125540-71-8; **11**, 125540-59-2; (*E*)-**11**, 125540-72-9; (*Z*)-**11**, 125540-73-0; (*E*)-**12**, 67615-58-1; (*Z*)-**12**, 67615-57-0; (*E*)-**13**, 125540-60-5; (*Z*)-**13**, 125540-74-1; (*E*)-**14**, 64235-56-9; (*Z*)-**14**, 125540-75-2; **15**, 125540-61-6; (*E*)-**16**, 57558-82-4; (*Z*)-**16**, 57558-65-3; (*E*)-**17**, 125540-62-7; (*Z*)-**17**, 125540-76-3; **18**, 125540-63-8; **19**, 83021-58-3; **20**, 125540-77-4; $Ni(COD)_2$, 1295-35-8; $TMSC{\equiv}C(CH_2)_3CH_3$, 3844-94-8.

Supplementary Material Available: ^1H NMR spectra showing the purity of the products **4**–**6** and **10**–**20** (12 pages). Ordering information is given on any current masthead page.

Sulfinic Acids and Related Compounds. 24. Monothioquinone *S,S*-Dioxides and Their Relation to Convergent Syntheses Involving Hydroxyarenesulfonyl Chlorides[1,2]

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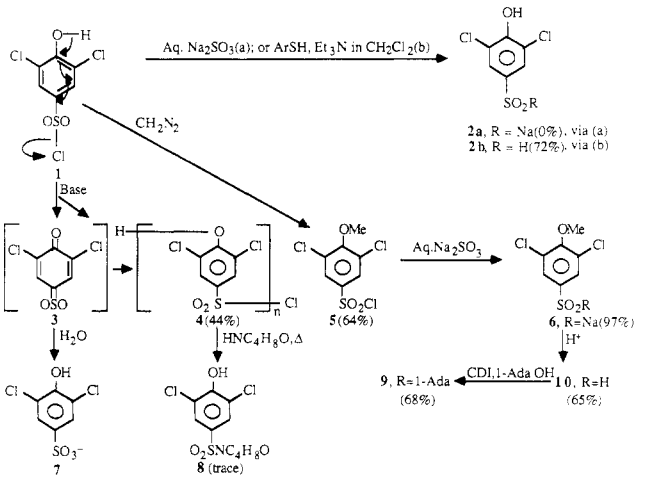
Molecules containing di- or trisulfide linkages together with sulfinate [S(O)OR] functions are promising antiradiation agents.[3] More flexible approaches to such agents might be afforded by convergent syntheses in which di- or trisulfides in one molecule could be connected to sulfinates in another, for example by reaction of CO_2H in one molecule with OH in the other. Convergent syntheses with aliphatic compounds were reported earlier.[4] For a convergent approach to aromatic systems, attractive hydroxyarenesulfinic acid components were **2a** (Scheme I) and **13a** (Scheme II), since the precursor sulfonyl chlorides **1** and **11** were known.[5] Although convergent syntheses ultimately were developed (vide infra), an emphasis of this paper is the unexpected intervention of the monothioquinone *S,S*-dioxides **3** (Scheme I) and **14** (Scheme II) in initial efforts.[6]

When **1** was reduced conventionally with aqueous Na_2SO_3 (pH ca. 9), the sole product was the *sulfonate* salt **7**, and no *sulfinate* salt (**2a**) could be isolated (Scheme I); as Scheme I indicates, however, we were able to reduce **1** to the sulfinic acid (**2b**) by a new approach with an arenethiol and amine,[1a] thus showing that **2a** was in fact an achievable target (the structure of **2b** was confirmed as a thiuronium salt and by dimethylation). At first, we attributed the exclusive formation of **7** with sodium sulfite simply to facile hydrolysis of **1** and, when modifications still led only to **7**, we turned to **11** (Scheme II). Again, the chief product was the sulfonate (**12**), although the sulfinate (**13a**) could be obtained;[8] the new route,[1a] as in the para series, with a thiol and amine gave the sulfinic acid (**13b**) without problems (Scheme II). Ultimately it occured to us that the dominating formation of the sulfonates **7** and **12** is best explained via the aromatic counterparts of sulfenes shown as **3** (Scheme I) and **14** (Scheme II).

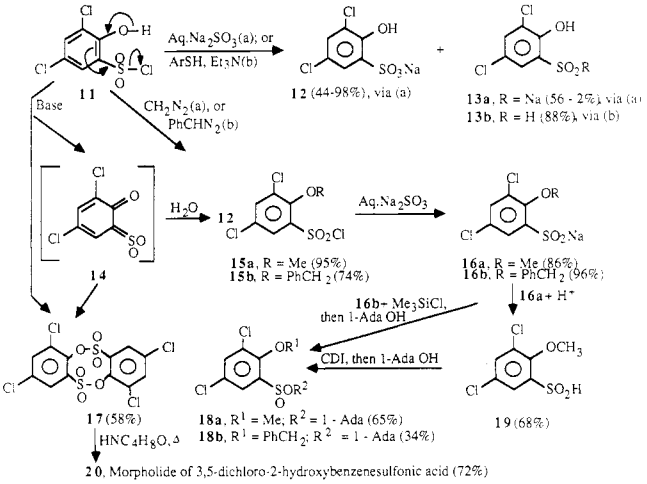
The likelihood of sulfene-like intermediates was strengthened for **1** by blocking the para hydroxyl group to give **5**, which then no longer could give **3** and which could be reduced smoothly with sodium sulfite to the sulfinate **6** (Scheme I); the identity of **6** was confirmed by conversion through **10** to the 1-adamantyl ester **9**. Similarly (Scheme II), blocking the ortho hydroxyl group of **11** with a methyl (**15a**) or benzyl (**15b**) group permitted smooth reduction to the sulfinate salts (**16a**, **16b**), which were characterized as esters (**18a**, **18b**).[9]

Scheme I[a]



[a] 1-Ada = 1-adamantyl; Ar = p-$CH_3C_6H_4$; CDI = carbonyldiimidazole; Me = CH_3; Ph = C_6H_5.

Scheme II[a]



[a] 1-Ada = 1-adamantanol; CDI = carbonyldiimidazole; Me = methyl; Ar = p-$CH_3C_6H_4$; Ph = phenyl.

(1) (a) Paper 23: Lee, C.; Field, L. *Synthesis*, in press. (b) This investigation was supported by the U.S. Army Medical Research and Development Command, Department of the Army, under Research Contract No. DAMD 17-85-C-5181; this paper has been designated as Contribution No. 1860 to the U.S. Army Drug Development Program. We thank Dr. John H. Hillhouse for calling our attention to the work of Cremlyn and Cronje (ref 5).

