Chemistry of the sulfur-nitrogen bond. VII. Rearrangement of sulfenimines (S-aryl thiooximes) to β-keto sulfides. Attempted synthesis of benzo[b]thiophenes

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2 AUTHORS:

Franklin A Davis
Temple University
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Torr); ir (neat) 3.23, 3.33, 6.56, 6.76, 8.22, and 9.30 μ; proton nmr (CCl_4) τ 5.96 (HC_2), 6.31 ($HC_{4,7}$), 8.51 ($HC_{5,6}$); *m/e* 101 (parent − *tert*-butyl).

2-*tert*-Butyl-4,7-dimethyl-1,3-dioxacycloheptane. The mixture of isomers distilled at 26° (0.3 Torr). The isomers were separated by glpc (8-ft 10% Apiezon-Chromosorb column) and the cis,cis isomer was the first peak: ir (neat) 3.38, 3.43, 3.50, 6.93, 8.78, 9.05 μ; proton nmr (CCl_4) τ 5.95 (HC_2), 6.21 (HC_7), 8.36 (HC_5, HC_6), 8.83 (CH_3), 9.12 (*tert*-butyl); *m/e* 130 (parent − *tert*-butyl). The cis,trans isomer was the second peak: proton nmr τ 5.94 (HC_2), 6.43 (HC_4), 6.04 (HC_7), 8.36 ($HC_{5,6}$), 8.86, 8.83 (CH_3), 9.12 (*tert*-butyl); *m/e* 130 (parent − *tert*-butyl).

5,5-Dimethyl-1,3-dioxacycloheptane. This compound was prepared in 75% yield from 2,2-dimethyl-1,4-butanediol and paraformaldehyde. The physical properties follow: bp 28° (0.3 Torr); proton nmr τ 5.28 (HC_2), 6.68 (HC_4), 6.31 (HC_7), 8.53 (HC_6), 9.10 (CH_3); *m/e* 130 (parent peak).

2-*tert*-Butyl-5,5-dimethyl-1,3-dioxacycloheptane. This compound was prepared in 57% yield from 2,2-dimethyl-1,4-butanediol and pivaldehyde: bp 22° (0.05 Torr); proton nmr τ 5.83 (HC_2), 6.30, 6.80 (HC_4, J = 11.5 Hz), 8.52 (HC_6), 9.02, 9.16 (CH_3), 9.12 (*tert*-butyl); *m/e* 186 (parent peak).

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References and Notes

(1) St. Michael's College. For the previous paper in this series see M. H. Gianni, J. Saavedra, and J. Savoy, *J. Org. Chem.*, **38**, 3971 (1973).
(2) New York State University at Albany.
(3) D. K. Dalling and D. M. Grant, *J. Amer. Chem. Soc.*, **94**, 5318 (1972).
(4) M. Christl and J. D. Roberts, *J. Org. Chem.*, **37**, 3443 (1972).
(5) A. J. Jones, E. L. Eliel, D. M. Grant, M. C. Knoeber, and W. F. Baily, *J. Amer. Chem. Soc.*, **93**, 4772 (1971).
(6) E. L. Eliel, N. L. Allinger, S. J. Angyal, and G. A. Morrison, "Conformational Analysis," Interscience, New York, N. Y., 1965.
(7) M. Christl, H. J. Reich, and J. D. Roberts, *J. Amer. Chem. Soc.*, **93**, 3462 (1971).
(8) W. E. Willy, G. Binsch, and E L. Eliel, *J. Amer. Chem. Soc.*, **92**, 5394 (1970).
(9) E. L. Eliel and M. C. Knoeber, *J. Amer. Chem. Soc.*, **88**, 5347 (1966).
(10) F. G. Riddell, *Quart. Rev., Chem. Soc.*, 364 (1967).
(11) F. G. Riddell, *J. Chem. Soc. B*, 331 (1970); (b) G. M. Kellie and F. G. Riddell, *ibid.*, 1030 (1971).
(12) H. G. Hertz, *Progr. Nucl. Magn. Resonance Spectrosc.*, **3**, 159 (1963).
(13) We use the Beilstein system of nomenclature (see also IUPAC Bulletin 35, June 1969) for cis–trans isomers with rings with more than two substituents whose stereochemistry must be indicated. The lowest number substituent of specified stereochemistry (equatorial 2-*tert*-butyl) is used as the reference point and given the prefix *r*. We follow Eliel[14] and use cis and trans instead of c and t for the purpose of homogeneity.
(14) E. L. Eliel and F. W. Nader, *J. Amer. Chem. Soc.*, **92**, 584 (1970).
(15) This equivalency is due to conformational averaging, since there are conformations which contain one axial and one equatorial methyl group.
(16) K. C. Branncock and G. Lappin, *J. Org. Chem.*, **21**, 1366 (1956).

