

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

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**Condensation of *N*-2-pyridylimidoyl-2-pyridylamidine with S<sub>2</sub>Cl<sub>2</sub> 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<sub>2</sub>TTAH). Oxidation of Py<sub>2</sub>TTAH 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.<sup>1,2</sup> Their application as spin bearing ligands in coordination complexes has also been actively pursued.<sup>1,3</sup> 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)<sup>4</sup> and dithiadiazolyls (**2**).<sup>5</sup> In principle, the 1,2,4,6-thiatriazinyl (**TTA**) framework,<sup>6</sup> a neutral seven  $\pi$ -electron ring system, represents an ideal building block in the rational design of chelating spin bearing ligands.<sup>7</sup> In particular, 3,5-bis(2-pyridyl)-1,2,4,6-thiatriazinyl (**3**; Py<sub>2</sub>TTA) 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.*).<sup>8</sup> 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.<sup>9</sup> 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**).

The first report of a TTA radical was described by Markovskii *et al.* using EPR spectroscopy.<sup>10</sup> Since then, both symmetrically and asymmetrically substituted TTA radicals have been prepared, most of which are, at least partly, functionalized with aryl groups.<sup>6,11–13</sup> Known preparative routes include the reaction of amidines with S<sub>3</sub>N<sub>3</sub>Cl<sub>3</sub><sup>6,11</sup> or condensation of imidoylamidine hydrochlorides with excess SCl<sub>2</sub>,<sup>13,14</sup> followed by reduction with Ph<sub>3</sub>Sb. 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<sub>3</sub>(g), was treated with S<sub>2</sub>Cl<sub>2</sub>. 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.

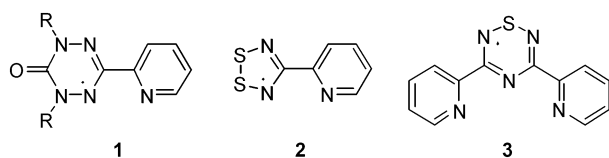


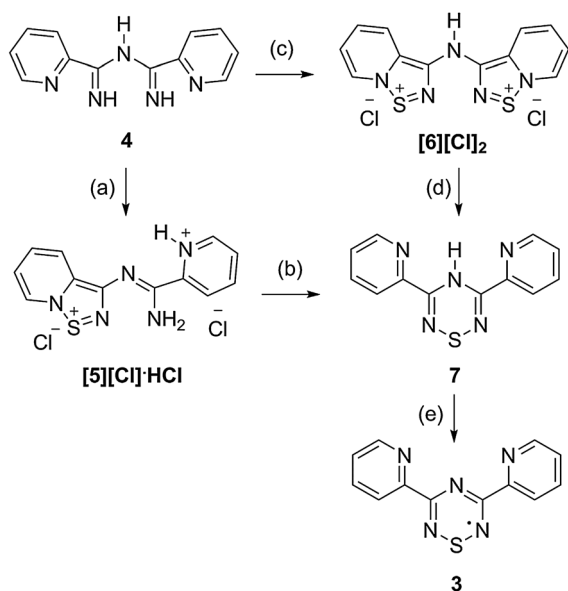
Chart 1

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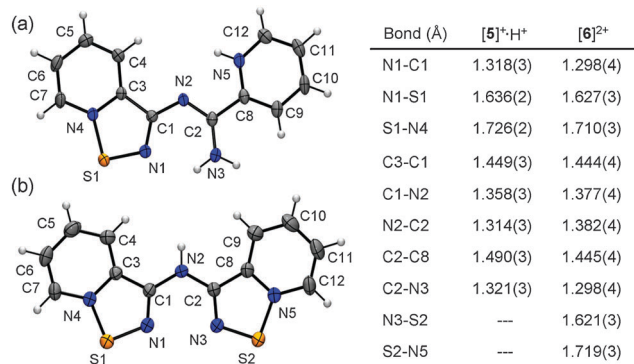
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† Electronic supplementary information (ESI) available: Synthetic procedures, crystallographic details and computational studies. CCDC 986942–986944. For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/c4cc01433b



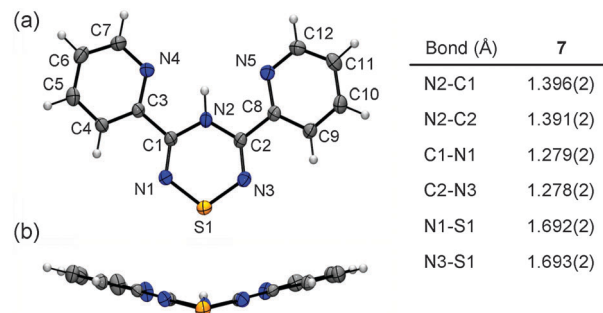


**Scheme 1** Synthesis of bis(2-pyridyl)-1,2,4,6-thiadiazinyl radical. *Reagents and conditions:* (a) (i)  $\text{S}_2\text{Cl}_2$ , MeCN, RT; (ii)  $100^\circ\text{C}$ ,  $10^{-2}$  mmHg; (b)  $140^\circ\text{C}$ ,  $10^{-2}$  mmHg; (c)  $\text{S}_2\text{Cl}_2$ , MeCN, reflux; (d)  $\text{Ph}_3\text{Sb}$ , MeCN, reflux; (e) DMAP,  $\text{I}_2$ , DCM.



