# A Sulfoxide-Based Ring Annelation Approach to Fused, Many-Membered Ring *N,S*-Heterocycles[1]

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An approach to many-membered ring *N,S*-heterocycles involving sulfoxide electrophilic sulfenylation (SES) followed by ring expansion of the derived sulfonium salt intermediate (in situ) is illustrated for 9- and 10-membered-ring compounds. Treatment of readily prepared sulfoxides **10a**, **10b**, **18a**, **18b**, **23a**, and **23b** with triflic anhydride (pyridine, $CH_2Cl_2$, 0 °C) provides heterocycles **13a** (65%), **13b** (60%), **19a** (67%), **19b** (67%), **24a** (42%), and **24b** (80%), respectively. Sulfoxides **5a** and **5b**, under several different conditions, give only the Pummerer dehydration products **6a** and **6b**, respectively. Diastereomeric sulfoxides **18a′** and **18b′**, upon treatment with triflic anhydride, do not produce clean product mixtures or any of the desired heterocyclic products but, upon heating in toluene, are converted to the more stable isomers **18a** and **18b**, respectively. Conducting this isomerization in the presence of 2-mercaptobenzothiazole produces a disulfide indicative of the intermediacy of a sulfenic acid. However, the importance of sulfenic acid derivatives in the SES process leading to many-membered ring heterocycles remains to be determined.

We have developed sulfoxide electrophilic sulfenylation (SES) as a mild procedure for intramolecular *C*-sulfenylation of electron-rich heterocycles,[3] which takes place under conditions and with reagents identical to those often used for Pummerer reactions. The process is thought to proceed by the same mechanism as the Pummerer reaction[4] except that attack occurs *at sulfur* before proton loss to a thionium ion[5] (the traditional Pummerer intermediate). The SES process often predominates "unexpectedly" over planned normal Pummerer reactions in substrates containing the sulfoxide tethered to an electron-rich aromatic[6] or heteroaromatic[7] ring.

SES also may be accomplished in some instances by simply heating the sulfoxide in an inert solvent,[8] providing the cyclized product and an alcohol (methanol from aryl methyl sulfoxides) as the only other product.

SES reactions proceed through a sulfonium salt that typically undergoes nucleophilic displacement.[9,10] In this paper, we describe an elimination-based ring expansion of sulfoxide-generated sulfonium salts leading to novel fused, large-ring heterocycles.

## Results and Discussion

SES reactions take place with an alkylsulfinyl moiety "tethered" in some way to an electron-rich aromatic ring, typically indole or pyrrole. The first compound studied, tetrahydrothiophene-2-carboxylic acid (**1**),[11] contains a one-carbon tether. Treatment of the derived acid chloride (**2**) with $NH_4OH$ produced amide **3**, which gave[12] the pyrrole **4b** in 69% yield. We were surprised to discover that 1,4-dichloro-1,4-dimethoxybutane[13] gave *indole* **4a** in 55% yield. Examination of the literature revealed, however, that further reaction of initially formed pyrroles to indoles or carbazoles with both 1,4-dichloro-1,4-dimethoxybutane[14] and 2,5-dimethoxytetrahydrofuran[15]

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(9) Picard, J. A.; Chen, S.; Bates, D. K. *Heterocycles* **1994**, *38*, 1775. This is an important point since other work, particularly with penem sulfoxides[9a] and other tertiary sulfoxides,[9b,c] established that electrophilic reactions of sulfoxides often take place in "reverse" order (to the SES reaction) involving cleavage of an S−C bond to produce a sulfenic acid as a prelude to electrophilic reaction rather than electrophilic reaction at sulfur to give, ultimately, a sulfonium salt followed by cleavage of the S−C bond by nucleophilic displacement of the alkyl group. (a) Sammes, P. G. *Chem. Rev.* **1976**, *76*, 113. (b) Wright, S. W.; Abelman, M. M.; Bostrom, L. L.; Corbett, R. L. *Tetrahedron Lett.* **1992**, *33*, 153. (c) Brichard, M.-H.; Musick, M.; Janousek, Z.; Viehe, H. G. *Synth. Commun.* **1990**, *20*, 2379.

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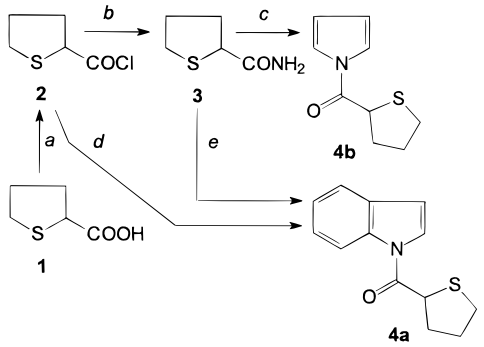
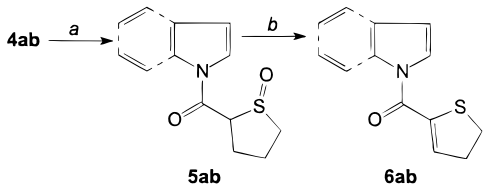
have been reported. Indole **4a** could also be prepared by acylation of indole with **2** under phase-transfer conditions.[16] Oxidation to sulfoxides (**5a**,**b**) proceeded well using Oxone,[17] producing predominately one of the two possible diastereomers.




( a) $SOCl_2$ (86%) (b) $NH_4OH$ (95%) (c) dimethoxyTHF, HOAc, reflux, 12 h, (69%) (d) indole, NaOH, $Bu_4NHSO_4$, $H_2O/CH_2Cl_2$ (95%) (e) 1,4-dichloro-1,4-dimethoxybutane, MeCN, Amberlyst resin, 55-60 °C, 24 h (55%).

Treatment of either **5a** or **5b** with TFAA/pyridine in $CH_2Cl_2$ gave only Pummerer dehydration[18] products **6a** and **6b**, respectively. The same products were formed when either sulfoxide was subjected to prolonged reflux in *p*-xylene.

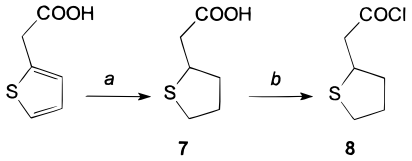



*(a)* Oxone, THF/$H_2O$/MeOH

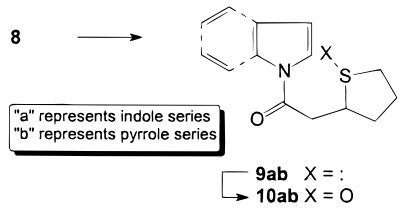
"a" represents indole series
"b" represents pyrrole series

| condition (*b*) | Yield of **6a** (%) | Yield of **6b** (%) |
|---|---|---|
| TFAA/pyr/ 0 °C | 94 | 88 |
| *p*-xylene/heat | 57 | 55 |
| $Tf_2O$/pyr/ 0 °C | 72 | 70 |

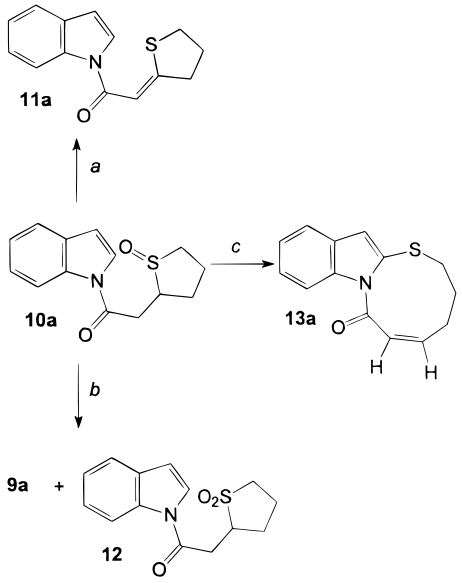
The failure of these reactions to produce ring expansion may be attributed to the acidity of the proton between the carbonyl and sulfoxide. Consequently, 2-tetrahydrothiophene acetic acid (**7**) having a less acidic proton α- to the sulfoxide (which incidentally provides a two-carbon atom tether) was prepared. Compound **7** was conveniently prepared by ionic hydrogenation[19] of commercially available thiophene-2-acetic acid in TFA containing a small amount of superacid ($HSbF_6$). This one-pot reaction provides **7** in a yield superior to the reported[20] process (58% vs 21%). Indole acylation using the derived acid chloride **8** (to **9a)** followed by oxidation ($NaIO_4$)[21] produced sulfoxide **10a**. Acid chloride **8** also readily provides pyrrole sulfide **9b** and sulfoxide **10b**. In each case, the sulfoxide isolated was predominately a single diastereomer.




