Investigation of Intramolecular Sulfur-Nitro Interactions in 2-(2'-Pyridylthio)-3-nitropyridine by ^{13}C-NMR Spectroscopy and X-Ray Crystallography

Michio Kimura and Stanley H. Simonsen (1)

Department of Chemistry, The University of Texas at Austin, Austin, Texas 78712

Steven R. Caldwell (2) and Gary E. Martin (1)

Department of Medicinal Chemistry and Pharmacognosy, College of Pharmacy, University of Houston, Houston, Texas 77004

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The single crystal X-ray diffraction structure of 2-(2'-pyridylthio)-3-nitropyridine is reported. A non-bonded interaction was observed between the sulfur atom and one of the oxygen atoms of the nitro group with an interatomic distance of 2.678 Å. Examination of the molecule's behavior in solution by ^{13}C-nmr spin-lattice (T_1) relaxation measurements showed the non-nitro bearing pyridyl ring to reorient anisotropically about the C2'-C5' bond axis. In contrast, the nitro substituted pyridine ring did not appear to exhibit anisotropic reorientation about the corresponding C2-C5 bond axis. Rather, approximately equivalent relaxation times were noted for all protonated ring carbons, indicating that the relaxations of this portion of the molecule were governed by the overall isotropic reorientation of the system. Based on these observations, it was concluded that the intramolecular sulfur-nitro interaction also operates in the solution state and is sufficiently strong to prevent free rotation of the substituted portion of the molecule about the C2-S bond axis.

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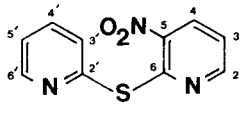
Intramolecular interactions between aromatic nitro substituents and ortho-sulfide linkages have been observed in a number of X-ray crystallographic studies (3-5). Evidence has also been reported from ^{13}C-nmr studies of suitably substituted phenoxathiin analogs which suggests the existence of such interactions in solution as well (6-8). Indeed, in the case of 9-nitro-1-azaphenoxathiin the existence of such an interaction was first predicted from ^{13}C-nmr chemical shift data (6) and subsequently confirmed in the crystal structure (9). As a part of our ongoing efforts to understand such interactions, we now report the results of our combined ^{13}C-nmr spectroscopic and X-ray crystallographic studies of 2-(2'-pyridylthio)-3-nitropyridine (1).



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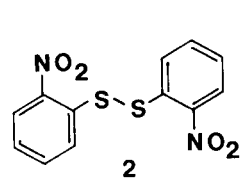
The synthesis of **1** was conducted, as previously described (10) by the reaction of sodium-2-pyridylthiolate with 2-chloro-3-nitropyridine in *N,N*-dimethylformamide. Following isolation, the compound was recrystallized from cyclohexane/acetone to give yellow prisms which were used for both the ^{13}C-nmr and X-ray diffraction portions of this work.

It was assumed from the outset that **1** would exhibit a sulfur-nitro interaction of the type described previously (3-5,9). Furthermore, the constitution of **1** is such that a strong interaction would prohibit the anisotropic reorientation about the C2-S bond axis. A consequence of this behavior is seen in the relaxation time of C5 relative to that of C4 and C6. Specifically, relaxation times for all three carbons would be expected to be equivalent, a characteristic of overall isotropic motion, in the absence of a defined reorientation about the C2-C5 axis. In contrast, it was also assumed that the non-nitro bearing pyridyl ring would reorient anisotropically about the corresponding C2'-C5' axis thereby resulting in a shortening of the T_1 relaxation time of C5' relative to that of C3', C4' and C6'.

The crystals of **1** employed in the X-ray diffraction studies were found to be in space group $P2_1/c$. Data collection, and refinement were conducted as described below in the experimental section. From a crystallographic standpoint, the structure of **1** determined in this study shares features with bis(*o*-nitrophenyl)disulfide (**2**) (3) and 2,4-bis(thiophenyl)nitrobenzene (**3**) (4).



