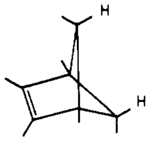
Reactivity of Dihydro Derivatives of Hexamethyl(Dewar benzene)

G. Capozzi and H. Hogeveen*

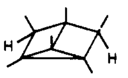
Contribution from the Department of Organic Chemistry, The University, Zernikelaan, Groningen, The Netherlands. *Received October 8, 1974*

Abstract: The reactivity of *endo,endo*-1,2,3,4,5,6-hexamethylbicyclo[2.1.1]hexene (**1**) and *exo,exo*-1,2,3,4,5,6-hexamethyltricyclo[2.2.0.0^{2,6}]hexane (**2**) toward electrophiles (FHSO$_3$, Br$_2$) is reported. It is shown that **1** reacts with pyridinium hydrobromide perbromide (Py$^+$HBr$_3$$^-$) to give *endo,endo*-1,4,5,6-tetramethyl-2,3-dimethylenebicyclo[2.1.1]hexane **4** in good yield. The low reactivity of **4** in the Diels-Alder cycloaddition to tetracyanoethylene is discussed in terms of different interactions of an ethylene and a *cis*-butadiene residue with a cyclobutane ring. Py$^+$HBr$_3$$^-$ induces isomerization of **2** to *cis*-1,2,3,4,5,6-hexamethylcyclohexa-1,4-diene (**8**). Reactions of **1** and **2** with FHSO$_3$-SbF$_5$ mixtures give exclusively *cis,cis*-1,2,3,4,5,6-hexamethylcyclohexenyl cation (**11**). Possible mechanisms for the stereospecific formation of **11** are suggested.

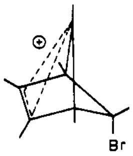
The syntheses of *endo,endo*-1,2,3,4,5,6-hexamethylbicyclo[2.1.1]hexene (**1**) and *exo,exo*-1,2,3,4,5,6-hexamethyltricyclo[2.2.0.0^{2,6}]hexane (**2**) in the reduction of **3** with lithium aluminum hydride have been recently reported.[1] The chemistry of **2** has been only briefly investigated in the transition-metal-catalyzed reaction,[2] but so far the chemical behavior of **1** has not been studied.



1



2



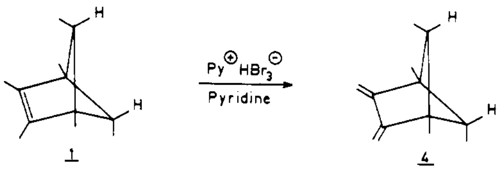
3

— = CH$_3$

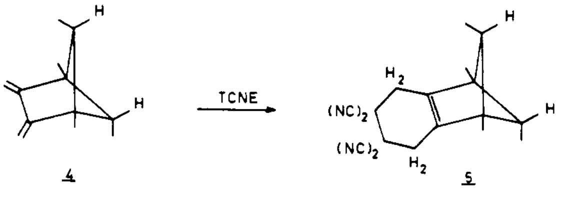
Our continuing interest in electrophilic addition to strained molecules[2,3] caused us to attempt to obtain long-lived bicyclohexyl cations[4] from both **1** and **2**. Moreover, compound **1** appeared to be a suitable starting product for the synthesis of the *endo,endo*-1,4,5,6-tetramethyl-2,3-dimethylenebicyclo[2.1.1]hexane (**4**).

Bromination Reactions

(a) Synthesis and Diels-Alder Reactivity of 4. Compound **4** was obtained in 69% yield in a one-pot reaction of **1** and pyridinium hydrobromide perbromide[5] (Py$^+$HBr$_3$$^-$) in pyridine at 0°. The use of other brominating agents, *e.g.*, free bromine or the pyridine complex of it, gave rise to extensive formation of rearranged products or to a much lower yield of **4**. The structure of **4** is based on correct elemental analysis, molecular weight, and spectral data (pmr, cmr, uv, ir) (see Experimental Section).

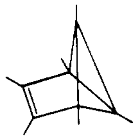


Reaction of **4** with tetracyanoethylene (TCNE) in chloroform at room temperature afforded only 5% of the Diels-Alder adduct **5** after 20 hr. Complete reaction was achieved after 20 hr at 55°.



