Chemistry of the Sulfur-Nitrogen Bond. 15.[1] Sulfenylation of Sulfenamide Enolate Equivalents (SEE): α-(Arylthio)sulfenimines

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Studies directed toward the synthesis of α-(arylthio)sulfenimine derivatives **3** via sulfenylation of sulfenamide enolate equivalents (SEE) are described. Addition of aryl disulfides to the SEE (direct quench) afforded both the α-(arylthio)sulfenimine, **3**, and an unexpected product, the enamino sulfide **4**. Addition of the SEE to phenyl disulfide or phenyl benzenethiosulfonate (indirect quench) gave the desired **3** in good to excellent yield. α,α-Bis(phenylthio)- and α,α,α,-tris(phenylthio)sulfenimines **8** and **7**, respectively, can be synthesized in good yield from the SEE by proper choice of reaction conditions.

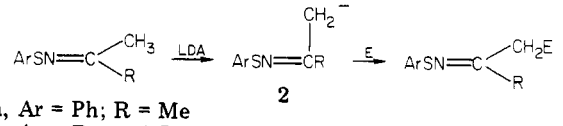
The application of α-thiocarbonyl compounds [$RSCH_2C(O)R'$] in organic synthesis is well documented and has been recently reviewed by Trost[2,3] and others.[4,5] The utility of such compounds is derived from the ability of sulfur to stabilize adjacent carbonium ions and carbanions as well as the ready transformation of the sulfur moiety to other functionalities.

Sulfenimine derivatives ($ArS(O)_nN{=}CR_2$, n = 0, 1, 2)[6] are also important synthetic intermediates. They are precursors of sulfenic acids (RSOH),[1,7] may be oxidized to 2-(arenesulfonyl)-3-aryloxaziridines,[8] and are unsubstituted imine (>C=NH) equivalents.[9] The synthetic utility of sulfenimines and the aforementioned α-thiocarbonyl compounds suggested that the analogous α-thiosulfenimines ($ArSN{=}C(R)CH_2SR'$) would also be of synthetic utility. We report here results of studies aimed at synthesizing this class of compounds.

Results and Discussion

Sulfenylation of metalloenolates is one of several procedures used to prepare α-thiocarbonyl compounds.[2,3] The regiochemistry of this method has been shown to be similar to that of the metalloenolate formation.[2] Sulfenylation of enamines,[10,11] metalloenamides,[12] and enol silyl ethers[13] reportedly gives good yields of the monosulfenylated product. Corey and Knapp reported the quantitative monosulfenylation of the lithium enolate of the *N,N*-dimethylhydrazone of 4-*tert*-butylcyclohexanone with dimethyl disulfide.[14]

We have explored a similar approach to α-thiosulfenimines, namely, the reaction of sulfenamide enolate equivalents (SEE), **2** (eq 1), with various sulfenylating



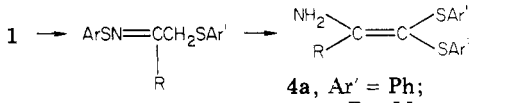
(1)

1a, Ar = Ph; R = Me
b, Ar = R = 4-ClPh

2

agents. SEE are prepared in excellent yields by treatment of sulfenimines, **1**, with lithium diisopropylamide (LDA).[15] These enolate equivalents, **2**, which have excellent stability, are formed in high yield with good regiochemistry, better than that of those from the analogous ketones.[16] They react with a variety of electrophiles (E) to afford high yields of the new sulfenimine derivatives.[15]

Addition of 1 equiv of phenyl disulfide (PhSSPh) to an ethereal solution of the SEE of *N*-isopropylidenebenzenesulfenamide (**1a**) affords, on workup and isolation by preparative TLC, the desired α-(phenylthio)sulfenimine **3a** (eq 2) in 24% yield and, unexpectedly, the enamino



(2)

3a, Ar = Ar' = Ph; R = Me
b, Ar = Ph; Ar' = 4-ClPh; R = Me
c, Ar = Ar' = R = 4-ClPh

4a, Ar' = Ph; R = Me
b, Ar' = 4-ClPh; R = Me
c, Ar' = R = ClPh

sulfide 1,1,-bis(phenylthio)-2-aminopropene (**4a**) in 28% yield (Table I, entry 1). A somewhat more reactive sulfenylating agent, such as 4-chlorophenyl disulfide, increases the yield of the enamino sulfide, **4b**, to 55%, apparently at the expense of **3b** (entry 6). The 4-chloroacetophenone sulfenimine **1b**, on treatment with 2–3 equiv of LDA and 2–2.5 equiv of 4-chlorophenyl disulfide, gave the enamino sulfide **4c** in 33–35% yield in addition to **3c** in 18–35% yield.