Chemistry of the Sulfur–Nitrogen Bond. VII.[1] Rearrangement of Sulfenimines (*S*-Aryl Thiooximes) to β-Keto Sulfides. Attempted Synthesis of Benzo[*b*]thiophenes

Franklin A. Davis* and Edward B. Skibo[2]

Department of Chemistry, Drexel University, Philadelphia, Pennsylvania 19104

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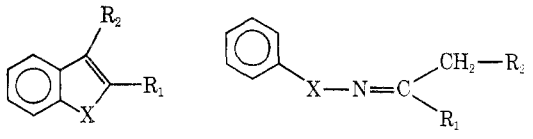
Attempts to rearrange sulfenimines **2** (X = S) to benzo[*b*]thiophenes are described. The major reaction is cleavage of the S–N bond. Sulfenimines in the presence of benzoyl chloride and 1,5-diazobicyclo[4.2.0]non-5-ene (DBN) rearrange to 2-benzamido-1-(arylthio)alkenes **11** and **13**. These compounds are readily hydrolyzed to β-keto sulfides. An intermolecular rearrangement involving a sulfenyl chloride is proposed to account for the formation of these products.

The synthesis of substituted indoles **1** (X = NH) involves a one-step rearrangement of the readily available phenylhydrazone **2** (X = NH). This rearrangement is known as the Fisher indole synthesis and is the primary synthetic route to these compounds.[3] Benzofurans **1** (X = O) have been prepared from the *O*-phenyl oxime ethers **2**



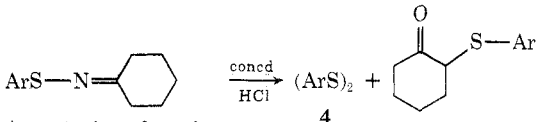
1 **2**

X = NH, O, S

(X = O).[4,5] These rearrangements are effected by heating the hydrazone or oxime ether in the presence of a Lewis acid or concentrated hydrochloric acid.[3-5] The rate-determining step is believed to involve a tautomerism of the hydrazone (or oxime ether) to the ene–hydrazine (ene–ether) followed by cyclization.[3,6]

The synthesis of substituted benzo[*b*]thiophenes **1** (X = S), however, generally involves multistep synthetic routes.[7] It would be convenient, therefore, if similar synthetic routes from the corresponding sulfenimines, **2** (X = S), were available for the synthesis of substituted benzo[*b*]thiophenes. Recently we reported a convenient one-step synthesis of sulfenimines, **2** (X = S), from silver nitrate, aromatic disulfides, ammonia and aldehydes, and ketones.[1,8]

Kaminsky, Shavel, and Meltzer reported an attempt to rearrange cyclohexanone sulfenimines **3a,b,** using concentrated hydrochloric acid, to the corresponding benzo[*b*]-



3a, Ar = 4-nitrophenyl
b, Ar = 2-pyridyl
c, Ar = 2-benzothiazole

4 **5**

Table I
Reaction of Sulfenimines and Related Compounds

Compd	Reaction conditions	Products (yield)
6a	BF_3 ether; reflux	**7a** (~100)
	Acetic acid, reflux	**7a** (45); **8a** (~3)[a]
	HCl–alcohol, reflux	**7a** (90); **8a** (~3)[a]
	Absolute alcohol–NaOH	NR
	DBN benzene, reflux	NR
	Aqueous alcohol–NaOH; CH_3I[b]	**9** (65)
	Aqueous alcohol–NaOH; CH_3I[c]	**7a** (25); **9** (26)
	Benzoyl chloride–DBN–benzene	**11a** (21); **7a** (3)
6d	Benzoyl chloride–DBN–benzene	**11d** (22)
12a	Benzoyl chloride–DBN–benzene	**13a** (26)
12b	Benzoyl chloride–DBN–benzene	**13b** (22)
11a	Water–alcohol, reflux	**8a** (100)[a]
11d	Water–alcohol, reflux	**8d** (95)
13a	Water–alcohol, reflux	**14a** (97)[d]
13b	Water–alcohol, reflux	**14b** (93)

[a] Reference 12. [b] Reaction time 15 hr. [c] Reaction time 7 hr. [d] P. Faller and P. Cagniant, *Bull. Soc. Chim. Fr.*, 30 (1962).

thiophene.[5] The major product isolated was the disulfide, **4**, and a low yield of β-keto sulfide **5**. A mechanism for this rearrangement was not proposed.

Electron-withdrawing groups on the phenyl ring are known to slow the rate of indolization of cyclohexanone phenylhydrazone[9] and in some cases completely inhibit the reaction.[10] The sulfur–nitrogen bond in sulfenamides is cleaved by acid to give disulfides.[11] We felt, therefore, that a more detailed investigation of the use of sulfenimines to prepare benzo[*b*]thiophenes was warranted. In this paper we report the results of that investigation.

Initial attempts to effect the rearrangement of sulfenimines to benzo[*b*]thiophenes were performed with acetone benzenesulfenimine **6a**. This sulfenimine does not contain electron-withdrawing groups and the reaction products are readily identified by glc techniques.

$$\underset{\textbf{6a, X = H}}{XC_6H_4SN{=}C(CH_3)_2} \xrightarrow{[H^+]} \underset{\textbf{7a}}{(XC_6H_4S)_2} + \underset{\textbf{8a}}{XC_6H_4SCH_2\overset{O}{\overset{\|}{C}}CH_3}$$

Treatment of **6a** with zinc chloride, silver nitrate, and mercuric chloride in refluxing ether produced no reaction. Boron trifluoride etherate gave a quantitative yield of disulfide **7a**. Acids such as acetic acid and concentrated hydrochloride primarily gave disulfide **7a** but also some of the β-keto sulfide **8a**[12] was detected.

