$C_{12}H_{10}N_2O_6$: C, 51.80; H, 3.60; N, 10.07. Found: C, 52.08; H, 3.86; N, 10.35.

A similar reaction mixture, worked up earlier and by NMR consisting of a 85:15 mixture of the azide **8** and the ketene imine **10** had the following spectral properties: IR ($CHCl_3$) ν_{max} 2150 cm^{-1} (N_3, s), 1730 (CO_2Me, s); ^1H NMR ($CDCl_3$) δ 3.59 (3 H, s, COOMe), 3.89 (3 H, s, COOMe), 7.61, 8.38 (4 H, AA'BB' q, J = 8.8 Hz, Ar); ^1H NMR (CD_3CN) δ 3.50 (3 H, s, COOMe), 3.82 (3 H, s, COOMe), 7.66, 8.30 (4 H, AA'BB' q, J = 8.8 Hz, Ar).

The ratio of **8** to **10** is likely to be dependent on the $7/[N_3^-]$ ratio since **8** is formed in a bimolecular process and decomposes to **10** in a monomolecular one. Indeed, when 345 mM KN_3 and 26 mM of **7** in $CDCl_3$ were reacted, the two stages of reaction were clearly separated. Only **8** was observed up to 2.5 h (25% reaction) and ≥95% of **10** was formed after 168 h.

Acknowledgment. We are indebted to Professor A. Hassner for discussions and comments and to the Israel Commission for Basic Research, The Israel Academy for Sciences and Humanities, who supported the work.

Registry No. **7**, 103883-91-6; **8**, 110242-48-3; **10**, 110242-49-4.

Competitive RO-6 Neighboring Group Participation and Solvent-Assisted Displacement with 2-(2-Methoxyethoxy)ethyl Tosylate

Samuel P. McManus,* Rashid M. Karaman, Bruce A. Hovanes, M. Steven Paley, and J. Milton Harris*

Department of Chemistry, University of Alabama in Huntsville, Huntsville, Alabama 35899

Received July 14, 1987

Pseudo-first-order rate constants for solvolysis of alkyl substrates have been assumed to be the sum of three contributing processes: solvent-assisted (k_s), neighboring group assisted (k_Δ), or nucleophilically unassisted (k_c), where the observed rate is defined by eq 1.[1] For almost

$$k_{obsd} = k_s + k_\Delta + k_c \quad (1)$$

all substrates only one pathway is observed because it is energetically favorable over the others. There are, however, some borderline examples where two of these processes are simultaneously important. For example, linear free energy relationships were used to show that 3-aryl-2-propyl substrates undergo a change in mechanism as the aryl substituent is changed; for some aryl groups, the k_Δ pathway competes with the k_s pathway.[2]

We recently examined two structurally related substrates, **1** and **2**, which followed different pathways, **1** reacting by solvent assistance and **2** reacting by RO-3

$$\underset{\mathbf{1}}{MeOCH_2CH_2X} \qquad \underset{\mathbf{2}}{MeOCMe_2CH_2X}$$

$$\underset{\mathbf{3}}{MeOCH_2CH_2OCH_2CH_2X}$$

neighboring group participation.[3] The change in mechanism in going from structure **1** to **2** is obviously caused by the introduction of the *gem*-dimethyl groups. They serve two roles in **2**; first they serve to severely hinder direct displacement at C-1 and secondly they enhance neighboring oxygen participation. Geminal dimethyl substitution is said to favor neighboring group participation by operation of the Thorpe-Ingold effect.[4] Additionally with 2-OBs, the *gem*-dimethyl groups stabilize the product of methoxy group migration, i.e., $Me_2C^+-CH_2OMe$.[3] The previous studies provide the basis for the present work which models the reactivity of simple polyethers like poly(ethylene glycol) (PEG) sulfonate esters.[5] In this report we have studied the polyether model substrate **3**-OTs, which has the opportunity for both RO-3 and RO-6 participation.

