**Acknowledgment.** I thank Drs. V. S. Rao, E. Ruediger, and H. Mastalerz for helpful discussions. The analytical research department (Syracuse, NY) is also acknowledged.

**Registry No.** 1 (R = $CH_3$, R′ = allyl), 91616-48-7; 1 (R = Et, R′ = allyl), 104034-79-9; 1 (R = cyclopentyl, R′ = allyl), 104034-80-2; 1 (R = *tert*-butyl, R′ = allyl), 104034-81-3; 1 (R = Et, R′ = $CH_3$), 104034-82-4; 1 (R = Et, R′ = $CH_2CH_2Si(CH_3)_3$), 104034-83-5; 1 (R = Et, R′ = benzyl), 86978-73-6; 1 (R = Et, R′ = *tert*-butyl), 104034-84-6; **2**, 19172-47-5; **3**, 88816-02-8; **4** (R = $CH_3$, R′ = allyl), 104034-71-1; 4 (R = Et, R′ = allyl), 104034-72-2; 4 (R = cyclopentyl, R′ = allyl), 104034-73-3; 4 (R = *tert*-butyl, R′ = allyl), 104034-74-4; 4 (R = Et, R′ = $CH_3$), 104034-75-5; 4 (R = Et, R′ = $(CH_2)_2Si(CH_3)_3$), 104034-76-6; 4 (R = Et, R′ = benzyl), 104034-77-7; 4 (R = Et, R′ = *tert*-butyl), 104034-78-8; **9**, 3469-17-8; **10**, 5393-99-7; **11**, 3893-35-4; **12**, 64273-28-5.

**Supplementary Material Available:** Full characterization data for all new compounds (2 pages). Ordering information is given on any current mashead page.

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# Mesyl Azide: A Superior Reagent for Diazo Transfer

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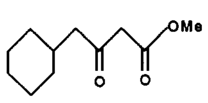
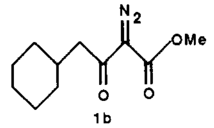
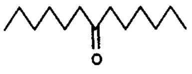
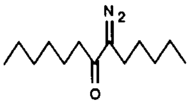
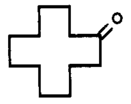
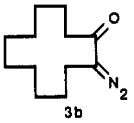
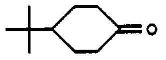
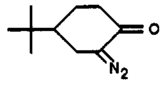
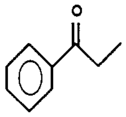
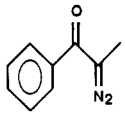
Base-catalyzed transfer of the diazo moiety to a methylene group adjacent to one or more electron-withdrawing groups is a well established and powerful synthetic tool.[2] The most commonly used reagent for diazo transfer has been *p*-toluenesulfonyl (tosyl) azide,[3] although isolated incidences of diazo transfer to β-dicarbonyl systems by other reagents have been reported.[4,5] Difficulties have been reported in the chromatographic separation of the desired product from excesss reagent and *p*-toluenesulfonamide following diazo transfer with tosyl azide.[6] Occasionally, there has been no choice but to use the resultant mixture in the subsequent step.[6b] We have found that methanesulfonyl (mesyl) azide is a generally superior reagent for diazo transfer.

**Table I**

| Entry | Substrate | Product | Yield[a] |
|---|---|---|---|
| 1 | <br>1a | <br>1b | 94% |
| 2 | <br>2a | <br>2b | 71% |
| 3 | <br>3a | <br>3b | 66%[b] |
| 4 | <br>4a | <br>4b | 68% |
| 5 | <br>5a | <br>5b | 71% |

[a] The yields are for pure chromatographed material.

[b] The yield is based on recovered starting material (conversion was 83%).

The advantage of mesyl azide is that it is easily separated from the desired product upon washing the organic phase with 10% aqueous NaOH solution.[7] The use of *p*-carboxybenzenesulfonyl azide has been recommended[5a,6c] because of its solubility in base, but its high cost makes mesyl azide the better choice.

Mesyl azide is easily prepared in high yield from the inexpensive mesyl chloride and sodium azide in absolute MeOH, by the method of Boyer.[8] [Caution: *Although we have never had any trouble with mesyl azide, it is potentially explosive*!] Diazo transfer works well for both β-ketoesters and formyl ketones (Table I). The formyl ketones were not isolated; rather, mesyl azide was added directly to the pot containing the enolate resulting from formylation. This one-pot procedure is limited to symmetrical ketones, and ketones for which one enolate is preferred substantially over the other. Otherwise, a mixture of α-diazo ketones will result.