Products were isolated by preparative TLC on silica gel. Although **3a**[17] (also **8**) after isolation by this method gave a single spot on TLC, a satisfactory elemental analysis could not be obtained. It was noted that **3a** (also **8**) slowly decomposed on standing.

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(17) As previously reported,[15] α-(phenylthio)sulfenimine **3a** was isolated as an oil for which a satisfactory elemental analysis could not be obtained.

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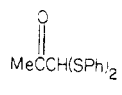
Table I. Sulfenylation of the Sulfenamide Enolate Equivalent (SEE) of *N*-Isopropylidenebenzenesulfenamide (3a)

entry	sulfenylating reagent (amt, equiv)	amt LDA, equiv	conditions[d]	product yield,[a] % 3a	4	8[b]	7	1a
1	PhSSPh (1)	1	ether, direct	24	28	6		17
2	PhSSPh (2)	2	ether, direct	15	47			
3	PhSSPh (1)	1	ether-HMPA, direct		65			
4	PhSSPh (1)	1	ether, indirect	44	17	3		13
5	PhSSPh (1)	1	ether-HMPA, indirect		70			
6	(*p*-ClPhS)$_2$ (1)	1	ether, direct	4	55			16
7	(*p*-ClPhS)$_2$ (2)	2	ether, direct		65			
8	(*p*-ClPhS)$_2$ (1)	1	ether, indirect	66	19			6
9	PhSCl (2.1)	1	ether, indirect	56	1	4		14
10	$PhSO_2SPh$ (1.1)	1	ether, direct	20		6	28	55
11	$PhSO_2SPh$ (2.4)	2	ether, direct	10		6	46	18
12	$PhSO_2SPh$ (4)	3.5	ether, direct	8		6	69	
13	$PhSO_2SPh$ (1.1)	1	ether, indirect	91		2	2	
14	$PhSO_2SPh$ (2.4)	2	ether, indirect[c]	21		48	13	5

[a] Isolated yields. [b] Yield determined by NMR with triphenylmethane as an internal standard, unless otherwise noted (see ref 11). [c] Indirect quenching procedure used twice (see Experimental Section). [d] The temperature was 0 °C in all cases except that of entry 9 where it was −78 °C.

Structural proof of **4a–c** is based on satisfactory elemental analysis and infrared, NMR, and mass spectra as well as chemical properties. Compounds **4a–c** display strong absorption in the IR at 3480 and 3380 cm^{-1} characteristic of the NH stretching vibration of a primary amine. The NMR spectra of **4a,b** consist of a singlet at δ 2.3 (Me), a broad singlet at δ 4.9 (NH_2) which exchanges with D_2O, and an aromatic absorption centered at δ 7.3. A strong molecular ion (M^+) in the mass spectrum of **4a** is observed at *m/e* 273.

Additional support for the proposed enamino sulfide structure is the isolation of α,α-bis(phenylthio)acetone (**5**)



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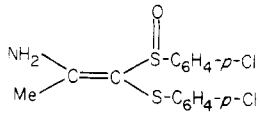

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in greater than 85% yield on brief refluxing of **4a** with 3 N HCl. Compound **5** gives a satisfactory elemental analysis and displays strong C=O absorption at 1710 cm^{-1} in the IR spectrum, and the NMR spectrum consists of singlets in the aliphatic region which appear at δ 2.3 (Me) and 4.9 [$CH(SPh)_2$].

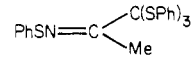
Oxidation of **4b** with 1 equiv of *m*-chloroperbenzoic acid (*m*-CPBA) gives a single monosulfoxide in greater than 80% yield. We have tentatively assigned the structure of this sulfoxide as the one in which S–O is cis to the amino group, **6**, on the basis of the rather low S–O stretching vibration appearing at 990 cm^{-1}. Typical S–O stretching vibrations for sulfoxides are observed in the region 1010–1080 cm^{-1}.[18] The low S–O stretching vibration may be the result of intramolecular hydrogen bonding between the sulfinyl and amino groups.

Stable primary enamines are relatively rare organic species, since in most cases the isomeric imine (>C=NH) predominates. Since such imines are highly reactive, undergo self-condensation reactions, and are readily hydrolyzed, the characterization of these species has proven difficult.[19] Methyl 2-amino-3-methyl-2-butenoate has been prepared by reduction of the corresponding nitro olefin.[20] Ogura and Tsuchihashi have prepared a series of enamino sulfides corresponding to **4** by reaction of the methyl (methylthio)methyl sulfoxide anion with nitriles.[21] The stability of compounds such as **4** undoubtedly results from stabilization of the C–C double bond by conjugation with the arylthio groups.