Bases such as sodium hydroxide in absolute ethanol or 1,5-diazabicyclo[4.3.0]non-5-ene (DBN) in benzene had no effect on the sulfenimine. When **6a** was treated with aqueous ethanolic sodium hydroxide followed by methyl iodide, a 65% yield of methyl phenyl sulfone (**9**) was ob-

$$\textbf{6a} + NaOH/CH_3CH_2OH/H_2O \longrightarrow [C_6H_5SO_2^-] \xrightarrow{CH_3I} \underset{\textbf{9}}{C_6H_5SO_2CH_3}$$

tained. The initial reaction probably involves hydrolysis of the sulfenimine to give the disulfide. Subsequent attack of hydroxide on the disulfide would give the sulfinic acid.[13] Shorter reaction times gave mixtures of disulfide and sulfone. Phenyl disulfide (**7a**), under the reaction conditions, gave a good yield of the sulfone. These results are summarized in Table I.

Acid chlorides are reported to add to the C–N double bond of imines to give addition products.[14] Consequently, if a similar reaction occurs with sulfenimines, it may be possible by treatment of the adduct with base to prepare the required ene–sulfenamide **10**.

Table II
Reaction of Sulfenimines with Benzoyl Chloride and DBN Followed by Hydrolysis

Sulfenimine	Solvent	Products (yield)
6a	Benzene	**8a** (33), **7a** (8)
6b	Benzene	**8b** (34),[a] **7b** (3)
6d	Benzene	**8d** (40)
12a	Benzene	**14a** (32), **7a** (13)
12b	Benzene	**14b** (36–45)
6c + 12b	Benzene	**8a** (19), **8c** (22),[b] **14a** (21), **14c** (23)[c]
6d	Cyclohexene	**8d** (42), **15** (13), **16** (21)

[a] Reference 12. [b] A. Boehringer, E. Boehringer, I. Liebrecht, and J. Liebrecht, British Patent 721,263 (1955); *Chem. Abstr.*, **50**, 4217 (1956). [c] P. Cagniant, P. Faller, and D. Cagniant, *Bull. Soc. Chim. Fr.*, 3055 (1966).

$$ArSN{=}C(CH_3)_2 + RC(O)Cl \longrightarrow ArSN(CH_3)C(O)(CH_3)C(O)R \xrightarrow{base} ArSNC(CH_3){=}CH_2C(O)R$$

10

Treatment of **6a** with benzoyl chloride and DBN in refluxing benzene produced an oil from which 2-benzamido-1-(phenylthio)propene (**11a**) was obtained. A small amount of the disulfide **7a** was also isolated. Sulfenimine **6d** under these conditions gave **11d**, and sulfenimines **12a,b**, prepared from 2-butanone, gave **13a,b**, respectively (Table I).

$$XC_6H_4SN{=}C(CH_3)_2 \xrightarrow[DBN]{C_6H_5C(O)Cl}$$

6a, X = H
b, X = 4CH$_3$
c, X = 4Cl
d, X = 3NO$_2$

$$XC_6H_4S(H)C{=}C(CH_3)NHC(O)C_6H_5 \xrightarrow{H_2O} XC_6H_4SCH_2C(O)CH_3$$

11a, X = H
d, X = 3NO$_2$

8a, X = H
b, X = 4CH$_3$
c, X = 4Cl
d, X = 3NO$_2$

$$XC_6H_4SN{=}CC_2H_5(CH_3) \xrightarrow[DBN]{C_6H_5C(O)Cl} XC_6H_4S(CH_3)C{=}CHNHC(O)C_6H_5 \xrightarrow{H_2O}$$

12a, X = H
b, X = 3NO$_2$

13a, X = H
b, X = 3NO$_2$

$$XC_6H_4SCH(CH_3)C(O)CH_3$$

14a, X = H
b, X = 3NO$_2$
c, X = 4Cl

Enamides **11a,d**, and **13a,b** were quantitatively hydrolyzed to β-keto sulfides **8a,d**, and **14a,b**, respectively (Table I). Since the enamides decomposed in the gas chromatograph, for analytical purposes the reaction mixture was hydrolyzed and the resulting ketones analyzed by gas chromatography. These results are summarized in Table II.

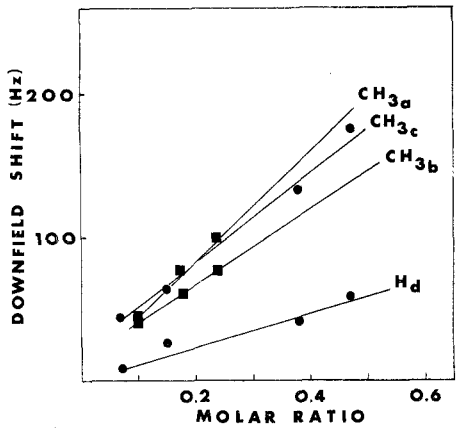


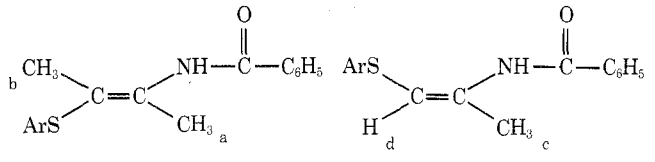
Figure 1. Variation of induced shift with molar ratio Eu(fod)$_3$–substrate for enamide **13b** and **11d**.

