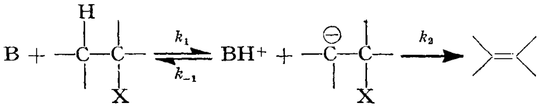
SECTION B
Physical Organic Chemistry

The *E*1cB Nature of the Transition State in the Elimination Reaction of Phenethyl Sulphoxides in Basic Media

By **R. Baker*** and **M. J. Spillett**, Chemistry Department, University of Southampton

Rates of elimination were determined for a number of *p*-X-phenethyl methyl sulphoxides (X = H, Me, OMe, and Cl) with potassium 1,1-dimethylethoxide in 1,1-dimethylethanol; correlation against Hammett σ-constants gave a ρ-value of +4·4. The reaction was found to have a β-deuterium isotope effect of 2·7 and no exchange of the β-hydrogens in the substrate was detected during the elimination. The transition state for the reaction is suggested to have substantial carbanion character.

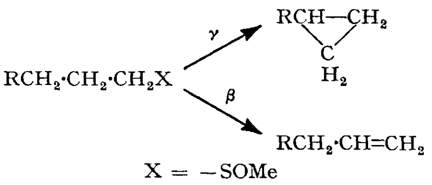
INVESTIGATIONS into the mechanism of elimination reactions have been extensive.[1,2] In particular, considerable effort has been expended in the investigation of the carbanion mechanism [3,4] of olefin-forming eliminations (*E*1cB). The mechanism differs from the more unusual bimolecular (*E*2) mode of elimination in that it is a stepwise process, involving the intermediacy of a discrete carbanion, whereas an *E*2 elimination is concerted and passes through a single transition-state.[5]



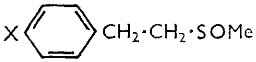
SCHEME 1 Carbanion mechanism (E1cB)

Two possibilities are apparent for the carbanionic elimination mechanism: (*a*) the first step is a rate-determining irreversible formation of the carbanion, and the second step is the relatively rapid ejection of the leaving group; (*b*) the first step is a rapidly attained equilibrium and the second is the rate-limiting, unimolecular decomposition of the carbanion.

In connection with our studies on the factors affecting the competition between β- and γ-eliminations [6] (Scheme 2) we were particularly interested in a detailed knowledge of the mechanism of the β-elimination of sulphoxides in basic media. In particular, we chose to study the rates of elimination, in potassium 1,1-dimethylethoxide–1,1-dimethylethanol, of the series of compounds (I).



SCHEME 2



(I)

a; X = H
b; X = Me
c; X = Cl
d; X = OMe

These sulphoxides have two properties which would be necessary for the existence of an *E*1cB elimination mechanism, *i.e.* a poor leaving group, and a substituent at the β-carbon capable of stabilising a carbanion formed at that site. Earlier work [7] with di-isopropyl sulphoxide has suggested that the elimination proceeds by a concerted mechanism in potassium 1,1-dimethylethoxide–dimethyl sulphoxide, on the basis of a lack of detectable hydrogen–tritium exchange in the unchanged sulphoxide.

RESULTS AND DISCUSSION

Reaction of sodium methyl sulphide with 1-bromo-2-phenylethane, and oxidation of the resulting methyl phenethyl sulphide by sodium metaperiodate gave methyl phenethyl sulphoxide (Ia). The *p*-substituted phenethyl methyl sulphoxides (Ib—d) were prepared by reaction of the toluene-*p*-sulphonate of the corresponding 2-arylethanol with sodium methyl sulphide and oxidation with sodium metaperiodate.

