



Structural and spectral studies of *N*-2-(pyridyl)-, *N*-2-(3-, 4-, 5-, and 6-picolyl)- and *N*-2-(4,6-lutidyl)-*N'*-2-thiomethoxyphenylthioureas

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Abstract

Structures of the following compounds have been obtained: *N*-(2-pyridyl)-*N'*-2-thiomethoxyphenylthiourea, PyTu2SMe, monoclinic, $P2_1/c$, $a = 11.905(3)$, $b = 4.7660(8)$, $c = 23.532(6)$ Å, $\beta = 95.993(8)^\circ$, $V = 1327.9(5)$ Å³ and $Z = 4$; *N*-2-(3-picolyl)-*N'*-2-thiomethoxyphenylthiourea, 3PicTu2SeMe, monoclinic, $C2/c$, $a = 22.870(5)$, $b = 7.564(1)$, $c = 16.941(4)$ Å, $\beta = 98.300(6)^\circ$, $V = 2899.9(9)$ Å³ and $Z = 8$; *N*-2-(4-picolyl)-*N'*-2-thiomethoxyphenylthiourea, 4PicTu2SMe, monoclinic $P2_1/a$, $a = 9.44(5)$, $b = 18.18(7)$, $c = 8.376(12)$ Å, $\beta = 91.62(5)^\circ$, $V = 1437(1)$ Å³ and $Z = 4$; *N*-2-(5-picolyl)-*N'*-2-thiomethoxyphenylthiourea, 5PicTu2SMe, monoclinic, $C2/c$, $a = 21.807(2)$, $b = 7.5940(9)$, $c = 17.500(2)$ Å, $\beta = 93.267(6)^\circ$, $V = 2893.3(5)$ Å³ and $Z = 8$; *N*-2-(6-picolyl)-*N'*-2-thiomethoxyphenylthiourea, 6PicTu2SMe, monoclinic, $P2_1/c$, $a = 8.499(4)$, $b = 7.819(2)$, $c = 22.291(8)$ Å, $\beta = 90.73(3)^\circ$, $V = 1481.2(9)$ Å³ and $Z = 4$ and *N*-2-(4,6-lutidyl)-*N'*-2-thiomethoxyphenylthiourea, 4,6LutTu2SMe, monoclinic, $P2_1/c$, $a = 11.621(1)$, $b = 9.324(1)$, $c = 14.604(1)$ Å, $\beta = 96.378(4)^\circ$, $V = 1572.4(2)$ Å³ and $Z = 4$. Comparisons with other *N*-2-pyridyl-*N'*-arylthioureas having substituents in the 2-position of the aryl ring are included. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: 2-Pyridylthioureas; Thiomethoxyphenylthioureas; Crystal structures; Hydrogen bonding

1. Introduction

Since the crystal structure of *N*-2-pyridyl-*N'*-phenylthiourea was reported [1], there have been a number of structural studies of substituted *N*-(2-pyridyl)-*N'*-arylthioureas [2–9]. Intramolecular $N'-H \cdots N$, intermolecular $N-H \cdots S$ and $C-H \cdots X$ hydrogen bonding interactions, as well as the planarity of

the molecules, have been the focus of these studies. A recent communication showed that some members of a series of *N*-(2-pyridyl)-*N'*-2-methoxyphenylthioureas possess bifurcated intramolecular hydrogen bonding to the pyridyl nitrogen and methoxy oxygen [10]. A study of the three *N*-2-(4,6-lutidyl)-*N'*-2-chlorophenylthioureas showed that *N*-2-(4,6-lutidyl)-*N'*-(2-chlorophenyl)thiourea could also be considered to be bifurcated [11], but the *N*-2-picolyl-*N'*-(2-chlorophenyl)thioureas did not have bifurcated hydrogen bonding [12]. We report here the structural studies of the analogous *N*-2-pyridyl-, *N*-2-(picolyl)- and

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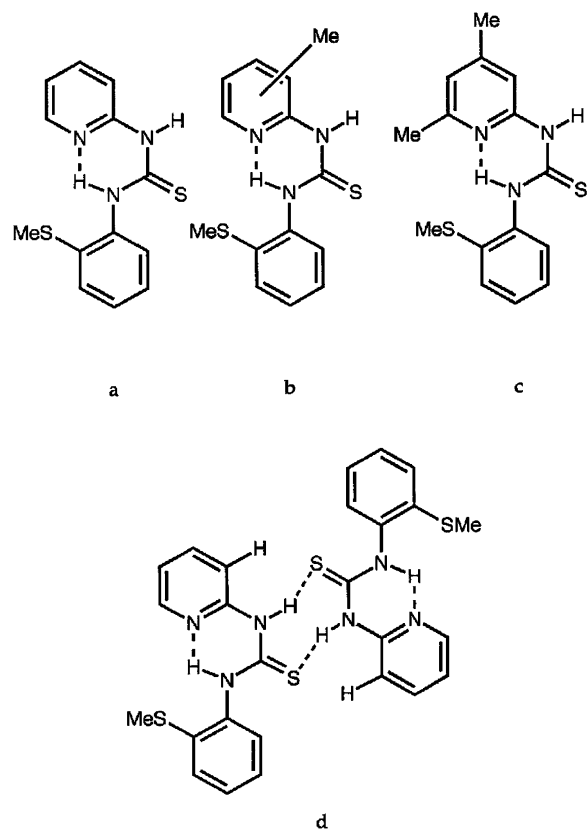


Fig. 1. Depiction of (a) PyTu2SMe, (b) the various PicTu2SMe thioureas (i.e. 3PicTu2SMe, 4PicTu2SMe, 5PicTu2SMe, 6PicTu2SMe) and (d) representation of a dimer of PyTu2SMe showing the intramolecular N3–H3a···N1 hydrogen bonding and the intermolecular N2–H2···S1 hydrogen bonding and the possibility that intermolecular C3–H3···S1 hydrogen bonding may exist.

N-2-(4,6-lutidyl)-*N'*-(2-thiomethoxyphenyl)thioureas (i.e. PyTu2SMe, 3PicTu2SMe, 4PicTu2SMe, 5PicTu2SMe, 6PicTu2SMe and 4,6LutTu2SMe) which are depicted in Fig. 1.

