



Effects of γ -Cyano Substituent in Allylic Bridgehead Solvolyses: Evidence for Cyano π Conjugation in Carbocations

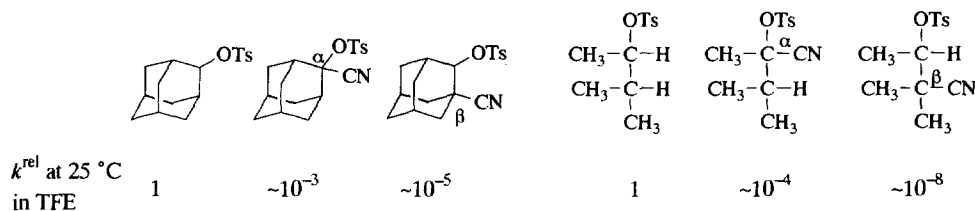
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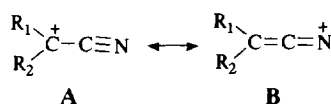
Abstract: Slightly flexible 4-methylene-3-homoadamantyl mesylate solvolyzes 2×10^5 times faster than rigid 2-methylene-1-adamantyl mesylate. Placement of a cyano substituent on the (*E*) position of the vinylic carbon of these systems hardly alter the rate ratio (6×10^5). The result suggests fortuitous cancellation of the inductive destabilizing effect of the cyano substituent by its mesomeric stabilizing effect toward the partially conjugated allylic cation. PM3 calculations on simple allylic cations as models supported the experimental results. © 1997 Elsevier Science Ltd.

INTRODUCTION

One of intriguing problems in physical organic chemistry in the past two decades has been the chemistry of highly destabilized carbenium ions having a strongly electron withdrawing substituent such as a trifluoromethyl, a carbonyl, or a cyano group.¹ Except for the trifluoromethyl substituent, the effects of the other two substituents on the stability of carbenium ions have been controversial.^{2,3} With respect to the cyano substituent, the faster rates of α -cyano substrates than β -cyano ones by a factor of $10^2 \sim 10^4$ (Scheme 1) have been taken as supporting the π conjugative stabilization of intermediate carbenium ions (**A** \leftrightarrow **B**).^{1a,1e,4}

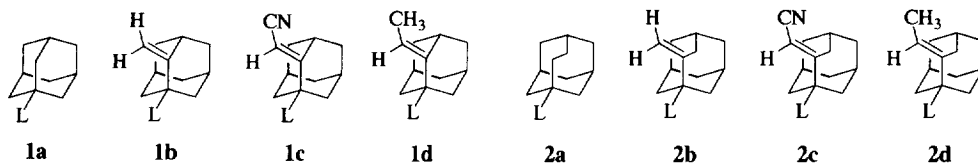


Scheme 1



For α -cyano cations under stable ion conditions, there have been reported a few pieces of evidence for the π conjugation based on NMR chemical shifts of a cationic carbon and cyano nitrogen.^{1e,5} On the other hand, Kirmse and coworkers pointed out the importance of geminal group interaction that may destabilize the ground state of α -cyano triflates, or sulfonates in general, and enhance the solvolysis rates.⁶ More recently, warning has been given on the use of solvolysis rates to evaluate the stability of intermediate carbocations.⁷

In this work we compare the rates of solvolysis of 1-adamantyl (**1a**) and 3-homoadamantyl (**2a**) substrates with those of the corresponding allylic (**1b** and **2b**), γ -cyanoallylic (**1c** and **2c**), and (*E*)-ethylidene (**1d** and **2d**) substrates.

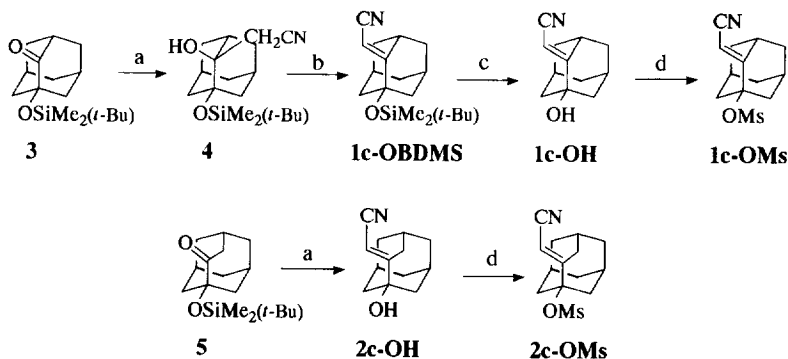


We assumed that the placement of a cyano group on the γ position of allylic systems can avert the destabilization of ground state ascribable to geminal group interaction. In the intermediate allylic carbocations of the 2-methylene bridgehead systems the delocalization of positive charge to the γ -allylic carbon increases as the structure is made more flexible and the p - π overlap increases.⁸ It was expected that if the cyano effect was solely inductive, the inductive destabilization of intermediate cation by the cyano substituent would be enhanced as the delocalization of positive charge to the γ position increased. The γ -cyano effects were compared with the γ -methyl effects in the 2-methylene-1-adamantyl and 4-methylene-3-homoadamantyl systems.

