= Me, R^4 = H, R^5 = OTMS), 101979-76-4; **9b** (R^1 = Ts, R^3 = R^5 = H, R^4 = OTMS), 101979-79-7; **9b** (R^1 = $SO_2OCH_2CCl_3$, R^3 = R^5 = H, R^4 = OTMS), 101979-80-0; **9b** (R^1 = $COCCl_3$, R^3 = R^5 = H, R^4 = OTMS), 101979-81-1; **10a** (R^1 = $SO_2OCH_2CCl_3$, R^2 = TMS), 101997-93-7; **10a** (R^1 = $COCCl_3$, R^2 = TBDMS), 101979-67-3; **10a** (R^1 = $COCCl_3$, R^2 = Me), 101979-72-0; **10b** (R^1 = $COCCl_3$, R^3 = Me, R^4 = H, R^5 = OTMS), 101979-77-5; **10b** (R^1 = $COCCl_3$, R^3 = R^5 = H, R^4 = OTMS), 101979-82-2; **11a** (R^2 = TMS), 101979-64-0; **11a** (R^2 = TBDMS), 101979-68-4; **11a** (R^2 = Me), 101979-73-1; **11b** (R^3 = Me, R^4 = H, R^5 = OTMS), 101979-78-6; **11b** (R^3 = R^5 = H, R^4 = OTMS), 101979-83-3; **12**, 101979-84-4; **13**, 101979-85-5; **14**, 101979-87-7; **15**, 101979-86-6; **16**, 101979-88-8.

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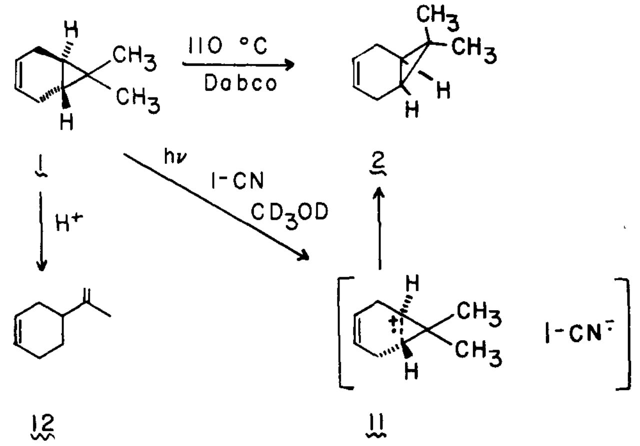
Synthesis and Photoinduced Electron-Transfer Promoted Isomerization of 7,7-Dimethyl-*trans*-bicyclo[4.1.0]hept-3-ene

Summary: The title compound, **1**, is highly reactive (very sensitive to acid, and, thermally isomerized to the cis isomer **2**, at 110 °C); photosensitized isomerization of **1** to **2** is effected by the excited state of 1-cyanonaphthalene.

Sir: Since it was first suggested that small, trans-fused bicyclic molecules should have unique bonding,[1] numerous attempts have been made to bridge the cyclopropyl moiety with a short carbon–carbon chain in a trans configuration.[2-5] Recently, we reported a simple approach to *trans*-bicyclo[4.1.0]hept-3-ene.[6] We now report the first synthesis of 7,7-dimethyl-*trans*-bicyclo[4.1.0]hept-3-ene (**1**). In addition, we have found that **1** was rapidly isomerized to 7,7-dimethyl-*cis*-bicyclo[4.1.0]hept-3-ene (**2**) in the presence of excited state 1-cyanonaphthalene (1-CN).

