## A Comparison of Crystallographic and NMR Data for Thieno[2,3-*b*:4,5-*b*']dipyridine and Its Monohydroperchlorate Salt

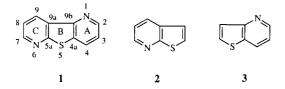
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X-ray crystallographic studies of thieno[2,3-b:4,5-b']dipyridine (1) and its monohydroperchlorate salt (1a) show that 1 is protonated at N1 in ring A and not at N6 in ring C. In each compound individual rings are planar, but there is a small dihedral angle-of-twist between the A and C rings. On going from 1 to 1a the largest changes in bond angles and bond lengths occur in ring A. <sup>1</sup>H and <sup>13</sup>C nmr spectra of 1 plus the <sup>13</sup>C nmr spectrum of 1a are reported.

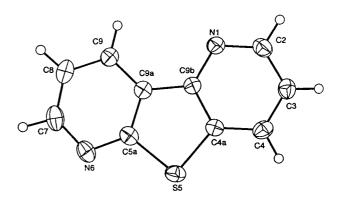
## J. Heterocyclic Chem., 37, 763 (2000).

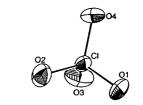
Tricyclic thieno[2,3-b:4,5-b']dipyridine (1) [1] bears the structural features of both bicyclic thieno[2,3-b]pyridine (2) and thieno[3,2-b]pyridine (3), compounds which have been synthesized and studied extensively in our laboratory [2-4]. Compounds 1-3 form crystalline monohydroper-chlorate salts (designated here as 1a-3a, respectively) with pK<sub>a</sub> values in water of 2.46, 2.75, and 4.35, respectively [5]. Based on the fact that the nitrogen atom in 3 is considerably more basic than that in 2, one might expect 1a to be protonated at N1 rather than at N6. However, the low basicity of 1 makes this supposition uncertain. The present research serves to ascertain (a) the location of the proton from addition of perchloric acid to 1 and (b) the effect on structural features which protonation produces in 1. Some nmr data for 1 and 1a are also reported.

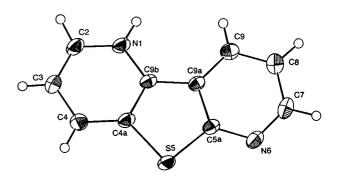


Crystallographic data for 1 and 1a are presented in Table 1 [6]. The ORTEP drawings for these compounds are shown in Figures 1 and 2, respectively. It is apparent from the latter figure that protonation of 1 has occurred at N1 and not at N6. Within experimental error all individual rings are planar in both compounds (see footnotes a and b to Table 2). Deviations of the various ring atoms from the least-squares mean plane in all six rings are only 0.003-0.008 Å. There is a small twist observable in each tricyclic unit, however. The dihedral angles between the least-squares planes for rings A and C are 2.1° in 1 and 4.0° in 1a [7].

Protonation of 1 causes some appreciable changes (>  $2.5^{\circ}$ ) in three internal bond angles in ring A, with smaller (<  $2.5^{\circ}$ ) changes in the analogous bond angles in ring C. For ring A the changes are +  $5.4^{\circ}$  at N1, - $3.0^{\circ}$  at C2, and - $4.3^{\circ}$  at C9b; while for ring C, they are + $2.4^{\circ}$  at N6, - $1.1^{\circ}$  at C7, and - $1.8^{\circ}$  at C5a. Accompanying the changes in bond angles are changes of  $0.014\text{\AA}$  or more in three bond lengths in each of these rings: -0.028 for C2-C3, +0.014 for C3-C4,







and + 0.019 for C9b-N1 in ring A; +0.015 for C7-C8, -0.014 for C5a-N6, and +0.014 for C5a-C9a in ring C. These comparisons might seem to imply that crystalline 1a contains some molecular ions bearing a proton on N6, rather than on N1 [8]. However, the crystallographic data

Table 1 Crystallographic Data and Structural Refinement for Compound 1 and Its Hydroperchlorate 1a [a]