2. Experimental

2.1. Preparation and physical methods

2-Aminopyridine, the 2-aminopicolines and 2-amino-4,6-lutidine, as well as 2-thiomethoxyphenyl isothiocyanate, were purchased from Aldrich and used as received. 2-Aminopyridine, a 2-aminopicoline or

2-amino-4,6-lutidine was mixed in a 1:1 molar ratio with 2-thiomethoxyphenyl isothiocyanate in 95% ethanol and the mixture stirred with warming for a minimum of 1 h. On cooling and slowly evaporating the reactant mixture (35 °C), the thioureas crystallized from solution. The solids were filtered, washed with cold isopropanol and dried on a warm plate. The yields are 50–60% for these thioureas and their melting points are as follows: PyTu2SMe, 128–130 °C; 3PicTu2SMe, 78–180 °C; 4PicTu2SMe, 180–181 °C; 5PicTu2SMe, 178–180 °C; 6PicTu2SMe, 166–168 °C; and 4,6LutTu2SMe, 156–158 °C. The ¹H NMR spectra were recorded in CDCl₃ with a Bruker 300 MHz spectrometer and the enthalpies of fusion were obtained with approximately 3 mg samples at a heating rate of 10°/min using a Perkin–Elmer Differential Scanning Calorimeter, DSC7.

2.2. X-ray data collection, structure solution and refinement

Crystals of the thioureas were grown by slow evaporation of 1:1 by volume acetone–anhydrous ethanol mixtures at room temperature. The colorless thiourea crystals were mounted in random orientation on a glass fiber on a Nonius MACH 3 (4PicTu2SMe and 6PicTu2SMe) or Nonius Kappa CCD Diffractometer, Mo K α ($\lambda = 0.71073 \text{ \AA}$) at 293 K, except for PyTu2SMe, 130(2) K. Cell constants and an orientation matrix for data collections were obtained by least squares refinements of the diffraction data from 25 or more reflections. The structures were solved by direct methods and missing atoms were found by difference-Fourier synthesis. The non-hydrogen atoms were refined with anisotropic temperature factors, and all hydrogens attached to nitrogens and aryl carbons (except for PyTu2SMe) were found on a difference Fourier map and refined isotropically. Methyl hydrogens were positioned on their parent carbon atoms. Scattering factors are from Waasmaier and Kirfel [13]. The structures were solved with MaXus [14], structure refinement was carried out with SHELXL-97 and the graphics used are ZORTEP [15]. Table 1 summarizes the crystal data, collection information and refinement data for these thioureas.

Table 1

Crystallographic data and methods of data collection, solution and refinement for PyTu2SMe, 3PicTu2SMe, 4PicTu2SMe, 5PicTu2SMe, 6PicTu2SMe and 4,6LutTu2SMe

Crystal data	PyTu2SMe	3PicTu2SMe	4PicTu2SMe
Empirical formula	C ₁₃ H ₁₃ N ₃ S ₂	C ₁₄ H ₁₅ N ₃ S ₂	C ₁₄ H ₁₅ N ₃ S ₂
Crystal color, habit	Colorless, needle	Colorless, prism	Colorless, prism
Crystal size (mm ³)	1.00 × 0.09 × 0.07	0.24 × 0.22 × 0.14	0.26 × 0.22 × 0.18
Temperature (K)	130(2)	293(2)	293(2)
Crystal system	Monoclinic	Monoclinic	Monoclinic
Space group	<i>P</i> 2 ₁ / <i>c</i> (#14)	<i>C</i> 2/ <i>c</i> (#15)	<i>P</i> 2 ₁ / <i>a</i> (#14)
<i>a</i> (Å)	11.905(3)	22.870(5)	9.44(5)
<i>b</i> (Å)	4.7660(8)	7.564(1)	18.18(7)
<i>c</i> (Å)	23.532(6)	16.941(4)	8.376(12)
β (°)	95.993(8)	98.300(6)	91.62(5)
Volume (Å ³)	1327.9(5)	2899.9(9)	1437(1)
<i>Z</i>	4	8	4
Formula weight	275.38	289.41	289.41
Density (calcd.) (g/cm ³)	1.377	1.326	1.338
Absorp. Coeff. (mm ⁻¹)	0.386	0.357	0.360
<i>F</i> (000)	576	1216	608
Index ranges	-12 ≤ <i>h</i> ≤ 12, -4 ≤ <i>k</i> ≤ 4, -25 ≤ <i>l</i> ≤ 25	-28 ≤ <i>h</i> ≤ 28, -8 ≤ <i>k</i> ≤ 8, -21 ≤ <i>l</i> ≤ 21	0 ≤ <i>h</i> ≤ 10, -20 ≤ <i>k</i> ≤ 20, -9 ≤ <i>l</i> ≤ 9
θ range for data collection	5.15–22.71	3.04–26.36	2.51–23.21
Total reflections, parameter	3027, 172	5018, 178	3744, 210
Independent reflects. <i>R</i> _{int}	1684, 0.898	2853, 0.0751	1998, 0.0873
Absorption correction	HKL-SCALEPACK	HKL-SCALEPACK	ψ -scan
Max. and min. transmissions	0.9735, 0.6990	0.9518, 0.9193	1.000, 0.568
Goodness-of-fit	1.017	1.001	1.070
Largest diff. peak (eÅ ⁻³)	0.308	0.267	0.328
Largest diff. hole (eÅ ⁻³)	-0.383	-0.181	-0.317
<i>R</i> ₁ , <i>wR</i> ₂	0.0687, 0.1431	0.0507, 0.0803	0.0558, 0.1006
<i>R</i> ₁ , <i>wR</i> ₂ (all reflections)	0.1321, 0.1666	0.1942, 0.0977	0.1753, 0.1543
Crystal data	5PicTu2Sme	6PicTu2Sme	4,6LutTu2SMe
Empirical formula	C ₁₄ H ₁₅ N ₃ S ₂	C ₁₄ H ₁₅ N ₃ S ₂	C ₁₅ H ₁₇ N ₃ S ₂
Crystal color, habit	Colorless, prism	Colorless, prism	Colorless, prism
Crystal size (mm)	0.26 × 0.24 × 0.14	0.26 × 0.18 × 0.16	0.31 × 0.29 × 0.21
Temperature (K)	293(2)	293(2)	293(2)
Crystal system	Monoclinic	Monoclinic	Monoclinic
Space group	<i>P</i> 2 ₁ / <i>c</i> (#15)	<i>P</i> 2 ₁ / <i>c</i> (#14)	<i>P</i> 2 ₁ / <i>c</i> (#14)
<i>a</i> (Å)	21.807(2)	8.499(4)	11.621(1)
<i>b</i> (Å)	7.5940(9)	7.819(2)	9.324(1)
<i>c</i> (Å)	17.500(2)	22.291(8)	14.604(1)
β (°)	93.267(6)	90.73(3)	96.378(4)
Volume (Å ³)	2893.3(5)	1481.2(9)	1572.4(2)