Structural proof of the enamides **11a, 11d,** and **13a,b** was based on their elemental analysis and infrared and nmr spectra. The infrared spectra of the enamides showed absorption at 3260–80 cm^{-1} (NH) and 1650–40 cm^{-1} (C=O). Compounds **11a** and **13a** showed strong absorption at 1520 cm^{-1} (amide II band). This region was obscured in **11d** and **13b** as a result of the presence of the nitro group.

The proton nmr spectra of the enamides further supports the proposed structures. The methyl groups in enamides **11a** and **11b** appeared as doublets at δ 2.65 (J = 1.3 Hz). The coupling constant of 1.3 Hz does not permit an unambiguous assignment of the enamides structure to the Z configuration since the 1,3 hydrogen–methyl coupling constant in (E)- and (Z)-2-methyl-2-butenoic acid has been reported to be 1.43 and 1.28 Hz, respectively.[15] Shift reagent experiments with Eu(fod)$_3$ do, however, suggest that **11a** and **11d** have the Z configuration (*vide infra*).

The methyl groups in enamides **13a,b** also appeared as doublets at δ 2.5 and 1.9 with a coupling constant of 1.5 Hz. This coupling constant agrees with that observed for (Z)-2-methyl-2-butenoic acid[15] and suggests that **13a** and **13b** have the E configuration.

Further support for this interpretation is obtained from shift reagent experiments using Eu(fod)$_3$. Assuming that Eu(fod)$_3$ is associated with the lone pair of electrons of the carbonyl[16] group, then a large induced chemical shift is expected for the $CH_{3,a}$ in **13b** and is observed (Figure 1). A similar magnitude for the induced shift for CH_{3b} is anticipated provided **13b** has the E configuration. Figure 1



13b, E Ar = 3-nitrophenyl **11d**, Z

shows that the induced shift for CH_{3b} is nearly identical with that observed for CH_{3a}. If, however, **13b** had the Z configuration it would not be possible for the shift reagent to come into close proximity to CH_{3b} and a much smaller shift would be expected. These results along with the coupling constant support the assignment of E configuration to **13a,b.**

A similar argument may now be used to assign the Z configuration to **11a** and **11b.** As anticipated a large induced shift for CH_{3c} in **11d,** similar to the shifts obtained for CH_{3a} and CH_{3b} in **13b,** was observed. If **11d** were in the E configuration where the proton H_d would be brought into close proximity to the shift reagent, a large induced shift would be expected. Figure 1 shows only a relatively small shift was observed for H_d. These results suggest that **11a** and **11d** have the Z configuration.

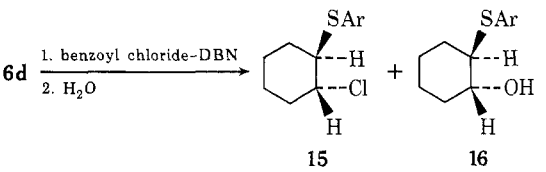
The β-keto sulfides **8a–d** and **14a–c** were identified by comparison of their properties with authentic samples prepared by procedures reported in the literature or synthesized independently.

Mechanism. An attractive mechanism for the rearrangment of sulfenimines to enamides is an intramolecular rearrangment involving the ene–sulfenamide **10.** Such a rearrangment would be analogous to the rearrangement of arenesulfenanilides to o- and p-aminodiphenyl sulfides.[17,18] Recently we have shown that this rearrangment is intramolecular.[18]

D'Amico has reported that, when 2-benzothiazolesulfenamide ($ArSNH_2$) was allowed to react with cyclohexanone and base for 1 week, **5c** was obtained in good yield.[19] If the reaction was stopped after 0.5 hr the sulfenimine **3c** was obtained. An intramolecular rearrangement involving tautomerism of the sulfenimine, **3c,** to the ene–sulfenamide was suggested.

To test for an intramolecular rearrangment under our reaction conditions, crossover experiments were performed. Sulfenimines **6c** and **12a** were refluxed together in benzene with DBN and benzoyl chloride. The reaction mixture was hydrolyzed and analyzed by glc. The four possible β-keto sulfides, **8a, 8c, 14a,** and **14c,** were formed in about equal amounts (Table II). This experiment clearly demonstrates that the rearrangment of sulfenimines to enamides cannot be intramolecular but must follow some intermolecular pathway.

When sulfenimine **6d** was reacted with DBN–benzoyl chloride in cyclohexene followed by hydrolysis, β-keto sulfide **8d** and addition products **15** and **16** were obtained (Table II). Identification of **15** and **16** was based on comparison of their spectral properties with authentic samples.



Ar = 3-nitrophenyl

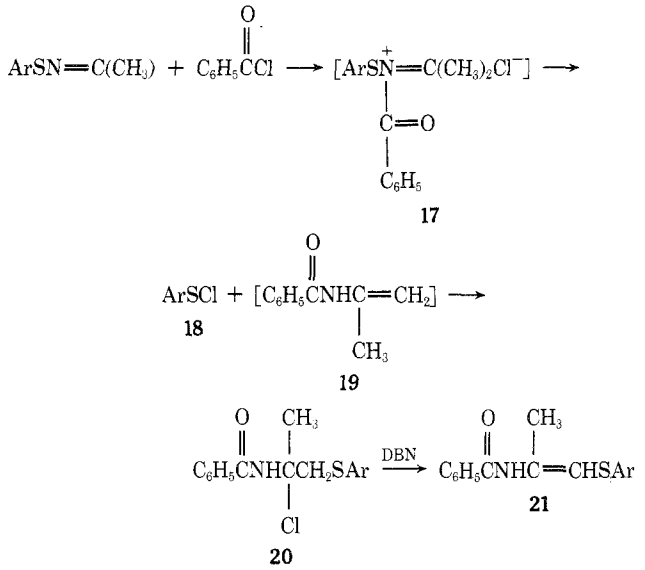
Compound **15** was prepared from 3-nitrobenzenesulfenyl chloride[20] and cyclohexene. Hydrolysis of **15** with ethanol and water gave **16** which was isolated as the phenylurethane. Sulfenyl halides are known to add exclusively trans to alkenes,[21] and anchimeric assistance to hydrolysis by the adjacent sulfur atom[22] would lead to the suggested stereochemistry in **15** and **16.**

