# Preparation and Trapping of Sulphenic Acids

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Benzene- and toluene-α-sulphenic acids have been prepared under mild conditions from 4-benzenesulphinyl- and 4-toluene-α-sulphinyl-4-methylpentan-2-one respectively. The acids were trapped with norbornadiene.

THE pyrolysis of sulphoxides bearing a β-hydrogen generates sulphenic acids by a concerted *syn*-elimination.[1] Although some anthraquinone sulphenic acids have been isolated,[2] in general the unstable sulphenic acids have been characterised by reactions with soft electrophiles or nucleophiles.[3] Examples of trapping are legion and most notable in penicillin sulphoxide chemistry.[4] We required a novel preparation of sulphenic acids so as to permit the preparation of adducts from thermally and/or acid sensitive alkenes under mild conditions. As model systems, new preparations of benzene- and toluene-α-sulphenic acids and their trapping by norbornadiene are described.

Both toluene-α-thiol[5] and thiophenol[6] readily added to 4-methylpent-3-en-2-one giving the sulphides (1a and c). The sulphide (1a) was oxidised with sodium metaperiodate to the stable crystalline sulphoxide (1b). The
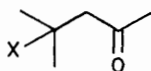
(1)

a; X = PhCH₂S
b; X = PhCH₂S(=O)
c; X = PhS
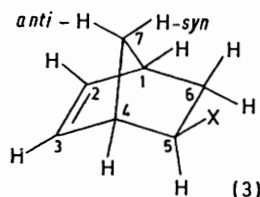d; X = PhS(=O)
e; X = PhCH₂SO₂
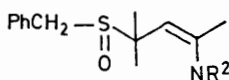
(2)

phenylthio-analogue (1c), however, gave an unstable homogeneous product (t.l.c.), most plausibly the sulphoxide (1d). The sulphoxide (1b) in cyclohexane decomposed slowly at room temperature and rapidly at 50 °C. Addition of a catalytic amount of pyrrolidine, piperidine, diethylamine, or methylamine, but not triethylamine or pyridine, decomposed the sulphoxide (1b) rapidly at room temperature. Possibly, the elimination proceeded *via* the enamine (2). By comparison with authentic samples,[7] the presence of dibenzyl disulphide, benzyl toluene-α-thiosulphonate, benzyl toluene-α-thiosulphinate, and 4-methylpent-3-en-2-one among the products was identified. Clearly,[7] toluene-α-sulphenic acid was the first intermediate. The presumed sulphoxide (1d) rapidly decomposed

giving diphenyl disulphide, phenyl benzenethiosulphonate, phenyl benzenethiosulphinate (traces), and 4-methylpent-3-en-2-one.

On heating in norbornadiene at 50 °C, the sulphoxide (1b) gave the trapped product (3a) in high yield. Without the rigorous exclusion of oxygen considerable quantities (60%) of the sulphone (1e) were also produced.

(3)
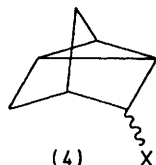
a; X = PhCH₂S(=O)
b; X = PhS(=O)
c; X = PhCH₂S
d; X = PhS

Rapid atmospheric oxidation of toluene-α-sulphenic acid and conjugate re-addition of toluene-α-sulphinic acid to 4-methylpent-3-en-2-one is a reasonable pathway. An authentic sample of the sulphone (1e) was prepared from the 3-chloroperoxybenzoic acid oxidation of the sulphide (1a). Formulation of the trapped product (3a) was in complete agreement with all spectral data and analysis.

Metaperiodate oxidation of the sulphide (1c) and reaction with norbornadiene at 50 °C *in situ* gave the sulphoxide (3b), the intermediates in this case being the sulphoxide (1d) and benzenesulphenic acid.

Deoxygenation of the sulphoxides (3a and b) using *o*-phenylene phosphorochloridite as detailed elsewhere[8] gave the sulphides (3c and d). Toluene-α-thiol was found to add efficiently *via* a radical pathway[9] to norbornadiene. The product monosulphide was different from the sulphide (3c). Oxidation of the monosulphide with sodium metaperiodate gave a new sulphoxide which lacked vinyl protons and differed from the trapped product (3a). The new products were assigned the tricyclic[9] structures (4a and b).

