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From Blatter Radical to 7-Substituted 1,3-Diphenyl-1,4-dihydrothiazolo[5′,4′:4,5]-benzo[1,2-*e*][1,2,4]triazin-4-yls: Toward Multifunctional Materials

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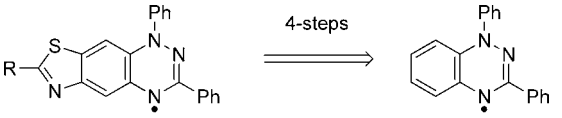
ABSTRACT



R = Me, CF_3, Ph, pyrid-2-yl, thien-2-yl

A Blatter radical is oxidized to benzotriazin-7(*H*)-one which after amination and subsequent acyl- and aroylation gives *N*-(benzotriazin-6-yl)-carboxamides that undergo ring closure with P_2S_5 to afford the corresponding thiazolo[5′,4′:4,5]benzo[1,2-*e*][1,2,4]triazin-4-yls. These highly delocalized radicals are air stable and show good reversible electrochemical behavior.

Molecular materials with multifunctional properties are candidates for new electronic devices.[1] Stable organic radicals can be building blocks for such materials because they can combine tunable transport and magnetic properties, e.g., for organic spintronic devices.[2a] Difficulties, however, in controlling their solid-state packing hinders the successful tailoring of their macroscopic properties, such as bulk ferromagnetism.[2]

Identifying "structure−magnetism relationships" can help unravel features that correlate structure and solid-state packing to the resultant magnetic properties. For example, extending the degree of spin delocalization[3a] can lead to further stabilization of π radicals and could enhance desirable ferromagnetic exchange interactions in the solid state.[3b]

1,3-Diphenyl-1,4-dihydro-1,2,4-benzotriazin-4-yl (**2a**) (Blatter's radical) is an air and moisture stable radical that for decades did not receive much attention.[4] So far benzotriazinyls form 1D-slipped π stacks in which the slippage can help keep the net overlap of SOMOs at nearly zero (orthogonal) to favor ferromagnetic interactions. For example, 7-trifluoromethylbenzotriazinyl **2b** is an exceptionally

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stable radical that crystallizes as a 1D linear ferromagnetic chain ($J = +1.05\ cm^{-1}$, $g = 2.0000$).[5,6] Additional magnetic susceptibility studies on related benzotriazinyls have also been recently reported.[7]

Recently, we developed a mild high-yielding synthesis of Blatter radical **2a** and several 7-substituted analogues through the catalytic oxidation of their amidrazone precursors **1** by using palladium-on-carbon and 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in air.[5] We also demonstrated that the 7-iodobenzotriazinyl **2c** can be further modified by means of Stille and Suzuki-Miyaura cross-coupling reactions to access a range of 7-aryl and 7-heteroaryl-1,2,4-benzotriazinyls **2d** (Figure 1).[8] These coupling reactions are often accompanied by the benzotriazin-7(*H*)-one **3** as a side product, which can be prepared directly from Blatter radical **2a** with either MnO_2 or $KMnO_4$ in 84 and 62% yield, respectively.[6]

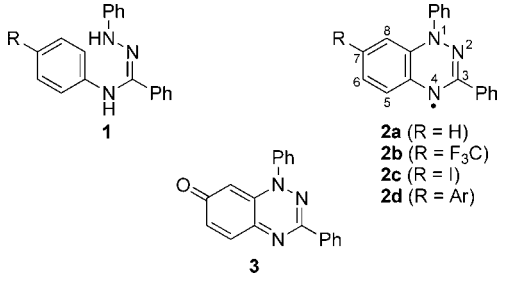


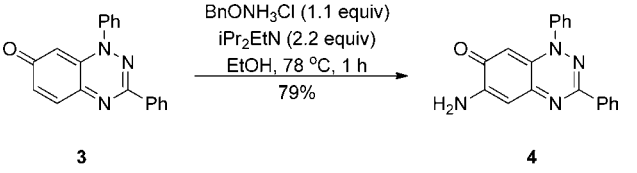
Figure 1. General structures of amidrazone precursors **1**; Blatter radical **2a**; the 7-trifluoromethyl, 7-iodo, and 7-aryl/hetroarylbenzotriazinyl radicals **2b**–**d**, respectively; and the benzotriazinone **3**.

