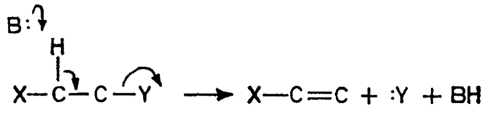
Elimination and Addition Reactions. Part XXIII.[1] Mechanisms of Elimination in Nitro-compounds bearing Phenoxy and Phenylthio Leaving Groups

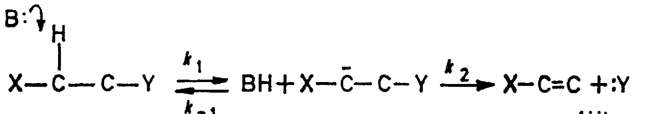
By **Peter F. Cann** and **Charles J. M. Stirling,*** School of Physical and Molecular Sciences, University College of North Wales, Bangor

Rates of elimination in 1-nitro-2-phenoxyethane and in 1-nitro-2-phenylthioethanes ($PhS{\cdot}CHY{\cdot}CH_2{\cdot}NO_2$: Y = H or Ar) have been measured in ethanolic sodium ethoxide, aqueous sodium hydroxide, and aqueous triethylamine. The phenoxy-compound reacts by rate-determining loss of phenoxide from the carbanion [(E_1) anion mechanism], while for the α-arylphenylthio-compounds, ionisation is rate-determining and rate constants agree with predictions made from ionisation rates of model substrates. The simple phenylthio-compound (Y = H) undergoes elimination with a primary deuterium isotope effect of 7·4 but rate constants are larger than predicted for rate-determining ionisation and the E_2 mechanism is tentatively assigned.

BASE-INITIATED 1,2-elimination reactions occur by two types of mechanism according to whether or not a carbanion is formed as an intermediate. In the concerted process, E_2, bonds to a β-hydrogen atom and to the leaving group are extended in a single transition state, albeit with possible variation[2] in the degree of extension [equation (i)]. Alternatively, an intermediate carbanion may be formed [equation (ii)]. If the equilibrium constant for formation of the carbanion is large ($k_1 \gg k_{-1}$) two situations may arise:



(i)



(ii)

(*a*) $k_{-1} \ll k_1 \ll k_2$. In this case, ionisation of the carbon acid is rate-limiting and the reaction shows second-order kinetics, first-order in substrate and in base. The reaction type is labelled[3] $(E_1cB)_I$ (I ≡ irreversible).

(*b*) $k_{-1} \ll k_1 \gg k_2$. In this case, loss of the leaving group is rate-determining and, because the substrate is effectively converted entirely into the conjugate base, the reaction shows first-order kinetics. This type is labelled[3] $(E_1)_{anion}$.

In earlier work[4] we have been concerned with substrate–base systems in which equilibrium constants are very small ($k_1 \ll k_{-1}$). In this paper, however, we are concerned with reactions of nitro-compounds in strongly basic media and, because equilibrium constants for formation of the carbanion are large, the reactions described must fall into one of the categories described above. Although there is disagreement as to whether the E_2 and $(E_1cB)_I$ processes merge[5] or are discontinuous,[6] distinction between the mechanisms is particularly difficult because the processes both have second-order kinetics, both should show substantial primary deuterium isotope effects, and both have a similar predicted response to solvent and structural effects. In addition, both show sensitivity to leaving group change, in the former mechanism because of differential bond cleavage and in the latter because of differential inductive effects on ionisation rate. This last criterion has, however, been employed in the assignment of the $(E_1cB)_I$ mechanism in those instances[3,7] for which a good match between elimination rate and predicted ionisation rate is obtained. We have used the same approach to this problem in the current work.

RESULTS AND DISCUSSION

Mechanisms of eliminations have been examined by studying the effect of general bases, solvent effects, the primary deuterium isotope effects, and the substituent effects on the rates of reactions. Rate constants are in Table 1.