We used the trifluoroethanol (TFE)-ethanol (EtOH) probe[6] and the thiourea probe[7] to determine if **3**-OTs is

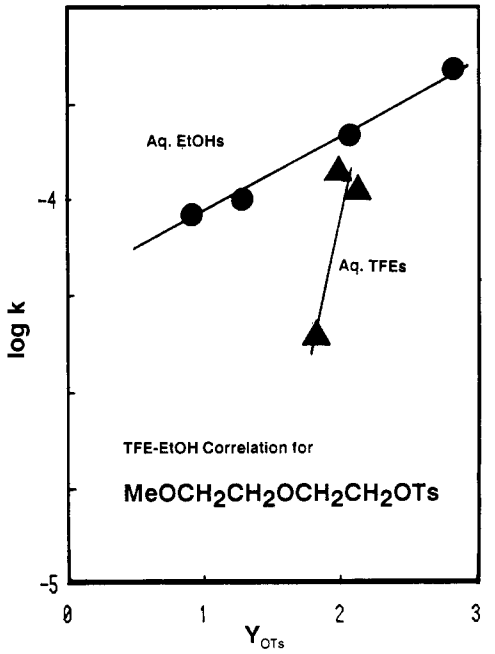


Figure 1. TFE-EtOH plot for **3**-OTs.

Table I. Solvolysis of 2-(2-Methoxyethoxy)ethyl Tosylate in 60% (v/v) Aqueous Ethanol at 85.0 °C with Added Thiourea

M, thiourea	10^4k (s^{-1})	k/k_0
0.0	0.90	1.00
0.1	2.30	2.55
0.2	3.39	3.76
0.5	5.07	5.64

Table II. Pseudo-First-Order Rates for the Solvolysis of 2-(2-Methoxyethoxy)ethyl Tosylate in Aqueous Ethanols (EtOH) and Trifluoroethanols (TFE) at 85 °C

solvent	10^4k (s^{-1})
60% (v/v) aqueous EtOH	0.90 + 0.01
50% (v/v) aqueous EtOH	0.99 + 0.03
40% (v/v) aqueous EtOH	1.45 + 0.03
30% (v/v) aqueous EtOH	2.19 + 0.11
97% (w/w) aqueous TFE	0.43 + 0.02
70% (w/w) aqueous TFE	1.17 + 0.22
50% (w/w) aqueous TFE	1.03 + 0.083

(1) Winstein, S.; Allred, E.; Heck, R.; Glick, R. *Tetrahedron* **1958**, *3*, 1.

(2) (a) Harris, J. M. *Prog. Phys. Org. Chem.* **1974**, *11*, 89. (b) Lancelot, C. J.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1969**, *91*, 4291, 4296, 4297. (c) Lancelot, C. J.; Harper, J. J.; Schleyer, P. v. R. *Ibid.* **1969**, *91*, 4294. Harris, J. M.; Schadt, F. L. (d) Schleyer, P. v. R.; Lancelot, C. J. *Ibid.* **1969**, *91*, 7508.

(3) McManus, S. P.; Karaman, R. M.; Sedaghat-Herati, R.; Neamati-Mazraeh, N.; Hovanes, B. A.; Paley, M. S.; Harris, J. M. *J. Org. Chem.* **1987**, *52*, 2518.

(4) Review: Eliel, E. L. *Stereochemistry of Carbon Compounds*; McGraw-Hill: New York, 1962; p 197. See also: Eliel, E. L.; Knox, D. E. *J. Am. Chem. Soc.* **1985**, *107*, 2946. Eliel, E. L.; Clawson, L.; Knox, D. E. *J. Org. Chem.* **1986**, *50*, 2707.

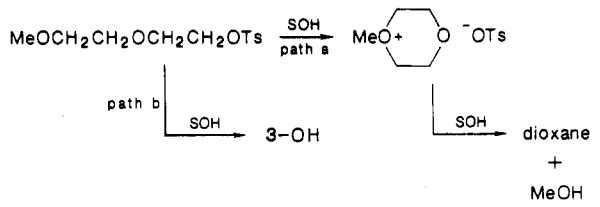
(5) McManus, S. P.; Karaman, R. M., Shannon, T. G.; Hovatter, T. W.; Hovanes, B. A.; Paley, M. S.; Harris, J. M. *Polym. Preprints (Am. Chem. Soc., Polym. Chem. Div.)* **1987**, *28*(2), 276.