(2) This paper is abstracted from the Ph.D. Dissertation of C. Lee, which may be consulted for further details (Vanderbilt University, May 1989).

(3) (a) Srivastava, P. K.; Field, L.; Grenan, M. M. *J. Med. Chem.* **1975**, *18*, 798. (b) Bowman, G. T.; Clement, J. J.; Davidson, D. E., Jr.; Eswarakrishnan, V.; Field, L.; Hoch, J. M.; Musallam, H. A.; Pick, R. O.; Ravichandran, R.; Srivastava, P. K. *Chem.-Biol. Interact.* **1986**, *57*, 161. (c) Chandra, R.; Clement, J. J.; Field, L.; Harmon, J. P.; Musallam, H. A.; Srivastava, P. K. *Sulfur Lett.* **1989**, *9*, 87.

(4) Lee, C.; Stidham, D. B.; Field, L. *Phosphorus, Sulfur Silicon Relat. Elem.* in press.

(5) Cremlyn, R. J.; Cronje, T. *Phosphorus Sulfur* **1979**, *6*, 413.

(6) The term monothioquinone *S,S*-dioxide is used in preference to alternatives mentioned in references below; cf. ref 1a in the present ref 7.

(7) Thea, S.; Cevasco, G.; Guanti, G.; Hopkins, A.; Kashefi-Naini, N.; Williams, A. *J. Org. Chem.* **1985**, *50*, 2158.

(8) For example, ratios of the sulfonate (**12**) to the sulfinate (**13a**) were as follows: for 1:4 Me_2CO/H_2O, 3 h at ca. 25 °C, 86:14; for H_2O, 3 h at ca 25 °C, 49:51; for H_2O, 3 h at 0 °C, 44:56.

(9) The uses shown in Scheme II of CDI and Me_3SiCl for preparing sulfinic esters have been reported recently.[10]

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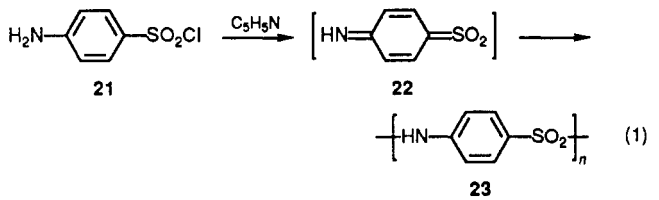
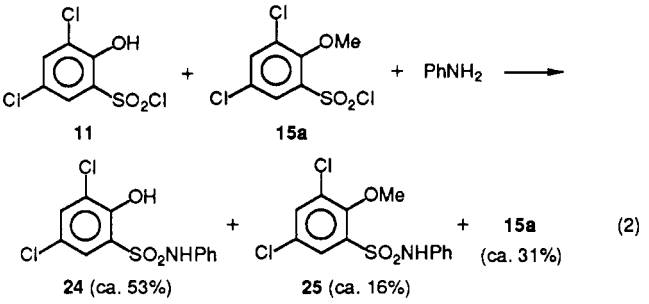
We then learned that we were not the first to invoke aromatic counterparts of aliphatic sulfenes.[11] In 1908, Zincke and Brune attributed a yellow color of the dibromoarene counterpart of **1** with base to the dibromo counterpart of **3**;[12] Oae and Kiritani (1965) could obtain no firm evidence for this dibromo intermediate by UV, IR, or ESR spectra but did suggest that a λ_{max} at 310 nm might be attributed to this "quinoid sulfene".[13] Hall (1966) examined reactions of *p*-hydroxyarenesulfonyl chlorides with amines *in ether* and assigned absorption at 313–328 nm simply to the deprotonated phenols, having found no evidence for thioquinone *S,S*-dioxides.[14] On the other hand, Thea and co-workers (1982–1985) concluded from kinetic studies that 2,4-dinitrophenyl 3,5-dimethyl-4-hydroxybenzenesulfonate formed a "sulfoquinone".[7,15]

Zincke and Brune concluded that a final product from their dibromo compound was a dimer (or trimer),[12] but others considered it a linear polymer;[13] both *p*-hydroxybenzenesulfonyl chloride and the 3,5-dimethyl derivative now are known to give high molecular weight polymers.[16] Our reaction of **1** with pyridine in CH_2Cl_2 gave an insoluble product indicated by elemental analysis to be **4** with n = ca. 3. Supporting evidence for **4** as a linear polymer is that only a trace of the morpholide **8** could be obtained (TLC comparison with authentic **8** from **1**, Scheme I); in contrast, the insoluble dimeric product from the ortho series (i.e. **17**) gave 72% of morpholide (**20**). Whether the formation of **4** proceeded through the thioquinone **3** or through direct reaction of **1** is unclear. Treatment of the *o*-hydroxy isomer (**11**) with pyridine in CH_2Cl_2 clearly gave a dimer (**17**), and, as mentioned, **17** gave the morpholide **20** in good yield. This result seems enough different from the behavior of **4** to indicate linear polymeric character for **4**; in addition, mass spectra gave a strong (49%) peak for the molecular ion of the dimer **17**, with no evidence of higher masses other than isotopic ones. It is worth adding that *p*-aminobenzenesulfonyl chloride (**21**) forms **22** en route to the polymer **23** (eq 1); **22** was not isolated but was considered to be "a stable compound with a reasonable half life at room temperature when protected against moisture".[17]



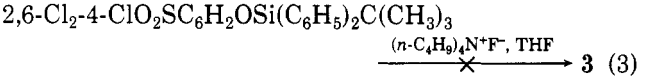
(1)

Reaction of an aryl 1-hydroxy-2-naphthalenesulfonate with *N*-methylaniline reportedly gave about twice the amount of anilide predicted from a kinetic analysis of second-order attack of aniline, "consistent with a mechanism involving rate-limiting intermediate formation" and buttressing other kinetic evidence that "sulfoquinones" are intermediates in the reactions of *o*- and *p*-hydroxyarenesulfonate esters.[7] A somewhat similar approach in our hands supports the intermediacy of **14**. Thus the hydroxy compound **11** and the *O*-methyl derivative **15a** were allowed to complete for one molar proportion of aniline in the presence of one of triethylamine. The faster reaction of **11** led to about three times the amount of anilide (**24**) produced by **15a**; much of the **15a** remained unchanged, and eq 2 shows the approximate composition of the product as estimated by NMR.



