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Highly Pyramidalized Alkenes

Generation, Trapping, and Dimerization of Pentacyclo[6.4.0.$0^{2,10}$.$0^{3,7}$.$0^{4,9}$]dodeca-5,8,11-triene: An Uncatalyzed Thermal [2+2+2+2] Cycloaddition**

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Pyramidalized alkenes are compounds that contain carbon–carbon double bonds in which one or both of the sp^2-hybridized carbon atoms does not lie in the same plane as the attached atoms.[1] Such alkenes are interesting targets for both synthetic and theoretical organic chemists owing to their intriguing physical properties and fascinating reactivity.[2] In recent years, we have been engaged in the synthesis, chemical trapping, dimerization, and cross-coupling of several highly pyramidalized alkenes that contain the bisnoradamantane skeleton.[3]

Herein we report the generation of pentacyclo[6.4.0.$0^{2,10}$.$0^{3,7}$.$0^{4,9}$]dodeca-5,8,11-triene (**4**), its trapping with 1,3-diphenylisobenzofuran, and its unusual dimerization to the polycyclic compound **6** by an uncatalyzed thermal [2+2+2+2] cycloaddition process with formation of four new carbon–carbon bonds (Scheme 1).

Previous work in this field showed that vicinal diiodo compounds are suitable precursors for highly pyramidalized alkenes,[2,3] so the generation of **4** was envisioned from the diiodo derivative **3**, whose preparation from the known compound **1** appeared to be straightforward.[4] The double bisdehydroxylation of **1** to **3** was accomplished by following the procedure of Eastwood et al.[5] Reaction of **1** with neat *N*,*N*-dimethylformamide dimethyl acetal gave bis(dimethylformamide cyclic acetal) **2** as a mixture of diastereomers. Heating **2** with acetic anhydride yielded **3** as a white solid in 83% overall yield. As expected, reaction of **3** with *tert*-butyllithium in THF at −67 °C in the presence of 1,3-

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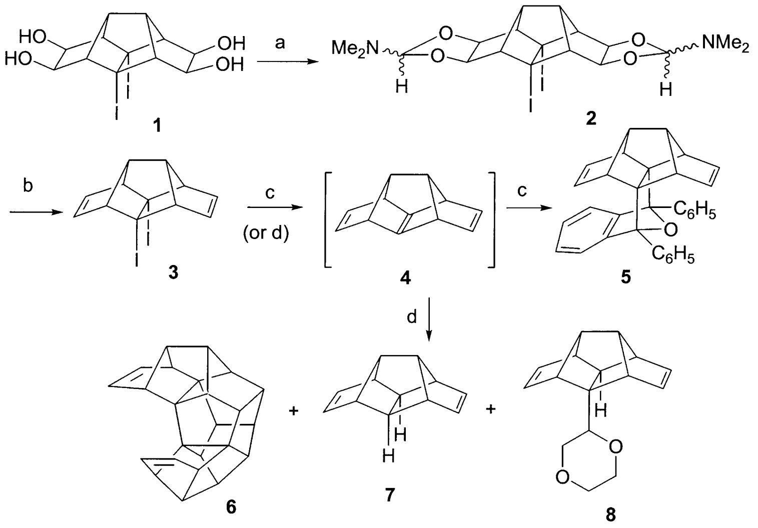
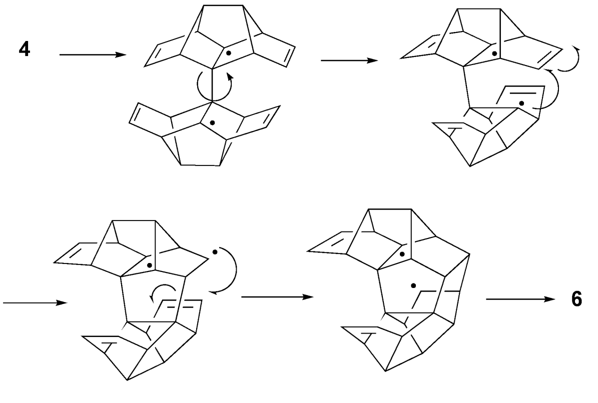


Scheme 1. Generation, trapping, and dimerization of triene **4**. a) $(MeO)_2CHNMe_2$, Δ; b) Ac_2O, reflux, 16 h, 83% of **3** from **1**; c) *t*BuLi, THF, 1,3-diphenylisobenzofuran, −67 °C, 63% of **5**. d) Na, dioxane, reflux, 4 h, 24% yield of pure **6**.

diphenylisobenzofuran gave Diels–Alder adduct **5** (63% yield). Reaction of **3** with 8 equivalents of molten sodium in 1,4-dioxane under reflux for 4 h gave a mixture of three main products (GC–MS). The product eluted first ($t_r = 12.7$ min, $M = 156$, 19.5% area ratio) corresponded to the known reduction product **7** (^{1}H NMR);[6] according to our previous results on related substrates,[4] the second product ($t_r = 22.9$ min, $M = 242$, 15.3% area ratio) could be **8**, derived from the addition of the intermediate pyramidalized alkene and the solvent (1,4-dioxane), and the third product ($t_r = 29.3$ min, $M = 308$, 62.6% area ratio) is a dimer of **4**. Column chromatography of this mixture (neutral aluminum oxide, hexane), allowed us to isolate dimer **6** in 24% yield. The ^{1}H and ^{13}C NMR spectra of this dimer showed the lack of the C_{2v} symmetry characteristic of the expected cyclobutane or derived dimers,[3,4] and the presence of C_2 symmetry, which led us to propose structure **6**, in which the two halves are orthogonally fused. X-ray diffraction analysis unequivocally established **6** as the structure of the isolated dimer.[7]

Dimer **6** is the result of a [2+2+2+2] cycloaddition of two molecules of triene **4**. A possible mechanism for the dimerization of **4** to **6** is shown in Scheme 2. Two units of **4** are first connected by forming a C–C single bond and, after rotation around the new C–C bond, a cascade radical process would give dimer **6** with formation of four new C–C bonds and three new rings.



