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Secondary α-Deuterium Kinetic Isotope Effects: Assumptions Simplifying Interpretations of Mechanisms of Solvolyses of Secondary Alkyl Sulfonates

T. William Bentley

Department of Chemistry, University of Wales, Swansea, Singleton Park, Swansea SA2 8PP, Wales, United Kingdom

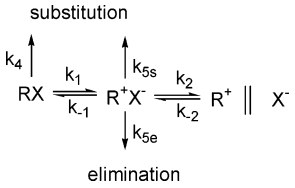
cmsolvol@swansea.ac.uk

Received December 8, 2003

Abstract: For solvolyses of 2-propyl and cyclopentyl sulfonates, logarithms of α-deuterium kinetic isotope effects (α-KIE) correlate linearly with logarithms of nucleophilic solvent assistance (NSA); correlations have the same slopes, but different intercepts, consistent with both solvent and structural effects on α-KIEs for heterolysis, further supported by recent theoretical and experimental data. It is argued that α- and *β*-KIEs cannot yet distinguish between mechanisms proceeding via one or more transition states of similar energies. Structural, solvent, and isotope effects can be rationalized by heterolysis accompanied by NSA.

A major, long-term, research program has focused on studies of secondary deuterium kinetic isotope effects (α-, *β*-, and *γ*-) for solvolyses of primary and secondary alkyl substrates,[1−4] to probe reaction mechanisms without the more substantial perturbations of the reaction system which arise when substituent or solvent effects are investigated. Mechanistic explanations, usually based on a simplified version of the extended ion pair mechanism of Winstein (Scheme 1),[5] include the timing of rate-determining nucleophilic attack (on covalent substrate or on various ion pairs)[1] and the kinetic and stereochemical consequences of competing elimination reactions.[3] For convenience, electrophilic solvation of the leaving group is almost always omitted, although it is generally agreed that it is important.[6] Also, nucleophilic solvation

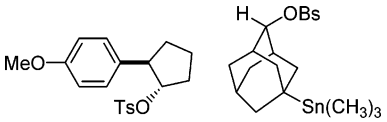
SCHEME 1. Simplified Version of Winstein's Extended Ion Pair Mechanism



of ion pair intermediates is usually not drawn; but Winstein et al. explicitly included this possibility.[7]

Two strongly assisted competing processes (k_Δ, anchimerically assisted, and k_s, nucleophilically solvent assisted) are required to explain the apparent lack of large rate enhancements due to anchimeric assistance in solvolyses of *β*-arylalkyl substrates.[7a,8] Product−rate correlations established that there was little or no crosssover between the two pathways,[8,9] so for k_s solvolyses, ionization occurred with nucleophilic solvent assistance (NSA) to give nucleophilically solvated cationic intermediates (i.e. they were not "free" to undergo aryl migration at that stage). Even acetolysis of *trans*-2-(4-methoxyphenyl)cyclopentyl tosylate (**1**), a less sterically accessible cycloalkyl substrate in a less nucleophilic carboxylic acid solvent, gave a product−rate correlation, implying ionization with NSA.[10]

To interpret secondary kinetic isotope effects for solvolyses of cyclopentyl sulfonates in various solvents, Shiner et al. considered that nucleophilically solvated ion pair intermediates might be present.[3b] However, for simplification, detailed quantitative fits to proposed mechanisms have subsequently[3b,4a,e] been based on the assumption (see 2, below) that isotope effects on individual reaction steps are solvent independent, i.e. nucleophilic solvation of ion pairs was excluded.[1,3b]



1 **2**

While each mechanism and quantitative fit has been carefully argued,[3,4] and by itself appears reasonable, 11 different rate-determining steps (RDS) have now been proposed for solvolyses of various secondary alkyl substrates (k_1, k_2, k_4, k_{5e}, and k_{5s} (Scheme 1), 2 for H-migration, 2 for alkyl migration, and 2 others; details are given in the Supporting Information, Table S1).[1,3,4,11] The present study was prompted by a recent report proposing

(1) Shiner, V. J., Jr. In *Isotope Effects in Chemical Reactions*; Collins, C. J., Bowman, N. S., Eds.; van Nostrand Reinhold: New York, 1970; Chapter 2, pp 90−159.