(a) $Et_3SiH$, TFA, $SbF_5$·HF (58%) (b) $(COCl)_2$ (86%)




Initial reactions of sulfoxide **10a** were disappointing. As with **5**, TFAA/pyridine in $CH_2Cl_2$ produced only the Pummerer dehydration product **11a**, while heating in *p*-xylene caused sulfoxide disproportionation[22] to **9a** and **12**.




(a) TFAA/pyr/$CH_2Cl_2$/ 0 °C (73%) (b) *p*-xylene, heat (71%)
(c) $Tf_2O$/pyr/$CH_2Cl_2$/ 0 °C (65%)

Conversion of the sulfoxide oxygen into a leaving group better than trifluoroacetate using trifluoromethanesulfonic anhydride[23] (triflic anhydride, $Tf_2O$) was next considered as a strategy for coaxing the acylated oxysulfonium ion intermediate to undergo attack at sulfur in preference to the elimination pathway leading to **6** or **11a**. To our satisfaction, treatment of **10ab** with triflic anhydride/

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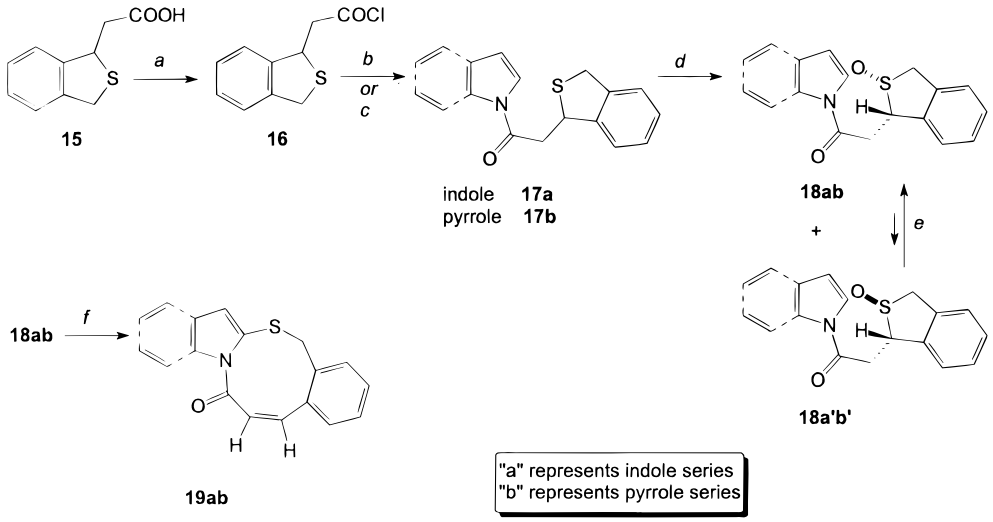
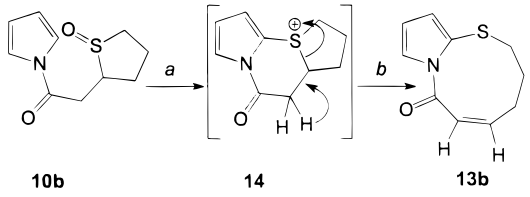
**Scheme 1**[a]




[a] Key: (a) $(COCl)_2$, $CH_2Cl_2$, rt, 4 h; (b) for **17a**: indole, $Bu_4NHSO_4$, NaOH, $H_2O/CH_2Cl_2$, rt, 3 h (63%); (c) for **17b**: $(MeO)_2$ THF, HOAc, reflux, 7 h (66%); (d) $NaIO_4$, $H_2O/CH_2Cl_2$/MeOH, rt; for indole series: (82%) **18a**:**18a′** ratio is 5:1; for pyrrole series (70%) **18b**:**18b′** ratio is 1.1:1; (e) benzene, reflux; (f) $Tf_2O$, pyr, $CH_2Cl_2$, rt, 3 h (**19a**, 67%), (**19b**, 67%).

pyridine in $CH_2Cl_2$ gave the novel heterocycles **13a** (65%) and **13b** (60%), respectively. *This is an unprecedented reaction of sulfoxides and potentially provides entry into a myriad of novel fused, many-membered ring heterocycles*.

Although the aromatic and olefinic proton absorptions in the NMR of **13a** are sharp at 25 °C, the three methylene groups of the nine-membered ring are very broad, indicating slow (on the NMR time scale) conformational changes taking place in this ring at room temperature. These absorptions sharpen considerably at −20 °C.




(a) $Tf_2O$/pyr/$CH_2Cl_2$/ 0 °C (60%)

Unfortunately, treatment of **5ab** with triflic anhydride did not change the course of the reaction, producing only Pummerer products **6a** and **6b**.

To explore the general utility of this annelation process, we selected two additional two-carbon-atom spaced substrates. Required acids 1,3-dihydrobenzo[*c*]thiophene-1-acetic acid (**15**)[20,24] and 3,4-dihydro-1*H*-2-benzothiopyran-1-acetic acid (**20**)[20] are readily converted to the corresponding indole and pyrrole sulfoxides (Schemes 1 and 2).

In the case of sulfide **17a**, oxidation using $NaIO_4$ produced a mixture of diastereomers **18a** and **18a′** (relative stereochemistry implied) in a 5:1 ratio, which could be separated chromatographically. Upon heating in benzene, both **18a′b′** were converted to a thermodynamic mixture containing predominately **18ab**.[25]

The relative stereochemistry of these compounds was determined by $^1$H NMR using aromatic solvent-induced shifts (ASIS),[26] $^1$H−$^1$H COSY, and NOE difference spectra, and the assignments agree with the general chromatographic order of elution observed for diastereomeric sulfoxides.[27]

Reaction of diastereomers **18a** and **18a′** with triflic anhydride produced interesting results. *Only diastereomer **18a** gave the expected SES product **19a** (67%).* Isomer **18a′** did not give a clean product mixture, and

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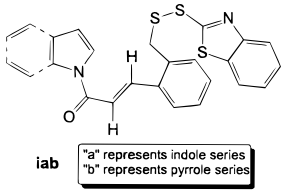
(25) The ease of conversion of **18a′** suggests the intermediacy of a sulfenic acid rather than pyramidal inversion at sulfur or homolytic scission−recombination.[25a] Thermal epimerization of penicillin sulfoxides in refluxing benzene via sulfenic acids is a well-known process,[25b−d] and $\gamma$-keto sulfoxides form sulfenic acid intermediates even more easily.[25e] Formation of sulfenic acids in these processes is a stereospecific, sigmatropic process in which the proton removed is on the group "*cis*" to the sulfoxide oxygen. If sulfenic acids are intermediates in epimerization of sulfoxides **18a′b′**, recyclization to sulfoxide is the sole reaction pathway since no products other than **18ab** are observed. Preliminary experiments indicate these sulfoxide epimerizations do indeed proceed via a sulfenic acid. For example, refluxing a mixture of pure **18a** in toluene for 1 h in the presence of excess benzothiazole 2-thiol[25f] gives a compound tentatively identified as **ia** (partial $^1$H NMR trans $\alpha,\beta$-unsaturated amide ($\delta$ 8.38, 7.14, $J$ = 15.3 Hz) and $ArCH_2$-SO ($\delta$ 4.38). A similar experiment (4 h) with an **18b**/**18b′** mixture gave a very similar compound tentatively identified as **ib** (partial $^1$H NMR trans $\alpha,\beta$-unsaturated amide ($\delta$ 8.39, 7.10, $J$ = 15.3 Hz) and $ArCH_2$-SO ($\delta$ 4.35)). (a) Cooper, R. D. G.; Hatfield, L. D.; Spry, D. O. *Acc. Chem. Res.* **1973**, *6*, 32. (b) Archer, R. A.; Demarco, P. V. *J. Chem. Soc. C* **1969**, 1530. (c) Cooper, R. D. G. *J. Am. Chem. Soc.* **1970**, *92*, 5010. (d) Spry, D. O. *J. Am. Chem. Soc.* **1970**, *92*, 5006. (e) Berges, D. A.; Taggart, J. J. *J. Org. Chem.* **1985**, *50*, 413. (f) Kamiya, T.; Teraji, T.; Saito, Y.; Hashimoto, M.; Nakaguchi, O.; Oku, T. *Tetrahedron Lett.* **1973**, 3001.

