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Non-innocent pyridyl nitrogens: unprecedented interconversion of *N*-bridgehead-thiadiazolium salts and thiatriazine in the generation of thiatriazinyl†

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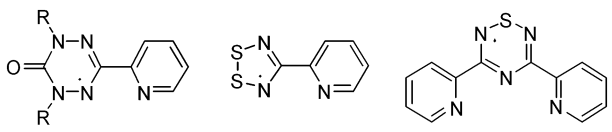
Condensation of *N*-2-pyridylimidoyl-2-pyridylamidine with S_2Cl_2 affords fused *N*-bridgehead-1,2,5-thiadiazolium salts, which can be converted to 3,5-bis(2-pyridyl)-4-hydro-1,2,4,6-thiatriazine (Py_2TTAH). Oxidation of Py_2TTAH with iodine yields the corresponding 1,2,4,6-thiatriazinyl radical, identified by EPR spectroscopy.

Over the past decade, much research has focused on the use of stable neutral radicals as building blocks for molecular conductors and magnetic materials.[1,2] Their application as spin bearing ligands in coordination complexes has also been actively pursued.[1,3] Within this context, the use of chelating heterocyclic neutral radicals is an attractive design strategy, as has been demonstrated by pyridyl functionalized verdazyls (**1**, Chart 1)[4] and dithiadiazolyls (**2**).[5] In principle, the 1,2,4,6-thiatriazinyl (**TTA**) framework,[6] a neutral seven π-electron ring system, represents an ideal building block in the rational design of chelating spin bearing ligands.[7] In particular, 3,5-bis(2-pyridyl)-1,2,4,6-thiatriazinyl (**3**; **Py_2TTA**) would possess a chelating environment similar to that of 2,2′;6′,2″-terpyridine (terpy); a tridentate ligand that has received a great deal of attention (*e.g.*, close to 3000 publications in the last five years) due to its potential in a wide range of research areas (*e.g.*, biomedical applications, catalysis, gas adsorption, magnetic materials, organic electronics, *etc.*).[8] Given the immense interest in coordination complexes based on terpy, the generation of a structural mimic in which one of the pyridine rings is replaced by a **TTA** radical is appealing. Although phenyl functionalized **TTA** radicals are known, the reactivity of the pyridyl derivatives described here is profoundly different due to the presence of non-innocent pyridyl nitrogens, which can coordinate to sulphur and generate *N*-bridgehead-heterocycles.[9] In that regard, the unprecedented but necessary interconversion of an *N*-bridgehead-1,2,5-thiadiazolium salt to a 1,2,4,6-thiatriazine (**TTAH**) precedes the generation of **3**. Herein, the synthetic sequence and molecular structures of the intermediates will be presented along with EPR characterization of the 3,5-bis(2-pyridyl)-1,2,4,6-thiatriazinyl radical (**3**).



1 2 3

Chart 1

The first report of a **TTA** radical was described by Markovskii *et al.* using EPR spectroscopy.[10] Since then, both symmetrically and asymmetrically substituted **TTA** radicals have been prepared, most of which are, at least partly, functionalized with aryl groups.[6,11–13] Known preparative routes include the reaction of amidines with $S_3N_3Cl_3$[6,11] or condensation of imidoylamidine hydrochlorides with excess SCl_2,[13,14] followed by reduction with Ph_3Sb. Our synthetic sequence followed a similar route, as outline in Scheme 1, in which *N*-2-pyridylimidoyl-2-pyridylamidine (**4**), prepared from reaction of 2-cyanopyridine with NH_3(g), was treated with S_2Cl_2. This reaction did not, however, generate the anticipated 3,5-bis(2-pyridyl)-1-chloro-1,2,4,6-thiatriazine. Instead, the condensation afforded [**5**][Cl]·HCl, a dication containing *N*-bridgehead-1,2,5-thiadiazolium and pyridinium moieties. This material was isolated as an insoluble chloride salt, which was metathesized using trimethylsilyl triflate to a soluble triflate salt ([**5**][OTf]·HOTf). Crystallization from acetonitrile (MeCN) afforded colourless needles suitable for X-ray analysis, the results of which are shown in Fig. 1a.‡ The planarity of [**5**][OTf]·HOTf (mean deviation of 0.0746 Å from the 18 atom framework), coupled with its short C–N bond lengths, suggests some degree of resonance delocalization along the central N–C–N–C–N backbone.

