Solvolysis of Optically Active 4-Methylcyclohexylidenemethyl Triflate: Evidence against a Primary Vinyl Cation as an Intermediate

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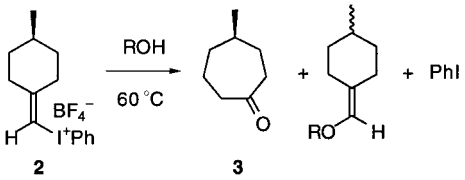
Solvolysis of (*R*)-4-methylcyclohexylidenemethyl triflate in aqueous methanol at 140 °C gave stereospecifically (*R*)-4-methylcycloheptanone to definitively rule out intermediate formation of the achiral primary vinyl cation. The rearrangement must occur via concerted σ-bond participation.

Primary vinyl cations are extremely unstable[1–3] and can only be generated under forced conditions in solution.[4–7] The only reasonable report that claims formation of such a cation under normal solvolytic conditions is, to our knowledge, that of Hanack and co-workers[8] concerning the solvolysis of cyclohexylidenemethyl triflate (**1**) in aqueous methanol at 140 °C. They obtained both cyclohexanecarbaldehyde and rearranged cycloheptanone as products, while the solvolysis did not proceed in less polar methanol at the same temperature. These results seemed to be compatible with an S_N1 mechanism via the primary vinyl cation as an intermediate.

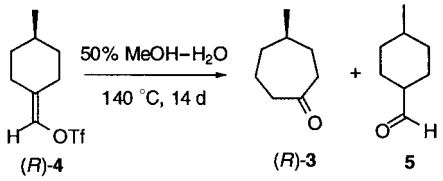
We have recently examined the feasibility of the intermediacy of a primary vinyl cation using vinyl iodonium salts as solvolysis substrates,[9] since we found that the iodonio group is about 10^6 times as good a leaving group as triflate.[10] However, all the results seemed to be incompatible with a mechanism involving the primary vinyl cation, although Hinkle and coworkers[11] suggested its formation from similar experiments. In order to reach a definitive conclusion about the intermediacy of primary vinyl cations, we employed a chirality probe approach:[12] optically active 4-methylcyclohexylidenemethyl(phenyl)iodonium tetrafluoroborate (**2**) was used as a substrate, and it was found that the chirality was completely transferred to the rearranged product, 4-methylcycloheptanone (**3**) on its formation (Scheme 1). This result definitively indicates that the achiral primary cation, 4-methylcyclohexylidenemethyl cation, is not involved but the product is formed via the chiral secondary 5-methylcyclohept-1-enyl cation generated directly from the substrate **2** by the σ-bond participation.



2 **3**

Scheme 1.

In this way, there is no doubt that the ionic substrate **2** with an excellent nucleofuge undergoes σ-bond participation to lead to a rearranged cation. However, there is still some doubt if a neutral substrate with a poorer nucleofuge like **1** also behave in the same way without formation of a primary vinyl cation. A chirality probe approach can be applied to the triflate solvolysis, and we prepared (*R*)-4-methylcyclohexylidenemethyl triflate ((*R*)-**4**) as a modified substrate of **1**. The solvolysis was examined under the same conditions as those employed previously.[8] The main product, (*R*)-4-methylcycloheptanone ((*R*)-**3**) was obtained essentially without loss of the optical purity of the substrate (Scheme 2). The triflate solvolysis was found to take place without formation of the primary vinyl cation contrary to the previous conclusion.[8] The experimental observations will be summarized in this communication.



(*R*)-**4** (*R*)-**3** **5**

Scheme 2.

The optically active triflate (*R*)-**4** was prepared from bromide (*R*)-**6** according to the reaction sequence given in Scheme 3.[13] The enantiomeric excesses (ee) of the substrate samples used were 73 and 68% as determined by gas chromatography using chiral columns.[13e]

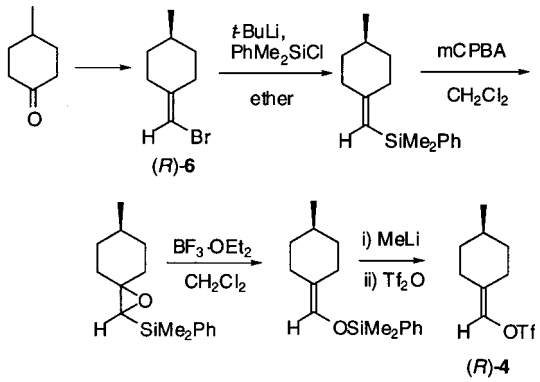
Solvolysis of (*R*)-**4** was carried out in various solvents in sealed pyrex tubes at 140 °C.[14] Products were identified and determined by GC and GC–MS by comparing with the authentic samples.[12] Yields of the products and the recovered substrate are summarized in Table 1 together with their ee's when applicable.