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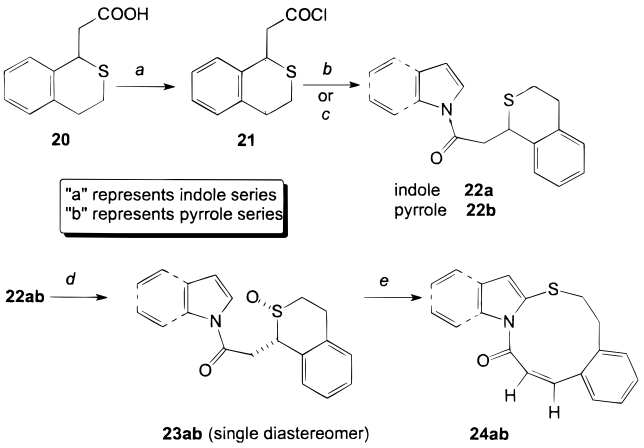
**Scheme 2**[a]




[a] Key: (a) $(COCl)_2$, $CH_2Cl_2$, rt, 2 h; (b) indole, $Bu_4NHSO_4$, NaOH, $H_2O/CH_2Cl_2$, rt, 2.5 h (68%); (c) (1) $NH_4OH$, rt, (84%), (2) dimethoxy THF, HOAc, reflux, 12 h (71%); (d) for **22a**: $NaIO_4$, $H_2O/CH_2Cl_2$/acetone, rt, 48 h (54%); for **22b**: $NaIO_4$, $H_2O/CH_2Cl_2$/acetone, rt, 30 h (80%) (e) $Tf_2O$, pyr, $CH_2Cl_2$, 0 °C, 3 h (**24a**, 42%) (**24b**, 80%).

from the single product isolated (structure unknown), it is apparent no cyclization to the indole ring has taken place. One explanation for this behavior is that the two diastereomers have very different abilities to achieve conformations suitable for bond formation between sulfur and C-2 of the indole.[28]

Due to the complicated behavior of **18a′** in the presence of triflic anhydride, the corresponding pyrrole diastereomer **18b′** has not been studied. However, **18b**, when treated with triflic anhydride under standard conditions, produces the SES/ring expansion product **19b** in 67% yield.

Sulfoxides **23ab** from the indole sulfide **22a** and pyrrole sulfide **22b** were isolated as single diastereomers. Without both diastereomers available it is not possible to clearly identify the relative stereochemistry of the compound isolated in the manner described above. However, on the basis of the relative stabilities of **18a** and **18a′**, it seems plausible that **23ab** have the sulfoxide oxygen and the heterocyclic side-chain in the same "*cis*"-orientation.

Treatment of these sulfoxides with triflic anhydride produced the fused, 10-membered ring-containing heterocycles **24a** and **24b** in yields of 42% and 80%, respectively. For reasons not yet understood, the reaction producing **24a** was not clean, and the product was very difficult to purify, while the reaction to produce the corresponding pyrrole derivative **24b** was straightforward.

## Conclusion

Synthesis of novel large-ring *N*,*S*-heterocyclic compounds via intermediates generated under Pummerer rearrangement conditions is demonstrated. This annelation approach has the potential to provide a wide range of novel compounds from carboxylic acids derivatives available from several synthetic protocols[20,29−31] for attachment via a two-carbon tether to an electron-rich heteroaromatic ring. Questions of utility (nonamide tethers, longer tethers, larger ring cyclic sulfides, other electron-rich rings, etc.) and mechanism (reactivity of sulfenic acid derivatives derived from trapped sulfenic acids, intermediacy of sulfenic acid derivatives vs direct attack of an electron-rich ring on tricoordinate sulfur) are under study.

## Experimental Section

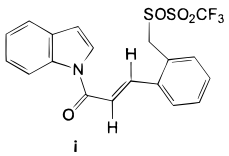
All reagents were used without purification unless otherwise noted. Chromatography refers to column chromatography on silica gel (70−230 mesh, 60 Å) with $CHCl_3$ as elution solvent unless otherwise indicated. Melting points were determined on a Fisher Johns melting point apparatus and are uncorrected. Mass spectra were recorded under electron impact at 70 eV. NMR spectra were recorded in $CDCl_3$ unless otherwise noted. Elemental analyses were performed by Galbraith Laboratories, Inc. (Knoxville, TN).

**2,3,4,5-Tetrahydrothiophene-2-carboxamide (3).** A solution of tetrahydrothiophene-2-carboxylic acid[11] (3.2 g, 0.024 mol) and thionyl chloride (7.4 mL, 0.101 mol) was stirred for 6 h. Excess thionyl chloride was removed, and the residue was distilled in vacuo to give 3.1 g (86%) of a colorless liquid (62−65 °C/1.5 Torr), which was added dropwise to concentrated ammonium hydroxide (20 mL) with stirring. Extraction with chloroform (3 × 20 mL), washing the combined organic layers with water (2 × 20 mL), drying ($MgSO_4$), and solvent removal gave (**3**) as a white solid (3.0 g, 95%): mp 145−147 °C; $^1$H NMR (200 MHz) $\delta$ 6.91 (br s, 2H), 3.85 (dd, $J$ = 7.3, 4.8 Hz, 1H), 2.93 (m, 2H), 2.21 (m, 2H), 1.99 (m, 2H); IR (KBr) 3345, 3169, 2927, 1649, 1440 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 131 ($M^+$, 25), 87 (80), 45 (100). Anal. Calcd for $C_5H_9NOS$: C, 45.77; H, 6.92; N, 10.67. Found: C, 45.68; H, 6.95; N, 10.47.

Oxalyl chloride may be substituted for thionyl chloride as the following preparation of **2,3,4,5-tetrahydrothiophene-2-acetamide** illustrates. Oxalyl chloride (16 mL, 0.18 mol) was added dropwise with efficient stirring to a solution of tetrahydrothiophene-2-acetic acid (3.0 g, 0.02 mol) in $CH_2Cl_2$ (20 mL) in an ice−water bath. After 2 h at 25 °C, volatiles were thoroughly removed to give tetrahydrothiophene-2-acetyl chloride, which was added dropwise to stirred concentrated ammonium hydroxide (30 mL). This was worked up as usual to give tetrahydrothiophene-2-acetamide as a white solid (2.5 g, 84%): mp 123−125 °C; $^1$H NMR (200 MHz) $\delta$ 5.65 (br s, 2H), 3.74 (m, 1H), 2.90 (m, 2H), 2.50 (m, 2H), 2.18 (m, 1H), 2.01 (m, 2H), 1.62 (m, 1H); $^{13}$C NMR (50 MHz) $\delta$ 173.6, 44.5, 43.6, 37.0, 32.6, 30.1; IR (KBr) 3371, 3186, 2951, 1661 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 145 ($M^+$, 100). Anal. Calcd for $C_6H_{11}NOS$: C, 49.62; H, 7.64; N, 9.65. Found: C, 49.72; H, 7.82; N, 9.53.

This procedure was also used to prepare **3,4-dihydro-1*H*-2-benzothiopyran-1-acetamide**: white solid (89%);

(28) However, the intervention of sulfenic acid chemistry must again be considered, especially in light of the report (Lee, W. S.; Hahn, H. G.; Nam, K. D. *J. Org. Chem.* **1986**, *51*, 2789) that only the "*cis*" diastereomer, which readily forms a sulfenic acid intermediate, undergoes a ring-opening reaction, whereas the "*trans*" isomer reacts only under much harsher conditions. This behavior parallels the observation that "*cis*"-**18a** forms a macrocycle, but the "*trans*" isomer (**18a′**) does not. Nonetheless, sulfenic acid intermediates must be considered improbable because direct cyclization of an open-chain sulfenic acid such as **i** to a nine-membered ring in high yield seems unlikely. Additional experiments are underway to study the chemistry of sulfenic acid derivatives such as **i** generated from trapped sulfenic acids.




**i**

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mp 91−93 °C; $^1$H NMR (400 MHz) $\delta$ 7.17 (m, 3H), 7.11 (m, 1H), 5.71 (br s, 2H), 4.38 (dd, $J$ = 8.8, 5.5 Hz, 1H), 3.03 (m, 2H), 2.93 (m, 1H), 2.81 (m, 3H); $^{13}$C NMR (100 MHz) $\delta$ 172.6, 137.2, 136.3, 129.6, 127.3, 127.0, 126.6, 44.5, 37.4, 30.7, 24.4; IR (KBr) 3500−3100, 3057, 2925, 1715, 1665 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 207 ($M^+$, 14), 115 (100). Anal. Calcd for $C_{11}H_{13}NOS$: C, 63.73; H, 6.32; N, 6.76. Found: C, 63.52; H, 6.43; N, 6.71.

