1090, 930, 860, 800, 740, 720 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 9.04 (s br, 1 H), 7.60–7.59 (d, 1 H), 7.43–7.42 (d, 1 H), 3.77 (t, 4 H), 3.11 (t, 3 H). Anal. Calcd for $C_{10}H_{11}Cl_2NO_4S$: C, 38.47; H, 3.55; N, 4.49. Found: C, 38.31; H, 3.63; N, 4.15. Reaction of the polymer **4**, n = 3, under the same conditions gave only a trace spot when a TLC of the product was compared with the spot of authentic **8** from **1** and morpholine.

Competition of the Hydroxy Sulfonyl Chloride 11 and the *O*-Methyl Derivative 15a for Aniline. Aniline (35 mg, 0.38 mmol) and Et_3N (40 mg, 0.40 mmol) in 5 mL of dioxane was added dropwise (10 min) to the solution of sulfonyl chloride **11** (100 mg, 0.38 mmol) and sulfonyl chloride **15a** (110 mg, 0.40 mmol) in 10 mL of dioxane. The solution was stirred for 1 h at 25 °C. The composition of the mixture (eq 2) was determined by ^{1}H NMR analysis. The authentic sulfonanilides **24** and **25** were prepared from aniline with chlorides **11** and **15a**; **24** had a ^{1}H NMR ($CDCl_3$) of δ 7.51–7.48 (m, 2 H), 7.29 (t, 2 H) 7.20 (t, 1 H), 7.10–7.18 (d, 2 H), and **25** had a ^{1}H NMR of δ 7.63–7.62 (d, 1 H), 7.52–7.51 (d, 1 H), 7.23 (t, 2 H), 7.15–7.13 (d, 1 H), 7.10–7.07 (d, 2 H), 4.13 (s, 3 H). The percent of **24** (53%), **25** (16%), and **15a** (31%) was calculated from the ratio of the integrals for the arene hydrogens of a given chlorine-substituted nucleus to the total of all such arene hydrogens: For example, percent of **15a** = [integral of δ 7.88–7.87 + 7.74–7.73 (for **15a**)]100/[integral of δ 7.51–7.48 (for **24**) + integral of 7.63–7.62 + 7.52–7.51 (for **25**) + integral of 7.88–7.87 + 7.74–7.73 (for **15a**)].

Bis[2-(methoxysulfinyl)-4,6-dichlorophenyl] 2,2′-Dithiodiacetate (28). Methyl 3,5-dichloro-2-hydroxybenzenesulfinate (**27**, 0.20 g, 0.83 mmol) and pyridine (0.13 g, 1.64 mmol) were dissolved in CH_2Cl_2 (30 mL), and 2,2′-dithiodiacetyl dichloride[4] (0.09 g, 0.41 mmol) in CH_2Cl_2 (10 mL) was added dropwise at 0 °C. The solution was stirred 15 min more and then was washed with H_2O (50 mL × 3) and dried. After removal of solvent, TLC of the yellow gum showed three spots. This product was purified by preparative TLC (2:98 EtOAc/CH_2Cl_2). The band with R_f 0.50 gave a colorless liquid, which crystallized in EtOAc at 0 °C during 24 h; yield of white **28**, 0.14 g (54%): mp 125–130 °C; IR 3100, 3025, 2975, 1760 s, 1575, 1440 s, 1240, 1220, 1120, 1100 s, 950 s, 880, 840, 790, 680 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 7.76–7.75 (d, 1 H), 7.66–7.65 (d, 1 H), 3.95 (m, 2 H), 3.42 (s, 3 H); ^{13}C NMR ($CDCl_3$) δ 165.99, 143.23, 139.05, 133.72, 133.36, 129.62, 125.49, 49.52, 40.76. Anal. Calcd for $C_{18}H_{14}Cl_4O_8S_4$: C, 34.40; H, 2.25; S, 20.41. Found: C, 34.51; H, 2.23; S, 20.60.

Bis[2-(methoxysulfinyl)ethyl] 2,2′-Dithiobisbenzoate (31). 2,2′-Dithiobisbenzoyl chloride (**30**, 0.83 g, 2.42 mmol)[25] and methyl 2-hydroxyethanesulfinate[4] (0.60 g, 4.83 mmol) were dissolved in benzene (40 mL) and cooled at 0 °C. A solution of Et_3N (0.50 g, 4.94 mmol) in benzene (10 mL) was added dropwise. The solution was stirred for 30 min at 0 °C and was then washed with cold brine (50 mL × 5) and dried. Benzene was removed to give a sticky yellow liquid. TLC showed one major spot and four trace spots. The crude product was purified by column chromatography with 1:4 EtOAc/CH_2Cl_2 as eluant. The fraction with R_f 0.50 gave a pale yellow oil, which crystallized with 10% hexane in EtOAc at 0 °C for 24 h; yield of white **31**, 0.80 g (64%): mp 96–98 °C; IR 2960, 1700 s, 1600, 1570, 1460, 1440, 1380, 1260 s br, 1140, 1120 s, 1060, 1040, 960, 740, 680 cm^{-1}; ^{1}H NMR ($CDCl_3$) 8.08–8.04 (d, 2 H), 7.76–7.74 (d, 2 H), 7.44 (t, 2 H), 7.26 (t, 2 H), 4.85–4.70 (m, 4 H), 3.85 (s, 6 H), 3.33–3.12 (m, 4 H); ^{13}C NMR ($CDCl_3$) δ 165.52, 140.23, 133.25, 131.44, 126.34, 125.59, 125.47, 58.11, 55.86, 54.75. Anal. Calcd for $C_{20}H_{22}O_8S_4$: C, 46.31; H, 4.28; S, 24.73. Found: C, 46.66; H, 4.47; S, 24.24.

