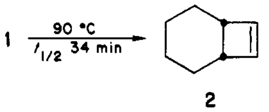

Attempted simulation of the racemization (MMP2) by incremental driving of the 1-2-3-4 angle in the stable form led to the cis,cis isomer with a barrier of 25.6 kcal/mol. Similar driving from the minor form led the same result with a 27.0 kcal/mol barrier. Assuming no activation entropy, this corresponds to rates similar to those for the **1** → **2** transformation. However, no complete exploration of the conformation space has been made, and lower energy paths leading to the enantiomer may exist.

Early theoretical and experimental studies of the relation between the absolute configuration and CD spectra of chiral cisoid 1,3-dienes, mostly 1,3-cyclohexadienes, led to the diene helicity rule,[27] stating that dienes with a positive dihedral angle (θ) between the double bonds (P helicity) have a positive rotational strength for the $N \rightarrow V_1$ and a negative value for the $N \rightarrow V_2$ transition. The CD spectrum of (−)-**1**, with the same sign for the first two bands, does not conform to this rule. In order to estimate to what extent the diene helicity contributes to the observed rotational strength, $|R| \geq 48 \times 10^{-40}$ cgs, for the first transition, the transition charge density was calculated by a CNDO/S-CI method[28] and scaled to conform to the oscillator strength derived from the UV spectrum. Calculation of R by the coupled oscillator model in the version of Schellman et al.[29] gave $R = 5.9 \times 10^{-40}$ cgs, positive for P helicity. With more advanced computations, Rauk and Peoples[30] obtained $R > 0$ for butadiene with P helicity but a minimum near zero for $\theta = +60°$. In a careful experimental and theoretical study of several 1,3-cyclohexadienes (θ ca. 17°), Lightner et al.[31] propose a subdivision of the rotational strength of the $N-V_1$ band into contributions from the various bonds. In this analysis the diene moiety gives a small negative contribution for P helicity, whereas an axial allylic bond gives a large positive (60×10^{-40} cgs) and the C5–C6 bond a large negative contribution (-52×10^{-40} cgs). In **1** with P helicity the C7–C8 bond is intermediate in orientation between an axial allylic and the C5–C6 bond in a 1,3-cyclohexadiene, and it can be assumed to give only a small contribution to R. Instead, the twisted trans double bond can be seen as the main source of rotational strength. The sense of twist is the same as in (−)-*trans*-cyclooctene,[32] in which the first strong transition has $R = -70 \times 10^{-40}$ cgs.[33,34] Our CNDO/S calculation supports the weight of this contribution, the transition dipole component along this bond being nearly 3 times stronger than the one along the *cis* double bond. We therefore propose that **1** with $R < 0$ for the $N \rightarrow V_1$ band, i.e., the first eluted enantiomer, has P helicity, although this admittedly is a rather crude approach. A safer assignment of the absolute configuration could be made by RPA calculations[35] or by an X-ray crystallographic study of a metal complex of **1** containing another chiral ligand of known configuration.

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Alkyl Group Migration in Photoinduced Cation Radical Reactions

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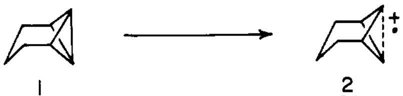
Recently, we have discussed in detail the ease with which an electron could be removed from the HOMOs of certain highly strained polycyclic molecules.[1,2] Electrochemical oxidations[1,2] and photosensitized single electron transfer reactions[3,4] proved to be very efficient in the conversion of highly strained saturated hydrocarbons into their corresponding cation radicals. Both experimental[1,3] and theoretical[2] studies of derivatives of bicyclo[1.1.0]butane indicated that removal of an electron from the HOMO of this system involved the central bond of the bicyclo[1.1.0]butane moiety. This was exemplified by the conversion of **1** to **2**. It was of interest that **2**, although extremely reactive, appeared to be relatively stable structurally.[5] In order to see if a major rearrangement[6] of a photogenerated cation radical could be induced on a preparative scale, **3** was prepared[10] and subjected to the conditions required for a photosensitized single electron transfer reaction. We now wish to report that **3** rapidly undergoes rearrangement to **4** under a variety of conditions which have previously been employed for the conversion of **1** to **2**.