Although the relative stereochemistry at sulphur in both sulphoxides (3a and b) was not assigned, the bicyclic products (3a—d) were all shown to have *exo* stereochemistry. This followed from analyses of the n.m.r. spectra (see Experimental section). In all the spectra, the proton assigned to H-5 was coupled to 6-*endo*-H (*J* 8 Hz), 6-*exo*-H (*J* 4 Hz), and 7-*anti*-H (*J* 2

Hz). In the sulphoxide (3b) the 7-*anti* proton clearly showed two **W** couplings (both J 2 Hz). The n.m.r. spectra of 5-*exo*- and *endo*-substituted norbornenes have been described elsewhere in detail.[10]

(4)   X

a; X = PhCH$_2$S
b; X = PhCH$_2$S(=O)

The mild low-temperature neutral generation of sulphenic acids herein described should prove of value in the selective functionalisation of unstable alkenes. Of recent note is the cyclisation of unsaturated sulphenic acids generated by a different route.[11] Enone protection by the addition of thiophenol and subsequent regeneration by the oxidative elimination of benzenesulphenic acid has been applied in a synthesis of turmerone.[12]

EXPERIMENTAL

Melting points were recorded on a Kofler hot stage and are corrected. Unless stated to the contrary, i.r. and n.m.r. spectra were recorded for solutions in chloroform and deuteriochloroform respectively. Solvents and reagents were purified by standard procedures.[13] Organic extracts were dried over sodium sulphate and evaporated under reduced pressure ($\leqslant 40°$). Light petroleum and petroleum refer to the redistilled fractions with respective b.p.s 40—60 and 60—80°. Preparative t.l.c. was carried out on Merck Kieselgel GF$_{254}$; the developing solvent is given in parentheses and compounds are listed in sequence of increasing polarity. General procedures are described in full in the first instance only.

4-*Methyl*-4-*benzylsulphinylpentan*-2-*one*   (1b).—Sodium (0.5 g) was added with stirring to toluene-α-thiol (12.42 g) in diethyl ether (100 ml). When dissolved (15—20 min), 4-methylpent-3-en-2-one (11.78 g) was added dropwise. After 1 h, the mixture was washed with 0.5% (v/v) sulphuric acid (3 × 25 ml), dried, and evaporated. Distillation gave 4-methyl-4-benzylthiopentan-2-one (1a) (18.66 g, 84%), b.p. 141—142° at 1 mmHg, (lit.,[4] 126—129° at 0.2 mmHg), τ 2.75br (5 H, s, Ph), 6.27 (2 H, s, SCH$_2$), 7.37 (2 H, s, COCH$_2$), 7.93 (3 H, s, COMe), and 8.58 (6 H, s, CMe$_2$). Sodium metaperiodate (6.42 g) in water (15 ml) was added to the sulphide (1a) (5.11 g) in THF (30 ml) under nitrogen. After 10—12 h in the dark, sodium iodate was removed by filtration and the filtrate extracted with chloroform (3 × 50 ml). The combined organic phase was washed with water, dried, and evaporated to give the sulphoxide (1b) (4.98 g, 91%). Recrystallisation from chloroform–light petroleum gave the *sulphoxide* (1b) m.p. 108—109°, ν$_{max.}$ 2 950m, 2 878m, 1 710vs, 1 600w, 1 450m, 1 350s, 1 300w, 1 120m, 1 010m, and 940w cm^{-1}, τ 2.74 (5 H, s, Ph), 6.3 (2 H, AB q, J 13 Hz, ArCH$_2$), 7.24 (2 H, AB q, J 16 Hz, COCH$_2$), 7.84 (3 H, s, COMe), and 8.59 (6 H, s, CMe$_2$), m/e 238 (M^+), 140, 99, 98, 91 (base), and 83 (Found: C, 65.7; H, 7.45; S, 13.5. C$_{13}$H$_{18}$O$_2$S requires C, 65.5; H, 7.6; S, 13.45%).