The rates of 1,2-elimination of the sulphoxides, in potassium 1,1-dimethylethoxide–1,1-dimethylethanol–dimethyl sulphoxide, were determined spectrophotometrically. Table 1 reports the second-order rate constants. The reactions were generally followed for 2—3 half-lives, and pseudo-first-order rate constants were determined (a base excess of 60 : 1 was used). Some deviation from linearity of the first-order plot was observed at *ca.* two half-lives in some cases and the rate constants are based on the initial linear portion. Product analyses for the reaction of the sulphoxides under the kinetic conditions were carried out at 50°, v.p.c. analysis of the reaction mixtures showed only the styrenes with no substitution product. No polymerisation

---

[1] W. H. Saunders, 'The Chemistry of the Alkenes,' ed. S. Patai, Interscience, New York, 1964.

[2] D. V. Banthorpe, 'Elimination Reactions,' Elsevier, Amsterdam, 1963.

[3] D. J. McLennan, *Quart. Rev.*, 1967, **21**, 490.

[4] C. K. Ingold, 'Structure and Mechanism in Organic Chemistry,' Cornell University Press, Ithaca, New York, 1953, p. 423.

[5] J. F. Burnett, *Angew. Chem., Internat. Edn.*, 1962, **1**, 225.

[6] R. Baker and M. J. Spillett, *Chem. Comm.*, 1966, 757.

[7] J. E. Hofmann, T. J. Wallace, and A. Schriesheim, *J. Amer. Chem. Soc.*, 1964, **86**, 1561.

Table 1

Rates of elimination[a] of $XC_6H_4\cdot[CH_2]_2\cdot SOMe$ with with Bu^tOK in Me_2SO[b]–Bu^tOH at 52·2°[c]

Sulphoxide	X	10^4k[d] × 10^4 (l. mole^{-1} sec.$^{-1}$)
(Id)	*p*-MeO	2·60 ± 0·05
(Ib)	*p*-Me	7·62 ± 0·1
(Ia)	*p*-H	38·0 ± 2·0
(II) (2,2-[$^2H_2$])	*p*-H	14·0 ± 0·1
(Ic)	*p*-Cl	419 ± 15·0

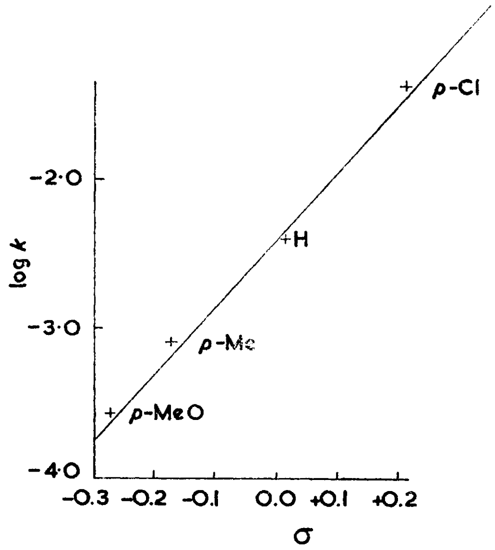
[a] Second-order rate constants determined from pseudo-first-order constants and base concentrations normally, substrate 7—8 × 10^{-4}M, base *ca.* 4·5 × 10^{-2}M. [b] Me_2SO concentration 2·18M. [c] ±0·1°. [d] Average of three or four runs.

was detected when the styrenes were left in the basic media used for the kinetics for more than 20 half-lives of the elimination reaction.

The sulphoxide (Ia) was treated with potassium 1,1-dimethylethoxide in 1,1-dimethylethan[^{2}H]ol to allow the reaction to proceed to 45% completion (72° for 2 hr.) and in potassium 1,1-dimethylethanol–37·5% [$^2H_6$]dimethyl sulphoxide–62·5% 1,1-dimethylethan[^{2}H]ol to 48% completion (25° for 30 min.). The reaction mixtures were analysed quantitatively by v.p.c. The amount of unchanged sulphoxide was not determined, but this was recovered from the reaction mixture and purified.