Bis[4-(methoxysulfinyl)phenyl] 2,2′-Dithiodiacetate (36). Methyl *p*-hydroxybenzenesulfinate (**35**; 0.30 g, 1.74 mmol) and 2,2′-dithiodiacetyl dichloride (0.21 g, 0.96 mmol)[4] were dissolved in benzene (20 mL) under Ar and cooled at 0 °C. A solution of pyridine (0.14 g, 1.77 mmol) in benzene (5 mL) was added dropwise to the above solution. The solution then was stirred for 15 min at 0 °C, washed with H_2O (50 mL × 2), and dried. After removal of benzene, TLC of the gum showed a complex mixture, which was purified by preparative TLC (1:9 EtOAc/CH_2Cl_2). Two major fractions were collected: Fraction 1 (R_f 0.57) was 8 mg of yellow liquid [3% calcd as methyl 4-(methoxysulfinyl)phenyl 2,2′-dithiodiacetate]: ^{1}H NMR ($CDCl_3$) δ 7.77–7.74 (d, 2 H), 7.37–7.34 (d, 2 H), 3.84 (s, 2 H), 3.76 (s, 3 H), 3.63 (s, 2 H), 3.50 (s, 3 H). Fraction 2 (R_f 0.42) was 0.06 g (14%) of **36** as a yellow gum: IR (neat) 3000, 2950, 1750 s br, 1595 s, 1480, 1400, 1380, 1240, 1200, 1160, 1120–1100 s br, 1040, 1010, 960 s, 920, 850, 670 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 7.75–7.72 (d, 4 H), 7.34–7.31 (d, 4 H), 3.87 (s, 4 H), 3.51 (s, 6 H); ^{13}C NMR ($CDCl_3$) δ 167.47, 153.37, 141.83, 127.10, 122.28, 49.95, 41.45. Anal. Calcd for $C_{18}H_{18}O_8S_4$ (**36**): C, 44.07; H, 3.70; S, 26.14. Found: C, 43.99; H, 3.75; S, 26.06.

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A General Method for the Reductive Carbamation and Sulfonamidation of Aldehydes

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The reductive amination of aldehydes and ketones is a very important method for the synthesis and homologation of amines.[1] The success of this methodology is based on the facile reaction of amines and ammonia with carbonyl compounds to form imines or iminium salts, which in turn are readily reduced by a variety of reagents. The corresponding transformation of amides and related compounds is much rarer and has found relatively little synthetic use to date.[2] The difficulty with effecting "reductive amidations" is due to the low nucleophilicity of amido compounds which inhibits imine formation. Moreover, imines bearing electron-withdrawing groups on nitrogen tend to be unstable and usually tautomerize or oligomerize.[3]

We recently described methodology which involves formation of *N*-sulfonylimines from aldehydes and *N*-sulfinylsulfonamides (Kresze reaction[4]) and trapping in situ of these electrophilic species by alkenes,[5a] 1,3-dienes,[5b] and organometallic reagents.[5c] In this paper is described an extension of these methodological studies which provides a convenient, general procedure for reductive carbamation and sulfonamidation of aldehydes.

If one treats an aldehyde **1** with a mixture of *N*-sulfinyl-*p*-toluenesulfonamide[6] and triethylsilane in benzene at 5 °C using boron trifluoride etherate as catalyst, good yields of reductive sulfonamidation products **3** are formed (Scheme I). This transformation presumably occurs via a Lewis acid complexed *N*-sulfonyliminium intermediate **2**.[4,5] The reductive sulfonamidation works well

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Scheme I

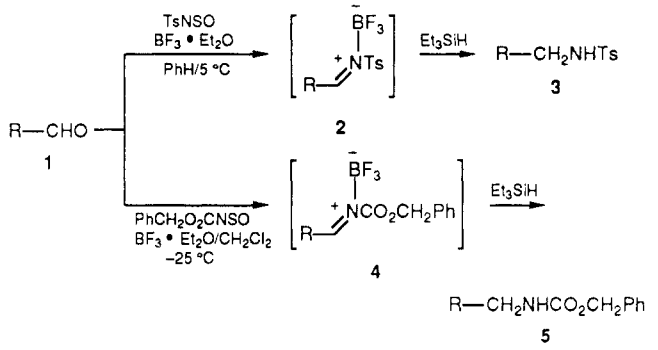
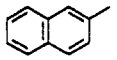
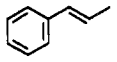