Elimination of phenol from 2-phenoxynitroethane (1a) occurs *via* the $(E_1)_{anion}$ mechanism. Other examples have been reported by Bordwell[8] and by Rappoport.[9] The rate of ionisation (k_1) is too large to be measured accurately, but at low hydroxide ion concentrations in water, an ' induction ' period of *ca.* 1 s at $[^-OH] = 5 \times 10^{-3}$M was observed before the first-order increase in the concentration of PhO^- occurred. If we assume this period to be about 4—5 half-lives of the ionisation reaction, k_1 is *ca.* 560—760 l mol^{-1} s^{-1}. In ethanolic sodium ethoxide, ionisation was complete within 0·8 s at $[EtO^-] = 10^{-3}$M, and k_1 (EtO^-/EtOH) can thus be estimated at not less than 4400 l mol^{-1} s^{-1}. If we take $\sigma^*(PhOCH_2)$ as 0·85[10] and the appropriate ρ^* values

---

[1] Part XXII, J. W. Batty, P. D. Howes, and C. J. M. Stirling, *J.C.S. Perkin I*, 1973, 65.

[2] J. F. Bunnett, *Survey Progr. Chem.*, 1969, **5**, 53.

[3] F. G. Bordwell, M. M. Vestling, and K. C. Yee, *J. Amer. Chem. Soc.*, 1970, **92**, 5950.

[4] J. Crosby and C. J. M. Stirling, *J. Chem. Soc.* (*B*), 1970, 679.

[5] F. G. Bordwell, *Accounts Chem. Res.*, 1970, **3**, 281.

[6] R. A. More O'Ferrall, *J. Chem. Soc.* (*B*), 1970, 274.

[7] R. C. Cavestri and L. R. Fedor, *J. Amer. Chem. Soc.*, 1970, **92**, 4610.

[8] F. G. Bordwell, K. C. Yee, and A. C. Knipe, *J. Amer. Chem. Soc.*, 1970, **92**, 5945.

[9] Z. Rappoport and E. Shohany, *J. Chem. Soc.* (*B*), 1971, 2060; Z. Rappoport, M. Albeck, and S. Hoz, *J.C.S. Perkin II*, 1972, 1248.

[10] J. Hine, 'Physical Organic Chemistry,' 2nd edn., McGraw-Hill, New York, 1962.

(preceding paper and Figure), the calculated rates of ionisation are *ca.* 360 l mol^{-1} s^{-1} for water and *ca.* 5800 l mol^{-1} s^{-1} for ethanol, in qualitative agreement with the experimental values. We could find no evidence for a concurrent (base-dependent) E_2 pathway; good first-order plots were obtained over a 25-fold change in [EtO$^-$].

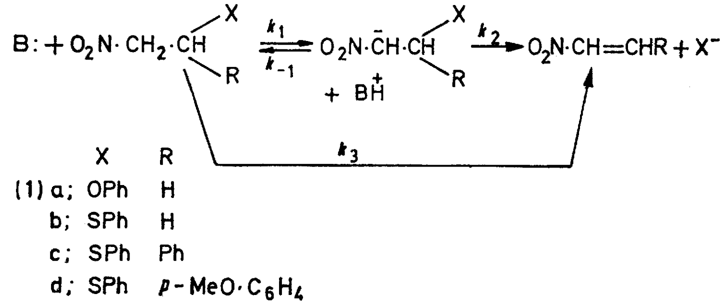
The variation of k_2 with change of solvent and the negative salt effect in ethanol (Table 1, footnote *d*) are both accommodated by the assumption that the nitronate anion (ground state) is stabilised more in a solvent of high dielectric constant or by added salt than is the transition state of elimination, in which charge is further delocalised over the leaving group.

TABLE 1

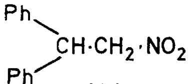
Rates of elimination and ionisation of nitro-compounds

Compound	$\Sigma\sigma^*$	k_{obs} [a,b] (EtO$^-$–EtOH)/ l mol^{-1} s^{-1}	[EtŌ]/mM	$\left[\frac{k_{obs}}{k_{calc}}\right]_{EtOH}$	k_{obs} [a,b](OH$^-$–H$_2$O)/ l mol^{-1} s^{-1}	[ŌH]/mM	$\frac{k_{obs}(EtOH)}{k_{obs}(H_2O)}$
(1a)	0·85	0·86 [c]	2·0		0·33 [c]	2·4	
		0·87 [c]	4·2	—	0·33 [d]	5·0	2·56
		0·90 [c]	53·5		0·34 [c]	7·5	
(1b)	0·66	$7·9 \times 10^3$	4·0 [e]		240	2·5	
		$8·3 \times 10^3$	11·0	3·0	222	5·0	34
		$5·5 \times 10^3$	20·0		229	7·5	
		$6·2 \times 10^3$	30·0				
		$8·5 \times 10^3$	54·0				
(1c)	0·88	$2·6 \times 10^3$	4·0	0·38 [f]			
		$1·5 \times 10^3$	22·0				
		$1·3 \times 10^3$	45				
		$0·62 \times 10^3$	54				
(1d)		$2·1 \times 10^3$	4·0				
(2)	0·44	$3·7 \times 10^2$	4·0	0·37			