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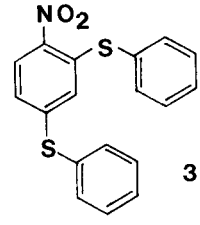

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Bond lengths and angles for **1** are shown on a ORTEP drawing of the isolated molecule in Figure 1. (bond lengths are shown by Figure 1A, while bond angles are shown in Figure 1B). Bond distances and angles within each of the pyridine rings were normal and, within experimental error,

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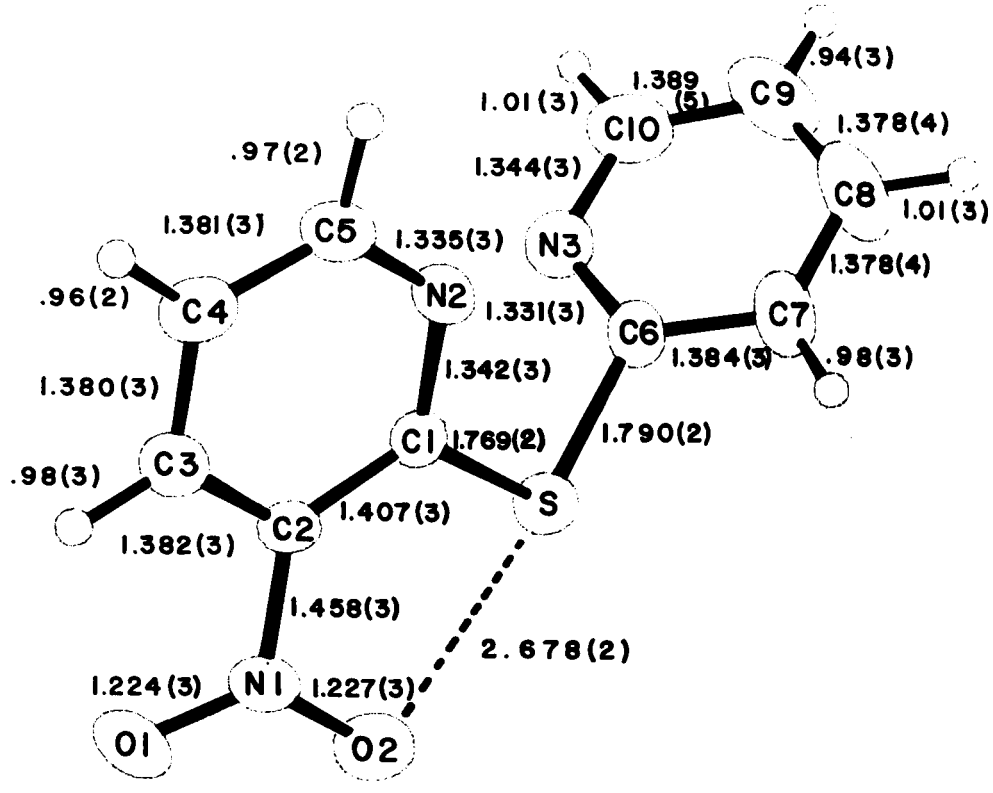


Figure 1A. Bond lengths of 2-(2′-Pyridylthio)-3-nitropyridine (1).

