squares refined in the anisotropic approximation. The calculations were performed using the programs in [14, 15].

General Procedure for Synthesis of Azomethines 1-3. Dry benzene (10 ml) and each of the starting aldehyde and amine (5 mmol) and then freshly calcined molecular sieves (5 g) were placed into a flask. The flask was then allowed to stand at room temperature; samples were periodically withdrawn and analyzed by GLC and GLC/MS. Over the course of a certain time period (depending on the substrates, Table 1), they converted practically completely to the corresponding products. At the end of the reaction, the sieves were filtered off and washed with benzene, and the filtrate was evaporated under reduced pressure (40°C/15 mm) and slight residues of the starting compounds were removed under vacuum (45-50°C/0.1 mm). The solid products were purified by recrystallization from hexane, and then the characteristics of the compounds obtained were determined (Table 1) and their ^{1}H NMR spectra were recorded.

2-Amino-N-[3-(2-furyl)-2-propenylidene]-4-methylpyridine (2a). GLC/MS, *m/z* (I_{rel}, %): 212 (20, M^+), 211 (10, $[M - H]^+$), 184 (15, $[M - CO]^+$), 183 (100, $[M - HCO]^+$), 168 (5, $[M - HCO - Me]^+$), 157 (4), 145 (3, $[M - Fur]^+$), 132 (15, Me - C_5H_3N - NCHCH$]^+$), 120 (7), 119 (3, M - [Fur–CH=CH]$^+$), 93 (26, Me - C_5H_3N-H]$^+$, [Fur–CH=CH]$^+$), 92 (14, [Me - C_5H_3N]$^+$), 78 (2, Py$^+$), 77 (3), 66 (15), 65 (24), 51 (14), 39 (19). ^{1}H NMR, δ (ppm), *J* (Hz): 2.36 (3H, s, CH_3); 6.47 (1H, dd, *J* = 3.4 and 1.6, FurH-4); 6.59 (1H, d, *J* = 3.4, FurH-3); 6.98 (1H, br. d, *J* = 5.0, PyH-5); 7.0-7.1 (2H, m, CH=CH); 7.09 (1H, s, PyH-3); 7.50 (1H, d, *J* = 1.6, FurH-5); 8.30 (1H, d, *J* = 5.0, PyH-6); 8.92 (1H, m, CH=N).

2-Amino-N-[3-(5-methylfur-2-yl)-2-propenylidene)]-4-methylpyridine (2b). GLC/MS, *m/z* (I_{rel}, %): 226 (8, M^+), 225 (6), 211 (2, $[M - Me]^+$), 184 (15), 183 (100, $[M - Me - CO]^+$), 168 (8, $[M - Me - Me - CO]^+$, 156 (2), 145 (2), 132 (10), 104 (2), 93 (16, $[Me - C_5H_3N - H]^+$), 92 (8, $[Me - C_5H_3N]^+$), 77 (5), 66 (8), 65 (14), 53 (5), 51 (6), 43 (9), 39 (11). ^{1}H NMR, δ (ppm), *J* (Hz): 2.36 (6H, s, 2 CH_3); 6.08 (1H, br. d, *J* = 3.2, FurH-4); 6.49 (1H, d, *J* = 3.2, FurH-3); 6.8-7.0 (3H, m, PyH-5 and CH=CH); 7.07 (1H, s, PyH-3); 8.30 (1H, d, *J* = 5.0, PyH-6); 8.90 (1H, m, CH=N).

2-Amino-4-methyl-N-(3-phenyl-2-propenylidene)pyridine (2c). GLC/MS, *m/z* (I_{rel}, %): 222 (31, M^+), 221 (44, $[M - H]^+$), 207 (1, $[M - Me]^+$), 194 (6), 146 (10), 145 (100, $[M - Ph]^+$), 130 (44, $[M - Me - Ph]^+$), 115 (14), 103 (7), 102 (9, $[Ph–CH=CH]^+$), 93 (47, $[Me - C_5H_3N - H]^+$), 92 (21, $[Me - C_5H_3N]^+$), 78 (7, Py^+), 77 (13, Ph^+), 66 (21), 65 (29), 64 (6), 52 (7), 51 (13), 39 (18). ^{1}H NMR, δ (ppm), *J* (Hz): 2.37 (3H, s, CH_3); 6.97 (1H, br. d, *J* = 5.0, PyH-5); 7.07 (1H, s, PyH-3); 7.13 (1H, dd, *J* = 16.0 and 8.5, CH_β), 7.28 (1H, d, *J* = 16.0, CH_α), 7.3-7.6 (5H, m, Ph); 8.31 (1H, d, *J* = 5.0, PyH-6); 8.99 (1H, d, *J* = 8.5, CH=N).

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