Table I. Reductive Carbamation and Sulfonamidation of Aldehydes

R in aldehyde 1	isolated yields, %	
	sulfonamide 3	carbamate 5
$MeCH_2$	55	73
$(Me)_2CH$	69	67
$Me(CH_2)_5$	69	64
	85	54[a]
	80	84[b]
	60	71
$PhCH_2$	56	65

[a] Reaction conducted at 0 °C. [b] Reaction conducted at room temperature.

with aliphatic, conjugated, and aromatic aldehydes as can be seen from Table I.

Reductive carbamation of aldehydes 1 can be effected in a similar procedure utilizing *N*-sulfinylbenzyl carbamate,[7] affording *O*-benzyl carbamates **5** (Scheme I). Once again, a variety of aldehydes participate in this process as shown in the table. It should be noted that aromatic and conjugated aldehydes are slower to form the *N*-acylimino species **4** than saturated aldehydes via the Kresze reaction, and somewhat higher reaction temperatures were required.

We also investigated the reductive amidation of aldehydes with *N*-sulfinylbenzamide[8] (eq 1). However, in this case yields were significantly lower than in the carbamation and sulfonamidation reactions, perhaps due to the rather slow conformation of *N*-benzoylimines from the *N*-sulfinyl compound.[4]

$$\text{R—CHO} \xrightarrow[\text{30–50\%}]{\substack{\text{PhCONSO}\\ \text{BF}_3\cdot\text{Et}_2\text{O}/\text{CH}_2\text{Cl}_2\\ \text{Et}_3\text{SiH}/0\ ^\circ\text{C}}} \text{R—CH}_2\text{NHCOPh} \quad (1)$$

(R = alkyl)

The procedure described here provides a simple *one-pot* conversion of aldehydes to N-protected primary amines. It avoids the problem of overalkylation often seen in reductive aminations of aldehydes with ammonia or its salts. One drawback of our procedure is that it does not work with simple ketones.[9] We are continuing to explore the chemistry of iminium compounds such as **2** and **4**.

Experimental Section

General Experimental Procedure. To an oven-dried two-necked 25-mL flask fitted with a syringe cap and a nitrogen inlet was added *N*-sulfinylbenzylcarbamate (0.3 mmol, 64 mg) and 5 mL of CH_2Cl_2. After cooling the reaction mixture to −25 °C, the aldehyde (0.13 mmol), triethylsilane (0.18 mmol, 0.029 mL), and $BF_3\cdot Et_2O$ (0.19 mmol, 0.024 mL) were added sequentially via syringe. The reaction mixture was stirred for 15 h at −25 °C, diluted with 10 mL of saturated $NaHCO_3$ solution, and extracted with 30 mL of CH_2Cl_2. The organic layer was washed with 20 mL of H_2O, dried over $MgSO_4$, and concentrated in vacuo. The product was purified by flash chromatography on silica gel (7/3 hexanes/ethyl acetate). Isolated product yields are shown in the table.

The reductive sulfonamidations using *N*-sulfinyltoluenesulfonamide were conducted as described above but in benzene at 5 °C. Product yields are given in the table.

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Registry No. 1 (R = $MeCH_2$), 123-38-6; 1 (R = *i*-Pr), 78-84-2; 1 (R = $Me(CH_2)_5$), 111-71-7; 1 (R = naphthyl), 66-99-9; 1 (R = PhCH=CH), 14371-10-9; 1 (R = 1-(3-cyclohexenyl)), 100-50-5; 1 (R = $PhCH_2$), 122-78-1; 3 (R = $MeCH_2$), 1133-12-6; 3 (R = *i*-Pr), 23705-38-6; 3 (R = $Me(CH_2)_5$), 124920-13-4; 3 (R = naphthyl), 125640-81-5; 3 (R = PhCH=CH), 32121-04-3; 3 (R = 1-(3-cyclohexenyl)), 125640-82-6; 3 (R = $PhCH_2$), 5450-75-9; 5 (R = $MeCH_2$), 65095-17-2; 5 (R = *i*-Pr), 125640-83-7; 5 (R = $Me(CH_2)_5$), 125640-84-8; 5 (R = naphthyl), 125640-85-9; 5 (R = PhCH=CH), 125640-86-0; 5 (R = 1-(3-cyclohexenyl)), 125640-87-1; 5 (R = $PhCH_2$), 70867-38-8; TsNSO, 4104-47-6; $PhCH_2OCONSO$, 86120-34-5; Et_3Si, 617-86-7; PhCONSO, 20043-21-4.

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