**Fig. 1** ORTEP drawings (50% thermal ellipsoids) of (a)  $[\mathbf{5}][\text{OTf}] \cdot \text{HOTf}$  and (b)  $[\mathbf{6}][\text{OTf}]_2$ . 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.*<sup>9</sup> Given the availability of two pyridyl substituents, the possibility of generating a bis(*N*-bridgehead-1,2,5-thiadiazolium) dication  $[\mathbf{6}]^{2+}$  was considered. To that end, *N*-2-pyridylimidoyl-2-pyridylamidine (**4**) was treated with excess  $\text{S}_2\text{Cl}_2$  at reflux, affording  $[\mathbf{6}]^{2+}$  as an insoluble chloride salt that gave a distinctly different IR spectrum compared to  $[\mathbf{5}][\text{Cl}] \cdot \text{HCl}$ . To confirm the identity of  $[\mathbf{6}]^{2+}$ , it was converted into the corresponding triflate salt,  $[\mathbf{6}][\text{OTf}]_2$ , by treatment with trimethylsilyl triflate. Colourless needles suitable for structural analysis were obtained by crystallization from MeCN (Fig. 1b), demonstrating that  $[\mathbf{6}]^{2+}$  is comprised of two nearly identical



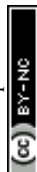
**Fig. 2** ORTEP drawings (50% thermal ellipsoids) of **7** viewed from (a) above and (b) side of the molecular framework.

*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  $33.26(4)^\circ$ .

With  $[\mathbf{6}]^{2+}$  in hand, a two-electron reduction could afford a diradical or lead to ring opening, as proposed by Rawson.<sup>9</sup> In our hands, treatment of  $[\mathbf{6}][\text{Cl}]_2$  with  $\text{Ph}_3\text{Sb}$  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-thiadiazine (**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  $153.83(3)^\circ$  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**.<sup>15</sup>

Alternatively, **7** can also be prepared *via* thermolysis of  $[\mathbf{5}][\text{Cl}] \cdot \text{HCl}$  at  $140^\circ\text{C}$  *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.*,  $\text{HCl}_{(\text{g})}$ ) regenerates  $[\mathbf{5}][\text{Cl}] \cdot \text{HCl}$ . Thus, thermal treatment of  $[\mathbf{5}][\text{Cl}] \cdot \text{HCl}$  causes rearrangement to the thiadiazine, whereas the presence of acid favours **TTAH** ring opening and generation of  $[\mathbf{5}][\text{Cl}] \cdot \text{HCl}$ . This unprecedented interconversion of the *N*-bridgehead-1,2,5-thiadiazolium and **TTAH** may be monitored visually, as  $[\mathbf{5}][\text{Cl}] \cdot \text{HCl}$  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-thiadiazinyl (**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.<sup>12,16</sup> Indeed the EPR spectrum of **3** is virtually identical to that reported for 3,5-bis(*p*-nitrophenyl)-1,2,4,6-thiadiazinyl (*cf.*  $g = 2.0055$ ;  $a_{\text{N}} = 0.372$  mT;  $a_{\text{N}} = 0.427$  mT).<sup>12</sup> 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  $^{14}\text{N}$  nuclei (experimentally derived



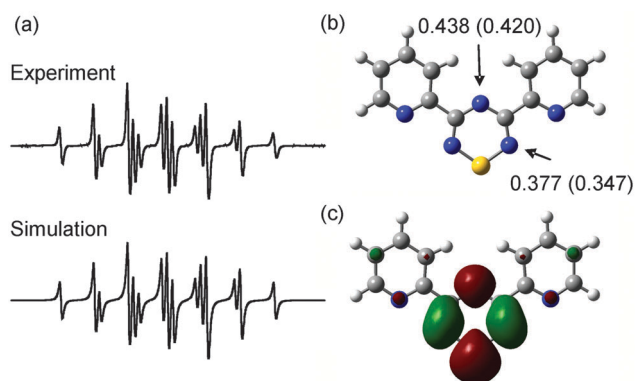


Fig. 3 (a) Experimental and simulated EPR spectrum of **3** in DCM ( $g = 2.0068$ ;  $SW = 3.5$  mT;  $LW = 0.024$  mT). (b) Experimentally derived and UB3LYP/EPR-II/6-31G(d)//UB3LYP/6-311G(d,p) calculated (in parenthesis) coupling constants  $a_N$  (in mT). (c) UB3LYP/6-311G(d,p) singly occupied molecular 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-thiatiazinyl 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  $[6]^{2+}$  and related compounds.

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## Notes and references

‡ Crystal data at 200(2) K for  $[5][OTf] \cdot HOTf$ :  $C_{14}H_{11}F_6N_5O_6S_3$ ,  $M = 555.46$ , triclinic,  $a = 9.1987(3)$  Å,  $b = 9.8364(3)$  Å,  $c = 11.7652(4)$  Å,  $\alpha = 94.5844(16)^\circ$ ,  $\beta = 102.6573(17)^\circ$ ,  $\gamma = 92.0173(17)^\circ$ ,  $V = 1033.82(6)$  Å<sup>3</sup>, space group  $P\bar{1}$ ,  $Z = 2$ , 5084 reflections measured, 3959 unique ( $R_{int} = 0.0288$ ). The final

$wR(F_2)$  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,  $\alpha = 88.7192(17)^\circ$ ,  $\beta = 78.5886(16)^\circ$ ,  $\gamma = 83.6975(17)^\circ$ ,  $V = 1059.12(6)$  Å<sup>3</sup>, space group  $P\bar{1}$ ,  $Z = 2$ , 4339 reflections measured, 3639 unique ( $R_{int} = 0.0188$ ). The final  $wR(F_2)$  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,  $\beta = 106.326(2)^\circ$ ,  $V = 1144.52(6)$  Å<sup>3</sup>, space group  $P2_1/c$ ,  $Z = 4$ , 2799 reflections measured, 2174 unique ( $R_{int} = 0.0377$ ). The final  $wR(F_2)$  was 0.1183 (all data).

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