(continued on next page)

Table 1 (continued)

Z	8	4	4
Formula weight	289.41	289.41	303.44
Density (calcd.) (g/cm ³)	1.329	1.298	1.282
Absorp. coeff. (mm ⁻¹)	0.358	0.349	0.332
<i>F</i> (000)	1216	608	640
Index ranges	$-25 \leq h \leq 25$, $-8 \leq k \leq 8$, $-20 \leq l \leq 20$	$0 \leq h \leq 9$, $0 \leq k \leq 8$, $-25 \leq l \leq 25$	$0 \leq h \leq 13$, $-10 \leq k \leq 10$, $-16 \leq l \leq 16$
θ range for data collection	3.50 – 24.71	2.39 – 23.76	2.81 – 24.71
Total reflections	4408, 216	2164, 210	4395, 216
Independent reflects, <i>R</i> _{int}	2415, 0.0479	2164, 0.0314	2640, 0.0391
Absorption correction	HKL-SCALEPACK	ψ -scan	HKL-SCALEPACK
Max. and min. transmissions	0.9516, 0.9128	0.9462, 0.9147	0.9365, 0.9040
Goodness-of-fit	1.006	1.064	1.011
Largest diff. peak (eÅ ⁻³)	0.199	0.185	0.183
Largest diff. hole (eÅ ⁻³)	-0.181	-0.199	-0.211
<i>R</i> ₁ , <i>wR</i> ₂	0.0429, 0.0833	0.0443, 0.1168	0.0402, 0.0834
<i>R</i> ₁ , <i>wR</i> ₂ (all reflections)	0.0949, 0.0942	0.0618, 0.1306	0.0842, 0.0936

3. Results and discussion

3.1. Structural studies

This is one of the first series of *N*-2-pyridyl-*N'*-arylthioureas in which all members of the series produced suitable crystals; the *N*-2-(3-picoly)-*N'*-arylthioureas are often the most difficult members of a series. Bond distances and angles are listed in Table 2, the hydrogen bonding parameters are in Table 3 and the mean plane data in Table 4. Ortep drawings for PyTu2SMe, 3PicTu2SMe, 4PicTu2SMe, 5PicTu2SMe, 6PicTu2SMe and 4,6LutTuSMe are shown in Figs. 2–7.

Inspection of Figs. 2–7 shows that 4PicTu2SMe, Fig. 4, has the SMe group positioned differently (i.e. ‘trans’ to H3a) than the other five members of the series. Although the aryl ring can be at angles close to 90° to the thiourea moiety (vide infra), many of the previously studied molecules approach planarity [2–12]. However, the position of SMe in 4PicTu2SMe precludes bifurcated hydrogen bonding by N3H3a, which occurs for *N*-2-(4-picoly)-*N'*-2-methoxyphenylthiourea, 4PicTu2OMe [10]. Interestingly, like 4PicTu2OMe, the chlorine atom in *N*-2-(4-picoly)-*N'*-2-chlorophenylthiourea, 4PicTu2Cl [12], is positioned like OMe in 4PicTu2OMe, but the methyl group in *N*-2-(4-picoly)-*N'*-2-tolylthiourea, 4PicTu2To [8], is positioned like the SMe group in 4PicTu2SMe.

Although there is some variation in bond distances among the six thioureas of the study, the variation is limited to a few of the bonds in 3PicTu2SMe. 3PicTu2SMe has the longest N2–C7 bond and the shortest N3–C7 bond, but the C7–S1 bond is not unusual. The long N2–C7 bond probably occurs to lessen the interaction between N2H and CH₃; similarly, the N2–C7 bond in *N*-2-(3-picoly)-*N'*-4-tolylthiourea, 3PicTu4To, is 1.410(7) Å compared to 1.368(4) Å for *N*-2-(4-picoly)-*N'*-4-tolylthiourea 4PicTu4To [8]. The bond angles of 3PicTu2SMe are not noticeably different and are very similar for the six members of the present series.

The parameters for the intramolecular N3–H3a···N1 hydrogen bond, Table 3, are similar for all but 3PicTu2SMe with the non-bonding N3···N1 distance largest for PyTu2SMe and smallest for 4,6LutTu2SMe suggesting a small inductive effect

Table 2
Selected bond distances (Å) and angles (°) for PyTu2SMe, 3PicTu2SMe, 4PicTu2SMe, 5PicTu2SMe, 6PicTu2SMe and 4,6LutTu2SMe