**Representative Preparation of Pyrroles from Amides. 1-[(2,3,4,5-Tetrahydro-2-thienyl)carbonyl]-1*H*-pyrrole (4b).** A solution of 2,5-dimethoxytetrahydrofuran (3.2 g, 0.024 mol) and **3** (2.2 g, 0.017 mol) in glacial acetic acid (18 mL) was refluxed under nitrogen for 12 h, at which time TLC showed no starting material. The reaction mixture was cooled, neutralized with 50% NaOH, and extracted with chloroform (3 × 30 mL). Removal of solvent from the chloroform extract left a thick brown oil that was purified by vacuum distillation to give **4b** (2.1 g, 69%) as a colorless oil: bp 123 °C/1 Torr; $^1$H NMR (200 MHz) $\delta$ 7.26 (apparent t, $J$ = 2.3 Hz, 2H), 6.27 (apparent t, $J$ = 2.3 Hz, 2H), 4.42 (dd, $J$ = 6.9, 4.2 Hz, 1H), 2.93 (m, 2H), 2.52 (m, 1H), 2.23−1.98 (m, 3H); $^{13}$C NMR (50 MHz) $\delta$ 171.0, 120.3, 114.4, 47.5, 35.0, 33.5, 32.2; IR (KBr) 3144, 2998, 1714, 1468 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 181 ($M^+$, 36), 87 (100).

This procedure was used to prepare the following compounds.

**1-[(2,3,4,5-Tetrahydro-2-thienyl)acetyl]-1*H*-pyrrole (9b):** light yellow oil (66%); $^1$H NMR (200 MHz) $\delta$ 7.25 (apparent t, $J$ = 2.3 Hz, 2H), 6.24 (apparent t, $J$ = 2.3 Hz, 2H), 3.84 (m, 1H), 3.09 (d, $J$ = 7.2 Hz, 2H), 2.84 (m, 2H), 2.19 (m, 1H), 2.01 (m, 2H), 1.65 (m, 1H); $^{13}$C NMR (50 MHz) $\delta$ 168.7, 118.9, 113.1, 43.1, 42.5, 36.8, 32.5, 30.1; IR (KBr) 3146, 2945, 1714 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 195 ($M^+$, 51), 87 (100).

**1-[(1,3-Dihydro-2-benzothienyl)acetyl]-1*H*-pyrrole (17b):** yellow semisolid (66%); $^1$H NMR (400 MHz) $\delta$ 7.27 (m, 6 H), 6.29 (apparent t, $J$ = 2.3 Hz, 2H), 5.21 (m, 1H), 4.33 (dd, $J$ = 14.0, 2.7 Hz, 1H), 4.20 (d, $J$ = 14.0 Hz, 1H), 3.53 (dd, $J$ = 17.1, 4.3 Hz, 1H), 3.37 (dd, $J$ = 17.1, 9.5 Hz, 1H); IR (KBr) 3049, 2934, 1715 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 243 ($M^+$, 7). In the preparation of this compound, we found it convenient to oxidize this sulfide directly to the sulfoxide, at which time it was much easier to chromatographically separate the desired product from a pyrrole derived from an unbrominated cinnamic acid derivative carried along through the sequence from an earlier incomplete reaction.

**1-[(3,4-Dihydro-1*H*-2-benzothiopyran-3-yl)acetyl]-1*H*-pyrrole (22b):** yellow semisolid (71%); $^1$H NMR (400 MHz) $\delta$ 7.29 (m, 2 H), 7.18 (m, 4H), 6.29 (apparent t, $J$ = 2.3 Hz, 2H), 4.61 (dd, $J$ = 9.0, 5.2 Hz, 1H), 3.49 (dd, $J$ = 16.5, 9.0 Hz, 1H), 3.33 (dd, $J$ = 16.5, 5.2 Hz, 1H), 3.08 (m, 2H), 2.96 (m, 1H), 2.84 (m, 1H); $^{13}$C NMR (100 MHz) $\delta$ 167.9, 136.7, 136.4, 129.8, 127.5, 127.2, 126.7, 118.9, 113.4, 43.7, 36.6, 30.8, 24.4; IR (KBr) 3058, 3018, 2923, 1714 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 257 ($M^+$, 11), 149 (100).

**2,3,4,5-Tetrahydrothiophene-2-acetic Acid (7). Ionic Hydrogenation in the Presence of $BF_3(OEt_2)$.** Trifluoroacetic acid (8.1 mL, 0.105 mol) and boron trifluoride diethyl etherate (2 mL, 0.015 mol) were slowly added to the mixture of 2-thiopheneacetic acid (2.1 g, 0.015 mol) and triethylsilane (7.0 g, 0.06 mol) with stirring. The resulting solution was refluxed for 107 h. After cooling and neutralization with 10% $Na_2CO_3$ and extraction with ether (3 × 30 mL), the combined organics were dried ($Na_2SO_4$). Solvent removal afforded **7** (1.0 g, 46%) as a light brown oil.

**Ionic Hydrogenation in the Presence of $SbF_5$·HF.** A mixture of trifluoroacetic acid (16.2 mL, 0.21 mol) and $HSbF_6$ (three drops) was slowly added to the mixture of 2-thiopheneacetic acid (4.2 g, 0.03 mol) and triethylsilane (10.5 g, 0.09 mol) with stirring. The resulting solution was refluxed for 56 h and then worked up as described above to afford **7** (2.54 g, 58%) as a light brown oil that was identical in all respects with authentic **7** made according to the literature.[20]

**1-[(2,3,4,5-Tetrahydro-2-thienyl)carbonyl]-1*H*-indole (4a). Method A. Reaction of 8 with 1,4-Dichloro-1,4-dimethoxybutane.** To a stirred suspension of **3** (2.2 g, 16.8 mmol) in acetonitrile (25 mL) was added 1,4-dichloro-1,4-dimethoxybutane[13] (5.6 g, 29.9 mmol) dropwise over 5 min. The solid dissolved to give a brown solution to which Amberlyst A-21 resin (8 g) was added in portions. The solution was heated at 55−60 °C for 24 h. The black mixture was filtered, and the solvent was removed in vacuo to give a black oil that was chromatographed to yield **4a** (1.5 g, 55%).

**Method B. Acylation of Indole.** To a well-stirred, ice-bath-cooled solution of indole (1.23 g, 10.5 mmol) and tetrabutylammonium hydrogensulfate (0.036 g, 0.105 mmol) in methylene chloride (30 mL) was added powdered sodium hydroxide (1.26 g, 31.5 mmol) followed by **7** (3.1 g, 20.6 mmol). After 30 min, the mixture was filtered, and the filtrate, after washing with water followed by solvent evaporation, gave a yellow oil. Chromatography gave **4a** (2.3 g, 95%) as a white solid: mp 96−98 °C; $^1$H NMR (200 MHz) $\delta$ 8.47 (dd, $J$ = 7.9, 1.6 Hz, 1H), 7.56 (dd, $J$ = 7.4, 1.8 Hz, 1H), 7.42 (d, $J$ = 3.8 Hz, 1H), 7.29 (m, 2H), 6.64 (d, $J$ = 3.8 Hz, 1H), 4.52 (dd, $J$ = 6.8, 4.4 Hz, 1H), 3.02 (m, 2H), 2.69 (m, 1H), 2.35 (m, 1H), 2.19 (m, 2H); $^{13}$C NMR (50 MHz) $\delta$ 170.8, 136.0, 130.5, 125.2, 124.6, 123.8, 120.9, 116.7, 109.5, 47.6, 34.0, 32.6, 31.3; IR (KBr) 3116, 2940, 1699 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 231 ($M^+$, 25), 87 (100). Anal. Calcd for $C_{13}H_{13}NOS$: C, 67.50; H, 5.67; N, 6.06. Found: C, 67.45; H, 5.80; N, 5.91.

Method B was used to prepare the following acyl indoles.

**1-[(2,3,4,5-Tetrahydro-2-thienyl)acetyl]-1*H*-indole (9a):** white solid (86%); mp 99.5−101.5 °C; $^1$H NMR (200 MHz) $\delta$ 8.45 (d, $J$ = 8.2 Hz, 1H), 7.55 (d, $J$ = 8.0 Hz, 1H), 7.42 (d, $J$ = 3.9 Hz, 1H), 7.30 (m, 2H), 6.63 (d, $J$ = 3.9 Hz, 1H), 3.95 (m, 1H), 3.22 (d, $J$ = 7.0 Hz, 2H), 2.90 (m, 2H), 2.28 (m, 1H), 2.08 (m, 2H), 1.69 (m, 1H); $^{13}$C NMR (50 MHz) $\delta$ 169.6, 135.6, 130.3, 125.1, 124.3, 123.7, 120.8, 116.6, 109.3, 43.8, 43.4, 36.9, 32.5, 30.2; IR (KBr) 3119, 2936, 1704 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 245 ($M^+$, 12), 129 (7), 117 (100). Anal. Calcd for $C_{14}H_{15}NOS$: C, 68.54; H, 6.16; N, 5.71. Found: C, 68.34; H, 6.26; N, 5.68.

