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On the sulfimidation of benzo[*b*]thiophene†‡

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Received (in Cambridge, UK) 28th April 2003, Accepted 3rd June 2003
First published as an Advance Article on the web 18th June 2003

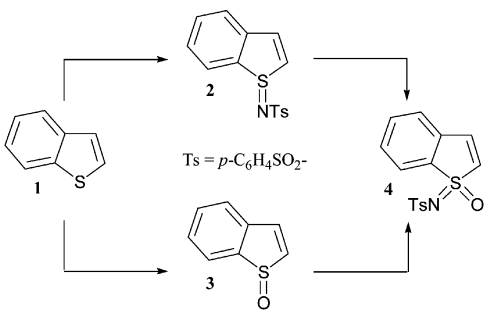
Benzo[*b*]thiophene and chloramine-T react in the presence of catalytic amounts of $[Cu(NCMe)_4]BF_4$ to yield a novel dihydrobenzothiazine arising from a ring-expansion; if the reaction is conducted in the absence of the copper(I) catalyst no reaction takes place, but the expected sulfimide can be made using [(*N*-tosylimino)iodo]benzene, PhI=NTs.

We have been investigating the reactions of unsaturated sulfur dipolarophiles and as part of this work we wanted to make the previously unreported sulfimide **2** and sulfoximide **4** derived from benzo[*b*]thiophene (thianaphthene) **1** (Scheme 1).

Sulfoximide **4** could in principle be prepared either by oxidation of sulfimide **2** or by sulfimidation of sulfoxide **3**.[1] The known sulfoxide **3** is unusual, however, in that it is only stable in dilute solution.[2] To overcome this problem we tried several one-pot methods of oxidation followed by imination, but came to the conclusion that this route was not viable. Thus for the preparation of the sulfoximide **4** we turned our focus to sulfimide **2**. This heterocycle has surprisingly not been reported in the literature, although thiophene-based sulfimides have recently been receiving attention.[3] Classically sulfimidation of sulfides[4] has been achieved in protic solvents using chloramine-T (the sodium salt of *N*-chloro-*p*-toluenesulfonamide), which is both cheap and readily available. The first formed chlorosulfonium salt can be prone to hydrolysis and the corresponding sulfoxide is often a by-product. To circumvent this problem metal catalysts have been used in the sulfimidation.[5] Morita recently noted[6] that the sulfimidation of thianthrene is best conducted without catalysis and in acetonitrile rather than protic solvents. Sharpless[7] has investigated this more extensively and shown that the reaction is consistent and high yielding with a wide range of substrates. In attempting to prepare **2** we found that benzo[*b*]thiophene and chloramine-T did not react in acetonitrile following the Sharpless procedure, nor did they using the classical solvents and conditions. A reaction did, however, take place in acetonitrile when in the presence of $[Cu(NCMe)_4]BF_4$, a conveniently prepared copper(I) salt[8] often used in our laboratory. The product, obtained in modest yield, was shown by X-ray crystallography[9] to be the unusual, ring-expanded 3,4-dihydro-1,2-benzothiazine **5** incorporating three tosyl groups (Fig. 1 and Scheme 2).

To investigate this transformation further, more reactions were undertaken. When repeated with a three- or five-fold excess of chloramine-T the yield of **5** was found to be dramatically lowered. With benzo[*b*]thiophene in excess, relative to the chloramine-T and catalyst, again the yield could not be improved upon. The reaction mixture turns dark green after a few seconds, implying that a copper(II) nitrene species is present, but we also wondered if the reaction was being catalysed by traces of HBF_4 left over from the preparation of the catalyst. However, addition of one drop of HBF_4 to the reaction mixture seemed to hinder rather than help product formation. Larger amounts of catalyst (> 5–10 mol%), relative to the chloramine-T, were also detrimental to the reaction and the presence or absence of a nitrogen atmosphere had no marked effect. The reaction took place neither in boiling acetonitrile[7] (no catalyst) nor methanol.