(2) Maskill, H. *The Physical Basis of Organic Chemistry*; Oxford University Press: Oxford, UK, 1985; pp 367−393.

(3) (a) Seib, R. C.; Shiner, V. J., Jr.; Sendijarević, V.; Humski, K. *J. Am. Chem. Soc.* **1978**, *100*, 8133−8137. (b) Shiner, V. J., Jr.; Nollen, D. A.; Humski, K. *J. Org. Chem.* **1979**, *44*, 2108−2115.

(4) (a) Wilgis F. P.; Neumann, T. E.; Shiner, V. J., Jr. *J. Am. Chem. Soc.* **1990**, *112*, 4435−4446. (b) Hiršl-Starćvić, S.; Majerski, Z.; Sunko, D. E. *J. Org. Chem.* **1980**, *45*, 3388−3394. (c) Stoelting, D. T.; Shiner, V. J., Jr. *J. Am. Chem. Soc.* **1993**, *115*, 1695−1705. (d) Shiner, V. J., Jr.; Imhoff, M. A. *J. Am. Chem. Soc.* **1985**, *107*, 2121−2124. (e) Imhoff, M. A.; Ragain, R. M.; Moore, K.; Shiner, V. J., Jr. *J. Org. Chem.* **1991**, *56*, 3542−3549. (f) Adcock, W.; Trout, N. A.; Vercoe, D.; Taylor, D. K.; Shiner, V. J., Jr.; Sorensen, T. S. *J. Org. Chem.* **2003**, *68*, 5399−5402. (g) Shiner, V. J., Jr.; Fisher, R. D.; Dowd, W. *J. Am. Chem. Soc.* **1969**, *91*, 7748−7749. (h) Shiner, V. J., Jr.; Neumann, T. E.; Basinger, B. B. *Croat. Chem. Acta* **1996**, *69*, 1405−1420.

(5) Winstein, S.; Appel, B.; Baker, R.; Diaz, A. In *Organic Reaction Mechanisms*; Special Publication No. 19; The Chemical Society: London, UK, 1965; pp 109−130.

(6) Bentley, T. W.; Schleyer, P. v. R. *Adv. Phys. Org. Chem.* **1977**, *14*, 1−67.

(7) (a) Winstein, S.; Allred, E.; Heck, R.; Glick, R. *Tetrahedron* **1958**, *3*, 1−13. (b) Diaz, A. F.; Lazdins, I.; Winstein, S. *J. Am. Chem. Soc.* **1968**, *90*, 1904−1905. (c) Winstein, S. *Chimica Teorica, VIII Corso Estivo Di Chimica*; Accademia Nazionale Dei Lincei: Rome, Italy, 1965; p 240.

(8) (a) Cram D. J.; Thompson, J. A. *J. Am. Chem. Soc.* **1967**, *89*, 6766−6768. (b) Lancelot, C. J.; Cram, D. J.; Schleyer, P. v. R. In *Carbonium Ions*; Olah, G. A., Schleyer, P. v. R., Eds.; Wiley: New York, 1972; Vol. 3, Chapter 27.

(9) Schadt, F. L.; Lancelot, C. J.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1978**, *100*, 228−246.

(10) Kim, C. J.; Brown, H. C. *J. Am. Chem. Soc.* **1972**, *94*, 5051−5060.

10.1021/jo035793x CCC: $27.50
Published on Web 02/11/2004

a new mechanism for solvolyses of the stannyl adamantyl brosylate (**2**),[4f] based in part on an unexpectedly high α-deuterium kinetic isotope effect (α-KIE) of 1.33. Assumptions underlying the interpretations of α-KIEs are reexamined and alternatives leading to fewer RDS are proposed.