Initially, isolation of [**5**][Cl]·HCl was surprising as we were expecting to generate 3,5-bis(2-pyridyl)-1-chloro-1,2,4,6-thiatriazine.

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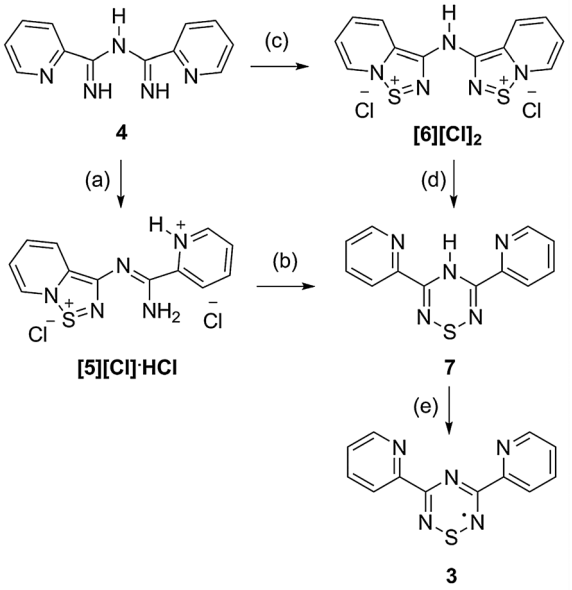
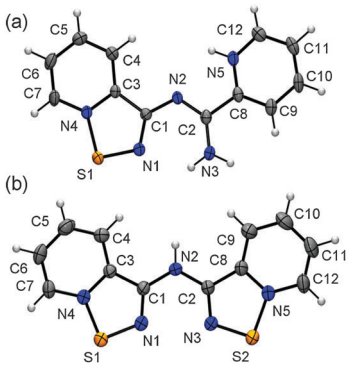


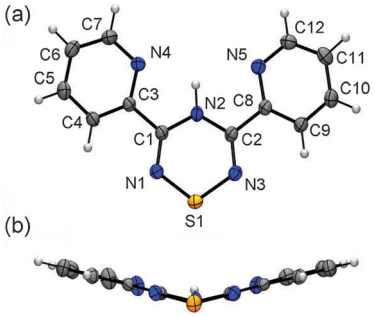
Scheme 1 Synthesis of bis(2-pyridyl)-1,2,4,6-thiatriazinyl radical. *Reagents and conditions*: (a) (i) S_2Cl_2, MeCN, RT; (ii) 100 °C, 10^{-2} mmHg; (b) 140 °C, 10^{-2} mmHg; (c) S_2Cl_2, MeCN, reflux; (d) Ph_3Sb, MeCN, reflux; (e) DMAP, I_2, DCM.



Bond (Å)	$[5]^{+}$·H^{+}	$[6]^{2+}$
N1-C1	1.318(3)	1.298(4)
N1-S1	1.636(2)	1.627(3)
S1-N4	1.726(2)	1.710(3)
C3-C1	1.449(3)	1.444(4)
C1-N2	1.358(3)	1.377(4)
N2-C2	1.314(3)	1.382(4)
C2-C8	1.490(3)	1.445(4)
C2-N3	1.321(3)	1.298(4)
N3-S2	---	1.621(3)
S2-N5	---	1.719(3)

Fig. 1 ORTEP drawings (50% thermal ellipsoids) of (a) [**5**][OTf]·HOTf and (b) [**6**][OTf]$_2$. Anions have been removed for clarity.