In an effort to maximize the yields of the α-(arylthio)sulfenimines **3** we explored the effects of the reaction conditions such as the type of sulfenylating reagent, the base concentration, the method of addition of the SEE to the sulfenylating reagent (quench), and the solvent on the product distribution. These results are summarized in Table I.

Inspection of Table I reveals several trends. First, use of a direct quench procedure (addition of the sulfenylating reagent to the SEE) resulted in an increase in the yield of the enamino sulfide **4** (entries 2 and 7). Use of ether–HMPA (1:1) as the solvent caused a dramatic increase in the yield of **4** (entries 3 and 5). The ability of HMPA to increase the reactivity of enolate anions has been reported by others.[21]

Direct quenching of the SEE with a more reactive disulfide than PhSSPh increases the yield of the enamino sulfides **4** while decreasing the yield of **3** (compare entries 1 and 6). On the other hand, the yield of the α-(phenylthio)sulfenimines **3a** can be increased by using a more highly reactive sulfenylating reagent such as benzensulfenyl chloride (PhSCl) or phenyl benzenethiosulfonate ($PhSO_2SPh$) (entries 9 and 10). Note that these reagents did not give any of the corresponding enamino sulfides **4**. With phenyl benzenethiosulfonate a new product identified as the α,α,α-tris(phenylthio)sulfenimine **7** was isolated (entry 10). The yield of **7** was increased to 69% by using a large excess of LDA and this sulfenylating reagent (entries 11 and 12).



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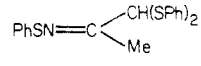

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The method of adding the sulfenylating reagent to the SEE (quench) also has an important effect on the product distribution. Addition of the sulfenylating reagent to the SEE (direct quench) gives higher yields of polysulfenylated products as well as of the enamino sulfides **4** than does addition of the SEE to the sulfenylating reagent (indirect quench) as seen by entries 1 and 2, 6 and 7, 11 and 13, and

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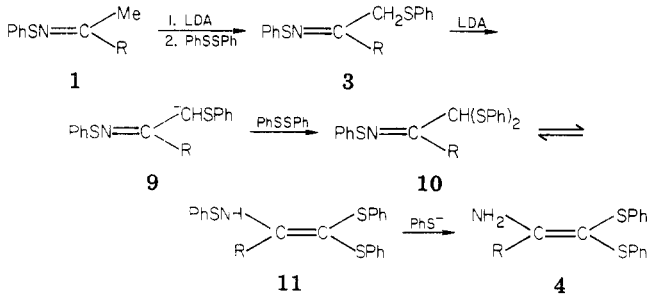
Scheme I

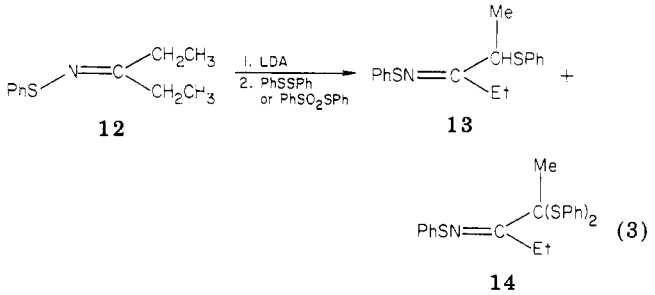


14 of Table I. An indirect quench, in all cases, affords the highest yields of α-(phenylthio)sulfenimine **3a**. In fact, α-(phenylthio)sulfenimine **3a** is isolated in greater than 90% yield by using $PhSO_2SPh$ and this method of quench (entry 13). This procedure also gives α,α-bis(phenylthio)sulfenimine **8** in 48% yield by using excess LDA and $PhSO_2SPh$ (entry 14).