1 2

Irradiation of a solution containing 1.35 g (7.5 mmol) of **3**, 0.76 g (5.0 mmol) of 1-cyanonaphthalene (1-CN), and 0.50 g of decane (as an internal GC standard) in 5.0 L of deoxygenated, dry tetrahydrofuran for 5 days in a Pyrex apparatus with a 450-W Hanovia medium-pressure mercury lamp gave a 58% yield of pure **4**.[11,12] The structure of **4** was established on the basis of spectral data and through independent synthesis from **7**. The ^{1}H NMR

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[4] Roth, H. D.; Schilling, M. L. M.; Gassman, P. G.; Smith, J. L. *J. Am. Chem. Soc.* **1984**, *106*, 2711.

[5] For preliminary indications that isomerization of **2** might occur; see ref 4.

[6] Numerous examples of photoinduced valence tautomerism via cation radical intermediates are known (e.g., quadricyclane to norbornadiene,[7] Dewar benzene to benzene[8]). However, we are aware of only one example of a major alkyl group migration and this involves a 1–3 allylic shift.[9a] For a recent example of a fragmentation reaction and leading references to electron transfer sensitized C–C bond cleavage, see ref 9b.

[7] Jones, G., II; Chiang, S.-H.; Becker, W. G.; Welch, J. A. *J. Phys. Chem.* **1982**, *86*, 2805 and references contained therein.

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[10] The synthesis of **3** involved (a) the reaction of [(trimethylsilyl)methyl]magnesium chloride with 3-bromocyclohexene to yield 3-[(trimethylsilyl)methyl]cyclohex-1-ene (**5**, 81% yield), (b) addition of dichlorocarbene to **5** to give *trans*-7,7-dichloro-2-[(trimethylsilyl)methyl]bicyclo[4.1.0]heptane (**6**, 69%), and (c) treatment of **6** with *n*-butyllithium to produce 2-[(trimethylsilyl)methyl]tricyclo[4.1.0.0^{2,7}]heptane (**3**, 56%). Satisfactory elemental analyses and/or exact mass molecular weights were obtained on all new compounds. All compounds prepared had ^{13}C NMR, ^{1}H NMR, and IR spectra that were consistent with the assigned structures.

[11] The use of either benzene or methanol as solvent also resulted in the formation of **4**. No trapping of intermediates by methanol was observed.

[12] Careful monitoring of yields by GC analysis showed that the yield of **4** was a function of the concentration of both **3** and 1-CN. When a tetrahydrofuran solution that was 1.31×10^{-3} M in **3** and 1.00×10^{-3} M in 1-CN was irradiated under the conditions indicated, an 82% yield of **4** was observed by GC analysis. Increasing the concentration of either **3** or 1-CN resulted in a systematic decrease in yield.

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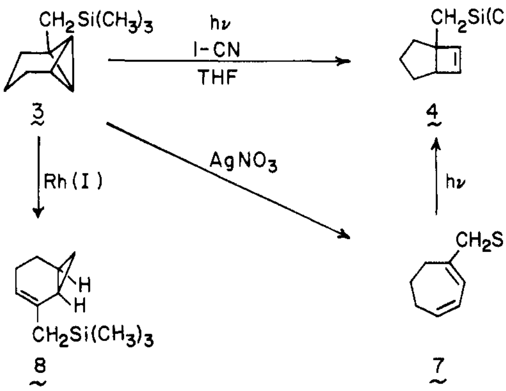
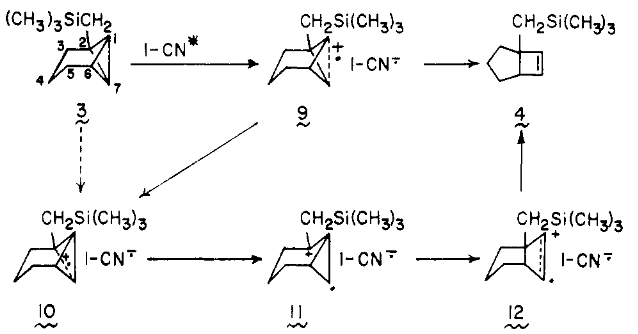