N.m.r. analysis of the sulphoxide (Ia) showed that the methylene hydrogens adjacent to the phenyl and sulphoxide groups absorbed in the same region. The hydrogens adjacent to the sulphoxide group are acidic, and hydrogen exchange with the deuteriated solvent occurred during the reaction. Hydrogen exchange in the benzylic position of (Ia) could not, therefore, be quantitatively determined. At 160°, however, 1,2-elimination readily occurs from sulphoxides to produce the olefin.[8] The styrene was separated from unpyrolysed sulphoxide and sulphur residues, and analysed for incorporation of deuterium by ^{1}H n.m.r. spectroscopy with the phenyl protons as an internal standard. Earlier work[9] suggests that exchange of the phenyl protons under the reaction conditions is negligible. The α- and β-hydrogens of styrene are distinguishable by ^{1}H n.m.r. analysis, and thus, by pyrolysis of the recovered sulphoxide, any exchange of the benzylic hydrogens could be detected. Successive integrations of the proton signals were carried out automatically with a digital voltmeter and a mean value obtained. The α-proton of styrene appeared as a broad multiplet due to deuteriation in the β-position (75%) as a result of exchange adjacent to the sulphoxide group in the basic media. Even with all possible precautions it was not possible to measure less than 10% hydrogen exchange with any precision. At *ca.* 50% sulphoxide decomposition in both basic media, essentially no exchange of the β-hydrogen in the substrate was detected. (A maximum limit of 10% exchange could certainly be set.)

A plot of the logarithm of the rate constants against the appropriate value for the Hammett substituent constant[10] (Figure) gave a straight line and a value of $\rho = +4\cdot4$. The high +ve ρ-value suggests that the transition state for the elimination reaction has a high degree of carbanion character. A ρ-value of 3 or higher is generally accepted as an indication of an *E*1cB-like transition state. De Puy has suggested that a ρ-value of +5 found from the rates of carbanion polymerisation of styrenes at 25° should be used as a guide for the value expected for an *E*1cB mechanism.[11] A ρ-value of +4·0 was obtained from the rates of exchange of substituted toluenes in potassium cyclohexylamide–cyclohexylamine, indicating considerable development of charge in the transition state.[12] An isotope effect >10 was found for the exchange reaction, indicating that the removal of the proton was the rate-determining step. Certainly, the ρ-value of +4·4 is the highest value obtained for any elimination reaction of 2-arylethyl derivatives (Table 2): thus, it is apparent that the transition state for these sulphoxide eliminations has more carbanion character than any similar system so far investigated.



Plot of logarithm of elimination rates of sulphoxides against Hammett substituent constants

Table 2

ρ-Values for the reaction of 2-arylethyl derivatives with EtONa–EtOH *

Leaving group	ρ-Value	Leaving group	ρ-Value
I	+2·07	Cl	2·61
Br	2·14	SMe_2	2·64
OTs	2·27	F	3·12
		NMe_3	3·77

* D. V. Banthorpe, 'Studies on Chemical Structure and Reactivity.' ed. J. H. Ridd, Methuen, London, 1966, p. 40.

---

[8] C. Walling and L. Bollzky, *J. Org. Chem.*, 1964, **29**, 2699; C. A. Kingsbury and D. J. Cram, *J. Amer. Chem. Soc.*, 1960, **82**, 1810.

[9] D. H. Hunter and D. J. Cram, *J. Amer. Chem. Soc.*, 1966, **88**, 5765.

[10] H. H. Jaffé, *Chem. Rev.* 1953, **53**, 191.

[11] C. H. De Puy, G. F. Morris, J. S. Smith, and R. J. Smat, *J. Amer. Chem. Soc.*, 1965, **87**, 2421.

[12] A. Streitwiser, jun., and H. F. Koch, *J. Amer. Chem. Soc.*, 1964, **86**, 404.

