Divergent Thermal Behaviour of Phenoxymethyl Phenyl Sulphoxide under Gas- and Condensed-phase Conditions

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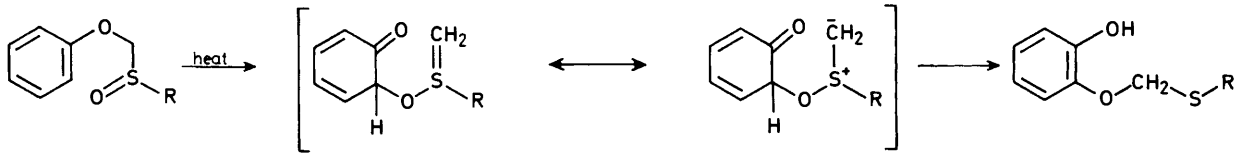
A comparison is made between the behaviour of phenoxymethyl phenyl sulphoxide (**2**) under different thermolytic conditions. Passage of (**2**) through a quartz tube in the gas phase at 600 °C results in products which can be rationalised by assuming homolytic cleavage of the S–C bond and the generation of both the phenylsulphinyl (**4**) and phenoxymethyl (**6**) radicals which decompose by separate pathways to yield *S*-phenyl benzenethiosulphonate (**3**) and benzaldehyde, respectively. On the other hand, solution thermolysis of (**2**) in [$^2H_8$]toluene at 110 °C leads to a facile $S \longrightarrow O$ 1,2-shift and the formation of thermally stable phenoxymethyl benzenesulphenate (**9**) in quantitative yield. A bimolecular oxygen-transfer mechanism is proposed for the conversion of (**2**) into (**9**) which is rationalised in terms of a double (stabilising) anomeric effect brought about by the acetal group in (**9**). Cross-over experiments support the mechanism.

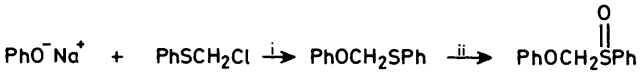
O-Aryl monothiocacetal *S*-oxides represent a sparsely studied group of compounds which intrigue us since conceptually they can undergo an as yet unreported Claisen-like rearrangement with the possibility of a further 1,2-anionic shift of the resulting Pummerer intermediate (Scheme 1). So far we have failed to observe such a transformation but in this paper we report details of the thermolytic behaviour of one of these compounds, *viz.* phenoxymethyl phenyl sulphoxide (**2**) under both gas- and solution-phase conditions, with particular reference to the mechanism of another highly unusual rearrangement brought about in the condensed phase.



Scheme 1.

