2-Methylbicyclo[3.2.2]non-3-en-2-yl Cation Involving Rearrangement of 1,3′-Spirocyclopropylbicyclo[2.2.2]oct-2′-yl Cation[1]

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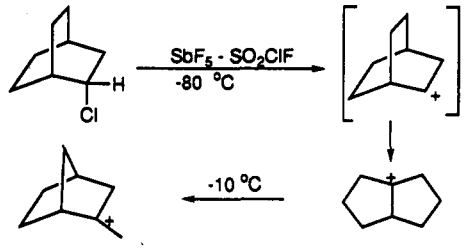
The 2-norbornyl cation has captured the attention of the majority of the physical organic community for over half a century. However, the higher homologue, secondary 2-bicyclo[2.2.2]octyl cation, has received relatively little attention. The nature of the cation and the σ-participation of the adjacent 1,6 and 1,7 C–C bonds could be inferred only from solvolysis studies.[2]

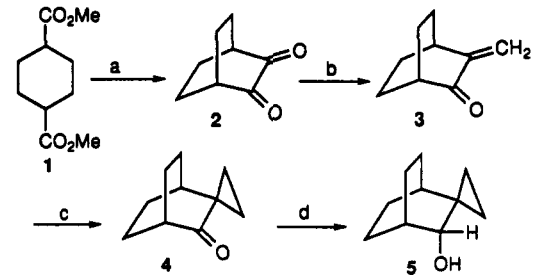
The tertiary 2-bicyclo[2.2.2]octyl cations have been studied in superacids at low temperatures. On the other hand, all attempts of preparation of the secondary 2-bicyclo[2.2.2]octyl cation resulted only in the rearrangement to the thermodynamically more stable bicyclo[3.3.0]-oct-1-yl cation,[3] which further rearranges to 2-methyl-2-norbornyl cation at higher temperatures.



A spirocyclopropyl group adjacent to the cation center was shown to significantly stabilize carbocations. Thus, for example, the presence of the α-spirocyclopropyl group makes possible the observation of an otherwise unstable secondary cyclohexyl cation, which rearranges to bicyclo-[3.3.0]oct-1-yl cation at higher temperatures.[4] Attempted preparation of the 1,3′-spirocyclopropyl-2′-norbornyl cation, on the other hand, resulted in the formation of the allyl cation, 2-methylbicyclo[3.2.1]oct-3-en-2-yl cation.[5]

We have now undertaken the preparation of the expectedly stabilized 1,3′-spirocyclopropylbicylo[2.2.2]oct-2′-yl cation (**6**) by ionizing the corresponding 1,3′-spirocyclopropylbicyclo[2.2.2]octan-2′-ol (**5**). However,

Scheme I[a]



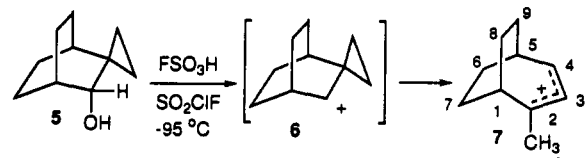
[a]Key: 1. Na/K; (a) ether, Me_3SiCl, reflux, 30 min; 2. Br_2/ether–hexane, 0 °C, 5 min; (b) CH_2=PPh3/THF–DMSO, 0 °C, 5 min; (c) CH_2I_2/Zn–Cu–ether, reflux; (d) $LiAlH_4$/ether, 0 °C to rt.

cation **6** could not be observed, and facile rearrangement resulted in the formation of the allylic 2-methylbicyclo-[3.2.2]non-3-en-2-yl cation (**7**).