The synthesis of **1** involved a major modification of our earlier synthetic approach to the intriguing *trans*-bicyclo[4.1.0]heptyl skeleton. As shown in Scheme I, Fisher esterification of commercial *trans*-β-hydromuconic acid (**3**)[7] gave an 85% yield of dimethyl *trans*-hex-3-ene-1,6-dioate (**4**).[8] Subsequent reduction of **4** with lithium aluminum hydride produced the diol, **5**, in 82% yield.[9] Treatment of **5** with carbon tetrabromide and triphenylphosphine gave **6**[9] in 85% yield. Phase-transfer-catalyzed addition of dibromocarbene to **6** using bromoform, sodium hydroxide, and triethylbenzylammonium chloride (as phase-transfer agent)[10] yielded 85% of the tetrabromide **7**.[11] Utilizing high dilution techniques, **7** was allowed to react with sodium sulfide to give 68% of 8,8-dibromo-4-thia-*trans*-bicyclo[5.1.0]octane (**8**). When **8** was allowed to react with a tenfold excess of lithium dimethylcuprate,[12] a 97% yield of a 47:53 mixture of **9** and its monomethylated counterpart, 8-methyl-4-thia-*trans*-bicyclo[5.1.0]octane, was obtained. The two cyclic sulfides were separated by preparative MPLC to give a 36% yield of **9**. Conversion of the sulfide to an α-chlorosulfone was accomplished in a two-step process involving treatment of **9** with *N*-chlorosuccinimide to α-chlorinate and then with *m*-chloroperbenzoic acid to oxidize the sulfide linkage to a sulfone. The mixture of stereoisomers represented by **10** was obtained in 90% yield. When **10** was treated with 5 equiv of potassium *tert*-butoxide in dimethyl sulfoxide, **1** was produced in 45% yield[13] for an overall yield of 5.0%.



The structure of **1** was established on the basis of spectral data and by its facile conversion to 7,7-dimethyl-*cis*-bicyclo[4.1.0]hept-3-ene (**2**) both thermally and photochemically. The ^1H NMR of **1** in benzene-d_6 showed: δ 5.96 (s, 2 H), 2.55 (dd, 2 H), 2.00 (m, 2 H), 1.10 (s, 6 H), and −0.50 (m, 2 H); ^{13}C NMR (C_6D_6) δ 131.61 (d), 32.49 (s), 31.76 (t), 30.99 (d), and 23.25 (q). The upfield position of the two bridgehead protons at δ = −0.50 was consistent with the similar position found for these protons in the nonmethylated parent hydrocarbon.[6] Thermally, **1** was converted into **2** at 110 °C in 93% yield.[14] This thermal

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[2] Cope, A. C.; Hecht, J. K. *J. Am. Chem. Soc.* **1963**, *85*, 1780. Corey, E. J.; Schulman, J. I. *Tetrahedron Lett.* **1968**, 3655. DePuy, C. H.; Marshall, J. L. *J. Org. Chem.* **1968**, *33*, 3326. Moshuk, G.; Petrowski, G.; Winstein, S. *J. Am. Chem. Soc.* **1968**, *90*, 2179. Gassman, P. G.; Williams, E. A.; Williams, F. J. *Ibid.* **1971**, *93*, 5199. Wiberg, K. B.; Nakahira, T. *Ibid.* **1971**, *93*, 5193. Wiberg, K. B.; Nakahira, T. *Tetrahedron Lett.* **1970**, 3759. Deyrup, J. A.; Betkouski, M. F. *J. Org. Chem.* **1975**, *40*, 284. Wiberg, K. B.; de Meijere, A. *Tetrahedron Lett.* **1969**, 59. Deyrup, J. A.; Betkouski, M.; Szabo, W.; Mathew, M.; Palenik, G. J. *J. Am. Chem. Soc.* **1972**, *94*, 2147.

[3] (a) Gassman, P. G.; Williams, F. J.; Seter, J. *J. Am. Chem. Soc.* **1968**, *90*, 6893. (b) Kirmse, W.; Hase, Ch. *Angew. Chem., Int. Ed. Engl.* **1968**, *7*, 891. (c) Wiberg, K. B.; de Meijere, A. *Tetrahedron Lett.* **1969**, 519. (d) Ashe, A. J., III. *Ibid.* **1969**, 523. (e) Gassman, P. G.; Seter, J.; Williams, F. J. *J. Am. Chem. Soc.* **1971**, *93*, 1673. (f) Gassman, P. G.; Williams, F. J. *Ibid.* **1971**, *93*, 2704. (g) Wiberg, K. B. *Angew. Chem., Int. Ed. Engl.* **1972**, *11*, 332. (h) Pirkle, W. H.; Lunsford, W. B. *J. Am. Chem. Soc.* **1972**, *94*, 7201.