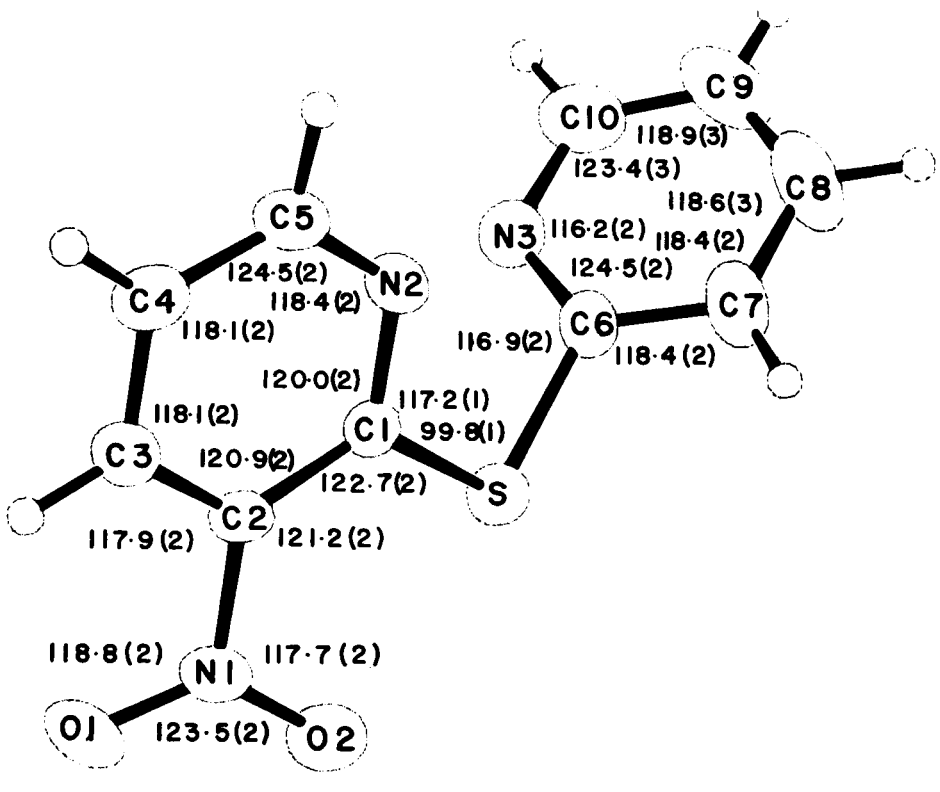


Figure 1B. Bond angles of 2-(2′-Pyridylthio)-3-nitropyridine (1).

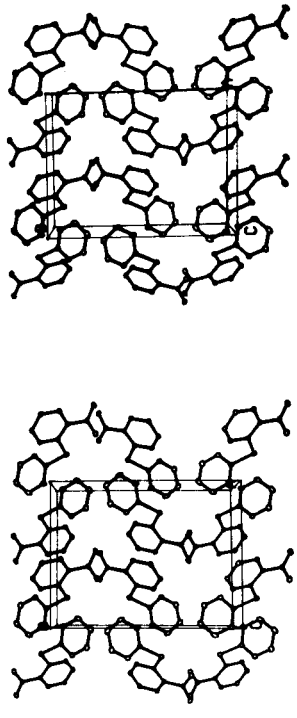
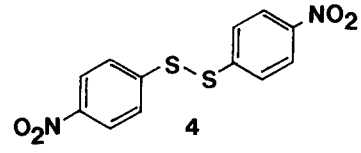


Figure 2. Stereo packing diagram of **1**.

were equivalent to one another.

The dihedral angles between the plane of the two pyridine rings is 74.9° while the angle formed by the plane of the nitro-bearing pyridine ring and the nitro group is 16.7°. These data compare favorably with the angles 75.3° and 18.6° for **2** (3) and for **3** (4), suggesting similar S-O interactions in all three compounds.

The C-N bond between the nitro group and the pyridine ring is somewhat shorter (1.458 Å) than the corresponding bonds of **2** and **3** (1.488 and 1.463, respectively). When compared to the C-N bond of bis(*p*-nitrophenyl) disulfide (**4**) (1.476 Å) which does not engage in an S-O interaction (11), the C-N bond of **1** was still found to be significantly shorter. In the case of **2**, **3** and **4**, the extent of resonance between the aromatic ring and the nitro groups is probably negligible. In the case of **1** however, the C-NO_2 bond shortening, in spite of the decreasing effectiveness of electron delocalization because of the dihedral angle of 16.1° between the plane of the nitro group and that of the pyridine ring, may suggest some electronic interaction between the nitro group and the annular nitrogen. This conclusion is further supported by the observed shortening of the C2-S bond distance (1.769 Å) relative to the C2′-S bond distance (1.790 Å).