A mechanistic scheme which rationalizes the formation of the enamino sulfides **4** is outlined in Scheme I. We propose that the the α-(phenylthio)sulfenimine, **3**, undergoes rapid proton transfer to afford enolate equivalent **9**. Reaction of **9** with disulfide affords **10**. Attack by the phenylthiolate ion (PhS^-) on the ene sulfenamide **11** would give the enamino sulfide **4**. The ene sulfenamide **11** is presumably formed via isomerization of **10**. Sulfenamides are compounds containing a sulfur attached to an sp^3-hybridized nitrogen atom. These compounds are an important class of sulfenylating agents and are known to be attacked by thiols and thiolate ions to afford disulfides.[6]

This mechanism is supported by the results summarized in Table I. As predicted by this mechanism, an increase in LDA and sulfenylating agent concentration increases the yield of the enamino sulfides **4** (entries 2 and 7). The direct-quench method also favors formation of **4** since the concentration of **3** is small with respect to the base concentration, and this favors formation of **9** (entries 4 and 8). Sulfenylating agents that generate poor nucleophiles should be incapable of effecting the transformation of **11** to **4**. Indeed, this is what is observed. Benzenesulfenyl chloride and phenyl benzenethiosulfonate, which generate poor nucleophiles (Cl^- and $PhSO_2^-$, respectively) give none of the enamino sulfides **4** (entries 9 and 10–14). Finally, when α-(phenylthio)sulfenimines **3a,b**, which are proposed intermediates in the transformation of **1** to **4**, are subjected to the reaction conditions, **4a,b** are isolated in 37 and 68% yields, respectively.

Reaction of *N*-(3-pentylidene)benzenesulfenamide (**12**) with 2 equiv of LDA and PhSSPh gives only α-(phenylthio)sulfenimine **13** in 69% yield (eq 3). With the more



(3)

reactive sulfenylating agent $PhSO_2SPh$, the SEE corresponding to **12** gives **14** in 80% yield. In neither case is any of the corresponding enamino sulfide detected. These results are also consistent with the proposed mechanism, since **14** would be incapable of isomerizing to the corresponding ene sulfenamide.

Conclusions

The reaction of SEE with sulfenylating agents provides additional information[15] on the reactivity of these species compared with other enolate equivalents. Low yields of sulfenylated products are observed in the reaction of SEE with dimethyl disulfide.[23] Under similar conditions the enolate of 2,6-dimethylcyclohexanone does not react at all.[21] On the other hand, the enolate equivalent of the *N,N*-dimethylhydrazone of 4-*tert*-butylcyclohexanone gives a quantitative yield of the methylthio derivative on reaction with dimethyl disulfide.[14] We interpret these results to mean that SEE are somewhat more reactive than carbonyl enolates but considerably less reactive than enolate equivalents derived from *N,N*-dimethylhydrazones. Of the three types of enolates, SEE give the most polysulfenylated products. Steric hindrance to approach of another molecule of disulfide in the α-(methylthio)-*N,N*-dimethylhydrazones may account for the lack of polysulfenylation products despite the higher reactivity of this enolate equivalent.

Proper choice of reaction conditions permits the synthesis in good to excellent yields from sulfenamide enolate equivalents (SEE) of all the possible sulfenylated products of sulfenimines **1**, including enamino sulfides **4**. Studies aimed at exploring the synthetic utility of these new reagents are currently in progress.

Experimental Section

Melting points were determined on a Mel-Temp apparatus and are uncorrected. ^1H NMR spectra were measured on a Varian A-60A spectrometer and IR spectra on a Perkin-Elmer 457 spectrometer. Mass spectra were measured at 70 eV on a Hitachi Perkin-Elmer RMU6-E single-focussing mass spectrometer. Elemental analyses were obtained from Chemalytics, Inc., or Micro Analysis, Inc.

All glassware, syringes and needles were dried in an oven at 130 °C for 2 h prior to use. The glassware was allowed to cool in a desiccator prior to assembly. After assembly, the apparatus was flamed with a Bunsen burner for 3–5 min with nitrogen being passed through the system. Ether and THF solvents were dried by distillation over sodium–benzophenone.

General Procedure for Preparation of Sulfenamide Enolate Equivalents (SEE). In a 100-mL, three-necked flask equipped with a magnetic stir bar, a reflux condenser, a dropping funnel, and nitrogen and syringe inlets is placed 0.22 g (2.2 mmol) of diisopropylamine (Aldrich) in 2–3 mL of the appropriate dry solvent (Table I). The reaction mixture is cooled to 0 °C in an ice bath and 2.2 mmol of methyllithium added via syringe. The formation of lithium diisopropylamide (LDA) is complete within 5 min, at which time 2.0 mmol of the appropriate sulfenimine (**1a, b** or **12**,[15] Table I) dissolved in 2 mL of the appropriate solvent (Table I) is added dropwise over 0.5 h. The reaction mixture is allowed to stir for an additional 0.5 h, and the SEE solution is used in one of the procedures described below.

