Weakly Nucleophilic Leaving Groups. Solvolyses of 1-Adamantyl and t-Butyl Heptafluorobutyrates and Trifluoroacetates

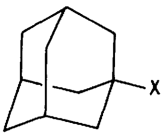
T. William Bentley* and Karl Roberts
Department of Chemistry, University College of Swansea, Singleton Park, Swansea SA2 8PP

Kinetic data are reported for solvolyses of 1-adamantyl and t-butyl heptafluorobutyrates and trifluoroacetates in binary aqueous mixtures with acetone, ethanol, and methanol and in 97% trifluoroethanol–water and hexafluoropropan-2-ol–water. Logarithms of solvolysis rates for t-butyl heptafluorobutyrate compared with t-butyl chloride (Figure 3) and with 1-adamantyl heptafluorobutyrate (Figure 4) show the relatively low reactivity of solvolyses of t-butyl heptafluorobutyrate in fluorinated alcohols, consistent with nucleophilic solvent assistance for solvolyses of t-butyl heptafluorobutyrate in the more nucleophilic solvents (*e.g.* aqueous methanol). In 97% hexafluoropropan-2-ol–water, 1-adamantyl heptafluorobutyrate solvolyses faster than t-butyl heptafluorobutyrate, supporting a recent prediction. Comparisons of relative rates of solvolyses of 1-adamantyl trifluoroacetate with those of 1-adamantyl chloride (Figure 2) and with Y_{OTs} (Figure 5) show the absence of substantial effects on relative rates due to electrophilic solvent assistance by fluorinated alcohols, other than those already included in the Y values. Solvolyses of triflates are anomalous in comparison with solvolyses involving other weakly nucleophilic leaving groups (perchlorate, trifluoroacetate, and heptafluorobutyrate).

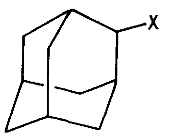
A systematic study of solvent effects on S_N1 reactivity for various leaving groups is in progress, with the adamantyl framework being employed as a relatively constant alkyl group.[1,2] This work is continuing the role of solvolytic reactions as a testing ground for mechanistic concepts of organic chemistry. Current studies are relevant to the development of force fields to model reactivity,[3] to the application of multi-parameter approaches to correlating solvent effects on reactivity,[4] to the separation of solvation effects from mechanistic changes,[5] and to the use of rate–rate profiles of solvent effects to predict mechanistic changes.[6]

Kinetic data over a wide range of reactivity can be obtained because the tertiary 1-adamantyl toluene-4-sulphonate (**1**; X = OTs) reacts *ca.* 10^5 times faster than the corresponding secondary toluene-4-sulphonate (**2**; X = OTs), and shows an almost identical response to changes in solvent ionizing power.[1c] Solvent effects on the reactivity of adamantyl substrates having tertiary carboxylate leaving groups (*e.g.* *p*-nitrobenzoates) have not yet been examined in detail, partly because of their low reactivity even for (**1**).[7] A recent report on solvolyses of tertiary heptafluorobutyrates in 80% ethanol–water showed that these solvolyses were accessible below 100 °C, and occurred by exclusive alkyl–oxygen cleavage.[8] Trifluoroacetates have also been studied kinetically *e.g.* hydrolysis of t-butyl trifluoroacetate[9] and solvolyses of cyclohexyl trifluoroacetates in trifluoroethanol–water.[10,†] Nicotinates are also being studied, and *N*-methylnicotinyl esters show solvolytic reactivities *ca.* 50 times greater than the corresponding *p*-nitrobenzoates.[12a] Solvent effects on the reactivity of tertiary *p*-nitrobenzoates more reactive than (**1**) have been examined.[12]

We now report kinetic data for solvolyses of 1-adamantyl heptafluorobutyrate and trifluoroacetate (**1**; X = $OCOC_3F_7$ and $OCOCF_3$), and t-butyl heptafluorobutyrate and trifluoroacetate (**3**; X = $OCOC_3F_7$ and $OCOCF_3$) in a range of aqueous and alcoholic solvents. These data are compared with solvolyses of chlorides (because reactivities are similar), and of toluene-4-sulphonates (because solvolyses of both carboxylates and sulphonates involve development of negative charge on oxygen). Heptafluorobutyrate and trifluoroacetate are the most weakly nucleophilic leaving groups for which kinetic data are available for both adamantyl (**1**) or (**2**) and t-butyl (**3**) substrates. The results provide an opportunity to assess critically recent proposals that (**1**) and (**3**) show significantly different susceptibilities to electrophilic solvent assistance by fluorinated alcohols. This work is also part of a link to studies of acid-catalysed hydrolyses of various esters.[13]



(**1**)



(**2**)

$(CH_3)_3CX$

(**3**)

Results

All solvolyses were investigated conductimetrically in dilute solutions ($<10^{-3}$ mol dm^{-3}). No buffers were added and complete dissociation of the strong acid product ($C_3F_7CO_2H$ or CF_3CO_2H) was assumed, consistent with the observed high precision fits to first order kinetics. The scope of this work was limited by the relatively low reactivity of the substrates in many of the less aqueous media. To reduce extrapolation errors, 50 °C was chosen as the standard temperature for comparisons of solvent effects. As $\Delta H^{\ddagger}$ values vary by over 10 kcal mol^{-1},[§] relative rates at 25 °C would be significantly different, but the main conclusions will not be affected. Variations in $\Delta G^{\ddagger}$ are much less. Difficulties were encountered with the low solubilities of heptafluorobutyrates (**1**) and (**3**); (X = $OCOC_3F_7$), even in 80% ethanol–water. Solvolyses of trifluoroacetates (**1**) and (**3**); (X = $OCOCF_3$) were also investigated, but these difficulties remained and studies in highly aqueous media (<40% v/v cosolvent–water) were not attempted.