To return to our desired sulfimide **2** we still needed an alternative method. The use of tosyl azide and iron(II) chloride was unsuccessful, although temperatures above 115 °C were not investigated.[11] Freshly prepared[12] [(*N*-tosylimino)iodo]benzene (PhI=NTs), however, reacted cleanly with benzo[*b*]thiophene in acetonitrile with $[Cu(NCMe)_4]BF_4$ catalysis to give the desired sulfimide **2** in 61% yield. A method for direct oxidation of **2** to sulfoximide **4** has yet to be discovered; many standard methods for the oxidation of sulfimide **2** to sulfox-



Scheme 1

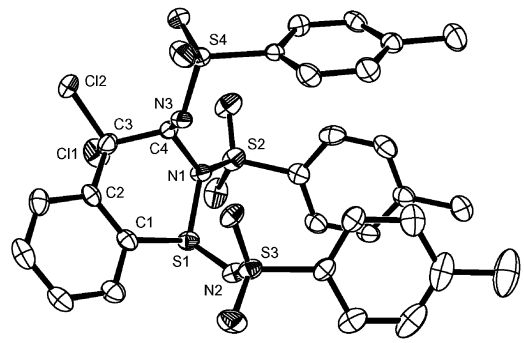
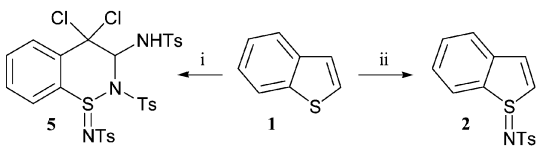


Fig. 1 ORTEP[10] (50% probability ellipsoids) view of the benzothiazine **5** (hydrogen atoms omitted for clarity). Selected bond lengths S1–N2 = 1.573(2) Å; S1–N1 = 1.735(2) Å; S2–N1 = 1.706(2) Å; N3–S4 = 1.636(2) Å.



Scheme 2 *Reagents and conditions*: i) benzo[*b*]thiophene, TsNClNa (1.1 eq.), $[Cu(NCMe)_4]BF_4$ (0.05 eq.), MeCN, 18 h, RT, (12% based on **1**); ii) benzo[*b*]thiophene (5 eq.), $[Cu(NCMe)_4]BF_4$ (0.05 eq.), TsN=IPh (1 eq.), MeCN, 1 h, RT (61%).‡

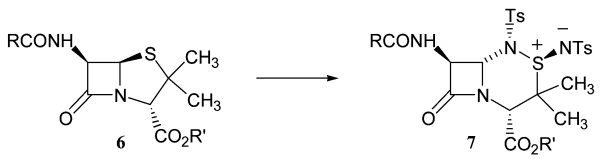
† This paper is dedicated to the late Richard M. Scrowston, formerly Reader in Heterocyclic Chemistry at the University of Hull and expert in the field of benzo[*b*]thiophene chemistry.
‡ Electronic supplementary information (ESI) available: synthetic methods for the preparation of **2** and **5**. See http://www.rsc.org/suppdata/cc/b3/b304696f/

DOI: 10.1039/b304696f

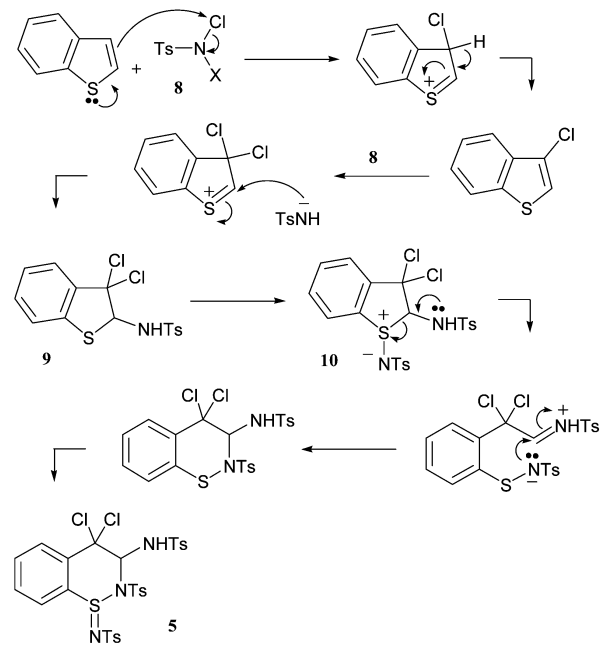
imide **4** (*e.g.* NaOCl, mCPBA, H_2O_2) have been investigated, however the sulfimide **2** seems to be surprisingly stable, unlike its corresponding sulfoxide counterpart. Using hydrogen peroxide in refluxing acetic acid gave the corresponding sulfone, but no other methods have so far been successful, with either recovered starting material or decomposition being the result.