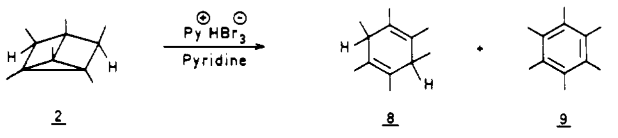
The comparison with the reactivity of 1,2,5,6-tetramethyl-3,4-dimethylenetricyclo[3.1.0.0^{2,6}]hexane (**6**) toward TCNE is striking. In this case, the reaction is complete within a few minutes at room temperature.[6] In compound **4** the two methyl groups in the endo position might interfere to some extent with the approaching dienophile; however, it is unlikely that steric effects alone can cause such a large difference in reactivity. It is more reasonable to ascribe this difference to a difference in orbital interactions of the ethylene and to butadiene residues bridging a cyclobutane and a bicyclobutane ring, respectively. Recent extended Hückel calculations[7] predict, in fact, a stabilizing orbital interaction between the cyclobutane ring and the butadiene bridge for the parent compound **4**, compared with a destabilizing orbital interaction between cyclobutane ring and ethylene residue in the parent compound **1**. Similar calculations carried out on the parent bicyclobutane derivatives **6** and **7**[8] show in both compounds stabilizing orbital interactions between the bicyclobutane ring and the bridging residues. Although kinetic data are needed to establish more accurately the difference in the activation energies of the two reactions, it seems that there is at least a qualitative agreement between the theoretical and experimental results.

6

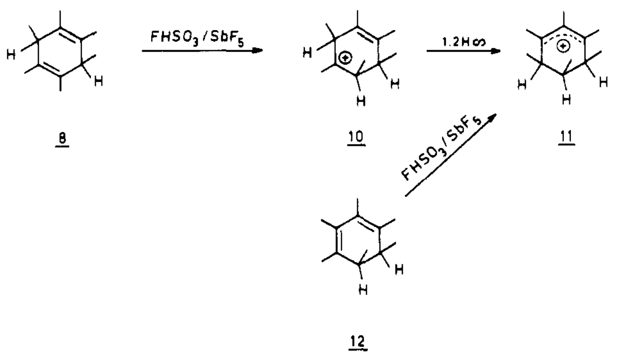


7

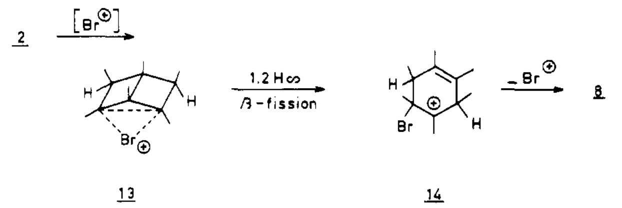
(b) Isomerization of 2. When **2** is treated with Py$^+$HBr$_3$$^-$ in pyridine, an isomerization process takes place, and *cis*-1,2,3,4,5,6-hexamethylcyclohexa-1,4-diene (**8**)[9] together with hexamethylbenzene (**9**) is obtained. The structure of **8** was deduced from spectroscopic data (see Experimental Section), but no information on the stereochemistry of **8** could be obtained from these measurements. The cis arrangement of the two methyl groups at positions 3 and 6 was proved by the exclusive formation of *cis,cis*-1,2,3,4,5,6-hexamethylcyclohexenyl cation (**11**)[10] on reaction of **8** at low temperature in FHSO$_3$-SbF$_5$ (10:1 molar ratio) mixture. The formation of **11** occurs with protonation on the least hindered side of **8** to give **10** followed by 1,2-hydride shift. Steric factors therefore play a very important



role in the protonation in strong acid of hexamethyl substituted cyclohexadienes. A similar stereoselectivity has in fact been observed in the protonation of *cis*-1,2,3,4,5,6-hexamethylcyclohexa-1,3-diene (**12**) in which case **11** was also the only ion formed.[10]

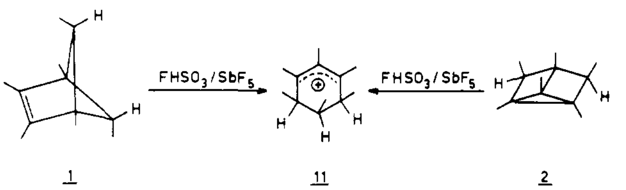


The formation of **8** in the reaction of **2** with Py$^+$HBr$_3^-$ can be explained by assuming an endo attack of the electrophile ("Br$^+$ ") at the cyclopropane ring of **2** with formation of **13** followed by a (possibly concerted) 1,2-hydride shift and *β* fission to give **14.** Release of "Br$^+$ " ion gives rise to **8.**