[†] Primary trifluoroacetates are hydrolysed by acyl–oxygen fission.[9,11]

[§] 1 cal = 4.184 J.

Table 1. Rate constants for solvolyses of 1-adamantyl heptafluorobutyrate (**1**; X = $OCOC_3F_7$).[a]

Solvent[b]	Temp/ °C	k/s^{-1}	$\Delta H^{\ddagger}$/ kcal mol^{-1}	$\Delta S^{\ddagger}$/cal K^{-1} mol^{-1}
80% EtOH	119.9[e]	$(5.70 \pm 0.10) \times 10^{-4}$		
	110.3[f]	$(2.80 \pm 0.15) \times 10^{-4}$	27.1	−5.0
	85.0[f]	$(1.87 \pm 0.10) \times 10^{-5}$		
	50.0[c]	2.8×10^{-7}		
	50.0[c,d]	$[4.59 \times 10^{-7}]$	[25.6]	[−8.6]
	50.0[c,g]	3.1×10^{-7}	27.1	−4.8
80% MeOH	110.2	$(8.97 \pm 0.21) \times 10^{-4}$		
	85.2	$(9.66 \pm 0.09) \times 10^{-5}$	[23.5]	[−11.6]
	50.0[c]	2.4×10^{-6}		
60% MeOH	100.0	$(2.20 \pm 0.09) \times 10^{-3}$		
	85.2	$(5.64 \pm 0.05) \times 10^{-4}$	24.5	−5.5
	65.5	$(6.9 \pm 0.3) \times 10^{-5}$		
	50.0[c]	1.17×10^{-5}		
40% MeOH	84.8	$(3.32 \pm 0.04) \times 10^{-3}$		
	65.0	$(5.20 \pm 0.14) \times 10^{-4}$	21.8	−9.3
	50.0[c]	1.10×10^{-4}		
60% $(CH_3)_2CO$	105.5	$(5.10 \pm 0.25) \times 10^{-4}$		
	85.2	$(9.08 \pm 0.20) \times 10^{-5}$	22.2	−15.5
	50.0[c]	2.7×10^{-6}		
97% CF_3CH_2OH	86.1	$(1.37 \pm 0.03) \times 10^{-3}$		
	66.2[f]	$(3.14 \pm 0.25) \times 10^{-4}$	17.2	−24
	50.0[c]	8.3×10^{-5}		
97% $(CF_3)_2CHOH$	50.0[f]	$(5.82 \times 0.29) \times 10^{-4}$		

[a] Determined conductimetrically in duplicate except where noted otherwise; errors shown are average deviations. [b] % EtOH refers to % ethanol–water (v/v); % MeOH refers to % methanol–water (v/v); % $(CH_3)_2CO$ refers to % acetone–water (v/v); % fluorinated alcohol refers to % fluorinated alcohol–water (w/w); to aid solubility the substrate was injected in dilute acetone solution amounting to < 1% of total volume of solvent. [c] Calculated from data at other temperatures. [d] Reference 8. [e] Single measurement of rate constant. [f] Triplicate measurement of rate constant. [g] Reference 8, excluding the preliminary data cited in Table 1, footnote g, of that paper.

Table 2. Rate constants for solvolyses of t-butyl heptafluorobutyrate (**3**; X = $OCOC_3F_7$).[a]

Solvent[b]	Temp/ °C	k/s^{-1}	$\Delta H^{\ddagger}$/ kcal mol^{-1}	$\Delta S^{\ddagger}$/cal K^{-1} mol^{-1}
80% EtOH	75.3	$(1.01 \pm 0.05) \times 10^{-3}$		
	50.0	$(5.87 \pm 0.02) \times 10^{-5}$	24.5	−2.4
	50.0[d]	6.62×10^{-5}	[20.9]	[−13.0]
MeOH	50.0	$(2.08 \pm 0.02) \times 10^{-5}$		
80% MeOH	65.0	$(7.36 \pm 0.24) \times 10^{-4}$		
	50.0	$(1.29 \pm 0.01) \times 10^{-4}$	24.6	−0.5
60% MeOH	65.0	$(3.23 \pm 0.01) \times 10^{-3}$	22.4	−3.9
	50.0	$(6.56 \pm 0.20) \times 10^{-4}$		
40%MeOH	50.0	$(3.28 \pm 0.16) \times 10^{-3}$	21.8	−2.5
	25.0	$(1.75 \pm 0.02) \times 10^{-4}$		
60%$(CH_3)_2CO$	65.5	$(1.06 \pm 0.04) \times 10^{-3}$		
	50.0	$(2.02 \pm 0.20) \times 10^{-4}$	22.6	−5.6
97% CF_3CH_2OH	80.0	$(2.27 \times 0.10) \times 10^{-3}$		
	65.5	$(6.48 \times 0.10) \times 10^{-4}$	19.9	−14.7
	50.0[c]	1.50×10^{-4}		
97% $(CF_3)_2CHOH$	50.0	$(4.85 \times 0.16) \times 10^{-4}$		

[a–d] As for Table 1.