(2)

Efforts did not succeed to trap **3** with 7,7,8,8-tetracyanoquinodimethane (recovered) or **14** with tetracyanoethylene[2] or with the known sulfene traps hexachloroacetone,[11] benzalaniline,[2,11] or 1-morpholino-1-cyclohexene.[2,18] Unavailing also were efforts to generate **3** by a method for generating sulfenes under neutral conditions,[19] so that a spectrum might be seen for **3** (eq 3).

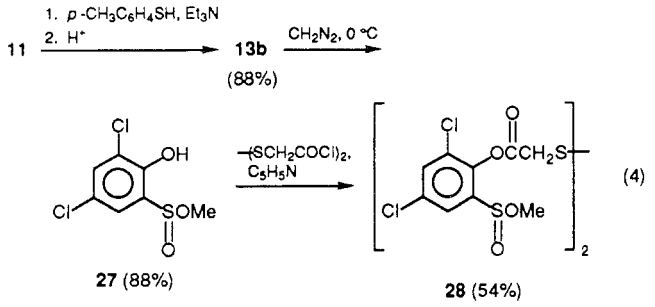


(3)

Our new evidence for the intervention of thioquinone *S,S*-dioxides in reactions of *o*- and *p*-hydroxyarenesulfonyl chlorides can be summarized as follows: (1) Reduction of **1** or **11** with Na_2SO_3 in H_2O (pH ca. 9) under usual conditions at ca. 50–60 °C leads largely or entirely to sulfonate salts. Persistence even at 0 °C points to a crucial atypical feature. (2) This atypical feature evidently is a thioquinone *S,S*-dioxide, since blocking the hydroxyl group leads to normal reduction to sulfinate salts (recall **5** vs **1** and **15a**, **15b** vs **11**). (3) Reaction of an *O*-methyl compound (recall **15a** vs **11**) with aniline is significantly slower than when a thioquinone *S,S*-dioxide can intervene. (4) In nonaqueous solvents the yellow color developed with a tertiary amine, assigned to phenoxide ion,[14] disappears only slowly (1–2 h), indicating that there is considerable time for dimerization (ortho systems) or polymerization (para systems) via the O^- and SO_2Cl functions; presumably the ammonium counterion inhibits conversion of the phenoxide ion to the thioquinone by forming a tight ion pair. In contrast, in aqueous basic media, the rapid loss of the yellow color (ca. 5–30 min) indicates rapid conversion of the free phenoxide ion to the thioquinone *S,S*-dioxide, which then is attacked by water to give the sulfonic acid before much dimerization or polymerization can occur.

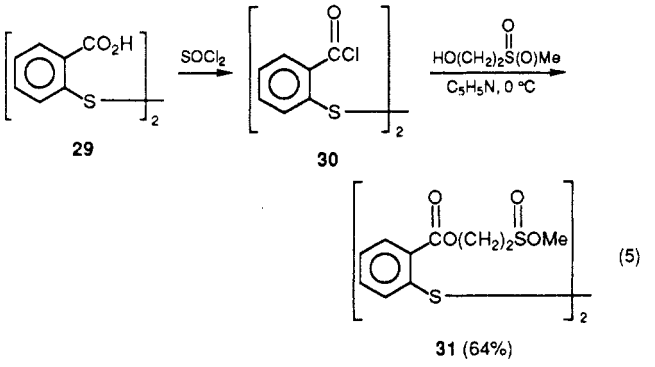
Ultimately it became possible by other routes to link hydroxysulfinates with carboxylic derivatives of disulfides in convergent syntheses. For **28** (eq 4), efforts to reduce the sulfonyl chloride (**11**) to the sulfinic acid (**13b**) failed with sodium sulfite, as recounted. Zinc in EtOH gave mostly polymer, and $LiAlH_4$, $NaBH_4$, or Na_2S gave intractable mixtures, as did an effort to debenzylate the benzyl ether **16b** with Na/liquid NH_3.[2] *p*-Thiocresol and triethylamine, however, gave **13b** quite well (Scheme II and eq 4; this method then was studied as reported earlier).[1a]

(10) Lee, C.; Field, L. *Phosphorus, Sulfur Silicon Relat. Elem.* **1989**, *45*, 35.
(11) For a recent review of sulfenes, see: Lenz, B. G.; Zwanenburg, B. In *Methoden der Organischen Chemie (Houben-Weyl)*, 4th ed.; Klamann, D., Ed.; G. Thieme Verlag: Stuttgart, 1985; Vol. E11, Part 2, pp 1326–1343.
(12) Zincke, T.; Brune, R. *Ber. Dtsch. Chem. Ges.* **1908**, *41*, 902.
(13) Oae, S.; Kiritani, R. *Bull. Chem. Soc. Jpn.* **1965**, *38*, 1543.
(14) Hall, W. L. *J. Org. Chem.* **1966**, *31*, 2672.
(15) Thea, S.; Guanti, G.; Hopkins, A.; Williams, A. *J. Am. Chem. Soc.* **1982**, *104*, 1128.
(16) Campbell, R. W.; Hill, H. W., Jr. *Macromolecules* **1973**, *6*, 492.
(17) Contreras, J.; Jones, J. I. *Brit. Polym. J.* **1980**, *12*, 205 and references there cited.
(18) King, J. F. *Acc. Chem. Res.* **1975**, *8*, 10.
(19) Block, E.; Aslam, M. *Tetrahedron Lett.* **1982**, *23*, 4203.

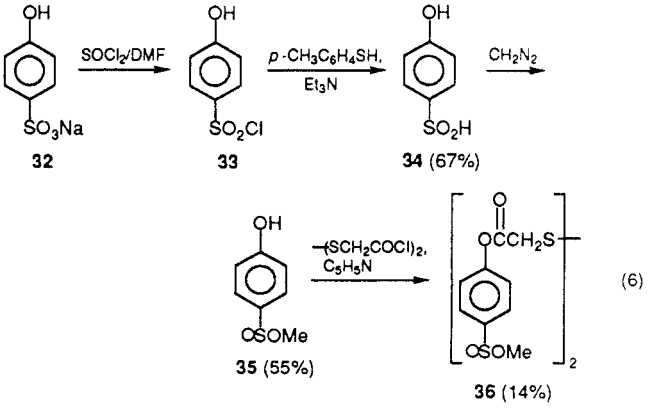


13b could be monomethylated and converted through **27** to **28** (eq 4). **27** was sensitive to moisture, and after 1 month when sealed under ambient conditions 90% of the sulfinic acid (**13b**) and 10% of the sulfonic acid resulted; however, the coupling product **28** was unchanged even after 2 months under ambient conditions.