A. Direct-Quench Sulfenylation Procedure. The reaction mixture is cooled to the prescribed temperature (Table I), and 1–4 equiv of the appropriate sulfenylating reagent (Table I) dissolved in 10–20 mL of ether (or 5–10 mL of HMPA if used) is added to the dropwise funnel via syringe. The sulfenylating reagent is added over a period of 0.5 h with stirring for an additional 2 h at the appropriate temperature, followed by warming and stirring at room temperature for 18 h. Quenching of the reaction mixture with 20 mL of water and separation and drying of the ether layer over $MgSO_4$ followed by removal of the solvent

(23) Sulfenylation of the SEE derived from **1a** in the usual manner by using MeSSMe gave a low yield (ca. 20%) of the corresponding α-(methylthio)sulfenimine in addition to starting material (40%), as judged by NMR spectroscopy. Isolation (TLC) of the α-(methylthio)sulfenimine gave an oil for which a satisfactory elemental analysis could not be obtained: NMR ($CDCl_3$) δ 2.0 (s, 3 H, Me), 2.1 (s, 2 H, Me), 3.3 (s, 2 H, CH_2), 7.1–7.4 (m, 5 H, arom).

under vacuum afforded the reaction products (Table I). If HMPA is used in the experiment, the reaction is quenched with 20 mL of water followed by the addition of 20 mL of ether. The solution is then washed with saturated NH_4Cl/water (3 × 40 mL).

B. Indirect- (Inverse) Quench Sulfenylation Procedure. The SEE derived from *N*-isopropylidenebenzenesulfenamide (**1a**) is transferred back into the dropping funnel via syringe. The appropriate sulfenylating agent (1–2.4 equiv, Table I) dissolved in 10–20 mL of ether (or 5–10 mL of HMPA is used) is added to the flask via syringe with cooling to the prescribed temperature. The solution containing the SEE is added dropwise to the sulfenylating reagent over a period of 0.5 h, followed by stirring for an additional 2 h at the prescribed temperature and warming and stirring at room temperature for 18 h. Quenching the reaction with 20 mL of water and separation and drying of the ether layer over $MgSO_4$ afford the reaction products (Table I).

C. Indirect- (Inverse) Quench Procedure Used Twice for Sulfenylation with Phenyl Benzenethiosulfonate (Table I, Entry 14). In a 100-mL three-necked flask equipped with a magnetic stir bar, a dropping funnel with a syringe cap, and nitrogen and syringe inlets is placed 0.55 g (2.18 mmol) of phenyl benzenethiosulfonate in 5 mL of dry ether. The SEE of **1a**, prepared as described above, is transferred to the dropping funnel via syringe and added dropwise over 0.45 h to the reaction mixture with stirring. After the mixture is stirred for an additional 3 h a solution of LDA (0.5 g, 1.91 mmol) prepared separately is added dropwise via the dropping funnel over a period of 0.5 h to the reaction mixture. After being stirred for an additional hour, the reaction mixture is transferred via syringe to a dropping funnel and added dropwise over 0.45 h to 0.55 g (2.18 mmol) of phenyl benzenethiolsulfonate in 5 mL of dry ether. After being stirred at 0 °C for 2 h, the reaction mixture is stirred at room temperature for 8 h. Hydrolysis of the reaction mixture is carried out as previously described.

Isolation and Purification of Products. Isolation and purification of products were accomplished by preparative TLC on silica gel (Analtech), eluting with 5% ether/95% *n*-pentane to 15% ether/85% *n*-pentane. The exact percentages of ether/*n*-pentane used were determined prior to separation by TLC. In general, products were readily separated by this method (R_f ≥0.1–0.2). Solid products were further purified by crystallization from ether/*n*-pentane. The products listed below were prepared by using one or more of the sulfenylating procedures described above. Yields are given in Table I.

***N*-[1-(Phenylthio)-2-propylidene]benzenesulfenamide (3a):** oil; NMR ($CDCl_3$) δ 2.15 (s, 3 H, Me), 3.75 (s, 2 H, CH_2), 7.1–7.6 (m, 10 H, arom); IR (film) 1600 cm^{-1} (C=N). A satisfactory elemental analysis could not be obtained.

***N*-[3-[(4-Chlorophenyl)thio]-2-propylidene]benzenesulfenamide (3b):** mp 33 °C; NMR ($CDCl_3$) δ 2.15 (s, 3 H, Me), 3.7 (s, 2 H, CH_2), 7.2–7.5 (m, 9 H, arom); IR (KBr) 1600 cm^{-1} (C=N).

Anal. Calcd for $C_{15}H_{14}ClNS_2$: C, 58.52; H, 4.58. Found: C, 58.56; H, 4.56.