(6) Raber, D. J.; Neal, W. C., Jr.; Dukes, M. D.; Harris, J. M.; Mount, D. L. *J. Am. Chem. Soc.* **1978**, *100*, 8137. Harris, J. M.; Mount, D. L.; Smith, M. R.; Neal, W. C., Jr.; Dukes, M. C.; Raber, D. J. *Ibid.* **1978**, *100*, 8147.

(7) McManus, S. P.; Neamati-Mazraeh, N.; Karaman, R. M.; Harris, J. M. *J. Org. Chem.* **1986**, *51*, 4876.

0022-3263/88/1953-0681$01.50/0 © 1988 American Chemical Society

Scheme I



sensitive to nucleophilic solvent participation. Having conclusively demonstrated with **1** that RO-3 participation *does not* occur[3] and knowing from studies with model methoxyalkyl substrates that RO-6 participation is kinetically superior to RO-3 participation,[1,8] it is safe to assume that any participation will involve six-membered ring formation. The kinetic effects of added thiourea on the solvolysis rate of 2-(2-methoxyethoxy)ethyl tosylate (**3**-OTs) are revealed by the data in Table I. Just like its simpler model, 2-methoxyethyl tosylate (**1**-OTs),[3] **3**-OTs is clearly sensitive to added nucleophiles; therefore, we conclude that it has a k_s component in its rate constant.[7] This conclusion is justified by the TFE–EtOH probe (Table II, Figure 1). The TFE–EtOH plot shows two distinct correlations as opposed to a single correlation of the rates and hence is characteristic of a substrate that undergoes solvolysis with nucleophilic solvent assistance.[6]

Before concluding that hydrolysis of **3**-OTs occurs solely by a k_s mechanism, it is necessary to determine if the RO-6 process is competitive. For this study the alcohol deuteriated at carbon-1, i.e., $MeOCH_2CH_2OCH_2CD_2OH$ (**3**-d_2-OH), was prepared and converted to its tosylate **3**-d_2-OTs. In 70:30 CD_3COCD_3–D_2O (v/v), the ^1H NMR spectra at 200 MHz of the deuteriated and nondeuteriated alcohols and tosylates were relatively uncomplicated (see Experimental Section). Hydrolysis of **3**-d_2-OTs was about half completed in 19 h at 80 °C. At 20% and 50% reaction the spectrum contained neither a singlet nor a multiplet resonance at 4.22 ppm, the location of the chemical shift for the methylene resonance, CH_2OTs, in tosylate **3**-OTs. This indicates that scrambling between the α and β carbons or the α and ϵ carbons is negligible. Several readily identifiable product peaks were present. With use of the chemical shifts of known structures, characteristic new singlets in the spectrum were assigned as follows: singlets at 3.32 and 4.26 ppm are due to methanol, a singlet at 3.66 ppm is due to dioxane, and the singlet at 3.36 ppm is assignable to CH_3O in **3**-d_2-OH. Other changes in the aliphatic portion of the spectra were not easily quantified because of the presence of overlapped multiplets in the region. By analysis of the integration, we can estimate that dioxane and methanol constitute about 55–60% of the products with the balance being 2-(2-methoxyethoxy)-ethanol. Methanol and dioxane are present in approximately equal amounts. From this product analysis, it is clear that *RO-6 participation is occurring*. Therefore, the rate constant for solvolysis has both k_s and k_Δ components.

The solvolytic behavior of **3**-OTs is diagrammed in Scheme I. Intramolecular nucleophilic attack by the remote oxygen (RO-6), path a, and direct displacement by solvent (SOH, i.e., water or alcohol), path b, compete. The neighboring group process leads to dioxane and methanol while direct displacement leads to the alcohol **3**-OH. Control experiments eliminated formation of dioxane by cyclization of **3**-OH after its formation. Dioxane is also the major product identified from hydrolysis of PEG derivatives.[5] These results would suggest that those derivatives may undergo hydrolysis by competitive mechanisms, giving dioxane by an O-6 process.

