

(0.13 mmol, 1.00 equiv) in dry THF (1.00 mL) was added Mosher's chloride (10  $\mu$ L, 0.13 mmol, 1.00 equiv) and propylene oxide (31  $\mu$ L, 0.52 mmol, 4.00 equiv). The resulting suspension was heated at reflux for 20 min, when the resulting solution was allowed to cool to room temperature. The solution was filtered and thoroughly evaporated yielding the desired Mosher's amide, usually as a white solid. The % ee's of each amino acid (**5**) were determined by an examination of the  $^{19}\text{F}$  NMR spectra of their respective MTPA amides.

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## Chemistry of Tetrathiotungstates: A Novel Synthesis of Disulfides from Sulfonyl Derivatives

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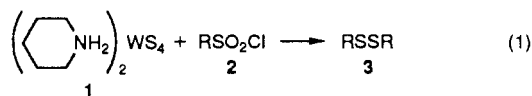
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In an unusually novel reaction, piperidinium tetrathiotungstate has been found to induce reductive dimerization of a variety of sulfonyl derivatives to the corresponding disulfides under very mild conditions.

Since sulfonyl chlorides are easily prepared by the chlorosulfonation of arenes and alkanes,<sup>2</sup> their conversion to other organic sulfur compounds with sulfur in the lower oxidation states is synthetically useful. Among these, organic disulfides are important from the point of view of biological activity<sup>3</sup> and industrial utility<sup>4</sup> and are valuable starting materials for the synthesis of a variety of sulfenyl<sup>5</sup> and sulfinyl<sup>6</sup> compounds. Thus the reductive coupling of sulfonyl chlorides to the corresponding disulfides constitutes an important synthetic methodology.

A wide variety of reagents are known to reduce the sulfonyl halides to the corresponding disulfides.<sup>7</sup> Harpp<sup>8</sup> reported an interesting observation where a persulfido complex of molybdenum,  $\text{Mo}_2\text{S}_{12}^{2-}$ , induces the formation of *p*-tolyl disulfide from *p*-toluenesulfonyl chloride in acetonitrile at 80 °C in 8 h. Recently, we have shown that alkyl halides can be converted to the corresponding disulfides in excellent yields using piperidinium tetrathiotungstate, **1**.<sup>9</sup> While exploring further the synthetic utility of tetrathiotungstate **1** we observed a novel transformation in the reaction of sulfonyl halides to the corresponding disulfides (eq 1). Aryl and alkyl sulfonyl chlorides react



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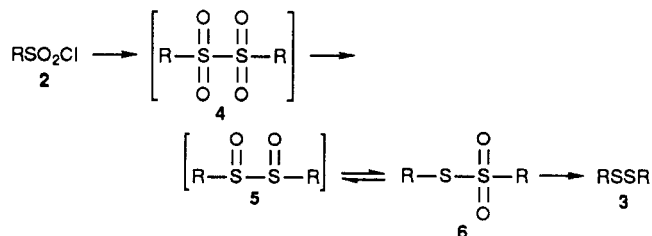
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**Table I. Reduction of the Sulfonyl Halides and Related Compounds with Piperidinium Tetrathiotungstate**