The kinetic isotope effect determined from (Ia) and (II) is $k_{\mathrm{H}}/k_{\mathrm{D}} = 2{\cdot}7$. Theory indicates[13] for a transition state in which the proton is half-transferred to the base, the maximum value of $k_{\mathrm{H}}/k_{\mathrm{D}} \sim 7$ should be obtained. For a transition state in which the proton is more or less than half-transferred, a lower value should be obtained. An *E*1cB pre-equilibrium mechanism would have a $k_{\mathrm{H}}/k_{\mathrm{D}}$ value near unity, since the substrate would exchange most of its deuterium for hydrogen from the solvent before appreciable olefin formation. The isotope effect of 2·7 clearly rules out a pre-equilibrium mechanism and the n.m.r. spectroscopic results indicate the absence of substantial deuterium incoporation in the 2-position adjacent to the aromatic ring in methyl phenethyl sulphoxides during reaction in potassium 1,1-dimethylethoxide–1,1-dimethylethan[^{2}H]ol. Breslow,[14] however, has questioned that even positive evidence for exchange in the unchanged substrate indicates an *E*1cB mechanism. For the *E*2 elimination of 2-arylethyl derivatives the lowest $k_{\mathrm{H}}/k_{\mathrm{D}}$ value of 3·0 was obtained for the reaction of 2-arylethyltrimethylammonium bromide in sodium ethoxide–ethanol at 50°.[15] There is no clear indication as to the expected $k_{\mathrm{H}}/k_{\mathrm{D}}$ for an elimination which involves the formation of a carbanion from which the leaving group is lost without any reprotonation. A value of 1·2 was recorded for the dehydrofluorination of 1,1,1-trifluoro-2-methyl-3-phenylpropane with potassium 1,1-dimethylethoxide–1,1-dimethylethanol[16] at 134°. No hydrogen exchange with the solvent occurred, and the elimination was suggested to proceed through a carbanion, formed irreversibly. For base-catalysed reactions which involve a rate-determining proton removal step (hydrogen isotope exchange, racemisation or allylic rearrangements) kinetic deuterium isotope effects of 0·5—3·0 have been obtained.

On the basis of a deuterium isotope effect of 2·7 and a ρ-value of +4·4, we suggest that the elimination reaction of methyl phenethyl sulphoxide, in potassium 1,1-dimethylethoxide–1,1-dimethylethanol–dimethyl sulphoxide, proceeds through a transition state with substantial carbanion character.

EXPERIMENTAL

1,1-Dimethylethanol was heated under reflux over calcium hydride for 24 hr., then fractionally distilled through a short vacuum-jacketed Vigreux column. The 1,1-dimethylethanol was finally fractionally distilled twice from potassium through a 12 in. column packed with glass helices.

Dimethyl sulphoxide was stored over calcium hydride for 2 days and then fractionally distilled twice under reduced pressure.

[^{2}H$_6$]Dimethyl sulphoxide was prepared by the method of Buncel.[17] The final product was fractionally distilled twice from molecular sieves through a 12 in. column packed with glass helices. The deuterium content was assessed by ^{1}H n.m.r. with di-iodomethane as an internal standard and found to have 97·8% deuterium content.

1,1-Dimethylethan[^{2}H]ol was prepared by the method of Cram and Rickborn.[18] The isotopic purity was 0·88 atoms D/molecule determined by ^{1}H n.m.r. using di-iodomethane as internal standard.

I.r. spectra were obtained with a Unicam SP 200 spectrophotometer, u.v. spectra were measured on a Unicam SP 800 spectrophotometer and ^{1}H n.m.r. spectra with a Varian A60 instrument at 60 Mc./sec.