Kinetic data are shown in Tables 1–4. Our data for solvolyses of (**1**; X = $OCOC_3F_7$) are in satisfactory agreement with the literature values, provided that the independent preliminary experiments (see footnote 10, ref. 8) are excluded from the Arrhenius plot (the rate constant reported[8] for 80.1 °C is slightly lower than the preliminary value obtained[8] at 75.0 °C). Our data for solvolyses of both (**1**) and (**3**); (X = $OCOC_3F_7$) in 80% ethanol–water at 50 °C are about 10% lower than the literature values.[8]

Although activation parameters may be regarded as useful guides to reaction mechanisms, we have found them to be more helpful for assessing the reliability of individual rate constants in sets of experimental data [*e.g.* see Table 3 of ref. 1(*c*)]. For solvolyses of sparingly soluble substrates it is possible to reproduce incorrect rate constants, probably because small aggregates of molecules can dissolve during the kinetic run. Changes in temperature may change the relative rates of dissolution and of solvolysis. One anomalous rate constant can be revealed, if reliable data at two other temperatures are available. However, for solvolyses of (**1**; X = $OCOCF_3$) in 40% acetone–water, results at three temperatures gave a consistent $\Delta H^{\ddagger}$ of 33 ± 1 kcal mol^{-1}, which by comparison with data in other solvents (Table 3) appears to be too high by about 8 kcal mol^{-1}. Typically, between 90% and 40% ethanol–water, methanol–water, and acetone–water, S_N1-like solvolyses show a gradual decrease in $\Delta H^{\ddagger}$ (trend 1).[1a,1b,1d,14,15] Also, in this range of solvents, 1-adamantyl chloride (**1**; X = Cl) solvolyses have $\Delta H^{\ddagger}$ values typically 1–2 kcal mol^{-1} greater than for t-butyl chloride solvolyses (trend 2).[1d,14a] For solvolyses of heptafluorobutyrates (Tables 1 and 2), the pattern of $\Delta H^{\ddagger}$ values is not entirely consistent with these two trends. It appears that solvolyses of (**1**; X = $OCOC_3F_7$) in 80% methanol–water should have given a $\Delta H^{\ddagger}$ value about 2 kcal mol^{-1} higher than the observed value of 23.5 (Table 1). Also, it seemed likely that the literature value[8] of $\Delta H^{\ddagger} = 20.9$ for solvolyses of (**3**; X = $OCOC_3F_7$) in 80% ethanol–water was incorrect, though it is based on studies of rate constants at five temperature. We found $\Delta H^{\ddagger} = 24.5$ (Table 2), in satisfactory agreement with the predictions.

Further comparisons of $\Delta H^{\ddagger}$ values made between solvolyses of (**1**; X = $OCOC_3F_7$) and of (**1**; X = $OCOCF_3$) (Tables 1 and 3) show very similar trends with $\Delta H^{\ddagger}$ for the heptafluorobutyrate about 2 kcal mol^{-1} higher than those for the trifluoroacetate. These results confirm the overall reliability of the kinetic data (Tables 1–3), with the exception of the three anomalous values noted above.

Discussion

Solvent Effects on Relative Rates.—The rates of solvolyses of 1-adamantyl trifluoroacetate (**1**; X = $OCOCF_3$) correlate well with those for the heptafluorobutyrate in the same solvent (Figure 1). A line close to unit slope (0.952 ± 0.044) could be drawn through all of the points in Figure 1. These results do not reveal any anomalous effects, attributable to differences in solvation between helptafluorobutyrate and trifluoroacetate leaving groups. In contrast with a previous estimate that trifluoroacetates would be 100 times less reactive than heptafluorobutyrates,[8] rates in the same solvent agree within a factor of two. Considering also the additional experimental difficulties caused by the lower (and/or slower) solubility of heptafluorobutyrates, additional evidence is needed to establish heptafluorobutyrates as the 'reactant of choice'[8] when nucleofugacity similar to that of halides is required.

Comparisons between solvent effects on the reactivity of the carboxylates can now be made with chlorides *e.g.* 1-adamantyl trifluoroacetate *vs.* 1-adamantyl chloride (Y_{Cl}, Figure 2) and t-butyl heptafluorobutyrate *vs.* t-butyl chloride (Y, Figure 3). Figure 2 shows a satisfactory correlation for all of the data points although it seems likely that the data point for 97% hexafluoropropan-2-ol–water (HFP) deviates significantly from a best line through the remaining points. In contrast, in the

Table 3. Rate constants for solvolyses of 1-adamantyl trifluoroacetate (1; X = $OCOCF_3$).[a]

Solvent[b]	Temp/ °C	k/s^{-1}	$\Delta H^{\ddagger}$/ kcal mol^{-1}	$\Delta S^{\ddagger}$/cal K^{-1} mol^{-1}
80% EtOH	127.6	$(1.48 \pm 0.08) \times 10^{-3}$		
	109.2^{e}	2.46×10^{-4}	28.0	−2.4
	84.2	$(1.85 \pm 0.01) \times 10^{-5}$		
	50.0^{c}	2.5×10^{-7}		
80% MeOH	106.6	$(8.64 \pm 0.06) \times 10^{-4}$		
	86.2	$(8.55 \pm 0.23) \times 10^{-5}$	28.0	0.5
	66.4	$(9.57 \pm 0.50) \times 10^{-6}$		
	50.0^{c}	1.06×10^{-6}		
60%MeOH	106.6	$(4.79 \pm 0.23) \times 10^{-3}$		
	86.2	$(6.00 \pm 0.12) \times 10^{-4}$	26.9	1.2
	50.0^{c}	7.9×10^{-6}		
40% MeOH	76.4^{f}	$(1.71 \pm 0.05) \times 10^{-3}$		
	51.4^{f}	$(1.15 \pm 0.10) \times 10^{-4}$	23.7	−3.6
	50.0^{c}	9.7×10^{-5}		
80% $(CH_3)_2CO$	117.9	$(1.58 \pm 0.04) \times 10^{-4}$		
	97.3	$(2.22 \pm 0.06) \times 10^{-5}$	26.6	−8.4
	50.0^{c}	9.8×10^{-8}		
60% $(CH_3)_2CO$	101.4	$(3.87 \pm 0.10) \times 10^{-4}$		
	84.3	$(7.25 \pm 0.35) \times 10^{-5}$	25.3	−7.0
	50.0^{c}	1.5×10^{-6}		
40% $(CH_3)_2CO$	81.2	$(4.93 \pm 0.10) \times 10^{-4}$		
	$50.0^{c,g}$	1.5×10^{-5}	$[24.8]^{g}$	
97% CF_3CH_2OH	76.5	$(2.86 \pm 0.06) \times 10^{-4}$		
	61.8^{f}	$(9.6 \pm 1.0) \times 10^{-5}$	14.8	−32.8
	51.7	$(5.29 \pm 0.20) \times 10^{-5}$		
	50.0^{c}	4.45×10^{-5}		
97% $(CF_3)_2CHOH$	50.0	$(5.86 \pm 0.20) \times 10^{-4}$		

