72939-30-1; **5**, 72939-31-2; **6**, 61899-31-8; **7**, 72939-32-3; **8**, 72939-33-4; **9**, 66393-66-6; **10**, 72939-34-5; **11**, 72939-35-6; 2,3-bis(bromomethyl)naphthalene, 38998-33-3; 1,4-bis(bromomethyl)naphthalene, 58791-49-4; 1,5-bis(bromomethyl)naphthalene, 21646-18-4; 1,3-bis(bromomethyl)naphthalene, 36015-77-7; 1-(chloromethyl)-2-(bromomethyl)naphthalene, 72953-44-7; 1,8-bis(bromomethyl)naphthalene, 2025-95-8; 2,3-dimethylnaphthalene, 581-40-8; dimethyl 1,8-naphthalenedicarboxylate, 10060-33-0; 1,8-bis(hydroxymethyl)naphthalene, 2026-08-6; 1,4-dimethylnaphthalene, 571-58-4; 1,5-dimethylnaphthalene, 571-61-9; 1,3-dimethylnaphthalene, 575-41-7; 1,2-dimethylnaphthalene, 573-98-8; triethylene glycol, 112-27-6; tetraethylene glycol, 112-60-7; pentaethylene glycol, 4792-15-8.

Notes

Photochemistry of α-Diazo Thioesters: Migratory Aptitude of Sulfur vs. Oxygen in the Photochemical Wolff Rearrangement

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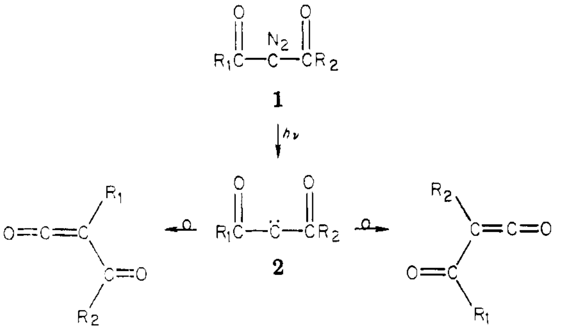
It has been shown that unsymmetrically substituted 2-diazo-1,3-dicarbonyl compounds **1** undergo a competitive rearrangement in which either R_1 or R_2 may migrate with concomitant elimination of nitrogen.[1]



1

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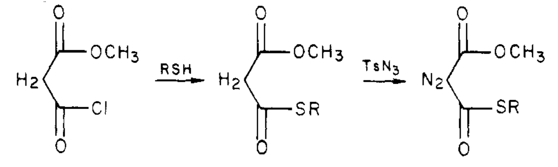
3

4

The relative migration tendencies of various groups where R_1 or R_2 = C, O, or N have been studied,[2] and it has been suggested that sulfur might exhibit an enhanced migratory capacity owing to the greater participative ability of covalent sulfur than that of nitrogen or oxygen.[3] In connection with our work on the synthesis of β-lactams[4a,b] we have investigated the photochemical behavior of a series of diazo compounds of type **1**, in which R_1 and R_2 are oxygen and sulfur, respectively. We have found that these compounds rearrange with remarkable ease and specificity to yield ketenes resulting from the selective migration of sulfur. This result contrasts markedly with analogous rearrangements involving mixed esters, keto esters, and ester amides which lack specificity and proceed in low yields.[3]

Results and Discussion

A series of diazo thioesters (**7a–d**) were readily prepared from (methoxycarbonyl)acetyl chloride (**5**).[7] Thus **5** was



5 **6a–d** **7a–d**

a, R = Me; b, R = Ph; c, R = allyl; d, R = *tert*-butyl

caused to react with the corresponding mercaptan (**a–d**) in anhydrous ether at 0 °C upon addition of pyridine to yield the methyl [[alkyl(and aryl)thio]carbonyl]acetates **6**. Diazo functionalization of **6** with tosyl azide according to known procedures[8] gave the diazo thioesters **7** in good yield.