of 4 in C_6D_6 showed δ 5.91 (1 H, d, J = 2.7 Hz), 5.80 (1 H, d, J = 2.7 Hz), 2.64 (1 H, d, J = 6.9 Hz), 1.6–1.2 (6 H, m), 1.00 (2 H, m), and 0.04 (9 H, s), while the ^{13}C NMR showed δ 141.64 (d), 134.57 (d), 57.48 (s), 56.42 (d), 34.56 (t), 26.56 (t), 26.30 (t), 25.04 (t), and 0.29 (q).

In order to obtain an independent synthesis of 4, we desired 7. Treatment of 3 with (triphenylphosphine)carbonylrhodium chloride dimer failed to produce 7, giving instead 8. Fortunately, the use of silver nitrate in benzene readily converted 3 into a 3:2 mixture of 7 and 8, respectively.[13,14] The diene 7 was purified by chromatography and showed the expected NMR properties, in addition to λ_{max} cyclohexane 265 nm (log ϵ 3.48). Direct (nonsensitized) irradiation of 7 gave a 96% yield of 4.

The ease with which 7 was converted to 4 raised the question of whether 7 was an intermediate in the photosensitized conversion of 3 into 4. Several lines of evidence indicate that 7 did not play such a role. Although 7 was readily oxidized ($E_{1/2}$ = 0.86 V vs. SCE) and reacted with excited state 1-CN at a diffusion controlled rate to quench the fluorescence of 1-CN the sensitized irradiation of 7 gave only low yields of 4. While this would appear to rule out 7 as an intermediate, the evidence was not unequivocal, since it could not be rigorously established that 7 would not be converted to 4 in higher yield if 7 were present in only trace amounts at any instant. More definitive evidence against the intermediacy of 7 was obtained via a study of the quantum yields for the formation of 4 from both 3 and 7 under 1-CN-sensitized conditions in Pyrex and soft glass. The limiting quantum yields for the formation of 4 from 3 were 0.19 and 0.18 in Pyrex and soft glass, respectively. The corresponding values for the conversion of 7 to 4 in the presence of 1-CN were 0.05 and 0.09. Lastly, in soft glass, the quantum yield for the unsensitized formation of 4 from 7 was ca. 0.01 for 1.1×10^{-3} M 7 in tetrahydrofuran. No buildup of 7 could be detected in any of the reactions involving the photosensitized conversion of 3 into 4. Thus, the cumulative evidence indicated that 7 was not an intermediate in the photoconversion of 3 into 4.

Mechanistically, all evidence pointed to a single electron transfer process. No photoreaction occurred in the absence of 1-CN. In addition, the easily oxidized ($E_{1/2}$ = 1.37 V vs. SCE) hydrocarbon 3 quenched the fluorescence of 1-CN at a diffusion-controlled rate ($k_q = 1.4 \times 10^{10}$ L/mol/s) in tetrahydrofuran. On the basis of earlier precedent,[3,4] we would propose that a tight cation radical–anion radical pair involving 9 and the radical anion of 1-CN was formed. "Leakage" of 9 to 10,[15] followed by opening of 10, would give 11.[16] Ample precedent for the closed and open forms of a cation radical exists in the recent work of Williams and co-workers.[17] Cyclopropylcarbinyl to cyclobutyl rearrangement of 11 to 12, followed by back electron transfer from 1-CN anion radical to 12 would then produce 4.[18]



We are continuing to explore the chemistry of cation radicals generated from highly strained ring systems.