[a–f] As for Table 1. [g] Kinetic data for 40% acetone–water at 61.9 °C ($k = 3.05 \times 10^{-5}$) and 70.9 °C ($k = 1.21 \times 10^{-4}$) gave $\Delta H^{\ddagger}$ *ca.* 33 kcal mol^{-1}. A value of $\Delta H^{\ddagger} = 24.8$ kcal mol^{-1} was assumed to be more reliable—data at lower temperatures (*e.g.* 60 °C for 60% acetone) also gave less reliable data.

Table 4. Rate constants for solvolyses of t-butyl trifluoroacetate (3; X = $OCOCF_3$).[a]

Solvent[b]	Temp/ °C	k/s^{-1}	$\Delta H^{\ddagger}$/ kcal mol^{-1}	$\Delta S^{\ddagger}$/cal K^{-1} mol^{-1}
40% MeOH	50.0	$(3.21 \pm 0.04) \times 10^{-3}$		
H_2O	$50.0^{c,e}$	4.07×10^{-2}	25.5	13.8
97% CF_3CH_2OH	50.0	$(1.34 \pm 0.01) \times 10^{-4}$		
97% $(CF_3)_2CHOH$	51.6	$(9.05 \pm 0.20) \times 10^{-4}$		
	50.0^{c}	8.1×10^{-4}	$[14]^{f}$	

[a–d] As for Table 1. [e] Ref. 9; solvent contained 0.01 mole fraction of acetone. [f] Assumed.

corresponding plot for t-butyl substrates (Figure 3), data points for both 97% trifluoroethanol–water (TFE) and 97% HFP deviate significantly from a correlation line through the remaining points, corresponding to solvolyses of t-butyl heptafluorobutyrate about five times slower than expected from 1-adamantyl solvolyses (*e.g.* Figure 2).

Kinetic data for t-butyl trifluoroacetate (Table 4) in a limited range of solvents establish that this compound would also give similar results to those in Figure 3. To confirm that major changes in product compositions in the weakly nucleophilic solvents could not account for the results, previous product studies for solvolyses of t-butyl choride, showing 30% elimination in 97% TFE at 25 °C,[16b] were extended to t-butyl heptafluorobutyrate which gave 50% elimination in 97% TFE at 50 °C. Dependence of product ratios on leaving group is well established for solvolyses of t-butyl substrates.[17] From activation parameters and solvent kinetic isotope effects, it was concluded[9] that hydrolysis of t-butyl trifluoroacetate in water

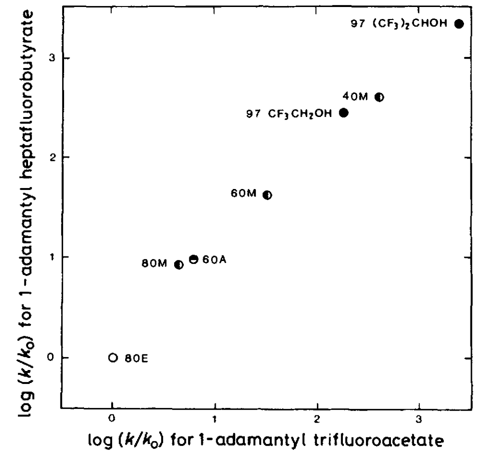


Figure 1. Correlations of logarithms of solvolysis rates (k_0 refers to 80% ethanol–water) for 1-adamantyl heptafluorobutyrate (1; X = $OCOC_3F_7$) *vs.* 1-adamantyl trifluoroacetate (1; X = $OCOCF_3$) at 50 °C. Data from Tables 1 and 3. For all data points: slope = 0.952 ± 0.044, correlation coefficient 0.995.

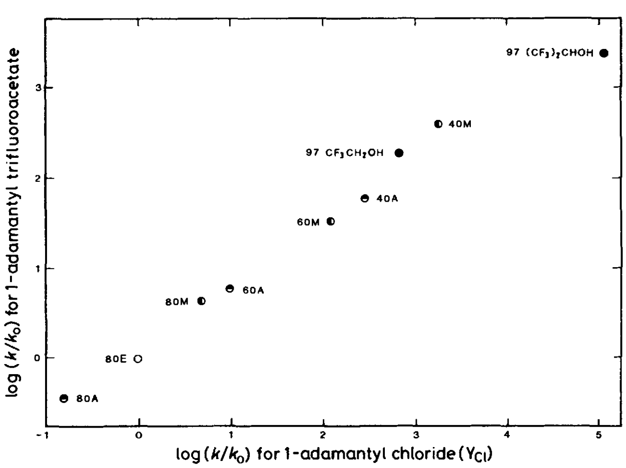


Figure 2. Correlation of logarithms of solvolysis rates (k_0 refers to 80% ethanol–water) for 1-adamantyl trifluoroacetate (1; X = $OCOCF_3$) at 50 °C *vs.* 1-adamantyl chloride (1; X = Cl) at 25 °C. Data from Table 3 and ref. 1(*d*). For all data points: slope = 0.681 ± 0.030, correlation coefficient 0.993; excluding data point for 97% $(CF_3)_2CHOH$: slope = 0.738 ± 0.027, correlation coefficient 0.996.

