

## Grunwald–Winstein Relations in the Solvolyses of Highly Congested Simple Secondary and Tertiary Alkyl Systems. Evidence for the Brønsted Base-Type Solvation in the Standard 1- and 2-Adamantyl Systems

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The improved Grunwald–Winstein relation (eq 1) is a linear free energy relationship between solvolysis rates and an empirical parameter  $Y_X$  related to solvent ionizing power. The  $Y_X$  scales are defined by  $\log(k/k_0)$  based on 1- or 2-adamantyl compounds (**1** and **2**, respectively) having the leaving group X.<sup>1,2</sup> In both eq 1 and  $Y_X$ ,  $k$  and  $k_0$  are specific rates in a given solvent and 80% aqueous ethanol, respectively, at 25 °C.

$$\log(k/k_0) = mY_X + c \quad (1)$$

The rear side of the standard 1- and 2-adamantyl systems is blocked to nucleophilic attack by solvent. Therefore, any downward dispersions of the  $\log(k/k_0)$  points in the plot against  $Y_X$  for a substrate in less nucleophilic solvents such as 2,2,2-trifluoroethanol (TFE), 1,1,1,3,3,3-hexafluoro-2-propanol (HFIP), and trifluoroacetic acid (TFA) have been interpreted to indicate that the rates in more nucleophilic solvents such as aqueous ethanol and aqueous acetone are enhanced by nucleophilic assistance to ionization by solvent.<sup>1,2</sup>

Recently, we reported that 2-chloro-2,4,4-trimethylpentane (**3**) exhibits an excellent linear correlation with  $Y_{Cl}$  for 17 solvents.<sup>3</sup> More recently, we found that the rate in 70% HFIP is also well accommodated to the linear relation.<sup>4</sup> The results were interpreted to show that the neopentyl group in **3** effectively shields the rear side in the manner to hinder the nucleophilic solvent intervention involving both of direct nucleophilic attack and nucleophilic solvation toward the carbocationic center.<sup>3,4</sup>

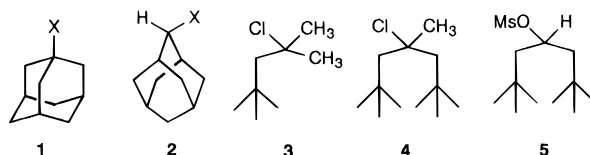
On the other hand, in the long history of the study of solvolysis reactions, there have not been reported any simple secondary and tertiary alkyl substrates whose  $mY_{OTs}$  or  $mY_{Cl}$  relations (eq 1) exhibit upward dispersion of the points for the fluorinated solvents. We now report that such behavior is observed in the solvolysis of heavily congested tertiary and secondary substrates, 4-chloro-2,2,4,6,6-pentamethylheptane (**4**) and 3,3-dimethyl-1-neopentylbutyl mesylate (**5**). We interpret the results to

**Table 1. Specific Rates of Solvolysis of 4-Chloro-2,2,4,6,6-pentamethylheptane (**4**) and 3,3-Dimethyl-1-neopentylbutyl Mesylate (**5**) at 25.0 °C**

solvent <sup>b</sup>	$k^a$ (s <sup>-1</sup> )	
	<b>4</b>	<b>5</b>
100E	$2.17 \times 10^{-4}$ <sup>c</sup>	$7.96 \times 10^{-7}$ <sup>d,e</sup>
90E	$1.56 \times 10^{-3}$ <sup>f</sup>	$3.24 \times 10^{-6}$ <sup>c</sup>
80E	$5.27 \times 10^{-3}$ <sup>f,g</sup>	$8.93 \times 10^{-6}$ <sup>c</sup>
70E	$1.50 \times 10^{-2}$ <sup>f</sup>	$1.72 \times 10^{-5}$ <sup>c</sup>
60E	$4.28 \times 10^{-2}$ <sup>f</sup>	$4.03 \times 10^{-5}$ <sup>c</sup>
100M	$2.02 \times 10^{-3}$ <sup>f</sup>	$3.66 \times 10^{-6}$ <sup>c,h</sup>
70A	$5.96 \times 10^{-3}$ <sup>f</sup>	$5.11 \times 10^{-6}$ <sup>c</sup>
50A	$6.14 \times 10^{-2}$ <sup>f</sup>	$5.68 \times 10^{-5}$ <sup>c</sup>
100T	2.8 <sup>d,i</sup>	$3.37 \times 10^{-4}$ <sup>c</sup>
70T	2.3 <sup>d,j</sup>	$2.70 \times 10^{-4}$ <sup>c</sup>
50T		$3.15 \times 10^{-4}$ <sup>c</sup>
97HFIP		$1.51 \times 10^{-2}$ <sup>f,k</sup>
AcOH	$1.34 \times 10^{-3}$ <sup>c,l</sup>	$4.09 \times 10^{-6}$ <sup>c,l</sup>