Three assumptions proposed previously about α-KIEs for single steps are as follows: (1) only α-KIEs < 1.08 are consistent with S_N2 reactions (k_4),[1] so alternative mechanisms are proposed to explain greater α-KIEs;[3,4,11] (2) single-step α-KIEs > 1.08 are solvent independent;[3b] and (3) single-step α-KIEs > 1.08 are independent of the structure of the alkyl group of the substrate.[3b,4]

Evidence against the validity of these assumptions is given below.

Assumption 1: For S_N2 reactions, Maskill[2] tabulated α-KIEs in the range 0.9−1.18; high values[12] are associated with S_N2 reactions via "exploded" transition states[13a] (with high carbocation character[13b]). Contrary to assumption 1, it is widely agreed[2,12,14−16] that α-KIEs for S_N2 reactions may be at least 1.18 (see also Table S2).

Assumption 2: If S_N2 solvolyses can have α-KIEs of at least 1.18 (see above), it is reasonable to examine relationships between higher α-KIEs and NSA. Solvolyses of 2-adamantyl substrates (2-AdOTs) react with little or no nucleophilic or anchimeric assistance,[17] and minimum estimates of the kinetic effects of NSA for solvolyses of secondary alkyl sulfonates (ROTs) can be obtained from eq 1,[18,19] assuming that solvolyses of ROTs in TFA occur without NSA.

$$\mathrm{NSA} = (k_{\mathrm{ROTs}}/k_{\mathrm{2-AdOTs}})_{\text{any solvent}}/(k_{\mathrm{ROTs}}/k_{\mathrm{2-AdOTs}})_{\mathrm{TFA}} \quad (1)$$

Logarithms of α-KIEs are energy terms,[1,2] and plots versus log NSA (Figure 1) for solvolyses of isopropyl and cyclopentyl sulfonates give satisfactory linear correlations having the same slope. Although experimental uncertainties due to random errors in individual values of k are small (<1%), larger uncertainties in α-KIE (>1%, Table 1) are significant in Figure 1, and may be partly due to differences in sulfonate leaving groups; the largest deviation (residual) in α-KIE is only 0.03 (for cyclopentyl in AcOH) and others are <0.017.

Assumption 3: As the intercepts of Figure 1 are different for solvolyses of *i*-Pr (α-KIE = 1.20) and cyclopentyl (1.25) sulfonates, it appears that α-KIEs depend on the structure of the alkyl substrate (ring vs open chain?), even when NSA is small.[21] For carbon−oxygen bonded substrates (Table 2), α-KIEs also show a lowering of ca. 0.05 by dimethyl (compare **3** with *i*-Pr, and **4** with **6**), and possible electronic effects of 0.15 for para-substituted benzhydrols (**7**). McLennan[22] questioned the proposed[1,11] maximum α-KIE of 1.22−1.23, calculated on the basis of Me as an alkyl group (rather than a secondary alkyl group), and suggested a maximum α-KIE of 1.35. This proposal is supported by the recent example of an α-KIE of 1.33 for solvolysis of **3**.[4f] In addition, solvolyses of *p*-methoxybenzal chloride show α-KIEs up to 1.21,which is significantly higher than the "maximum" of 1.15 expected for chloride as a leaving group.[22,24]

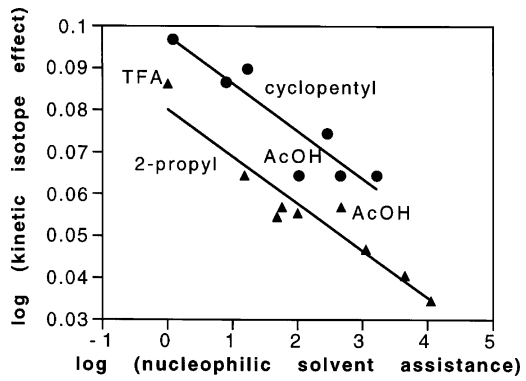


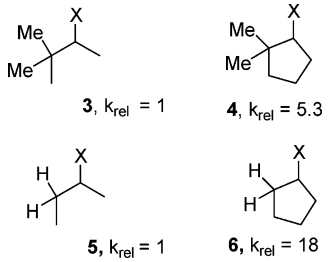
FIGURE 1. Correlation of logarithms of α-KIE with logarithms of minimum estimates of nucleophilic solvent assistance (eq 1) for solvolyses of *i*-Pr (n = 9; slope, −0.0112 ± 0.0013; intercept, 0.080 ± 0.003; r = 0.955) and cyclopentyl sulfonates (n = 7; slope, −0.0113 ± 0.0022; intercept, 0.098 ± 0.005; r = 0.914 or 0.967, excluding AcOH); data from Table S3.