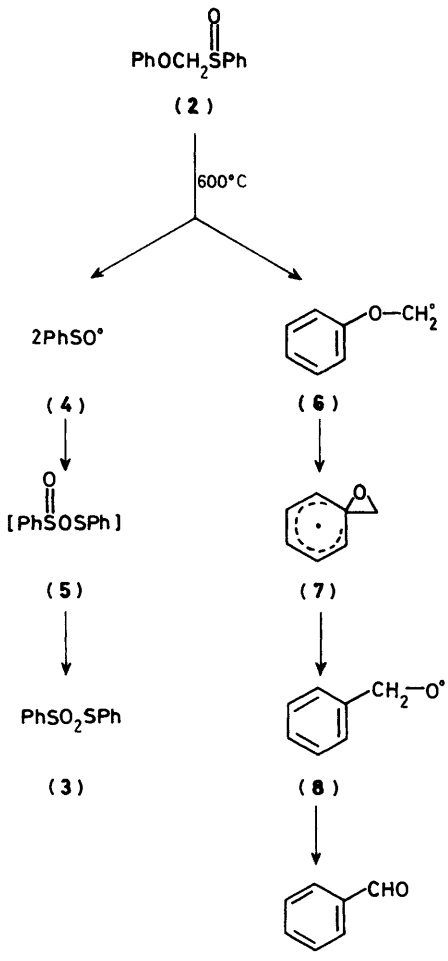
Results and Discussion

The title compound (**2**) was prepared as outlined in Scheme 2 by the reaction of sodium phenoxide with α-chloromethyl phenyl sulphide in dimethylformamide (DMF) at room temperature to give (**1**) in 75% yield, followed by quantitative oxidation with 1 equiv. of *m*-chloroperbenzoic acid (MCPBA) in methylene chloride at −40 °C. Pumping the vapour of (**2**) at 600 °C through a quartz tube resulted in the formation of two distinct products. The first, collected from the neck of the outlet trap, consisted almost entirely of *S*-phenyl benzenethiosulphonate (**3**) as shown by comparison with an authentic sample. The second, more volatile product, which collected in the main body of the outlet trap, was found to consist almost entirely of benzaldehyde. The formation of these products in virtually quantitative yields can be explained on the basis of homolytic scission of the relatively weak S(O)–C bond (D = 230 kJ mol^{-1})[1] in (**2**) which simultaneously generates both the phenylsulphinyl (**4**) and phenoxymethyl (**6**) radicals, which decompose by separate pathways (Scheme 3) to yield the end-products (**3**) and benzaldehyde, respectively. Both these pathways have been observed independently, but never together. Thus, Topping and Kharasch[2] reported the formation of the thiosulphonate ester (**3**) from the thermal decomposition of phenylsulphenylnitrate by coupling of the phenylsulphinyl radical (**4**) to give the intermediate sulphinylsulphenate (**5**), which then undergoes an $O \longrightarrow S$ 1,2-shift to yield (**3**). The conversion of the phenoxymethyl radical (**6**) into benzaldehyde presumably occurs *via* the spiranic oxirane radical (**7**), followed by rearrangement to the benzoyloxy radical (**8**) and loss of a hydrogen, as postulated by De Mayo and Marty[3] to account for the similar formation of 2-hydroxy-4-methylbenzaldehyde from 4-methyl-2-nitroanisole upon pyrolytic expulsion of NO_2. Whether the loss of the hydrogen atom entails the formation of molecular hydrogen or involves an abstraction has not been established, but thermochemical estimates have shown that the former process is at least reasonable in certain cases.[4]



Scheme 2. *Reagents and conditions:* i, DMF, 20 °C; ii, MCPBA, −40 °C.

In contrast with the behaviour of (**2**) in the gas phase, solution thermolysis of (**2**) in [$^2H_8$]toluene at 110 °C over a period of *ca.* 2 h resulted in a facile rearrangement to phenoxymethyl benzenesulphenate (**9**) in quantitative yield. The product was found to be stable in solution at room temperature for at least 3 months. The reaction was readily monitored by either ^{1}H n.m.r. or i.r. spectroscopy. Initially the ^{1}H n.m.r. spectrum showed a pair of doublets at δ 4.83 and 4.99 (J = 10 Hz) corresponding to the prochiral methylene protons in (**2**); these gradually collapsed when the sample was heated to

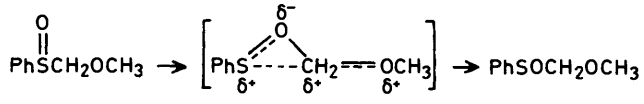


Scheme 3.

a singlet at δ 5.40 due to the sulphenate (**9**). Similarly, the i.r. S=O band at 1 042 cm^{-1} disappeared with the simultaneous appearance of a strong, broad absorption at 950 cm^{-1} characteristic of the S–O stretching in sulphenates.