The diazo thioesters **7a–d** were independently dissolved in wet benzene and irradiated with a 450-W Hanovia lamp equipped with a Pyrex filter. The reactions were monitored by IR and irradiated until the diazo band at 2140 cm^{-1} had completely disappeared. Removal of the benzene and distillation of the resulting residues produced in each case a single isolated product resulting from the selective migration of sulfur. These products **12**, as well as our preferred mechanism for their formation, are shown in Scheme I below. The structures of these photolysis products were confirmed via independent synthesis and comparison of IR and NMR spectra.

It is possible that an intermediate sulfonium ylide **9** may account for the overall selectivity of the reaction. Such an ylide would result from an intramolecular bond formation between the singlet carbene **8** and the electron pair on sulfur. Such carbene–sulfur interactions are precedented,[3] however, not in cases where other heteroatoms might compete with sulfur. The factors controlling the relative migration of various alkoxy or amido radicals are not understood, and the lack of correspondence between theoretical expectations and experimental results has been summarized and commented upon previously.[3a] In the

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(1) H. Meier and K. P. Zeller, *Angew. Chem., Int. Ed. Engl.*, **14**, 32 (1975); "New Synthetic Methods", Vol. 4, Verlag Chemie, Weinheim/Bergstr., Germany, 1979, Chapter 1.

(2) See the second reference of ref 1, section 4.5, and references contained therein.

(3) (a) H. Chaimovich, R. J. Vaughan, and F. H. Westheimer, *J. Am. Chem. Soc.*, **90**, 4088 (1968). (b) J. H. Robson and H. Schecter, *ibid.*, **89**, 7112 (1967). (c) For evidence for the enhanced migratory aptitude of sulfur to a carbene center in related systems, see S. S. Hixson and S. H. Hixson, *J. Org. Chem.*, **37**, 1279 (1972), and references cited therein.

(4) (a) S. K. Boyer, Ph.D. Thesis, Tufts University, 1976; (b) V. Georgian, S. K. Boyer, and B. Edwards, *Heterocycles*, 1003 (1977).

(5) (a) For a review of references, see: W. A. Noyes, Jr., and I. Unger, *Pure Appl. Chem.*, **9**, 461 (1964). Irrespective of disagreement as to quantum yield determinations and secondary reaction mechanisms for the decarbonylation of ketene to ethylene and carbon monoxide, Ross and Kistiakowsky[5b] showed that it is efficient at 313 nm but immeasurably slow at 366 nm. Acetone displays its UV cutoff at 330 nm, thus protecting the ketene derivative, but permitting sufficient absorption by diazo thioester **7a**. (b) W. F. Ross and G. B. Kistiakowsky, *J. Am. Chem. Soc.*, **56**, 1112 (1934).

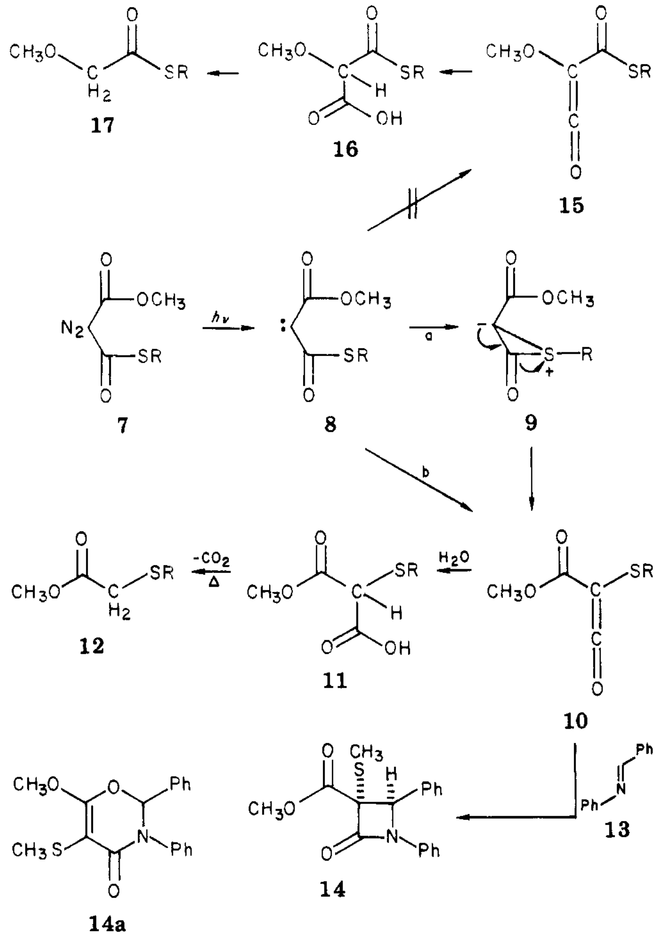
(6) L. G. Drayton and H. W. Thompson, *J. Chem. Soc.*, 1416 (1948).