Results and Discussion

A standard procedure for the preparation of α-spirocyclopropyl alcohols involves the Simmons–Smith reaction of the corresponding enones followed by the reduction of the carbonyl group. However, the precursor enone, 3-methylenebicyclo[2.2.2]octan-2-one (**3**), is unreported (Scheme I). We have developed a convenient synthesis of the enone by a modified acyloin condensation[6] of dimethyl 1,4-cyclohexanedicarboxylate and selective Wittig reaction of the bicyclo[2.2.2]octane-2,3-dione (**2**). The acyloin condensation using a dispersion of sodium in toluene gave poor yields of the diketone **2**. However, using a sodium–potassium alloy in ether solution provided **2** in high yield under mild conditions. The Simmons–Smith reaction of **3** using Zn/Cu in refluxing ether gave the α-spirocyclopropyl ketone **4**. The alcohol **5** was obtained by the reduction of the ketone using lithium aluminum hydride.

Ionization of the alcohol **5** in FSO_3H in low nucleophilicity solvent, sulfuryl chloride fluoride, at −95 °C gave the allyl cation, 2-methylbicyclo[3.2.2]non-3-en-2-yl cation (**7**). The proton-coupled ^{13}C NMR spectrum confirmed



the structure and aided in the assignments of the chemical shifts to the individual carbons. The tertiary cationic center (C2) is significantly more positively charged compared to C4, as evidenced by the more deshielded C2 carbon (δC2 = 249, δC4 = 206). The absorption for C1 is correspondingly more deshielded than that of the C5 ($\delta^{13}C$ 45.4 and 36.6, respectively). The allylic cation **7** shows ^{13}C NMR signals similar to those of 2-methylbicyclo[3.2.1]-oct-3-en-2-yl cation.[4]

The formation of the 2-methylbicyclo[3.2.2]non-3-en-2-yl cation implies the involvement of the 1,3′-spirocyclopropylbicyclo[2.2.2]oct-2′-yl cation (**6**) as a highly energetic intermediate. Several consecutive intramolecular 1,2-hydride and alkyl shifts may intervene in the rearrangement of this cation to the observed allyl cation, **7**. A similar mechanism may be operative in the case of the lower homologous 2-norbornyl derivative.[4]

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It is known that the cyclopropyl group provides significant participation in the bisected conformation.[7] The spirocyclopropyl group in both 2-bicyclo[2.2.2]octyl and 2-norbornyl systems is sterically restricted in the bisected conformation, providing overwhelming participation over the adjacent 1,6 or 1,7 σ-participation. The participation of the spirocyclopropyl group diminishes when the cationic center is stabilized by adjacent electron-releasing groups such as phenyl and cyclopropyl, as shown by us earlier.[8] The cation **6**, and its 2-norbornyl analogue, being secondary in nature, exert much electron demand on the neighboring spirocyclopropyl group, resulting in their spontaneous rearrangement.

In conclusion, we have prepared the interesting allylic cation, **7**, from a route involving the α-spirocyclopropyl group participation in the intermediate short-lived cation **6**.

Experimental Section

Diethyl ether and tetrahydrofuran were distilled from sodium–benzophenone ketyl immediately before use. Dimethyl sulfoxide was distilled from calcium hydride and dried over 4-Å molecular sieves.

Melting points were measured in capillary tubes using a Mel-Temp II melting point apparatus. ^{1}H and ^{13}C NMR spectra were obtained for $CDCl_3$ solutions on a Varian VXR-200, or a Bruker-360 instrument, equipped with a variable-temperature probe. The chemical shifts of the compounds are referenced with respect to internal tetramethylsilane, whereas those of the carbocation were referenced with respect to the external capillary tetramethylsilane. GC/MS analyses were achieved on a Finnigan Mat/Incos-50 mass spectrometer equipped with a Varian 3400 gas chromatograph.