RESULTS AND DISCUSSION

Synthesis

The new precursor alcohols, **1c-OH**, **2c-OH**, and **2d-OH** were synthesized following the routes summarized in Scheme 2.



Reagents and conditions: (a) $\text{LiCH}_2\text{CN}/\text{THF}$, -78°C then r.t.; (b) $\text{SOCl}_2/\text{Py}/\text{Bz}$, 0°C then r.t.; (c) $n\text{-Bu}_4\text{NF}/\text{THF}$, reflux; (d) $n\text{-BuLi}/\text{THF}$ then MsCl .

Scheme 2

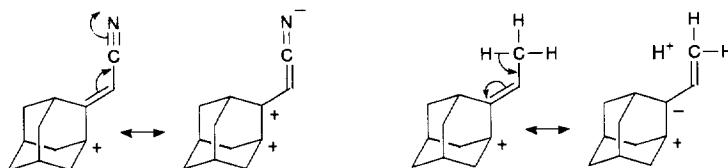
The synthetic routes to (*E*)-2-(cyanomethylene)-1-adamantanol (**1c-OH**) and (*E*)-4-(cyanomethylene)-3-homoadamantanol (**2c-OH**) were essentially the same (Scheme 2). Treatment of 1-(*t*-butyldimethylsiloxy)-2-adamantanone (**3**) with cyanomethylolithium⁹ afforded the alcohol **4**, which on chlorination with thionyl chloride gave the silyl ether **1c-OBDS**. Desilylation followed by lithiation and subsequent treatment with methanesulfonyl chloride gave **1c-OMs**. Fortunately, **2c-OH** was directly obtained at the step of LiCH_2CN addition to **5**.

(*E*)-4-Ethylidene-3-homoadamantanol (**2d-OH**) was formed as a mixture with the (*Z*) isomer by the Wittig ethyldienation of 3-hydroxy-4-homoadamantanone: the mixture was separated by liquid chromatography to give the (*E*) and (*Z*) alcohols in 29 and 34% yields, respectively. The solvolysis was conducted for heptafluorobutyrate **2d-OHFB**. The (*E*) structure of **1c-OH**, **2c-OH**, and **2d-OH** was determined by NOE difference experiments.

Rate Studies

The rates of solvolysis were determined in 80% ethanol: the results are summarized in Table 1. The rates of heptafluorobutyrate of the homoadamantyl system have been converted to those of the corresponding mesylates by using a MsO/HFBO conversion factor (5.6×10^5) for the 1-adamantyl system in 80% ethanol at 25 °C.¹⁰

In the allylic 1-adamantyl carbocations generated from **1b**, **1c**, and **1d** the cationic bridgehead p orbital is perpendicular to the π system. Therefore, the positive charge hardly delocalizes to the allylic framework.¹¹ Meanwhile, the cyano and the methyl substituents are attached to the sp^2 carbon; therefore, their resonance and hyperconjugative effects should be transmitted to the C(2) position (Scheme 3), and the substituent effects on the solvolysis rates would be properly assessed by Hammett's σ_p . In fact, the $\log k$ values for **1b-OMs**, **1c-OMs**, and **1d-OMs** are correlated with σ_p with a slope -6.46 and a correlation coefficient 0.999.



Scheme 3

3-Homoadamantyl mesylate (**2a-OMs**) solvolyzes 2×10^2 times faster than 1-adamantyl mesylate (**1a-OMs**) since the former can more easily attain flattened bridgehead than the latter in the transition state. 4-Methylene-3-homoadamantyl mesylate (**2b-OMs**) solvolyzes 2×10^5 times faster than 2-methylene-1-adamantyl mesylate (**1b-OMs**). The accelerated rate of **2b-OMs** as compared with **1b-OMs** by a factor of 10^3 has been attributed to the partial allylic conjugation in the transition state of the rather flexible **2b-OMs**.⁸

We now compare the γ -cyano effect between the homoadamantyl and adamantyl systems. **2c-OMs** solvolyzes 6×10^5 times faster than **1c-OMs**. The magnitude of this factor is very close to the above factor of 2×10^5 for **2b-OMs/1b-OMs**. We cannot find any enhanced destabilization of the carbocation from **2c-OMs**, although the positive charge is partially delocalized to the allylic γ -carbon. A reasonable interpretation involves fortuitous cancellation of the inductive destabilizing effect by mesomeric electron donation from the cyano substituent. On the other hand, the effect of the methyl substituent in **2d-OMs** is significant. The rate ratio **2d-OMs/1d-OMs** is 3.5×10^6 , which should be compared with the above rate ratio 2×10^5 for **2b-OMs/1b-OMs**. The stabilizing effect of the methyl substituent is evident.

It is important to recognize that the allylic delocalization of positive charge surely occurs in the carbocations generated from **2c-OMs**. The rate ratio between the cyanomethylene-substituted substrate to the parent substrate increases from **1c-OMs/1a-OMs** ($= 10^{-7.4}$) to **2c-OMs/2a-OMs** ($= 10^{-3.8}$). If the allylic conjugation were cut off owing to the inductive destabilizing effect of the cyano substituent, the rate ratios would have been of similar values ($\sim 10^{-7}$).

