sulfonyl fluoride[13] as a reaction product.

4,5-Dichloro-1,3-benzenedisulfonyl Chloride. *o*-Dichlorobenzene (19.5 g, 0.133 mol) and chlorosulfonic acid (180 mL, 2.7 mol) were refluxed for 40 h. Workup gave 29.3 g of crude product, which was recrystallized from hexanes/benzene (100/40) to give pure material (20.5 g), mp 114-5 °C (lit.[14] mp 110-111 °C): IR (Nujol) 1190 and 1172 cm^{-1} (SO_2Cl); ^{1}H NMR δ 8.65 (d, 1 H, J = 2 Hz), 8.4 (d, 1 H). Anal. Calcd for $C_6H_2Cl_4S_2O_4$: C, 20.95; H, 0.59. Found: C, 20.76; H, 0.55.

4,5-Dichloro-1,3-benzenedisulfonyl Fluoride. The above disulfonyl chloride (19.1 g, 56 mmol), 19.1 g (0.33 mol) of dry KF, 0.3 g of 18-crown-6, and 125 mL of CH_3CN were refluxed for 7.5 h. The cooled mixture was filtered, and the solvent was removed by rotary evaporation. ^{19}F NMR indicated that no ring chlorines had exchanged (singlets at 66.0 and 57.3 ppm downfield from $CFCl_3$). Crude material, containing some residual crown ether, was used in the fluorodesulfonylation described below.

3-Chloro-4,5-difluorobenzenesulfonyl Fluoride. Crude 4,5-dichloro-1,3-benzenedisulfonyl fluoride (19.0 g, 0.06 mol) was heated in 65 mL of DMF containing 10 g (0.17 mol) of KF to reflux over a period of 30 min and held at reflux for an additional 45 min. The mixture was cooled, poured into 400 mL of water, and extracted with ether. The combined ether extracts were washed with water and brine and dried over $MgSO_4$. After removing the ether, the residue (10.4 g) was distilled under vacuum. The fraction boiling at 71-86 °C (7.2 g) contained 5-10% 3,4,5-trifluorobenzenesulfonyl fluoride (GC-MS, m/e 214 (parent); ^{19}F NMR showed aromatic fluorine at ϕ^* 127.2 (dd) and 146 (dtt)). Pure (97%) 3-chloro-4,5-difluorobenzenesulfonyl fluoride was obtained by redistillation (bp 78-80 °C at 4 mmHg): GC-MS, m/e 230 (P), P + 2 ca. 30% of P, 135 (base); ^{19}F NMR ϕ^* -65.8 (s), 124.1, 128.2. Anal. Calcd for $C_6H_2ClF_3O_2S$: C, 31.25; H, 0.87. Found: C, 30.88; H, 0.87.

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Selectivity in the Solvolysis in Binary Solvents of 1-Adamantyl Derivatives Bearing Leaving Groups That Depart as Neutral Molecules

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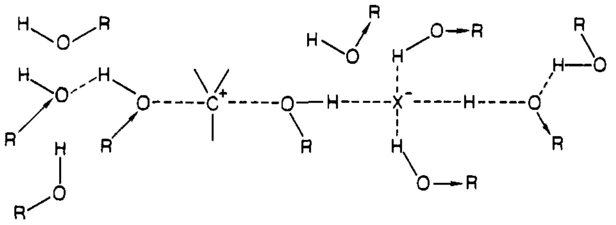
In solvolysis of alkyl halides or tosylates which can undergo backside solvolytic displacement, ethanol (EtOH) is found to be 2-3 orders of magnitude more nucleophilic than trifluoroethanol (TFE).[1] However, with 1-adamantyl derivatives where only front-side displacement occurs, EtOH and TFE have been found to exhibit similar reactivities as measured by product studies and using eq 1 to calculate relative reactivities or selectivities (S).[2-7]

$$S = k_{\mathrm{TFE}}/k_{\mathrm{EtOH}} = ([\text{1-AdOTFE}]/[\text{1-AdOEt}])([\mathrm{EtOH}]/[\mathrm{TFE}]) \quad (1)$$

Previous studies of the selectivity of substitution of 1-adamantyl derivatives in binary solvents have failed to agree on the factors leading to the abnormal nucleophilicity orders.[2-7] Since solvent-separated ion pairs are thought to be involved in these solvolytic reactions, it has generally been assumed that the selectivities reflect the relative stabilities of the two solvent-separated ion pairs.[8] Other factors, however, have not been rigorously excluded. McManus and Zutaut[2] recently concluded that solvent bulk and electrophilicity are significant in solvolytic displacements involving 1-adamantyl derivatives and that intrinsic nucleophilicity[1] is of lesser significance. That study dealt with solvolytic substitution of 1-adamantyl derivatives in binary solvents of varying nucleophilicities and electrophilicities including fluorinated solvents. A complementary study by Allard and Casadevall has appeared.[3] Together these reports extend the previous work of Ando,[4] Pross,[5] Rappoport,[6] and Whiting.[7] A puzzling aspect of the earlier reports was the finding of an unusual selectivity for water and for trifluoroethanol (TFE) in water-ethanol (EtOH) and water-TFE binary solvent mixtures, respectively. Since these reactions only involve front-side solvent attack (i.e. reaction with retention of stereochemistry), quite clearly, solvent electrophilicity may be responsible for the unusual selectivities observed.