Scheme 2. Possible pathway for the dimerization of **4**.

This proposal was based on a) the fact that, some time ago, Eaton and Lukin provided the first demonstration of the intermediacy of biradicals in the dimerization of strained olefins by using 1-iodoadamantane as a probe in the dimerization of cubene,[2a] and b) the biradical character of 11% for **4**, calculated by using the two-configuration self-consistent field (TCSCF) procedure of Gaussian 98[8] and the 6-31G(d) basis set with the HF/6-31G(d) optimized geometry.

The first [2+2+2+2] cycloaddition was discovered 55 years ago by Reppe, and several additional examples were described later.[9] All these reactions are stepwise processes catalyzed by complexes of Ni,[9] Fe, Mo, or Rh.[10] Although a pericyclic process of the type $[_{\pi}2_s+_{\pi}2_s+_{\pi}2_s+_{\pi}2_s]$ is not thermally allowed according to the Woodward–Hoffman rules, photochemically it would be allowed. However, to the best of our knowledge, examples of [2+2+2+2] cycloadditions in the absence of a metal catalyst, either thermally or photochemically induced, have never been described, with the exception of the tetramerization of 1,2-cyclohexadiene to give, among other products, two isomeric cyclooctane derivatives.[11]

In conclusion, the dimerization of the highly pyramidalized alkene **4**[12] to its dimer **6** described herein is a unique example of an uncatalyzed thermal [2+2+2+2] cycloaddition. Moreover, this type of process may be extended to more complex transformations; for instance, the dimerization of a triquinacene derivative that contains a highly pyramidalized C=C bond with its opened face in an *endo* arrangement could provide a dodecahedrane derivative by a [2+2+2+2+2+2] cycloaddition, a type of transformation that many have tried without success till now with triquinacene and numerous triquinacene derivatives under different reaction conditions.

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[7] Crystal data of **6**: A prismatic crystal was selected and mounted on an Enraf-Nonius CAD4 four-circle diffractometer. Unit-cell parameters were determined from automatic centering of 25 reflections ($12 < \theta < 21°$) and refined by the least-squares method. Intensities were collected with graphite-monochromated Mo$_{K\alpha}$ radiation by using the $\omega/2\theta$ scan technique. 2195 reflections were measured in the range $2.92 = \theta = 29.97°$, 2090 of which were nonequivalent by symmetry (R_{int}(on I) = 0.026) and 1111 reflections were assumed as observed ($I > 2\sigma(I)$). Three reflections were measured every 2 hours as orientation and intensity control; significant intensity decay was not observed. Corrections were made for Lorentzian polarization but not for absorption. The structure was solved by direct methods with the SHELXS computer program (G. M. Sheldrick, *Acta Crystallogr. Sect. A* **1990**, *46*, 467–473) and refined by full-matrix least-squares methods with the SHELX97 computer program (G. M. Sheldrick, SHELX-97, A computer Program for the Determination of Crystal Structure, University of Göttingen, Göttingen, Germany, **1998**), using 2090 reflections (very negative intensities were not assumed). The function minimized was $\Sigma w ||F_o|^2 - |F_c|^2|^2$, where $w = [\sigma^2(I) + (0.0728P)^2]^{-1}$, and $P = (|F_o|^2 + 2|F_c|^2)/3$, f, f' and f'' were taken from the literature (*International Tables of X-ray Crystallography, Vol. IV* (Eds.: J. A. Ibers, W. C. Hamilton), Kynoch, Birmingham, **1974**, pp. 99–100, 149). All H atoms were located from a difference synthesis and refined with an overall isotropic temperature factor. GOF = 0.950 for all observed reflections. Max. shift/esd = 0.00, mean shift/esd = 0.00, max./min. peaks in final difference synthesis: 0.248/–0193 e Å^{-3}. $C_{24}H_{20}$, $M_r = 308.40$, monoclinic, space group $C2/c$, $a = 16.268(2)$, $b = 7.718(3)$, $c = 11.686(2)$ Å, $\alpha = 90$, $\beta = 93.85(2)$, $\gamma = 90°$, $V = 1463.9(6)$ Å^3, $Z = 4$, $F(000) = 656$, $\rho_{calcd} = 1.399$ g cm^{-3}; crystal dimensions, $0.1 \times 0.1 \times 0.2$ mm; $\mu(\text{Mo}_{K\alpha}) = 0.079$ mm^{-1}; Mo$_{K\alpha}$ radiation ($\lambda = 0.71069$ Å), $T = 293(2)$ K; 2090 reflections and 131 parameters were used for the full matrix, least-squares refinement on F^2, $R1 = 0.0571$, and $wR2 = 0.1184$. CCDC-199680 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB21EZ, UK; fax: (+44) 1223-336-033; or deposit@ccdc.cam.ac.uk).

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[12] The pyramidalization angle Φ of the C8–C9 double bond of **4** was calculated to be 62.6 and 63.7° at the B3LYP6-31G(d) and MP2/6-31G(d) levels, respectively, by using the Gaussian 98 program,[8] in good agreement with values previously calculated for related highly pyramidalized alkenes that contain the tricyclo[3.3.0.0^{3,7}]oct-1(5)-ene skeleton.[3d]