

## Comparison of Nucleofugalities in 1, 2- and 1, 3-Elimination Reactions

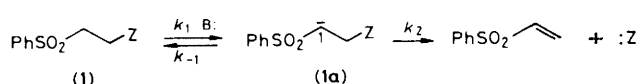
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Ranks (= nucleofugalities) of Br, Cl, OSO<sub>2</sub>C<sub>6</sub>H<sub>4</sub>Me, SO<sub>2</sub>Ph, SPh, and OPh as leaving groups in sulphonyl-activated cyclopropane-forming eliminations have been determined; a rectilinear correlation between rank and the pK<sub>a</sub> of the conjugate acid of the leaving group is found in direct contrast with behaviour in alkene-forming elimination.

Leaving group rank (= nucleofugality) is an elusive quantity because of the lack of suitable systems for its determination.<sup>1</sup> Some measurements are available for leaving groups, Z, in carbonyl, imine, and sulphene- and keten-forming<sup>2</sup> reactions,

1, 2-elimination



1, 3-elimination

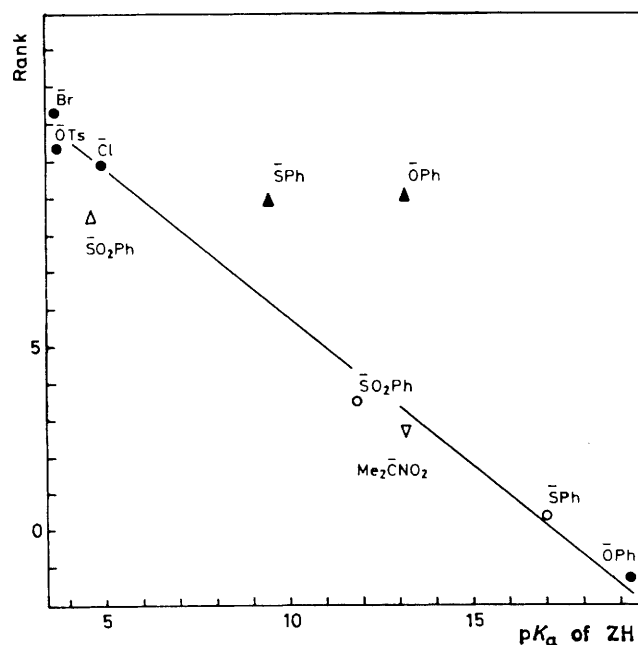
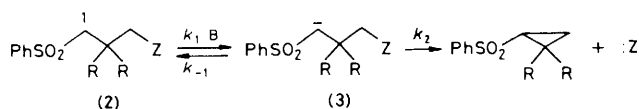


Figure 1. Rank-pK<sub>a</sub><sup>Z-H</sup> correlations for systems (1) and (2; R = Me). ▲, 1, 2-eliminations in EtONa-EtOH; literature values of pK<sub>a</sub><sup>Z-H</sup> for 95% EtOH-H<sub>2</sub>O (G. Swarzenbach and E. Rudin, *Helv. Chim. Acta.*, 1939, 22, 360); △, value estimated from mean (pK<sub>a</sub> in 95% EtOH - pK<sub>a</sub> in H<sub>2</sub>O) for other groups; ▽, pK<sub>a</sub> in methanol (M. Varma and C. J. M. Stirling, *J. Chem. Soc., Chem. Commun.*, 1981, 553); ●, 1, 3-eliminations in Bu<sup>t</sup>OK-Bu<sup>t</sup>OH; pK<sub>a</sub><sup>Z-H</sup> values in Bu<sup>t</sup>OH from N. P. Dzyuba, *Khim. Farm. Zh.*, 1971, 5, 39; ○, value of pK<sub>a</sub><sup>Z-H</sup> estimated from mean (pK<sub>a</sub><sup>Z-H</sup> in Bu<sup>t</sup>OH - pK<sub>a</sub><sup>Z-H</sup> in H<sub>2</sub>O) for other groups.

but most data have been derived from alkene-forming reactions.<sup>1</sup> As a general class, 1, 2-eliminations show substantial variation in the relationship between reactivity and pK<sub>a</sub><sup>Z-H</sup>, the inverse of the basicity of the leaving group. Provided that variation in the leaving group is small, as in a series of aryloxy-groups, correlations of reactivity with leaving group pK<sub>a</sub><sup>Z-H</sup> are good, albeit with sensitivities that vary widely between alkene-forming<sup>3</sup> and keten-forming reactions.<sup>2</sup> When, however, in alkene-forming eliminations the atom connection to the leaving group is changed, no relationship between rank and pK<sub>a</sub><sup>Z-H</sup> (Figure 1) for a wide variety of leaving groups is discernible.<sup>1</sup>

All evidence bearing upon transition state structure in systems such as (1) suggests a small degree of transfer of charge from C-1 in the carbanion (1a) to the leaving group, and a small extent of cleavage of the bond to the leaving group.