Fortunately, the benzotriazinone **3** proved to be a versatile scaffold that could undergo regiospecific nucleophilic substitution at C6, electrophilic substitution at C8,[9a] and a range of cyclization reactions to yield linear and angular fused benzotriazinones,[9b,c] some of which were unusual zwitterionic compounds.[9c] We considered benzotriazinone **3**, the oxidation product of Blatter radical **2a**, to be a potentially useful scaffold for new π-extended benzotriazinyl radicals. For example, thiazolobenzotriazinyl radicals, because of an extended acene core and the presence of sulfur and nitrogen atoms that can participate in intermolecular contacts, could lead to multidimensional magnetic behavior. Interestingly, conducting polymers comprised of thiazoloacenes have shown enhanced properties attributed to the presence of S···N interchain contacts.[10] Herein we present the three-step synthesis of thiazolo-[5′,4′:4,5]benzo[1,2-*e*][1,2,4]triazin-4-yls **6** starting from benzotriazinone **3**.

The preparation of the thiazolobenzotriazinyls began with the attempted direct synthesis of the *N*-(benzotriazin-6-yl)benzamide **5**; however, treating benzotriazinone **3** with benzamide in EtOH and Hünig's base (2 equiv) at reflux for 2 d gave mainly unreacted **3**, while treating benzotriazinone **3** with benzamide in DMA and NaH (2 equiv) at *ca.* 100 °C for 24 h led to decomposition. In light of the above, a two-step synthesis was pursued that required 6-aminobenzotriazinone **4**.

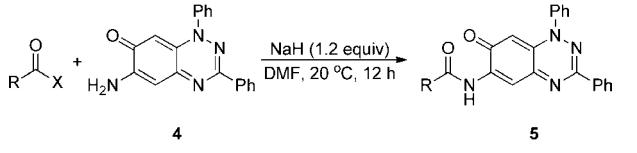
Previously, we prepared aminobenzotriazinone **4** by treating benzotriazinone **3** with gaseous ammonia;[9a] however, product isolation required chromatography which did not facilitate scale-up. As such, we directly aminated using *O*-benzylhydroxylamine hydrochloride and Hünig's base in refluxing ethanol, which gave the desired product cleanly as a precipitate on a multigram scale in 79% yield (Scheme 1).

Scheme 1. Synthesis of Aminobenzotriazinone **4** from Benzotriazinone **3**



Subsequent reaction of 6-aminobenzotriazinone **4** with acyl or aroyl halides or trifluoroacetic anhydride and NaH (1.2 equiv) in DMF at *ca.* 20 °C for 12 h gave a range of *N*-(benzotriazin-6-yl)carboxamides **5a**–**g** (Table 1). In most cases the reactions also worked well in chloroform using Hünig's base; however, under these conditions picolinoyl chloride and trifluoroacetic anhydride failed to react and only unreacted 6-aminobenzotriazinone **4** was recovered.

Table 1. Acyl and Aroylation of Aminobenzotriazinone **4**



R	X	yields (%)
Me	Br	**5a** (84)
F_3C	F_3CCO_2	**5b** (84)
EtO	Cl	**5c** (64)
prop-2-enyl	Cl	**5d** (84)
Ph	Cl	**5e** (86)
pyridin-2-yl	Cl	**5f** (86)[a]
thien-2-yl	Cl	**5g** (87)

[a] Hydrochloride salt of picolinoyl chloride used.

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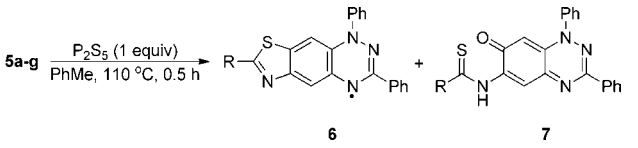
Attempts to obtain the desired thiazolobenzotriazinyls by treating the *N*-(benzotriazin-6-yl)carboxamides **5a**–**g** with Lawesson's reagent in refluxing PhMe or PhCl gave no reaction. Fortunately, the reaction of the *N*-(benzotriazin-6-yl)carboxamides **5a**–**g** with P_2S_5 (1 equiv) in refluxing PhMe gave in most cases the desired thiazolobenzotriazinyls **6a**,**b**,**e**–**g** in high yields (Table 2). The reaction worked equally well in the higher boiling PhCl.