(7) H. Staudinger and H. Becker, *Chem. Ber.*, **50**, 1023 (1911); W. Koster, Ph.D. Thesis, Tufts University, 1972.

(8) G. Cannic, G. Linstrumelle, S. Julia, et al., *Bull Soc. Chim. Fr.*, 4913 (1968).

0022-3263/80/1945-1686$01.00/0

Scheme I



present work, the striking singular migration of sulfur results in no detectable products which might be formed via an oxirene intermediate.[1] Additionally, in the case of **7c**, attack of the carbene on the sulfur atom must proceed several times faster than addition to the carbon π system of the allyl group. These results may be accounted for by postulating the intercession of sulfonium ylide **9**, with its attendant $d\pi-p\pi$ stabilization, which rearranges to the corresponding ketene **10**. Addition of water to form the α-(methoxycarbonyl) alkyl(or aryl)thioacetic acid **11**, followed by decarboxylation, results in the observed overall rearrangement products **12**.

The intermediate α-carboxy acids **11a–c** could be isolated by careful workup of the reaction mixtures at low temperatures. These compounds were identified by their characteristic IRs (COOH, 3500–3300 cm^{-1}, br) and NMRs (see Experimental Section). Compounds **11a–c** decarboxylated smoothly to yield the observed products **12a–c**.

To examine for the possible rearrangement via oxygen migration to whatever small degree, we also synthesized the anticipated compounds **17a,b** independently, and comparison of their NMR spectra with those of the crude photoproducts revealed no detectable amounts of these compounds. Hence, it may be assumed that in all cases oxygen migration does not compete significantly.

Evidence for the intermediate ketene species **10** was obtained by trapping experiments and by NMR and IR monitoring of the photorearrangement reaction. When the diazo thioester **7a** was irradiated under anhydrous conditions in the presence of a suitable imine acceptor, **13**, a good yield of a single isolated β-lactam, **14**, was obtained.[4b] Interestingly, this ketene addition reaction appears to be stereoselective, with the product's sulfur substituent being cis to the lone β-lactam hydrogen. This was determined by nuclear Overhauser experiments which further helped to confirm the structure of **14** and rule out an alternative methoxyketene **15** adduct. The β-lactam proton at 5.06 ppm showed a 26% enhancement on irradiation of the thiomethyl group. In addition, the ^{13}C NMR of **14** showed two carbonyl carbon atoms at 167 and 162 ppm, and the mass spectrum was consistent with the expected structure **14**, showing m/e 59 ($COOCH_3$), this evidence thus ruling out an alternative isomeric structure **14a** which might have been considered.