<sup>a</sup> Determined by duplicate runs for **4** and a single run for **5**, their initial concentrations being 0.02 mol L<sup>-1</sup> in titrimetric runs and  $(1-2) \times 10^{-4}$  mol L<sup>-1</sup> in conductimetric runs. <sup>b</sup> Buffered with 0.025 mol L<sup>-1</sup> 2,6-lutidine unless otherwise noted. E, M, A, and T denote ethanol, methanol, acetone, and 2,2,2-trifluoroethanol, respectively, and the numbers preceding E, M, and A indicate volume % of the organic components in aqueous mixtures at 25 °C and those for T and HFIP denote weight % of T and HFIP. <sup>c</sup> Determined titrimetrically within an experimental error  $\pm 2\%$ . <sup>d</sup> Extrapolated from data at other temperatures. <sup>e</sup> The titrimetric specific rates were  $2.16 \times 10^{-5}$  s<sup>-1</sup> at 50.0 °C and  $3.65 \times 10^{-4}$  s<sup>-1</sup> at 75.0 °C. <sup>f</sup> Determined conductimetrically within an experimental error  $\pm 0.5\%$ . <sup>g</sup> A reported value is  $5.25 \times 10^{-3}$  s<sup>-1</sup> (ref 6). <sup>h</sup> The specific rate at 50.0 °C was  $9.17 \times 10^{-5}$  s<sup>-1</sup>. <sup>i</sup> The specific rates determined in the presence of 0.0012 mol L<sup>-1</sup> 2,6-lutidine were 0.0547 s<sup>-1</sup> at -20.0 °C, 0.124 s<sup>-1</sup> at -12.0 °C, and 0.351 s<sup>-1</sup> at -0.6 °C. <sup>j</sup> The specific rates determined in the presence of 0.0012 mol L<sup>-1</sup> 2,6-lutidine were 0.0575 s<sup>-1</sup> at -10.5 °C, 0.108 s<sup>-1</sup> at -5.0 °C, 0.180 s<sup>-1</sup> at -0.6 °C, and 0.177 s<sup>-1</sup> at -0.4 °C. <sup>k</sup> No buffer was added. <sup>l</sup> Buffered with 0.025 mol L<sup>-1</sup> NaOAc.

suggest stronger Brønsted base-type solvation<sup>5</sup> (solvation by hydrogen-bonding) toward the cationic moiety of standard systems **1** and **2** than in substrates **4** and **5**.



The known chloride **4**<sup>6</sup> and new mesylate **5**<sup>7</sup> were prepared from the corresponding known alcohols. The solvolysis rates were determined under buffered conditions (except aqueous HFIP): the data at 25 °C are listed in Table 1. Figure 1 shows the plots of  $\log k$  values for **4** and **5** against  $Y_{Cl}$ <sup>1b</sup> and  $Y_{OTs}$ ,<sup>8,9</sup> respectively.

The straight lines in Figure 1 have been drawn for ethanol and aqueous ethanol points to give  $m_{EW}$  for **4** and **5** of  $0.58 \pm 0.02$  ( $r$  0.998) and  $0.63 \pm 0.03$  ( $r$  0.998), respectively. The points of methanol and aqueous acetone for **4** and those of these solvents and acetic acid

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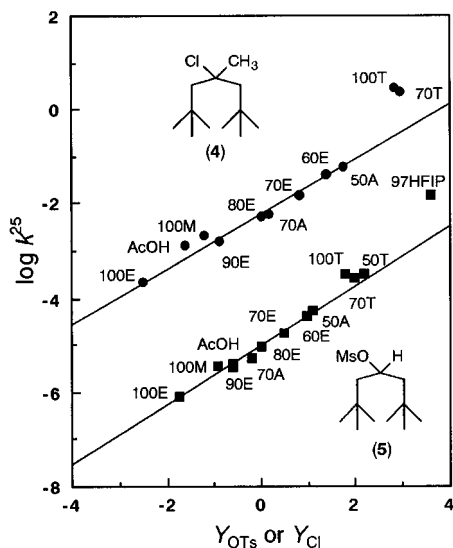
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(9) In this paper, we employ the  $Y_{OTs}$  values revised by Fujio et al.<sup>8</sup> Previous values reported by Bentley et al. are compiled in ref 1b.



**Figure 1.** Plots of  $\log k$  values for **4** and **5** in various solvents at 25 °C against  $Y_{Cl}$  and  $Y_{OTs}$ , respectively. The straight lines have been drawn for the 100E, 90E, 80E, 70E, and 60E points by the least-squares analyses. For the  $Y_{Cl}$  and  $Y_{OTs}$  values, see refs 1b and 8, respectively.

for **5** are fairly well accommodated to the ethanol–aqueous ethanol lines. The most notable feature is that the points of fluorinated alcohols deviate *upward* from the ethanol–aqueous ethanol lines. It is also noted that the rates of **4** and **5** in TFE are faster than in 70% TFE despite the smaller  $Y_{Cl}$  and  $Y_{OTs}$  values of the former solvent than those of the latter one. The *upward* deviations of TFE points from the ethanol–aqueous ethanol lines for **4** and **5** in Figure 1 amount to 1.0 and 0.47 on the  $\log(k/k_0)$  scale, respectively. The similar deviation of the 97% HFIP point for **5** is 0.96.