It is possible that some **3**-OH formed via attack by water at one of the methylene carbons of the cyclic oxonium ion. In theory our NMR experiment with **3**-d_2-OTs could reveal whether this occurs since the two methylene carbons are not equivalent in the deuterium-labeled tosylate. However, the complexity of the ^1H NMR spectrum in the methylene region did not allow us to determine this. We also evaluated the ^2H NMR spectra of the analogous solutions of **3**-d_2-OTs in aqueous acetone, hoping that these spectra would provide a resolution to the question of whether attack at the methylene carbon occurs. However, the observed resonances can be attributed to the deuterium-unscrambled alcohol (the k_s product) and deuteriated dioxane. If the deuterium-scrambled alcohol is present, the $MeOCD_2$ resonance falls under the resonance of one of the other peaks, perhaps that of dioxane.

The apparent absence of this labeled-scrambled alcohol was a surprise to us since we did not expect a high selectively for attack at the methyl group relative to the methylene carbons in these ions. However, a review of some precedents provides support for these results. Allred and Winstein found that the analogous *O*-methyltetrahydropyranium cation gives a 2.3:1 preference for ethanol attack at the methyl group.[9] Also, Meerwein et al. found that the trimethyloxonium ion undergoes hydrolysis about ten times faster than the trishomologous triethyloxonium cation.[10] Therefore, with the extra ring oxygen in the *O*-methyldioxanylium cation reducing the charge at the α (methylene) carbons, a high selectivity for methyl attack by water is not unexpected.

Experimental Section

General. Nuclear magnetic resonance spectra were obtained on an IBM 200-MHz high resolution nuclear magnetic resonance spectrometer in 5-mm tubes with the proton probe or in 10-mm tubes with the broadband probe. All the conductimetric kinetic data were measured by using an automated system which consists basically of three components: an HP-3497A data acquisition unit, an HP-85F microcomputer, and a Cole-Parmer 1481 conductivity bridge.[11]

2-(2-Methoxyethoxy)ethanol-1,1-d_2 (3-d_2-OH). To an ice bath cooled flask fitted with a dry N_2 purge and containing 40 g of bromoacetyl chloride (0.254 mol) in 150 mL of CH_2Cl_2 was added 30 g of 2-methoxyethanol (0.394 mol). After hydrogen chloride evolution ceased, the solution was allowed to warm to room temperature and stand for 1 h. The solution was then washed with three portions of saturated $NaHCO_3$, dried, and concentrated, leaving crude 2-methoxyethyl bromoacetate. To a stirred suspension of sodium hydride in mineral oil (7.7 g, 80% suspension, 0.256 mol) contained in a flask fitted with a dry N_2 purge was added 20 mL of anhydrous ether and 100 mL of 2-methoxyethanol, the latter dropwise while H_2 evolved. As the temperature was being raised to 100 °C, the crude bromoacetate was added dropwise (rapidly). After being heated overnight (100 °C), the solution was cooled and the precipitated NaBr was filtered and washed with methylene chloride. The combined filtrate was distilled in vacuo and 40 g (83%) of 2-methoxyethyl (2-methoxyethoxy)acetate, pure by GLC, was collected at 70 °C/0.25 mm. To a cold, stirred suspension of 3.0 g of lithium aluminum deuteride (0.071 mol) in 50 mL of anhydrous ether in a dry N_2 purged flask was added dropwise 25 g of 2-methoxyethyl (2-methoxyethoxy)acetate in 50 mL of ether. The resulting suspension was heated to reflux for 1.5 h and worked up by slow, sequential

(8) Review: Capon, B.; McManus, S. P. *Neighboring Group Participation*; Plenum Press: New York, 1976; Chapter 5.

(9) Allred, E. L.; Winstein, S. *J. Am. Chem. Soc.* **1967**, *89*, 4012.

(10) Meerwein, H.; Battenberg, E.; Gold, H.; Pfeil, E.; Willfang, G. *J. Prakt. Chem.* **1939**, *154*, 83.

(11) Hovanes, B. A.; Harris, J. M.; McManus, S. P. *Am. Lab.* **1984**, *16*(6), 22. McManus, S. P.; Lam, D. H. *J. Org. Chem.* **1978**, *43*, 650.

dropwise addition of 3 mL of H_2O, 4.1 mL of 3 M aqueous NaOH, and then 8 mL of H_2O. The suspension was filtered to remove the solid residue and the residue was thoroughly washed with CH_2Cl_2. The combined filtrates were concentrated in vacuo and then distilled to give 14 g (87%) of **3-d_2-OH**, bp 85 °C/10 mm, which was pure by GLC: ^{1}H NMR (CD_3COCD_3–D_2O, 50:50 v/v) δ 4.2 (s, 1 H, OH), 3.65–3.56 (m, 4 H, CH_2CH_2), 3.57 (s, 2 H, CH_2CD_2), 3.36 (s, 3 H, CH_3).