[a] Solutions made up to μ = 0·1M with NaClO$_4$. [b] At 25·0 °C (mean values; standard deviations as percentage of k_{obs} all within range 1·4—4·2). [c] Units s^{-1}. [d] k_{obs} (μ = 0·0) = 1·49 s^{-1}. [e] k_{obs} for NO$_2$·CD$_2$CH$_2$SPh at this [EtŌ] = $1·07 \times 10^{-3}$. [f] k Value at [EtO$^-$] = 4 mM.



SCHEME


(2)

PhS·CH$_2$·CD$_2$·NO$_2$ (3)

PhSO$_2$·CH$_2$·CH$_2$·OPh (4)

PhSO$_2$·CHPh·CHPh·OPh (5)

Elimination of benzenethiol from 1-nitro-2-phenylthioethane (1b) follows a different mechanism. This is apparent from the change in kinetic order (Table 1). Change of benzenethiolate for phenoxide as leaving group has previously been shown [11] to decrease the rate of elimination in β-substituted sulphones. These reactions [11,12] have the $(E_1cB)_R$ mechanism and it is reasonable to attribute the decrease in overall rate to effects both on k_2 and on K_1 ($\equiv k_1/k_{-1}$). In the present case, second-order kinetics can only be consistent either with the $(E_1cB)_I$ mechanism or the E_2 (concerted) process. In the former alternative, for k_1 to become rate-determining, values of k_{obs} = *ca.* 2600 l mol^{-1} s^{-1} in ethanol [from Figure using σ^*(PhSCH$_2$) [13] = 0·66] and of *ca.* 160 l mol^{-1} s^{-1} in water would be required. The observed rate constants are *ca.* 3 times and 1·5 times greater, respectively. In addition, the increase by a factor of 34·4 in k_{obs} when changing from solvent water (μ = 0·1M) to ethanol (μ = 0·1M) (Table 1) is larger than the expected average of *ca.* 20 for ionisation of simple nitro-compounds.[14] These results suggest that this elimination may occur either wholly or partly *via* the E_2 pathway. The proportion of the total reaction that can be attributed to the E_2 route cannot be gauged from the above results, however, since the expected magnitudes of the various effects on k_1 and k_3 are unknown and the transition states for the two processes must be

---

[11] R. P. Redman and C. J. M. Stirling, *Chem. Comm.*, 1970, 633.

[12] K. N. Barlow, D. R. Marshall, R. P. Redman, and C. J. M. Stirling, unpublished work.

[13] A. Chambers and C. J. M. Stirling, *J. Chem. Soc.*, 1965, 4558.

[14] P. F. Cann and C. J. M. Stirling, preceding paper.

very similar. As the difference between k_{obs} and calculated values of k_1 is larger for ethanol than for water, the E_2 pathway may be more important in ethanol than in water.

TABLE 2

Elimination rates of 1-nitro-2-phenylthioethane in aqueous triethylamine [a]

$\frac{[Et_3N]}{[Et_3NHCl]}$	$10^3[Et_3N]$	k_{obs}/s^{-1}	r	k_{Et_3N} [b] l mol^{-1} s^{-1}	k_{OH} [c] l mol^{-1} s^{-1}
0·28	2·8	0·109	0·995	18·0	280
0·28	4·9	0·155			
0·28	7·0	0·178			
0·28	8·4	0·212			
0·28	11·2	0·267			
1·00	10·0	0·339	0·999	17·0	246
1·00	20·0	0·534			
1·00	30·0	0·704			
1·00	40·0	0·845			
1·00	50·0	1·02			

[a] All solutions brought to 0·1M ionic strength by the addition of $NaClO_4$; rates measured at 25·0°. [b] From the slopes of plots of k_{obs} *vs.* $[Et_3N]$. [c] From the intercepts of the plots in *b*.