A second convergent product in the ortho series was obtained as shown by eq 5. This product, **31**, also was unchanged after 2 months under ambient conditions.



In the para series, 2,6-dichloro-4-hydroxybenzenesulfinic acid (**2b**) differed from the *o*-hydroxy acid (**13b**) in eq 4; **13b** could be monomethylated by slow addition of CH_2N_2 at 0 °C, but attempted monomethylation of **2b** led almost entirely to methylation of both the phenolic OH and the SO_2H function. The acid **34**, however, lacking the chlorine substituents could be monomethylated to the ester **35**. The convergent synthesis shown by eq 6 then could be achieved, although the yield of **36** was low and the product (**36**) unstable.



Comparison of the relative stabilities of the acids **2b**, **13b**, and **34** by NMR revealed notable differences.[2] As solids, ca. 10–20% of **2b** and **13b** became oxidized to the sulfonic acid in 60 days, but 20% of **34** was lost in 2 days and all of it in 10 days. All three solid acids could be kept under argon at –60 °C, without change for several months. In D_2O, half-survival times were ca. 17 (**34**) to 29 days (**13b**), and none remained after ca. 2 months; the acid **2b** had a half-survival time of ca. 50 days. The sodium salts of **2b**, **13b**, and **34** could be kept at least for several months at ca. 25 °C, with exclusion of oxygen.

Experimental Section

Melting points were determined by using a Thomas-Hoover stirred-liquid apparatus and are corrected. Moist extracts were dried over $MgSO_4$, and the solvent then was removed with use of a rotary-flask evaporator at aspirator pressure. ^1H NMR spectra, reported in parts per million (ppm, δ), were recorded with a IBM NR/300 spectrometer (300 MHz) with Me_4Si (TMS) as an internal standard, except with $Me_3Si(CH_2)_3SO_3Na$ (DSS) in D_2O; ^{13}C NMR spectra were obtained at 50.3 MHz with a IBM NR/200 spectrometer. IR spectra were obtained with use of KBr pellets, unless otherwise specified, with a Perkin-Elmer Model 727 spectrometer; bands other than the 4–5 strongest (s) were medium or weak; br = broad. Mass spectra were obtained with a VG70-250 GC–MS instrument (resolving power, 10 000) in the EI exact mass mode at 70 eV with a direct introduction probe and consecutively averaged scans; they were kindly provided by Prof. Brian J. Sweetman (Department of Pharmacology, funds provided by the NIH Division of Research Resources Grant RR 01688). TLC was performed with Whatman K6F silica gel plates with visualization by UV. Flash chromatography was performed with use of a 4 × 45 cm or 2.5 × 30 cm column containing ca. 50 g of silica gel per gram of product with use of Baker 7024 silica gel (40 μM). Elemental analysis was done by Galbraith Laboratories, Knoxville, TN. Titration of sulfinic acids with aqueous $NaNO_2$, based on a method of Marvel and Johnson,[20] was described previously.[1a] Usual cautions were exercised with CH_2N_2; a slight excess was used to give a pale yellow color, and this color was destroyed with ca. 2 drops of AcOH before the Et_2O was evaporated. All other materials were commercial products unless otherwise specified.

Preparation of the Hydroxyarenesulfinic Acids 2b, 13b, and 34 and Derivatives. Relative Stabilities. A. For **2b**, in a modification of a reported general procedure,[1a] a solution of *p*-thiocresol (1.90 g, 15.3 mmol) and Et_3N (1.55 g, 15.3 mmol) in CH_2Cl_2 (30 mL) was added during 3 min to 3,5-dichloro-4-hydroxybenzenesulfonyl chloride (**1**; 2.00 g, 7.65 mmol)[5] in CH_2Cl_2 (30 mL) at –76 °C. Much as usual,[1a] the solution then was stirred for 15 min at –76 °C (reaction at 0 °C led to a yield of 63%). A water extract (20 mL × 5) then was washed with Et_2O (20 mL × 2), cooled to 0 °C, and acidified with concentrated HCl (2.0 mL, 24 mmol). After being extracted with Et_2O (30 mL × 3), the aqueous layer was saturated with NaCl and extracted further (30 mL × 2). The combined ethereal extracts, dried and evaporated, gave 1.25 g (72%) of **3,5-dichloro-4-hydroxybenzenesulfinic acid (2b)** as a white solid; titration with $NaNO_2$ showed the purity to be 100%: mp 135–150 °C dec. This **2b** was identical with similarly prepared **2b** that had the following properties: mp 135–155 °C dec; IR 3300–2300 br, 1570, 1470, 1390, 1320, 1230, 1130, 1080, 1030 s, 830, 790 cm^{-1}; ^1H NMR (D_2O) δ 7.54 (s, 2 H); ^{13}C NMR (MeOH-d_4) δ 153.56, 141.21, 126.09, 123.86. Anal. Calcd for $C_6H_4Cl_2O_3S$: C, 31.73; H, 1.78; S, 14.12. Found: C, 31.80; H, 1.74; S, 14.08. When 2 drops of 30% H_2O_2 was added to **2b** in D_2O, the ^1H NMR spectrum changed to δ 7.76 (s, 2 H; the sulfonic acid). The *S*-benzylthiuronium salt of **2b** was prepared by warming a solution of 2-benzyl-2-thiopseudourea hydrochloride (1.00 g, 4.93 mmol) in H_2O (20 mL) to 40 °C and adding it to one of **2b** (1.00 g, 4.40 mmol) in H_2O (5 mL). After 10 min, the mixture was cooled at 5 °C for 48 h; the precipitated ***S*-benzylthiuronium salt of 2b** was washed with ice water and dried; yield 1.30 g (75%): mp 160–162 °C; IR 3450–2550 br, 1660, 1620, 1550, 1460, 1430, 1380, 1300, 1200, 1150, 1110, 1030, 1010, 930 cm^{-1}; ^1H NMR (CD_3OD) δ 7.67 (s, 2 H), 7.42–7.32 (m, 5 H), 4.41 (s, 2 H). Anal. Calcd for $C_{14}H_{14}Cl_2N_2O_3S_2$: C, 42.75; H, 3.59; N, 7.12; S, 16.30; Cl, 18.03. Found: C, 42.66; H, 3.53; N, 7.02; S, 16.38; Cl, 18.30. **Methyl 3,5-dichloro-4-methoxybenzenesulfinate** (Scheme I) was prepared by adding ethereal CH_2N_2 to 0.20 g (0.88 mmol) of **2b** in Et_2O. Removal of Et_2O and then TLC (1:4 hexane/

(20) Marvel, C. S.; Johnson, R. S. *J. Org. Chem.* **1948**, *13*, 822. See also ref 21.
(21) Kice, J. L., Bowers, K. W. *J. Am. Chem. Soc.* **1962**, *84*, 605.