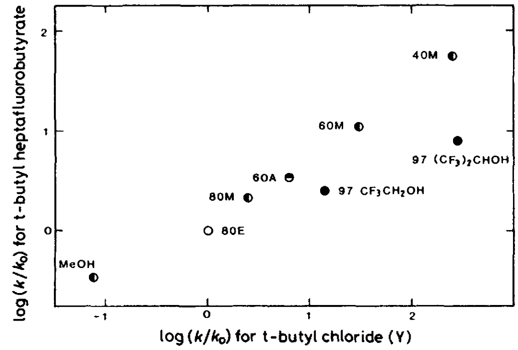


Figure 3. Correlation of logarithms of solvolysis rates (k_0 refers to 80% ethanol–water) for t-butyl heptafluorobutyrate (3; X = $OCOC_3F_7$) at 50 °C *vs.* t-butyl chloride (3; X = Cl) at 25 °C. Data from Table 2 and ref. 16. For data points excluding fluorinated alcohols: slope = 0.641 ± 0.041, correlation coefficient 0.992.

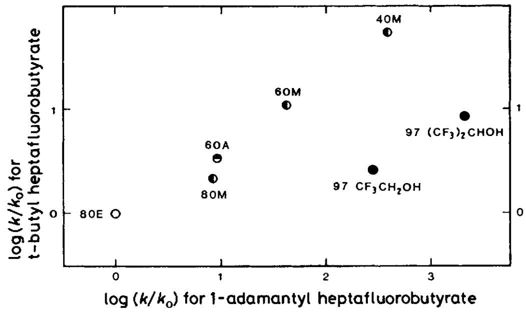


Figure 4. Correlation of logarithms of solvolysis rates (k_0 refers to 80% ethanol–water) for t-butyl heptafluorobutyrate (**3**; X = $OCOC_3F_7$) at 50 °C *vs.* 1-adamantyl heptafluorobutyrate (**1**; X = $OCOC_3F_7$) at 50 °C. Data from Tables 1 and 2. For data points, excluding fluorinated alcohols: slope = 0.702 ± 0.071, correlation coefficient 0.984.

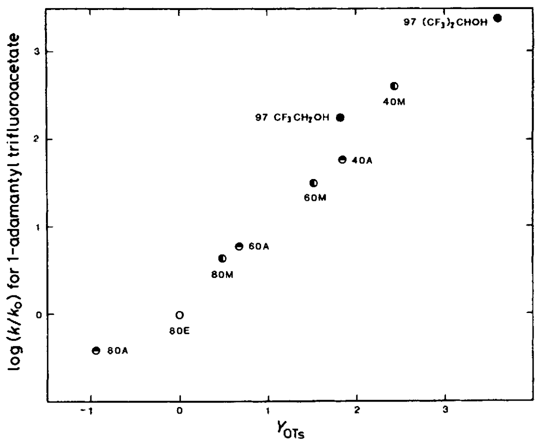


Figure 5. Correlation of logarithms of solvolysis rates (k_0 refers to 80% ethanol–water) for 1-adamantyl trifluoroacetate (**1**; X = $OCOCF_3$) at 50 °C *vs.* Y_{OTs}. Data from Table 3 and refs. 1(*c*), 2(*c*), and 19. For data point excluding 80% acetone, slope = 0.944 ± 0.065, correlation coefficient 0.986; also excluding 97% $(CF_3)_2CHOH$: slope = 1.04 ± 0.08, correlation coefficient 0.986.

occurred by alkyl–oxygen fission, so a major change of substitution mechanism in aqueous methanol seems very unlikely.

Chlorides are expected to be more sensitive than heptafluorobutyrates and trifluoroacetates to electrophilic solvent assistance in fluorinated alcohols.[8] The deviation of the data point for 97% HFP from the plot for 1-adamantyl substrates (Figure 2) illustrates this small effect. The larger deviations for t-butyl substrates (Figure 3) could, in principle, be explained by greater sensitivity of t-butyl than 1-adamantyl substrates to electrophilic assistance. However, others[4b,8] have proposed the opposite effect, that solvolyses of 1-adamantyl chloride are more sensitive than t-butyl chloride to electrophilic solvent assistance. It seems likely that the sensitivities of the two substrates to electrophilic assistance are very similar, because only small effects are observed even when different halide leaving groups are compared.[1b,18] An alternative preferred explanation is given below.

Nucleophilic Solvent Assistance for t-Butyl Solvolyses.—Solvolyses of t-butyl heptafluorobutyrate in nucleophilic media (*e.g.* aqueous methanol) may be accelerated more by nucleophilic solvent assistance than solvolyses of t-butyl chloride.[1d] A well established trend is that increasing sensitivity to nucleophilic solvent assistance leads to a decreasing sensitivity to solvent ionizing power [see equation (12) of ref. 19 and ref. 20]. The converse may also apply. Heptafluorobutyrates are less sensitive to solvent ionizing power than chlorides (see slopes of Figures 2 and 4, *ca.* 0.7), and are also less reactive than chlorides in solvents of high ionizing power. Hence, heptafluorobutyrates may be more sensitive than chlorides to nucleophilic solvent assistance.* This conclusion is supported by the greater slope of Figure 2 (0.74) than Figure 3 (0.64) and Figure 4 (0.70) although this is not clear cut because of uncertainties in the slopes; the latter refers to solvolyses for a constant heptafluorobutyrate leaving group, and major deviations from the trend line for other solvents are observed for 97% TFE and 97% HFP. These deviations correspond to l = (0.40 ± 0.07), whereas for 1-adamantyl and t-butyl chlorides l = (0.30 ± 0.04) (see the Appendix for details).