2,3-Bis(trimethylsiloxy)bicyclo[2.2.2]oct-2-ene. A dry 1-L round-bottomed flask was equipped with an efficient reflux condenser, a magnetic stirrer, and an addition funnel. The flask was charged with sodium (15 g, 0.65 mol) and potassium (26 g, 0.63 mol) as small pieces under a blanket of dry nitrogen and was heated with a heating mantle until the alloy was formed as a melt. About 400 mL of ether was added to the contents, and a glass stirring bar was placed in the flask. The contents were stirred for 5 min to disperse the alloy. A solution of dimethyl 1,4-cyclohexanedicarboxylate (44 g, 0.22 mol, a mixture of 2:1 cis/trans isomers, Aldrich) and chlorotrimethylsilane (107.5 g, 0.99 mol, 4.5 equiv) in 100 mL of ether was then added dropwise to the contents at such a rate as to maintain a gentle reflux (about 30 min). The reaction was exothermic, and an instantaneous orange-brown precipitate formed during the addition of the reactants. After the vigorous reaction subsided (30 min), the contents were refluxed for 30 min and cooled to room temperature. The reaction mixture was filtered through a sintered glass funnel under vacuum in a nitrogen atmosphere. The residue was washed with dry ether, and the solvent was removed under vacuum. The 2,3-bis(trimethylsiloxy)bicyclo[2.2.2]oct-2-ene (35 g, 56%) was obtained upon distillation: bp 95–98 °C/1 mm; ^{1}H NMR, δ ^{1}H 0.154 (s, 18 H, $Si(CH_3)_3$, 2.36 (d, J = 1.2 Hz, 2 H, C1, C4-H), 1.434 (s, 8 H); ^{13}C NMR, δ ^{13}C 132.7 (olefinic), 36.1 (allylic), 26.9 (CH_2), 0.55 $Si(CH_3)_3$.

Bicyclo[2.2.2]octane-2,3-dione (2). A dry 100-mL round-bottomed flask was charged with 2,3-bis(trimethylsiloxy)-2-bicyclo[2.2.2]octene (34 g, 0.12 mol) and 10 mL of dry ether. The flask was cooled to 0 °C, and bromine (19 g, 6.1 mL, 0.12 mol) dissolved in 10 mL of hexane was added dropwise with continuous stirring. The reaction was instantaneous, the orange color of the bromine disappeared, and a yellow precipitate formed. At the end, slight orange color resulted. A few additional drops of the bis(trimethylsilyl) ether were added until the yellow color returned. The precipitated compound (14 g, 85%) was filtered through a Buchner funnel and recrystallized from ether–hexane: mp 162–164 °C; MS (m/z), 138 (M^+, 14.8), 110 (20.7), 92 (7.5), 81 (15.6), 67 (100), 54 (70.8); ^{1}H NMR δ ^{1}H 2.79 (d, J = 1.41 Hz, 2 H, C1, C4-H), 2.02 (s, 8 H).

3-Methylenebicyclo[2.2.2]octan-2-one (3). Methyltriphenylphosphonium bromide (8.53 g, 0.0239 mol) was suspended in 30 mL of ether in a dry 100 mL flask equipped with a magnetic stirrer, an addition funnel, a reflux condenser, and a nitrogen inlet. *tert*-Butyllithium (14 mL, 0.0239 mol) was added dropwise to the contents with stirring at 0 °C. Dimethyl sulfoxide (30 mL) was added, and the resulting deep-red solution was added dropwise to a solution of bicyclo[2.2.2]octane-2,3-dione (3 g, 0.0217 mol) in 20 mL of dry tetrahydrofuran contained in a 250-mL three-necked round-bottom flask equipped with a magnetic stirrer, an addition funnel, and a nitrogen inlet. The reaction was instantaneous, and the deep-red color of the ylide changed to the yellow. After 5 min of stirring at 0 °C, the contents were poured into 100 mL of water, washed with 15% hydrogen peroxide (50 mL) and saturated sodium bicarbonate (5 mL), and dried ($MgSO_4$) and the solvents removed by evaporation under reduced pressure. Pentane (200 mL) was added, and the clear solution was filtered from the precipitated triphenylphosphine oxide. Evaporation of the pentane gave the enone **3** (2.2 g, 75%) as a colorless liquid: MS (m/z), 136 (M^+, 35.1), 121 (3.2), 108 (33.4), 107 (20.4), 93 (44), 79 (100), 67 (32.9); ^{1}H NMR δ ^{1}H, 5.92 (d, 1 H, J = 1.7 Hz, olefinic H), 5.15 (d, J = 1.5 Hz, olefinic H), 2.7 (br s, 1 H, allylic H), 2.4 (br s, 1 H, C1-H), 1.6–2.0 (m, 8 H); ^{13}C NMR δ ^{13}C 204.35 (>C=O), 148.31 (C3), 116.37 (=CH_2), 42.25 (C1), 36.1 (C4), 25.52 (C6, C7), 23.07 (C5, C8).