**1-[(1,3-Dihydro-2-benzothienyl)acetyl]-1*H*-indole (17a):** white solid (63%); mp 146−148 °C; $^1$H NMR (400 MHz) $\delta$ 8.51 (d, $J$ = 7.6 Hz, 1H), 7.55 (d, $J$ = 7.9 Hz, 1H), 7.27 (m, 7H), 6.62 (d, $J$ = 3.7 Hz, 1H), 5.28 (m, 1H), 4.34 (d, $J$ = 14.3 Hz, 1H), 4.23 (d, $J$ = 14.3 Hz, 1H), 3.64 (d, $J$ = 16.8 Hz, 1H), 3.46 (dd, $J$ = 16.8, 9.5 Hz, 1H); $^{13}$C NMR (100 MHz) $\delta$ 170.3, 143.5, 141.7, 136.7, 131.4, 128.7, 128.2, 126.4, 126.3, 125.4, 124.9, 122.0, 117.8, 110.6, 50.0, 47.5, 38.0; $^{13}$C NMR (100 MHz, $CD_3COCD_3$) $\delta$ 171.0, 143.9, 141.9, 136.6, 131.7, 128.3, 127.9, 126.7, 126.1, 125.7, 125.6, 124.6, 121.9, 117.3, 109.6, 49.9, 46.9, 37.0; $^1$H NMR (400 MHz, $C_6D_6$) $\delta$ 8.85 (d, $J$ = 7.9 Hz, 1H), 7.40 (d, $J$ = 7.6 Hz, 1H), 7.23 (m, 1H), 7.15 (m, 1H), 6.96 (m, 3H), 6.82 (m, 1H), 6.52 (m, 1H), 6.19 (d, $J$ = 3.7 Hz, 1H), 5.20 (m, 1H), 3.96 (dd, $J$ = 14.0, 2.8 Hz, 1H), 3.82 (d, $J$ = 14.0 Hz, 1H), 2.84 (d, $J$ = 6.7 Hz, 2H); IR (KBr) 3047, 2914, 1709 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 293 ($M^+$, 8), 135 (100). Anal. Calcd for $C_{18}H_{15}NOS$: C, 73.69; H, 5.15; N, 4.77. Found: C, 73.63; H, 5.16; N, 4.65.

**1-[(3,4-Dihydro-1*H*-2-benzothiopyran-3-yl)acetyl]-1*H*-indole (22a):** white solid (68%); mp 121−123 °C; $^1$H NMR (400 MHz) $\delta$ 8.54 (d, $J$ = 8.2 Hz, 1H), 7.57 (d, $J$ = 7.9 Hz, 1H), 7.38 (m, 2H), 7.29 (td, $J$ = 7.6, 0.9 Hz, 1H), 7.21 (m, 4H), 6.64 (d, $J$ = 3.4 Hz, 1H), 4.71 (dd, $J$ = 9.2, 4.9 Hz, 1H), 3.59 (dd, $J$ = 16.5, 9.2 Hz, 1H), 3.44 (dd, $J$ = 16.5, 4.9 Hz, 1H), 3.11 (m, 2H), 2.99 (m, 1H), 2.87 (m, 1H); $^{13}$C NMR (100 MHz) $\delta$ 168.7, 136.8, 136.5, 135.6, 130.3, 129.7, 127.4, 127.1, 126.7, 125.2, 124.2, 123.8, 120.8, 116.7, 109.4, 44.8, 36.7, 30.8, 24.5; IR (KBr) 3020, 2924, 1705, 1452 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 307 ($M^+$, 12), 117 (100). Anal. Calcd for $C_{19}H_{17}NOS$: C, 74.23; H, 5.58; N, 4.56. Found: C, 74.49; H, 5.67; N, 4.47.

**Representative Procedure for Sulfide Oxidation with Oxone. 1-[(2,3,4,5-Tetrahydro-2-thienyl)carbonyl]-1*H*-indole *S*-Oxide (5a).** To a solution of **4a** (1.5 g, 6.5 mmol) in THF (13 mL) and methanol (12 mL) was added Oxone (2.6 g, 4.23 mmol) in water (12 mL) at 0 °C. The mixture was stirred at 0 °C for 40 min and at 28 °C for 4 h, at which time TLC showed no starting material. Extractive workup with $CH_2Cl_2$ afforded a light yellow crude product that was chromatographed to give the sulfoxide **10a** (1.5 g, 93%) as a white solid: mp 134−136 °C; $^1$H NMR (200 MHz) $\delta$ 8.40 (d, $J$ = 7.9

Hz, 1H), 7.63 (d, $J$ = 3.8 Hz, 1H), 7.57 (m, 1H), 7.33 (m, 2H), 6.72 (d, $J$ = 3.8 Hz, 1H), 4.44 (t, $J$ = 7.0 Hz, 1H), 3.09 (m, 1H), 3.01 (m, 1H), 2.73 (m, 2H), 2.53 (m, 2H); $^{13}$C NMR (50 MHz) $\delta$ 167.3, 136.3, 131.3, 126.2, 125.1, 121.8, 117.3, 111.5, 74.7, 55.5, 30.4, 27.5; IR (KBr) 3102, 2942, 1693, 1035 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 247 (M$^+$, 26), 117 (100). Anal. Calcd for $C_{13}H_{13}NO_2S$: C, 63.13; H, 5.30; N, 5.66. Found: C, 63.19; H, 5.44; N, 5.60.

This procedure was also used to prepare **1-[(2,3,4,5-tetrahydro-2-thienyl)carbonyl]-1*H*-pyrrole *S*-oxide (5b):** colorless oil (97%); $^1$H NMR (200 MHz) $\delta$ 7.37 (apparent t, $J$ = 2.3 Hz, 2H), 6.34 (apparent t, $J$ = 2.3 Hz, 2H), 4.33 (t, $J$ = 6.9 Hz, 1 H), 3.06 (m, 1H), 2.86 (m, 1H), 2.62 (m, 2H), 2.41 (m, 2H); $^{13}$C NMR (50 MHz) $\delta$ 166.0, 119.3, 114.5, 73.0, 54.7, 29.7, 26.8; IR (KBr) 3138, 2946, 1700, 1472, 1041 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 197 (M$^+$, 8), 67 (100).

**Representative Procedure for Sulfide Oxidation with $NaIO_4$. 1-[(2,3,4,5-Tetrahydro-2-thienyl)acetyl]-1*H*-indole *S*-Oxide (10a).** A solution of $NaIO_4$ (0.36 g, 1.70 mmol) in water (4 mL) was added to a solution of **9a** (0.4 g, 1.63 mmol) in acetone (8 mL). The mixture was stirred for 26 h, at which time TLC showed no sulfide. The volatile was removed in vacuo. Extractive workup with $CHCl_3/H_2O$ afforded a crude product that was chromatographed to give of **10a** (0.36 g, 85%) as a white solid: mp 172−174 °C; $^1$H NMR (200 MHz) $\delta$ 8.42 (d, $J$ = 8.2 Hz, 1H), 7.50 (m, 1H), 7.44 (d, $J$ = 3.8 Hz, 1H), 7.27 (m, 2H), 6.60 (d, $J$ = 3.8 Hz, 1H), 3.57 (m, 1H), 3.12 (m, 3H), 2.80 (m, 1H), 2.30 (m, 2H), 2.08 (m,1H), 1.90 (m, 1H); $^{13}$C NMR (50 MHz) $\delta$ 168.7, 135.6, 130.4, 125.2, 124.3, 123.9, 120.9, 116.5, 109.8, 58.7, 54.6, 33.0, 30.7, 24.8; IR (KBr) 3140, 2945, 1707, 1016 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 261 (M$^+$, 7), 145 (100). Anal. Calcd for $C_{14}H_{15}NO_2S$: C, 64.34; H, 5.79; N, 5.36. Found: C, 64.04; H, 5.94; N, 5.32.

**1-[(2,3,4,5-Tetrahydro-2-thienyl)acetyl]-1*H*-pyrrole *S*-oxide (10b):** white solid (68%); mp 96−98 °C; $^1$H NMR (200 MHz) $\delta$ 7.32 (t, $J$ = 2.3 Hz, 2H), 6.29 (t, $J$ = 2.3 Hz, 2H), 3.54 (m, 1H), 3.20 (m, 3H), 2.85 (m, 1H), 2.38 (m, 2H), 1.92−2.12 (m, 2H); $^{13}$C NMR (50 MHz) $\delta$ 168.1, 118.9, 113.5, 58.3, 54.5, 31.8, 30.6, 24.7; IR (KBr) 3098, 2931, 1715, 1007 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 211 (M$^+$, 2), 145 (100). Anal. Calcd for $C_{10}H_{13}NO_2S$: C, 56.85; H, 6.20; N, 6.63. Found: C, 57.03; H, 6.39; N, 6.59.

