Product–Rate Correlation in Acetolysis of *threo*-3-Aryl-2-butyl Brosylates. Supporting Evidence for the Existence of Two Discrete Pathways

Sir:

Recent data emphasized[1] that the aryl group in the *threo*-3-aryl-2-butyl or the *trans*-2-arylcyclopentyl system has major influence on the stereochemistry of the acetolysis products, while the magnitude of the rate acceleration attributable to aryl participation remains quite small. Several possible explanations for this observation were considered.[1] At the same time, it was reported that rates and products of some secondary β-arylalkyl derivatives can be adequately correlated by assuming two independent processes:[2a] aryl assisted (Fk_Δ) and solvent assisted (k_s).

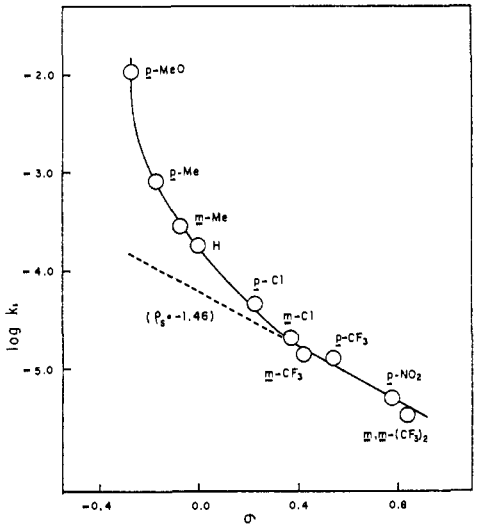
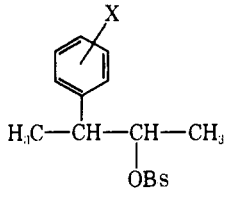


Figure 1. Rates of acetolysis of *threo*-3-aryl-2-butyl brosylates at 75.0° *vs.* the σ constants.

Accordingly, we decided to subject the *threo*-3-aryl-2-butyl system (I-X) to an intensive examination with the aid of recently developed refined kinetic methods[1,2] and accurate product analysis so as to establish whether or not a satisfactory product–rate correlation actually exists for this representative secondary β-arylalkyl system.



threo

I-X; X = *p*-MeO, *p*-Me, *m*-Me, H, *p*-Cl, *m*-Cl, *m*-CF_3, *p*-CF_3, *p*-NO_2, *m*,*m*'-$(CF_3)_2$

In addition to those compounds studied previously,[1] we synthesized two new compounds, I-*p*-CF_3 and I-*m*,*m*'-$(CF_3)_2$, by previously described methods.[1] Rate measurements and product studies were conducted at 75.0° in order to avoid any extrapolation error, and the results are summarized in Table I. The Hammett plot of the rate constants is shown in Figure 1.

Table I. Rates[a] and Products[b] of Acetolysis of Substituted *threo*-3-Phenyl-2-butyl Brosylates at 75.0°

I-X; X =	10^5k_t, sec^{-1}	Product, % Olefins	Acetate *tert*	Acetate *erythro*	Acetate *threo*
p-MeO	1060[c]	~0.3[h,i]			99.7[h,i]
p-Me	81.4[d]	12	0	0	88
m-Me	28.2[e]	31	0	1	68
H	18.0[f]	38	0	3	59
p-Cl	4.53[f]	53	1	6	39
m-Cl	2.05[e]	76	1	11	12
m-CF_3	1.38[f]	76	1	18	6
p-CF_3	1.26	75	1	14	11
p-NO_2	0.495[g]	68[g,i]		12[g,i]	1[g,i]
m,*m*'-$(CF_3)_2$	0.330	62	3	34	1

[a] Each run was carried out with a 0.01 or 0.02 *M* solution of the substrate. [b] Each run was carried out with a solution 0.050 *M* in brosylate and 0.053 *M* in sodium acetate for 7–*ca.* 10 half-lives. [c] Estimated from the data of S. Winstein and G. C. Robinson, *J. Amer. Chem. Soc.*, **80**, 169 (1958). [d] Extrapolated value. [e] Previous results.[1] [f] Average values of previous[1] and present studies. [g] Estimated from the data of D. J. Cram and J. A. Thompson, *J. Amer. Chem. Soc.*, **89**, 6766 (1967). [h] S. Winstein and R. Baker, *ibid.*, **86**, 2071 (1964). [i] At 50°. [j] At 100°.

The overall rates (k_t) were dissected into Fk_Δ and k_s according to the previously described procedure.[1-3] The product data were examined by assuming that only retained substitution product is formed through the aryl-assisted pathway, and all other products through the unassisted pathway.[2a,4] Comparisons of rate-derived (Fk_Δ/k_t) and product-derived (per cent yield of retained product) measures of aryl participation are shown in Table II. The agreement between the observed and predicted values is excellent for all the compounds examined.