Spectral evidence for the generation of ketene intermediate **10** (R = CH_3) was elicited in the following manner. When diazo thioester **7a** was irradiated in anhydrous methylene chloride, the band characteristic of the diazo function at 2140 cm^{-1} had disappeared after 4 h, but there was no evidence of a surviving ketene discernible by IR means. It was reasoned that the ketene could have undergone photolytic decarbonylation as it was generated.[5] Thus when the irradiation of **7a**, now in anhydrous $CDCl_3$, was conducted through a 1-cm acetone filter to shield the ketene species from subsequent photolytic damage, **10** (R = CH_3) revealed itself clearly. After a period of approximately 5 h, the diazo band at 2140 cm^{-1} was replaced by an equally intense and somewhat sharper band at 2120 cm^{-1}.[6] During this time there was a gradual progression in the NMR spectra from that for initial **7a** with singlets at 3.83 ppm (OCH_3) and 2.35 ppm (SCH_3) to that for the final ketene **10** with singlets at 3.72 ppm (OCH_3) and 2.26 ppm (SCH_3). To the solution of ketene thus available was added an equimolar quantity of acceptor **13**, and after a 12-h period at ambient temperature the now familiar β-lactam adduct **14** was obtained.

It is interesting, as noted, that when the irradiation of **7a** was conducted in the presence of benzalaniline (**13**), the diazo decomposition proceeded at a very much slower rate. This can be understood as owing to a spectral filtering by benzalaniline, with its broad and intense absorption extending downward from about 360 nm.

These results show that carbenes generated in malonyl monothioester systems undergo a very rapid and selective Wolff-type rearrangement and provide further information concerning atomic and participative factors in the rearrangement of β substituents to divalent carbon.

Applications of this rearrangement toward the stereoselective synthesis of sulfur-substituted β-lactams are in progress.

Experimental Section

All microanalyses were performed by Spang Laboratories. Melting points were determined on a Thomas-Hoover Unimelt apparatus and are uncorrected. IR spectra were taken on Perkin-Elmer Model 237 and Model 727-B spectrophotometers and were calibrated against the 1601-cm^{-1} band of polystyrene; all IR absorptions reported herein are expressed in cm^{-1}. NMR spectra were determined on Varian A-60A and HA-100 spectrometers. Chemical shifts are expressed in parts per million (δ) downfield from tetramethylsilane. Irradiations were carried out with a Hanovia 450-W medium-pressure mercury lamp equipped with a Pyrex filter.

General Procedure. Synthesis of Methyl [(Methylthio)carbonyl]acetate (6a). To a solution of (methoxycarbonyl)acetyl chloride[7] (3.0 g, 0.022 mol) in 30 mL of anhydrous ether at 0 °C was added methyl mercaptan (1.06 g, 0.022 mol). The cooled reaction mixture was flushed with nitrogen, and to this was added pyridine (1.74 g, 0.022 mol) dropwise. The reaction mixture was stirred overnight and filtered, and the filtrate was washed with 5% $NaHCO_3$ and then with a saturated salt solution. The ether layer was dried over anhydrous sodium sulfate and concentrated in vacuo, affording 2.5 g (80%) of methyl [(methylthio)carbonyl]acetate (**6a**): bp 55–58 °C (0.075 mm); NMR

(CDCl$_3$) 3.83 (s, 3 H, OCH$_3$), 3.60 (s, 2 H, CH$_2$), 2.33 (s, 3 H, SCH$_3$); IR 2950 (CH), 1740 (C=O), 1682 (C=O), 1483, 1310, 1260. Also prepared by this method were the following. Methyl [(phenylthio)carbonyl]acetate (**6b**): 84% yield; bp 108–110 °C (0.1 mm); NMR (CDCl$_3$) 7.38 (s, 5 H, Ar), 3.70 (s, 3 H, OCH$_3$), 3.61 (s, 2 H, CH$_2$); IR (neat) 1740, 1580, 1479, 1010, 715. Methyl [(allylthio)carbonyl]acetate (**6c**): 40% yield; bp 66–67 °C (0.025 mm); NMR (CDCl$_3$) 4.02–4.98 (m, 3 H, vinyl), 3.70 (s, 3 H, OCH$_3$), 3.60 (s, 2 H, CH$_2$), 3.55 (d, 2 H, allyl); IR (neat) 1747 (C=O), 1690 (C=O), 1635 (C=C), 1430, 1320. Methyl [(*tert*-butylthio)carbonyl]acetate (**6d**): ~50% yield; bp 55–57 °C (0.25 mm); NMR (CDCl$_3$) 3.69 (s, 3 H, OCH$_3$), 3.45 (s, 2 H, CH$_2$), 1.48 (s, 9 H, *tert*-butyl).