This rearrangement is analogous in outcome to the thermal $N \longrightarrow O$ 1,2-shift in the Meisenheimer rearrangement of amine *N*-oxides to substituted hydroxylamines[5] and is in direct contrast with the generally preferred thermal $O \longrightarrow S$ 1,2-shifts of the sulphenate ⟶ sulphoxide,[6] sulphoxylate ⟶ sulphinate,[7] and sulphinate ⟶ sulphone rarrangements,[8] and the $O \longrightarrow P$ 1,2-shift in the phosphinate ⟶ phosphine oxide rearrangement.[9]

The observation of such a sulphoxide ⟶ sulphenate rearrangement is rare, although it is invoked[10] to account for sulphoxide racemisations *via* reversible sulphenate formation. In the only instance to date in which the product from an $S \longrightarrow O$ 1,2-shift could be isolated and identified, Maricich and Harrington[11] reported the extremely facile rearrangement of methoxymethyl phenylsulphoxide to the corresponding sulphenate (Scheme 4). However, both the sulphoxide and

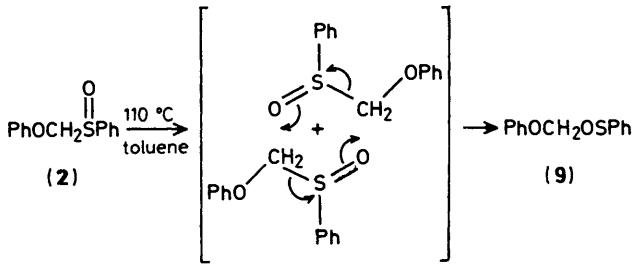


Scheme 4.

the sulphenate were thermally labile at room temperature, resulting in the irreversible disproportionation of the sulphenate to *S*-phenyl benzenethiol sulphinate and bis(methoxymethyl) ether.

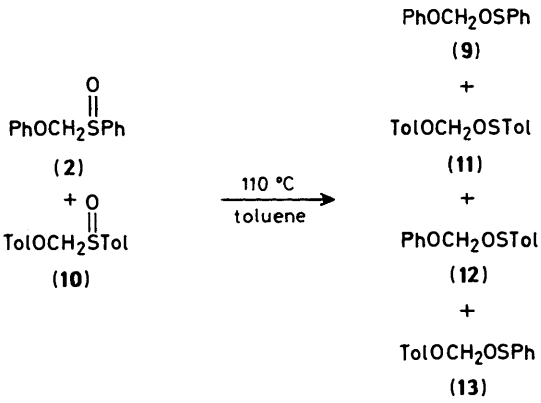
Whilst the Meisenheimer rearrangement has been shown to occur *via* a radical scission–recombination mechanism,[12] Maricich and Harrington proposed that the sulphoxide ⟶ sulphenate rearrangement proceeded by an intramolecular pathway involving a three-membered, polarised activated complex as depicted in Scheme 4. Such a transition state was rejected in the case of the Meisenheimer rearrangement on steric grounds,[13] but a radical mechanism also seems unlikely in view of the quantitative formation of the sulphenate (**9**), *i.e.* the absence of any decomposition products as observed in the gas-phase reaction. Moreover, the use of toluene as the solvent would render radical abstraction processes (*e.g.* formation of bibenzyl) a distinct but unobserved likelihood even allowing for a cage effect.

A third possibility that has not been considered previously involves a bimolecular oxygen-transfer mechanism as depicted in Scheme 5, whereby the sulphoxide oxygen is exchanged with



Scheme 5.

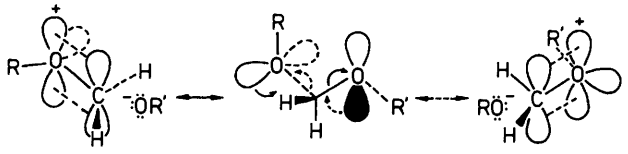
that of another molecule. In order to test this hypothesis, a 'cross-over' experiment was carried out by heating a mixture of (**2**) and the disubstituted *p*-methyl derivative (**10**) under the same conditions (Scheme 6). ^1H N.m.r. monitoring of the



Scheme 6.

reaction showed the disappearance of the four distinct pairs of doublets due to the prochiral methylene protons in (**2**) and (**10**), with the concomitant appearance of four singlets due to the methylene protons in (**9**), (**11**), and the two cross-over products (**12**) and (**13**). Similarly, the two methyl resonances in (**10**) were replaced by four methyl resonances for compounds (**11**), (**12**), and (**13**). These results would seem to confirm the postulation that a bimolecular oxygen-transfer mechanism is operating for the conversion of (**2**) into (**9**) (Scheme 5). Preclusion of an intramolecular $S \longrightarrow O$ 1,2-shift followed by bimolecular oxygen transfer was established by rearranging both (**2**) and (**10**) independently, followed by heating a mixture of equimolar amounts of (**9**) and (**11**). No reaction took place as established by the non-appearance of any methylene or methyl resonances corresponding to the cross-over compounds (**12**) and (**13**).