Table 1. Specific Rates, Activation Parameters, and Rate Ratios for Solvolysis in 80% Ethanol of Various Bridgehead Substrates.

Compound ^a	Temp (°C)	<i>k</i> ^b (s ⁻¹)	ΔH^\ddagger (kcal mol ⁻¹)	ΔS^\ddagger (cal K ⁻¹ mol ⁻¹)	Rate ratio at 25 °C	
1a-OMs	25	4.17×10^{-3} ^c			1.0	1.0
1b-OMs	25	2.91×10^{-7} ^d	24.6	-6.0	$10^{-4.2}$	1.0
	50	7.79×10^{-6}				
	75	1.30×10^{-4}				
1c-OMs	25	$(1.7 \pm 0.3) \times 10^{-10}$ ^d	30.0	-2.5	$10^{-7.4}$	1.0
	100	5.63×10^{-6}				
	125	7.53×10^{-5}				
1d-OMs	25	1.83×10^{-6}	24.9	-1.1	$10^{-3.4}$	1.0
	50	5.14×10^{-5}				
2a-OMs	25	8.0×10^{-1} ^e			1.0	2×10^2
2b-OMs	25	5.9×10^{-2} ^f			$10^{-1.1}$	2×10^5
2c-OMs	25	1.06×10^{-4}	22.5	-1.1	$10^{-3.8}$	6×10^5
	50	2.17×10^{-3}				
2d-OHFB	25	1.14×10^{-5}	24.3	0.2		
	50	2.92×10^{-4}				
2d-OMs	25	6.4 ^g			$10^{0.9}$	3.5×10^6

^a OMs and OHFB denote methanesulfonate and heptafluorobutyrate, respectively. ^b Determined titrimetrically by a single run in the presence of 0.025 mol L⁻¹ 2,6-lutidine with the correlation coefficient for the first order plot greater than 0.999. ^c Ref 10a.

^d Extrapolated from data at higher temperatures. ^e Estimated from the specific rate (1.42×10^{-6} s⁻¹) of **2a-OHFB** (ref 8) by using the conversion factor for 1-AdOMs/1-AdOHFB ($= 5.6 \times 10^5$). ^f Estimated from the specific rate (1.04×10^{-7} s⁻¹) of **2b-OHFB** (ref 8) by using the conversion factor for 1-AdOMs/1-AdOHFB ($= 5.6 \times 10^5$). ^g Estimated from the specific rate of **2d-OHFB** by using the conversion factor for 1-AdOMs/1-AdOHFB ($= 5.6 \times 10^5$).

Calculations

PM3 calculations were attempted for the carbocations examined in this work, but 4-substituted 3-homoadamantyl cations could not be converged to energy minima, probably because of their flexible structures. Therefore, calculations were carried out for the 2-propenyl, (*E*)-3-cyano-2-propenyl, and (*E*)-2-butenyl cations as

model systems, the conformations having been changed to give fully conjugated and non-conjugated conformers. The pertinent bond orders, net atomic charges, and heats of formation are summarized in Table 2.

Table 2. Bond Orders, Net Atomic Charges, and Heats of Formation for 2-Propenyl, (*E*)-3-Cyano-2-propenyl, and (*E*)-2-Butenyl Cations Calculated by PM3.

Cation						
2-Propenyl		(<i>E</i>)-3-Cyano-2-propenyl		(<i>E</i>)-2-Butenyl		
Conjugated	Non-conjugated	Conjugated	Non-conjugated	Conjugated	Non-conjugated	
Bond order ^a						
C(1)-C(2)	1.484	1.175	1.530	1.178	1.588	1.186
C(2)-C(3)	1.484	1.873	1.393	1.796	1.350	1.787
C(3)-C(4)			1.103	1.041	1.107	1.031
C(4)-N			2.801	2.875		
Net atomic charge						
C(1)	0.366	0.656	0.326	0.662	0.284	0.415
C(3)	0.366	0.136	0.482	0.296	0.357	0.263
N			0.254	0.148		
ΔH_f	232.7	251.3	273.2	294.5	211.9	237.6
(kcal mol ⁻¹)						
$\Delta\Delta H_f$	18.6		21.3		25.7	
(kcal mol ⁻¹)						

^a Degree of bonding; for definition, see: Armstrong, D. R.; Perkins, P. G.; Stewart, J. J. P. *J. Chem. Soc., Dalton* **1973**, 838-840.

Comparisons of bond orders for conjugated systems show that the C(1)-C(2) bond order increases in the sequence 2-propenyl (1.484) < (*E*)-3-cyano-2-propenyl (1.530) < (*E*)-2-butenyl (1.588). Notably, the delocalization of π electrons to C(1)-C(2) bond is greater in the (*E*)-3-cyano-2-propenyl cation than in the 2-propenyl cation. In the (*E*)-3-cyano-2-propenyl cation the change of conformation from non-conjugated to fully conjugated results in the decrease in the C(4)-N bond order and the increase in the C(3)-C(4) bond order. This suggests that the C \equiv N π electrons are slightly delocalized to the C(3) cationic carbon. In harmony with this, the net atomic charge on the nitrogen increases from non-conjugated (0.148) to conjugated (0.254).