TABLE 1. Assessment of Experimental Uncertainties in Measurements of α-Deuterium Kinetic Isotope Effects for Solvolyses of Isopropyl and Cyclopentyl Sulfonates

substrate	solvent	*T*/°C	1st result	2nd result
isopropyl	water	30.0	1.13(4)[a]	1.14(3)[b]
isopropyl	50% TFE	25.0	1.122[c,d]	1.136[c,e]
cyclopentyl	97% TFE	25−30	1.25[c,f]	1.221[c,g]

[a] Data for tosylate from ref 20. [b] Data for mesylate from ref 20. [c] Data for brosylates. [d] References 1 and 4g. [e] See Table S3, footnote *h*. [f] Initial result at 30 °C,− ref 3a. [g] Value at 25 °C, ref 3a.

SCHEME 2. Effect of Dimethyl Groups on Solvolytic Reactivity in Trifluoroethanol



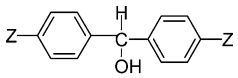
(11) Shiner, V. J.; Fisher, R. D. *J. Am. Chem. Soc.* **1971**, *93*, 2553−2554.
(12) (a) Craze, G. A.; Kirby, A. J.; Osborne, R. J. *J. Chem. Soc., Perkin Trans. 2* **1978**, 357−368. (b) Knier, B. L.; Jencks, W. P. *J. Am. Chem. Soc.* **1980**, *102*, 6789−6798.
(13) (a) Jencks, W. P. *Acc. Chem. Res.* **1980**, *13*, 161−169. (b) Bentley, T. W.; Bowen, C. T. *J. Chem. Soc., Perkin Trans. 2* **1978**, 557−562.
(14) Bentley, T. W.; Bowen, C. T.; Morten, D. H.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1981**, *103*, 5466−5475.
(15) Hayami, J.; Hihara, N.; Tanaka, N.; Kaji, A. *Bull. Chem. Soc. Jpn.* **1979**, *52*, 831−835.
(16) Westaway, K.; Ali, S. F. *Can. J. Chem.* **1979**, *57*, 1089−1097.
(17) Fry, J. L.; Lancelot, C. J.; Lam, L. K. M.; Harris, J. M.; Bingham. R. C.; Raber, D. J.; Hall, R. E.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1970**, *92*, 2538−2540.
(18) Schleyer, P. v. R.; Fry, J. L.; Lam, L. K. M.; Lancelot, C. J. *J. Am. Chem. Soc.* **1970**, *92*, 2542−2544.
(19) Schadt, F. L.; Bentley, T. W.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1976**, *98*, 7667−7674.
(20) Leffek, K. T.; Llewellyn, J. A.; Robertson, R. E. *Can. J. Chem.* **1960**, *38*, 1505−1510.
(21) Bentley, T. W.; Liggero, S. H.; Imhoff, M. A.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1974**, *96*, 1970−1973.
(22) McLennan, D. J. *J. Chem. Soc., Perkin Trans. 2* **1981**, 1316−1324.
(23) Mocek, M. M.; Stewart, R. *Can J. Chem.* **1963**, *41*, 1641−1643.