	PyTu2SMe	3PicTu2SMe	4PicTu2SMe	5PicTu2Sme	6PicTu2SMe	4,6LutTu2SMe
<i>Bond (Å)</i>						
S1–C7	1.675(6)	1.672(4)	1.665(7)	1.684(3)	1.693(3)	1.686(2)
N1–C2	1.339(7)	1.316(4)	1.323(8)	1.325(3)	1.338(4)	1.330(3)
N1–C6	1.346(8)	1.364(4)	1.355(9)	1.346(4)	1.354(4)	1.356(3)
C2–N2	1.380(7)	1.392(4)	1.390(8)	1.406(3)	1.403(4)	1.403(3)
N2–C7	1.357(7)	1.398(4)	1.363(9)	1.352(3)	1.377(4)	1.364(3)
N3–C7	1.348(7)	1.322(4)	1.324(8)	1.338(3)	1.335(4)	1.330(3)
N3–C8	1.423(8)	1.431(4)	1.426(8)	1.429(4)	1.427(4)	1.422(3)
C9–S2	1.752(6)	1.762(3)	1.754(9)	1.756(3)	1.771(3)	1.758(2)
<i>Angles (°)</i>						
C2–N1–C6	116.4(5)	118.7(4)	115.8(6)	116.8(3)	119.9(2)	117.8(2)
N1–C2–C3	122.3(6)	120.2(4)	124.1(6)	122.5(3)	122.1(3)	123.3(2)
N1–C2–N2	117.7(5)	120.6(4)	116.7(6)	118.4(3)	119.1(2)	117.7(2)
N2–C2–C3	120.0(6)	119.2(4)	119.2(6)	119.1(3)	118.8(3)	119.0(2)
C2–N2–C7	132.0(5)	128.2(4)	133.0(6)	131.0(3)	130.2(2)	129.8(2)
S1–C7–N2	120.3(4)	117.8(3)	120.5(5)	119.6(2)	118.9(2)	119.9(2)
N2–C7–N3	116.3(6)	116.2(4)	115.6(6)	116.8(3)	115.9(3)	117.9(2)
S1–C7–N3	123.3(5)	126.0(3)	123.9(5)	123.6(2)	125.2(2)	123.2(2)
C7–N3–C8	123.3(6)	125.5(3)	123.6(6)	126.8(3)	126.6(3)	125.4(2)
N3–C8–C9	119.3(6)	118.1(3)	119.1(5)	118.8(3)	117.8(3)	119.2(2)
N3–C8–C13	120.1(6)	120.0(3)	119.6(7)	120.7(3)	121.1(3)	120.2(2)
C8–C9–S2	117.2(4)	118.1(3)	116.9(5)	117.5(2)	117.8(2)	116.8(2)
C10–C9–S2	124.6(5)	123.5(3)	124.7(6)	124.0(3)	124.3(3)	124.8(2)
C9–S2–C15 ^a	103.7(3)	103.7(2)	104.2(4)	103.3(2)	103.6(2)	103.0(1)

^a C14 for PyTu2SMe and C16 for 4,6LutTu2SMe.

by methyl groups on the pyridine ring. Even though the N3···N1 distance for 3PicTu2SMe is similar to the other five thioureas, the N3–H3 and H3···N1 distances suggest a somewhat stronger interaction. The N3–H3a···N1 angles are between 135 and 150°,

which is within the range found for previously studied thioureas attached to the pyridine ring [2–12]. In contrast to some of the *N*-2-pyridyl-*N'*-2-methoxyphenylthioureas [12], there is no bifurcated hydrogen bonding involving the thiomethoxy sulfur atom.

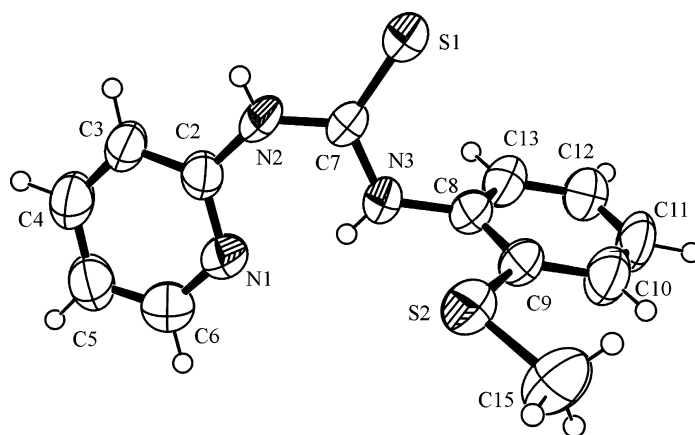


Fig. 2. ORTEP diagram showing PyTu2SMe with atom numbering scheme and displacement ellipsoids at 50% probability level.

Table 3

Intramolecular and intermolecular hydrogen bond distances (Å) and angles (°) for PyTu2SMe, 3PicTu2SMe, 4PicTu2SMe, 5PicTu2SMe, 6PicTu2SMe and 4,6LutTu2SMe

Thiourea	D	A	D–H	H···A	D–H···A	∠(D–H···A)
<i>Intramolecular</i>						
PyTu2SMe	N3	N1	0.80(5)	1.99(5)	2.686(8)	146(5)
3PicTu2SMe	N3	N1	1.00(3)	1.81(3)	2.631(5)	137(3)
4PicTu2SMe	N3	N1	0.92(5)	1.92(5)	2.648(9)	134(4)
5PicTu2SMe	N3	N1	0.87(3)	1.92(3)	2.657(3)	142(3)
6PicTu2SMe	N3	N1	0.85(4)	1.94(4)	2.653(4)	140(5)
4,6LutTu2SMe	N3	N1	0.88(2)	1.90(2)	2.636(3)	141(2)
<i>Intermolecular</i>						
PyTu2SMe ^a	N2	S1#1	0.80(5)	2.71(5)	3.484(6)	163(4)
	C3	S1#1	0.95	2.82	3.626(6)	143
3PicTu2SMe ^b	N2	S1#1	0.92(3)	3.07(3)	3.952(3)	162(3)
4PicTu2SMe ^c	N2	S1#1	0.67(4)	2.80(5)	3.41(1)	153(5)
	C3	S1#1	0.98(6)	2.86(6)	3.609(9)	134(4)
	C5	S2#2	1.02(6)	2.91(6)	3.77(1)	143(4)
	C12	N1#3	0.98(6)	2.96(6)	3.55(1)	120(4)
	C15	N2#4	0.96	2.75	3.61(1)	149
5PicTu2SMe ^d	N2	S1#1	0.89(2)	2.46(3)	3.336(2)	170(2)
	C3	S1#1	0.99(3)	2.91(3)	3.715(3)	140(2)
6PicTu2SMe ^e	N2	S1#1	0.84(3)	2.74(4)	3.553(3)	166(2)
	C3	S1#1	1.00(4)	2.85(4)	3.752(4)	150(3)
4,6LutTu2SMe ^f	N2	S1#1	0.85(3)	2.52(3)	3.351(2)	165(2)
	C3	S1#1	0.95(2)	2.84(2)	3.685(3)	149(2)
	C5	N1#2	0.94(3)	2.95(3)	3.757(3)	145(2)

^a #1: 1 - x, 1 - y, 1 - z.