The difference in the heat of formation (ΔH_f) between the non-conjugated and conjugated conformations is a measure of conjugative stabilization of allylic cations. The value $\Delta\Delta H_f$ increases in the order 2-propenyl (18.6)

< (*E*)-3-cyano-2-propenyl (21.3) < (*E*)-2-butenyl (25.7), suggesting the electron donating mesomeric contribution (+M) of the cyano substituent.

Product Studies

All the adamantyl and homoadamantyl compounds used in this work gave only the expected bridgehead substitution products in the solvolysis in 80% ethanol in the presence of excess 2,6-lutidine.

CONCLUSION

Geminal interaction between the cyano substituent and a sulfonate leaving group is known to destabilize the ground state and enhance the solvolysis rates. Therefore, solvolysis rates might lead to wrong conclusion regarding the electronic effect of the directly attached cyano substituent on the stability of carbocation. The placement of the cyano substituent on the γ -position of allylic systems averts this ambiguity. By changing the allylic system from the rigid 2-methylene-1-adamantyl to the slightly flexible 4-methylene-3-homoadamantyl, the cyano substituent is shown to mesomerically stabilize the carbocation by partially offsetting the inductive destabilization. Investigation of the γ -methyl substituent effect reinforces the reliability of the present approach.

EXPERIMENTAL

General

Melting points are uncorrected. IR spectra were recorded as solutions. ^1H NMR spectra were recorded at 90, 270, or 400 MHz in CDCl_3 . ^{13}C NMR spectra were obtained at 22.5, 68, or 100 MHz in the same solvent. Gas chromatographic analyses were conducted on a PEG-20M column (3 mm \times 2 m). The substrates **1b-OMs**,¹² **1d-OMs**,¹³ **2a-OHFB**,¹⁴ and **2b-OHFB**⁸ were reported previously. Solvolysis solvents were purified by previously described methods.¹⁵ Anhydrous solvents used for synthesis were purified by the standard procedures. 2,6-Lutidine was distilled over CaH_2 . Other commercially available reagents were of a reagent-grade quality and used as received. Medium-pressure liquid chromatography (MPLC) was conducted on Merck silica gel 60 (230–400 mesh).

1-(*tert*-Butyldimethylsiloxy)-2-(cyanomethyl)-2-adamantanol (**4**)

To a solution of *n*-BuLi in hexane (1.6 mol L^{-1} , 1.22 mL) and THF (1.8 mL) prepared at -78°C was added a solution of CH_3CN (93 μL , 1.8 mmol) in THF (1.7 mL) at -78°C . After stirring for 1 h, a solution of 1-(*tert*-butyldimethylsiloxy)-2-adamantanone¹³ (**3**) (500 mg, 1.78 mmol) in THF (1.7 mL) was added over 6 min. After stirring at r.t. for 20 min the reaction mixture was worked up in the usual manner to give a crude product, which was subjected to MPLC (SiO_2) to yield **4** as colorless crystals (482 mg) in 84% yield: mp 76.0 – 77.0°C (from hexane); IR (CCl_4) 3573, 2929, 2251 cm^{-1} ; ^1H NMR (270.05 MHz, CDCl_3) δ 0.11 (s, 3H), 0.13 (s, 3H), 0.88 (s, 9H), 1.43–1.84 (m, 8H), 2.08–2.32 (m, 5H), 2.36 (s, 1H), 2.83 (d, 1H, $J = 17.0$ Hz), 2.87 (d, 1H, $J = 17.0$ Hz); ^{13}C NMR (CDCl_3) δ 118.0 (C), 76.5 (C), 75.2 (C), 41.7 (CH_2), 40.8 (CH_2), 36.6 (CH_2), 36.2 (CH), 33.2 (CH_2), 31.0 (CH_2), 30.2 (CH), 30.0 (CH), 25.7 (CH_3), 24.8 (CH_2), 18.0 (C), -2.00 (CH_3), -2.07 (CH_3). Anal. Calcd for $\text{C}_{18}\text{H}_{31}\text{NO}_2\text{Si}$: C, 67.24; H, 9.72. Found: C, 66.97; H, 9.96.

(*E*)-1-(*tert*-Butyldimethylsiloxy)-2-(cyanomethylene)adamantane (**1c-OBDMs**)

To a solution of SOCl_2 (0.033 mL, 0.46 mmol) in benzene (1.6 mL) was added **4** (133 mg, 0.415 mmol) and pyridine (0.100 mL, 1.24 mmol) in benzene (2.2 mL) over 8 min at 0°C , and then stirring was continued for 45 min and then 50 min at r.t. After the usual work up, the crude product was subjected to MPLC (SiO_2 , hexane-diethyl ether (1:1)) to give **1c-OBDMs** as colorless crystals (107 mg) in 85% yield: mp 100.5 – 101.5°C (from

hexane); IR (CCl₄) 2930, 2218, 1634 cm⁻¹; ¹H NMR (399.65 MHz, CDCl₃) δ 0.09 (s, 6H), 0.86 (s, 9H), 1.69 (s, 4H), 1.83 (s, 4H), 1.96 (s, 2H), 2.18 (s, 2H), 3.32 (s, 1H), 5.39 (s, 1H); ¹³C NMR (CDCl₃) δ 175.8 (C), 117.5 (C), 86.4 (CH), 74.7 (C), 47.5 (CH₂), 38.3 (CH), 38.0 (CH₂), 35.1 (CH₂), 30.2 (CH), 25.7 (CH₃), 18.0 (C), -1.8 (CH₃). Anal. Calcd for C₁₈H₂₉NOSi: C, 71.23; H, 9.63. Found: C, 71.12; H, 9.69.