α-[(4-Chlorophenyl)thio]-4-chloroacetophenone 4-chlorobenzenesulfenimine (3c): mp 125–127 °C; NMR ($CDCl_3$) δ 4.2 (s, 2 H, CH_2), 7.1–7.6 (m, 12 H, arom); IR (KBr) 1600 cm^{-1} (C=N).

Anal. Calcd for $C_{20}H_{14}S_2NCl_3$: C, 54.74; H, 3.22. Found: C, 55.00; H, 3.49.

1,1-Bis(phenylthio)-2-amino-1-propene (enamino sulfide 4a): mp 85–86 °C; NMR ($CDCl_3$) δ 2.3 (s, 3 H, Me), 4.9 (br s, 2 H, NH_2 exchange with D_2O), 7.2 (s, 10 H, arom); IR (KBr) 3480, 3380 cm^{-1} (NH_2).

Anal. Calcd for $C_{15}H_{15}NS_2$: C, 65.89; H, 5.53. Found: C, 65.77; H, 5.78.

1,1-Bis[4-chlorophenyl)thio]-2-amino-1-propene (enamino sulfide 4b): mp 86–87 °C; NMR ($CDCl_3$) δ 2.3 (s, 3 H, Me), 5.0 (br s, 2 H, NH_2 exchange with D_2O), 7.0–7.3 (m, 8 H, arom); IR (KBr) 3480, 3370 cm^{-1} (NH_2).

Anal. Calcd for $C_{15}H_{13}NS_2Cl_3$: C, 51.73; H, 3.76. Found: C, 51.84; H, 3.75.

1,1-Bis[(4-chlorophenyl)thio]-2-(4-chlorophenyl)-2-aminoethane (enamino sulfide 4c): mp 131–133 °C; NMR ($CDCl_3$) δ 5.1 (br s, 2 H, NH_2 exchange with D_2O), 7.0–7.4 (m, 12 H, arom); IR (KBr) 3460, 3350 cm^{-1} (NH_2).

Anal. Calcd for $C_{20}H_{14}NS_2Cl_3$: C, 54.74; H, 3.22. Found: C, 54.67; H, 2.99.

***N*-[1,1,1-Tris(phenylthio)-2-propylidene]benzenesulfenamide (7):** mp 91–92 °C; NMR ($CDCl_3$) δ 2.2 (s, 3 H, Me), 7.15–7.65 (m, 20 H, arom); IR (KBr) 1880 cm^{-1} (C=N).

Anal. Calcd for $C_{27}H_{23}S_4N$: C, 66.22; H, 4.73. Found: C, 66.45; H, 4.75.

***N*-[1,1-Bis(phenylthio)-2-propylidene]benzenesulfenamide (8):** oil; NMR ($CDCl_3$) δ 2.18 (s, 3 H, Me), 5.2 (s, H, CH), 7.0–7.5 (m, 15 H, arom); IR (film) 1600 cm^{-1} (C=N). A satisfactory elemental analysis could not be obtained.

Hydrolysis of 1,1-Bis(phenylthio)-2-amino-1-propene (Enamino Sulfide 4a). In a 50-mL round-bottomed flask equipped with a magnetic stir bar and a reflux condenser is placed 0.27 g (1.0 mmol) of 1,1-bis(phenylthio)-2-amino-1-propene (**4a**) in 25 mL of 3 N HCl. After being refluxed for 2 h, the mixture is cooled and extracted with ether (3 × 20 mL). The ether extracts are dried over $MgSO_4$, and the solvent is removed to give 0.25 g of an oil. The product was purified by preparative TLC on silica gel (eluting with 5% ether/95% pentane) to afford 0.23 g (85%) of a compound identified as α,α-bis(phenylthio)acetone (**5**). Compound **5** has the following properties: mp 37–39 °C; NMR ($CDCl_3$) δ 2.3 (s, 3 H, Me), 4.9 (s, H, CH), 7.2–7.6 (m, 10 H, arom); IR (KBr) 1710 cm^{-1} (C=O).

Anal. Calcd for $C_{15}H_{14}OS_2$: C, 65.66; H, 5.14. Found: C, 65.56; H, 5.08.