^b #1: 1 - x, y, 1.5 - z.

^c #1: 1 - x, -y, -z; #2: 2 - x, -y, 1 - z; #3: x, 0.5 - y, -0.5 + z; #4: 2 - x, -y, -z.

^d #1: -x, y, 0.5 - z.

^e #1: 1 - x, 1 - y, 2 - z.

^f #1: 1 - x, -y, 1 - z; #2: 1 - x, 0.5 + y, 1.5 - z.

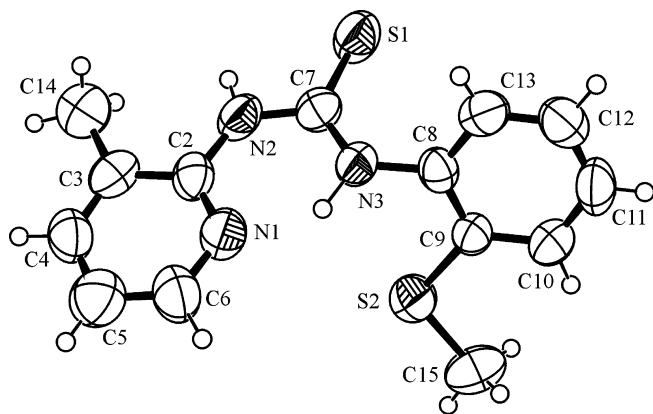


Fig. 3. ORTEP diagram showing 3PicTu2SMe with atom numbering scheme and displacement ellipsoids at 50% probability level.

Table 4
Mean plane data and angles between planes for PyTu2SMe, 3PicTu2SMe, 4PicTu2SMe, 5PicTu2SMe, 6PicTu2SMe and 4,6LutTu2SMe

Compound	Plane	Plane #	Mean plane deviation	Atom with greatest deviation	Plane/plane	Angle
PyTu2SMe	N1–C2–C3–C4–C5–C6	1	0.0078	C6, 0.0119(0.0048)	2/1	15.35(0.36)
	N2–C7–S1–N3	2	0.0076	C7, 0.0131(0.0048)	3/2	79.77(0.15)
	C8–C9–C10–C11–C12–C13	3	0.0059	C9, 0.0071(0.0041)	1/3	75.23(0.18)
3PicTu2SMe	N1–C2–C3–C4–C5–C6	1	0.0109	C6, 0.0162(0.0028)	2/1	6.21(0.11)
	N2–C7–S1–N3	2	0.0030	C7, 0.0053(0.0026)	3/2	59.90(0.10)
	C8–C9–C10–C11–C12–C13	3	0.0068	C12, 0.0100(0.0026)	1/3	57.43(0.12)
4PicTu2SMe	N1–C2–C3–C4–C5–C6	1	0.0089	C6, 0.0138(0.0056)	2/1	5.53(0.09)
	N2–C7–S1–N3	2	0.0005	C7, 0.0009(0.0050)	3/2	56.27(0.09)
	C8–C9–C10–C11–C12–C13	3	0.0097	C8, 0.0140(0.0043)	1/3	51.30(0.11)
5PicTu2SMe	N1–C2–C3–C4–C5–C6	1	0.0028	C6, 0.0047(0.0022)	2/1	5.52(0.08)
	N2–C7–S1–N3	2	0.0029	C7, 0.0051(0.0022)	3/2	56.29(0.09)
	C8–C9–C10–C11–C12–C13	3	0.0052	C8, 0.0087(0.0018)	1/3	51.31(0.10)
6PicTu2SMe	N1–C2–C3–C4–C5–C6	1	0.0034	C6, 0.0051(0.0020)	2/1	7.26(0.16)
	N2–C7–S1–N3	2	0.0006	C7, 0.0010(0.0021)	3/2	58.26(0.08)
	C8–C9–C10–C11–C12–C13	3	0.0094	C9, 0.0154(0.0020)	1/3	53.89(0.08)
4,6LutTu2SMe	N1–C2–C3–C4–C5–C6	1	0.0036	C2, 0.0057(0.0015)	2/1	5.45(0.13)
	N2–C7–S1–N3	2	0.0021	C7, 0.0036(0.0018)	3/2	64.77(0.06)
	C8–C9–C10–C11–C12–C13	3	0.0052	C8, 0.0082(0.0015)	1/3	62.67(0.06)

The intermolecular N2–H2···S1 interaction also has parameters typical of 2-pyridylthioureas; the lone exception being 3PicTu2SMe, which has a much weaker interaction. *N*-2-(3-picolyl)-*N'*-phenylthiourea, 3PicTuPh [6] and 3PicTu4To [8] also have weak interaction; the H2···S1 distances are greater than 3.0 Å and comparable to 3PicTu2SMe. Although the additional bulkiness of the methyl group in the 3-position of the pyridine ring is a major factor in weakening this interaction for 3PicTu2SMe, 3PicTuPh and 3PicTu4To, the lack of C3–H3···S1 hydrogen bonding, which complements the N2–H2···S1 interaction, also probably contributes to its weakness. For some of these thioureas (i.e.

PyTu2SMe, 4PicTu2SMe and 6PicTu2SMe) the C3–H3···S1 interaction is almost as strong based on similar H3···S1 and H2···S1 distances. Other weak intermolecular interactions involving C5–H5 occur in 4PicTu2SMe and 4,6LutTu2SMe. Finally, unique to 4PicTu2SMe is the interaction by a hydrogen of the SCH₃ group; C15–H15···N2, based on H···N distance is a reasonably strong interaction, Fig. 8, and is the probably cause of the difference in positioning of the SMe discussed earlier.