CH_2Cl_2) gave the ester (R_f 0.56); yield 0.20 g (89%): IR 3100, 2975, 1560, 1470, 1420, 1380, 1260, 1140 s, 1080, 990 s, 960 s, 800, 680 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.64 (s, 2 H), 3.96 (s, 3 H), 3.53 (s, 3 H). Anal. Calcd for $C_8H_8Cl_2O_3S$: C, 37.66; H, 3.16; S, 12.57. Found: C, 37.80; H, 3.01; S, 12.56.

B. 3,5-Dichloro-2-hydroxybenzenesulfinic acid (13b) was prepared from 2.00 g (7.65 mmol) of 3,5-dichloro-2-hydroxybenzenesulfonyl chloride (**11**) in the same way as **2b**, except that H_2O at ca. 40 °C (20 mL × 6) was used to extract the triethylammonium sulfinate; yield of **13b** 1.52 g (88%): mp 115–116 °C dec; $NaNO_2$ titration, 99%. This **13b** was identical with **13b** that had properties as follows: mp 115–117 °C dec; IR 3400–2300 s br, 1600, 1580, 1460, 1400, 1300, 1280, 1220, 1160, 1080, 1030–1000 s br, 880, 860, 830, 780, 720 cm^{-1}; ^1H NMR (D_2O) δ 7.50–7.49 (d, 1 H), 7.38–7.37 (d, 1 H); ^{13}C NMR (CD_3OD) δ 151.64, 137.85, 133.34, 125.91, 124.03. Anal. Calcd for $C_6H_4Cl_2O_3S$: C, 31.73; H, 1.78; S, 14.12. Found: C, 31.81; H, 1.94; S, 14.51. The sulfinate salt of **13b** atypically gave no precipitate of the ferric sulfinate with aqueous $FeCl_3$; instead, the purple *solution* typical of phenols is seen. Two drops of 30% H_2O_2 in a D_2O solution of **13b** caused the NMR spectrum to change [δ 7.65–7.64 (d, 1 H), 7.58–7.57 (d, 1 H)], consistent with oxidation of **13b** to the sulfonic acid. Reaction of the sulfonyl chloride and *p*-thiocresol at 15–25 °C instead of −76 °C led to **13b** in only 46% yield. **Methyl 3,5-dichloro-2-hydroxybenzenesulfinate (27)** was prepared by adding ethereal CH_2N_2 to a solution of 0.80 g (3.52 mmol) of **13b** in Et_2O (30 mL) at 0 °C with stirring. Excess CH_2N_2 was destroyed, the solution was dried, and ether was removed to give a colorless oil. EtOAc (1.5 mL) was added, and the solution was cooled at 0 °C and rubbed with pentane or hexane (50 mL). The white solid obtained was removed and dried; yield of **27** 0.75 g (88%): mp 96–97 °C; R_f 0.80 (TLC, 6:94 CH_3OH/CH_2Cl_2); IR 3300 br, 3100, 2950, 1570, 1460, 1400, 1300, 1280, 1220, 1100 s br, 960, 900, 880, 860, 780, 740, 700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 9.67 (s, 1 H), 7.53–7.52 (d, 1 H), 7.21–7.20 (d, 1 H), 3.68 (s, 3 H); ^{13}C NMR ($CDCl_3$) δ 153.15, 133.84, 125.06, 123.95, 50.91. Anal. Calcd for $C_7H_6Cl_2O_3S$: C, 34.87; H, 2.51; S, 13.30. Found: C, 34.71; H, 2.45; S, 13.43.

C. *p*-Hydroxybenzenesulfinic acid (34) was prepared from 2.00 g (10.4 mmol) of *p*-hydroxybenzenesulfonyl chloride (**33**)[22] essentially with use of the same procedure and proportions of reagents used for **2b** (reaction at 0–25 °C instead of at −76 °C led to a yield of 49%). Removal of Et_2O at 15 °C, rubbing with pentane (20 mL), and drying of the white solid obtained in a stream of Ar gave 1.10 g (67%) of **34**; white **34** can be obtained only if Et_2O is totally removed at 15 °C under reduced pressure; **34** becomes brown if impurities are present: mp 82–84 °C dec; lit.[23] mp 67–70 °C dec; $NaNO_2$ titration, 99%. This **34** was identical by ^1H NMR with earlier **34** that had the following properties: mp 84–87 °C dec; IR 3250–2350 s br, 1590 s, 1460, 1390, 1250, 1180, 1100 s, 1060 s, 830, 800 cm^{-1}; ^1H NMR (D_2O) δ 7.61–7.59 (d, 2 H), 7.03–7.01 (d, 2 H); ^{13}C NMR (D_2O) δ 161.72, 140.15, 129.04, 118.56. Anal. Calcd for $C_6H_6O_3S$: C, 45.56; H, 3.82; S, 20.27. Found: C, 45.95; H, 3.67; S, 20.28. When 2 drops of 30% H_2O_2 was added to **34** in D_2O, the ^1H NMR spectrum changed to δ 7.70–7.67 (d, 2 H), 6.98–6.95 (d, 2 H) of the sulfonic acid. **Methyl *p*-hydroxybenzenesulfinate (35)** was prepared like methyl 3,5-dichloro-2-hydroxybenzenesulfinate from 0.20 g (1.26 mmol) of **34** but was an oil. TLC (1:4 $EtOAc/CH_2Cl_2$) separated oil with R_f 0.47 that solidified after a week at 0 °C. Rubbing with pentane (5 mL) gave 0.12 g (55%) of **35**: mp 44–45 °C; IR (neat) 3650–3050 s br, 2940, 1600 s, 1560 s, 1490, 1435, 1365, 1270–1225 s br, 1165, 1080 s br, 960 s br, 830 s, 680 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.59–7.56 (d, 2 H), 7.49 (s br, O*H*), 7.04–7.01 (d, 2 H), 3.50 (s, 3 H); ^{13}C NMR ($CDCl_3$) δ 160.62, 133.24, 127.34, 116.22, 49.93. Anal. Calcd for $C_7H_8O_3S$: C, 48.82; H, 4.68; S, 18.62. Found: C, 48.50; H, 4.88; S, 18.99.