Methyl Phenethyl Sulphoxide.—This (b.p. 58—59°/2·5 mm.[19]) was prepared in 75% yield by reaction of sodium methyl sulphide with 1-bromo-2-phenylethane[20] and was treated with sodium metaperiodate at 0° for 15 hr.[21] Sodium iodate was filtered off and the filtrate was extracted with dichloromethane; the extracts were dried ($\mathrm{MgSO_4}$), the solvent was evaporated off, and the remaining oil was chromatographed on silica gel to remove traces of sulphide. The sulphoxide was eluted with methanol–ether (1 : 24) and finally distilled through a short-path micro-distillation apparatus; this gave 84% yield of product, b.p. 120°/0·05 mm., $\nu_{\max.}$ 1050 and 700 cm.$^{-1}$, ^{1}H n.m.r. spectrum ($\mathrm{CCl_4}$): τ 2·82 (5H, s, aromatic), 6·8—7·3 (4H, m, methylene), 7·57 (3H, s, methyl).

Methyl Phen[2,2-^{2}*H*$_2$]*ethyl Sulphoxide*.—Methyl phen[2,2-^{2}H$_2$]ethyl sulphide was prepared by the procedure of Saunders.[22] The isotopic purity was 1·95 atoms D/molecule, b.p. 83—84°/2 mm.; n.m.r. spectrum ($\mathrm{CCl_4}$); τ 2·9 (5H, s, Ar), 7·4br (2H, s, $\mathrm{CH_2}$), 8·04 (3H, s, Me). Oxidation with sodium metaperiodate, column chromatography, and distillation gave methyl phen[2,2-^{2}H$_2$]ethyl sulphoxide b.p. 120°/0·05 mm., $\nu_{\max.}$ 1050 and 700 cm.$^{-1}$; ^{1}H n.m.r. spectrum ($\mathrm{CCl_4}$); τ 2·84 (5H, s, Ar), 7·2br (2, s, $\mathrm{CH_2}$), 7·63 (3, s, Me).

para-*Substituted Phenethyl Methyl Sulphoxides*.—4-Methylacetophenone (0·5 mole), sulphur (0·78 mole), and morpholine (0·78 mole) were heated under reflux overnight. The cooled solution was poured into warm, absolute ethanol (100 ml.); further cooling gave crystals of the thiomorpholide (74 g.), m.p. 96—99°. This was heated under reflux overnight with potassium hydroxide (120 g. in 400 ml. of water); the solution was acidified, with cooling, with dilute sulphuric acid [conc. sulphuric acid–water (1 : 1)] until no more solid separated. This was filtered off, washed with water, and dried (yield 75%), m.p. 88·5—91·5° (lit,[23] 94°). The acid was heated under reflux overnight with absolute ethanol saturated with hydrogen chloride, to yield ethyl *p*-tolylacetate (70%), b.p. 102°/2·5 mm. Reduction of the ester with lithium aluminium hydride gave 2-*p*-tolylethanol which was converted to the toluene-*p*-sulphonate by Tipson's procedure.[24] Treatment of toluene-*p*-sulphonate

---

[13] F. H. Westheimer, *Chem. Rev.*, 1961, **61**, 265.

[14] R. Breslow, *Tetrahedron Letters*, 1964, **8**, 399.

[15] W. H. Saunders, jun., D. G. Bushman, and A. F. Cockerill, *J. Amer. Chem. Soc.*, 1968, **90**, 1775.

[16] D. J. Cram and A. S. Wingrove, *J. Amer. Chem. Soc.*, 1964, **86**, 5490.

[17] E. Buncel, E. A. Symons, and A. W. Zabel, *Chem. Comm.*, 1965, 173.

[18] D. J. Cram and B. Rickborn, *J. Amer. Chem. Soc.*, 1961, **83**, 2182.

[19] W. H. Saunders, jun., and R. A. Williams, *J. Amer. Chem. Soc.*, 1957, **79**, 3712.

[20] D. Perlman, D. Davidson, and M. T. Bogart, *J. Org. Chem.*, 1966, **1**, 288.

[21] N. J. Leonard and C. R. Johnson, *J. Org. Chem.*, 1962, **27**, 282.

[22] W. H. Saunders, jun., and D. H. Edison, *J. Amer. Chem. Soc.*, 1960, **82**, 138.