As nucleophilic solvent assistance for t-butyl solvolyses increases, the t-butyl/1-adamantyl (Bu^t/1-Ad) rate ratio increases substantially (from *ca.* 3 to >1 000).[1d,2a] Lower Bu^t/1-Ad ratios (<1) were predicted[1d] from gas-phase ion equilibria. This prediction is now supported by the Bu^t/1-Ad ratio of 0.83 for heptafluorobutyrates in 97% HFP (1.4 for trifluoroacetates), and contrasts with the assumption[8] that the Bu^t/1-Ad rate ratio of 2.5 for bromides in 97% HFP would be independent of the leaving group. These results may be explained by greater electron demand on the alkyl group in the ion-pair transition states[17] when the nucleophilicity of the leaving group decreases.

Other groups[2a,4b,22] have recently obtained independent experimental evidence, supporting the case for nucleophilic participation in solvolyses of t-butyl substrates, *e.g.* solvolyses of t-butyl chloride in 60% ethanol–water are accelerated by thiourea.[22] However, there may be additional complications. All of the experimental data has not yet been fully explained,[23,24] and possible contributions from internal ion-pair return are difficult to assess.[19]

Comparisons with Sulphonates and Related Leaving Groups.—In recent comparisons of toluene-4-sulphonates with picrates, perchlorates, and triflates, all having oxygen atoms on which charge developed during heterolysis,[1a,2b,2c] anomalously low reactivity was observed for triflates (X = OSO_2CF_3) in weakly nucleophilic media (carboxylic acids and fluorinated alcohols). Although these results could be attributed to the weakly basic nature of the triflate anion,[2b] it is surprising that only minor deviations were observed for perchlorates (also weakly basic).[1a] An alternative explanation, that there are anomalous solvation effects of CF_3 groups,[1a] is ruled out by the following evidence. Logarithms of rates of solvolyses of (**1**; X = $OCOCF_3$) at 50 °C show very similar solvent effects to 2-adamantyl toluene-4-sulphonate (**2**; X = OTs) at 25 °C, the original model compound for the Y_{OTs} scale of solvent ionizing power (slope = m_{OTs} = 1.0, Figure 5). In addition, studies of the sulphinate leaving group (SO_2CF_3),[25] in which solvolyses of cumenyl trifluoromethyl sulphone correlate well with Y_{OTs}, do not show deviations for acetic acid and HFP. Solvolyses of other sulphonates (X = $OSO_2CH_2CF_3$) also correlate well with Y_{OTs}.[2d,2f]

Solvation of CF_3 groups does not appear to influence greatly the slope of plots *vs.* Y_{OTs}; *e.g.* in alcohol water mixtures, 2-adamantyl triflate gives m_{OTs} = 0.95.[1a] For trifluoroacetates having only two oxygen atoms on which charge can be delocalized, a slope of Figure 5 significantly greater than the observed value of unity might have been expected from electrostatic effects;[1a] There may be a small effect because if the trifluoroacetate data had been extrapolated to 25 °C the slope

---

* Similarly, the extent of assistance by neighbouring group participation may decrease as solvent ionizing power increases.[21]

Table 5. Detailed analysis of deviations from equation (1) for solvolyses of t-butyl chloride.

Solvent[a]	N_{OTs}[b]	Y_{Cl}[c]	$\log(k/k_o)$ Obs.[d]	$\log(k/k_o)$ Calc.[e]	Error in $\log k$[f]	$0.76\,Y_{Cl}$[g]	Deviations[h] Obs.[i]	Deviations[h] Calc.[j]
80% EtOH	0	0.00	0.00	0.006	0.006	0.00	0.00	−0.006
50% EtOH	−0.09	2.02	1.66	1.52	−0.14	1.54	−0.12	0.02
EtOH	0.00	−2.50	−2.03	−1.90	0.13	−1.90	0.13	0.00
CH_3CO_2H	−2.35	−1.60	−1.64	−1.92	−0.28	−1.22	0.42	0.70
HCO_2H	−2.35	3.20	2.05	1.73	−0.32	2.43	0.38	0.70
CF_3CO_2H	−5.56	4.60	1.81	1.83	0.02	3.50	1.69	1.67
CH_3OH	−0.04	−1.20	−1.09	−0.92	0.17	−0.91	0.18	0.01
97% CF_3CH_2OH	−2.79	2.83	1.15	1.32	0.17	2.15	1.0	0.83
70% CF_3CH_2OH	−1.20	2.96	1.66	1.90	0.24	2.25	0.59	0.35
97% $(CF_3)_2CHOH$	−4.27	5.08	2.45	2.59	0.14	3.86	1.41	1.27
Water	−0.44	4.57	3.49	3.35	−0.14	3.47	−0.02	0.12

[a] The standard 11 solvents [ref. 1(*d*)], providing a diverse range of *N* and *Y* values. [b] Ref. 19. [c] Ref. 1(*d*). [d] Observed rate constants (data from ref. 16). [e] Calculated from equation (1) with $m = 0.76$ and $l = 0.30$. [f] $\log(k/k_o)_{calc} - \log(k/k_o)_{obs}$. [g] This term represents the best line through the typical aqueous and alcoholic media, as well as the optimised mY_{Cl} term [equation (1)] for the standard 11 solvents. [h] Calculated from plots of $\log(k/k_o)$ for t-butyl chloride *vs.* Y_{Cl}; a line of slope 0.76 correlates data for typical aqueous and alcoholic media (footnote *g*) and deviations from this line are calculated in the *y*-axis direction [the data are plotted in ref. 1(*d*)]. [i] Column 7–column 4. [j] Column 7–column 5.