General base catalysis is observed with triethylamine buffers in water (Table 2) and the primary deuterium isotope effect ($k_H/k_D = 7{\cdot}4$) for ethoxide–ethanol reactions confirms that proton removal is rate-limiting with the proton about half transferred in the transition state. These results, however, offer no differentiation between the E_2 and $(E_1cB)_I$ routes.

There was no indication of mixed-order kinetics at high base concentrations as would be occasioned by the magnitudes of $k_{-1}[BH]$ and k_2 becoming comparable. The implication is that k_2 is greater than $k_{-1}[B]$ even at the highest base concentrations used. This allows minimum values for k_2 of 79 s^{-1} in ethanol and 1·61 s^{-1} in water to be assigned. These are substantially greater than the k_2 values for the phenoxy-compound (1a) and earlier work[11] suggests that benzenethiolate is a *poorer* leaving group than phenoxide in this type of system. These results thus also contraindicate the $(E_1cB)_I$ mechanism.

At first sight it is surprising that the phenyl group in 2-nitro-1-phenyl-1-phenylthioethane (1c) should have a rate-retarding effect relative to the hydrogen atom in (1b) (Table 1). Both the $(E_1cB)_I$ and the E_2 pathways should be accelerated by this change; for the former because of the positive σ^* value of the phenyl group and for the latter by partial conjugation in the transition state leading to the product.

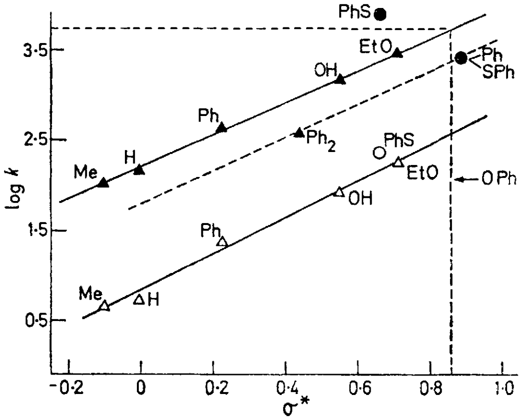
The Figure and the last column of Table 1 show that the retardation of elimination in compound (1c) by a α-phenyl group is *identical* to that on the simple ionisation[14] of compound (II). This suggests the $(E_1cB)_I$ mechanism for reaction with the α-phenyl phenylthio-compound (1c), *i.e.* k_{obs} (1c) $= k_1$.

We were unable to compile a full Hammett plot because addition of ethoxide to the nitrostyrene products interferes with observation of the elimination step. (This also precluded the determination of the primary deuterium isotope effect for this reaction.) The rate constants for compounds (1c) and (1d), however, give a two-point Hammett plot with $\rho = 0{\cdot}8$. From Bordwell's results[15] for the same two points in the system (iii), $\rho = 1{\cdot}02$.

$$\mathrm{ArCH_2{\cdot}CHMe{\cdot}NO_2} \xrightarrow[k\ \text{ionisation}]{\mathrm{Me\bar{O}-MeOH}} [\mathrm{ArCH_2{\cdot}CMe{:}NO_2}]^- \qquad \text{(iii)}$$

The smaller ρ value in our system is to be expected from the presence of the α-PhS group because the carbanion bearing the phenylthiomethyl substituent ($\rho^* = 0{\cdot}65$) will be stabilised, and hence the transition state for ionisation will resemble the reactants more closely.

A further piece of evidence for the $(E_1cB)_I$ pathway for (1c) and (1d) is the decrease in k_{obs} as $[EtO^-]$ is increased at constant ionic strength. Thus for $[EtO^-] = 0{\cdot}054$M, k_{obs} (1c) is 3 times smaller (Table 1) than the limiting value at low $[EtO^-]$ (*ca.* 10^{-3}M). As mentioned above, this is suggestive of a changeover from an $(E_1cB)_I$ to an $(E_1)_{anion}$ mechanism. While it therefore seems likely that the $(E_1cB)_I$ mechanism accounts for the pathway of elimination from (1c) and (1d) to a large extent, we have been unable to obtain direct evidence against an E_2 or part-E_2 pathway. The failure to adopt the more favourable E_2 pathway in these compounds is strange, for the α-phenyl group should stabilise the E_2 transition state relative to that of compound (1b).