TABLE 2. Dependence of α-Deuterium Kinetic and Equilibrium Isotope Effects (α-IE) on the Structure of Carbon−Oxygen Bonded Secondary Substituent at 25 °C

substrate	α-IE	reaction
7, Z = Cl	1.35	equil for cation formation in conc H_2SO_4[a]
7, Z = H	1.29	equil for cation formation in conc H_2SO_4[a]
7, Z = Me	1.20	equil for cation formation in conc H_2SO_4[a]
2	1.33	kinetic of solvolysis in 97% TFE[b]
6, X = OBs	1.25	kinetics of solvolysis in 97% HFIP[c]
2-AdOTr[d]	1.22−1.23	kinetics of solvolyses in aq alcohol
4, X = OBs	1.19−1.20	kinetics of solvolyses in aq alcohol[e]
i-PrOTs	1.20	kinetics of S_N1 solvolysis (intercept of Figure 1)
3, X = OBs	1.15	kinetics of solvolyses in aq alcohol[f]

[a] Reference 23. [b] Reference 4f. [c] Reference 3a. [d] 2-Adamantyl tresylate, ref 11. [e] Reference 4d. [f] References 1 and 4g.

Other assumptions or parameters refer to KIEs for individual steps;[3b] the most important (assumption 4) is the single-step α-KIE of 1.15 for k_1 (Scheme 1),[3b,4e] based initially on solvolyses of pinacolyl brosylate (**3**, X = OBs),[1,4g] but later used for cyclopentyl substrates (**6**).[3b,4e] Instead of a structural effect on α-KIE, additional mechanisms involving ion pair return are proposed to account for higher α-KIEs.[1,3,4,11] However, a slightly higher α-KIE of 1.165 for solvolyses of 2,2-dimethyl-3-pentyl brosylate was attributed to "slightly enhanced steric congestion of the alpha CH bond in the initial state"[4h] (i.e. even incorporation of one extra methyl group into **3** increases the α-KIE).



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Alternatively, observed α-KIEs of 1.19−1.25 were classified[2] as S_N1 reactions. Also, α-KIEs of 1.15−1.17 were obtained for anchimerically assisted processes,[4b,c] so the α-KIEs for **3** and 2,2-dimethyl-3-pentyl could be lowered by interactions with a nucleophile or a neighboring group. Despite having a hindered structure, pinacolyl tosylate (**3**, X = OTs) reacts with lithium cyclopentadienide in THF by nucleophilic attack to give substitution with almost complete inversion, with little evidence for elimination.[25] Therefore, **3** is susceptible to nucleophilic attack, and solvolyses may be classified as weak k_s,[14] although (as noted[3b,4d]) the α-KIE is not markedly dependent on solvent.[4g,4h]

Changes in α-KIEs as small as 0.03 have led to proposals of mechanistic changes,[1,3,4] but if any of the above four assumptions are incorrect, small changes in α-KIEs are not necessarily due to changes in mechanism. A need for greater theoretical understanding of KIEs is also emphasized by other subtle effects: α-KIEs may depend on the concentrations of reactants,[26a] or on added salts;[24] also there are β-KIEs on partition of *p*-nitrophenyl acetate between water and cyclohexane.[26b]

Assumptions to simplify interpretations of α-KIEs, reducing the number of RDS: (A) Variations in α-KIE with changes in solvent can be explained by nucleophilic solvent assistance (NSA) during heterolytic cleavage of covalent substrate (RX),[19,22] e.g. for solvolyses of *i*-Pr and cyclopentyl sulfonates (Figure 1); contrary to assumptions 1 and 2, a change in RDS is not required. Stereochemistry of substitution for 2-octyl[27,28] and cyclopentyl[3a] sulfonates is often close to 100% inversion, as expected for concerted processes.[12b,29] Even for solvolysis of cyclopentyl brosylate in 97% TFE (NSA only 8, Table S3), the ether product is 91% inverted.[3a]

(B) Even when NSA is small and contrary to assumption 3, there are variations in α-KIE values for heterolysis of R−X, due to the structure of the alkyl or aryl group (Table 2).[21,22] β-KIEs provide important support for mechanisms proposed by Shiner et al.[3b] Alternative explanations are that reactions may be concerted[12b,29] (via a single transition state) due to vanishingly small lifetimes of potential intermediates,[12b,13a] or may occur via competing concerted reactions (e.g. for substitution, elimination,[30] and ^{18}O-scrambling[29]) or via nucleophilically solvated ion pair intermediates (possibly with small amounts of ion pair return).[27] As the various transition states are likely to be similar in energy and structure,[4d] published explanations[1,3,4] could be adapted to account for β-KIEs.