would be *ca.* 10% higher. Solvolyses of cumenyl trifluoromethyl sulphone give a lower slope ($m_{OTs} = 0.82$),[25] perhaps because the longer C–S bond increases charge delocalization. The deviation of the data point for 80% acetone–water (Figure 5) was also observed in similar plots *vs.* Y_{OTs} for picrate, perchlorate, and triflate,[1a] but not for sulphinate.[25] Generalizations covering all solvents and leaving groups are difficult to make and continued use of Y_x scales, requiring various model compounds having different leaving groups, appears to be necessary to account for specific solvation effects.[1,2]

Conclusions

Tertiary heptafluorobutyrates react at similar rates to trifluoroacetates, but are less sensitive to solvent ionizing power than chlorides. Fluorinated alcohols (97% TFE and 97% HFP) having high hydrogen-bond donor acidities (α-values)[4b] do not show major deviations in comparisons of solvent effects for 1-adamantyl heptafluorobutyrate, trifluoroacetate and chloride (Figures 1 and 2), in contrast with proposals by others that even different tertiary chlorides can vary in sensitivity to specific electrophilic solvent assistance (as distinct from that already included in the *Y* values).[4b,8] However, 97% TFE and 97% HFP do give major deviations from the trend line for other aqueous and alcoholic solvents in comparisons of t-butyl heptafluorobutyrate with t-butyl chloride (Figure 3) and with 1-adamantyl heptafluorobutyrate (Figure 4). Nucleophilic solvent assistance can account for these observations, in agreement with previous work.[1d,2a,4b,22] Alternative proposals[8,24] that these effects can be explained solely by varying sensitivity to electrophilic solvent assistance are inconsistent with these data (see also the Appendix). A comparison of solvent effects for 1-adamantyl trifluoroacetate with Y_{OTs} (Figure 5) and other data[25] show that anomalous results for triflates[1a,2b] in weakly nucleophilic media cannot be accounted for by specific solvation of CF_3 groups. The behaviour of triflates is anomalous by comparison with other weakly nucleophilic leaving groups (perchlorates, heptafluorobutyrates, and trifluoroacetates).

Experimental

Chemicals.—1-Adamantyl heptafluorobutyrate (**1**; X = $OCOC_3F_7$)[8] and trifluoroacetate (**1**; X = $OCOCF_3$)[26] and t-butyl heptafluorobutyrate (**3**; X = $OCOC_3F_7$)[8] and trifluoroacetate (**3**; X = $OCOCF_3$)[27] were prepared, purified, and characterised by standard methods. 1-Adamantyl trifluoroacetate (b.p. 216 °C) was further purified by column chromatography (Found: C, 57.7; H, 6.2. Calc. for $C_{12}H_{15}O_2F_3$: C, 58.04; H, 6.09%). Solvents for kinetics were prepared as described previously.[1b]

Kinetic Methods.—The equipment and techniques were straightforward adaptions of previously described methods,[1a,b] including extensive use of ultrasonics to improve the homogeneity of solutions.

Appendix

In response to criticisms,[8] details of correlations[1d] of rate data for solvolyses of t-butyl chloride, using the extended Grunwald–Winstein equation (1) are given in Table 5. In equation (1),

$$\log(k/k_o) = mY_{Cl} + lN_{OTs} \qquad (1)$$

k refers to the rate constant in any solvent relative to 80% ethanol–water (k_o); optimization gives *m*, the sensitivity of the substrate to changes in solvent ionizing power (Y_{Cl}),[1d] and *l*, the sensitivity to solvent nucleophilicity—the results are illustrated using N_{OTs}[19] (N_{KL}[28] gives similar values). Errors in calculated values of log *k* (Table 5, column 6) are $\leqslant 0.32$ (*i.e.* within a factor of two in rate). However, errors in values for acetic and formic acids are of opposite sign from those of the fluorinated alcohols. These results can be expressed as deviations in the *y*-axis direction from the best line through the typical aqueous and alcoholic media, using the same *m* value but omitting *l*, *i.e.* $\log(k/k_o) = 0.76\,Y_{Cl}$, (Table 5, columns 8 and 9). Agreement between observed and calculated deviations remains within a factor of two in rate, but the calculated deviations are not in the same order (of decreasing magnitude of deviation) as observed deviations. Calculated deviations for 97 and 70% TFE are slightly too small and those for acetic and formic acids are slightly too large. These minor errors are the wrong predictions,[8] claimed to show that nucleophilic solvent assistance is not needed to explain these results. Minor errors in the same direction and of similar magnitude (*i.e.* fluorinated alcohols showing observed rates greater than predicted and carboxylic acids showing the opposite) have previously been observed in lN/mY correlations for solvolyses of 2-propyl toluene-4-sulphonate and cyclohexyl toluene-4-sulphonates (Figures 2 and 3 of ref. 19). Such deviations may be attributed to steric effects on solvent nucleophilicity,[18b] because carboxylic acid solvents may be less sensitive than fluorinated alcohols to variations in structure of alkyl groups from methyl toluene-4-sulphonate (used to define N_{OTs} values[19]) to t-butyl substrates.

Acknowledgements

This work was supported by the SERC (Grant GR/C12739). We are grateful to G. Llewellyn for technical assistance.

References

1 (*a*) T. W. Bentley and K. Roberts, *J. Org. Chem.*, 1985, **50**, 4821; (*b*) T. W. Bentley, G. E. Carter, and K. Roberts, *ibid.*, 1984, **49**, 5183; (*c*) T. W. Bentley and G. E. Carter, *ibid.*, 1983, **48**, 579; (*d*) *J. Am. Chem. Soc.*, 1982, **104**, 5741.