2-(2-Methoxyethoxy)ethyl Tosylate (3-OTs). The standard pyridine procedure[12] was followed to give **3-OTs** (in 36% yield) as a solid (from hexane at −80 °C) which melted below 0 °C when warmed. The structure of the tosylate was confirmed by ^{1}H NMR (CD_3Cl) spectroscopy: δ 7.78 (d, J = 8.0, 2 H, Ar H), 7.43 (d, J = 8.0, 2 H, Ar H), 4.10 (m, 2 H, CH_2OSO_2), 3.58 (m, 2 H, $CH_2CH_2OSO_2$), 3.39–3.50 (m, 4 H, $MeOCH_2CH_2$), 3.26 (s, 3 H, CH_3O), 2.44 (s, 3 H, CH_3Ar).

2-(2-Methoxyethoxy)ethyl-1,1-d_2 Tosylate (3-d_2-OTs). Using **3-d_2-OH**, the deuteriated tosylate was prepared and isolated from the cold (−80 °C) hexane solution (35.6% yield); it melted below 0 °C when warmed. Its structure was confirmed by ^{1}H NMR ($CDCl_3$) spectroscopy: δ 7.78 (d, J = 8.0, 2 H, ArH), 7.43 (d, J = 8.0, 2 H, Ar H), 3.58 (s, 2 H, CH_2CD_2), 3.39–3.50 (m, 4 H, $MeOCH_2CH_2$), 3.26 (s, 3 H, CH_3O), 2.44 (s, 3 H, CH_3Ar).

Kinetic Measurements. The conductivity of the appropriate solutions, which were 10^{-3} M each in substrate and 2,6-lutidine, was measured at specific times by means of a computer-actuated conductivity bridge.[11] First-order rate constants were calculated by using the LSKIN program. Multiple determinations were made for each concentration.

Acknowledgment is made to the U.S. Army Research Office (DAAL03-86-K-0026) and to the National Aeronautical and Space Administration (NAGW-812) for financial support.

Registry No. 3-OTS, 50586-80-6; 3-OH-d_2, 83326-05-0; 3-OTs-d_2, 111959-31-0.

(12) Fieser, L. F.; Fieser, M. *Reagents for Organic Synthesis*; Wiley: New York, 1967; pp 1179–1180.

One-Pot Synthesis of 3-Chloro-1,1,2-trimethylindenes from Trifluoromethanesulfonic Acid Catalyzed Benzoylation of 2-Methyl-2-butene

Christian Roussel,* Harivelo G. Rajoharison, Lucien Bizzari, and Latifa Shaimi

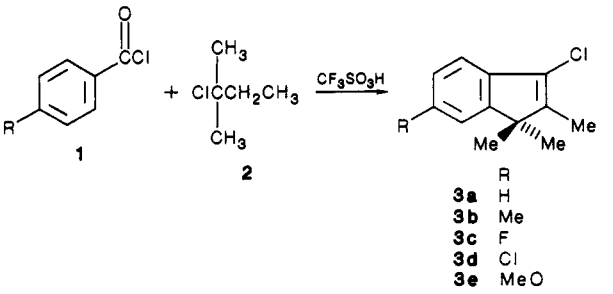
ESIPSOI, UA CNRS 126, University Aix-Marseille III, Rue Normandie-Niemen, 13397 Marseille, Cedex 13, France

Received May 22, 1987

Acylation of alkenes, with aliphatic acyl halides, in the presence of Lewis acids or protonic acids is a versatile method to prepare various derivatives resulting from monoacylation,[1] diacylation[2,3] (pyrylium synthesis), triacylation,[3] and tetraacylation.[4]

Continuing our study on acylations catalyzed by sulfonic acids,[3b,5] we have found that acylation of alkenes (or alkenes precursors) with aromatic acylhalides, in the presence of 15% trifluoromethanesulfonic acid leads to an unprecedented one-pot synthesis of 3-chloroindenes.