General Diazofunctionalization Procedure. Synthesis of Methyl α-Diazo-α-[(methylthio)carbonyl]acetate (7a). The general procedure of Julia et al. was used.[8] To a solution of methyl [(methylthio)carbonyl]acetate (**6a**; 10 g, 0.07 mol) and tosyl azide (13.2 g, 0.07 mol) in 250 mL of anhydrous ether was added dropwise at 0 °C triethylamine (6.8 g, 0.07 mol). The reaction was stirred overnight and worked up by cooling to 0 °C and adding 100 mL of pentane. The precipitate was filtered and the process repeated to recover tosylamide, 17.1 g (91%). The filtrate was concentrated in vacuo to yield a crude yellow crystalline product which was recrystallized from cyclohexane to yield **7a**: 9.4 g (77%); mp 53–55 °C; NMR (CDCl$_3$) 3.83 (s, 3 H, OCH$_3$), 2.35 (s, 3 H, SCH$_3$); IR (CHCl$_3$) 2900, 2140 (diazo), 1710 (br, C=O), 1620 (C=N), 1450, 1330, 1130, 955. Anal. Calcd for $C_5H_6N_2O_3S$: C, 34.47; H, 3.47; N, 16.08; S, 18.40. Found: C, 34.41; H, 3.49; N, 16.07; S, 18.33. The following compounds were similarly prepared. **7b**: 70% yield; mp 94–95.5 °C (from cyclohexane); NMR (CDCl$_3$) 7.40 (s, 5 H, Ar), 3.82 (s, 3 H, OCH$_3$); IR (C_6H_6) 2950 (CH, weak), 2145 (diazo), 1720 (C=O), 1625 (C=N), 1439, 1320 (d), 1120, 740. Anal. Calcd for $C_{10}H_8N_2O_3S$: C, 50.84; H, 3.41; N, 11.85; S, 13.57. Found: C, 50.91; H, 3.51; N, 11.84; S, 13.56. **7c**: 63% yield; bp 79–81 °C (0.005 mm); NMR (CDCl$_3$) 6.20–4.90 (m, vinyl), 3.80 (s, 3 H, OCH$_3$), 3.58 (d, 2 H, allyl); IR (neat) 2149 (diazo), 1725 (2 C=O), 1625, 1435, 1325, 1130, 900. Anal. Calcd for $C_7H_8N_2O_3S$: C, 41.99; H, 4.02; N, 13.99; S, 16.01. Found: C, 41.90; H, 4.02; N, 13.68; S, 15.99. **7d**: 96% yield; NMR (CDCl$_3$) 3.78 (s, 3 H, OCH$_3$), 2.50 (s, 9 H, *tert*-butyl); IR (neat) 2960, 2125, (diazo), 1718 (C=O), 1610 (C=N), 1440, 1320, 960.