Table II. Dissection of the Titrimetric Rate Constant (k_t) into the Assisted (Fk_Δ) and Unassisted (k_s) Components. Comparison of the Predicted and Observed Amount of Retained Product

I-X; X =	k_t	k_s[a,c]	Fk_Δ[b,c]	k_t/k_s	Retained substitution product, % Calcd[d]	Obsd
p-MeO	1060	14.9	1045	71	99	100
p-Me	81.4	10.7	70.7	7.6	87	88
m-Me	28.2	7.66	20.5	3.7	73	68
H	18.0	6.08	11.9	3.0	66	59
p-Cl	4.53	2.85	1.68	1.6	37	39

[a] Taken from k_s line in Figure 1. [b] $Fk_\Delta = k_t - k_s$. [c] 10^5k, sec^{-1}. [d] Calculated by $100Fk_\Delta/k_t$.

In conclusion, we indeed find a satisfactory product–rate correlation in the acetolysis of *threo*-3-aryl-2-butyl brosylates, which supports the hypothesis that the reaction proceeds *via* two independent pathways *with no significant crossover between these pathways.*[2,5]

(1) C. J. Kim and H. C. Brown, *J. Amer. Chem. Soc.*, **91**, 4287, 4289 (1969).

(2) (a) C. J. Lancelot, J. J. Harper, and P. von R. Schleyer, *ibid.*, **91**, 4291, 4294, 4296, (1969); (b) J. M. Harris, F. L. Schadt, P. von R. Schleyer, and C. J. Lancelot, *ibid.*, **91**, 7508 (1969)

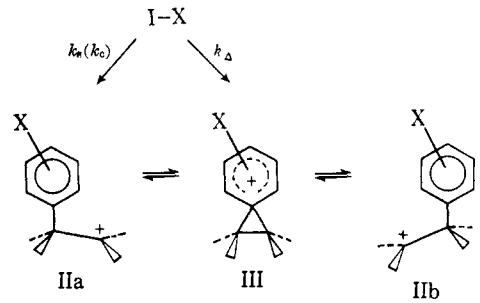
(3) As small amounts of retained products were detected even for the deactivated compounds, small corrections of k_t were carried out by $k_s = k_t(1 -$ fraction of retained product). The k_s line in Figure 1 is the result of least-squares treatment of these k_s values.

(4) For example, hydride-shift products were included in the k_s pathway here. For the parent compound (I-H), Cram estimated *ca.* 20% of the product arises from the benzyl tertiary cation: D. J. Cram, *J. Amer. Chem. Soc.*, **74**, 2137 (1952).

Since primary carbonium ions are very unstable, the acetolysis of primary derivatives, such as β-arylethyl, would be expected to involve strong solvent participation; no crossover between the Fk_Δ and k_s pathways would be anticipated, and none is found.[2b,6] In contrast, the behavior of secondary β-arylalkyl derivatives is not so easily interpreted, largely as a consequence of confusion in the literature dealing with the nature of solvolysis of secondary substrates.

Traditionally, the solvolysis of simple secondary substrates has been formulated as borderline: that is, SN2-like behavior was expected in the more nucleophilic solvents such as alcohols, but a tendency toward more limiting behavior (*e.g.*, carbonium ions or ion pair intermediates without nucleophilic solvation) was expected in the less nucleophilic solvents such as acetic and formic acids.[7,8]

In view of this propensity of secondary substrates toward more limiting behavior[7,8] it is reasonable to expect that the acetolysis of secondary β-arylalkyl derivatives would be more prone to crossover than primary β-arylalkyl systems.[7e] Specifically, if the solvolysis of secondary derivatives does approach limiting character, with little or no nucleophilic solvent interaction with the carbonium center, there should be only a small energy barrier between the k_Δ and k_s (essentially k_c) processes. Consequently, rapid interconversion would be anticipated between the ions III (k_Δ) and II



($k_s \approx k_c$) and also between the isomeric open cations (or ion pairs) IIa and IIb.[9] This situation, in contrast to our experimental observations, would not be expected to lead to a quantitative correlation between rates and products.

In spite of the borderline (or near limiting) behavior which has been ascribed to the acetolysis and formolysis of simple secondary systems,[7,8] the solvolysis of secondary β-arylalkyl systems was consistently depicted by Cram[10] and by Winstein[10] in terms of competition between aryl-assisted and *solvent-assisted* mechanisms. No explicit reason was given why the presence of β-aryl substituents should *increase* the importance of nucleophilic solvent assistance in the k_s pathway. In fact, because of the bulk of a β-aryl substituent, just the opposite would be expected: solvent assistance should be *less important* in the β-arylalkyl systems. The first real evidence that the degree of nucleophilic solvent assistance in the k_s process for secondary β-arylalkyl systems was sufficient to prevent crossover between the k_Δ and k_s pathways was not presented until 1969.[2,5,11] Moreover, recent data from several different approaches[12] support the position that nucleophilic solvent participation in the acetolysis of secondary arenesulfonates must be a major factor in the solvolytic process.