Why the rearrangement of (**2**) to thermally stable (**9**) occurs may be a consequence of significant stereoelectronic factors brought about by the acetal group. It seems probable that (**9**) can adopt a conformation (**14**) whereby it takes advantage of a double (stabilising) anomeric effect[14] such that the lone-pairs on the oxygen atoms take up an antiperiplanar arrangement relative to the other O–R group. In terms of the so called 'double-bond–no-bond resonance' concept,[15] this is illustrated by structures (**15**) and (**16**). The modern interpretation of this



(**15**) (**14**) (**16**)

electronic delocalisation may be expressed in terms of overlap of an electron-pair orbital of the oxygen atom with the antibonding orbital of the C–OR σ-bond.[16] Such stereoelectronic stabilisation is unavailable to (**2**). Furthermore, a possible destabilising anomeric effect might operate in (**2**), whereby there is 'lone pair–lone pair' repulsion between the sulphoxide and oxygen non-bonded electron pairs.

Experimental

M.p.s were recorded on a Riechert hot-stage melting-point apparatus and are uncorrected. ^{1}H N.m.r. spectra were recorded on either a Bruker WP200SY or a Bruker WP80SY spectrometer operating at 200 or 80 MHz, respectively. ^{13}C N.m.r. spectra were recorded on a Bruker WP200SY spectrometer operating at 50.3 MHz. I.r. spectra were recorded on Perkin-Elmer 781 infrared spectrophotometer. Mass spectra were recorded on a Kratos MS50TC mass spectrometer.

Ether refers to diethyl ether throughout. Light petroleum refers to the fraction boiling at 40–60°C. Flash chromatography was performed on Fluka Kieselgel GF_{254}.

Preparation of Phenoxymethyl Phenyl Sulphide (**1**).—A modification of the method employed by Kornblum and Lurie[17] was used. To a partial suspension of sodium phenoxide (2.21 g, 19 mmol) in dry DMF (25 cm^3) was added a solution of chloromethyl phenyl sulphide (3.0 g, 25 mmol) in dry DMF (15 cm^3). The reaction mixture was stirred at room temperature for a further 17 h and then poured into water (200 cm^3). This was acidified with 10% aq. HCl and extracted with pentane (6 × 50 cm^3). The combined organic extracts were then washed with water (4 × 50 cm^3), dried and evaporated. The resultant yellow oil was distilled (bulb-to-bulb) at 130 °C and 0.005 mmHg to yield *phenoxymethyl phenyl sulphide* (**1**) (3.03 g, 75%) as a colourless oil; $\nu_{max.}$ 3 100 (C–H), 2.920 (CH_2), 1 598 (C=C), 1 586 (C–C), 1 480 (C=C), 1 438 (C–H), 1 200 (C–O), 740 (C–H), and 690 cm^{-1} (C–H); δ_H(60 MHz; $CDCl_3$) 5.33 (2 H, s, CH_2), 6.69–7.60 (10 H, cm, Ar); δ_C(50 MHz; $CDCl_3$) 72.83, 115.90, 121.76, 126.90, 128.78, 129.29, 130.31, 135.01 (quat. C), and 156.56 (quat. C); *m/z* 216 (*M*$^+$, 50%), 156 (24), 122 (100), 108 (10), 94 (9), 77 (52) (Found: *M*$^+$, 216.0610. $C_{13}H_{12}OS$ requires *M*, 216.0609).