		For 1	For 1a
Empirical formula		$C_{10}H_6N_2S$	C <sub>10</sub> H <sub>7</sub> CIN <sub>2</sub> O <sub>4</sub> S
Formula weight		186.23	286.69
Crystal appearance		colorless plate	yellow lath [b]
Crystal dimensions (mm)		$0.50 \times 0.29 \times 0.015$	$0.065 \times 0.19 \times 0.57$
Crystal system		orthorhombic	triclinic
		Pna2 <sub>1</sub>	P(-1)
Space group Unit cell dimensions (Å)  a		18.722 (4)	5.454 (1)
Onit cen dimensions (A)	a b	3.877 (1)	8.095 (1)
	-	11.445 (1)	13.053 (2)
TT 'A 11 1 (0)	c ~	90	101.65 (1)
Unit cell angles (°)	α	90	92.08 (1)
	β	90	93.17 (1)
**************	γ		562.9 (2)
Unit cell volume (Å <sup>3</sup> )		830.7 (2)	2
Z		4	1.691
Density (calculated) (g/cm <sup>3</sup> )		1.489	5.32 cm <sup>-1</sup>
Linear absorption coefficient (μ)		3.32 cm <sup>-1</sup>	292
F (000)		384	
Temperature (°C)		22	23 50°
Maximum 20		54°	• •
Index ranges, h, k, l		$0 \rightarrow 23, 0 \rightarrow 4, 0 \rightarrow 14$	$0 \rightarrow 6, -9 \rightarrow 9, -15 \rightarrow 15$
Scan mode		ω -2θ	ω -2θ
Scan speed on ω (°/min)		3.3	4.1
Scan width (°)		$0.95 + 0.35 \tan\theta$	$1.15 + 0.35 \tan\theta$
Reference reflections		3, every 3600s exposure	
Independent rflxns. scanned		943	1967
$R_{int}$ (on $F^2$ )		none measured	0.011
Absorption correction		none	azimuthal scans
Relative correction factors			0.83-1.00
Secondary extinction parameter		fixed at zero	fixed at zero
Reflections in refinement (N)		943 (all data)	1645 [ <b>I≥</b> σ( <b>I</b> )]
Number of parameters (V)		117	191
Function minimized		$\Sigma w( F_0 ^2 -  F_c ^2)^2$	$\Sigma w( F_o - F_c )^2$
Weighting factor w		$1/\sigma^2(F)$	1/σ <sup>2</sup> (F)
$R(F)$ , $wR(F)$ [ $I \ge \sigma(I)$ ] [a]			0.045, 0.051
$R(F^2)$ , $wR(F^2)$ (all data) [a]		0.075, 0.088	
S [a]		1.15 (all data)	2.31 [I≥σ(I)]
Maximum Δ/σ, last cycle		0.01	0.01
Max., min. in final difference map $(e/Å^3)$		0.47, -0.55	0.45, -0.37
man, man. in imat difference map (or i )		v, v.e-	• •

[a] For the diffractometer, radiation wavelength, and monochromator used, as well as the algebraic relationships for R(F), wR(F), wR(F<sup>2</sup>), and S, see references 13 and 14. [b] Analogously, colorless benzo[h]quinoline forms yellow salts with hydrogen chloride and with sulfuric acid. See J. Buckingham and S. M. Donaghy, eds, Dictionary of Organic Compounds, 5<sup>th</sup> Ed, Vol. 1, Chapman and Hall, New York, 1982, p 575.