Oxidation of 1,1-Bis[(4-chlorophenyl)thio]-2-amino-1-propene (Enamino Sulfide 4b). In a 100-mL, three-necked flask equipped with a mechanical stirrer and a dropping funnel is placed 0.34 g (1.0 mmol) of enamino sulfide **4b** in 10 mL of CH_2Cl_2. *m*-Chloroperoxybenzoic acid (0.18 g, 1.05 mmol) dissolved in 10 mL of CH_2Cl_2 is added dropwise over a period of 1 h with cooling to 0 °C. Stirring of the reaction mixture is continued for an additional 4 h, and then the mixture is filtered while still cold. The filtrate is washed with a 5% solution of sodium sulfite (Na_2SO_3, 3 × 10 mL). After the reaction mixture is dried over anhydrous potassium carbonate, the solvent is removed to afford 0.32 g of the crude sulfoxide. The product was crystallized from *n*-pentane to give 0.29 g (81%) of enamino sulfoxide **6**. Compound **6** had the following properties: mp 124–127 °C; NMR (CDCl) δ 2.45 (s, 3 H, Me), 5.35 (br s, 2 H, NH exchange with D_2O), 6.85–7.3 (m, 8 H, arom); IR (KBr) 3360, 3290 (br) (NH_2), 990 cm^{-1} (S=O).

Anal. Calcd for $C_{15}H_{13}S_2NOCl_2$: C, 50.28; H, 3.66. Found: C, 49.99; H, 3.59.

General Procedure for the Sulfenylation of α-(Arylthio)sulfenimines 3a and 3b with Lithium Diisopropylamide and Aryl Disulfides. Into a 25-mL, single-necked flask equipped with a magnetic stir bar and nitrogen and syringe inlets is placed 0.65 mmol of freshly prepared 0.5 M lithium diisopropylamide in 1.2 mL of dry ether. The reaction is cooled to 0 °C, and 0.65 mmol of the appropriate α-(arylthio)sulfenimine (**3a** or **3b**) dissolved in 1 mL of dry ether is added dropwise over 5 min via syringe. After being stirred at 0 °C for an additional 2 h, the reaction mixture is warmed and stirred for an additional 18 h at room temperature before quenching with 5 mL of water. Separation and drying of the ether layer over $MgSO_4$ followed by removal of solvent affords the crude enamino sulfides **4a** and **4b**. The products are purified by preparative TLC (eluting with 10% ether/90% pentane) to give 0.6 g (37%) of enamino sulfide **4a** and 0.14 g (68%) of enamino sulfide **4b**.

General Procedure for the Sulfenylation of the SEE Derived from *N*-(3-Pentylidene)benzenesulfenamide (12). Formation of the SEE derived from *N*-(3-pentylidene)benzenesulfenamine (**12**)[15] is accomplished as previously described except for an additional 1.5 h of refluxing. Sulfenylation is accomplished by using 4.4 mmol of the appropriate sulfenylating reagent (phenyl disulfide or phenyl benzenethiosulfonate) by the direct-quench procedure. The products are purified by preparative TLC on silica gel, eluting with 10% ether/90% pentane. Compounds **13** and **14** are prepared and isolated by using this procedure, and their properties are listed below.

***N*-[4-(Phenylthio)-3-pentylidene]benzenesulfenamide (13):** 69% yield; oil, mixture of *E* and *Z* isomers 77:23; NMR ($CDCl_3$) δ 1.35–1.3 (t, 3 H, Me, *J* = 7 Hz), 2.3–2.8 (dq, 1 H, CH, *J* = 7 Hz), 7.0–7.4 (m, 10 H, arom); IR (film) 1600 cm^{-1} (C=N).

Anal. Calcd for $C_{17}H_{19}S_2N$: C, 67.73; H, 6.35. Found: C, 67.48; H, 6.10.

***N*-[4,4-Bis(phenylthio)-3-pentylidene]benzenesulfenamide (14):** 80% yield; oil; NMR ($CDCl_3$) δ 1.6 (s, 3 H, Me), 1.2–1.5 (t, 3 H, Me, J = 7, 5 Hz), 2.7–3.1 (q, 2 H, CH_2, J = 7, 5 Hz), 7.1–7.5 (m, 15 H, arom); IR (film) 1580 cm^{-1} (C=N).

Anal. Calcd for $C_{23}H_{23}NS_3$: C, 67.94; H, 5.70. Found: C, 67.96; H, 5.52.

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Registry No. 1a, 38206-14-3; **1b**, 73557-35-4; **3a**, 65276-67-7; **3b**, 65276-68-8; **3c**, 73557-36-5; **4a**, 73557-37-6; **4b**, 73557-38-7; **4c**, 73557-39-8; **5**, 69753-44-2; **6**, 73557-40-1; **7**, 73557-41-2; **8**, 73557-42-3; **12**, 65276-63-3; (*E*)-**13**, 73557-43-4; (*Z*)-**13**, 73557-44-5; **14**, 73557-45-6; PhSSPh, 882-33-7; $(p\text{-ClPhS})_2$, 1142-19-4; PhSCl, 931-59-9; $PhSO_2SPh$, 1212-08-4.