Plot of log $k_{ionisation}$ *vs.* σ*: ▲ reactions in EtO^-–EtOH; △ reactions in ^-OH–H_2O; ● elimination reactions in EtO^-–EtOH; ○ elimination reaction in ^-OH–H_2O

Rate depression by insertion of phenyl groups α to the leaving group is known in other systems. Thus the sulphone (4) undergoes elimination 21 times faster than *erythro*-(5) and 1280 times as fast as *threo*-(5) in ethanolic sodium ethoxide. Deuterium exchange experiments in these systems show that $k_{-1}[BH] \gg k_2$ and that the $(E_1cB)_R$ mechanism is operating.[16] Rate depression of ionisation in other systems is also known.[15]

The similarity between the transition states for the

---

[15] F. G. Bordwell, W. J. Boyle, and K. C. Yee, *J. Amer. Chem. Soc.*, 1970, **92**, 5926.

[16] R. P. Redman and C. J. M. Stirling, unpublished work.

$(E_1cB)_I$ and carbanion-like E_2 reactions (and hence the almost identical effects of changes in reaction conditions and substituents on their rates) makes the mechanisms hard to distinguish. Such a distinction seems valid, however, and has been made on both conceptual[3] and theoretical[6] grounds. In this paper we have attempted to distinguish them by extrapolation from model systems of known mechanism. Such extrapolation is approximate owing to an ignorance of some of the factors involved in each system but the distinctions appear sufficiently definite to allow the assignments made.

EXPERIMENTAL

For general procedures see the preceding paper. Triethylamine was distilled from sodium and stored in the dark over molecular sieves (4A). Amine buffers were prepared from the calculated amounts of hydrochloric acid and amine solutions. Buffer solutions were titrated for excess of amine against standard hydrochloric acid with Methyl Red as indicator.

For phenyl ethers the change in intensity of the 291 nm maximum in the phenoxide ion spectrum was monitored, while reactions of phenyl thioethers were monitored at 275 nm. For compound (1d), monitoring of the reaction at the 350 nm maximum of the product gave a rate constant identical with that obtained by observation of the 275 nm maximum.

1-Nitro-2-phenoxyethane had[17] m.p. 42·1°.

1-*Nitro-2-phenylthioethane*.—Nitroethylene was prepared by dehydration of 2-nitroethanol (16 g, 0·175 mol) with phthalic anhydride (28 g, 0·19 mol) according to the method of Buckley and Scaife.[18] The alkene was distilled straight onto benzenethiol (22 g, 0·2 mol) containing sodium ethoxide (0·1 g). The reaction was exothermic and the mixture was kept at 25° by external cooling. When distillation of the alkene was complete the mixture was stirred at 25° for 0·5 h and was then diluted with ether (50 ml). The ethereal solution was washed with dilute aqueous acetic acid and water, dried (Na_2SO_4), and evaporated. Distillation of the residue (screen) gave a forerun of benzenethiol (b.p. *ca.* 30° at 0·2 mmHg) and the yellow *nitro-sulphide* (15·4 g, 48%), b.p. 103° at 0·3 mmHg, n_D^{18} 1·5774 (Found: C, 52·3; H, 4·9; N, 7·4. $C_8H_9NO_2S$ requires C, 52·5; H, 4·9; N, 7·7%), τ (CCl_4) 2·36 (5H, m), 5·39 (2H, t, J 7 Hz), and 6·55 (2H, t, J 7 Hz).

1-*Nitro-2-phenylthio*[1,1-$^2H_2$]*ethane*.—The preceding compound (5 g), triethylamine (3 drops), deuterium oxide (10 ml), and dry ether (10 ml) were stirred at 25° for 12 h. The ^1H n.m.r. spectrum of the organic layer showed conversion to be 93%. Repetition with fresh deuterium oxide (10 ml) and subsequent separation, drying, and distillation of the organic layer gave the product (2·3 g, 46%) >98% isotopically pure (^1H n.m.r.).