(E)-2-(Cyanomethylene)-1-adamantanol (1c-OH)

A solution of **1c-OBDMs** (634 mg, 2.09 mmol) and *n*-Bu₄NF (1 mol L⁻¹ in THF, 4.2 mL) in THF (9 mL) was heated at reflux for 37 h. After the usual work up, the crude product was subjected to MPLC (SiO₂, hexane–diethyl ether (1:1)) to give **1c-OH** (337 mg) in 85% yield: mp 70.5–71.5 °C (from hexane–benzene); IR (CCl₄) 3608, 3462, 2931, 2219 cm⁻¹; ¹H NMR (270.05 MHz, CDCl₃) δ 1.73–1.94 (m, 11H), 2.25 (s, 2H), 3.36 (s, 1H), 5.40 (s, 1H); ¹³C NMR (CDCl₃) δ 175.6 (C), 117.2 (C), 86.1 (CH), 72.3 (C), 47.0 (CH₂), 38.3 (CH), 38.0 (CH₂), 34.9 (CH₂), 30.0 (CH). Anal. Calcd for C₁₂H₁₅NO: C, 76.16; H, 7.99. Found: C, 76.09; H, 7.96.

(E)-2-(Cyanomethylene)-1-adamantyl Mesylate (1c-OMs)

To a solution of **1c-OH** (410 mg, 2.17 mmol) in THF (3.5 mL) was added *n*-BuLi (1.6 mol L⁻¹ in hexane, 1.35 mL, 2.17 mmol) at -78 °C and the mixture was stirred for 1 h at -40 °C. A solution of methanesulfonyl chloride (0.168 mL, 1.17 mmol) in THF (3 mL) was added at -40 °C and the resulted mixture was stirred for 4 h at -40 °C. The reaction mixture was worked up in the usual manner to give a yellow semisolid, which was recrystallized in hexane–diethyl ether to give **1c-OMs** (197 mg, 34%): mp 99.0–99.7 °C (from hexane–diethyl ether); IR (CCl₄) 3026, 2937, 2223, 1177 cm⁻¹; ¹H NMR (270.05 MHz, CDCl₃) δ 1.81–1.96 (m, 6H), 2.24 (d, 2H, *J* = 11.3 Hz), 2.34 (s, 2H), 2.73 (d, 2H, *J* = 11.3 Hz), 3.09 (s, 3H), 3.43 (s, 1H), 5.36 (s, 1H); ¹³C NMR (CDCl₃) δ 169.0 (C), 116.0 (C), 89.9 (C), 88.1 (CH), 44.1 (CH₂), 40.8 (CH₃), 39.3 (CH), 37.4 (CH₂), 34.3 (CH₂), 30.5 (CH). Anal. Calcd for C₁₃H₁₇NO₃S: C, 58.40; H, 6.41. Found: C, 58.35; H, 6.52.

(E)-4-(Cyanomethylene)-3-homoadamantanol (2c-OH)

To a solution of *n*-BuLi in hexane (1.6 mol L⁻¹, 7.0 mL) and THF (10 mL) prepared at -78 °C was added a solution of CH₃CN (0.58 mL, 11 mmol) in THF (8 mL) at -78 °C. After stirring for 1 h, a solution of 3-(*tert*-butyldimethylsiloxy)-4-homoadamantanone⁸ (**5**) (2.99 g, 10.1 mmol) in THF (8 mL) was added, and the reaction mixture was stirred at r.t. for 30 min and worked up in the usual manner. The crude product was subjected to MPLC (SiO₂, hexane–diethyl ether 9:1, 1:1) to give unreacted **5** (1.97 g, 66%) and **2c-OH** (416 mg, 20%) as colorless crystals: mp 110.5–111.5 °C (from hexane); IR (CCl₄) 3587, 3542, 3023, 2924, 2216, 1604 cm⁻¹; ¹H NMR (89.55 MHz, CDCl₃) δ 1.5–2.5 (m, 14H), 2.8 (br m, 2H), 5.76 (t, 1H, *J* = 2.0 Hz); ¹³C NMR (CDCl₃) δ 174.9 (C), 117.7 (C), 92.6 (CH), 74.6 (C), 45.0 (CH₂), 39.1 (CH₂), 36.1 (CH₂), 34.5 (CH₂), 28.8 (CH), 27.5 (CH). Anal. Calcd for C₁₃H₁₇NO: C, 76.81; H, 8.43. Found: C, 77.09; H, 8.51.