4-*Phenylsulphinyl*-4-*methylpentan*-2-*one* (1d).—4-Methyl-4-phenylthiopentan-2-one [5] (1c) (70%) was prepared

similarly to the sulphide (1a). An aliquot was purified by preparative t.l.c. (petroleum), ν$_{max.}$ (film) 3 060w, 2 970m, 2 930w, 1 725vs, 1 580w, 1 480m, 1 440s, 1 360s, 1 160m, 1 120s, 1 028m, 750s, and 695s cm^{-1}, λ$_{max.}$ (CHCl$_3$) 267 nm (ε 1 400), τ 2.64 (5 H, m, Ph), 7.35 (2 H, s, COCH$_2$), 7.89 (3 H, s, COMe), and 8.79 (6 H, s, CMe$_2$), m/e 208 (M^+), 110 (100%), 99, and 43 (Found: C, 69.55; H, 7.85. Calc. for C$_{12}$H$_{16}$OS: C, 69.2; H, 7.75%). Phosphate buffer (pH 6.8; 0.025M; 3 ml) and sodium metaperiodate (1.05 g) were added in sequence to the sulphide (1c) (0.975 g) in THF (5 ml) under nitrogen. After 5 h in the dark (t.l.c.), work-up as for the sulphoxide (1b) resulted in decomposition. Preparative t.l.c. (diethyl ether–light petroleum 1 : 19) gave diphenyl disulphide (0.22 g, 43%), phenyl benzenethiosulphonate (0.26 g, 44%), phenyl benzenethiosulphinate [traces (t.l.c.)], and 4-methylpent-3-en-2-one (0.39 g, 85%). All were identical (m.p., t.l.c., and i.r., n.m.r., and mass spectra) with authentic samples.[7] Subsequently, the sulphoxide was not isolated but used in solution after removal of sodium iodate by filtration.

4-*Methyl*-4-*benzylsulphonylpentan*-2-*one*   (1e).—3-Chloroperoxybenzoic acid (1.57 g) was added to the sulphide (1a) (1 g) in chloroform (15 ml). After 2 h, the solution was washed with aqueous sodium metabisulphite and water (twice), dried, and evaporated, and the product recrystallised from chloroform–light petroleum to give the *sulphone* (1e) (1.06 g, 93%), m.p. 129—129.5°, ν$_{max.}$ 3 010m, 2 920m, 1 740vs, 1 480w, 1 460m, 1 360m, 1 300vs, 1 150s, 1 100vs, 1 028w, and 940w cm^{-1}, τ 2.67br (5 H, s, Ph), 6.17 (2 H, s, ArCH$_2$), 7.15 (2 H, s, COCH$_2$), 7.89 (3 H, s, COMe), and 8.45 (6 H, s, CMe$_2$), m/e 254 (M^+) 132, 99, 98, 91, 90, and 43 (Found: C, 61.3; H, 7.1. C$_{13}$H$_{18}$O$_3$S requires C, 61.4; H, 7.15%).

Decomposition of the Sulphoxide (1b).—The sulphoxide (1b) (300 mg) in cyclohexane (4 ml) was heated to 50 °C for 2 h, cooled, and evaporated, and the residue was separated by preparative t.l.c. (diethyl ether–light petroleum 1 : 19) to give dibenzyl disulphide (35 mg, 23%), benzyl toluene-α-thiosulphonate (39 mg, 22%), benzyl toluene-α-thiosulphinate (81 mg, 49%), and 4-methylpent-3-en-2-one (94 mg, 76%), all identical (m.p., t.l.c., and i.r., n.m.r., and mass spectra) with authentic samples.[7] The sulphoxide (1b) decomposed only slowly (>60 h) at room temperature in cyclohexane solution. Decomposition was rapid (<30 min) in the presence of a catalytic amount of pyrrolidine, piperidine, diethylamine, or methylamine but not triethylamine nor pyridine. In each case, dibenzyl disulphide, benzyl toluene-α-thiosulphonate, benzene toluene-α-thiosulphinate, and 4-methylpent-3-en-2-one were detected (t.l.c.).