D. Relative Stabilities of the Acids 2b, 13b, and 34. As solids, these were assessed by placing a sample of each in each of six test tubes, sealing the tubes, and leaving them at ca. 25 °C. At appropriate times, a sample was dissolved in D_2O, and the ^1H NMR spectrum was determined. The relative percentage of sulfonic acid was calculated from the ratio of the integrals for the arene hydrogens of the sulfonic acid noted above to the total of all arene hydrogens, i.e., % $ArSO_3H$ = [(protons of $ArSO_3H$)/(protons of $ArSO_3H$ + protons of $ArSO_2H$)](100). The relative stabilities in D_2O at ca. 25 °C were determined in the same way, by keeping solutions in D_2O. There was no indication of any products in these experiments other than the sulfinic and sulfonic acids.

Reduction of the Sulfonyl Chlorides 1 and 11 with $Na_2SO_3/NaHCO_3$. 3,5-Dichloro-4-hydroxybenzenesulfonyl chloride (**1**) and 3,5-dichloro-2-hydroxybenzenesulfonyl chloride, **11** (0.20 g of each), were ground to powder, and each powder then was added to $Na_2SO_3/NaHCO_3$ (2/1 molar ratio to the sulfonyl chloride) in 5 mL of H_2O during 5–10 min. Each solution was stirred at 25 °C or 0 °C for 3, 6, or 12 h. Each of the 12 solutions then was extracted with CH_2Cl_2 (3 mL); the aqueous solution was collected and freeze-dried. The relative percentage of sodium sulfonate in the crude products was calculated from the ratio of the integrals for the arene hydrogens of the sodium sulfonate to the total of all arene hydrogens, i.e., % $ArSO_3Na$ = [(protons of $ArSO_3$ Na)/(protons of $ArSO_3Na$ + protons of $ArSO_2Na$)](100). The chemical shifts of sodium sulfinate and sulfonate were determined as follows: The sulfinic acid and the same molar amount of $NaHCO_3$ were dissolved in D_2O. The ^1H NMR spectrum showed the sodium sulfinate. Later, 2 drops of 30% H_2O_2 was added to the above sulfinate solution (in the NMR tube), and the new chemical shift was recorded that corresponded to the sodium sulfonate. The chemical shifts of the sodium sulfinates are as follows: **2a** (D_2O) δ 7.42 (s); **13a** (D_2O) δ 7.46–7.45 (d, 1 H), 7.33–7.32 (d, 1 H). The chemical shifts for the sodium sulfonates are as follows: **7** (D_2O) δ 7.74 (s); **12** (D_2O) δ 7.66–7.65 (d, 1 H), 7.60–7.59 (d, 1 H). The proportion of sulfonate (**7**) with the sulfinate (**2a**) for the *p*-hydroxy compound in the set of six experiments was 96–100% of sulfonate; in confirmation, this product did not reduce aqueous $KMnO_4$ rapidly. The proportion of sulfonate for the *o*-hydroxy series of sulfonate (**12**) with the sulfinate (**13a**) was 44–60% of sulfonate; at 50 °C *only* the sulfonate (**12**) was obtained (mass spectra; NMR identical with authentic **12**).

Preparation and Characterization of 3,5-Dichloro-4-methoxybenzenesulfinic Acid (10). For the preparation of **3,5-dichloro-4-methoxybenzenesulfonyl chloride (5)**, 3,5-dichloro-4-hydroxybenzenesulfonyl chloride (**1**, 9.00 g, 34.4 mmol)[5] in Et_2O (100 mL) was treated with ethereal CH_2N_2 at ca. 25 °C to give white solid. Flash chromatography (1:1 CH_2Cl_2/hexane) gave the chloride **5** as a fraction of 6.10 g (64%): R_f 0.70 (1:1 CH_2Cl_2/hexane); mp 63–64 °C; IR 3120, 2980, 1560, 1480, 1420, 1380, 1270, 1180, 1120, 1080, 980, 880, 860, 805, 760, 700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.98 (s, 2 H), 4.02 (s, 3 H). For the conversion of **5** to **sodium 3,5-dichloro-4-methoxybenzenesulfinate (6)**, Na_2SO_3 (3.66 g, 29.0 mmol) and $NaHCO_3$ (2.44 g, 29.0 mmol) were dissolved in 80 mL of H_2O, and the solution was added slowly (3 min) to the sulfonyl chloride **5** (4.00 g, 14.5 mmol) in 30 mL of acetone. The mixture then was heated at 50 °C with stirring for 1 h. The solution was cooled, washed with CH_2Cl_2 (50 mL), and freeze-dried. The white solid was partially dissolved in 50 mL of MeOH. Inorganic solid was removed by filtration, and the volume of MeOH was reduced to 10 mL. Et_2O (10 mL) was added slowly, the mixture was centrifuged, and precipitate was discarded. The sodium sulfinate **6** then was precipitated with 50 mL of Et_2O. After centrifugation, the white solid was dried at 2 Torr; yield, 3.70 g (97%) of sulfinate **6**: IR (Nujol) 1560, 1420, 1260, 1060, 1030 s, 990 s, 880, 840, 800 cm^{-1}; ^1H NMR (D_2O) δ 7.56 (s, 2 H), 3.92 (s, 3 H). For the conversion of the sulfinate **6** to **3,5-dichloro-4-methoxybenzenesulfinic acid (10)**, 1.00 g (3.80 mmol) of **6** in 5 mL of H_2O, was cooled at 0 °C for 5 min; concentrated HCl (0.4 mL, 4.8 mmol) was then added dropwise with slow stirring. A white precipitate came out immediately, and the mixture was extracted with CH_2Cl_2 (50 mL × 2). The organic layer was washed with cold brine (20 mL) and dried. Solvent was removed, and the resulting solid then was dried at 2 Torr for 6 h; yield, 0.60 g (65%) of the sulfinic acid **10**: mp 106–107 °C; IR 3100–2300 br, 1560, 1480, 1430, 1390, 1270, 1140, 1060 s br, 1020 s, 990 s, 860 br, 800 cm^{-1}; ^1H NMR ($CDCl_3$) δ 9.28 (s br, 1 H), 7.61 (s, 2 H), 3.93 (s, 3 H). The acid **10** was converted to **1-adamantyl 3,5-dichloro-4-methoxybenzenesulfinate (9)** by dissolving 0.60