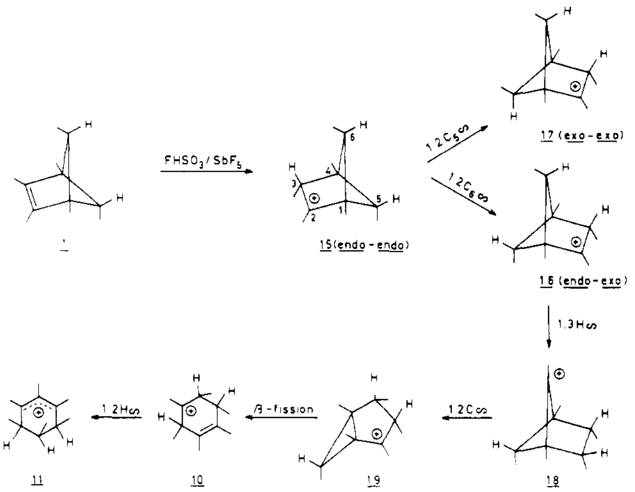


Reaction with Strong Acids

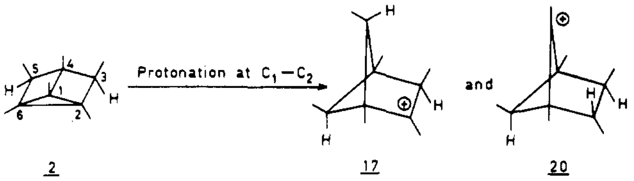
When **1** or **2** was treated with FHSO$_3$–SbF$_5$ mixtures at low temperature, none of the primarily formed bicyclohexyl cations could be observed. Even at −95°, **11** was the only species present in solution. It is worthwhile to point out that of the three possible stereoisomers of 1,2,3,4,5,6-hexamethylcyclohexenyl cation,[10-12] **11** is selectively formed. This implies stereospecific protonation and/or stereochemically controlled steps during the rearrangement. It is reasonable to assume protonation occurring on **1** at the double bond with formation of *endo,endo*-**15.** A 1,2-carbon shift of C$_6$ then gives the *endo,exo*-**16.** A similar 1,2-carbon shift of C$_5$ would lead to the *exo,exo*-bicyclo[2.1.1]hexyl cation (**17**). Models show that the huge steric interaction between the two methyl groups at C$_5$ and C$_6$ in the latter carbonium ion will inhibit this shift to occur, however. The observed cyclohexenyl cation **11** is likely to be formed from **16** through the intermediates **18, 19,** and **10** which are consecutively generated from **16** by a 1,3-hydride shift, a 1,2-carbon shift, and a *β* fission. It is of interest to observe that a similar sequence of reactions in the case of **17** would lead to a mixture of isomeric 1,2,3,4,5,6-hexamethylcyclohexenyl cations.[11,12]



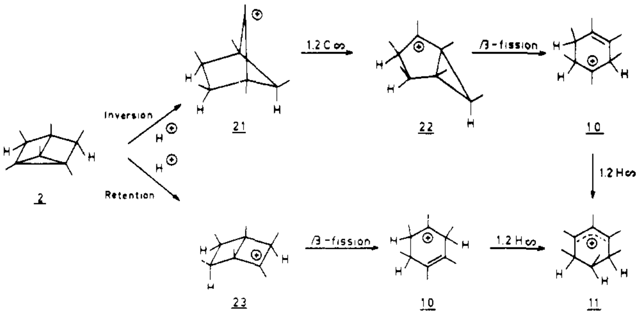
Scheme I



Protonation of **2** is expected to occur at the cyclopropane ring because of the high reactivity of this ring system toward electrophiles.[13] For steric reasons, such a protonation is likely to take place at the endo side of the molecule, *i.e.*, at the C$_2$–C$_6$ bond. Moreover, attack from the exo side of the molecule, *i.e.*, at the C$_1$–C$_2$ (C$_1$–C$_6$) bond, would lead, at least with a retention mechanism, to the formation of **17** and **20** which can both be disregarded: **17** for the reasons mentioned above and **20** for the trans configuration of the methyl groups at the 2 and 3 positions. In fact, the sequence of reactions outlined for the protonation of **1** would give in the case of **20,** a mixture of isomeric *trans,trans*- and *cis,trans*-1,2,3,4,5,6-hexamethylcyclohexenyl cations.[11] The attack at the cyclopropane ring from the endo side of **2** can, in principle, occur with retention or with inversion[13,14] and will lead in both cases to the formation of the observed cation **11** as outlined in Scheme II. In the inversion pathway, the cation **11** is formed *via* a sequence of reactions similar to that proposed for the protonation of **1.** Ring opening of **2** with retention generates the bicyclo[2.2.0]hexyl cation **23** which after *β* fission and 1,2-hydride shift gives the cyclohexenyl cation **11.**