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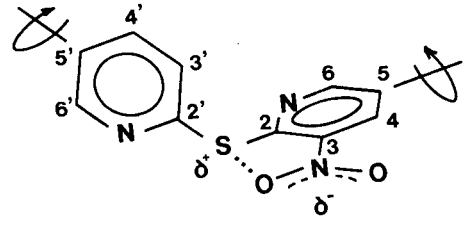
The most interesting structural feature of **1** is the sulfur-oxygen interaction, where the distance (2.678 Å) is well below the sum of the van der Waal's radii (3.25 Å) and quite comparable to the non-bonded S-O distances of 2.636 Å and 2.644 Å seen for **2** and **3**, respectively (3,4). Accordingly, it is logical to assume that this compound shares the same π-sytem comprised of S-C-C-NO_2 with the other two molecules.

Solution behavior of **1** was begun by the preliminary acquisition of decoupled ^{13}C-nmr and a ^{1}H-^{13}C spin coupled spectrum acquired under gated decoupling conditions. Molecular motion was assessed by measurement of the spin-lattice (T_1) relaxation times using the inversion recovery method (12,13). Relaxation data were evaluated using the three-parameter non-linear fit program (14) with no attempt made to measure the relaxation times of the non-protonated carbons C2, C3, and C2′. (Chemical shift and relaxation are summarized in Table I.)

Table I

25.2 MHz ^{13}C-Nmr Chemical Shifts and T_1 Relaxation Times for 2-(2′-Pyridylthio)-3-nitropyridine (**1**) in Deuteriochloroform



Carbon	2	3	4	5	6	2′	3′	4′	5′	6′
δ	152.54	141.59	133.25	119.84	152.98	156.67	131.01	136.94	123.39	150.38
T_1(sec)	–	–	2.07	2.32	2.36	–	3.03	2.93	2.18	2.83

Tumbling preference about S-C2′-C5′ bond axis ϱ = 2.04. Reorientational correlation time = 2.1 × 10^{-11} second.

Table II

Crystal Data

Molecular Formula	$C_{10}H_7N_3O_2S$
Molecular Weight	233.26
Space Group	$P2_1/c$
Cell Constants	
a, Å	10.400 (1)
b, Å	13.296 (1)
c, Å	7.396 (1)
β	92.633 (7)°
Vol, Å^3	1021.66
Z	4
ϱ, g cm^{-3}	1.516 (X-ray, −35° C)
Crystal Dimension	0.15 × 0.16 × 0.20 mm
μ, cm^{-1}	3.02 (Mokα)

Based on the relaxation data, obtained, several conclusions can readily be drawn. As anticipated, the non-substituted pyridyl ring undergoes anisotropic reorientation about the C2′-C5′ axis with a consequent lengthening of the T_1 relaxation times of carbons C3′, C4′ and C6′ relative to that of C5′. This facet of the relaxation behavior of **1** can be explained by the angular dependance of the term χ_H, which governs the contribution of the C-H bond vector in dipolar relaxation. Thus, relaxation may be described by the expression

$$1/T_1 DD = N\hbar^2\gamma_c^2\gamma_H^2 r_{cH}^{-6}\chi_H$$

where χ_H may be defined by the expression

$$\chi_H = 1/4(3\cos^2\Theta - 1)^2 + 18(5 + \varrho)\sin^2\Theta \cos^2\Theta + 9/4(1 + 2\varrho)^{-1}\sin^4\Theta$$

Based on this treatment, as has been shown with various substituted aromatics and biphenyls (15,16), it follows that the carbons bearing a hydrogen with a C-H bond vector co-incident with the reorientational axis will relax more efficiently than those with a C-H vector 60° to the same axis. In contrast, the relaxation times observed for the nitro-substituted ring are equivalent within experimental error and are thus indicative of the absence of anisotropic reorientation. Furthermore, it is probable that the overall relaxation of the substituted pyridyl ring is governed by the overall isotropic motion of the entire molecular framework in solution. In conclusion, the data show that 2-(2′-pyridylthio)-3-nitropyridine exhibits a sulfur-nitro interaction in both the crystal and in solution, a conclusion previously supported only by speculation. The stereo drawing of the molecular packing as shown in Figure II represents a view along the b-axis. In two molecules related by the center of symmetry, the nitro-bearing pyridines as well as the other pyridines are almost oriented in parallel in the unit cell and produce columns along the b-axis. This manner of crystal packing is similar to that of **2**. A pair of nitro-bearing pyridines is placed in the opposite direction because of the repulsion of the nitro groups of two pyridines. Further studies are at present underway on related compounds and will be forthcoming.