## Experimental Section

**General Data.** $^1H$ and $^{13}C$ NMR spectra were obtained on a Bruker WM-250 spectrometer as solutions in $CDCl_3$. Chemical shifts are reported in δ units downfield from the internal reference tetramethyl silane. The couplings (*J*) are reported in hertz (Hz). The infrared (IR) spectra were determined on a Nicolet 5DXB FTIR spectrometer as solutions in $CCl_4$ and are reported in reciprocal centimeters ($cm^{-1}$). Mass spectra (MS) were taken at 70 eV on a Du Pont 21-492B mass spectrometer and are reported as mass per unit charge (*m*/*z*), with intensities (as a percentage of the peak of greatest ion current having $m/z \geq 100$) in parentheses. Organic chemicals were purchased from Aldrich Chemical Co. Anhydrous ether was distilled from sodium metal

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(1) Fellow of the Alfred P. Sloan Foundation 1982–1987.

(2) (a) Taber, D. F.; Schuchardt, J. L. *J. Am. Chem. Soc.* **1985**, *107*, 5289. (b) Chen, E. Y. *J. Org. Chem.* **1984**, *49*, 3245. (c) Crow, W. D.; Gosney, I.; Ormiston, R. A. *J. Chem. Soc., Chem. Commun.* **1983**, 643. (d) Adams, J. L.; Metcalf, B. W. *Tetrahedron Lett.* **1984**, *25*, 919. (e) Regitz, M.; Menz, F. *Chem. Ber.* **1968**, *101*, 2622.

(3) Regitz, M. *Angew. Chem., Int. Ed. Engl.* **1967**, *6*, 733.

(4) For previous uses of mesyl azide as a diazo-transfer reagent, see: (a) Lowe, G.; Ransay, M. V. J. *J. Chem. Soc., Perkin Trans. 1* **1973**, 479. (b) Stork, G.; Szajewski, R. P. *J. Am. Chem. Soc.* **1974**, *96*, 5787.

(5) For the use of alternative sulfonyl azides as diazo-transfer reagents, see: (a) *p*-Carboxybenzenesulfonyl azide, *p*-nitrobenzenesulfonyl azide, picryl azide, and *p*-chlorobenzenesulfonyl azide: Hendrickson, J. B.; Wolff, W. A. *J. Org. Chem.* **1968**, *33*, 3610. (b) Trifluoromethanesulfonyl azide: Cavender, C. J.; Shiner, V. J., Jr. *J. Org. Chem.* **1972**, *37*, 3567. (c) 2-Azido-3-ethylbenzenethiazolium tetrafluoroborate and 1-ethyl-2-azidopyridinium tetrafluoroborate: Balli, H.; Low, R.; Muller, V.; Rempfler, H.; Sezen-Gezgin, G. *Helv. Chim. Acta* **1978**, *61*, 97. (d) (Azidochloromethylene)dimethylammonium chloride: Kokel, B.; Viehe, H. G. *Angew. Chem.* **1980**, *92*, 754. (e) Naphthalene-2-sulfonyl azide and *p*-(*n*-dodecyl)benzenesulfonyl azide: Hazen, G. G.; Weinstock, L. M.; Connell, R.; Bollinger, F. W. *Synth. Commun.* **1981**, *11* 947. (f) Trisyl azide: Lombardo, L.; Mander, L. N. *Synthesis* **1980**, 368. (g) Diphenyl phosphorazindaze: Mori, S.; Sakai, I.; Aoyama, T.; Shioini, T. *Chem. Pharm. Bull* **1982**, *30*, 3380. (h) *p*-Nitrophenyl azide: Herbranson, D. E.; Hawley, M. D. *J. Electroanal. Chem.* **1983**, *144*, 423.

(6) (a) Regitz, M. *Org. Synth.* **1971**, *51*, 86. (b) Hudlicky, T.; Govindan, S. V.; Frazier, J. O. *J. Org. Chem.* **1985**, *50* 4166. (c) Doyle, M. P.; Dorow, R. L.; Terpstra, J. W.; Rodenhouse, R. A. *J. Org. Chem.* **1985**, *50*, 1663.

(7) It should be noted that just washing the organic phase with water[4a] did not remove all the mesyl impurity.

(8) Boyer, J. H.; Mack, C. H.; Goebel, W.; Morgan, L. R., Jr. *J. Org. Chem.* **1959**, *23*, 1051.