Scheme II



In conclusion, the results described above clearly show the stereospecific nature of the processes occurring during and/or after protonation of the *endo,endo*-1,2,3,4,5,6-hexamethylbicyclo[2.1.1]hexene (**1**) and the *exo,exo*-1,2,3,4,5,6-hexamethyltricyclo[2.2.0.0^{2,6}]hexane (**2**). This is probably due to the steric hindrance exerted by the methyl groups present in these molecules and is in agreement with a number of previous findings in hexamethyl-substituted compounds.[10,14,15]

Experimental Section

Proton magnetic resonance spectra were recorded on a Varian A-60D or a Jeol C-60HL spectrometer equipped with variabletemperature probes. Chemical shifts were calculated relative to internal TMS at $\delta = 0$. Natural abundance carbon-13 nuclear resonance spectra were obtained with a Varian XL-100 spectrometer operating at 25.2 MHz using a Fourier transform. Carbon-13 chemical shifts were calculated relative to internal TMS. Mass spectra were obtained with an AEI MS 9 spectrometer. Preparative and analytical glc was performed by using SE-30 columns (glass) with all the temperatures kept below 150°.

***endo,endo*-1,4,5,6-Tetramethyl-2,3-dimethylenebicyclo[2.1.1]hexane (4).** To a solution of 1.10 g (6.7 mmol) of **1**[1a] in pyridine (6 ml) cooled at 0° pyridinium hydrobromide perbromide[5] (3.15 g, 10 mmol) was added in small portions during 15 min. The reaction mixture was allowed to reach room temperature and pyridinium hydrobromide started to precipitate. After 30 min, the mixture was poured into ice and extracted several times with pentane. The pentane was washed with water to remove the pyridine, dried over $CaCl_2$, and evaporated, leaving 0.75 g (4.6 mmol, 69% yield) of **4**. Analytically pure samples were obtained by preparative glc, mp 51-53°. Compound **4** shows a great tendency to sublime at room temperature: mass spectrum, parent peak at *m/e* 162; ir absorptions at 3140 (=CH_2 stretching), 1650 (C=C stretching), and 855 cm^{-1} (=CH_2 out of plane deformation); uv (ethanol) λ_{max} 233 nm (log ϵ 4.26) and 240 (log ϵ 4.29); pmr (CCl_4) δ 5.37 (s, 2 H), 4.70 (s, 2 H), 1.55 (q, 2 H, $J = 6.0$ Hz), 1.08 (s, 6 H), 0.55 (d, 6 H, $J = 6.0$ Hz); cmr ($CDCl_3$) peaks at 152.2 (broad s), 99.0 (t, $J_{C-H} = 157$ Hz), 55.4 (s), 53.1 (d, $J_{C-H} = 140$ Hz), 12.0 (q, $J_{C-H} = 125$ Hz), and 8.3 (q, $J_{C-H} = 125$ Hz) ppm.

Anal. Calcd for $C_{12}H_{18}$: C, 88.82; H, 11.18. Found: C, 88.75; H, 11.15.

Reaction of 4 with Tetracyanoethylene. To a solution of 0.18 g (1.1 mmol) of **4** in $CHCl_3$ was added 0.15 g (1.1 mmol) of tetracyanoethylene. After the reaction mixture had been kept at 55° for 20 hr, the solvent was evaporated to leave 0.30 g (1.0 mmol, 91% yield) of **7** which was crystallized from ethanol: mp 221-223° dec; mass spectrum, parent peak at *m/e* 290; pmr spectrum ($CDCl_3$) signals at δ 3.33 (s, 4 H), 2.62 (q, 2 H, $J = 6.0$ Hz), 1.03 (s, 6 H), and 0.98 (d, 6 H, $J = 6.0$ Hz; the downfield peak of the doublet being superimposed on the singlet at 1.03).

Anal. Calcd for $C_{18}H_{18}N_4$: C, 74.45; H, 6.25; N, 19.30. Found: C, 74.0; H, 6.25; N, 19.3.