(E)-4-(Cyanomethylene)-3-homoadamantyl Mesylate (2c-OMs)

To **2c-OH** (174 mg, 0.854 mmol) in THF (3.0 mL) was added *n*-BuLi in hexane (1.6 mol L⁻¹, 0.534 mL) at -72 °C, and then stirring was continued for 1 h at -40 °C. To the solution was added a solution of methanesulfonyl chloride (0.066 mL, 0.854 mmol) in THF (1.5 mL) and the mixture was stirred for 4 h at -40 °C. The reaction mixture was worked up in the usual manner to give a pale yellow solid, which was recrystallized from diethyl ether–hexane (7:3) to give **2c-OMs** in 34% yield: mp 102.5–103.5 °C (from diethyl ether–hexane); IR (CHCl₃) 3026, 2922, 2221, 1611 cm⁻¹; ¹H NMR (89.55 MHz, CDCl₃) δ 1.52–1.70 (m, 4H), 1.91 (dt, 2H, *J* = 13.9, 4.9 Hz), 2.18–2.31 (m, 5H), 2.56 (dd, 2H *J* = 12.7, 4.1 Hz), 2.90 (d, 2H, *J* = 3.3 Hz), 3.08 (s, 3H), 5.70 (s, 1H); ¹³C NMR (CDCl₃) δ 169.7 (C), 116.8 (C), 95.9 (CH), 94.4 (C), 42.5 (CH₂), 41.5 (CH₃), 38.6

(CH₂), 35.8 (CH₂), 34.4 (CH₂), 28.3 (CH), 27.8 (CH). Anal. Calcd for C₁₄H₁₉NO₃S: C, 59.76; H, 6.81. Found: C, 59.83; H, 6.96.

(E)-4-Ethylidene-3-homoadamantanol (2d-OH)

Following a literature method for Wittig methylenation,¹⁶ 3-hydroxy-4-homoadamantanone (**5-OH**) (2.00 g, 11.1 mmol) was treated in DMSO (100 mL) under N₂ with ethylenetriphenylphosphorane which had been generated from ethyltriphenylphosphonium bromide (12.4 g, 33.4 mmol) and NaH (60% dispersion 1.33 g, 33.3 mmol), at 75 °C for 70 h. The reaction mixture was poured into ice-water and worked up in the usual manner to give a yellow semisolid, which was subjected to MPLC (SiO₂, hexane–diethyl ether) to yield a mixture (929 mg) of (*E*)-4-ethylidene-3-homoadamantanol (**2d-OH**) and **5-OH**, and (*Z*)-4-ethylidene-3-homoadamantanol (724 mg, 34%). The mixture was treated with LiAlH₄ in diethyl ether to convert **5-OH** to 3,4-homoadamantanediol and the resulted mixture was separated by MPLC (SiO₂, hexane–diethyl ether) to give **2d-OH** (612 mg, 29%). **2d-OH**: mp 92.0–92.5 °C (from hexane); IR (CHCl₃) 3589, 3456, 3050, 2919, 1380 cm⁻¹; ¹H NMR (270.05 MHz, CDCl₃) δ 1.46 (br s, 1H), 1.51 (br s, 1H), 1.57 (dt, 3H, *J* = 6.8, 1.6 Hz) overlapped with 2H, 1.73 (br s, 1H), 1.78 (br s, 2H), 1.86–1.92 (m, 4H), 2.01 (m, 2H), 2.19 (m, 1H), 2.40 (m, 2H), 5.72 (qt, 1H, *J* = 6.8, 2.2 Hz); ¹³C NMR (CDCl₃) δ 147.5 (C), 121.9 (CH), 74.6 (C), 45.6 (CH₂), 44.0 (CH₂), 36.5 (CH₂), 36.2 (CH₂), 29.2 (CH), 28.4 (CH), 15.2 (CH₃). Anal. Calcd for C₁₃H₂₀O: C, 81.20; H, 10.48. Found: C, 80.96; H, 10.68. (*Z*)-4-Ethylidene-3-homoadamantanol: mp 76.5–77.0 °C (from hexane); IR (CHCl₃) 3597, 3443, 3045, 2917, 1393 cm⁻¹; ¹H NMR (270.05 MHz, CDCl₃) δ 1.48–1.57 (m, 4H), 1.68–1.82 (m, 5H) 1.87 (dt, 3H, *J* = 7.3, 1.4 Hz), 2.00 (t, 2H, *J* = 2.9 Hz), 2.06 (br s, 2H), 2.11 (br s, 1H), 2.37–2.42 (m, 2H), 5.24 (qt, 1H, *J* = 7.3, 1.6 Hz); ¹³C NMR (CDCl₃) δ 147.5 (C), 114.5 (CH), 74.6 (C), 46.5 (CH₂), 37.1 (CH₂), 36.2 (CH₂), 35.3 (CH₂), 29.8 (CH), 28.1 (CH), 13.0 (CH₃). Anal. Calcd for C₁₃H₂₀O: C, 81.20; H, 10.48. Found: C, 80.94; H, 10.76.