exo-5-*Benzylsulphinylbicyclo*[2.2.1]*hept*-2-*ene*   (3a).— The sulphoxide (1b) (0.5 g) was added to norbornadiene (5 ml) whilst oxygen-free nitrogen was bubbled through the mixture. The mixture was heated to 50 °C for 0.5—1 h (t.l.c.) to give a clear solution. After cooling and evaporation, the residue was recrystallised from chloroform–light petroleum to give the *sulphoxide* (3a) (428 mg, 92%), m.p. 108—108.5°, ν$_{max.}$ (Nujol) 1 450s, 1 290w, 1 280w, 1 260w, 1 140m, 1 090m, 1 035s, 1 000w, 930w, 890w, 750s, 730s, and 695s cm^{-1}, τ 2.78 (5 H, s, Ph), 3.83 (1 H, dd, $J_{2,3}$ 6, $J_{3,4}$ 3 Hz, 3-H), 4.00 (1 H, dd, J 6, $J_{1,2}$ 3 Hz, 2-H), 6.09 (2 H, ABq, J 14 Hz, ArCH$_2$), 7.04br (1 H, s, 4-H), 7.13br (1 H, s, 1-H), 7.74 (2 H, m, 5-H, 6-*exo*-H), 8.26br (1 H, d, $J_{7-syn, 7-anti}$ 8 Hz, 7-*syn*-H), and 8.62 (2 H, m, 7-*anti*-H, 6-*endo*-H); irradiation at τ 7.04—7.13 resulted in form-

ation of an AB quartet at τ 3.83 and 4.00 (2 H, J 6 Hz), m/e 232 (M^+) 93, 92, 91 (base), 77, and 65 (Found: C, 72.25; H, 6.9. $C_{14}H_{16}OS$ requires C, 72.4; H, 6.95%). When the trapping was carried out without rigorous exclusion of oxygen, the sulphoxide (3a) was obtained contaminated by the sulphone (1e) (60%), identical with authentic material. Although the sulphoxide (1b) rapidly decomposed under secondary amine catalysis (see above), no addition to norbornadiene was observed in this case.

exo-5-*Phenylsulphinylbicyclo*[2.2.1]*hept*-2-ene (3b).—Reaction of the sulphoxide (1d) and norbornadiene as above gave, on distillation at 145° and 10^{-4} mmHg, the *sulphoxide* (3b), m.p. 66—67° (from $CHCl_3$–light petroleum), $\nu_{max.}$ (Nujol) 1 450m, 1 340m, 1 280w, 1 260w, 1 140brm, 1 080m, 1 030s, 980m, 750s, 730s, and 690s cm^{-1}, τ 2.48 (5 H, s, Ph), 3.80 (1 H, dd, $J_{2,3}$ 6, $J_{3,4}$ 3 Hz, 3-H), 3.94 (1 H, dd, J 6, $J_{1,2}$ 3 Hz, 2-H), 6.94vbr (1 H, s, 4-H), 7.04vbr (1 H, s, 4-H), 7.04vbr (1 H, s, 1-H), 7.48 (1 H, ddd, $J_{5,6-endo}$ 8, $J_{5,6-exo}$ 4, $J_{5,7-anti}$ 2 Hz, 5-H), 7.86 (1 H, ddd, $J_{6-exo,6-endo}$ 12, J 4, $J_{6-exo,1}$ 3 Hz, 6-exo-H), 8.16br (1 H, d, $J_{7-syn,7-anti}$ 9 Hz, 7-syn-H), 8.56 (1 H, d, with 2 smaller couplings J 8, 2, and 2 Hz, 7-anti-H), and 8.86 (1 H, ddd, J 12 and 8, $J_{6-endo,7-anti}$ 2 Hz, 6-endo-H); irradiation at τ 6.94—7.04 resulted in formation of an ABq at τ 3.80, 3.94 (2 H, J 6 Hz) and a dd at τ 7.86 (1 H, J 12 and 4 Hz), and irradiation at τ 7.48 resulted in a dd at 8.56 (1 H, J 8 and 2 Hz), m/e 218 (M^+), 136, 94, 93, 91, 78, 77, 65, 51, 42, 41, and 39 (Found: C, 71.6; H, 6.5. $C_{13}H_{14}OS$ requires C, 71.5; H, 6.45%).