[23] Dictionary of Organic Compounds, Eyre and Spottiswoode, London, 1965.

[24] R. S. Tipson, *J. Org. Chem.*, 1944, **9**, 235.

with sodium methyl sulphide and oxidation of the product thus obtained with sodium metaperiodate gave the corresponding sulphoxides in high yield. These were crystallised from ether–light petroleum (b.p. 40—60°). This procedure was applied generally with a series of 2-arylethanols to yield the following compounds.

p-*Methoxyphenethyl methyl sulphoxide*, m.p. 56—58° (Found: C, 60·6; H, 7·1. $C_{10}H_{14}SO_2$ requires C, 60·4; H, 6·9%), $\nu_{max.}$ (CCl_4), 1240, 1030, and 820 $cm.^{-1}$, $\lambda_{max.}$ 277 mμ (3·145); ^{1}H n.m.r. spectrum (CCl_4); τ 2·92 (2H, d, Ar), 3·30 (2H, d, Ar), 6·3 (3H, s, MeO), 6·85—7·35 (4H, m, CH_2), and 7·60 (3H, s, Me).

p-*Chlorophenylethyl methyl sulphoxide*, m.p. 84·5—85·0° (Found: C, 53·2; H, 5·45; Cl, 17·5. $C_9H_{11}ClSO$ requires C, 53·15; H, 5·75; Cl, 17·35%), $\nu_{max.}$ 1030 $cm.^{-1}$, $\lambda_{max.}$ 268 mμ (2·401); ^{1}H n.m.r. spectrum (CCl_4); τ 2·81 (4H, s, Ar), 6·75—7·43 (4H, m, CH_2), and 7·55 (3H, s, Me).

p-*Methylphenethyl methyl sulphoxide*, m.p. 63—64·5° (Found: C, 65·8; H. 7·75. $C_{10}H_{14}OS$ requires C, 65·65; H, 7·6%), $\nu_{max.}$ 1033 $cm.^{-1}$, $\lambda_{max.}$ 274 mμ (2·525), 273 mμ (2·533); ^{1}H n.m.r. spectrum (CCl_4): τ 2·98 (4H, s, Ar), 6·9—7·35 (4H, m, CH_2), 7·6 (3, s, Me), and 7·73 (3H, s, Me).

Kinetics.—The approximate weight of potassium was weighed in paraffin oil, and the potassium plus paraffin oil was transferred to a small, stoppered flask and placed in a dry-box. The potassium was wiped and added to a small beaker of dry 1,1-dimethylethanol. When the metal was clean (surface coating dissolved), it was removed and placed in a flask containing fresh 1,1-dimethylethanol. Two 1-ml. portions (diluted with 5 ml. of distilled water) were titrated against 0·1N-sulphuric acid with Bromocresol Green as indicator. The concentration of this stock, base solution was *ca.* 0·5M.

A solvent mixture, 17% dimethyl sulphoxide–1,1-dimethylethanol, was prepared and stored in a dry box. The sulphoxide (*ca.* 50 mg.) was dissolved in the solvent mixture (10 ml.) and diluted 10 fold.

A base-solvent solution was prepared (2 ml. of base solution and 10 ml. of solvent mixture), and aliquots (2 ml.) were added to five test-tubes fitted with Quickfit stoppers. To one of the tubes was added 1-ml. of diluted solvent mixture. This solution was used in the reference cells, and was of identical base and solvent composition to that used in the reaction cells. Constant-volume pipettes (previously calibrated) were used throughout. The test-tubes were stoppered and placed with two substrate solutions in a 50° thermostat bath to equilibrate for 15 min. The reference solution was placed in a cell in the spectrophotometer (Unicam SP 800A). After equilibration, a 1-ml. aliquot of a particular substrate solution was added to each of two of the test-tubes, and a 1-ml. aliquot of the other substrate solution was added to the two remaining test-tubes. The solutions were rapidly mixed and quickly transferred to the four reaction cells (1 mm.) and placed in the cell compartment of the spectrophotometer. The cell block was maintained at the stated temperature (±0·1°) by circulation of water from a constant-temperature bath. This procedure gave a base concentration of 0·045M and a base excess over substrate of *ca.* 60.