General Photolysis Procedure. Photolysis of Methyl α-Diazo-α-[(allylthio)carbonyl]acetate (7c). In a typical experiment **7c** (2.0 g, 0.01 mol) was taken up in 800 mL of benzene which had been previously shaken with water. The reaction mixture was irradiated and the course of the reaction followed by the disappearance of the diazo band at 2140 cm^{-1} in the IR. At this concentration the reaction was complete after about 3 h. The benzene was removed under reduced pressure to afford a yellow residue. This residue was taken up in benzene, dried over anhydrous MgSO$_4$, and concentrated again to yield α-(methoxycarbonyl)-α-allylthioacetic acid (**11c**): 1.3 g (~70%); NMR (CDCl$_3$) 10.00 (s, 1 H, COOH), 5.90–4.75 (m, 3 H, vinyl), 4.18 (s, 1 H, CH), 3.58 (s, 3 H, CH$_3$), 3.18 (d, 2 H, allyl); IR (neat) 3300–3100 (br, COOH), 1745 (C=O), 1627 (C=C), 1427, 1399, 1149, 1002, 917. The following compounds were similarly isolated. **11a**: >90% yield; NMR (CDCl$_3$) 10.00 (s, 1 H, COOH), 4.23 (s, 1 H, CH), 3.77 (s, 3 H, OCH$_3$), 2.28 (s, 3 H, SCH$_3$); IR 3400–3300 (br, COOH), 1740 (C=O). **11b**: 85% yield; IR (benzene) 3300–2800 (COOH), 1745–1710 (C=O), 1420, 1270, 1140. **11d** was not isolated. Distillation of the reaction residues resulted in the following observed overall products. **12a**: bp 57–60 °C (14 mm);[9a] NMR (CDCl$_3$) 3.70 (s, 3 H, OCH$_3$), 3.18 (s, 2 H, CH$_2$), 2.20 (s, 3 H, SCH$_3$); IR (neat) 2950 (CH), 1430, 1270, 1130, 1010. **12b**: bp 77–82 °C (0.01 mm);[9b] NMR 7.50–6.90 (m, 5 H, Ar), 3.64 (s, 3 H, OCH$_3$), 3.62 (s, 2 H, CH$_2$); IR 2940, 1740 (C=O), 1590, 1440, 745. **12c**: bp 42–43 °C (0.10 mm); NMR (CDCl$_3$) 6.15–4.80 (m, 3 H, vinyl), 3.68 (s, 3 H, OCH$_3$), 3.20 (d, 2 H, allyl), 3.18 (s, 2 H, CH$_2$); IR (neat) 2950, 1740 (C=O), 1630 (C=C), 1427, 1275, 1150, 1005, 915. **12d**: bp 30–35 °C (0.1 mm);[9c] NMR (CDCl$_3$) 3.69 (s, 3 H, OCH$_3$), 3.27 (s, 2 H, CH$_2$), 1.32 (s, 9 H, *t*-Bu); IR 2960, 1740, 1460, 1435, 1360.

General Procedure. Synthesis of Alternate Possible Photoproduct *S*-Methyl Methoxythioacetate (17a). To a stirred solution of 10.8 g (0.10 mol) of methoxyacetyl chloride and 4.8 g (0.10 mol) of methyl mercaptan in 200 mL of anhydrous ether, under a nitrogen atmosphere, was added dropwise, at 0 °C, 7.5 g (0.10 mol) of pyridine. The reaction mixture was allowed to warm to room temperature and was stirred an additional 2.5 h. The reaction mixture was filtered, and the filtrate was washed with 3% HCl solution (once), 5% NaHCO$_3$ solution (twice), and saturated salt solution (three times). The ether layer was dried (Na$_2$SO$_4$) and the ether removed under reduced pressure. The residue was distilled to yield 11.4 g (94%) of *S*-methyl methoxythioacetate (**17a**): bp 27–30 °C (0.05 mm); IR (neat) 2925 (CH), 1685 (C=O), 1440, 1420, 1190, 1125, 1080, 875; NMR (CDCl$_3$) 4.10 (s, 2 H, CH$_2$), 3.47 (s, 3 H, OCH$_3$), 2.28 (s, 3 H, SCH$_3$). *S*-Phenyl methoxythioacetate (**17b**): 90%; bp 86–89 °C (0.20 mm); IR (neat) 2905, 1695 (C=O), 1480, 1440, 1200, 1130, 1070, 910; NMR (CDCl$_3$) 7.33 (s, 5 H, Ar), 4.10 (s, 2 H, CH$_2$), 3.45 (s, 3 H, OCH$_3$).