If it were important, solvent sorting or organization around the substrate in order to provide the lowest energy solvated form is a factor that could affect selectivities. There is, however, no concrete evidence for solvent sorting around intermediates or transition states. Nevertheless, in an EtOH-TFE solvent mixture, it is reasonable to suggest that there would be a favorable enthalpy change (but not necessarily a favorable entropy change) for solvation of the leaving group by the more electrophilic TFE molecules and for solvation of the developing carbocation by the more nucleophilic EtOH molecules. This view is depicted below.



By the above line of reasoning, solvolysis should lead to the more electrophilic TFE molecules being preferentially incorporated by front-side attack while ethanol molecules should be preferentially incorporated by back-side attack. Of course, with 1-adamantyl substrates there is no backside solvation; hence, one may expect to see an abnormal selectivity with this substrate if solvent sorting is important in these reactions. Thus, one could argue that the unusual selectivities reported for TFE-water and EtOH-TFE may be accounted for by solvent sorting. This theory can be tested by using an adamantyl derivative that contains a positively charged leaving group at C-1. In such cases the

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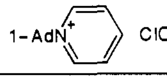
Table I

	S, k_{TFE}/k_{EtOH}			
solvent	1-AdOTs	1-AdBr	1-AdS$^+$Me$_2$ OTf$^-$	
TFE/EtOH	1.72 (±0.10)	1.50 (±0.17)	0.91 (±0.11)	0.60 (±0.06)

leaving group departs as a neutral molecule with a significant reduction in the need for electrophilic assistance.

To gain evidence that may relate to the phenomenon of solvent sorting in solvolytic substitution reactions, we have carried out the solvolysis in mixtures of ethanol and trifluoroethanol of two 1-adamantyl substrates each having a positively charged leaving group. If the above theory is correct, one should expect to see a significant change in the selectivity values since, compared to a negatively charged ion, a group departing as a neutral molecule ought to have a lower demand for electrophilic solvation. In fact if electrophilic solvation of the neutral leaving group is less important than nucleophilic solvation of the carbocation, one would expect selectivity values that more closely resemble intrinsic nucleophilicity of the solvents, i.e. one would predict that $k_{TFE}/k_{EtOH} < 0.01$ based on N values.[1]

1-Adamantyl dimethylsulfonium triflate[9] and 1-adamantyl pyridinium perchlorate[10] were prepared in connection with other studies by two of us. Those studies suggested that these substrates would make excellent substrates for the present study. Thus these salts were each solvolyzed in 70/30 and 30/70 mixtures of EtOH–TFE at 200 °C. As with the bromide[2,3] and tosylate,[3] the selectivities were essentially independent of solvent composition. The results are compared in Table I with those of the bromide[2] and tosylate[3] measured at 25–35 °C. The bromide selectivities have been determined independently at two temperatures in a range of solvent compositions; the selectivities reported are $k_{TFE}/k_{EtOH} = 1.69 \pm 0.10$ at 35 °C[3] and 1.50 ± 0.17 at 25 °C.[2] The temperature differences are not thought to be critical for the comparison since a temperature change has been shown to have a negligible effect on selectivities for 1-adamantyl bromide[4,7] and for 2-adamantyl tosylate[8] over a 50-degree range. To confirm this we determined that the selectivity (k_{water}/k_{EtOH}) for 1-adamantyl bromide in 80% aqueous ethanol at temperatures between 100 and 200 °C is relatively unaffected by temperature ($k_{water}/k_{EtOH} = 1.30 \pm 0.22$). Also, there is no significant solvent effect on selectivity for these compositions.

Our data show that the selectivities for the substrates with neutral leaving groups are still around unity. We do not observe k_{TFE}/k_{EtOH} values of 0.01 or smaller as expected if intrinsic nucleophilicity begins to dominate with neutral leaving groups. This leads to the conclusion that the higher front-side nucleophilicity of TFE as compared to EtOH is due *primarily* to something other than the effect of the solvent's electrophilicity on leaving group departure.