A sulfenyl halide is a probable intermediate in the rearrangement of sulfenimines to enamides under these conditions. Consistent with these results is the mechanism proposed in Scheme I.

Benzoyl chloride reacts with the sulfenimines to give adduct **17.** The chloride ion rather than adding across the C–N double bond attacks the more reactive S–N bond to give the sulfenyl chloride, **18,** and enamide, **19.** The S–N bond in sulfenamides is known to be readily attacked by nucleophiles[8,23] and sulfenyl chlorides react with ketones to give β-keto sulfides.[12,24] Addition presumably occurs across the enolized ketone.

Enamides such as **19** have been reported and they decolorize bromine and add hydrogen.[25] Addition of the sulfenyl chloride **18** to **19** would yield **20** and subsequent reaction of the chloride with DBN results in the enamide **21.** In all reactions only one isomer was detected.[26] A sim-

Scheme I



ilar mechanism can be used to explain the rearrangement of sulfenimines **3a,b** to β-keto sulfides **5a,b**.[5]

Since our finding that the rearrangement of sulfenimines to β-keto sulfides was intermolecular and conflicted with the results obtained by D'Amico,[19] we decided to reinvestigate his results. 2-Benzothiazolesulfenamide ($ArSNH_2$) was allowed to react with base and cyclohexanone according to the experimental procedure reported by D'Amico. A good yield of the β-keto sulfide **5c** was obtained. D'Amico's mechanism, however, required the sulfenimine **3c** act as an intermediate in the rearrangement. When **3c** was subjected to the reaction conditions only starting material was obtained; the sulfide, **5c**, was not detected.

Sulfenamides have recently been shown to react with compounds containing activated methylene groups to give mono- and disulfenylated products.[8] These reactions presumably involve attack of the conjugate base of the active methylene compound on the S–N bond of the sulfenamide. 3-Nitrobenzenesulfenamide, for example, reacts with acetylacetone to give 3-(3-nitrophenyl)-2,4-pentanedione.[1] D'Amico's reaction may well be a member of this class of reactions.

The inability to effect the rearrangment of sulfenimines **2** (X = S) to benzo[*b*]thiophenes **1** (X = S) under acid and base conditions most probably reflects the lack of formation of the ene-sulfenamide required for cyclization. The major reaction of sulfenimines with acids and bases is cleavage of the sulfur–nitrogen bond. In this respect, the chemistry of the sulfur–nitrogen bond in sulfenimines parallels the chemistry of the sulfur–nitrogen bond in sulfenamides.[8]

Experimental Section

Sulfenimines **6a, 6b, 6d,** and **12b** were prepared from the corresponding disulfides as previously described.[1] Melting points were measured on a Fisher–Johns apparatus. Proton nmr spectra were measured on a Varian A-60A instrument, and infrared spectra were measured on a Perkin-Elmer 457 spectrometer. Gas chromatographic analyses were obtained on a Perkin-Elmer 900 gas chromatograph using a 6 ft 3% OV-1 or OV-17 on 80–100 mesh Chromosorb W (regular) column. The analyses were performed by comparison of peak areas with standard solutions of the reaction products.

Acetone 4-Tolylsulfenimine (6b). Sulfenimine **6b** was prepared as previously described[1] from 5.0 g (0.02 mol) of *p*-tolyl disulfide to give after crystallization from pentane–ether 2.4 g (65%) of white needles: mp 41–2°; nmr ($CDCl_3$) δ 2.1 (d, J = 4 Hz, 6 H, CH_3), 2.3 (s, 3 H, CH_3), and 7.3 (q, 4 H).

Anal. Calcd for $C_{10}H_{13}NS$: C, 67.04; H, 7.26. Found: C, 66.85; H, 6.94.

2-Butanone Benzenesulfenimine (12a). Sulfenimine **12a** was prepared from 5.0 g (0.023 mol) of phenyl disulfide as previously described[1] to give, after washing at 0° with a 5% HCl solution saturated with Na_2SO_4, an oil which was distilled giving 3.5 g (88%) of a colorless oil: bp 79–81° (0.04 mm); ir (thin film) 1615 cm^{-1} (C=N); nmr ($CDCl_3$), sample contains both the *E* and *Z* forms,[1] δ 1.1 (q, 3 H), 2.0 (d, 3 H), 2.2 (q, 2 H), 7.4 (m, 4 H); mass spectrum *m/e* (rel intensity), 179 (46) M, 109 (100) M-C_4H_8N. A satisfactory elemental analysis could not be obtained. See reference 1.