2 (*a*) D. N. Kevill and S. W. Anderson, *J. Am. Chem. Soc.*, 1986, **108**, 1579; (*b*) *J. Org. Chem.*, 1985, **50**, 3330; see also X. Creary and S. R. McDonald, *ibid.*, 1985, **50**, 474; (*c*) D. N. Kevill, M. S. Bahari, and S. W. Anderson, *J. Am. Chem. Soc.*, 1984, **106**, 2895; (*d*) K. Takeuchi, K. Ikae, T. Shibata, and A. Tsugeno, *J. Org. Chem.*, 1988, **53**, 2852; (*e*) D. C. Hawkinson and D. N. Kevill, *ibid.*, 1988, **53**, 3857; (*f*) D. N. Kevill and D. C. Hawkinson, *ibid.*, 1989, **54**, 154.

3 (*a*) T. W. Bentley and K. Roberts, *J. Org. Chem.*, 1985, **50**, 5852; (*b*) P. Müller and J. Mareda, *Helv. Chim. Acta*, 1987, **70**, 1017, see also H. J. Schneider, N. Becker, G. Schmidt, and F. Thomas, *J. Org. Chem.*, 1986, **51**, 3602.

4 (*a*) C. G. Swain, M. S. Swain, A. L. Powell, and S. Alunni, *J. Am. Chem. Soc.*, 1983, **105**, 502; (*b*) M. H. Abraham, R. M. Doherty, M. J. Kamlet, J. M. Harris, and R. W. Taft, *J. Chem. Soc., Perkin Trans. 2*, 1987, 913.

5 T. W. Bentley and H. C. Harris, *J. Org. Chem.*, 1988, **53**, 724.

6 T. W. Bentley and H. C. Harris, *J. Chem. Soc., Perkin Trans. 2*, 1986, 619.

7 I. Mergelsberg and C. Rüchardt, *Tetrahedron Lett.*, 1982, **23**, 1809.

8 D. Fărcaşiu, J. Jähme, and C. Rüchardt, *J. Am. Chem. Soc.*, 1985, **107**, 5717.

9 J. G. Winter and J. M. W. Scott, *Can. J. Chem.*, 1968, **46**, 2887.

10 J. B. Lambert, G. Wang, R. B. Finzel, and D. H. Teramura, *J. Am. Chem. Soc.*, 1987, **109**, 7838.

11 C. A. Bunton and T. Hadwick, *J. Chem. Soc.*, 1958, 3248.

12 (*a*) B. Juršić, D. E. Sunko, and M. Ladika, *Tetrahedron*, 1987, **43**, 4367; (*b*) A. D. Allen, V. M. Kanagasabapathy, and T. T. Tidwell, *J. Am. Chem. Soc.*, 1986, **108**, 3470; (*c*) D. J. McLennan and P. L. Martin, *J. Chem. Soc., Perkin Trans. 2*, 1982, 1091.

13 T. W. Bentley, S. Jurczyk, K. Roberts, and D. J. Williams, *J. Chem. Soc., Perkin Trans. 2*, 1987, 293.

14 (*a*) S. Winstein and A. H. Fainberg, *J. Am. Chem. Soc.*, 1957, **79**, 5937; (*b*) A. H. Fainberg and S. Winstein, *ibid.*, p. 1597; (*c*) *ibid.*, p. 1602.

15 E. Grunwald, *J. Am. Chem. Soc.*, 1984, **106**, 5414.

16 (*a*) A. H. Fainberg and S. Winstein, *J. Am. Chem. Soc.*, 1956, **78**, 2770; (*b*) V. J. Shiner, Jr., W. Dowd, R. D. Fisher, M. A. Hartshorn, M. A. Kessick, L. Milakofsky, and M. W. Rapp, *ibid.*, 1969, **91**, 4838; (*c*) D. E. Sunko and I. Szele, *Tetrahedron Lett.*, 1972, 3617.

17 M. Cocivera and S. Winstein, *J. Am. Chem. Soc.*, 1963, **85**, 1702.

18 T. W. Bentley, *Adv. Chem. Ser.*, 1987, **215**; (*a*) 263; (*b*) 264.

19 F. L. Schadt, T. W. Bentley, and P. v. R. Schleyer, *J. Am. Chem. Soc.*, 1976, **98**, 7667.

20 D. N. Kevill and T. J. Rissmann, *J. Chem. Res.*, (*S*) 1986, 252.

21 J. Laureillard, A. Casadevall, and E. Casadevall, *Helv. Chim. Acta*, 1984, **67**, 352.

22 S. P. McManus, N. Neamati-Mazraeh, R. M. Karaman, and J. M. Harris, *J. Org. Chem.*, 1986, **51**, 4876.

23 G. F. Dvorko, E. A. Ponomareva, and N. I. Kulik, *Russ. Chem. Rev.* (*Engl. Transl.*), 1984, **53**, 547.

24 A. R. Katritzky and B. Brycki, *J. Am. Chem. Soc.*, 1986, **108**, 7295.

25 X. Creary, *J. Org. Chem.*, 1985, **50**, 5080.

26 S. R. Jones and J. M. Mellor, *J. Chem. Soc., Perkin Trans. 1*, 1976, 2576.

27 E. J. Bourne, M. Stacey, J. C. Tatlow, and R. Worrall, *J. Chem. Soc.*, 1958, 3268.

28 D. N. Kevill and G. M. L. Lin, *J. Am. Chem. Soc.*, 1979, **101**, 3916.

Received 17*th August* 1988; *Paper* 8/03338B