Clearly the reactivity of the pyridyl derivatives described here is in marked contrast to the previously reported phenyl functionalized **TTA** analogues. This is attributed to the ability of the pyridyl nitrogen atoms to coordinate to sulphur. To our knowledge, the only other example of such an interaction was reported by Rawson *et al.*[9] Given the availability of two pyridyl substituents, the possibility of generating a bis(*N*-bridgehead-1,2,5-thiadiazolium) dication $[6]^{2+}$ was considered. To that end, *N*-2-pyridylimidoyl-2-pyridylamidine (**4**) was treated with excess S_2Cl_2 at reflux, affording $[6]^{2+}$ as an insoluble chloride salt that gave a distinctly different IR spectrum compared to [**5**][Cl]·HCl. To confirm the identity of $[6]^{2+}$, it was converted into the corresponding triflate salt, [**6**][OTf]$_2$, by treatment with trimethylsilyl triflate. Colourless needles suitable for structural analysis were obtained by crystallization from MeCN (Fig. 1b), demonstrating that $[6]^{2+}$ is comprised of two nearly identical



Bond (Å)	7
N2-C1	1.396(2)
N2-C2	1.391(2)
C1-N1	1.279(2)
C2-N3	1.278(2)
N1-S1	1.692(2)
N3-S1	1.693(2)

Fig. 2 ORTEP drawings (50% thermal ellipsoids) of **7** viewed from (a) above and (b) side of the molecular framework.

N-bridgehead-1,2,5-thiadiazolium moieties linked together by a central nitrogen atom, which are twisted with respect to one another by an angle of 33.26(4)°.

With $[6]^{2+}$ in hand, a two-electron reduction could afford a diradical or lead to ring opening, as proposed by Rawson.[9] In our hands, treatment of [**6**][Cl]$_2$ with Ph_3Sb at reflux generated a deep burgundy solution which, upon cooling, afforded deep red needles of 3,5-bis(2-pyridyl)-4-hydro-1,2,4,6-thiatriazine (**7**); the structural identity of which was confirmed by X-ray analysis (Fig. 2). This closed-shell molecule is bent along the N2–S1 axis with an angle of 153.83(3)° between the two halves of the framework. This, coupled with the short C1–N1 and C2–N3 bond lengths, indicates an antiaromatic structure, as is expected for **TTAH**.[15]

Alternatively, **7** can also be prepared *via* thermolysis of [**5**][Cl]·HCl at 140 °C *in vacuo* or at reflux in chlorobenzene. It is therefore apparent that the key intermediates in the formation of pyridine functionalized **TTA** heterocycles are the *N*-bridgehead-1,2,5-thiadiazolium cations. Furthermore, treatment of **7** with a proton source (*e.g.*, $HCl_{(g)}$) regenerates [**5**][Cl]·HCl. Thus, thermal treatment of [**5**][Cl]·HCl causes rearrangement to the thiatriazine, whereas the presence of acid favours **TTAH** ring opening and generation of [**5**][Cl]·HCl. This unprecedented interconversion of the *N*-bridgehead-1,2,5-thiadiazolium and **TTAH** may be monitored visually, as [**5**][Cl]·HCl is a colourless solid and **7** is deep red. Accordingly, this system may have potential in thermo/acidochromic applications.

Regardless of how pyridine functionalized **TTAH** is prepared, its conversion to the corresponding radical, 3,5-bis-(2-pyridyl)-1,2,4,6-thiatriazinyl (**3**), can be effected by oxidation. To that end, treatment of **7** with half an equivalent of iodine in the presence of base (*e.g.*, 4-dimethylaminopyridine) yields a dark red solution that exhibits a strong and persistent EPR signal (Fig. 3) whose appearance is consistent with **TTA** radicals bearing electron-withdrawing substituents that polarize spin density away from the N–S–N region of the **TTA** core.[12,16] Indeed the EPR spectrum of **3** is virtually identical to that reported for 3,5-bis(*p*-nitrophenyl)-1,2,4,6-thiatriazinyl (*cf.* g = 2.0055; a_N = 0.372 mT; a_N = 0.427 mT).[12] Accordingly, the observed signal consists of a complex multiplet that can be simulated using a model based on hyperfine coupling to two equivalent and one unique ^{14}N nuclei (experimentally derived