EXPERIMENTAL

Collection and Reduction of Crystallographic Data.

The crystal selected for the measurement of lattice parameters and intensity data was a cleaved fragment which had approximate dimensions of 0.15 × 0.16 × 0.20 mm. A preliminary examination of the crystal carried out on a Syntex $P2_1$ diffractometer showed it to be monoclinic. Systematic absences of $\ell = 2n + 1$ for $h0\ell$, and $k = 2n + 1$ for $0k0$ established the space group to belong to $P2_1/c$. The unit cell parameters at −35° were refined by least-squares using the Bragg angles (Mokα, λ = .791069 Å) of thirty reflections ($25° < 2\Theta < 30°$). The unit cell dimensions and other crystal data are listed in Table II. Intensity data were collected at −35° on the Syntex $P2_1$ diffractometer with Mokα radiation by a graphite crystal.

Table III

Final Positional and Thermal Parameters of Non-Hydrogen Atoms with Estimated Standard Deviations in Parentheses (all U's are X 10^4)

Atom	X	Y	Z	U11	U22	U33	U12	U13	U23
S	.2048(1)	.5852(0)	.2914(1)	39(0)	33(0)	42(0)	1(0)	−12(0)	6(0)
O1	.5211(2)	.7417(1)	.5637(3)	52(1)	35(1)	66(1)	−15(1)	−6(1)	−2(1)
O2	.3377(2)	.7454(1)	.4151(3)	59(1)	34(1)	71(1)	−2(1)	−13(1)	18(1)
N1	.4186(2)	.7032(1)	.5143(2)	41(1)	25(1)	37(1)	−2(1)	3(1)	−3(1)
N2	.2664(2)	.4513(1)	.5491(2)	32(1)	29(1)	35(1)	−4(1)	1(1)	3(1)
N3	.2086(2)	.4041(2)	.1357(3)	43(1)	42(1)	41(1)	1(1)	−2(1)	2(1)
C1	.2929(2)	.5436(2)	.4875(3)	26(1)	27(1)	30(1)	3(1)	3(1)	−1(1)
C2	.3903(2)	.6016(1)	.5747(3)	32(1)	22(1)	29(1)	1(1)	5(1)	−1(1)
C3	.4643(2)	.5629(2)	.7184(3)	36(1)	31(1)	29(1)	−0(1)	0(1)	−8(1)
C4	.4363(2)	.4675(2)	.7783(3)	47(1)	31(1)	25(1)	5(1)	−5(1)	−1(1)
C5	.3360(2)	.4162(2)	.6914(3)	43(1)	28(1)	30(1)	−3(1)	4(1)	3(1)
C6	.1333(2)	.4688(2)	.2182(3)	31(1)	41(1)	29(1)	−1(1)	−6(1)	3(1)
C7	.0027(2)	.4555(2)	.2376(3)	34(1)	64(2)	39(1)	−7(1)	−2(1)	−0(1)
C8	−.0544(3)	.3695(3)	.1678(4)	48(2)	87(2)	45(1)	−28(2)	−3(1)	1(2)
C9	.0210(3)	.3004(3)	.0831(4)	80(2)	63(2)	38(1)	−32(2)	−7(1)	−2(1)
C10	.1514(3)	.3202(2)	.0701(4)	72(2)	44(1)	39(1)	−1(1)	1(1)	1(1)

Table IV

Final Positional and Thermal Parameters of Hydrogen Atoms With Estimated Standard Deviations in Parentheses (all U's are $\times 10^4$)

Atom	X	Y	Z	U
H-C3	.537(2)	.602(2)	.769(3)	.045(7)
H-C4	.485(2)	.440(2)	.881(3)	.039(6)
H-C5	.309(2)	.350(2)	.732(3)	.032(6)
H-C7	−.041(3)	.508(2)	.303(4)	.065(9)
H-C8	−.151(3)	.358(2)	.170(4)	.077(9)
H-C9	−.019(3)	.243(3)	.031(5)	.082(10)
H-C10	.208(3)	.272(2)	.006(4)	.057(8)