The present results clearly confirm that crossover must be unimportant in the acetolysis of secondary β-arylalkyl derivatives, such as 3-phenyl-2-butyl tosylate. This supplies additional evidence that solvent participation must be a major factor in the acetolysis of simple secondary alkyl arenesulfonates as well,[11,12] in contrast to the original belief.[7,8] This conclusion, if accepted, requires an extensive reinterpretation of the acetolysis studies of secondary derivatives conducted over the past 20 years.

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(5) A. Diaz and S. Winstein, *J. Amer. Chem. Soc.*, **91**, 4300 (1969).

(6) S. Winstein and R. Heck, *ibid.*, **78**, 4801 (1956); A. Diaz, I. Lazdins, and S. Winstein, *ibid.*, **90**, 6546 (1968); M. G. Jones and J. L. Coke, *ibid.*, **91**, 4284 (1968).

(7) (a) S. Winstein and E. Grunwald, *ibid.*, 70, 828, 846 (1948); (b) S. Winstein and N. J. Holness, *ibid.*, 77, 5562 (1955); (c) "... isopropyl *p*-bromobenzenesulfonate or bromide may approach the Lim. category in acetic acid and more closely in formic acid," S. Winstein, E. Grunwald, and H. W. Jones, *ibid.*, 73, 2700 (1951); (d) "To make the solvolysis of the compounds in question... as nearly limiting (Lim.) with respect to the solvent role..., we have studied acetolysis of benzenesulfonates," S. Winstein, B. K. Morse, E. Grunwald, K. C. Schreiber, and J. Corse, *ibid.*, 74, 1112 (1952); (e) "With simple primary systems there is no crossing over; with secondary and tertiary systems it is more likely to have cross-over between the different routes," S. Winstein, Chemica Theorica, Conferenze VIII. Corso Estivo di Chimica, Academia Nationale dei Lincei, Rome, 1965, p 251.

(8) (a) A. Streitwieser, "Solvolytic Displacement Reactions," McGraw-Hill, New York, N. Y., 1962; (b) C. K. Ingold, "Structure and Mechanism in Organic Chemistry," 2nd ed, Cornell University Press, Ithaca, N. Y., Chapter VII, p 418ff.

(9) This describes essentially the "rapidly equilibrating ions" explanation for β-arylalkyl behavior discussed by H. C. Brown, K. J. Morgan, and F. J. Chloupek, *J. Amer. Chem. Soc.*, 87, 2137 (1965). Such rapidly equilibrating ions were considered early by Winstein as an alternative to the $Fk_\Delta + k_s$ treatment: S. Winstein and B. K. Morse, *ibid.*, 74, 1133 (1952). Winstein's reasons for abandoning this formulation were never stated explicitly in the literature.

(10) For a summary of the earlier work of the UCLA school, see D. J. Cram, *ibid.*, **86**, 3767 (1964).

(11) J. A. Thompson and D. J. Cram, *ibid.*, **91**, 1778 (1969); *cf.* D. J. Cram and J. A. Thompson, *ibid.*, **89**, 6766 (1967). The magnitude of anchimeric assistance (k_t/k_s) estimated by these authors is too large (also see ref 10), while an earlier, lower estimate[8a] [*cf.* H. C. Brown and C. J. Kim, *ibid.*, 90, 2082 (1968)] is shown by the present work to have been almost exactly correct.

(12) J. L. Fry, C. J. Lancelot, L. K. M. Lam, J. M. Harris, R. C. Bingham, D. J. Raber, R. E. Hall, and P. v. R. Schleyer, *ibid.*, **92**, 2538 (1970); J. L. Fry, J. M. Harris, R. C. Bingham, and P. v. R. Schleyer, *ibid.*, **92**, 2540 (1970); P. v. R. Schleyer, J. L. Fry, L. K. M. Lam, and C. J. Lancelot, *ibid.*, **92**, 2542 (1970), and earlier papers cited, especially P. E. Peterson, R. J. Bopp, D. M. Chevli, E. L. Curran, D. E. Dillard, and R. J. Kamat, *ibid.*, **89**, 5902 (1967).

(13) (a) Address correspondence to this author; (b) Postdoctoral Research Associate, 1969–1970.

(14) American Can Company Fellow, 1966–1967; National Institutes of Health Predoctoral Fellow, 1967–1968, at Princeton University.

Herbert C. Brown,[13a] C. J. Kim[13b]
Richard B. Wetherill Laboratory
Purdue University, Lafayette, Indiana 47907

Charles J. Lancelot[14]
Chemical Research and Development Center, FMC Corporation
Princeton, New Jersey 08540

Paul v. R. Schleyer
Department of Chemistry, Princeton University
Princeton, New Jersey 08540

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