We now report on nucleofugality in the related system (2). Earlier work has defined the mechanism of cyclisation for the chloride<sup>4</sup> (R = H, Z = Cl) and for arenesulphonates (R = H, Z = OSO<sub>2</sub>Ar),<sup>5</sup> as proceeding via the carbanion (3)

and the (E1cB)<sub>R</sub> mechanism (k<sub>2</sub> ≪ k<sub>-1</sub>{BH}) operates. Extension of the range of leaving groups gives the results of Table 1. Included in Table 1 are rate constants for detritiation at C-1 of substrates showing the expected small sensitivity of this process (∝ k<sub>1</sub>) to change of leaving group. All substrates show either deuterium-hydrogen exchange or detritiation occurring more rapidly than cyclisation, establishing, in each case, except for the bromide (R = Me, Z = Br) (Table 1), the (E1cB)<sub>R</sub> mechanism. Ranks are calculated from equation (1).<sup>6</sup>

$$\text{Rank} = \Delta \log k_2 = \log k_{\text{obs}} - \log k_1 + 11 \quad (1)$$

A number of conclusions emerge, as follows.

(i) 1, 3-Eliminations in Bu<sup>t</sup>OK-Bu<sup>t</sup>OH are much slower than 1, 2-eliminations in EtONa-EtOH for the same leaving group even when the accelerative effect of *gem*-dimethyl substitution is allowed for. In this connection, the bromide (2; R = Me) is ca. 10<sup>3</sup> times as reactive (Table 1) as the bromide (2; R = H) under the same conditions.<sup>7</sup> This, surprisingly, is the first quantification of the Thorpe-Ingold effect<sup>8</sup> in cyclopropane formation.

(ii) The slowness of the reactions, even for leaving groups such as halogen, permits evaluation of rank data for such groups. This is impossible for the very much faster 1, 2-eliminations in which, for example, when Z = Br or I the mechanism is E2.<sup>9</sup> By the same token, for substrates (2; R = H, Z = OPh<sup>10</sup> or SO<sub>2</sub>Ph<sup>11</sup>), 1, 2-elimination, unactivated by an  $\alpha$ -sulphonyl group occurs in preference to cyclopropane formation.

(iii) Ranks in 1, 2- and 1, 3-eliminations differ considerably. In contrast with the former, the latter correlate remarkably well with pK<sub>a</sub><sup>Z-H</sup> data. The excellent correlation (Figure 1) and the slope (-0.8) suggest that in the transition state for these reactions, there is a large degree of cleavage of the bond to the leaving group. If bond order is conserved along the reaction

**Table 1.** Leaving groups in 1, 2- and 1, 3- eliminations.

Z	1, 2 <sup>a</sup>		1, 3		
	$k_{\text{obs}}^{\text{b}}$	Rank <sup>c</sup>	$k_{\text{obs}}^{\text{d}}$	$k_{\text{detrit}}^{\text{e}}$	Rank <sup>e</sup>
SO <sub>2</sub> C <sub>6</sub> H <sub>4</sub> Me	6700	f	1.03	4.0 <sup>g</sup>	10.4
Br	2600	f	6.81 <sup>h</sup>	3.3 <sup>g</sup>	11.3 <sup>i</sup>
Cl	780	f	0.15	2.1 <sup>g</sup>	9.9
PhSO <sub>2</sub>	1.05	8.7	$1 \times 10^{-7}$ <sup>j</sup>	6.4	3.5
PhS	0.021	8.7	$3 \times 10^{-11}$ <sup>j</sup>	1.1	0.4
PhO	0.35	8.9	$5 \times 10^{-13}$ <sup>j</sup>	1.1	-1.4
H	—	—	—	0.13	—

<sup>a</sup> Data from ref. 1. <sup>b</sup> Units dm<sup>3</sup>mol<sup>-1</sup>s<sup>-1</sup> at 25 °C for reactions in EtONa–EtOH. <sup>c</sup> See the text. <sup>d</sup> Units dm<sup>3</sup>mol<sup>-1</sup>s<sup>-1</sup> at 30 °C for reactions in Bu<sup>t</sup>OK–Bu<sup>t</sup>OH. <sup>e</sup> Rank = log  $k_{\text{obs}}$  – log  $k_{\text{detrit}}$  + 11. <sup>f</sup> Not evaluable (*cf.* ref. 1). <sup>g</sup> Value from  $\rho^*\sigma^*$  plot for detritiation. <sup>h</sup> Value for (2; R = H, Ph = tolyl),  $3.7 \times 10^{-3}$  at 30 °C. <sup>i</sup> *N.B.*, mechanism uncertain. <sup>j</sup> By extrapolation from reactions in range 72–160 °C.

co-ordinate,<sup>12</sup> the corollary is that there is a large degree of bond formation in the transition state. This is in agreement with a recent conclusion drawn from the observation that for 3-arylsulphonyloxypropyl sulphones (2; R = H, Z = OSO<sub>2</sub>Ar) cyclisation rate constants show a 50% larger value of  $\rho_Z$  than the analogous intermolecular reaction between a bis-sulphonyl stabilized carbanion and a series of methyl arene-sulphonates. Similar behaviour, leading to similar conclusions has been reported for keten-forming elimination.<sup>2</sup> The postulate that there is a large degree of bond formation in the transition state of a reaction leading to a highly strained product may appear surprising but again is entirely consistent with earlier work. The very much more rapid formation of cyclopropanes than cyclopentanes by intramolecular displacement in carbanions is thought<sup>13</sup> to be under conjugative control which demands a large degree of ring formation at the transition state. In eliminative ring fission of cyclopropanes,<sup>14</sup> structural effects show clearly that there is little ring cleavage at the energy maximum.

We thank the S.E.R.C. and U.C.N.W. for support.

Received, 12th March 1982; Com. 287

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