Ring expansions of benzo[*b*]thiophene are rare,[13] but we did find that a related ring expansion had been observed in a penicillin derivative. Campbell *et al.* reported[14] that certain 6β-amidopenicillanates, **6**, in reaction with chloramine-T gave β-lactam-fused thiadiazine *S*-imides **7** (Scheme 3). This reaction, as with ours, was found to be highly dependent on the solvent, the concentration of the reactants, temperature and reaction time, and so the mechanism for the ring-expansion was not established definitely. Whatever copper species is formed from chloramine-T and copper(I), it is clearly not the same as that derived from PhI=NTs under these conditions. None of the sulfimide **2** is detected during the course of the reaction by TLC. Separate treatment of sulfimide **2** (obtained from the reaction with PhI=NTs) with one equivalent of chloramine-T and 5 mol% of $[Cu(NCMe)_4]BF_4$ again showed that none of the ring-expanded product **5** was formed. This implies that **2** is not the first formed product in the reaction sequence. Based on these observations and the reaction reported by Campbell we can propose a mechanism for our transformation (Scheme 4).

Chloramine-T is a known chlorinating agent and so initial electrophilic attack at C3 may be possible with a copper species such as **8** acting as a chlorinating agent [Scheme 4, X = $Cu(NCMe)_n$]. Unfortunately we were unable to isolate or identify any 3-chlorobenzo[*b*]thiophene at the end of the reaction. Indeed, other than product the only materials recovered were the starting material and *p*-toluenesulfonamide. The formation of **9** by addition of the toluenesulfonamide ion is reminiscent of the Pummerer rearrangement.[15] In our proposed mechanism it is perhaps pertinent to note that the intermediate **10** can be considered as being related to the penicillin **6**. In both cases the nitrogen atom carries an electron withdrawing group (N–C=O *vs.* NTs) and is β to the sulfur atom. Upon sulfimidation of **9**, perhaps *via* a chlorosulfonium ion and a non metal-catalysed mechanism, the subsequent ring opening–closing reactions can then take place *via* an iminium ion intermediate.



Scheme 3



Scheme 4

In conclusion we report an unprecedented ring expansion of benzo[*b*]thiophene which gives a novel 3,4-dihydro-1,2-benzothiazine heterocycle, **5**. We have additionally found that the novel sulfimide of benzo[*b*]thiophene (**2**) can easily be prepared using [(*N*-tosylimino)iodo]benzene. Importantly, this derivative has been found to be much more stable than its sulfoxide counterpart; it can be isolated and purified by recrystallization and is stable at room temperature over several months. The utility of benzo[*b*]thiophene derivatives in cycloaddition reactions[16,17] is well precedented and the utility of sulfimide **2** as dipolaro- and dienophile is now being investigated.

We thank the EPSRC for providing funds for the purchase of a new X-ray diffractometer and also acknowledge the financial support of the Ministry of Science and Technology of the Republic of Croatia and the Faculty of Agriculture at the University of Osijek for a scholarship to NP.

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9 Crystal data for **5**: Colourless crystal (0.15 × 0.10 × 0.10 mm) from ethanol, coated with perfluoropolyether oil mounted on a glass fibre, $C_{29}H_{27}Cl_2N_3O_6S_4$, M = 338.40, monoclinic, space group $P2_1/n$, a = 9.5409(10), b = 13.9647(9), c = 23.344(2) Å, β = 96.450(8)°, V = 3090.5(5) Å^3, T = 150(2) K, Z = 4, D_c = 1.532 g cm^{-3}, μ(Mo-K$_\alpha$) = 0.529 mm^{-1}, 16166 reflections measured, 8100 unique (R_{int} = 0.0852) which were used in all calculations. $R1$ = 0.0377 on $F > 4\sigma(F)$, $wR2$ = 0.0652 on all data. CCDC 209586. See http://www.rsc.org/suppdata/cc/b3/b304696f/ for crystallographic data in CIF or other electronic format.

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