Solvent and structural effects on reactivity: A complete mechanism should account for products (including stereochemistry) and isotope effects (as achieved quantitatively[1,3,4]), but should also be consistent with a broader view of changes in reactivity due to solvent effects and structural effects. Solvent effects on rate constants for solvolyses of many secondary sulfonates fit a simple blending equation (eq 2), relating solvolyses of secondary sulfonates (ROTs) to solvolyses of 2-AdOTs and *i*-PrOTs, where *k* refers to solvolysis in any solvent relative to k_0 (80% v/v ethanol/water).[14] Equation 3 is the modified Grunwald−Winstein mY_{OTs} equation ($Y_{OTs} = \log(k/k_o)_{2-AdOTs}$).[31]

$$\log(k/k_o)_{ROTs} = Q' \log(k/k_o)_{2-AdOTs} + (1 - Q') \log(k/k_o)_{i-PrOTs} + c \quad (2)$$

$$\log(k/k_o)_{ROTs} = m \log(k/k_o)_{2-AdOTs} + c \quad (3)$$

For solvolyses of cyclopentyl tosylate, eq 2 gives an excellent fit ($Q' = 0.30 \pm 0.03$, $r = 0.995$, stand deviation in log $k = 0.14$), with a negligible intercept (*c*) and no additional slope term, so in effect Q' is the only adjustable parameter (Table S4). Even after varying both *m* and *c* (i.e. with two adjustable parameters), the fit for eq 3 is far inferior ($m = 0.51 \pm 0.07$, $r = 0.926$, $c = -0.28 \pm 0.18$; standard deviation in log $k = 0.48$). The results indicate that solvolyses of cyclopentyl tosylate have

(24) Vitullo, V. P.; Wilgis, F. P. *J. Am. Chem. Soc.* **1981**, *103*, 880−883.
(25) Baar, C. R.; Levy, C. J.; Min, E. Y.-J.; Henling, L. M.; Day, M. W.; Bercaw, J. E. Submitted for publication.
(26) (a) Westaway, K. C.; Waszczylo, Z.; Smith, P. J.; Rangappa, K. S. *Tetrahedron Lett.* **1985**, *26*, 25−28. (b) Kovach, I. M.; Quinn, D. M. *J. Am. Chem. Soc.* **1983**, *105*, 1947−1950.
(27) Bentley, T. W.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1976**, *98*, 7658−7666.
(28) Wiener, H.; Sneen, R. A. *J. Am. Chem. Soc.* **1965**, *87*, 287−291.
(29) Dietze, P. E.; Wojciechowski, M. *J. Am. Chem. Soc.* **1990**, *112*, 5240−5244.
(30) Gregoriou, G. A.; Varveri, F. S. *J. Chem. Soc., Perkin Trans. 2* **1981**, 985−990.
(31) Bentley, T. W.; Llewellyn, G. *Prog. Phys. Org. Chem.* **1990**, *17*, 121−158.

substantial isopropyl character, which can be correlated quantitatively with solvent nucleophilicity and with S_N2 solvolyses of methyl sulfonates.[19,32]

Structural effects on solvolytic reactivity also fit a simple pattern in solvents of low nucleophilicity, when NSA is minimized. It is agreed that **3** does not undergo internal ion pair return (RDS is k_1),[1,4g] but k_2 is proposed[1] as the RDS for trifluoroacetolyses of other secondary alkyl sulfonates (so ion pair return should lower rates[21]); however, rates including **3** correlate linearly with σ^*.[21,33] Also, solvolyses of the cyclopentyl analogue **4** are 5.3 times faster than those of **3** in 97% TFE[4d] (Scheme 2), whereas cyclopentyl tosylate (**6**, X = OTs) reacts 18 times faster than 2-butyl tosylate (**5**, X = OTs) in 100% TFE.[14] The small difference between rate factors of 18.3 and 5.3 could be due to conformational effects, and none of these solvolyses may be greatly affected by ion pair return (less than a rate factor of 5[27]).