$\text{RSO}_2\text{X} \xrightarrow{1} \text{RSSR}$			
entry	substrate	time, h	yield, <sup>a</sup> %
1	$\text{C}_6\text{H}_5\text{SO}_2\text{Cl}$ , <b>2a</b>	2.0	78
2	<i>p</i> - $\text{CH}_3\text{-C}_6\text{H}_4\text{SO}_2\text{Cl}$ , <b>2b</b>	2.0	69
3	<i>p</i> - $\text{OCH}_3\text{-C}_6\text{H}_4\text{SO}_2\text{Cl}$ , <b>2c</b>	2.5	61
4	<i>p</i> - $\text{Br-C}_6\text{H}_4\text{SO}_2\text{Cl}$ , <b>2d</b>	2.0	53
5	<i>p</i> - $\text{Cl-C}_6\text{H}_4\text{SO}_2\text{Cl}$ , <b>2e</b>	2.0	57
6	$\text{C}_6\text{H}_5\text{CH}_2\text{SO}_2\text{Cl}$ , <b>2f</b>	4	59
7	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{SO}_2\text{Cl}$ , <b>2g</b>	3	41
8	<i>p</i> - $\text{CH}_3\text{-C}_6\text{H}_4\text{SOCl}$ , <b>2h</b>	0.5	96
9	<i>p</i> - $\text{CH}_3\text{-C}_6\text{H}_4\text{SO}_2\text{H}$ , <b>2i</b>	0.5	98
10	<i>p</i> - $\text{CH}_3\text{-C}_6\text{H}_4\text{SO}_2\text{SO}_2\text{C}_6\text{H}_4\text{-CH}_3$ , <b>4a</b>	12	88
11	<i>p</i> - $\text{CH}_3\text{-C}_6\text{H}_4\text{SO}_2\text{SC}_6\text{H}_4\text{-CH}_3$ , <b>6a</b>	0.5	92
12	$\text{C}_6\text{H}_5\text{SO}_2\text{SC}_6\text{H}_5$ , <b>6b</b>	0.5	67
13	<i>p</i> - $\text{CH}_3\text{-C}_6\text{H}_4\text{SO}_2\text{SC}_6\text{H}_5$ , <b>6c</b>	0.5	mixture of disulfides
14	<i>p</i> - $\text{CH}_3\text{-C}_6\text{H}_4\text{SO}_2\text{SC}_2\text{H}_5$ , <b>6d</b>	1	mixture of disulfides
15	$\text{C}_6\text{H}_5\text{SOC}_6\text{H}_5$ , <b>7</b>	24	no reaction
16	$\text{C}_6\text{H}_5\text{SO}_2\text{C}_6\text{H}_5$ , <b>8</b>	24	no reaction
17	$\text{C}_6\text{H}_5\text{SO}_3\text{H}$ , <b>9</b>	24	no reaction

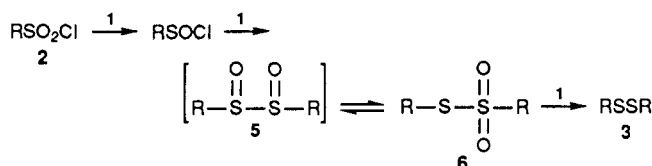
<sup>a</sup>All compounds gave satisfactory IR,  $^1\text{H}$  NMR, mass spectral data, and melting/boiling point.

### Scheme I



rapidly with 1 molar equiv of **1** at room temperature to afford the corresponding disulfides in good yield (entries 1-7, Table I). Sulfinyl chloride (entry 8), sulfonic acid (entry 9),  $\alpha$ -disulfone (entry 10), and thiosulfonates (entries 11-14) are also smoothly converted to the corresponding disulfides. It is interesting, however, to note that sulfoxide (entry 15), sulfone (entry 16), and sulfonic acid (entry 17), remain unaffected on treatment with **1** even after a long reaction time. In terms of reactivity, alkyl sulfonyl chlo-

Scheme II



rides react with 1 slower than the aryl sulfonyl chlorides. Chan et al.<sup>7g</sup> have earlier reported essentially similar results with an entirely different reagent system consisting of tri-*n*-propylamine and trichlorosilane.

Although no intermediate has so far been isolated in these reactions, a preliminary investigation has revealed some interesting facts. Reductive dimerization of sulfonyl chlorides 2 to disulfides 3 are generally believed to go through different stages as shown in Scheme I.<sup>8,10</sup>