Reaction of Sulfenimine 6a with Acid and Lewis Acids. Sulfenimine **6a,** 2.0 g (0.012 mol), was allowed to react with 5 ml of boron trifluoride etherate at −78° or refluxed with 10 ml of concentrated HCl or glacial acetic acid for 20 min. Water was added and the reaction mixture extracted with ether (3 × 50 ml) and dried over $MgSO_4$. The solvent was removed and the residue dissolved in methylene chloride and analyzed by gas chromatography.

Reaction of Sulfenimine 6a with Alcoholic Sodium Hydroxide. In a 100-ml three-necked flask equipped with a magnetic stir bar and reflux condenser was placed 2.0 g (0.012 mol) of **6a** in 25 ml of 75% aqueous ethanol containing 0.74 g (0.024 mol) of sodium hydroxide. After the reaction mixture was refluxed for the specified time period (Table I), the solution was cooled, 5 ml of methyl iodide added, and the reaction mixture refluxed for 1 hr. The reaction mixture was diluted with water and extracted with ether (3 × 50 ml). After drying over $MgSO_4$ the ether solvent was removed to give an oil which was crystallized from pentane–ethanol to give 1.2 g (65%) of white plates, mp 88–9° (lit.[27] mp 88°), identified as methyl phenyl sulfone (**9**).

General Procedure for the Rearrangment of Sulfenimines to Enamides with Benzoyl Chloride and DBN. In a 100-ml three-necked flask equipped with magnetic stir bar, reflux condenser with drying tube, and dropping funnel were placed 0.03 mol of the appropriate sulfenimine and 3.7 g (0.03 mol) of DBN (Aldrich) in 30 ml of dry benzene. The reaction mixture was heated to reflux and 4.2 g (0.03 mol) of benzoyl chloride in 20 ml of benzene added rapidly. After refluxing the reaction mixture for 15 hr the solution was cooled to room temperature and washed with water (4 × 20 ml) followed by washing with 20 ml of an ice-cold 2% HCl solution saturated with Na_2SO_4. After drying over $MgSO_4$ the solvent was removed to give the enamide.

2-Benzamido-1-(phenylthio)propene (11a). Recrystallization from ethanol gave 1.7 g (21%) of white crystals: mp 108–109°; ir (KBr) 3260 (NH), 1645 cm^{-1} (C=O); nmr ($CDCl_3$) δ 2.1 (d, J = 1.3 Hz, 3 H, CH_3), 5.4 (d, J = 1.3 Hz, 1 H), 7.5 (m, 10 H).

Anal. Calcd for $C_{16}H_{15}NOS$: C, 71.35; H, 5.61. Found: C, 71.10; H, 5.35.

2-Benzamido-1-(3-nitrophenyl)propene (11d). Crystallization from ethanol gave 2.1 g (22%) of yellow needles: mp 123–124°; ir (KBr) 3260 (NH), 1650 cm^{-1} (C=O); nmr ($CDCl_3$) δ 2.2 (d, J = 1.3 Hz, 3 H, CH_3), 5.4 (d, J = 1.3 Hz, 1 H), 7.4 (m, 9 H).

Anal. Calcd for $C_{16}H_{14}N_2O_3S$: C, 61.13; H, 4.48. Found: C, 61.28; H, 4.46.

2-Benzamido-3-(phenylthio)butene (13a). Crystallization from ethanol gave 2.3 g (26%) of white crystals: mp 125–126°; ir (KBr) 3290 (NH), 1650 cm^{-1} (CO); nmr ($CDCl_2$) δ 1.9 (d, J = 1.5 Hz, 3 H, CH_3), 2.4 (d, J = 1.5 Hz, 3 H, CH_3), 7.3 (m, 10 H).

Anal. Calcd for $C_{17}H_{17}NOS$: C, 72.08; H, 6.0. Found: 71.82; H, 5.72.

2-Benzamido-3-(3-nitrophenylthio)butene (13b). The enamide was sublimed at 150° (2 mm) and crystallized from ethanol to give 2.2 g (22%) of yellow needles: mp 161–162°; ir (KBr) 3280 (NH), 1650 cm^{-1} (C=O); nmr ($CDCl_3$) δ 2.2 (d, J = 1.5 Hz, 3 H, CH_3), 2.5 (d, J = 1.5 Hz, 3 H, CH_3), 7.4 (m, 9 H).

Anal. Calcd for $C_{17}H_{16}N_2O_3S$: C, 62.2; H, 4.87. Found: C, 61.73; H, 4.77.

Hydrolysis of Enamides. In a 100-ml flask equipped with magnetic stir bar and reflux condenser was placed 0.02 mol of the appropriate enamide in 25 ml of 75% aqueous ethanol. After refluxing the reaction mixture for 5 min the solvent was removed under vacuum and the residue dissolved in ether and dried over $MgSO_4$. The solvent was removed and the residue redissolved in methylene chloride and analyzed by glc.

General Procedure for the Hydrolysis of the Sulfenimine, DBN, Benzoyl Chloride Reaction Mixture. The sulfenimine, benzoyl chloride, and DBN were reacted as described above in dry benzene or cyclohexene (Table II). After separating the sol-

vent from the DBN residue the latter was dissolved in water. After extracting the aqueous solution with benzene (3 × 50 ml) the organic solvents were combined and washed with water and the solvent removed under vacuum. The residue was dissolved in 75% aqueous ethanol and refluxed for 5 min, the solvent removed, and the residue redissolved in ether and dried over $MgSO_4$. The solvent was removed and the residue dissolved in methylene chloride and analyzed by glc.