The kinetic effects of NSA in secondary solvolyses are significantly larger than those associated with ion pair return. NSA (eq 1) varies over 10^4-fold, depending on steric effects in the substrate and solvent nucleophilicity.[18,19] Also, relative rates of solvolyses of **6** and **4** vary over 100-fold from >10 in 90% ethanol to 0.1 in 90% HFIP.[4e] NSA explains why acetolysis of **6** is faster than that of **4**,[14,34] an observation that led to the study of **4**.[4d]

As solvents usually influence ion pair return (if present),[27,35] and if solvolyses of **4** undergo a rate-determining methyl shift (as proposed[4d]) in a contact ion pair (i.e. ion pair return occurs), it is surprising that relative rates of solvolyses of **4** and **3** vary only from 4.1 in 70% ethanol to 5.6 in 90% HFIP.[4d] Alternatively, the explanation[4d] that there are "similarities in charge separation in the two rate-determining transition states" implies a surprising lack of solvent dependence of ion pair partitioning. Furthermore, if the transition states are so similar, it is not clear how secondary isotope effects can show[4d] that the reactions of **4** occur by a rate-determining reaction of the contact ion pair.

Recent theoretical studies: In support of assumption B (see above), AM1/COSMO calculations for $H_2O + ROH_2^+$ predict a structural dependence of α-KIE for S_N1 reactions (from 1.36 to 1.25 for R = Me, Et, *i*-Pr) and an α-KIE of 1.17 for the S_N2 reaction with R = *i*-Pr (supporting assumption A).[36]

In conclusion, the success of eqs 2 and 3 in correlating the solvent effects on secondary solvolyses (e.g. for cyclopentyl sulfonates) indicates that there is an underlying mechanistic simplicity.[14] Adoption of assumptions A and B (above) (i) permits mechanistic explanations consistent with a long-established mechanistic framework[7−10] involving two main competing pathways, a nucleophilically solvent-assisted pathway (α-KIE values are solvent dependent; solvent effects correlated with eq 2), and an anchimerically assisted $k_\Delta - k_c$ pathway (solvent effects correlated with eq 3); (ii) reduces the number of RDS from 11 to 3; and (iii) makes mechanistic interpretations of secondary KIEs more consistent with those of structural and solvent effects on reactivity.

Acknowledgment. Some of this work was presented at the 7th Latin American Conference on Physical Organic Chemistry, Florianópolis, September 2003. Helpful comments and/or information from J. E. Bercaw, C. A. Bunton, G. A. Gregoriou, D. N. Kevill, H. Maskill, P. v. R. Schleyer, J. F. Mata-Segreda, J. S. Siegel, and I. H. Williams are gratefully acknowledged.

Supporting Information Available: Additional kinetic data (Table S1, α-deuterium kinetic isotope effects and previously proposed rate determining steps and mechanisms of solvolyses of secondary alkyl sulfonates; Table S2, examples of relatively high values of α-deuterium kinetic isotope effects for S_N2 reactions; Table S3, minimum estimates of nucleophilic solvent assistance (k_s/k_c) and α-deuterium kinetic isotope effects for solvolyses of 2-propyl and cyclopentyl sulfonates at 25 °C; and Table S4, correlations of solvent effects for solvolyses of cyclopentyl tosylate). additional comments, and additional references. This material is available free of charge via the Internet at http://pubs.acs.org.

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(32) Kevill, D. N.; D'Souza, M. J.; Ren, H. *Can. J. Chem.* **1998**, *76*, 751−757.
(33) Peterson, P. E.; Kelley, R. E., Jr.; Belloli, R.; Sipp, K. A. *J. Am. Chem. Soc.* **1965**, *87*, 5169−5171.
(34) Streitwieser, A., Jr.; Dafforn, G. A. *Tetrahedron Lett.* **1969**, 1263−1266.
(35) See however: Kevill, D. N.; Kyong, J. B.; Weitl, F. L. *J. Org. Chem.* **1990**, *56*, 4304−4311.
(36) Ruggiero G. D.; Williams, I. H. *J. Chem. Soc., Perkin Trans. 2* **2001**, 448−458.