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[5] A second derivative of *trans*-bicyclo[4.1.0]heptane has been reported as a nonisolable intermediate. See: Casadevall, E.; Pouet, Y. *Tetrahedron* **1978**, *34*, 1921. For an example of an unsuccessful attempt to prepare a *trans*-bicyclo[4.1.0]hept-3-ene derivative by an acyloin condensation, see: Delbaere, C. U. L.; Whitham, G. H. *J. Chem. Soc., Perkin Trans. 1* **1974**, 879. See also: Blancou, H.; Casadevall, E. *Tetrahedron* **1976**, *32*, 2907. For an additional unsuccessful approach see ref 3g.

[6] Gassman, P. G.; Bonser, S. M. *J. Am. Chem. Soc.* **1983**, *105*, 667. See also: Gassman, P. G.; Bonser, S. M. *Tetrahedron Lett.* **1983**, *24*, 3431.

[7] Available from Aldrich Chemical Co., Inc.

[8] Linstead, R. P.; Owen, L. N.; Wells, R. J. *J. Chem. Soc.* **1953**, 1225.

[9] Lukes, R.; Dudek, V. *Collect. Czech. Chem. Commun.* **1959**, *24*, 2484.

[10] The phase-transfer conditions used are essentially those described in the literature. Makosza, M.; Fadorynski, M. *Synth. Commun.* **1973**, 305.

[11] Satisfactory elemental analyses and/or exact mass molecular weights have been obtained on all new compounds shown. Spectral data were consistent with the assigned structures in all cases. All yields are of purified materials.

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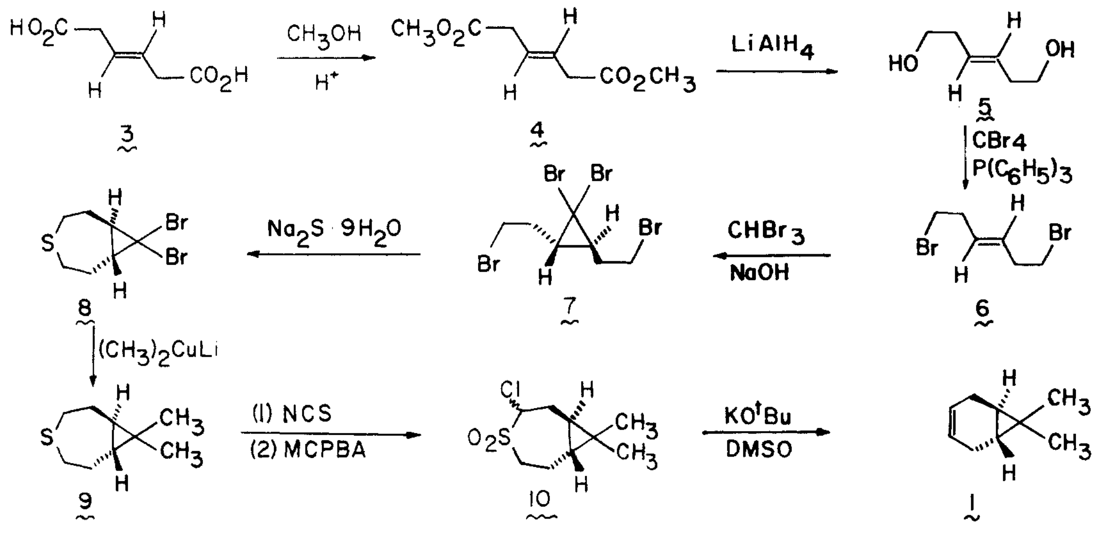
[13] This classical Ramberg–Bäcklund reaction was carried out at ambient temperature. For a review, see: Paquette, L. A. *Org. React.* (*N.Y.*) **1977**, *25*, 1.

0022-3263/86/1951-2397$01.50/0

Scheme I



rearrangement product was identical in all respects with an authentic sample of 2 prepared by the addition of 1 equiv of dibromocarbene to 1,4-cyclohexadiene, followed by replacement of the bromines by methyl groups through the use of lithium dimethylcuprate.[12] At 110 °C the thermal rearrangement of 1 to 2 occurred 8 times faster than the rearrangement of the parent hydrocarbon.