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and benzophenone immediately before use. The "extracting solvent" used was a mixture of recovered organic solvents, including methylene chloride, ethyl acetate, and petroleum ether. The solvent mixtures used for chromatography are volume/volume mixtures. $R_f$ values indicated refer to thin-layer chromatography (TLC) on Analtech (2.5 × 10 cm, 250 μm) analytical plates coated with silica gel GF. Column chromatography was carried out with TLC-mesh silica gel, following the procedure we have described.[9]

**Preparation of 1b.** A flame-dried, one-necked flask equipped with an $N_2$ inlet and septum was charged with **1a** (523 mg, 2.6 mmol), methanesulfonyl azide [*Caution*: *Although we have never had any trouble with mesyl azide, it is potentially explosive*!] (351 mg, 2.9 mmol, 1.1 equiv), and $CH_3CN$ (5 mL). To this solution was added triethylamine (0.74 mL, 5.3 mmol, 2 equiv). The reaction was followed by TLC. Typically, it was complete in 3 h. The mixture was diluted with 10% aqueous NaOH and extracted with extraction solvent (3 × 20 mL). The combined organic extracts were dried over $MgSO_4$ and concentrated in vacuo. The residual oil was chromatographed on 20 g of silica gel with 2.5% EtOAc/petroleum ether. The first 100 mL was discarded. The next 250 mL was concentrated in vacuo to give α-diazo β-ketoester **1b** as a clear yellow oil: 549 mg (94%); $R_f$ (20% EtOAc/hexane) 0.54; $^1H$ NMR δ 0.9–1.9 (m, 11 H), 2.74 (d, $J$ = 6.8 Hz, 2 H), 3.84 (s, 3 H); $^{13}C$ NMR: 26.1 (t, 2), 26.2 (t), 33.1 (t, 2), 34.6 (d), 47.3 (t), 52.1 (q), 76.05 (s), 161.8 (s), 192.4 (s); IR 2930, 2850, 2140, 1730, 1660, 1560, 1455, 1440, 1315, 1200, 1020, 910 cm$^{-1}$; MS, $m/z$ (relative intensity) 143 (23), 142 (100), 125 (11), 101 (21); exact mass calcd for $C_{11}H_{16}N_2O_3$ 224.116, obsd 224.116.

**Preparation of 2b**: A flame-dried, two-necked, 25-mL round-bottomed flask equipped with a septum and nitrogen purge was flushed with $N_2$ and charged with 144 mg (3.03 mmol) of 50% sodium hydride dispersion in mineral oil, one drop of absolute ethanol, and 2 mL of anhydrous ether. This mixture, while magnetically stirred, was cooled in an ice bath. Then 200 mg (1.01 mmol) of dihexyl ketone and 222 mg (3.01 mmol) of ethyl formate in an additional 2 mL of ether were added dropwise. This reaction was stirred for 3 h in the ice/water bath and then overnight at room temperature. Mesyl azide (363 mg, 3.03 mmol) in 5 mL of ether was then added, and stirring was continued for an additional 2 h. The reaction was quenched with 1 mL of water. The organic layer was washed with 30 mL of 10% aqueous NaOH solution, and the aqueous layer was back extracted with three 30-mL portions of extraction solvent. The combined organic layers were dried over anhydrous $MgSO_4$ and concentrated in vacuo. The residue was chromatographed on 20 g of silica gel with 1% EtOAc/petroleum ether. The first 120 mL was discarded. The next 120 mL was concentrated in vacuo to give 160 mg (0.714 mmol, 71%) of **2b** as a yellow oil: $R_f$ (10% EtOAc/hexane) 0.51; $^1H$ NMR δ 0.88 (s, 6 H), 1.29 (bs, 10 H), 1.47 (m, 2 H), 1.62 (m, 2 H), 2.34 (t, $J$ = 7 Hz, 2 H), 2.43 (t, $J$ = 7 Hz, 2 H); $^{13}C$ NMR δ 14.0 (q, 2), 22.4 (t, 2), 22.5 (t), 24.9 (t), 26.7 (t), 28.9 (t), 31.0 (t), 31.6 (t), 38.1 (t), 66.5 (s), 194.6 (s); IR 2959, 2931, 2860, 2064, 1643 cm$^{-1}$; MS, $m/z$ (relative intensity) 196 (27), 167 (50), 126 (60), 125 (31), 113 (100), 112 (55), 111 (95); methane chemical ionization exact mass calculated for $C_{13}H_{25}N_2O$ 225.1966, obsd 225.196.