**1-[(1,3-Dihydro-2-benzothienyl)acetyl]-1*H*-indole *S*-Oxides (18a and 18a′).** Sulfoxide **18a** (white solid, 68%): mp 198−201 °C; $^1$H NMR (400 MHz) $\delta$ 8.48 (d, $J$ = 7.9 Hz, 1H), 7.56 (d, $J$ = 7.6 Hz, 1H), 7.53 (d, $J$ = 3.9 Hz, 1H), 7.35 (m, 6H), 6.66 (d, $J$ = 3.9 Hz, 1H), 4.96 (dd, $J$ = 8.2, 5.2 Hz, 1H), 4.35 (d, $J$ = 16.4 Hz, 1H), 4.13 (d, $J$ = 16.4 Hz, 1H), 3.91 (dd, $J$ = 17.7, 8.2 Hz, 1H), 3.56 (dd, $J$ = 17.7, 5.2 Hz, 1H); $^{13}$C NMR (100 MHz) $\delta$ 168.5, 137.7, 135.7, 135.2, 130.4, 129.0, 128.6, 126.9, 125.9, 125.4, 124.3, 124.0, 121.0, 116.6, 110.1, 61.7, 57.1, 32.3; $^1$H NMR (400 MHz, $C_6D_6$) $\delta$ 8.84 (d, $J$ = 8.2 Hz, 1H), 7.39 (d, $J$ = 7.6 Hz, 1H), 7.25 (m, 1H), 7.15 (m, 1H), 6.96 (m, 3H), 6.74 (m, 2H), 6.19 (d, $J$ = 3.7 Hz, 1H), 4.47 (dd, $J$ = 7.9, 5.8 Hz, 1H), 3.56 (dd, $J$ = 17.7, 7.9 Hz, 1H), 3.49 (d, $J$ = 16.1 Hz, 1H), 3.29 (d, $J$ = 16.1 Hz, 1H), 2.76 (dd, $J$ = 17.7, 5.8 Hz, 1H); IR (KBr) 3049, 2902, 1695, 1025 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 309 (M$^+$, 5), 193 (100). Anal. Calcd for $C_{18}H_{15}NO_2S$: C, 69.88; H, 4.89; N, 4.53. Found: C, 69.67; H, 4.85; N, 4.40.

Sulfoxide **18a′** (bright yellow semisolid, 14%): $^1$H NMR (400 MHz) $\delta$ 8.36 (d, $J$ = 7.9 Hz, 1H), 7.51 (d, $J$ = 7.3 Hz, 1H), 7.27 (m, 7 H), 6.60 (d, $J$ = 3.9 Hz, 1H), 4.71 (dd, $J$ = 6.1, 5.8 Hz, 1H), 4.65 (d, $J$ = 16.1 Hz, 1H), 4.04 (d, $J$ = 16.1 Hz, 1H), 3.52 (m, 2H); $^{13}$C NMR (100 MHz) $\delta$ 167.3, 137.9, 135.7, 135.3, 130.1, 128.7, 128.4, 126.5, 125.6, 125.3, 124.0, 120.9, 116.4, 110.0, 69.8, 58.3, 37.0; $^{13}$C NMR (100 MHz, $CD_3COCD_3$) $\delta$ 170.0, 140.7, 138.2, 136.5, 131.6, 129.4, 129.0, 127.7, 127.5, 126.6, 125.8, 124.7, 121.9, 117.2, 109.9, 70.7, 58.4, 37.5; $^1$H NMR (400 MHz, $C_6D_6$) $\delta$ 8.63 (d, $J$ = 7.0 Hz, 1H), 7.37 (d, $J$ = 7.3 Hz, 1H), 7.15 (m, 2H), 6.94 (m, 3H), 6.77 (m, 1H), 6.46 (m, 1H), 6.19 (d, $J$ = 3.7 Hz, 1H), 4.54 (dd, $J$ = 7.0, 5.5 Hz, 1H), 3.93 (d, $J$ = 15.9 Hz, 1H), 3.65 (d, $J$ = 15.9 Hz, 1H), 2.69 (dd, $J$ = 17.7, 5.5 Hz, 1H), 2.52 (dd, $J$ = 17.7, 7.0 Hz, 1H); IR (KBr) 3069, 2982, 1702, 1035 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 309 (M$^+$, 13), 117 (100).

**1-[(1,3-Dihydro-2-benzothienyl)acetyl]-1*H*-pyrrole *S*-Oxides (18b and 18b′).** Sulfoxide **18b** (light yellow solid, 37%): mp 188−190 °C; $^1$H NMR (400 MHz) $\delta$ 7.33 (m, 6H), 6.30 (t, $J$ = 2.4 Hz, 2H), 4.86 (dd, $J$ = 8.6, 5.2 Hz, 1H), 4.32 (d, $J$ = 16.2 Hz, 1H), 4.09 (d, $J$ = 16.2 Hz, 1H), 3.80 (dd, $J$ = 18.0, 8.6 Hz, 1H), 3.46 (dd, $J$ = 18.0, 5.2 Hz, 1H); $^{13}$C NMR (100 MHz) $\delta$ 167.9, 137.5, 135.0, 129.0, 128.6, 126.8, 125.8, 119.1, 113.7, 61.3, 56.9, 31.2; $^1$H NMR (400 MHz, $C_6D_6$) $\delta$ 7.06 (m, 1H), 6.90 (m, 4H), 6.68 (m, 1H), 6.00 (t, $J$ = 2.4 Hz, 2H), 4.33 (m, 1H), 3.47 (dd, $J$ = 18.0, 7.9 Hz, 1H), 3.41 (d, $J$ = 16.2 Hz, 1H), 3.24 (d, $J$ = 16.2 Hz, 1H), 2.67 (dd, $J$ = 18.0, 5.5 Hz, 1H); IR (KBr) 3012, 1714, 1470, 1039 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 259 (M$^+$, 1.0), 193 (100). Anal. Calcd for $C_{14}H_{13}NO_2S$: C, 64.84; H, 5.05; N, 5.40. Found: C, 64.62; H, 5.11; N, 5.28.

Sulfoxide **18b′** (yellow semisolid, 33%): $^1$H NMR (400 MHz) $\delta$ 7.28 (m, 6H), 6.25 (t, $J$ = 2.4 Hz, 2H), 4.66 (t, $J$ = 6.1 Hz, 1H), 4.61 (d, $J$ = 16.2 Hz, 1H), 4.03 (d, $J$ = 16.2 Hz, 1H), 3.49 (poorly resolved t, 2H); $^{13}$C NMR (100 MHz) $\delta$ 166.8, 137.7, 135.7, 128.9, 128.5, 126.5, 125.6, 118.9, 113.8, 69.7, 58.4, 36.0; IR (KBr) 3010, 1716, 1470, 1037 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 242 (M$^+$ − OH, 0.8). This compound could not be obtained free from **18b** (epimerization apparently takes place at room temperature on the chromatography column).

**1-[(3,4-Dihydro-1*H*-2-benzothiopyran-3-yl)acetyl]-1*H*-indole *S*-oxide (23a):** white solid (54%); mp 191−193 °C; $^1$H NMR (400 MHz) $\delta$ 8.43 (d, $J$ = 8.5 Hz, 1H), 7.58 (d, $J$ = 8.2 Hz, 1H), 7.56 (d, $J$ = 3.4 Hz, 1H), 7.36 (td, $J$ = 8.2, 1.2 Hz, 1H), 7.29 (td, $J$ = 7.6, 0.9 Hz, 1H), 7.24 (m, 4H), 6.71 (d, $J$ = 3.4 Hz, 1H), 4.54 (dd, $J$ = 8.5, 4.0 Hz, 1H), 3.88 (dd, $J$ = 17.1, 4.0 Hz, 1H), 3.70 (dd, $J$ = 17.1, 8.5 Hz, 1H), 3.53 (m, 1H), 3.17 (m, 3H); $^{13}$C NMR (100 MHz) $\delta$ 167.5, 136.2, 135.7, 130.5, 130.3, 128.7, 128.3, 127.6, 127.4, 125.5, 124.1, 124.0, 121.0, 116.7, 110.3, 58.4, 46.8, 35.3, 24.3; IR (KBr) 3055, 3025, 2928, 1698, 1452, 1041 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 323 (M$^+$, 6), 116 (100). Anal. Calcd for $C_{19}H_{17}NO_2S$: C, 70.56; H, 5.30; N, 4.33. Found: C, 70.85; H, 5.39; N, 4.15.