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g (2.49 mmol) of **10** in 20 mL of CH_2Cl_2, adding carbonyldiimidazole (CDI; 0.60 g, 3.70 mmol) in 20 mL of CH_2Cl_2, and stirring the mixture for 20 min at 25 °C. 1-Adamantanol (0.30 g, 1.97 mmol) in 20 mL of CH_2Cl_2 was added, and the solution was stirred for 2 h more. The solution was washed with 10 mL of 10% HCl and H_2O (50 mL × 2), and the organic layer was dried. Removal of CH_2Cl_2 gave 0.65 g of oily solid, which was purified by flash chromatography (1:4 EtOAc/hexane). A fraction with R_f 0.71 gave 0.50 g (68%) of the ester **9** as colorless oil, which crystallized from petroleum ether at 0 °C as white solid: mp 95–96 °C; IR 3100, 2950, 2880, 1560, 1475, 1420, 1380, 1360, 1300, 1260, 1200, 1140 s, 1045 s, 990, 890, 780, 760 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.59 (s, 2 H), 3.94 (s, 3 H), 2.28 (s, 3 H), 2.10 (s, two small shoulders, 6 H), 1.70 (s, two small shoulders, 6 H). Anal. Calcd for $C_{17}H_{20}Cl_2O_3S$: C, 54.40; H, 5.34; S, 8.54. Found: C, 54.49; H, 5.48; S, 8.65.

Preparation and Characterization of 3,5-Dichloro-2-methoxybenzenesulfinic Acid (19). 3,5-Dichloro-2-methoxybenzenesulfonyl chloride (15a) was prepared, essentially as described for **5**, by the use of ethereal CH_2N_2 with 3.00 g (11.5 mmol) of 3,5-dichloro-2-hydroxybenzenesulfonyl chloride (**11**; Aldrich); 3.00 g (95% yield) of **15a** was obtained as colorless oil that crystallized after 24 h at 0 °C: mp 37–39 °C; IR (neat) 3100, 3050, 2950, 1580, 1550, 1470 s, 1420 s, 1380 s, 1260 s, 1180 s, 1140, 1080, 980 s, 880, 850, 760, 700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.88–7.87 (d, 1 H), 7.74–7.73 (d, 1 H), 4.12 (s, 3 H). The chloride **15a** was reduced to **sodium 3,5-dichloro-2-methoxybenzenesulfinate (16a)** by adding 2.47 g (19.6 mmol) of Na_2SO_3 and 1.65 g (19.6 mmol) of $NaHCO_3$ in 50 mL of H_2O during 10 min to neat **15a** (2.56 g, 9.29 mmol) with vigorous stirring. The resulting solution was heated at 60 °C for 3 h and then, as with **6**, was washed with CH_2Cl_2 and freeze-dried. The solid obtained was dissolved in MeOH (50 mL), inorganic solid was removed, the volume of MeOH was reduced to 15 mL, and 15 mL of Et_2O was added slowly. Precipitate was discarded, and the sulfinate salt **16a** was then precipitated with 50 mL of Et_2O and was dried at 2 Torr; yield of **16a**, 2.10 g (86%): TLC R_f 0.67 (3:7 MeOH/Et_2O); IR 2975, 1560, 1460, 1420, 1270, 1240, 1120, 1070, 1040 s, 980 s, 860, 840, 750 cm^{-1}; ^1H NMR (D_2O) δ 7.54 (s, 2 H), 3.96 (s, 3 H). Acidification of 1.00 g (3.80 mmol) of the sodium sulfinate (**16a**) in 4 mL of H_2O at 0 °C by dropwise addition of 0.50 mL (6.0 mmol) of concentrated HCl with slow stirring gave **3,5-dichloro-2-methoxybenzenesulfinic acid (19)**. The precipitate of **19** was extracted with CH_2Cl_2 (30 mL), and the extract was washed with cold brine (20 mL × 2), dried, and concentrated to give 0.62 g (68%) of **19**: mp 93–95 °C; IR (Nujol) 1560, 1420, 1260, 1240, 1140, 1080 s, 1050 s, 980 s, 870, 840, 820, 750, 720, 700, 600 cm^{-1}; ^1H NMR (D_2O) δ 7.62–7.61 (d, 1 H), 7.58–7.57 (d, 1 H), 3.96 (s, 3 H). For further characterization, 0.62 g (2.57 mmol) of the acid **19** was converted to **1-adamantyl 3,5-dichloro-2-methoxybenzenesulfinate (18a)**, essentially as for **9**, with CDI (0.54 g, 3.33 mmol) and 1-adamantanol (0.31 g, 2.04 mmol). The 0.7 g of crude **18a** obtained was purified by flash chromatography (1:19 EtOAc/hexane) to give 0.50 g (65%) of **18a** as an oil of R_f 0.17 that crystallized in petroleum ether at 0 °C during 24 h: mp 70–72 °C; IR (as the neat oil) 3100, 2950, 2850, 1580, 1460, 1410, 1350, 1300, 1260, 1240, 1130 s, 1045, 990, 895, 780, 750 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.78–7.77 (d, 1 H), 7.50–7.49 (d, 1 H), 3.95 (s, 3 H), 2.26 (s, 3 H), 2.09 (s, two small shoulders, 6 H), 1.68 (s, 6 H). Anal. Calcd for $C_{17}H_{20}Cl_2O_3S$: C, 54.40; H, 5.34, S, 8.54. Found: C, 54.53; H, 5.13; S, 9.03.