D = 11 d = 11 = 10	Table 2	droparabloreta 1a	
Bond Angles (*Bond Angles (*Bond Angle	) for Compound 1 and Its Hy for 1 [a]	for 1a [b,c]	N6-C7-C8 C7-C8-C9
C9b-N1-C2	116.5 (4)	121.9 (3)	C8-C9-C9a
N1-C2-C3	123.7 (5)	120.7 (3)	C9-C9a-C5a
C2-C3-C4	119.7 (5)	120.0 (4)	C9a-C5a-N6
C3-C4-C4a C4-C4a-C9b C4a-C9b-N1	117.0 (5) 120.7 (5) 122.4 (5)	118.6 (3) 120.7 (3) 118.1 (3)	[a] $\Sigma$ angles in ring A 720.0 ± 3.0°. [b] $\Sigma$ and 1.1° ring $\Gamma$ 720.0 ±
C4a-S5-C5a	91.0 (2)	90.6 (1)	1.1°; ring C: 720.0 ± 110.2 ± 0.2°.
S5-C5a-C9a	112.7 (3)	113.3 (2)	
C5a-C9a-C9b	111.3 (4)	109.7 (3)	
C9a-C9b-C4a	113.2 (5)	114.8 (3)	molecule all refi
C9b-C4a-S5	111.9 (4)	111.4 (2)	
C5a-N6-C7	113.3 (5)	115.7 (3)	

are consistent only with exclusive protonation at N1 (see Experimental). Thus, there is no evidence of disorder in the crystalline structure. The seven hydrogen atoms in the

Table 2 (continued)

N6-C7-C8	125.8 (5)	124.7 (3)
C7-C8-C9	118.9 (6)	118.7 (4)
C8-C9-C9a	118.2 (5)	118.4 (3)
C9-C9a-C5a	117.5 (4)	118.0 (3)
C9a-C5a-N6	126.3 (5)	124.5 (3)

[a]  $\Sigma$  angles in ring A (of 1) 720.0  $\pm$  2.9°; ring B: 540.1  $\pm$  1.8°; ring C: 720.0  $\pm$  3.0°. [b]  $\Sigma$  angles in ring A (of 1a): 720.0  $\pm$  1.9°; ring B: 539.8  $\pm$  1.1°; ring C: 720.0  $\pm$  1.9°. [c] O-Cl-O angles vary from 107.4  $\pm$  0.2° to 110.2  $\pm$  0.2°.

molecule all refine satisfactorily with isotropic thermal parameters without, at any stage, indicating the presence of residual electron density near N6 for location of a hydrogen atom there. Also, while N1 is within hydrogen-bonding distance of perchlorate oxygen atom O1, there are no contacts between N6 and any anionic oxygen of such nature.

Table 3

Bond Lengths (Å) for Compound 1 and Its Hydroperchlorate 1a				
Bond	for 1	for <b>1a</b> [a]		
N1-C2	1.335 (6)	1.332 (4)		
C2-C3	1.391 (8)	1.363 (5)		
C3-C4	1.373 (7)	1.387 (5)		
C4-C4a	1.374 (7)	1.374 (5)		
C4a-S5	1.745 (5)	1.743 (3)		
S5-C5a	1.748 (5)	1.753 (3)		
C5a-N6	1.341 (6)	1.327 (4)		
N6-C7	1.333 (8)	1.323 (5)		
C7-C8	1.388 (9)	1.403 (5)		
C8-C9	1.372 (7)	1.368 (5)		
C9-C9a	1.383 (6)	1.385 (5)		
C9a-C9b	1.436 (6)	1.422 (4)		
C9b-N1	1.345 (6)	1.364 (4)		
C4a-C9b	1.392 (6)	1.395 (4)		
C5a-C9a	1.398 (6)	1.412 (4)		

[a] Also CI-O bond lengths in the perchlorate ion: To O1, 1.431 (3); to O2, 1.419 (3); to O3, 1.413 (3); to O4, 1.424 (3). C-H bond lengths fall in the range of 0.88 (4) to 0.94 (3). The N1-H bond is 0.88 (3).

Therefore, we ascribe the aforementioned changes in ring C to secondary structural adjustments to protonation at N1.

A direct comparison of  $^{1}\text{H}$  and  $^{13}\text{C}$  nmr data for 1 and 1a was not possible because of major differences in solubilities of these compounds. No common nmr solvent could be found. Compound 1 dissolves readily in deuteriochloroform which we used. A mixture of deuteriated methanol/deuterium oxide (2:1) was the only solvent we found for 1a. It provided a suitable  $^{13}\text{C}$  spectrum, but not a  $^{1}\text{H}$  one since it led to partial H/D exchange. The signals for the alpha protons of 1 (in rings A and C) overlap downfield at  $\delta$  8.72 and the beta protons show identical double doublets at 7.46 and 7.39. Bay-region proton H-9 is shifted downfield to 8.67 (compared to 8.17 for H-4) [9].