In order to test the validity of the intervention of these intermediates in our reaction, authentic samples of  $\alpha$ -disulfone 4a<sup>11</sup> and thiosulfonate esters 6a-d<sup>12</sup> were prepared and subjected to reaction with 1. Although the thiosulfonate esters 6a-d reacted very rapidly to give the corresponding disulfides, the disulfone 4a took nearly 12 h to react with 1 to give the corresponding disulfide. Hence it is very unlikely that the  $\alpha$ -disulfones 4 are the intermediates in the overall transformation. The fact that thiosulfonate esters 6a-d react almost instantaneously to give the corresponding disulfides suggest that in the conversion of 2  $\rightarrow$  3 thiosulfonate esters 6 are more likely to be intermediates. However, thiosulfonate esters 6 could not be detected or isolated as intermediates in the reaction of 2 with 1.<sup>13</sup> Since sulfinyl chloride reacts faster than sulfonyl chloride, we believe the overall transformation probably goes as indicated in Scheme II. Here 2 gets converted to the sulfinyl chloride, which then undergoes oxidative coupling to give  $\alpha$ -disulfoxide 5. These  $\alpha$ -disulfoxides are known to rearrange readily to the thiosulfonate esters 6, which undergo reduction to give disulfides. Recently Harpp<sup>14</sup> has reported that sulfinyl chlorides on treatment with lithium organotin are converted to the corresponding thiosulfonates where  $\alpha$ -di-

sulfoxides have been detected as intermediates.

In the case of reduction of thiosulfonates by 1 one would anticipate the formation of unsymmetrical disulfides starting from thiosulfonate esters having different substituents at the sulfonyl and sulfenyl sulfur. However, in the reaction of 6c and 6d, with 1 a mixture of unsymmetrical and both possible symmetric disulfides was always produced.<sup>7f,15</sup> This could be due to the disproportionation of the unsymmetrical disulfide formed upon reduction<sup>16</sup> or rather by cleavage of the S-S bond in thiosulfonate by 1 initially and reformation of the bond later. It would still be of interest to study how tetrathiotungstate brings about this interesting transformation.

At the present time, however, it can be used as a mild and efficient methodology for the synthesis of disulfides from sulfonyl derivatives.

### Experimental Section

Melting points are uncorrected. All sulfonyl derivatives were either commercially available or were prepared using standard procedures.

**Representative Procedure.** To a stirred solution of piperidinium tetrathiotungstate (484 mg, 1 mmol) in 5 mL of dry DMF was added dropwise *p*-toluenesulfonyl chloride (191 mg, 1 mmol) in 3 mL of DMF at room temperature. The color of the reaction mixture changed instantaneously to dark brown. Reaction was monitored by TLC. After the completion of the reaction, DMF was distilled under vacuum. The residue was dissolved in 30 mL of  $\text{CH}_2\text{Cl}_2$  and washed several times with water until the aqueous washings were almost colorless. The organic layer was then dried over anhydrous  $\text{MgSO}_4$ , and the solvent was removed under reduced pressure to give *p*-tolyl disulfide, which on chromatographic purification using 5% ether/petroleum ether (60–80 °C) gave pure *p*-tolyl disulfide (85 mg, 69%) mp 44 °C (lit.<sup>17</sup> mp 46 °C).

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**Registry No.** 1, 56181-21-6; 2a, 98-09-9; 2b, 98-59-9; 2c, 98-68-0; 2d, 98-58-8; 2e, 98-60-2; 2f, 1939-99-7; 2g, 2386-60-9; 2h, 10439-23-3; 2i, 536-57-2; 3 (R =  $\text{C}_6\text{H}_5$ ), 882-33-7; 3 (R = *p*- $\text{CH}_3\text{C}_6\text{H}_4$ ), 103-19-5; 3 (R = *p*- $\text{OCH}_3\text{C}_6\text{H}_4$ ), 5335-87-5; 3 (R = *p*- $\text{BrC}_6\text{H}_4$ ), 5335-84-2; 3 (R = *p*- $\text{ClC}_6\text{H}_4$ ), 1142-19-4; 3 (R =  $\text{C}_6\text{H}_5\text{CH}_2$ ), 150-60-7; 3 (R =  $\text{CH}_3(\text{CH}_2)_3$ ), 629-45-8; 3 (R =  $\text{C}_2\text{H}_5$ ), 110-81-6; 4a, 10409-07-1; 6a, 2943-42-2; 6b, 1212-08-4; 6c, 3541-14-8; 6d, 28519-30-4; *p*- $\text{CH}_3\text{C}_6\text{H}_4\text{SSC}_6\text{H}_5$ , 29627-34-7;  $\text{PhSSC}_4\text{H}_9$ , 20129-23-1; *p*- $\text{CH}_3\text{C}_6\text{H}_4\text{SSC}_2\text{H}_5$ , 61565-48-8.

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