Preparation of β-Keto Sulfides 8d and 14b. 3-Nitrophenyl disulfide, 5.0 g (0.016 mol), was placed in 250 ml of absolute ethanol in a 500 ml three-necked flask equipped with mechanical stirrer, reflux condenser with nitrogen inlet, and dropping funnel. Sodium metal, 0.7 g (0.033 mol), was added and the reaction mixture stirred under N_2 until the sodium had dissolved. The reaction mixture was then heated to reflux and an equivalent amount of 2-chloroacetone (Eastman) or 3-chlorobutanone[28] was added dropwise. The reaction mixture was refluxed for 3 hr, the precipitated salts removed by filtration, and the solvent evaporated. The resulting oil was distilled or crystallized.

2-(3-Nitrophenylthio)acetone (8d). Crystallization from ether–pentane gave 4.5 g (45%) of yellow needles: mp 61–62°; ir (KBr) 1700 cm^{-1} (C=O); nmr ($CDCl_3$) δ 2.3 (s, 3 H, CH_3), 3.8 (s, 2 H, CH_2), 7.2–8.2 (m, 4 H).

Anal. Calcd as the 2,4-DNPH (mp 138–140°) for $C_{15}H_{13}N_5O_6S$: C, 46.04, H, 3.32. Found: C, 47.79; H, 3.27.

3-(3-Nitrophenylthio)-2-butanone (14b). The oil was distilled at 180° (0.05 mm) to give 4.7 g (65%) of a yellow oil: ir (thin film) 1720 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.4 (d, J = 7 Hz, 3 H, CH_3), 2.3 (s, 3 H, CH_3), 3.9 (q, J = 7 Hz, 1 H), 7.9 (m, 4 H).

Anal. Calcd as the 2,4-DNPH (mp 132–133°) for $C_{16}H_{15}N_5O_6S$: C, 47.43, H, 3.70. Found: C, 47.70; H, 3.37.

2-(3-Nitrophenylthio)chlorocyclohexane (15). In a 250-ml three-necked flask equipped with gas inlet, addition funnel, magnetic stir bar, and reflux condenser with drying tube was placed 5.0 g (0.016 mol) of 3-nitrophenyl disulfide in 50 ml of dry methylene chloride. The reaction was cooled to 0° and dry chlorine gas was passed through the solution for 15 min followed by dry nitrogen for 30 min. Anhydrous aluminum chloride, 0.5 g (0.004 mol), was added followed by dropwise addition of 5 ml of cyclohexene in 25 ml of methylene chloride. After refluxing the reaction mixture for 4 hr water was added and the organic layer dried over $MgSO_4$. The solvent was removed and the resulting oil chromatographed on Florisil. Elution with pentane–benzene (1:3) gave 8.0 g (94%) of an oil identified as **15**: nmr ($CDCl_3$) δ 1.2–2.3 (m, 8 H, cyclohexane ring), 3.4 (m, 1 H), 4.0 (m, 1 H), 7.6 (m, 4 H).

Anal. Calcd for $C_{12}H_{14}ClNO_2S$: C, 53.03; H, 5.19. Found: C, 53.13; H, 5.46.

2-(3-Nitrophenylthio)cyclohexanol (16). In a 100-ml flask equipped with a magnetic stir bar and reflux condenser was placed 8.0 g of the crude chloride, **15**, in 75% aqueous ethanol. After refluxing for 1 hr the solvent was removed under vacuum and the residue dissolved in ether and dried over $MgSO_4$. After removal of the solvent the residue was chromatographed on Florisil. Elution with pentane–benzene (1:3) gave 2.0 g (25%) of an oil identified as **15**. Further elution with benzene gave 4.0 g (54%) of an oil: ir (thin film) 3400 cm^{-1} (broad, OH); nmr ($CDCl_3$) δ 1.1–2.3 (m, 8 H), 2.6–3.6 (broad, m, 3 H), 7.7 (m, 4 H).

Anal. Calcd for the phenylurethane (mp 94–95°) for $C_{19}H_{20}N_2O_4S$: C, 61.30; H, 5.37. Found: C, 61.11; H, 5.20.

Reaction of Cyclohexanone 2-Benzothiazolesulfenimine (3c) with Base. Sulfenimine **3c**, 0.1 g (0.0004 mol), in 0.2 ml of 0.2 N sodium hydroxide and 0.5 ml of water in 25 ml of ethanol, was allowed to stand for 1 week at room temperature. The reaction mixture was than diluted with water and extracted with ether (3 × 50 ml). After drying over $MgSO_4$, the solvent was evaporated to give 0.09 g (90%) of **5c**, mp 106° (lit.[19] mp 106–107°).

Shift Reagent Experiments. The enamides, 0.74–1.1 mmol, were dissolved in dry $CDCl_3$ to which was added an appropriate amount of tris(1,1,1,2,2,3,3-heptafluoro-7,7-dimethyl-3,5-octanedionato)europium, Eu(fod)$_3$ (Aldrich). Induced chemical shifts were measured relative to internal TMS.