The <sup>13</sup>C nmr signals for 1 and 1a occur over the same ranges of 120-162 ppm. As expected, the spectrum of 1 shows four signals of low intensity (assigned to the four ring juncture carbon atoms) and six signals of greater intensity. Structural assignments of the signals for 1 are made by assuming that (a) there is a similar order of chemical shifts for the carbon atoms in ring A and those in the pyridine ring of 3 and (b) the same relationship occurs between carbon atoms in ring C and those in the pyridine ring of 2 [10]. In 1 the pairs of C2, C7; C4, C9; and C3, C8 show only slightly different chemical shifts. For 1a, the preceding patterns are altered by the signal for C2, which is believed to be partially deuteriated. Since this should lower the intensity of the signal [11], it was not possible to clearly distinguish between resonances for C2 and C4a. Nonetheless, it appears that the C2 resonance in 1a falls either 8 or 14 ppm upfield from that for C7. This upfield shift is probably the result of protonation at N1 [12].

## **EXPERIMENTAL**

All nmr spectra were recorded on a Varian INOVA 300 MHz spectrometer. X-ray crystallographic studies of 1 and 1a were

conducted with the apparatus and radiation as previously described [13,14]. A SIR92 E-map [15] showed all of the nonhydrogen atoms in each case. The identities of the nitrogen atoms were confirmed from their low thermal parameters when refined as carbon, and from bond lengths. The hydrogen atoms of 1 could not be clearly distinguished in a difference map following anisotropic refinement of the non-hydrogen atoms. They are shown (Figure 1) at positions recalculated after each cycle of refinement for  $B(H) = 1.2B_{eq}(C)$ ; and d(C-H) = 0.95 Å. On the other hand, all hydrogens of **1a** were located and refined isotropically (Figure 2). The final syntheses were featureless. The TeXsan program package [16], which incorporates complex atomic scattering factors, was used in all calculations (see Table 1). Bond angles are given in Table 2 and bond lengths in Table 3. N1 is hydrogen-bonded to O1 of the perchlorate ion with a distance of 3.038Å [17] and an N-H··O angle of 177  $\pm$  3°.

Thieno[2,3-*b*:4,5-*b*']dipyridine (1), mp 116-117° [1] is shown as ORTEP Figure 1;  $^{1}$ H nmr (deuteriochloroform):  $\delta$  8.72 (two overlapping dd, 2H, H-2 and H-7), 8.67 (dd,  $J_{7,9}$  = 1.8 Hz, 1H, H-9), 8.17 (dd,  $J_{2,4}$  = 1.5 Hz, 1H, H-4), 7.46 and 7.39 (2 dd,  $J_{2,3}$  =  $J_{7,8}$  = 4.7 Hz,  $J_{3,4}$  =  $J_{8,9}$  = 7.9 Hz, 2H, H-3 and H-8);  $^{13}$ C nmr:  $\delta$  161.9 (C-5a), 150.2 and 147.0 (C-2 and C-7), 149.5 (C-9b), 133.1 (C-4a), 130.8 and 130.5 (C-4 and C-9), 128.6 (C-9a), 121.7 and 120.1 (C-3 and C-8).

1 · Hydroperchlorate (1a), mp 198.5-200° [5] is shown as ORTEP Figure 2;  $^{13}$ C nmr (CD<sub>3</sub>OD/D<sub>2</sub>O;2:1 by volume): δ 162.1 (C-5a), 152.4 (C-7), 144.2 (C-2?), 144.9 (C-9b), 138.5 (C-4a?), 136.2 and 133.7 (C-4 and C-9), 126.2 (C-9a), 124.4 and 122.7 (C-3 and C-8) [18].

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