**Preparation of 3b**: $R_f$ (20% EtOAc/hexane) 0.50; $^1H$ NMR δ 1.20–1.85 (m, 16 H) 2.0–2.15 (m, 1 H), 2.15–2.30 (m, 1 H), 2.70–2.90 (m, 2 H); $^{13}C$ NMR δ 22.6 (t), 23.4 (t), 23.6 (t, 2), 23.9 (t), 24.0 (t), 25.0 (t), 25.3 (t, 2), 38.6 (t), 65.7 (s), 196.3 (s); IR 2934, 2064, 1640, 1341 cm$^{-1}$; MS $m/z$ (relative intensity) 180 (39), 137 (30, 123 (48), 112 (30), 111 (48), 110 (42), 109 (100). Methane chemical ionization exact mass calculated for $C_{12}H_{21}N_2O$: 209.1653, obsd 209.164.

**Preparation of 4b**: $R_f$ (20% EtOAc/hexane) 0.25; $^1H$ NMR δ 0.96 (s, 9 H), 1.30–1.55 (m, 2 H), 1.90–2.05 (m, 1 H), 2.25 (dt, $J$ = 5, 7 Hz, 1 H), 2.35–2.75 (m, 3 H); $^{13}C$ NMR δ 23.4 δ (t), 23.8 (t), 27.2 (q, 2), 32.7 (s), 37.8 (t), 44.5 (d), 65.8 (s), 194.4 (s); IR 2965, 2084, 1635, 1337, 1227 cm$^{-1}$; MS, $m/z$ (relative intensity) 152(82), 125(73), 115 (83), 109 (100); methane chemical ionization exact mass calculated for $C_{10}H_{17}N_2O$ 181.134, obsd 181.134.

**Preparation of 5b**: $R_f$ (20% EtOAc/hexane) 0.37; $^1H$ NMR δ 2.10 (s, 3 H), 7.30–7.70 (m, 5 H); $^{13}C$ NMR δ 9.6 (q), 62.8 (s), 127.3 (d, 2), 128.6 (d, 2), 131.4 (d,), 137.8 (s), 190.1 (s); IR 2070, 1628, 1341 cm$^{-1}$; MS, $m/z$ (relative intensity) 132 (16), 106 (17), 105 (100), 104 (38), 103 (25); methane chemical ionization exact mass calculated for $C_9H_9N_2O$ 161.0714, obsd 161.075.

**Acknowledgment.** We thank the National Science Foundation (CHE 8306692) and the National Institutes of Health (GM 32027) for support of this work. D.F.T. thanks ICI Americas for an unrestricted research grant.

**Registry No.** **1a**, 51414-42-7; **1b**, 104156-32-3; **2a**, 462-18-0; **2b**, 104156-33-4; **3a**, 830-13-7; **3b**, 14078-83-2; **4a**, 98-53-3; **4b**, 104156-34-5; **5a**, 93-55-0; **5b**, 14088-57-4; $MeSO_2N_3$, 1516-70-7.

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[9] Taber, D. F. *J. Org. Chem.* **1982**, *47*, 1351.

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# The Iodide Reduction of Sulfilimines. Secondary Deuterium Isotope Effects on Sulfurane Formation

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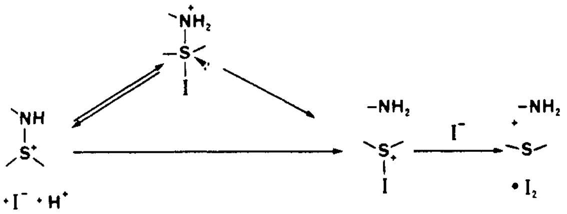
*Received March 4, 1985*

## Introduction

Sulfilimmonium cations are readily reduced by iodide anion in dilute acid solution to give iodine, the amine, and the corresponding sulfide.[1-6] The mechanism of the reaction is suggested to involve addition of iodide anion to the tricoordinate sulfur to give a tetracoordinate sulfurane intermediate.[2,4,6] Protonation of this intermediate followed by cleavage of the sulfur–nitrogen bond gives the free amine and an iodosulfonium ion which is rapidly reduced by a second mole of iodide to give the observed products (eq 1).



(1)

Addition–elimination reactions such as these offer a variety of mechanistic possibilities in which different steps may be rate-limiting, depending on intermediate lifetimes, proton transfer rates, etc.[7] In addition–elimination reactions occurring at carbonyl carbons, β-deuterium isotope effects have proven to be useful in both diagnosing the rate-limiting step and in understanding the subtleties of transition state structure.[8] In order to explore the utility of secondary isotope effects in reactions at tricoordinate sulfur we have examined the rates of the proton-catalyzed iodide reduction of $N$-substituted-$S,S$-di(methyl-$d_3$)-

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