**1-[(3,4-Dihydro-1*H*-2-benzothiopyran-3-yl)acetyl]-1*H*-pyrrole *S*-oxide (23b):** yellow semisolid (80%); $^1$H NMR (400 MHz) $\delta$ 7.37 (apparent s, 2H), 7.25 (m, 3H), 7.18 (m, 1H), 6.34 (t, $J$ = 2.3 Hz, 2H), 4.47 (dd, $J$ = 8.4, 4.6 Hz, 1H), 3.72 (dd, $J$ = 17.4, 4.6 Hz, 1H), 3.58 (dd, $J$ = 17.4, 8.4 Hz, 1H), 3.50 (m, 1H), 3.15 (m, 3H); $^{13}$C NMR (100 MHz) $\delta$ 166.8, 135.8, 130.3, 128.7, 128.2, 127.5, 119.0, 113.8, 57.9, 46.1, 34.4, 23.9; $^1$H NMR (400 MHz, $CD_3COCD_3$) $\delta$ 7.49 (t, $J$ = 2.3 Hz, 2H), 7.33 (m, 1H), 7.24 (m, 3H), 6.31 (t, $J$ = 2.3 Hz, 2H), 4.49 (t, $J$ = 6.7 Hz, 1H), 3.65 (d, $J$ = 6.7 Hz, 2H), 3.45 (m, 1H), 3.20 (m, 1H), 3.03 (m, 2H); $^{13}$C NMR (100 MHz, $CD_3COCD_3$) $\delta$ 168.8, 136.4, 132.6, 130.7, 130.0, 128.6, 128.0, 120.4, 114.1, 57.0, 43.1, 37.2, 22.5; $^1$H NMR (400 MHz, $C_6D_6$) $\delta$ 7.11 (apparent s, 2H), 6.85 (m, 3H), 6.68 (d, $J$ = 7.3 Hz, 1H), 6.02 (t, $J$ = 2.4 Hz, 2H), 4.30 (dd, $J$ = 8.5, 4.6 Hz, 1H), 3.20 (dd, $J$ = 17.4, 4.6 Hz, 1H), 2.93 (dd, $J$ = 17.4, 8.5 Hz, 1H), 2.89 (m, 1H), 2.45 (m, 1H), 2.25 (m, 2H); IR (KBr) 3061, 3022, 2924, 1713, 1040 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 273 (M$^+$, 6), 115 (100).

**Representative Reaction of Sulfoxides with TFAA.** To a well-stirred solution of TFAA (1.3 mL, 8.0 mmol) in $CH_2Cl_2$ (13 mL) at 0 °C was added pyridine (0.7 mL, 8.0 mmol). A solution of sulfoxide **5a** (0.49 g, 2.0 mmol) in $CH_2Cl_2$ (5 mL) was then added. The mixture was stirred at 0 °C for 3 h and at room temperature for 0.5 h. The solution was poured into 10% aqueous $Na_2CO_3$ (30 mL). The layers were separated, and the aqueous layer was extracted with $CH_2Cl_2$ (2 × 15 mL). The combined organics were washed with 5% HCl and water and dried ($Na_2SO_4$). The solvent was removed in vacuo, and the residue was chromatographed ($CHCl_3$/hexane) to afford **1-[(4,5-dihydro-2-thienyl)]carbonyl]-1*H*-indole** (**6a**) (0.43 g, 94%) as a yellow semisolid: $^1$H NMR (200 MHz) $\delta$ 8.39 (d, $J$ = 7.8 Hz, 1H), 7.60 (d, $J$ = 3.8 Hz, 1H), 7.55 (m, 1H), 7.32 (m, 2H), 6.61 (d, $J$ = 3.8 Hz, 1H), 6.28 (t, $J$ = 3.0 Hz, 1H), 3.41 (t, $J$ = 8.6 Hz, 2H), 3.02 (td, $J$ = 8.6, 3.0 Hz, 2H); $^{13}$C NMR (50 MHz) $\delta$ 162.7, 137.5, 135.5, 131.7, 130.7, 126.5, 124.9, 124.0, 120.8, 116.4, 108.8, 36.7, 32.8; IR (KBr) 3117, 3052, 2936, 1677 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 229 (M$^+$, 78), 113 (100).

The following products were formed from the same procedure (variations in reactions times are given in parentheses).

**1-[(4,5-Dihydro-2-thienyl)]carbonyl]-1*H*-pyrrole (6b):** 4 h at 0 °C and 3 h at 25 °C; 88%; yellow oil: $^1$H NMR (200 MHz) $\delta$ 7.34 (t, $J$ = 2.0 Hz, 2H), 6.33 (t, $J$ = 3.1 Hz, 1H), 6.28 (t, $J$ = 2.0 Hz, 2H), 3.38 (t, $J$ = 8.5 Hz, 2H), 3.00 (td, $J$ = 8.5, 3.1 Hz, 2H); $^{13}$C NMR (50 MHz) $\delta$ 161.7, 136.9, 133.4, 120.3, 113.3, 36.8, 32.6; IR (KBr) 3148, 2936, 1688, 1588 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 179 ($M^+$, 21), 45 (100).

**1-[[4,5-Dihydro-2(3*H*)-thiophenyliden]acetyl]-1*H*-indole (11a):** 15 min at 0 °C and 3 h at room temperature; white solid (73%); mp 143−146 °C; $^1$H NMR (400 MHz) $\delta$ 8.59 (d, $J$ = 8.2 Hz, 1H), 7.56 (d, $J$ = 7.6 Hz, 1H), 7.50 (d, $J$ = 3.9 Hz, 1H), 7.33 (m, 1H), 7.24 (m, 1H), 6.72 (t, $J$ = 1.2 Hz, 1H), 6.61 (d, $J$ = 3.9 Hz, 1H), 3.11 (t, $J$ = 6.4 Hz, 2H), 2.92 (td, $J$ = 7.0, 1.2 Hz, 2H), 2.09 (p, $J$ = 6.7 Hz, 2H); $^{13}$C NMR (100 MHz) $\delta$ 172.4, 164.3, 135.7, 130.3, 124.43, 124.35, 123.0, 120.6, 116.5, 108.0, 105.0, 40.1, 35.3, 27.9; IR (KBr) 3033, 2956, 1655 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 243 ($M^+$, 30), 117 (100). Anal. Calcd for $C_{14}H_{13}NOS$: C, 69.10; H, 5.38; N, 5.76. Found: C, 69.32; H, 5.31; N, 5.57.

**Representative Procedure for Thermal Reactions of Sulfoxides.** Sulfoxide **5a** (0.95 g, 3.85 mmol) was refluxed in *p*-xylene (30 mL) for 53 h during which time TLC indicated formation of a new product. Solvent evaporation and chromatography (chloroform/hexane) yielded 0.24 g (57% based on 0.5 g recovered starting material) of **6a** as a yellow semisolid, which was spectroscopically and chromatographically identical to the sample obtained from the TFAA reaction.

The following compounds were obtained by the same procedure. If no spectral data are provided, the compound identity was verified by comparing spectroscopic and chromatographic behavior with samples obtained using a different method.

**1-[(4,5-Dihydro-2-thienyl)]carbonyl]-1*H*-pyrrole (6b):** 48 h gave 60% conversion of starting material and a 55% yield (based on recovered starting material) of **6b**.

**Redox Products 9a and 12:** 24 h; sulfide **9a** (37%) (identical to the compound used to prepare sulfoxide **10a**). Sulfone **12** (35%) is a light brown solid: mp 189−191 °C; $^1$H NMR (200 MHz) $\delta$ 8.41 (d, $J$ = 8.1 Hz, 1H), 7.56 (m, 1H), 7.45 (d, $J$ = 3.8 Hz, 1H), 7.31 (m, 2H), 6.67 (d, $J$ = 3.8 Hz, 1H), 3.55 (m, 2H), 3.14 (m, 3H), 2.95 (m, 1H), 2.21 (m, 2H), 1.90 (m, 1H); $^{13}$C NMR (50 MHz) $\delta$ 167.5, 135.6, 133.9, 130.3, 125.4, 124.0, 121.0, 116.5, 110.1, 56.5, 51.0, 34.6, 29.5, 20.2; IR (KBr) 3137, 2966, 1705, 1324, 1127 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 277 ($M^+$, 8), 117 (100). Anal. Calcd for $C_{14}H_{15}NO_3S$: C, 60.63; H, 5.45; N, 5.05. Found: C, 60.43; H, 5.61; N, 5.01.