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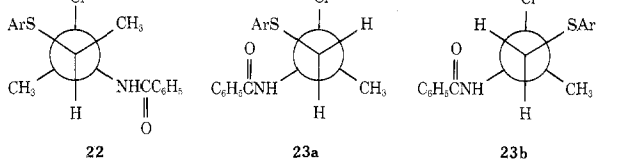
Registry No.—**6b**, 50314-90-4; **8d** (2,4-DNPH), 50314-91-5; **11a**, 50314-92-6; **11d**, 50314-93-7; **12a**, 50314-94-8; **13a**, 50314-95-9; **13b**, 50314-96-0; **14b** (2,4-DNPH), 50314-97-1; **15**, 50314-98-2; **16** (phenylurethane derivative), 50404-54-1; phenyl disulfide, 882-33-7; benzoyl chloride, 35913-09-8; DBN, 3001-72-7; 3-nitrophenyl disulfide, 537-91-7; 2-chloroacetone, 78-95-5; 3-chlorobutanone, 4091-39-8.

References and Notes

(1) Part VI: F. A. Davis, W. A. R. Slegeir, S. Evans, A. Schwartz, D. L. Goff, and R. Plamer, *J. Org. Chem.*, **38**, 2809 (1973).
(2) National Science Foundation Undergraduate Research Participant, 1972.
(3) For reviews on the Fisher indole synthesis, see B. Robinson, *Chem. Rev.*, **63**, 376 (1963); **68**, 227 (1968).
(4) T. Sheradsky, *Tetrahedron Lett.*, 5225 (1966).
(5) D. Kaminsky, J. Shavel, Sr., and R. I. Meltzer, *Tetrahedron Lett.*, 859 (1967).
(6) H. J. Shine, "Aromatic Rearrangements," Vol. 6, Elsevier, New York, N. Y. 1967, p 190.
(7) H. D. Hartough and S. L. Meisel, "Compounds with Condensed Thiophene Rings," Interscience, New York, N. Y., Chapter 2; B. Iddon and R. M. Scrowston, *Advan. Heterocycl. Chem.*, **11**, 178 (1970).
(8) For a recent review of the chemistry of sulfenimines, see F. A. Davis, *Int. J. Sulfur Chem., Part B*, in press.
(9) K. H. Pausacker and C. I. Schubert, *J. Chem. Soc.*, 1814 (1950).
(10) D. Desaty and D. Keglavic, *Croat. Chem. Acta*, **36**, 103 (1964).
(11) L. Zervas, D. Borovas, and E. Gazis, *J. Amer. Chem. Soc.*, **85**, 3660 (1963).
(12) J. A. Barltop and K. J. Morgan, *J. Chem. Soc.*, 4486 (1960).
(13) E. Fromm and J. Wittmann, *Chem. Ber.*, **41**, 2269 (1908); R. Schiller and R. Otto, *ibid.*, **9**, 1636 (1876); see also W. E. Truce and A. M. Murphy, *Chem. Rev.*, **48**, 69 (1950).
(14) H. Bohme and K. Hartke, *Chem. Ber.*, **96**, 600 (1963); H. Bohme, S. Ebel, and K. Hartke, *ibid.*, **98**, 1463 (1965).
(15) R. R. Fraser, *Can. J. Chem.*, **38**, 549 (1960).
(16) M. R. Peterson, Jr., and G. H. Wahl, Jr., *J. Chem. Educ.*, **49**, 790 (1972).
(17) F. A. Davis, E. R. Fretz, and C. J. Horner, *J. Org Chem.*, **38**, 690 (1973).
(18) F. A. Davis, C. J. Horner, E. R. Fretz, and J. F. Stackhouse, *J. Org. Chem.*, **38**, 695 (1973).
(19) J. J. D'Amico, *J. Org. Chem.*, **26**, 3436 (1961).
(20) H. Z. Lecher and F. M. Hardy, *J. Org. Chem.*, **20**, 475 (1955).
(21) N. Kharasch and A. J. Havlik, *J. Amer. Chem. Soc.*, **75**, 374 (1953); D. I. Relyea, *J. Org. Chem.*, **31**, 3577 (1966); W. H. Mueller and P. E. Butler, *J. Amer. Chem. Soc.*, **90**, 2075 (1968).
(22) For leading references see G. M. Underwood, A. K. Chan, T. Green, C. T. Watts, and C. A. Kingsbury, *J. Org. Chem.*, **38**, 2735 (1973).
(23) F. A. Davis, S. Divald, and A. H. Confer, *Chem. Commun.*, 294 (1971).
(24) N. Kharasch in "Organic Sulfur Compounds," Vol. 1, N. Kharasch, Ed., Pergamon Press, New York, N. Y., 1961, Chapter 32.
(25) D. Ben-Ishai and R. Giger, *Tetrahedron Lett.*, 4523 (1965).
(26) The isolation of **13a,b** in the *E* configuration requires the formation of rotamer **22** since a trans elimination is required. Rotamer **22** would be formed by a trans addition of the sulfenyl chloride to the enamide form of **22**. The preference of the *Z* configuration for enamides **11a** and **11d** is, however, not clear. The formation of enamides **11a** and **11d** in the *Z* configuration requires exclusive elimination from rotamer **23a**.



(27) H. Bohme and H. Fisher, *Chem. Ber.*, **75**, 1310 (1942).
(28) E. M. Kosower, W. J. Cole, G. S. Wu, D. E. Cardy, and G. Meisters, *J. Org. Chem.*, **28**, 630 (1963).