exo-5-*Benzylthiobicyclo*[2.2.1]*hept*-2-ene (3c) —Deoxygenation of the sulphoxide (3a) with o-phenylene phosphorochloridite [8] and distillation gave the *sulphide* (3c) (85%), b.p. 96—96.5° at 2 × 10^{-4} mmHg, $\nu_{max.}$ 3 010w, 2 990w, 2 970s, 1 605m, 1 495m, 1 450m, 1 330s, 1 280w, and 900w cm^{-1}, τ 2.79 (5 H, m, Ph), 4.00 (1 H, dd, $J_{2,3}$ 5, $J_{3,4}$ 3 Hz, 3-H), 4.09 (1 H, dd, J 5, $J_{1,2}$ 3 Hz, 2-H), 6.24 (2 H, s, ArCH$_2$), 7.19vbr (1 H, s, 4-H), 7.23vbr (1 H, s, 1-H), 7.51 (1 H, ddd, $J_{5,6-endo}$ 8, $J_{5,6-exo}$ 4, $J_{5,7-anti}$ 2 Hz, 5-H), 8.34br (1 H, d, $J_{7-anti,7-syn}$ 9 Hz, 7-anti-H), and 8.60 (3 H, m, 6-exo-, 6-endo-, and 7-syn-H); irradiation at 7.19—7.23 resulted in an AB q at 4.00, 4.09 (2 H, J 5 Hz), m/e 216 (M^+), 150, 125, 92, and 91 (base) (Found: C, 77.45; H, 7.65. $C_{14}H_{16}S$ requires C, 77.75; H, 7.45%).

exo-5-*Phenylthiobicyclo*[2.2.1]*hept*-2-ene (3d).—Deoxygenation [8] of the sulphoxide (3b) gave the sulphide (3d) (83%), b.p. 95° at 5 × 10^{-4} mmHg, $\nu_{max.}$ (film) 3 070w, 2 980s, 2 880w, 1 590m, 1 480s, 1 448m, 1 340s, 1 320w, 1 280w, 1 250w, 1 150w, 1 100w, 1 028w, 910w, 740s, and 695s cm^{-1}, $\lambda_{max.}$ (THF) 256 nm (ε 6 000), τ 2.74 (5 H, s, Ph), 3.89 (1 H, dd, $J_{2,3}$ 5.5, $J_{3,4}$ 3 Hz, 3-H), 4.00 (1 H, dd, J 5.5, $J_{1,2}$ 3 Hz, 2-H), 6.96 (1 H, ddd, $J_{5,6-endo}$ 8, $J_{5,6-exo}$ 4, $J_{5,7-anti}$ 2 Hz, 5-H), 7.10vbr (1 H, s, 4-H), 7.17vbr (1 H, s, 1-H), 8.26vbr (1 H, d, $J_{7-syn,7-anti}$ 8.5 Hz, 7-syn-

H), and 8.49 (3 H, m, 6-exo-, 6-endo-, and 7-anti-H), m/e 202 (M^+), 137, 136 (base), 135, 91, and 77 (Found: C, 76.9; H, 7.25. Calc. for $C_{13}H_{14}S$: C, 77.2; H, 7.0%).

Addition of Toluene-α-thiol to Norbornadiene.—Toluene-α-thiol (2.48 g) was added dropwise at −5 °C to norbornadiene (1.8 g) under nitrogen. After 18—20 h at room temperature (t.l.c.) the mixture was evaporated and the residue chromatographed on silica (eluant light petroleum) and separated by preparative t.l.c. (diethyl ether–light petroleum 1 : 19). The crude oily sulphide (4a) (3.68 g, 87%) was oxidised with sodium metaperiodate as for the sulphide (1a) to give the sulphoxide (4b) (3.28 g, 83%), m.p. 114—116°, τ 2.64br (5 H, s, Ph), 6.07 (2 H, s, ArCH$_2$), 7.34 (1 H, m, SCH), 7.54, 8.4, and 8.47, m/e 232 (M^+), 93 (base), 92, 91 (base), 77, and 65 (Found: C, 72.35; H, 7.0. $C_{14}H_{16}OS$ requires C, 72.4; H, 6.95%).

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