Preparation and Characterization of Sodium 3,5-Dichloro-2-(benzyloxy)benzenesulfinate (16b). 3,5-Dichloro-2-(benzyloxy)benzenesulfonyl chloride (15b) was prepared by adding ethereal phenyldiazomethane[24] dropwise with stirring to an ether solution of 2.50 g (9.56 mmol) of the sulfonyl chloride **11** in 50 mL of Et_2O until a faint red persisted. Excess diazo compound was destroyed with a few drops of AcOH, the solution was dried, and Et_2O was removed. Flash chromatography with 1:1 CH_2Cl_2/hexane of the residual solid gave a fraction with R_f 0.71 that contained 2.50 g (74%) of **15b**: mp 95–97 °C; IR ($CHCl_3$) 3100, 3050, 1510, 1440, 1400, 1380, 1260, 1220, 1200, 1180, 1140, 1080, 950, 920, 880, 840, 700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.93–7.92 (d, 1 H), 7.79–7.78 (d, 1 H), 7.62–7.60 (d, 2 H), 7.48–7.40 (m, 3 H), 5.26 (s, 2 H). The sulfonyl chloride (**15b**) was reduced to **sodium 3,5-dichloro-2-(benzyloxy)benzenesulfinate (16b)** by adding 7.75 g (61.5 mmol) of Na_2SO_3 and 5.16 g (61.4 mmol) of $NaHCO_3$ in 150 mL of H_2O during 30 min to 10.0 g (28.4 mmol) of the sulfonyl chloride (**15b**) in 100 mL of acetone at 0 °C. The solution was stirred for 15 min more at 0 °C (reaction at ca. 25 °C led to significant side reactions). Acetone then was removed under reduced pressure at 25 °C for 6 h, and the residue was extracted with CH_2Cl_2 (50 mL). As with **16a**, the solution was freeze-dried, the solid was partially dissolved in MeOH (50 mL), the solid was removed, the volume was reduced to 20 mL, Et_2O (20 mL) was added, the precipitate was discarded, and the product was precipitated with Et_2O (200 mL) and dried; yield, 9.20 g (96%) of the sulfinate salt **16b**: IR (Nujol) 3100, 3050, 1560, 1440, 1370, 1260, 1220, 1120, 1080, 1044 s, 980 s, 880, 840, 760, 720 cm^{-1}; ^1H NMR (D_2O) δ 7.60–7.54 (m, 4 H), 7.46–7.40 (m, 3 H), 5.10 (s, 2 H). For characterization of the sulfinate salt (**16b**) as **1-adamantyl 3,5-dichloro-2-(benzyloxy)benzenesulfinate (18b)**, the sulfinate (1.00 g, 2.95 mmol) was dissolved in 5 mL of THF, and chlorotrimethylsilane (2.56 g, 23.6 mmol) was added (cf. ref 10). The mixture was stirred for 1 h at 25 °C. 1-Adamantanol (0.30 g, 1.97 mmol) in 2 mL of THF was added to the mixture, which then was stirred for 24 h at 25 °C. THF was removed, and 60 mL of CH_2Cl_2 was added. The CH_2Cl_2 extract was washed with cold brine (50 mL × 2) and dried. Removal of CH_2Cl_2 left an oil, which was purified by preparative TLC (1:4 acetone/hexane). A fraction with R_f 0.55 amounted to 0.30 g (34%) of **18b** as a colorless oil, which crystallized in pentane at 0 °C after 24 h: mp 109–111 °C; IR (neat) 3050, 2925, 2850, 1570, 1440 s, 1360, 1260 s, 1120 s, 1040 s, 960, 890, 780, 720, 700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.80–7.79 (d, 1 H), 7.54–7.53 (d, 1 H), 7.49–7.37 (m, 5 H), 5.28–4.97 (dd, 2 H), 2.13 (s, 3 H), 1.92 (s, two small shoulders, 6 H), 1.57 (s, two small shoulders, 6 H). Anal. Calcd for $C_{23}H_{24}Cl_2O_3S$: C, 61.20; H, 5.36; S, 7.10. Found: C, 61.14; H, 5.40; S, 7.58. Also, a fraction of 0.14 g with R_f 0.49 was collected: ^1H NMR ($CDCl_3$) δ 7.82–7.71 (d, 1 H), 7.76–7.75 (d, 1 H), 7.53–7.41 (m, 5 H), 5.20–5.11 (dd, 2 H), 3.52 (s, 3 H); the NMR spectrum indicated this compound to be methyl 3,5-dichloro-2-(benzyloxy)benzenesulfinate, no doubt produced from MeOH present in the sodium sulfinate (**16b**); formation of this methyl ester presumably accounts for the lower yield than expected of **18b**.

Reactions of the Hydroxyarenesulfonyl Halides 1 and 11 with Pyridine To Give Polymer (4, n = ca. 3) and Dimer (17), Respectively. For the reaction of the *p*-hydroxy chloride (**1**), 1.00 g (3.82 mmol)[5] of **1** was dissolved in 15 mL of CH_2Cl_2, and pyridine (0.30 g, 3.80 mmol) in 5 mL of CH_2Cl_2 was added dropwise. After 2 h of stirring, a white precipitate was removed, washed with cold water and acetone, and dried. The resulting white solid amounted to 0.40 g (44%, calcd as **4**, n = 3, with H, Cl terminals): mp >250 °C; insoluble in H_2O, CH_2Cl_2, or $CHCl_3$: IR 3150, 3120, 1560 s, 1430, 1400 s br, 1220 s, 1180 s br, 1110, 1060, 870, 790 s br, 740, 640 cm^{-1}. Anal. Calcd for $C_{18}H_7Cl_7O_9S_3$ (**4**, n = 3, + H, Cl terminals): C, 30.39; H, 0.99; S, 13.52; Cl, 34.88. Found: C, 30.44; H, 1.36; S, 13.81; Cl, 34.85.

For reaction of the *o*-hydroxy compound (**11**), 1.00 g of **11** (3.82 mmol) was dissolved in CH_2Cl_2 (20 mL). A solution of pyridine (0.31 g, 3.92 mmol) in CH_2Cl_2 (5 mL) was added dropwise. The resulting yellow color of the solution faded after 1.5 h. A white precipitate then was isolated by filtration, rinsed with H_2O (20 mL) and acetone (10 mL), and dried; yield, 0.50 g (58% calcd as the dimer **17**): mp >250 °C; IR 3075, 1560 s, 1420 s, 1380 s, 1260, 1180 s, 1110, 1060, 870, 800, 750 cm^{-1}; MS m/z (relative intensity) 97 (56), 126 (66), 160 (77), 208 (35), 224 (100), 448 ($m^{\cdot+}$, 49), 450 (m + 2, 68), 452 (m + 4, 37), 456 (m + 6, 10), 458 (m + 8, 2). Anal. Calcd for $C_{12}H_4Cl_4O_6S_2$ (**17**): C, 32.02; H, 0.90; S, 14.25. Found: C, 32.29; H, 0.93; S, 15.69.

The dimer **17** (0.30 g, 0.67 mmol) was suspended in 10 mL of toluene containing 0.12 g (1.38 mmol) of morpholine, and the mixture was heated under reflux for 24 h. The resulting solution was cooled, washed with H_2O (100 mL), and dried. Removal of the toluene gave 0.30 g (72%) of the morpholide **20**, mp 149–151 °C, undepressed by authentic **20** prepared from the sulfonyl chloride (**11**), morpholine, and Et_3N; the ^1H NMR spectrum was identical with that of authentic **20**. The authentic morpholide (**20**) had the following properties: mp 150–152 °C; IR 3350 s, 3100, 3000, 2925, 2895, 1600, 1475, 1420, 1330, 1260, 1240, 1150, 1110,

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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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