As aforementioned, the *downward* dispersions of the points for fluorinated solvents in the solvolysis of *tert*-butyl chloride and various secondary substrates have been ascribed to their enhanced rates in more nucleophilic solvents such as ethanol, methanol, and their aqueous mixtures.<sup>1</sup> Application of this notion to the present findings leads to a postulate that the solvolyses of **4** and **5** are less nucleophilically assisted by solvent than respective standard compounds **1** and **2**. Although the major reaction of both of **4** and **5** is elimination (E1),<sup>10</sup> it seems difficult to find other explanations to rationalize their unexpectedly fast rates in fluorinated alcohols (or slow rates in aqueous ethanol).<sup>11</sup>

Let us compare **1** and **4**. The rear side of the cationic carbon of **1** is perfectly blocked to nucleophilic attack of

solvent, whereas the six  $\beta$ -hydrogens (and perhaps three  $\gamma$ -hydrogens also) are available for the Brønsted base-type solvation. In **4**, the solvation to  $\beta$ -methylene and methyl hydrogens would be severely blocked by the bulky *tert*-butyl groups. In the 2-adamantyl system **2**, the Brønsted base-type solvation is expected to occur most strongly to the  $\alpha$ -hydrogen and to a less extent to the two  $\beta$ -hydrogens on the bridgehead positions. In the secondary system **5**, the  $\alpha$ -hydrogen would be solvated similarly, but the solvation to the  $\beta$ -hydrogens would be hindered for the same reason as described for the tertiary system **4**.

Sterically congested 1-(1-adamantyl)ethyl<sup>2,8</sup> and 1-*tert*-butylneopentyl<sup>13</sup> tosylates show improved behavior in the  $mY_{OTs}$  relation in comparison with isopropyl tosylate.<sup>2a</sup> This has been explained in terms of steric hindrance to nucleophilic solvent assistance. We applied the azide probe<sup>14</sup> to the solvolysis of **5** and found that it is classified to a secondary  $k_c$  substrate; the  $b$  value associated with the rate acceleration by a strong nucleophile  $N_3^-$  ion [ $k = k_0(1 + b[N_3^-])$ ] is  $2.0 \pm 0.9$  in 80% ethanol at 25 °C, which is comparable with the values  $2.0 \pm 0.5$  for 1-bromo-2-adamantane (**1-Br**) and  $2.7 \pm 0.3$  for 2-adamantyl tosylate (**2-OTs**) in 80% ethanol at 75 °C.<sup>15</sup> For a comparison, the  $b$ -value for isopropyl tosylate is  $33 \pm 2$  in the same solvent at 50 °C.<sup>15</sup>

Dispersed Grunwald–Winstein relations of simple alkyl substrates have customarily been handled by an extended equation involving a nucleophilicity parameter  $N_T$ .<sup>1b,c,e</sup> Equation 2 represents a typical relationship that contains Kevill's  $N_T$  scale.<sup>1e,16</sup>

$$\log(k/k_0) = lN_T + mY_X + c \quad (2)$$

As expected from the dispersion patterns in Figure 1, the  $l$  values are negative with  $-0.32 \pm 0.08$  and  $-0.14 \pm 0.04$  for **4** and **5**, respectively, the respective  $m$  values being  $0.54 \pm 0.06$  and  $0.64 \pm 0.05$ . The  $m$  value of  $0.54 \pm 0.06$  is exceptionally small for a tertiary alkyl chloride. Previous treatments of the solvolysis data for **3** and *tert*-butyl chloride gave the respective  $m$  values based on eq 2 of  $0.74 \pm 0.01^3$  and  $0.86 \pm 0.02$ .<sup>16b</sup> The  $m$  value decreases as the structure is more crowded and the rate of solvolysis in TFE increases.<sup>17</sup>

In conclusion, the Grunwald–Winstein-type relations in the solvolysis of highly congested tertiary and secondary substrates **4** and **5** strongly suggest a greater extent of the Brønsted base-type solvation in the standard 1- and 2-adamantyl substrates than in **4** and **5** in the transition state of ionization.

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(10) The normal substitution product was formed in 6.2% (in MeOH) and <2% yield (in TFE) from **4** and 2.3% (in MeOH) and 1.3% yield (in TFE) from **5** in the presence of excess 2,6-lutidine at 25 °C, the rest being unrearranged olefins.

(11) A reviewer suggested that possible decrease in ion-pair return in the solvolysis of **1** and **2** in aqueous ethanol might result in their accelerated solvolysis rates. This might also be a contributing factor, although minimal fractions of ion-pair return have been reported to be rather insensitive to solvent in the solvolysis of 1- and 2-adamantyl arenesulfonates<sup>12a,b</sup> and 1-adamantyl chloroformate.<sup>12c</sup> However, we have found that 1-(2-chloro-2-methylpropyl)adamantane that has a bulky 1-adamantyl group in place of the *tert*-butyl group in **3** and 1-bromo-3,5,7-trimethyladamantane, where cation solvation would be less effective than 1-bromo-2-adamantane, also exhibit upward deviations of TFE or 97% HFIP points. The data will be reported in a full paper.