1,3′-Spirocyclopropylbicyclo[2.2.2]octan-2′-one (4). A dry 100-mL round-bottomed flask was charged with zinc (3.1 g, 0.047 mol), cuprous chloride (0.47 g, 0.0047 mol), and 10 mL of ether. The contents were refluxed for 30 min, and diiodomethane (2.82 g, 0.0105 mol) was added, followed by 3-methylenebicyclo[2.2.2]-octan-2-one (1.1 g, 8.1 mmol) in 5 mL of ether. The contents were refluxed overnight, cooled to room temperature, poured into 200 mL of water, and extracted with ether (2 × 50 mL). The ether layers were washed with 10% HCl (50 mL), dried ($MgSO_4$), and filtered and the solvents removed under reduced pressure. Compound **4** (0.95 g, 78%) was obtained as a pale yellow liquid. MS (m/z), 150 (M^+, 27), 135 (2.6), 122 (100), 107 (16.8), 93 (24.6), 91 (22.9), 79 (68.8); ^{1}H NMR δ ^{1}H 2.36 (br s, 1 H, C1-H), 1.7–1.9 (m, 8 H), 1.37 (br s, 1 H), 1.27 (q, J = 3.4 Hz, 2 H, cyclopropyl-H), 0.79 (q, J = 3.4, 2 H, cyclopropyl H).

1,3′-Spirocyclopropylbicyclo[2.2.2]octan-2′-ol (5). Compound **4** (1.5 g, 0.01 mol) dissolved in 50 mL of dry ether was cooled to 0 °C, and lithium aluminum hydride (0.38 g, 0.01 mol) was added to the contents in a dry round-bottom flask under a blanket of nitrogen. The contents were stirred at 0 °C for 1 h and at room temperature overnight. The reaction mixture was quenched with water and extracted with ether. The organic layers were dried ($MgSO_4$), and the solvent was removed under reduced pressure. Compound **5** was obtained as a colorless crystalline solid after purification through column chromatography on silica gel using pentane and dichloromethane as successive eluents: mp 64–66 °C; MS (m/z), 152 (M^+, 1.11), 134 (3.7), 124 (42.3), 109 (11.2), 96 (100), 91 (20.5), 79 (22); ^{1}H NMR δ ^{1}H 3.5 (d, J = 3.4 Hz, C2-H), 1.92–1.25 (m, 10 H), 0.9–0.8, (m, 1 H), 0.66 (br s, 1 H), 0.6–0.4 (m, 2 H), 0.21–0.31 (m, 1 H); ^{13}C NMR δ ^{13}C 75.74 (C2), 35.33 (C1), 32.7 (C4), 24.64 (C3), 23.98, 18.0, 14.63, and 7.38.

Preparation of 2-Methylbicyclo[3.2.2]non-3-en-2-yl Cation (7). Compound **6** was suspended in SO_2ClF solvent in a 5-mm NMR tube and cooled in powdered dry ice–acetone bath (−78 °C). Fluorosulfuric acid (FSO_3H) was added dropwise, and the contents were intermittently stirred using a vortex stirrer until a clear solution was obtained. The ^{13}C NMR spectrum was immediately recorded at −95 °C; ^{13}C NMR δ ^{13}C 249.1 (s, C2), 206.1 (d, J = 163 Hz, C4), 141.4 (d, J = 175 Hz, C3), 45.4 (d, J = 140 Hz, C1), 36.6 (d, J = 149 Hz, C5), 25.3 (CH_3) 18.5 (t, J = 133 Hz, C7, C8), 15.35 (t, J = 129, C6, C9).

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Supplementary Material Available: NMR spectra of 2,3-bis(trimethylsiloxy)bicyclo[2.2.2]oct-2-ene and compounds **3–5** (7 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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