A surprising feature of the data is the trend of the selectivity values. Since the data are arranged (left to right) in order of decreasing solvolytic reactivity with the most reactive substrate (the tosylate) first, a reactivity–selectivity relationship seems to exist with the 1-adamantyl substrates in TFE–EtOH mixtures. To develop a reactivity–selectivity relationship one must perform temperature extrapolations of literature rates to obtain data at one temperaure. Because the rate of 1-adamantyl pyridinium perchlorate was only determined at one temperature in three pure solvents,[10] that temperature (190 °C) was chosen for comparison of the four substrates below. Also, since rates in TFE–EtOH were not available, the rates in 80% aqueous EtOH, available for three of the compounds at multiple temperatures[11] and readily extrapolated for the other one using the Grunwald–Winstein relationship, were used. The aqueous EtOH data give a plot of log k versus log (k_{TFE}/k_{EtOH}) with a correlation coefficient (r) of 0.881, indicating an imperfect correlation. The data are shown in Table II along with the calculated S values (k_{TFE}/k_{EtOH}) from the correlation. A quick look at the data reveals an abnormal relative rate order; the bromide is incorrectly predicted to be slower than the sulfonium salt. This no doubt is an error from the long temperature extrapolation. If the pyridinium salt is deleted from the comparison, the other three substrates can be compared at 40 °C, in the range of the actual rate measurements. This comparison gives no improvement in the correlation coefficient, $r = 0.880$. Since this relatively low correlation coefficient predicts low confidence in the relationship, we can assume that the trend may be fortuitous (Table III).

Table II

substrate	log K, 190 °C, 80% EtOH	calcd S	exptl S
1-AdOTs	3.06	1.94	1.7
1-AdBr	0.0546	1.13	1.5
1-AdS$^+$Me$_2$ OTf$^-$	0.443	1.22	0.91
1-AdPy$^+$ ClO$_4^-$	−4.30	0.52	0.60

Table III

substrate	log k, 40 °C, 80% EtOH	calcd S	exptl S
1-AdOTs	−1.67	1.99	1.7
1-AdBr	−5.66	1.24	1.5
1-AdS$^+$Me$_2$ OTf$^-$	−7.90	0.95	0.91

In view of the referenced studies of Pross[5] and Whiting,[7] it would be surprising to find a reactivity–selectivity relationship in these studies. Whiting's studies of the tosylate, picrate, bromide, and chloride derivatives reveal that these substrates have considerably different reactivities in 80% aqueous EtOH[11] but almost the same selectivities (k_{water}/k_{EtOH} = ca. 2) (Table IV). There is no reactivity–selectivity relationship ($r = 0.21$ for the plot). However, some workers have suggested that there may be a balance of factors that make these selectivity values the same. Our data in TFE–EtOH may support this interpretation. Given the problems in the interpretation and use of reactivity–selectivity relationships,[12,13] it would be speculative to make further comment about the meaning of these reactivity–selectivity trends.

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[10] Katritzky, A. R.; Brycki, B. *J. Am. Chem. Soc.* **1986**, *108*, 7295.

[11] Rates in 80% aqueous EtOH for 1-AdOTs are from Kevill, D. N.; Kolwyck, K. C.; Weitl, F. L. *J. Am. Chem. Soc.* **1970**, *92*, 7300. Rates for 1-AdBr and 1-AdCl are from Bentley, T. W.; Carter, G. E. *Ibid.* **1982**, *104*, 5741.

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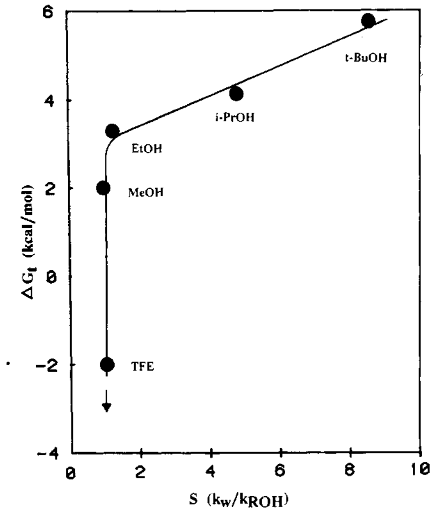

Figure 1. Plot of 1-adamantyl bromide alcohol–water S values versus free energies of transfer of tetramethylammonium bromide from water to the respective alcohol solvent.