**Representative Reaction of Sulfoxides with Trifluoromethanesulfonic Anhydride.** To a well-stirred solution of trifluoromethanesulfonic anhydride (0.45 mL, 2.69 mmol) in $CH_2Cl_2$ (5 mL) at 0 °C was added pyridine (0.23 mL, 2.91 mmol) followed by a solution of sulfoxide **5a** (0.18 g, 0.728 mmol) in $CH_2Cl_2$ (5 mL). The resulting mixture was stirred for 15 min at 0 °C and 3 h at room temperature. The solution was poured into 10% $Na_2CO_3$ (10 mL) and stirred for 10 min. The layers were separated, and the aqueous layer was extracted with $CH_2Cl_2$ (3 × 8 mL). The combined organics were washed with 5% HCl and water and dried ($Na_2SO_4$). The solvent was removed in vacuo, and the residue was chromatographed ($CHCl_3$/hexane) to afford **6a** (0.12 g, 72%) as a yellow semisolid that was spectroscopically and chromatographically identical to the sample obtained from the TFAA reaction.

The following compounds were obtained by the same procedure (variations in reactions times are given in parentheses). If no spectral data are provided, compound identity was verified by comparing spectroscopic and chromatographic behavior with samples obtained using a different method.

**1-[(4,5-Dihydro-2-thienyl)]carbonyl]-1*H*-pyrrole (6b):** 30 min at 0 °C and 3 h at room temperature; 70% yield.

**3,4-Dihydroindolo[2,1-*b*][1,3]thiazonin-7(2*H*)-one (13a):** 30 min at 0 °C and 3 h at room temperature; light yellow semisolid (65%); $^1$H NMR (400 MHz, 23 °C) $\delta$ 8.36 (d, $J$ = 8.5 Hz, 1H), 7.53 (dd, $J$ = 7.8, 1.4 Hz, 1H), 7.37 (m, 1H), 7.27 (m, 1H), 7.00 (s, 1H), 6.24 (m, 2H), 2.82−3.39 (br s, 2H), 2.18−2.30 (br s, 2H), 1.75−1.90 (br s, 2H); $^{13}$C NMR (100 MHz, 23 °C) $\delta$ 167.3, 142.3, 138.3, 133.2, 128.5, 125.7, 124.8, 123.8, 121.5, 120.1, 116.7, 42.6, 27.4, 24.4; IR (KBr) 3068, 2921, 1677 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 243 ($M^+$, 100); $^1$H NMR (400 MHz, −20 °C) $\delta$ 8.33 (d, $J$ = 8.2 Hz, 1H), 7.52 (dd, $J$ = 7.7, 1.3 Hz, 1H), 7.37 (m, 1H), 7.27 (m, 1H), 7.01 (s, 1H), 6.24 (m, 2H), 3.34 (m, 1H), 2.94 (m, 1H), 2.26 (m, 1H), 2.18 (m, 1H), 1.89 (m, 1H), 1.76 (m, 1H); $^{13}$C NMR (100 MHz, −20 °C) $\delta$ 167.4, 143.5, 138.2, 133.5, 128.5, 125.9, 124.5, 124.0, 121.8, 120.3, 116.8, 43.4, 27.5, 24.5.

**3,4-Dihydropyrrolo[2,1-*b*][1,3]thiazonin-7(2*H*)-one (13b):** 15 min at 0 °C and 7 h at room temperature (60%); light yellow oil; $^1$H NMR (400 MHz, 23 °C) $\delta$ 7.64 (dd, $J$ = 3.6, 1.9 Hz, 1H), 6.60 (dd, $J$ = 3.1, 1.9 Hz, 1H), 6.26 (m, 2H), 6.10 (d, $J$ = 12.0 Hz, 1H), 2.62−3.19 (br s, 2H), 2.21 (m, 2H), 1.80 (m, 2H); $^{13}$C NMR (100 MHz, 23 °C) $\delta$ 166.9, 145.0, 127.3, 127.1, 125.6, 123.4, 113.0, 43.6, 28.8, 25.6; IR (KBr) 3146, 2920, 1683 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 193 ($M^+$, 20), 67 (100).

**Indolo[2,1-*b*][1,3]benzo[*g*]thiazonin-9(2*H*)-one (19a):** 15 min at 0 °C and 3 h at room temperature; yellow solid (67%); mp 169−172 °C; $^1$H NMR (400 MHz) $\delta$ 7.96 (d, $J$ = 8.5 Hz, 1H), 7.28 (m, 2 H), 7.19 (m, 1H), 7.08 (m, 1H), 6.88 (m, 4H), 6.62 (d, $J$ = 12.1 Hz, 1H), 6.57 (s, 1H), 4.02 (d, $J$ = 10.7 Hz, 1H), 3.86 (d, $J$ = 10.7 Hz, 1H); $^{13}$C NMR (100 MHz) $\delta$ 167.0, 138.0, 136.3, 136.1, 132.6, 130.6, 129.0, 128.4, 127.65, 127.59, 126.4, 126.3, 125.5, 123.4, 123.2, 120.1, 115.4, 38.5; IR ($CHCl_3$) 3070, 2929, 1672 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 291 ($M^+$, 33), 115 (100). Anal. Calcd for $C_{18}H_{13}NOS$: C, 74.20; H, 4.50; N, 4.81. Found: C, 74.01; H, 4.63; N, 4.72.

**Pyrrolo[2,1-*b*][1,3]benzo[*g*]thiazonin-9(2*H*)-one (19b):** 15 min at 0 °C and 3 h at room temperature; brownish semisolid (67%); $^1$H NMR (400 MHz) $\delta$ 7.32 (d, $J$ = 12.0 Hz, 1H), 7.14 (dd, $J$ = 3.7, 1.8 Hz, 1H), 7.05 (m, 2H), 6.93 (m, 1H), 6.86 (m, 1H), 6.53 (d, $J$ = 12.0 Hz, 1H), 6.19 (dd, $J$ = 3.3, 1.8 Hz, 1H), 5.90 (t, $J$ = 3.3 Hz, 1H), 3.92 (d, $J$ = 11.0 Hz, 1H), 3.72 (d, $J$ = 11.0 Hz, 1H); $^{13}$C NMR (100 MHz) $\delta$ 165.9, 137.8, 136.0, 133.0, 130.7, 127.94, 127.89, 127.4, 127.3, 126.7, 124.6, 119.0, 112.1, 38.7; IR (KBr) 3010, 1687 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 241 ($M^+$, 46), 115 (100).

**2,3-Dihydro-10*H*-indolo[2,1-*b*][1,3]benzo[*g*]thiazecin-10-one (24a):** 15 min at 0 °C and 4 h at room temperature; yellow semisolid (42%); $^1$H NMR (400 MHz) $\delta$ 7.94 (d, $J$ = 8.2 Hz, 1H), 7.47 (d, $J$ = 11.9 Hz, 1H), 7.13 (m, 3H), 6.93 (m, 1H), 6.81 (m, 1H), 6.64 (m, 1H), 6.62 (d, $J$ = 11.9 Hz, 1H), 6.43 (td, $J$ = 7.6, 0.9 Hz, 1H), 6.33 (s, 1H), 3.35 (m, 2H), 3.08 (m, 2H); $^{13}$C NMR (100 MHz) $\delta$ 168.0, 142.2, 137.4, 136.4, 135.4, 129.7, 128.6, 128.1, 127.3, 126.2, 125.9, 124.5, 122.9, 118.9, 116.6, 114.2, 43.4, 34.8; IR ($CHCl_3$): 3020, 1682 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 305 ($M^+$, 15). Unlike **24b**, this compound was not stable and could not purified to an acceptable level of purity. The data provided here is from this impure material, but spectra contained other unidentified peaks.

**2,3-Dihydro-10*H*-pyrrolo[2,1-*b*][1,3]benzo[*g*]thiazecin-10-one (24b):** 15 min at 0 °C and 3 h at room temperature; yellow semisolid (80%); $^1$H NMR (400 MHz) $\delta$ 7.50 (d, $J$ = 11.9 Hz, 1H), 7.07 (m, 2H), 6.96 (m, 3H), 6.55 (d, $J$ = 11.9 Hz, 1H), 6.11 (dd, $J$ = 3.3, 1.8 Hz, 1H), 5.88 (t, $J$ = 3.3 Hz, 1H), 3.21 (m, 2H), 3.1−2.9 (m, 2H); $^{13}$C NMR (100 MHz) $\delta$ 167.1, 141.8, 137.1, 135.3, 128.6, 128.5, 127.9, 127.1, 126.5, 123.2, 123.10, 123.07, 112.0, 43.0, 34.9; IR (KBr) 1687, 1617 cm$^{-1}$; MS [*m*/*z* (rel intensity)] 255 ($M^+$, 18), 153 (100).

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**Supporting Information Available:** $^1$H (400 MHz) and $^{13}$C NMR (100 MHz) spectra for **19b**, **22b**, **23b**, and **24b** and $^{13}$C NMR (50 MHz) spectra for **4b**, **5b**, **6a**,**b**, **9b**, and **13b** (14 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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