Generation of α-Oxo Dithioesters by Dithiolanium Ylide Cycloreversion. Synthesis of 2-Acyl-3,6-dihydro-2*H*-thiopyrans

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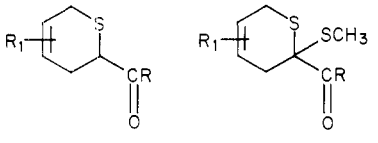
Methylation of 2-acyl-1,3-dithiolanes with CH_3OSO_2F affords sulfonium salts which undergo cycloreversion to α-oxo dithioesters $RCOCS_2CH_3$ (R = CH_3, C_5H_5). In the presence of dienes (2,3-dimethyl-, 1-methyl-, or 1,3-dimethylbutadiene), good yields of 2-acyl-2-(methylthio)-3,6-dihydrothiopyrans are formed. Treatment of the adducts with thiophiles affords 2-acyl-3,6-dihydro-2*H*-thiopyrans **1**. Diels–Alder trapping (15%) of a reactive thioaldehyde (NCCHS) by 2-ethoxybutadiene is also described.

Synthetic projects in our laboratory require a variety of six-membered sulfur heterocycles as intermediates. In particular, α-acyl derivatives such as **1** are desired for

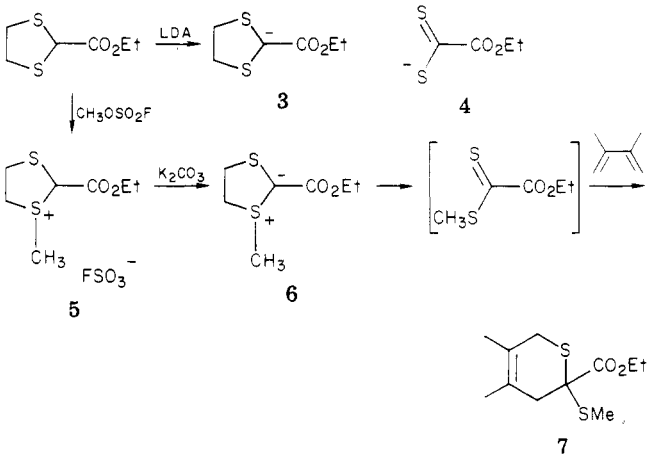


1 **2**

conversion into 2-alkenyl dihydrothiopyrans which are versatile substrates for "ring growing" reactions.[1] The hetero Diels–Alder reaction of dithioesters with dienes is an attractive route to dihydrothiopyrans, and adaptations of this approach are now described.

Cyanodithioformate esters are known to undergo 2 + 4 cycloaddition under mild conditions.[2] This precedent suggests that α-oxo dithioesters would also react readily with Diels–Alder partners to give adducts **2** which might be converted into the desired **1** by desulfenylation. However, α-oxo dithioesters were unknown until recently and only the aromatic derivatives $ArCOCS_2CH_3$ have been reported.[3]

A versatile method for synthesis of dithioesters (XCS_2CH_3) having an electron-withdrawing substitutent (X = RCO, ROCO, etc.) has been developed. The process uses a mildly basic variant of the known cycloreversion of 2-lithiodithiolanes.[4,5] Early experiments under strongly basic conditions suggested that the product dithiocarboxylates (XCS_2^-) would not survive if X is RCO or ROCO. For example, the enolate **3** was generated at −78



5 **6** **7**

°C and was found to be stable to cycloreversion at that temperature. Slow warming to 20 °C and quenching with methyl iodide gave a complex mixture. The expected formation of the known $C_2H_5O_2CCS_2CH_3$[6] could not be confirmed, and whether or not the cycloreversion product **4** was formed could not be established.

More promising results were obtained by using a modified cycloreversion substrate. The starting 2-(carboethoxy)-1,3-dithiolane was first converted into the crystalline sulfonium salt **5** with methyl fluorosulfonate. When **5** was treated with solid K_2CO_3 in the presence of 2,3-dimethylbutadiene (20 °C), the expected thiocarbonyl cycloadduct **7** was obtained in 75% yield. A labile ylide **6** was apparently formed as the intermediate which underwent cycloreversion to $C_2H_5O_2CCS_2CH_3$ under nearly neutral conditions. The same adduct **7** was formed from authentic $C_2H_5O_2CCS_2CH_3$ prepared by the literature method.[6]

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