Table IV

substrate	log k, 40 °C, 80% EtOH	calcd S	exptl S
1-AdOTs	−1.67	1.95	2.13
1-AdOPic	−2.84	1.92	1.73
1-AdBr	−5.66	1.88	1.78
1-AdCl	−7.16	1.86	1.98

Since we now have established that solvent electrophilicity assisting leaving group departure is a factor but not the dominant force in controlling product selectivities, we should address what the major factor may be. McManus and Zutaut[2] and Allard and Casavadell[3] reached opposite conclusions about the importance of solvent bulk. A reexamination of the data of both studies suggests that solvent bulk is probably a secondary contributor. Can we rationalize the results in terms of solvent-separated ion pair stability as the primary contributor to the product selectivities? In the absence of a direct measure of ion pair stabilities we may look at data concerning free energies of transfer from one pure solvent to another of ion pairs and free ions. A significant amount of data is available on such transfers for tetramethylammonium chloride and bromide. Unfortunately data for the fluorinated solvents is incomplete. Nevertheless if we plot the 1-adamantyl bromide selectivity data of McManus and Zutaut[2] against free energies of transfer of tetramethylammonium bromide from water to another alcoholic solvent, we get a correlation, albeit only a roughly linear one (Figure 1). Part of the nonlinearity may be because the adamantyl system is improperly modeled by the ammonium salt.[14]

One could argue that the above treatment ought not explain the systems with charged leaving groups since they do not form the same type of intermediate. Actually they may be very similar. After the transition state is passed the first intermediate should be an intermediate that resembles a solvent-separated ion pair. With the sulfonium salt, for example, it could mimic a solvent-separated ion pair with 1-Ad$^+$ OTf$^-$ separated by a dimethyl sulfide molecule. If this dimethyl sulfide ion pair exchanges neutrals with a solvent molecule, the solvent-separated ion pair would be an intermediate. This is shown in Scheme I. Alternatively, if one assumes that the substrate is present in solution as free ions, a different picture exists.

Scheme I

$$1\text{-AdSMe}_2^+//\text{SOH}//\text{OTf}^- \rightarrow$$
$$1\text{-Ad}^+//\text{Me}_2\text{S}//\text{SOH}//\text{OTf}^- \xrightarrow[-\text{Me}_2\text{S}]{\text{SOH}}$$
$$1\text{-Ad}^+//\text{SOH}//\text{OTf}^- \rightarrow \text{products}$$

Initially, the species formed is the solvent-separated ion molecule, 1-Ad$^+$/SOH/SMe$_2$. This may be the stage from which product forms. This is shown in Scheme II.

Scheme II

$$1\text{-AdSMe}_2^+ \rightarrow 1\text{-Ad}^+//\text{Me}_2\text{S}//\text{SOH} \xrightarrow[-\text{Me}_2\text{S}]{\text{SOH}} \text{products}$$

However, if dimethyl sulfide of the solvent-separated ion molecule were replaced by triflate ion, a normal solvent-separated ion would result. Whether one scheme or the other occurs probably depends on the initial extent of ion pairing. Of course such a scheme requires that the intermediates be stable enough to undergo solvent exchange. Indeed the current data would suggest that solvent exchange does occur.

There have been other selectivity studies with substrates bearing a charged leaving group that bear on this study. McManus, Naumann, and Zutaut[15] found that the presence of a remote charged atom in a 2-adamantyl arenesulfonate had no significant effect on the selectivity for ethanol and trifluoroethanol. Kevill et al.[9] previously reported that the ethanol–water selectivities for 1-adamantyl dimethylsulfonium triflate in aqueous EtOH are similar to that of other 1-adamantyl substrates. Finally, it is worth noting that product formation via solvent-separated ion pairs best explains solvolytic product data for tertiary silyl halides.[16]

Experimental Section

The preparation of the adamantyl salts is discussed elsewhere.[9,10] Reactions were carried out in sealed ampoules with substrate concentrations of ca. 10^{-2}–10^{-3} M. Analyses were carried out gas chromatographically on multiple samples as previously described.[2]

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Registry No. 1-AdBr, 768-90-1; 1-AdS$^+$Me$_2$OTf$^-$, 100790-98-5; 1-AdPy$^+$ClO$_4^-$, 93588-29-5.

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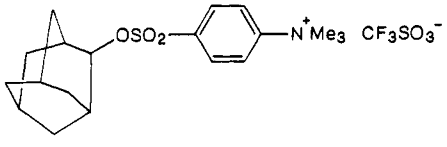
[15] Like other 2-adamantyl arenesulfonates, the 2-adamantyl amsylate salt i was found to have a preference for TFE in TFE–EtOH binary mixtures. For example, with i k_{TFE}/k_{EtOH} = 2.13 in 70% TFE–30% EtOH; cf. McManus, S. P.; Naumann, R. W.; Zutaut, S. E., unpublished results, 1983.



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[16] Kevill, D. N. *J. Chem. Res., Synop.* **1987**, 272.