Preparation of Phenoxymethyl Phenyl Sulphoxide (**2**).—To a solution of sulphide (**1**) (1.0 g, 4.63 mmol) in dry methylene chloride (20 cm^3) at −40 °C was added, dropwise with stirring over 15 min, a solution of MCPBA (0.779 g, 4.60 mmol) in dry methylene chloride (20 cm^3). The resulting mixture was stirred at −40 °C for a further 1 h. Gaseous ammonia was then blown over the surface of the reaction mixture for about 1.5 min, and the precipitated salts were filtered. The filtrate was washed with saturated $NaHCO_3$ and brine, filtered, and evaporated. T.l.c. of the reaction mixture showed two spots, one of which was coincident with the starting material. This mixture was then subjected to dry flash-chromatography over silica using a light petroleum–diethyl ether gradient to give *phenoxymethyl phenyl sulphoxide* (**2**) (0.57 g, 57%) as colourless platelets, m.p. 61.5–63 °C (Found: C, 66.23; H, 5.09. $C_{13}H_{12}O_2S$ requires C, 66.22; H, 5.21%); $\nu_{max.}$ 3 060 (C–H), 2 918 (CH_2), 1 598 (C=C), 1 590 (C=C), 1 490 (C=C), 1 440 (CH_2), 1 200 (C–O), 1 042 (S=O), 750 (C–H), 690 cm^{-1} (C–H); δ_H(200 MHz; CD_2Br_2) 4.83 (1 H, d, *J* 10 Hz, CH_2), 4.9 (1 H, d, *J* 10 Hz, CH_2), 6.97–7.67 (10 H, cm, Ar); δ_C(50 MHz; CD_2Br_2) 88.15, 115.66, 122.63, 124.37, 129.10, 129.52, 131.27, 140.87 (quat. C), and 157.14 (quat. C); *m/z* 232 (*M*$^+$, 5%), 125 (6), 123 (10), 107 (93), 93 (12), 77 (100), and 51 (25).

Gas-phase Pyrolysis of Phenoxymethyl Phenyl Sulphoxide (**2**).—The sulphoxide (**2**) (50 mg) was pyrolysed at 600 °C and 0.003 mmHg through a quartz tube. The pyrolysate was collected in quantitative yield in two portions, one from the side-arm of the trap and the other in the main body of the trap. The condensate on the main body was shown by ^{1}H n.m.r. and i.r. spectroscopy to consist almost completely of benzaldehyde, whereas the fraction collected from the side-arm of the trap was found by ^{1}H n.m.r. spectroscopy to consist almost entirely of *S*-phenyl benzenethiosulphonate. This compound had properties identical with those in the literature.[18]

Solution Thermolysis of Phenoxymethyl Phenyl Sulphoxide (**2**).—A solution of sulphoxide (**2**) (50 mg) in [$^2H_8$]toluene (0.5 cm^3) was heated in an oil bath at 110 °C. The progress of the reaction was monitored by ^{1}H n.m.r. spectroscopy and after 75 min the reaction was complete, yielding *phenoxymethyl benzenesulphenate* (**9**) in quantitative yield; $\nu_{max.}$ 3 060 (C–H), 2.922 (C–H), 1 600 (C=C), 1 590 (C=C), 1 494 (C=C), 1 220br (C–O), 950 (S–O), 756 (C–H), 740 (C–H), 690 cm^{-1} (C–H); δ_H(200 MHz; CD_2Br_2) 5.40 (2 H, s, CH_2), 6.93—7.39 (10 H, m, Ar); δ_C(50 MHz; CD_2Br_2) 98.47, 116.32, 122.40, 126.25, 127.55, 129.28, 139.09 (quat. C), and 156.44 (quat. C); *m/z* 232 (*M*$^+$, 8%), 125 (6), 123 (2), 109 (48), 107 (100), and 77 (60) (Found: *M*$^+$, 232.0561. $C_{13}H_{12}O_2S$ requires *M*, 232.0558). This reaction also takes place in [$^2H_3$]nitromethane at 98 °C and [$^2H_4$]dibromoethane at 100 °C.