The mean plane data is shown in Table 4, and there is little deviation from planarity for the pyridyl ring, thiourea moiety and aryl ring in these thioureas. However, there is considerable difference among the

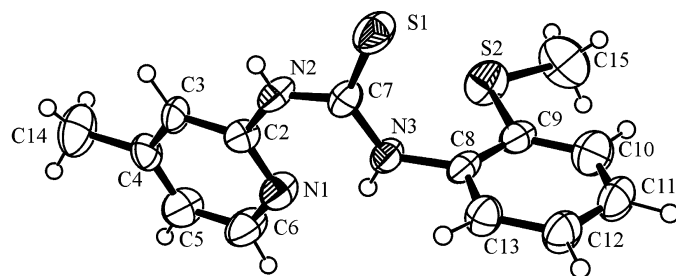


Fig. 4. ORTEP diagram showing 4PicTu2SMe with atom numbering scheme and displacement ellipsoids at 50% probability level.

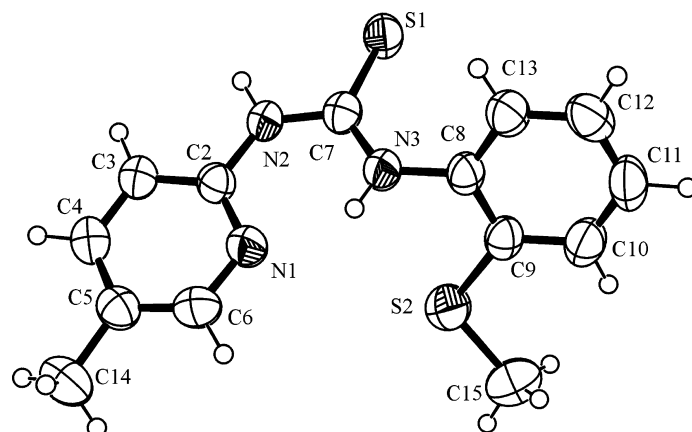


Fig. 5. ORTEP diagram showing 5PicTu2SMe with atom numbering scheme and displacement ellipsoids at 50% probability level.

angles between mean planes and all of the molecules deviate significantly from planarity. A convenient measure of planarity of *N*-2-pyridyl-*N'*-arylthioureas is the angle between the pyridyl and aryl mean planes; the smallest angle, $51.30(0.11)^\circ$, for 4PicTu2SMe is much larger than the comparable angle for 4PicTu2OMe, $16.8(0.6)^\circ$ [10]. The order of $\text{PyTu2SMe} > 4,6\text{LuTu2SMe} > 3\text{PicTu2SMe} > 6\text{PicTu2SMe} \cong 5\text{PicTu2SMe} > 4\text{PicTu2SMe}$ is similar to $\text{PicTu2OMe} > 5\text{PicTu2OMe} > 4,6\text{LutTu2OMe} > 6\text{PicTu2OMe} > 4\text{PicTu2OMe}$ [10] (i.e. crystals of 3PicTu2OMe have not been obtained), but the angles are all significantly larger in the present series of thioureas suggesting a significant steric effect by the SMe group. Adding credibility to our

suggestion of a steric effect by the function in the 2-position is that 4PicTu2Cl has an angle between the mean planes of the two rings of $26.57(0.43)^\circ$, but 4PicTu2To has the largest angle, $67.03(0.15)^\circ$ [9], suggesting that other factors besides size are important.

In order to compare the effect of different substituents in the 2-position, we have compiled Table 5 for a number *N*-2-pyridylthioureas with solved crystal structures. The present series of thioureas are among the least planar based on the angle between the mean planes of the two rings. For the *N*-2-pyridyl-*N'*-arylthioureas listed first in Table 5 there is not a correlation for the angle between the mean planes of the two rings and any of the hydrogen

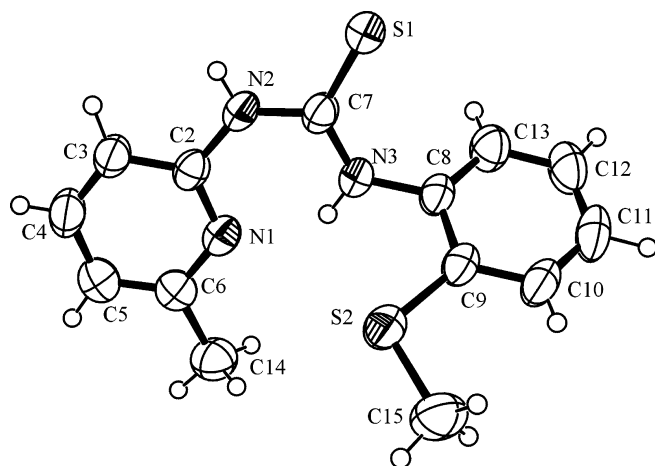


Fig. 6. ORTEP diagram showing 6PicTu2SMe with atom numbering scheme and displacement ellipsoids at 50% probability level.

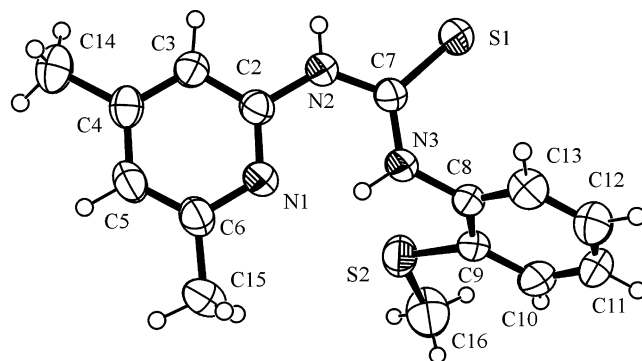


Fig. 7. ORTEP diagram showing 4,6LutTu2SMe with atom numbering scheme and displacement ellipsoids at 50% probability level.

bonding parameters. As indicated earlier, an insufficient number of crystal structures of *N*-2-(3-pyridyl)-*N'*-arylthioureas have been solved to allow for comparisons. There is a general correlation with a decreasing angle between ring and a decreasing $d(\text{N}3 \cdots \text{N}1)$ non-bonding distance for the *N*-2-(4-picolyl)-*N'*-arylthioureas and increasing $d(\text{N}2 \cdots \text{S}1)$ distance for the *N*-2-(5-picolyl)-*N'*-arylthioureas. In contrast, a decreasing angle between the rings is accompanied by a decrease in the $d(\text{N}2 \cdots \text{S}1)$ distance for the *N*-2-(6-picolyl)-*N'*-arylthioureas, but an increase for the *N*-2-(4,6-lutidyl)-*N'*-arylthioureas. There seems to be no correlation among the angles for either type of hydrogen bonding.