Absorbance was usually measured at 260 mμ. Absorption of dimethyl sulphoxide was strong in the region of 250 mμ and the region below 250 mμ could not be used for following the reaction. The $\lambda_{max.}$ value for *p*-methoxystyrene is 258 mμ and the kinetics were followed at this wavelength; the absorption maximum of the other styrenes was close to 250 mμ. Empirical end points (10 half-lives) were determined in the cell block; for slower reacting sulphoxides the infinity-point was reached in a short time by placing the remaining ampoule in a 75° thermostat bath. Reactions were generally followed for 2—3 half-lives and several runs were recorded for each substrate. The rate constants were determined graphically from a plot of log $(D_\infty - D_t)$ against time (where D_t = absorbance at time t, and D_∞ = absorbance after 10 half-lives).

Product Studies.—Each sulphoxide (0·25M) was treated with potassium 1,1-dimethylethoxide (0·5M) in 17% dimethyl sulphoxide–1,1-dimethylethoxide at 50° in sealed ampoules. The reaction was quenched with water after ten half-lives, extracted with ether, and analysed by v.p.c. on a 2-m. 20% silicone grease column at 90° and 15 lb./sq. in. Analysis showed on the styrene product for all the sulphoxides.

Possible loss of styrene product under the reaction condition used for the kinetics was checked by following the absorbance (at 260 mμ) for over 20 half-lives. No evidence for polymerisation in the reaction was found.

Hydrogen Exchange Studies of (Ia) *in Potassium* 1,1-*Diethylethoxide in* 1,1-*Dimethylethan*[^{2}*H*]*ol*.—The sulphoxide (0·0039 mole) was weighed into a 100-ml. flask, which was stoppered and placed in a dry-box. 1,1-Dimethylethan-[^{2}H]ol (15 ml.) was pipetted into the flask which was flushed with nitrogen and placed in a thermostat bath at 75°. After equilibration an aliquot (5 ml.) of base solution (0·80M) was added and the reaction was continued for 2 hr. The reaction was quenched with ice–water, with cooling. A known weight of cumene was added and the reaction extracted with ether. The extract was dried, the solvent removed through an 8 in. Vigreux column and the remaining oil was analysed by v.p.c. on a 2-m. 20% TCEP column at 90°. A low injection-block temperature (70—80°) was used to avoid pyrolysis of the unchanged sulphoxide.

The remaining solvent was removed at reduced pressure, and the residue was chromatographed on a small silica-gel column; elution was with light petroleum (b.p. 40—60°) to remove hydrocarbons and 5% methanol–ether for the sulphoxide. This was pyrolysed in a short-path distillation apparatus at 250° for 45 min. at atmospheric pressure; the product was then distilled at reduced pressure. The styrene was further purified by chromatography on silica gel.

The styrene was analysed by ^{1}H n.m.r. Multiple integrations were carried out on each signal by the use of a digital voltmeter in circuit with the A60 machine, 26 values were recorded for each peak. Comparison with the integrated signal for the phenyl protons enabled the deuterium content to be determined.

A similar technique was utilised for the investigation of hydrogen exchange of (Ia) (0·0048 mole) in potassium 1,1-dimethylethoxide–37·5% [$^2H_6$]dimethyl sulphoxide–62·5% 1,1-dimethylethan[^{2}H]ol (24 ml.; 0·19M).

Thanks are due to S.R.C. for a maintenance grant to one of us (M. J. S.) and also for a grant for the purchase of the vapour phase chromatography equipment.

[8/1835 *Received, December* 12*th*, 1968]