(E)-4-Ethylidene-3-homoadamantyl Heptafluorobutyrate (2d-OHFB)

To **2d-OH** (250 mg, 1.30 mmol) in pyridine (1.8 mL, 22 mmol) was added heptafluorobutryl chloride (514 mg, 2.21 mmol) in CH₂Cl₂ (2.0 mL), and then the mixture was stored in a refrigerator at 4 °C for 54 h. The reaction mixture was worked up in the usual manner to give crude **2d-OHFB** as a yellowish liquid, which was essentially pure by ¹³C NMR, and used for solvolysis without further purification: IR (CHCl₃) 2916, 1778 cm⁻¹; ¹H NMR (270.05 MHz, CDCl₃) δ 1.59 (t, 3H, *J* = 6.9 Hz) overlapped with 4H, 1.8–1.9 (m, 2H), 2.0–2.1 (m, 4H), 2.24 (t, 1H, *J* = 4.8 Hz), 2.3–2.4 (m, 2H), 2.49 (s, 2H), 5.40 (qt, 1H, *J* = 6.9, 1.8 Hz); ¹³C NMR (CDCl₃) δ 155.8 (C), 141.1 (C), 117.4 (CH), 92.1 (C), 43.1 (CH₂), 36.6 (CH₂), 35.3 (CH₂), 34.3 (CH₂), 29.1 (CH), 27.9 (CH), 13.2 (CH₃), with *n*-C₃F₇CO signals being omitted.

NOE Difference Experiments

Nuclear Overhauser enhancement was measured on degassed CDCl₃ solutions of **1c-OH**, **2c-OH**, **2d-OH**, and the (*Z*) isomer of **2d-OH**, in the manner described previously.¹² In the previous studies¹² irradiation of the vinylic proton of **1d-OH** and its (*Z*) isomer caused the enhancement of the C(3) proton, 0% and 17%, respectively. Irradiation of the vinylic proton of **1c-OH** caused only 0.9% enhancement of C(3) proton, which was taken as evidence for the (*E*) structure of **1c-OH**. The determination of the structure of **2d-OH** was based on the small (0.9%) enhancement of C(5) protons on irradiation of the vinylic proton: the measurement on the corresponding (*Z*) isomer showed 5.1% enhancement. A similar experiment on **2c-OH** showed only 0.7% enhancement of C(5) protons, which was taken as evidence for the (*E*) structure of **2c-OH**.

Products of Solvolysis

Product distributions were determined by GLC (PEG 20M column) or by isolation by means of MPLC. The ethyl ethers **1b-OEt** and **1d-OEt** were described previously.¹² **1c-OEt**, **2c-OEt**, and **2d-OEt** were identified by their spectra. **1c-OEt**: mp 50.0–51.8 °C; IR (CHCl₃) 3022, 2933, 2218, 1630, 1220 cm⁻¹; ¹H

NMR (270.05 MHz, CDCl_3) δ 1.20 (t, 3H, $J = 7.0$ Hz), 1.43–2.07 (m, 10H), 2.24 (s, 2H), 3.35 (s, 1H), 3.50 (q, 2H, $J = 7.0$ Hz), 5.31 (s, 1H); ^{13}C NMR (CDCl_3) δ 174.0 (C), 117.5 (C), 86.8 (CH), 75.9 (C), 56.7 (CH_2), 43.2 (CH_2), 38.6 (CH), 38.4 (CH_2), 35.4 (CH_2), 29.9 (CH), 15.8 (CH_3). **2c-OEt**: mp 58.0–60.9 °C; IR (CHCl_3) 3021, 2926, 2216, 1606 cm^{-1} ; ^1H NMR (270.05 MHz, CDCl_3) δ 1.16 (t, 3H, $J = 7.0$ Hz), 1.48–1.60 (m, 4H), 1.82–2.08 (m, 8H), 2.26 (t, 1H, $J = 4.6$ Hz), 2.83 (dd, 2H, $J = 1.6, 4.6$ Hz), 3.29 (q, 2H, $J = 7.0$ Hz), 5.46 (t, 1H, $J = 1.6$ Hz); ^{13}C NMR (CDCl_3) δ 172.8 (C), 118.1 (C), 94.1 (CH), 79.7 (C), 57.0 (CH_2), 42.7 (CH_2), 39.9 (CH_2), 36.4 (CH_2), 35.3 (CH_2), 28.9 (CH), 27.5 (CH), 15.6 (CH_3). **2d-OEt**: oil; IR (CCl_4) 2973, 1545 cm^{-1} ; ^1H NMR (270.05 MHz, CDCl_3) δ 1.15 (t, 3H, $J = 7.0$ Hz), 1.43–1.54 (m, 4H), 1.60 (d, 3H, $J = 7.0$ Hz), 1.83 (m, 6H), 2.00 (t, 2H, $J = 3.0$ Hz), 2.15 (t, 1H, $J = 4.9$ Hz), 2.36 (s, 2H), 3.35 (q, 2H, $J = 7.0$ Hz), 5.59 (qt, 1H, $J = 7.0, 1.9$ Hz); ^{13}C NMR (CDCl_3) δ 142.6 (C), 116.9 (CH), 79.5 (C), 56.0 (CH_2), 44.1 (CH_2), 37.1 (CH_2), 35.9 (CH_2), 35.4 (CH_2), 29.6 (CH), 28.0 (CH), 15.9 (CH_3), 13.2 (CH_3).