The product distribution obtained in 50 vol% aqueous methanol is similar to that observed previously for **1** under the

Table 1. Products of solvolysis of triflate (*R*)-**4** in aqueous methanol at 140 °C

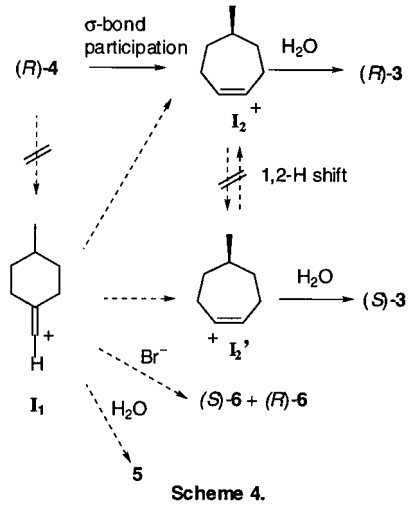
Substrate %ee	Solvent vol% methanol	Time/ day	%Yield (%ee) (*R*)-**3**	**5**	(*S*)-**6**	(*R*)-**4**
73	50	14	59 (71)	17	–	0
73	50	4	43 (71)	4	–	22 (73)
73	50 (Br^-)[a]	14	32 (71)	8	2 (64)	0
68	20	7	67 (67)	7	–	3 (68)
68	80	7	13 (67)	15	–	47 (68)
0	100	28	3 (0)	3	–	68 (0)
73	100 (Br^-)[a]	14	3 (70)	trace	12 (71)	65 (73)

[a]Tetrabutylammonium bromide (0.1 mol dm^{-3}) was added.



Scheme 3.

same conditions.[8] The remarkable result of the present solvolysis is that the rearranged product **3** retains essentially the optical purity of the substrate (*R*)-**4**. The stereochemistry of **3** is determined as *R* by comparison with an authentic sample.[12] This observation definitively excludes the intermediacy of the achiral primary vinyl cation $\mathbf{I_1}$ for the formation of **3**, but is reasonably explained by a σ-bond participation mechanism leading directly to the rearranged secondary cation $\mathbf{I_2}$, which is trapped by water to give (*R*)-**3** as illustrated in Scheme 4. The substrate recovered from the reaction in a shorter time maintained its original optical purity.



Scheme 4.

The unrearranged product, aldehyde **5**, is achiral, but some chiral unrearranged substitution product **6** was obtained in the presence of added bromide salt. The 4-methylcyclohexylidenemethyl bromide (**6**) obtained was found to have the *S* configuration. That is, the substitution reaction occurs largely with inversion of configuration. This means that **6** is not formed from trapping of the intermediate vinyl cation $\mathbf{I_1}$, but it must arise directly from (*R*)-**4** via a vinylic S_N2 pathway.[9,15,16]

The effects of solvent composition of aqueous methanol were also examined. The complete chirality transfer from the substrate **4** to the rearranged product **3** was always observed. The increased content of methanol decreases the rate of solvolysis and also the fraction of the rearranged product **3**. The transition state for the rearrangement must be more polar than that for the formation of unrearranged product. In pure methanol, Hanack et al.[8] did not find any reaction of **1** taking place, but we found small amounts of products **3** and **5** from **4**. Furthermore, bromide gave again the inverted substitution product (*S*)-**6** in methanol.

These results strongly suggest that the unrearranged products are not derived from intermediate primary cation $\mathbf{I_1}$, but through some other pathway with a less polar transition state than the σ-participation mechanism. A possible pathway may involve a nucleophilic reaction at the sulfonic sulfur.

In conclusion, the possibility of intermediate formation of the primary vinyl cation during the solvolysis of either the triflate or iodonium substrates was definitively ruled out by using a chirality probe approach.

References and Notes

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13 a) Preparation of (*R*)-**4**: Triflate (*R*)-**4** was prepared from the (*R*)-dimethylphenylsilyl derivative obtained from bromide (*R*)-**6**[13b] via the consecutive epoxidation and rearrangement to the silyl enol ether,[13c] followed by sulfonylation.[13d] The product was purified by chromatography (SiO_2, hexane) and obtained as a colorless oil. The enantiomeric excess of one sample of (*R*)-**4** was determined as 73% and $[\alpha]^{20}_D$ = –7.3 (*c* 1.15 $CHCl_3$), while the other preparation gave a sample of 68% ee. ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.34 (s, 1H), 2.77–2.70 (m, 1H), 2.20–2.12 (m, 1H), 2.00–1.93 (m, 1H), 1.83–1.78 (m, 3H), 1.59–1.50 (m, 1H), 1.05–0.93 (m, 2H), 0.90 (d, *J* = 6.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 133.3, 127.6, 118.6 (q, *J* = 318.5 Hz), 35.6, 34.6, 32.2, 29.3, 25.5, 21.8; MS (EI) *m/z* (%) 258 (M^+; 6), 107 (78), 79 (76), 69 (83), 55 (100); HRMS (EI) calcd for $C_9H_{13}SO_3F_3$ (M^+) 258.0538, found 258.0557. b) W. H. Perkin and W. J. Pope, *J. Chem. Soc.*, **99**, 1510 (1911); H. Gerlach, *Helv. Chim. Acta*, **49**, 1291 (1966); H. M. Walborsky and R. B. Banks, *Bull. Soc. Chim. Belg.*, **89**, 849 (1980). c) I. Fleming and T. W. Newton, *J. Chem. Soc. Perkin Trans. 1*, **1984**, 119. d) P. J. Stang and M. Hanack, *Synthesis*, **1982**, 85. e) The ee's of the substrate and products were determined by gas chromatography using complementally three chiral columns, Chrompack-Chirasil-DEX CB, Supelco β-DEX 120, and Supelco β-DEX 325. Accuracy of the gas chromatographic analysis was evaluated to be within ±0.5%.
14 Solvolysis was carried out in a sealed pyrex glass tube with about 2 mg of (*R*)-**4** in 4 mL of aqueous methanol. The reaction mixture was kept at 140 ˚C from 4 days to a few weeks, and the products were extracted with pentane containing tetradecane as an internal standard for analysis.
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