Reaction of 2 with Pyridinium Hydrobromide Perbromide. To a solution of 1.30 g (7.9 mmol) of **2**[1] in pyridine (10 ml) cooled at 0°, 3.70 g (11.8 mmol) of pyridinium hydrobromide perbromide[5] was added in small portions during 15 min. The reaction was allowed to reach room temperature, and pyridinium hydrobromide precipitated. After 1 hr, the mixture was poured into ice and extracted with pentane; the organic layer was washed with water, dried over $CaCl_2$, and evaporated, leaving 1.10 g of a semisolid. Distillation of this mixture at room temperature (0.1 mm) afforded 0.60 g (3.7 mmol) of **2** (collected in a trap at −196°). A pmr spectrum of the residue showed the presence of hexamethylbenzene (**9**) and *cis*-1,2,3,4,5,6-hexamethylcyclohexa-1,4-diene (**8**). The latter compound was isolated by preparative glc, 0.16 g (0.98 mmol, 12% yield): mass spectrum, parent peak at 164 *m/e;* uv (ethanol) λ_{max} 241 nm (log ϵ 3.05) [compare with *cis*-1,2,3,4,5,6-hexamethylcyclohexa-1,3-diene (**12**), λ_{max} 268,[15] and methyl-substituted cyclohexa-1,4-dienes,[16] no absorption above 250 nm]; pmr ($CDCl_3$) peaks at 2.39 (broad q, 2 H, $J = 7.0$ Hz), 1.60 (d, 12 H, $J = 0.5$ Hz), and 0.99 (broad d, 6 H, $J = 7.0$ Hz); cmr ($CHCl_3$) signals at 129.3 (s), 43.7 (d, $J_{C-H} = 120$ Hz), 20.4 (q, $J_{C-H} = 125$ Hz), and 17.1 (q, $J_{C-H} = 125$ Hz) ppm.

Anal. Calcd for $C_{12}H_{20}$: C, 87.73; H, 12.27. Found: C, 87.5; H, 12.1.

***cis,cis*-1,2,3,4,5,6-Hexamethylcyclohexenyl Cation (11).** Cation **11** was obtained from **1**, **2**, or **8** in $FHSO_3$-SbF_5 (1:1 or 10:1 molar ratios) with or without the use of a cosolvent (SO_2F_2 or SO_2). Solutions of **11** were prepared by addition of the acid mixtures to a solution of the precursor in SO_2F_2 (or SO_2) in a nmr tube kept cooled in liquid nitrogen. The tube was slowly warmed until stirring was possible, and spectra were recorded at various temperatures. Solutions of **11** showed pmr spectra identical with those of authentic species[10,12] at the same temperatures.

Acknowledgment. One of us (G.C.) wishes to acknowledge receipt of a grant from the Italian National Research Council (C.N.R., Rome).

References and Notes

(1) (a) H. Hogeveen, P. W. Kwant, and J. Thio, *Recl. Trav. Chim. Pays-Bas*, **93**, 152 (1974); (b) P. Tauchner and R. Hüttel, *Tetrahedron Lett.*, 4733 (1972).

(2) H. Hogeveen and J. Thio, *Tetrahedron Lett.*, 3463 (1973).

(3) (a) H. Hogeveen and P. W. Kwant, *J. Amer. Chem. Soc.*, **95**, 7315 (1973); (b) *ibid.*, **96**, 2208 (1974); (c) H. Hogeveen, P. W. Kwant, E. P. Schudde, and P. A. Wade, *ibid.*, **96**, 7518 (1974), and references cited therein.

(4) The parent bicyclo[2.1.1]hexyl cation has been reported by G. Seybold, P. Vogel, M. Saunders, and K. B. Wiberg, *J. Amer. Chem. Soc.*, **95**, 2045 (1973).

(5) L. F. Fieser and M. Fieser, "Reagents for Organic Synthesis," Wiley, New York, N.Y., 1967, p 967.

(6) H. Hogeveen and P. W. Kwant, *J. Org. Chem.*, **39**, 2624 (1974).

(7) W. L. Jorgensen and W. T. Borden, *J. Amer. Chem. Soc.*, **95**, 6649 (1973).

(8) W. T. Borden, private communication to H. H., June 1974.

(9) The cyclohexadiene **8** is also formed when a solution of **2** in $CHCl_3$ is treated with $AgClO_4$ at −50°. Because of the small spectral differences, **8** has previously been identified as **12**.[2]

(10) H. Hogeveen, C. J. Gaasbeek, and H. C. Volger, *Recl. Trav. Chim. Pays-Bas*, **88**, 379 (1969).

(11) H. Hogeveen and A. A. Kiffen, *Recl. Trav. Chim. Pays-Bas*, **91**, 1205 (1972).

(12) H. Hogeveen and H. C. Volger, *Recl. Trav. Chim. Pays-Bas*, **87**, 1047 (1968).

(13) C. H. De Puy, *Top. Cur. Chem.*, **40**, 73 (1973).

(14) H. Hogeveen, C. F. Roobeek, and H. C. Volger, *Tetrahedron Lett.*, 221 (1972).

(15) H. C. Volger and H. Hogeveen, *Recl. Trav. Chim. Pays-Bas*, **87**, 1356 (1968).

(16) W. Hückel and R. Cramer, *Justus Liebigs Ann. Chem.*, **630**, 100 (1960).