In view of our interest in the electrochemical[15] and photoinduced electron-transfer-promoted reactions[16] of highly strained polycyclic molecules, we examined the oxidation of 1 under single-sweep cyclic voltammetry conditions which showed that 1 had an $E_{1/2}$ vs. a saturated calomel electrode of 1.34 V.[17] This value was sufficiently low that electron transfer from 1 to a variety of excited state photosensitizers was anticipated. Irradiation of a solution of 1 in methanol-d_4 containing 5 mol % of 1-CN as photosensitizer for 3.5 h with a Rayonet photochemical reactor containing 16 300-nm, 21-W lamps gave a 78% yield of 2. Since this photochemistry was carried out in Pyrex glassware, only the 1-CN was excited. We believe that a tight cation radical–anion radical pair, which could be represented by 11 is formed.[18] Isomerization of the cation radical of 1 (11) to the cation radical of 2, followed by back electron transfer from the anion radical of 1-CN would then produce 2.

Lastly, we indicate that 1 is extremely acid-sensitive. It was rapidly isomerized to 12 in the presence of trace amounts of acid. We are continuing to explore the chemistry of 1 and of related derivatives of trans-fused bicyclic alkanes.

Acknowledgment. We are indebted to the National Science Foundation for Grant CHE-8414359 which supported this investigation.

Registry No. **1**, 101934-24-1; **2**, 36168-41-9; **3**, 29311-53-3; **4**, 25126-93-6; **5**, 71655-17-9; **6**, 59533-63-0; **7**, 101934-25-2; **8**, 101934-26-3; **9**, 101934-27-4; **10** (isomer 1), 101934-28-5; **10** (isomer 2), 102044-02-0; **12**, 26325-89-3; 1-CN, 86-53-3; $CHBr_3$, 75-25-2; Na_2S, 1313-82-2; $(CH_3)_2CuLi$, 15681-48-8; 8-methyl-4-thiabicyclo[5.1.0]octane, 101934-29-6.

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Received January 13, 1986

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[14] In addition to 93% of 2, the formation of ca. 7% of 12 was observed. In the absence of Dabco, the percentage of 12 varied, ranging up to 30% of the reaction mixture. This implies that 12 was formed in an acid-catalyzed process (vide post).

[15] Gassman, P. G.; Yamaguchi, R. *J. Am. Chem. Soc.* 1979, *101*, 1308. Gassman, P. G.; Mullins, M. J.; Richtsmeier, S.; Dixon, D. A. *Ibid.* 1979, *101*, 5793. Gassman, P. G.; Mullins, M. J. *Tetrahedron Lett.* 1980, *21*, 2219.

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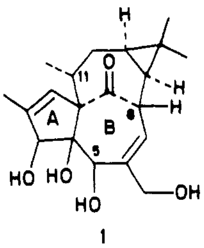
[17] This value can be compared to $E_{1/2}$ = 1.52 V measured for *trans*-bicyclo[4.1.0]hept-3-ene.[6] The effect of the methyl groups at C7 is consistent with the HOMO being associated with the C1–C6 bond.[15] All $E_{1/2}$ values were determined by single-sweep cyclic voltammetry and are nonreversible.

[18] While we show the C1–C6 bond as a one-electron bond in 11, we cannot rule out the possibility that the isomerization of 1 to 2, under the described photochemical conditions, involves a cation radical derived from removal of an electron from the C1–C7 bond. Also, on the basis of presently available data, we are unable to determine whether the photoinduced isomerization of 1 to 2 is a cation radical-chain process.

Synthetic Studies on the Ingenane Diterpenes. Inter- and Intramolecular [6 + 4] Tropone–Diene Cycloaddition Reactions[†]

Summary: Thermally allowed inter- and intramolecular [6 + 4] tropone–diene cycloadditions have been employed for the construction of intermediates in the synthesis of the cocarcinogenic diterpene ingenol.

Sir: The ingenanes represent a structurally unique class of highly oxygenated tetracyclic diterpene esters which exhibit potent tumor-promoting properties.[1] Ingenol (1) serves as the parent diterpene nucleus from which many of these biologically active esters are derived.



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[†] Portions of this work were presented at the 190th American Chemical Society National Meeting in Chicago, IL, September 10, 1985, Abstract ORGN102.