Scheme I



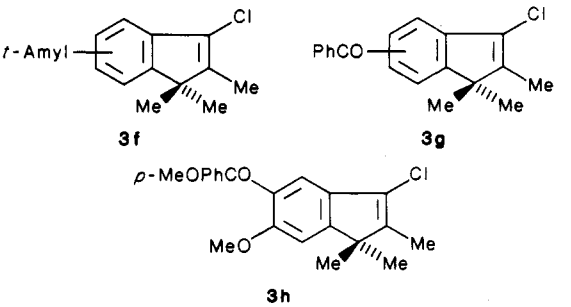
Results and Discussion

The acylations were performed by benzoyl chloride or various para-substituted benzoyl chlorides and trifluoromethanesulfonic acid on 2-chloro-2-methylbutane, according to Scheme I.

In a typical run, the alkyl halide and the aroyl chloride are put together at 0 °C, and CF_3SO_3H is added dropwise (5 min). The reaction mixture is then warmed at 80 °C for 24 h. After cooling, treatment of the crude reaction medium with dry pentane affords a substituted benzoic acid in large amount and traces of pyrylium salts, which were not further analyzed. The reaction medium is then treated with a 10% NaOH solution in order to eliminate the sulfonic acid and to hydrolyze unreacted benzoyl chloride. Dichloromethane extraction, drying, and evaporation afford an oil, which is submitted to bulb-to-bulb distillation followed by flash chromatography of the volatile fraction to give 3-chloroindene derivatives. Table I reports the experimental conditions and the yields in chloroindenes isolated in pure state according to the general procedure. All the 3-chloroindenes were identified by conventional methods (GC/MS, IR, ^{1}H and ^{13}C NMR).

Results given in Table I indicate that the experimental conditions and the substituent on the aromatic ring are of importance in the course of the reaction.

Benzoyl chloride and *p*-methoxybenzoyl chloride give low yields of chloroindene **3a** (run 1) and chloroindene **3e** (run 8), respectively. In both cases, the reaction does not stop after the formation of the initial chloroindene and chloroindenes **3f**, **3g**, and **3h**, resulting from further alkylation or further acylation were isolated in larger amount than **3a** and **3e** (Table I).[6] This is often the case in Friedel–Crafts chemistry when the obtained products are still reactive.



It was found impossible to have more than 50% yield when stoichiometric amounts of alkyl halide and benzoyl chloride were used. The reaction should proceed according to Scheme II. It involves the formation of 2-methyl-2-

(1) (a) Nenitzescu, C. D.; Balaban, A. T. In *Friedel–Crafts and Related Reactions*; Olah G. A., Ed.; Interscience: New York 1964; Vol III, Chapter XXXVII Part 2, p 1033. (b) Groves, J. K. *Chem. Soc. Rev.* **1972**, 73.

(2) Balaban, A. T.; Dinculescu, A.; Dorofeenko, G. N.; Fischer, G. W.; Koblik, A. V.; Mezheritskii, V. V.; Schroth, W. *Advances in Heterocyclic Chemistry*; Katritzky, A. R., Ed.; Academic: New York, 1982; Supplement 2.

(3) (a) Diallo, A.; Hirchmüller, A.; Arnaud, M.; Roussel, C.; Mathieu, D.; Phan Tan Luu, R. *Nouv. J. Chim.* **1983**, 7, 433. (b) Rajoharison, H. G.; Roussel, C. *Nouv. J. Chim.* **1985**, 9, 681.

(4) Erre, C. H.; Roussel, C. *Bull. Soc. Chim. Fr.* **1984**, 449.

(5) Rajoharison, H. G.; Roussel, C. *Bull. Soc. Chim. Fr.* **1986**, 307.

(6) The multiplicity pattern of coupling constants in the aromatic region of the ^{1}H NMR spectra and coupling constants in ^{13}C NMR spectra indicate that the substituent is situated in position 5 or 6 and not in position 4 or 7 in **3f**, **3g**, and **3h**.

0022-3263/88/1953-0683$01.50/0 © 1988 American Chemical Society