Table 2. Synthesis of 7-Substituted Thiazolobenzotriazinyls **6** from Carboxamides **5** and P_2S_5

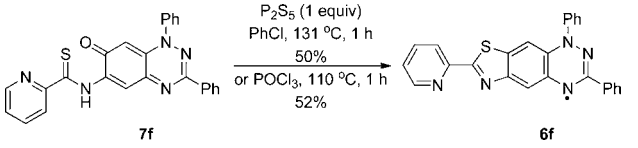


	yields (%)	
R	**6**	**7**
Me	**6a** (81)	–
F_3C	**6b** (80)[a]	–
EtO	–	**7c** (80)
prop-2-enyl	[b]	[b]
Ph	**6e** (74)	–
pyridin-2-yl	**6f** (42)	**7f** (56)
thien-2-yl	**6g** (77)	–

[a] Reaction time extended to 1 h; at 0.5 h yield of **6b** was only 53%. [b] Traces of unidentified products and mainly baseline material by TLC.

The cyclization of the ethoxy- and prop-2-enyl-amidoquinones **5c** and **5d** failed; the former gave instead the corresponding thioamides **7c** while the latter gave mainly intractable residues. The reaction of the pyridin-2-yl **5f** with P_2S_5 gave the desired thiazolobenzotriazinyl **6f** (42%) together with *N*-(7-oxo-1,3-diphenyl-1,7-dihydrobenzo[*e*]-[1,2,4]triazin-6-yl)picolinethioamide (**7f**) in 56% yield. Treating the pure thioamides **7c** and **7f** with either $POCl_3$ (1.5 equiv) as a dehydrating agent or additional P_2S_5 (1 equiv) gave, in the former case, a complex reaction mixture that could not be resolved and, in the latter case, the desired thiazolobenzotriazinyl **6f** in moderate yields 50 and 52%, respectively, together with some unreacted starting thioamide **7f** (Scheme 2).

Scheme 2. Conversion of the Picolinethioamide **7f** into Thiazolobenzotriazinyl **6f**



Single crystal X-ray crystallography on the thiazolobenzotriazinyl **6e** supported the structures. Suitable single crystals were obtained by slow diffusion of *n*-pentane into a solution of the radical in benzene. Radical **6e** crystallizes in the triclinic *P*1(2) space group with one molecule in the asymmetric unit (Figure 2). The intramolecular geometrical parameters are similar to previously studied benzotriazinyl radicals.[6,7]

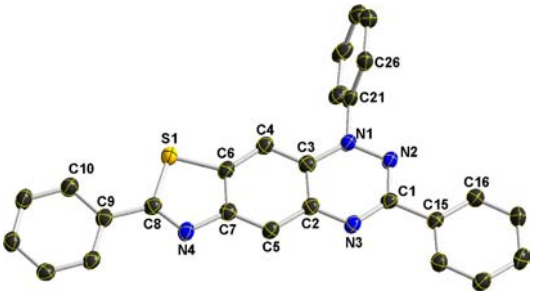


Figure 2. Ellipsoid diagram of radical's **6e** crystal structure. Hydrogen atoms are omitted for clarity, and atom numbering that is used in the discussion of X-ray structure differs from IUPAC.

The 1,2,4-amidrazonyl moiety is almost planar, deviating from planarity by 2.02° as defined by the angle measured between the plane of N1, N2, C1, N3 atoms and the plane of the fused benzothiazole. Strong delocalization in the amidrazonyl moiety is supported by the C–N bond lengths [C1–N2, 1.350(4) Å; C1–N3, 1.329(1) Å] which are intermediate between typical single and double bonds and also by the C1–N2–N1 and C1–N3–C2 angles [115.1(2)° and 116.6(2)°] that are typical for sp^2 hybridized nitrogen. The thiazole is planar with interatomic distances and angles typical of other benzothiazoles; S1–C6, 1.736(2) Å; N4–C7, 1.387(3) Å and C8–S1–C6, 89.1(2)°; C8–N4–C7, 110.8(2)°. Moreover, the phenyl substituted rings at C1 (3-Ph) and C8 (7-Ph) are close to planarity with dihedral angles of N2–C1–C15–C16, 0.4(4)° and S1–C8–C9-C10, 7.1(4)°, respectively.