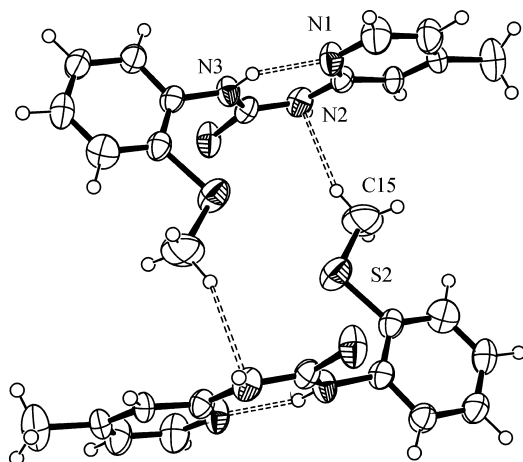


Fig. 8. Partial packing diagram for 4PicTu2SMe showing the intramolecular $\text{N}3\text{-H}3 \cdots \text{N}1$ and intermolecular $\text{C}15\text{-H} \cdots \text{N}2$ interactions.

3.2. ^1H NMR spectral data

Important ^1H NMR assignments are shown in Table 6 and there is little variation in them except for the two NH peaks. $\text{N}3\text{H}$ is usually found in the 13–14.5 ppm region for *N*-2-pyridylthioureas [2–12] suggesting that all the thioureas of this study, except for 3PicTu2SMe, undergo a structural change on dissolution that weakens the intramolecular $\text{N}3\text{-H} \cdots \text{N}1$ hydrogen bond. The chemical shift of the $\text{N}2\text{H}$ resonance is consistent with the solid state dimers, Fig. 8, becoming monomers in CDCl_3 solution and is in the same region as found for the various *N*-2-pyridyl-*N'*-2-methoxyphenylthioureas [10]. The 2-methoxyphenylthioureas have OCH_3 at ca. 3.9 ppm compared to the SCH_3 assignment in the 2.4–2.5 ppm region, consistent with the greater electronegativity of the former.

3.3. Thermal data

Enthalpies of fusion were not measured for the *N*-2-pyridyl-*N'*-2-methoxyphenylthioureas [10], but values for other thioureas with a substituent in the 2-position of the aryl ring are known [8,9,12]. 4PicTu2SMe has a value of 32.6 kJ/mol, which is lower than 44.5 and 53.7 kJ/mol found for 4PicTu2Cl [12] and 4PicTu2To [9], respectively. Similarly 6PicTu2SMe, 24.1 kJ/mol, is lower than 6PicTu2Cl, 27.3 kJ/mol [12], and 6PicTu2To, 44.1 kJ/mol [8]. The melting points (Section 2) for the present thioureas are also lower than found for the previously studied thioureas [8,9,12] as well as substantially lower than for each of the six analogous

Table 5

A comparison of hydrogen bonding distances and angles with the angle between the mean planes of the pyridyl and aryl rings for various series of *N*(2)-pyridyl-*N'*-arylthioureas

Thiourea	\angle pyridyl/aryl	$d(\text{N3}\cdots\text{N1})$	$\angle(\text{N3}-\text{H}\cdots\text{N1})$	$d(\text{N2}\cdots\text{S1})$	$\angle(\text{N2}-\text{H}\cdots\text{S1})$	Ref.
PyTu2Ome	80.8(5)	2.668(5)	140(1)	3.409(3)	150(1)	[10]
PyTu2SMe	75.2(2)	2.686(8)	146(5)	3.487(6)	165(4)	This work
PyTu2To	67.4(1)	2.687(4)	140(3)	3.401(2)	159(2)	[2]
PyTuPh	63.2(1)	2.646(4)	133(2)	3.412(3)	163(2)	[1]
3PicTu2SMe	57.4(1)	2.631(5)	137(3)	3.952(3)	162(3)	This work
3PicTuPh	8.8(3)	2.645(6)	141(2)	3.754(4)	122(3)	[6]
4PicTu2To	67.0(2)	2.646(4)	142(4)	3.437(3)	167(3)	[9]
4PicTu2SMe	51.3(1)	2.648(9)	134(4)	3.41(1)	153(5)	This work
4PicTu2Cl	26.6(2)	2.635(10)	142(9)	3.441(10)	152(7)	[12]
4PicTuPh	24.4(9)	2.622(4)	147(3)	3.405(3)	159(3)	[6]
4PicTu2OMe	6.7(1)	2.618(2)	141(1)	3.503(2)	158(1)	[10]
5PicTu2SMe	51.3(2)	2.657(3)	142(3)	3.336(2)	170(2)	This work
5PicTu2OMe	48.9(5)	2.662(3)	137(1)	3.404(2)	167(1)	[10]
5PicTuPh	28.8(11)	2.65(2)	140(5)	3.433(7)	156(5)	[6]
6PicTu2SMe	53.9(1)	2.653(4)	140(5)	3.553(3)	166(2)	This work
6PicTu2Br	47.7(2)	2.660(8)	148(5)	3.461(6)	149(6)	[12]
6PicTu2Cl	47.4(1)	2.657(3)	139(3)	3.463(3)	163(3)	[12]
6PicTu2To	46.6(2)	2.642(2)	142(2)	3.429(2)	168(2)	[8]
6PicTu2OMe	25.0(5)	2.667(5)	135(1)	3.420(3)	162(1)	[10]
6PicTuPh	11.2(7)	2.645(4)	146(3)	3.383(3)	167(3)	[6]
4,6LutTu2To	64.1(3)	2.667(3)	141(2)	3.348(3)	158(1)	[3]
4,6LutTu2SMe	62.7(1)	2.636(3)	141(2)	3.351(2)	165(2)	This work
4,6LutTu2Cl	38.4(1)	2.788(3)	141(2)	3.398(2)	162(2)	[11]
4,6LutTu2OMe	27.2(5)	2.648(4)	142(1)	3.426(3)	168(1)	[10]
4,6LutTuPh	13.9(9)	2.629(4)	152(3)	3.461(2)	165(3)	[6]

Values of the angle between planes and their esd values have been rounded off.