Preparation of p-*Tolyl* p-*Tolyoxymethyl Sulphoxide* (**10**).—To a suspension of freshly prepared sodium 4-methylphenoxide (0.84 g, 6.48 mmol) in dry DMF (50 cm^3) was added a solution of chloromethyl-*p*-tolylsulphoxide[19] (1.0 g, 6.48 mmol) in DMF (20 cm^3). The reaction mixture was stirred at 70 °C for 10 h, then cooled and poured into water (200 cm^3). The solution was neutralized with 10% aq. HCl and extracted with pentane (6 × 50 cm^3). The combined organic extracts were washed with water (4 × 50 cm^3), dried ($MgSO_4$) and evaporated. The crude product was purified by dry flash chromatography over silica gel (75 g, Merck; 230–400 using diethyl ether–light petroleum, 1:1 as the eluant) followed by crystallization from diethyl ether–light petroleum to give p-*tolyl* p-*tolyloxymethyl sulphoxide* (**10**) as colourless needles, m.p. 95–96 °C (Found: C, 69.20; H, 6.19. $C_{15}H_{16}SO_2$ requires C, 69.20; H, 6.19%); $\nu_{max.}$(KBr) 1 202 cm^{-1} (SO); δ_H(200 MHz; $CDCl_3$) 2.25 (3 H, s, 4-CH_3), 2.37 (3 H, s, 4-CH_3), 4.73 (1 H, d, *J* 9.8 Hz, CH_2), 4.95 (1 H, d, *J* 9.8 Hz, CH_2), 6.87–7.55 (8 H, 2 × AB system, Ar); δ_C(50 MHz; $CDCl_3$) 20.26, 21.17, 88.93, 115.70, 124.44, 129.85, 129.95, 132.17, 137.89, 141.93, and 155.38.

Solution Thermolysis of p-*Tolyl* p-*Tolyloxymethyl Sulphoxide* (**10**).—A solution of sulphoxide (**10**) (0.10 g, 0.384 mmol) in

[$^2H_8$]toluene (0.4 cm^3) was sealed in an n.m.r. tube and heated at 139 °C in boiling xylene for 2.25 h after which time ^1H n.m.r. spectroscopy showed the rearangement to be complete and quantitative. The product (**11**) was purified by distillation (Kugelrohr), b.p. 130–132 °C (0.05 mmHg) (Found: C, 69.20; H, 6.18. $C_{15}H_{16}SO_2$ requires C, 69.20; H, 6.19%); δ_H(80 MHz; [$^2H_8$]toluene) 2.09 (3 H, s, 4-CH_3), 2.19 (3 H, s, 4-CH_3), 5.11 (2 H, s, CH_2), 6.79–7.58 (8 H, 2 × AB system, Ar); δ_H(200 MHz; $CDCl_3$) 2.30 (3 H, s, 4-CH_3), 2.32 (3 H, s, 4-CH_3), 5.67 (2 H, s, CH_2), and 7.01–7.41 (8 H, 2 × AB system, Ar); δ_C(50 MHz; $CDCl_3$) 20.97, 21.59, 91.62, 116.36, 128.41, 129.82, 133.77, 134.52, and 155.38.

Cross-over Experiment Between (**2**) *and* (**10**).—A solution of phenoxymethyl phenyl sulphoxide (**2**) (0.050 g, 0.215 mmol) and *p*-tolyl *p*-tolyloxymethyl sulphoxide (**10**) (0.056 g, 0.215 mmol) in [$^2H_8$]toluene (0.4 cm^3) was heated at 110 °C for 48 h in a sealed n.m.r. tube. Examination of the reaction mixture by ^1H n.m.r. spectroscopy revealed the presence of only four distinct singlets formed in equal proportions at δ 5.06, 5.08, 5.10, and 5.12, corresponding to the methylene groups in the rearranged products (**9**), (**12**), (**13**), and (**11**). In a complementary experiment, no resonances at δ 5.08 and 5.10, which would correspond to the cross-over products (**12**) and (**13**), were observed when equimolar amounts of (**9**) and (**11**) were heated together in a sealed n.m.r. tube at 110 °C for 28 h.

Acknowledgements

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