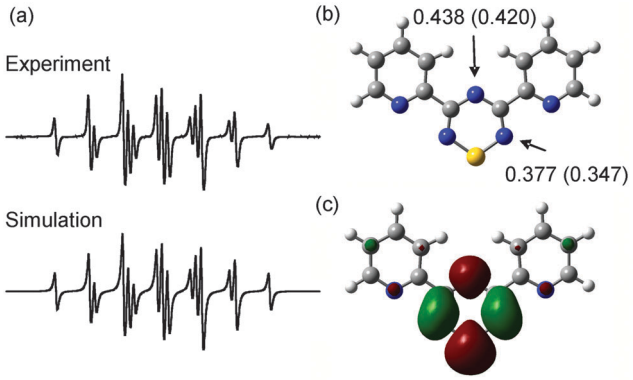


Fig. 3 (a) Experimental and simulated EPR spectrum of **3** in DCM (g = 2.0068; SW = 3.5 mT; LW = 0.024 mT). (b) Experimentally derived and UB3LYP/EPR-II/6-31G(d)//UB3LYP/6-311G(d,p) calculated (in parenthesis) coupling constants a_N (in mT). (c) UB3LYP/6-311G(d,p) singly occupied molecular orbital.

constants: a_N = 0.377 mT; a_N = 0.438 mT; calculated coupling constants: a_N = 0.347 mT; a_N = 0.420 mT).

Based on this study, it is clear the presence of pyridyl substituents in the development of sulphur/nitrogen heterocycles has a significant impact on reaction pathways. In particular, the coordinating ability of the pyridine nitrogen atoms, and the apparent proclivity of pyridyl ligands to form *N*-bridgehead-heterocycles, is an important finding and holds potential in the design of novel open and closed shell heterocyclic compounds. The synthetic challenges associated with non-innocent pyridyl nitrogens can be overcome, as demonstrated here in the preparation of the 3,5-bis(2-pyridyl)-1,2,4,6-thiatriazinyl radical (**3**). In conclusion, not only do we anticipate rich coordination chemistry for this radical acting as a multidentate chelating ligand, we also foresee the possibility of developing new radical ion and biradical systems from controlled reduction of $[\mathbf{6}]^{2+}$ and related compounds.

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Notes and references

‡ Crystal data at 200(2) K for [**5**][OTf]·HOTf: $C_{14}H_{11}F_6N_5O_6S_3$, M = 555.46, triclinic, a = 9.1987(3) Å, b = 9.8364(3) Å, c = 11.7652(4) Å, α = 94.5844(16)°, β = 102.6573(17)°, γ = 92.0173(17)°, V = 1033.82(6) Å^3, space group $P\bar{1}$, Z = 2, 5084 reflections measured, 3959 unique (R_{int} = 0.0288). The final w$R(F_2)$ was 0.1220 (all data). Crystal data at 296(2) K for [**6**][OTf]$_2$: $C_{14}H_9F_6N_5O_6S_4$, M = 585.50, triclinic, a = 8.4770(3) Å, b = 10.1380(3) Å, c = 12.6490(4) Å, α = 88.7192(17)°, β = 78.5886(16)°, γ = 83.6975(17)°, V = 1059.12(6) Å^3, space group $P\bar{1}$, Z = 2, 4339 reflections measured, 3639 unique (R_{int} = 0.0188). The final w$R(F_2)$ was 0.1195 (all data). Crystal data at 200(2) K for **7**: $C_{12}H_9N_5S$, M = 255.30, monoclinic, a = 13.6633(4) Å, b = 3.84480(10) Å, c = 22.7022(7) Å, β = 106.326(2)°, V = 1144.52(6) Å^3, space group $P2_1/c$, Z = 4, 2799 reflections measured, 2174 unique (R_{int} = 0.0377). The final w$R(F_2)$ was 0.1183 (all data).

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