N-2-pyridyl-*N'*-2-methoxyphenylthioureas [10].

There seems to be little correlation between thermal stability and the data for the intermolecular hydrogen bonding presented in Table 5. However, a comparison of the H2 \cdots S1 distances of these thioureas, which is a better measure of hydrogen bonding strength, but a

less accurately known value, shows a direct correlation. For example, the average H2 \cdots S1 distance of these thiomethoxy thioureas compared to the analogous methoxy thioureas (excluding 3PicTu2SMe, the crystal data for the analogous 3PicTu2OMe was not reported) is 2.65 Å compared to 2.52 Å.

Table 6

Melting points (°C), ΔH_{fus} values (kJ/mol) and selected ^1H NMR (CDCl_3) assignments for the *N*-2-pyridyl-*N'*-2-thiomethoxyphenylthioureas

Thiourea	m.p.	ΔH_{fus}	N3H	N2H	C6H	SCH ₃	CH ₃
PyTu2SMe	128–130		11.91	8.38	8.25	2.47	
3PicTu2SMe	78–80		13.89	8.69	8.11	2.45	1.26
4PicTu2SMe	180–181	32.6	11.83	8.24	8.10	2.50	1.23
5PicTu2SMe	178–180		11.83	8.70	8.17	2.45	1.26
6PicTu2SMe	166–168	24.1	12.05	8.03		2.47	1.25
4,6LutTu2Sme	156–158		12.02	8.20		2.49	1.47, 1.27

4. Conclusion

Structures of the six representatives of the present series have allowed a comparison of structural properties within the series, as well as with other *N*-2-pyridyl-*N'*-arylthioureas with a 2-substituent on the aryl ring. The thiomethoxy sulfur atom is not involved in hydrogen bonding, but a hydrogen of its methyl group weakly interacts intermolecularly in 4Pic-Tu2SMe to alter its structure compared to the other members of the series. Since a number of crystal structures have been solved, we are able to show some correlations between their structural, spectral and thermal properties.

5. Supplementary material

Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Center as supplementary publication no CCDC-174245 for PyTu2SMe, CCDC-1748246 for 3Pic-Tu2SMe, CCDC-174247 for 4PicTu2SMe, 174248 for 5PicTu2SMe, 174249 for 6PicTu2SMe and CCDC-174250 for 4,6LutTu2SMe. Copies of available material can be obtained, free of charge, on application to The Director, CCDC, 12 Union Road, Cambridge CB21EZ, UK, (fax: +44-1223-336033 or E-mail: deposit@ccdc.cam.ac.uk).

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References

- [1] D.X. West, A.K. Hermetet, L.J. Ackerman, J. Valdés-Martínez, S. Hernández-Ortega, *Acta Cryst.* C55 (1999) 811.
- [2] J. Valdés-Martínez, S. Hernández-Ortega, D.X. West, L.J. Ackerman, J.K. Swearingen, A.K. Hermetet, *J. Mol. Struct.* 478 (1999) 219.
- [3] D.X. West, J.K. Swearingen, A.K. Hermetet, L.J. Ackerman, C. Presto, *J. Mol. Struct.* 522 (2000) 27.
- [4] E.A. Sudbeck, J.D. Jennissen, T.K. Venkatachalam, F.M. Uekun, *Acta Cryst.* C55 (1999) 2122.
- [5] L.F. Szczepura, K.K. Eilts, A.K. Hermetet, L.J. Ackerman, J.K. Swearingen, D.X. West, *J. Mol. Struct.* 607 (2002) 101.
- [6] J. Valdés-Martínez, S. Hernández-Ortega, G. Espinosa-Pérez, C.A. Presto, A.K. Hermetet, K.D. Haslow, L.J. Ackerman, L.F. Szczepura, K.I. Goldberg, J.M. Giesen, W. Kaminsky, D.X. West, *J. Mol. Struct.* 608 (2002) 77–87.
- [7] L.F. Szczepura, D.R. Kelman, A.K. Hermetet, L.J. Ackerman, K.I. Goldberg, K.A. Claborn, W. Kaminsky, D.X. West, *J. Mol. Struct.* 608 (2002) 245.
- [8] J. Valdés-Martínez, S. Hernández-Ortega, A.K. Hermetet, L.J. Ackerman, C.A. Presto, J.K. Swearingen, D.R. Kelman, K.I. Goldberg, W. Kaminsky, D.X. West, *J. Chem. Crystallogr.* in press.
- [9] A.K. Hermetet, L.J. Ackerman, J.K. Swearingen, C.A. Presto, D.R. Kelman, J.M. Giesen, K.I. Goldberg, W. Kaminsky, D.X. West, *J. Chem. Crystallogr.* 32 (2002) 17.
- [10] D.X. West, J.K. Swearingen, A.K. Hermetet, L.J. Ackerman, *J. Mol. Struct.* 562 (2001) 95.
- [11] A.K. Hermetet, L.J. Ackerman, K.K. Eilts, T.K. Johnson, J.K. Swearingen, J.M. Giesen, K.I. Goldberg, W. Kaminsky, D.X. West, *J. Mol. Struct.* 605 (2002) 241.
- [12] D.R. Kelman, L.F. Szczepura, K.I. Goldberg, W. Kaminsky, A.K. Hermetet, L.J. Ackerman, J.K. Swearingen, D.X. West, *J. Mol. Struct.* 610 (2002) 143.
- [13] D. Waasmaier, A. Kirfel, *Acta Cryst.* A51 (1995) 416.
- [14] S. Mackay, C. Edwards, A. Henderson, C. Gilmore, N. Stewart, K. Shankland, A. Donald, MaXus, a computer program for the solution and refinement of Crystal Structures and diffraction data. University of Glasgow, Scotland, 1997.
- [15] L. Zsolnai, G. Huttner, ZORTEP, A Graphical ORTEP program, University of Heidelberg, Germany, 1997.