Acknowledgment. We are indebted to the National Science Foundation for support of this investigation.

Registry No. 3, 96503-08-1; **4**, 96503-09-2; **5**, 56432-00-9; **6**, 96532-34-2; **7**, 96503-10-5; **8**, 96503-11-6; [Rh(CO)Cl(PPh$_3$)]$_2$, 34676-63-6; AgNO$_3$, 7761-88-8; 1-CN, 86-53-3; [(trimethylsilyl)methyl]magnesium chloride, 13170-43-9; 3-bromocyclohexene, 1521-51-3; dichlorocarbene, 1605-72-7; 2-methylbicyclo[4.1.0]hept-2-ene, 53262-14-9.

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[13] Acid-catalyzed rearrangement of 3 gave 2-methylbicyclo[4.1.0]-hept-2-ene.

[14] A nonphotochemical, Lewis acid catalyzed isomerization of the tricyclo[4.1.0.0^{2,7}]heptyl ring system to the bicyclo[3.2.0]hept-6-enyl ring system has previously been reported: Gassman, P. G.; Atkins, T. J. *J. Am. Chem. Soc.* **1972**, *94*, 7748.

[15] The possibility of the direct conversion of 3 into 10 must also be considered. Theoretical calculations on simple bicyclo[1.1.0]butane derivatives indicate that carbocation stabilizing groups in the 2-position of a bicyclo-[1.1.0]butane do not result in the HOMO shifting from its association with the central bond.[2] Comparison of the ease of oxidation of 3 ($E_{1/2}$ = 1.37 V vs. SCE) to that of 1 ($E_{1/2}$ = 1.50 V vs. SCE)[3] indicated that the addition of the (trimethylsilyl)methyl group of 1 had relatively little effect on the energy of the HOMO.

[16] We cannot rule out the possible conversion of 9 to an "open" cation radical followed by a cyclobutyl to cyclpropylcarbinyl rearrangement of the open form of 9 to produce 11.

[17] Qin, X.-Z.; Snow, L. D.; Williams, F. *J. Am. Chem. Soc.* **1984**, *106*, 7640. See also: Roth, H. D.; Schilling, M. L. M. *J. Am. Chem. Soc.* **1980**, *102*, 7956; **1983**, *105*, 6805.

[18] Back electron transfer could also occur prior to the rearrangement of 11 to 12. However, this would require that the intermediate zwitterion (or diradical) rearrange rather than reform the C_2–C_7 bond.

Prooxidant Effects of Glutathione in Aerobic Hemoglobin Solutions. Superoxide Generation from Uncoordinated Dioxygen

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Glutathione (GSH), the tripeptide Glu-Cys-Gly, is found widely in nature at relatively high concentrations.[1,2] Intracellular concentrations range from 0.5 to 10 mM in mammalian cells.[3] In human red blood cells the thiol GSH is normally ca. 2 mM and the disulfide GSSG 0.0035 mM.[4] The GSH redox cycle (GSH peroxidase–GSSG reductase) provides cells with important protection against oxidant damage from H_2O_2.[5] GSH generally limits chemically induced injury to cells and tissues[6] and is also considered highly effective as an antioxidant, e.g., by reacting directly with free radicals.[7] However, we find that the addition

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[2] "Functions of Glutathione: Biochemical, Physiological, Toxicological, and Clinical Aspects"; Larsson, A., Orrenius, S., Holmgren, A., Mannervik, B., Eds.; Raven Press: New York, 1983.

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[7] Moldéus, P.; Jernström, B., ref 2, pp 99–108. Meister, A. *Hepatology (Baltimore)* **1984**, *4*, 739–742. Siems, W.; Mielke, B.; Müller, M.; Heumann, C.; Räder, L.; Gerber, G. *Biomed. Biochim. Acta* **1983**, *42*, 1079–1089.

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