Kinetic Methods

The preparation of solvents and kinetic studies followed the methods described previously.^{12,13,15}

Calculations

Semiempirical PM3 calculations were performed through the MOPAC package¹⁷ on an IBM RS/6000 computer.

REFERENCES

1. Reviews: (a) Gassman, P. G.; Tidwell, T. T. *Acc. Chem. Res.* **1983**, *16*, 279–285. (b) Tidwell, T. T. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 20–32. (c) Creary, X. *Acc. Chem. Res.* **1985**, *18*, 3–8. (d) Creary, X.; Hopkinson, A. C.; Lee-Ruff, E. α -Carbonyl Cations. In *Advances in Carbocation Chemistry*, Vol. 1; Creary, X., Ed.; JAI Press: Greenwich, 1989, pp. 45–92. (e) Creary, X. *Chem. Rev.* **1991**, *91*, 1625–1678.
2. (a) Creary, X.; Geiger, C. C. *J. Am. Chem. Soc.* **1982**, *104*, 4151–4162. (b) Creary, X. *J. Am. Chem. Soc.* **1984**, *106*, 5568–5577.
3. (a) Takeuchi, K.; Akiyama, F.; Ikai, K.; Shibata, T.; Kato, M. *Tetrahedron Lett.* **1988**, *29*, 873–876. (b) Takeuchi, K.; Yoshida, M.; Ohga, Y.; Tsugeno, A.; Kitagawa, T. *J. Org. Chem.* **1990**, *55*, 6063–6065. (c) Tokunaga, K.; Ohga, Y.; Takeuchi, K. *Tetrahedron Lett.* **1996**, *37*, 2241–2242. (d) Takeuchi, K.; Ohga, Y. *Bull. Chem. Soc. Jpn.* **1996**, *69*, 833–851.
4. (a) Gassman, P. G.; Saito, K.; Talley, J. J. *J. Am. Chem. Soc.* **1980**, *102*, 7613–7615. (b) Gassman, P. G.; Saito, K. *Tetrahedron Lett.* **1981**, *22*, 1311–1314.
5. (a) Olah, G. A.; Arvanaghi, M.; Prakash, G. K. S. *J. Am. Chem. Soc.* **1982**, *104*, 1628–1631. (b) Olah, G. A.; Prakash, G. K. S.; Arvanaghi, M. *J. Am. Chem. Soc.* **1980**, *102*, 6640–6641. (c) Mertens, A.; Olah, G. A. *Chem. Ber.* **1983**, *116*, 103–108.
6. (a) Kirmse, W.; Goer, B. *J. Am. Chem. Soc.* **1990**, *112*, 4556–4557. (b) Wu, Y.-D.; Kirmse, W.; Houk, K. N. *J. Am. Chem. Soc.* **1990**, *112*, 4557–4560.
7. (a) Apeloig, Y.; Biton, R.; Abu-Freih, A. *J. Am. Chem. Soc.* **1993**, *115*, 2522–2523. (b) Richard, J. P.; Amyes, T. L.; Rice, D. J. *J. Am. Chem. Soc.* **1993**, *115*, 2523–2524. (c) Kirmse, W.; Wonner, A.; Allen, A. D.; Tidwell, T. T. *J. Am. Chem. Soc.* **1992**, *114*, 8828–8835.
8. Takeuchi, K.; Kitagawa, T.; Ohga, Y.; Yoshida, M.; Akiyama, F.; Tsugeno, A. *J. Org. Chem.* **1992**, *57*, 280–291.
9. Kaiser, E. M.; Hauser, C. R. *J. Org. Chem.* **1968**, *33*, 3402–3404.
10. (a) Bentley, T. W.; Carter, G. E. *J. Org. Chem.* **1983**, *48*, 579–584. (b) Bentley, T. W.; Roberts, K. J. *Chem. Soc., Perkin Trans. 2*, **1989**, 1055–1060.

11. (a) Ree, B. R.; Martin, J. C. *J. Am. Chem. Soc.* **1970**, *92*, 1660–1666. (b) Buss, V.; Gleiter, R.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1971**, *93*, 3927–3933.
12. Ohga, Y.; Munakata, M.; Kitagawa, T.; Kinoshita, T.; Takeuchi, K.; Oishi, Y.; Fujimoto, H. *J. Org. Chem.* **1994**, *59*, 4056–4067.
13. Ohga, Y.; Takeuchi, K. *J. Phys. Org. Chem.* **1993**, *6*, 293–301.
14. Fărcașiu, D.; Jähme, J.; Rüchardt, C. *J. Am. Chem. Soc.* **1985**, *107*, 5717–5722.
15. Takeuchi, K.; Ikai, K.; Shibata, T.; Tsugeno, A. *J. Org. Chem.* **1988**, *53*, 2852–2855.
16. Greenwald, R.; Chaykovsky, M.; Corey, E. J. *J. Org. Chem.* **1963**, *28*, 1128–1129.
17. MOPAC Ver. 6, Stewart, J. J. P. *QCPE* No. 455; revised as Ver. 6.01 by Hirano, T., The University of Tokyo, for UNIX machine.

(Received in Japan 2 April 1997; accepted 6 May 1997)