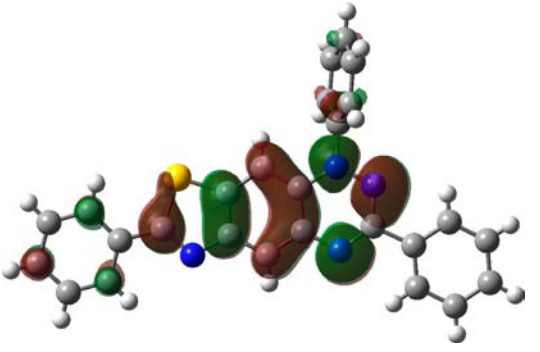


Figure 3. Calculated SOMO orbital of radical **6e**.

Extensive spin delocalization is anticipated since the central fused tricyclic thiazolobenzotriazinyl fragment is

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planar. The SOMO orbital, calculated at the UB3LYP/6-311++G(d,p) level of theory from the crystal structure, indicates that there is significant orbital density over the thiazolobenzotriazinyl core, somewhat less on the phenyl substituents at N1 and C7, and none over the 3-phenyl substituent (Figure 3). EPR-determined hyperfine coupling constants (Tables S1, S2 in the Supporting Information) show that the spin density is mainly delocalized over the 1,2,4-triazinyl ring; however, electron-withdrawing substituents, e.g., the trifluoromethyl group in **6b**, shift some spin density toward the thiazolo ring.

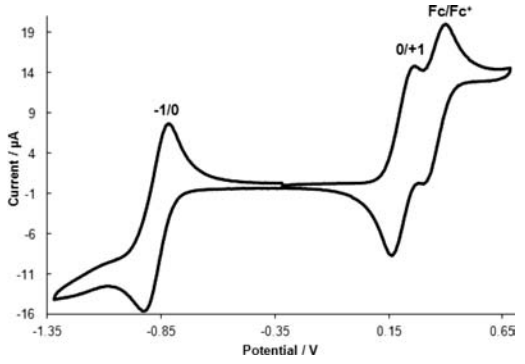

Figure 4. Cyclic voltammogram of benzotriazinyl **6e** (1 mM), *n*-Bu_4NPF_6 0.1 M, CH_2Cl_2, rt, 50 mV/s.

The redox behavior of the thiazolobenzotriazinyls **6a**,**b**, **e**−**g** is typical of benzotriazinyl radicals: Two fully reversible waves appear that correspond to the −1/0 and 0/+1 processes (Figure 4). The oxidation potentials are slightly higher than that of Blatter radical **2a** (+0.1 V).[11] While the thiazole ring does not greatly affect the electrochemical behavior of the benzotriazinyl radicals, the substituents at C7 do alter the electron density around the molecule, affecting the oxidation and reduction potentials (Table 3). Radical **6b** with an electron-withdrawing 7-F_3C substituent has the highest oxidation potential (+0.38 V) similar to that of the 7-F_3C substituted benzotriazinyl **2b** (+0.36 V).[6]

Table 3. Cyclic Voltammetry Data of Thiazolobenzotriazinyls **6**[a]

radical	$E_{1/2}^{0/+1}$	$E_{1/2}^{-1/0}$	E_{cell}[b]
6a	0.18	−0.93	1.11
6b	0.38	−0.76	1.14
6e	0.21	−0.87	1.08
6f	0.23	−0.85	1.08
6e	0.20	−0.86	1.06

[a] The concentration of radicals used was 1 mM in CH_2Cl_2. A 0.1 M CH_2Cl_2 solution of *n*-Bu_4NPF_6 was used as electrolyte. Reference electrode = Ag/AgCl; scan rate = 50 mV/s. Ferrocene was used as internal reference. [b] $E_{cell} = E_{1/2}^{0/+1} - E_{1/2}^{-1/0}$.

The fully reversible and low oxidation potentials of radicals **6a**,**b**,**e**−**g** coupled with their planar spin-bearing acene core make them good donor candidates for charge-transfer salts, e.g., the pressure-dependent semiconductor complex Blatter radical **2a**:TCNQ,[11] and as cathodic components in organic radical batteries,[12] or as redox mediators in dye sensitized solar cells.[13]

In conclusion, we prepared five thiazolobenzotriazinyl radicals starting from the Blatter radical **2a** in moderate yields. The extended acene core and presence of sulfur and additional nitrogen atoms can further stabilize the radicals and provide useful magnetic and transport properties. Solid-state "magneto-structural" characterizations are underway and will be reported shortly.

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Supporting Information Available. Experimental procedures and spectroscopic data including simulated EPR data for all new compounds and the computed spin density for radical **6e**. This material is available free of charge via the Internet at http://pubs.acs.org.

The authors declare no competing financial interest.

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