(2-*Nitro-*1-*phenylthioethyl*)*benzenes*.—β-Nitrostyrene,[19] *p*-chloro-β-nitrostyrene,[20] and *p*-methoxy-β-nitrostyrene[21] were prepared according to published procedures. The nitrostyrene (0·025 mol) and benzenethiol (2·8 g, 0·025 mol) in tetrahydrofuran (50 ml) were warmed to 40°, and then kept at 25° for 4 h. The yellow colour was completely discharged and evaporation gave the product which was crystallised from light petroleum (b.p. 40—60°) as needles (*ca.* 80%). The p-*chloro-compound* had m.p. 65·6° (Found: C, 57·3; H, 4·1; N, 4·7. $C_{14}H_{12}ClNO_2S$ requires C, 57·2; H, 4·1; N, 4·8%), τ ($CDCl_3$) 2·4 (9H, m) and 5·1 (3H, m). The p-*hydrogen compound* had m.p. 72·7° (Found: C, 64·7; H, 5·3; N, 5·7. $C_{14}H_{13}NO_2S$ requires C, 64·8; H, 5·0; N, 5·4%), τ ($CDCl_3$) 2·2—2·4 (10H, m) and 4·9—5·05 (3H, m). The p-*methoxy-compound* had m.p. 104·7° (Found: C, 62·1; H, 4·9; N, 4·7. $C_{15}H_{15}NO_3S$ requires C, 62·1; H, 5·2; N, 4·8%), τ ($CDCl_3$) 2·3 (5H, s), 2·45 and 2·85 (4H, AB, J_{AB} 10 Hz), and 4·9—5·1 (3H, m).

Product Analyses.—Details for 1-nitro-2-phenoxyethane have been given earlier.[17]

1-*Nitro-*2-*phenylthioethane*. The nitro-sulphide (0·02 mol) and piperidine (0·1 mol) in ethanol (25 ml) were treated with ethanolic M-sodium ethoxide (25 ml). The solution was set aside for 6 h at 25° under N_2, and then was poured into saturated brine (100 ml). The excess of piperidine was extracted with dichloromethane and the aqueous layer was acidified (HCl) and re-extracted. Evaporation of the extracts and treatment of the residue with anhydrous ether gave 1-nitro-2-piperidinoethane hydrochloride (92%), m.p. and mixed[17] m.p. 139°. Distillation of the ethereal solution gave benzenethiol (95%), b.p. 65° at 15 mmHg (i.r. spectrum identical with that of an authentic specimen).

(2-*Nitro-*1-*phenylthioethyl*)*benzene* (1c). The compound in ethanolic M-sodium ethoxide (0·025 mol) was set aside for 1 month under nitrogen. A white precipitate of polymerised nitroalkene (1·05 g, 71%) was filtered off and washed with water and ether. The filtrate was poured into saturated brine (50 ml), neutralised with acetic acid, and extracted with dichloromethane (5 × 20 ml). The extracts were dried and distilled as before to give benzenethiol (0·98 g, 89%).

Because of the difficulty of isolation of nitro-containing product due to polymerisation during work-up, the u.v. spectrum of the product mixture in ethanol was simulated using 2-nitrostyrene (0·05mM), benzenethiol (0·05mM), and sodium ethoxide (10mM) in ethanol. This solution showed an absorbance of 0·95 at $\lambda_{max.}$ 266 nm; that of the product mixture was 0·98 at $\lambda_{max.}$ 265 nm.

We thank the S.R.C. for provision of equipment and a post-doctoral fellowship (to P. F. C.), and Mrs. B. Davies for technical assistance.

[3/2372 *Received*, 19*th November*, 1973]

---

[17] J. Crosby and C. J. M. Stirling, *J. Chem. Soc.* (*B*), 1970, 671.

[18] G. D. Buckley and C. W. Scaife, *J. Chem. Soc.*, 1947, 1471.

[19] A. I. Vogel, 'Practical Organic Chemistry,' 3rd edn., Longmans, London, 1956, p. 717.

[20] M. J. Kamlet, *J. Amer. Chem. Soc.*, 1955, **77**, 4896.

[21] J. Michel and E. Henry-Bash, *Compt. rend.*, 1966, **262***C*, 1274.