(Carbomethoxy)(methylthio)ketene (10, R = CH$_3$). A solution of **7a** (174 mg) in 2 mL of anhydrous CH$_2$Cl$_2$ or CDCl$_3$ (P$_2$O$_5$) was placed in an NMR tube and degassed with argon via a long syringe needle. The tube was outfitted with a septum and a gas release valve and attached to the outside of a standard immersion reactor containing acetone (1-cm path length) and a Pyrex filter sleeve. The unit was submerged in a cooling bath maintained at −5 °C. The course of the irradiation was followed for 5 h by N$_2$ release and by monitoring the disappearance of the IR band at 1620 cm^{-1} (C=N component of the diazo function). The resulting clear, colorless solution was then subjected to instrumental analysis: IR (CH$_2$Cl$_2$) 2950, 2120 ($C\equiv O^+$), 1720 (C=O), 1580, 1430, 1230; NMR (CDCl$_3$) 3.72 (s, OCH$_3$), 2.25 (s, SCH$_3$).

Benzalaniline (**13**, 181 mg) in 1.5 mL of anhydrous solvent was added with agitation to the above solution. The tube was allowed to stand overnight at room temperature. The NMR revealed a spectrum identical with that of β-lactam **14**: IR (CDCl$_3$) 1745 (β-lactam C=O), 1710 (C=O), 1380, 1255; NMR (CDCl$_3$) 7.30–7.00 (m, 10 H, Ar), 5.01 (s, 1 H, β-lactam H), 3.25 (s, 3 H, OCH$_3$), 2.25 (s, 3 H, SCH$_3$).

Alternatively, addition of CH$_3$OH to the photolyzed solution caused the IR band at 2120 cm^{-1} to disappear instantly.

Registry No. 5, 37517-81-0; **6a**, 66301-57-3; **6b**, 72867-13-1; **6c**, 72867-14-2; **6d**, 72867-15-3; **7a**, 66301-56-2; **7b**, 72867-16-4; **7c**, 72867-17-5; **7d**, 72867-18-6; **10** (R = CH$_3$), 72867-19-7; **11a**, 72867-20-0; **11b**, 72867-21-1; **11c**, 72867-22-2; **12a**, 16630-66-3; **12b**, 17277-58-6; **12c**, 72867-23-3; **12d**, 49827-06-7; **13**, 538-51-2; **14**, 66301-58-4; **17a**, 17640-24-3; **17b**, 72867-24-4; methyl mercaptan, 74-93-1; phenyl mercaptan, 108-98-5; 2-propenyl mercaptan, 870-23-5; *tert*-butyl mercaptan, 16812-19-4.

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(9) (a) Reported boiling point of 45–46 °C (11 mm): R. Näf-Müller and B. Willhalm, *Helv. Chim. Acta*, **54**, 1880 (1971). (b) Reported boiling point of 87–90 °C (0.3 mm): R. H. Hiskey and F. I. Carrol, *J. Am. Chem. Soc.*, **83**, 4647 (1961). (c) The compound was mentioned without physical properties. S. Kamata, S. Uylo, N. Haga, and W. Nagata, *Synth. Commun.*, **3**, 265 (1973).

Reactions of Arenesulfenyl Chlorides with Indole. ^{13}C and ^{1}H Nuclear Magnetic Resonance Spectra of 3-(Arylthio)indoles[1]

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Indole is an ambident nucleophile and is known to react with electrophiles both at nitrogen and at C-3.[2] The position of attack depends on the electrophile used as well as the state of the indole, i.e., whether it reacts as the

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[1] (a) This work was supported by the National Science Foundation. (b) Abstracted from the thesis submitted by L.-J.C. in partial fulfillment for the requirements of the M.S. degree, Wayne State University, 1979.

[2] Sundberg, R. S. "The Chemistry of Indoles"; Academic Press: New York, 1970.

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