The ω scans of 1.0° were employed with scan rates which varied from 2.0 to 5.0° min^{-1} depending in a direct manner on the number of counts obtained in a rapid preliminary count of the peak. Background counts were taken at both ends of the scan with ω displaced ± 1.0° from the Kα peak; the time of each measurement was one-half the scan time. A total of 2290 unique reflections of the type h, k, ±1 were measured in the range $4° < 2\theta < 55°$. The intensities of four standard reflections were measured after every 96 reflections; these intensities dropped by an average of a few percent over the period of data collection, but no correction factor was applied because the decrease was not considered significant. No absorption corrections were applied (μ = 3.02 cm^{-1}). Lorentz and polarization corrections were applied to convert intensities to structure amplitudes. Standard deviations in the intensities, σ(I), and in the structure amplitudes, σ(Fo), were derived directly from counting statistics.

Solution and Refinement of the Structure.

The structure was solved by direct methods using MULTAN (17) to calculate phases for the 200 | E | values greater than 1.70. The E map computed from the phase set with the largest combined figure of merit revealed all non-hydrogen atoms (18) except for one carbon of pyridine ring. The subsequent difference Fourier map readily gave the remaining carbon atom.

The 1562 reflections for which Io > 3σ(Io) were used by the full-matrix least-squares refinement of the structure. The function minimized was $\Sigma w(|F_o| - |F_c|)^2$, where w is the weight calculated as $1/\sigma^2$(Fo). An initial refinement using individual isotropic temperature factors for the non-hydrogen atoms led to a conventional $R = \frac{\Sigma \| Fo| - |Fc\|}{\Sigma |Fo|}$ of 0.111. After the successive refinement with the anisotropic temperature factors, all of the hydrogen atoms were readily located from the difference Fourier map. Included in the further refinement were isotropic thermal parameters for hydrogen atoms, which were started with those of the carbon atoms to which they are attached. The refinement, after 3 cycles full-matrix least-squares calculation, had converged to a conventional R of 0.033 and weighted $Rw = (\Sigma\omega(|Fo| - |Fc|)^2/\Sigma\omega|Fo|^2)^{1/2}$ of 0.040. An extinction parameter was not refined, because extinction effects were not considered significant.

The hydrogen atoms refined normally and the isotropic thermal parameters ranged from 2.57 to 6.43. The refinement was completed when the largest shift in any parameters among the non-hydrogen atoms was 0.05 σ, while the largest shift for the hydrogen atoms was 0.09 σ. The final positional and thermal parameters are given in Table III. The largest peak in the final difference map, 0.2 e $Å^{-3}$, located near the S atom. The atomic scattering factors for S, O, N and C were those of Cromer and Weber; for H, the scattering factors of Stewart, Davidson, and Simpson were used. Mathematical and computational details are noted elsewhere (18).

Supplementary Material Available.

A listing of the observed and calculated structure amplitudes from the final cycle of least-squares refinement is available. Ordering information is given on any current masthead page.

^{13}C-NMR Spectroscopic Studies.

All ^{13}C-nmr spectral studies were conducted on a sample prepared by dissolving 250 mg of **1**, prepared according to the procedure of Caldwell, Turley and Martin (10), in 3.0 ml of deuteriochloroform after which the sample was degassed with zero-grade argon for 20 minutes. All spectra were acquired on a Varian XL-100-15 spectrometer operating at 25.158 MHz in the Fourier transform mode which was equipped with a Nicolet TT-100 data system, on an NT-440 frequency synthesizer and an NT-760 decoupler. Typical instrument parameters were as follows: sweep width 5 KHz; 90° pulses were obtained with a 19 μ second pulse; interpulse delays were maintained at 4.0 seconds for decoupled and coupled spectra. Relaxation time measurements were obtained using the inversion-recovery pulse sequence (12,13) with thirteen tau values which ranged from 250 μ seconds to 8.0 seconds. During the execution of the relaxation experiments, tau values were randomized to minimize experimental error and then reordered during data processing. Data reduction was conducted using the Three-Parameter Non-linear Fitting program (14).

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