High-Energy Cage Compounds

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Octacyclopropylcubane and Some of Its Isomers**

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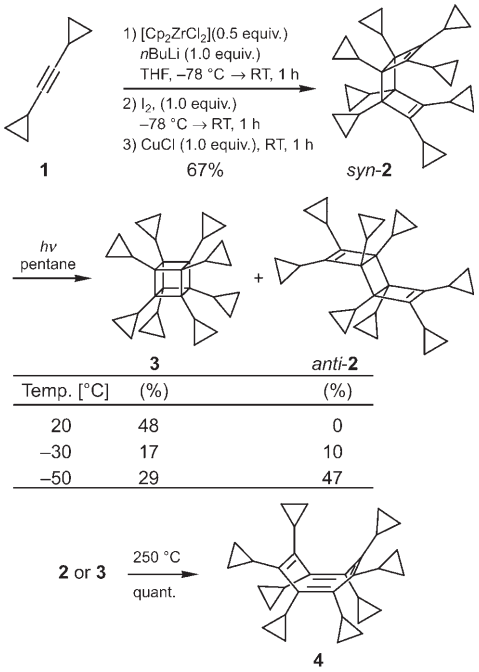
Dedicated to Professor Philip E. Eaton on the occasion of his 70th birthday

When first synthesized in 1964 by Eaton et al., cubane was an extreme novelty.[1] In the past 40-odd years, however, numerous substituted cubanes have been prepared, either by interconversions of other cubane derivatives or by photoisomerization of substituted *syn*-tricyclooctadienes.[2] The latter approach is particularly suitable for symmetrically octasubstituted cubanes, as has been demonstrated in particular by Gleiter et al.[3] Nevertheless, octanitrocubane had to be prepared along a unique multistep route.[4] Recently, we came across a facile access to octacyclopropyl-*syn*-tricyclo[4.2.0.0^{2,5}]octa-3,7-diene (*syn*-**2**),[5] and here we report its conversion to octacyclopropylcubane (**3**) as well as some chemical and physical properties of the latter.

Adopting a protocol of Takahashi et al.,[6] we reacted dicyclopropylacetylene (**1**)[7] with zirconocene dichloride and *n*-butyllithium, and the reaction mixture was then treated with iodine and subsequently cuprous chloride to furnish, by Diels–Alder-type dimerization of the intermediate tetracyclopropylcyclobutadiene, *syn*-**2** in 67% yield. A solution of *syn*-**2** in pentane was irradiated with a medium-pressure mercury lamp in a quartz sleeve at ambient temperature to give octacyclopropylpentacyclo[4.2.0.0^{2,5}.0^{3,8}.0^{4,7}]octane (**3**) in 48% yield (Scheme 1). When the irradiation was carried out at lower temperatures (−30 and −50 °C), significant amounts of the *anti*-tricyclo[4.2.0.0^{2,5}]octa-3,7-diene (*anti*-**2**) (10 and



Temp. [°C]	3 (%)	anti-2 (%)
20	48	0
−30	17	10
−50	29	47

Scheme 1. Preparative accesses to octacyclopropylcubane and some of its isomers.

47%, respectively) were formed along with the cubane **3**. The *syn* and *anti* isomers of **2** can be clearly distinguished by their ^{1}H and ^{13}C NMR spectra. The structures of *anti*-**2** and **3** in the crystals were established by X-ray diffraction (Figure 1).[8] The orientation of the eight cyclopropyl substituents in **3** is such that the overall symmetry of the molecule in the crystal is

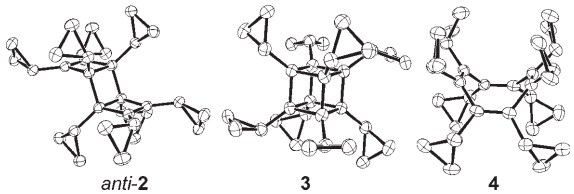


Figure 1. Structures of *anti*-**2**, **3**, and **4** in the crystals.[8]

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C_{4h}. The bonds in the cubane core of **3** with an average length of 158.3 pm are slightly, yet distinctly longer than those in cubane itself (156.5 pm in the gas phase,[9] 155.1 pm in the crystal[10]). In spite of this bond lengthening in **3** and its tremendous overall strain of 390 kcal mol^{-1} (166 kcal mol^{-1} for the core[2] and 224.8 kcal mol^{-1} for eight cyclopropyl groups), octacyclopropylcubane **3** has a half-life of $\approx$3 h at 250 °C. Without melting at temperatures of up to 300 °C, it rearranges in the solid state to octacyclopropylcycloocta-1,3,5,7-tetraene (**4**), as can be monitored by ^{1}H NMR spectroscopy. In the differential scanning calorimetry (DSC) curve, at a heating rate of 5 K min^{-1}, this process manifests itself with two exotherme peaks at 300 and 308 °C, the first one probably corresponding to an initial rearrangement of **3** to *syn*-**2**, which then opens up to **4**. Compared to cubane itself, which has a half-life of 24 min at 250 °C,[10] **3** experiences remarkable kinetic stabilization, and this must be a consequence of the steric encumbrance exerted on the core by the eight surrounding cyclopropyl groups.[12] Yet, the eight cyclopropyl groups are not that close to each other that their internal rotation could be frozen down to −100 °C.[13]

The *syn*- and *anti*-tricyclooctadienes *syn*-**2**/*anti*-**2**, when heated at 250 °C, also rearrange in the solid state to yield **4**.[14] the cyclooctatetraene **4** could be recrystallized from methanol and its structure proved by X-ray crystallography (Figure 1).[8]

Octacyclopropylcubane **3**, unlike cubane itself,[2] is stable towards $AgClO_4$, $AgBF_4$, and [{Rh(cod)Cl}$_2$] (cod = cyclooctadiene) even at 80 °C. This is an apparent consequence of a significantly higher oxidation potential of **3**. While cubane in acetontrile has an oxidation half-wave potential $E_{1/2}$ vs. SCE of +1.73 V, the octacyclopropyl derivative **3** is irreversibly oxidized at +1.91 V vs. SCE.[15] Apparently, the eight cyclopropyl groups in **3**, owing to the enhanced electronegativity of their carbon atoms,[16] only exert a σ-electron-withdrawing effect on the cubane core.

In conclusion, the decoration of cubane with eight cyclopropyl groups not only leads to an esthetically appealing molecule which has an impressive overall strain energy, but also a remarkable kinetic stability. In fact, the steric effect of eight cyclopropyl groups apparently even favors the formation of the cubane skeleton from the correspondingly substituted *syn*-tricyclo[4.2.0.0^{2,5}]octa-3,7-diene (*syn*-**2**). Whereas **3** could be isolated in 48% yield, octamethyl- and octaethylcubane were obtained by irradiation of the corresponding *syn*-tricyclooctadienes in only 1 and 2% yield, respectively.[3] The highest yield previously (20%) had been achieved for the preparation of octa(trifluoromethyl)cubane from the respective *syn*-tricyclooctadiene.[17]

Experimental Section

syn-**2**: A solution of dicyclopropylethyne (**1**) (1.00 g, 9.42 mmol) and zirconocene dichloride (1.38 g, 4.72 mmol) in 30 mL of anhydrous tetrahydrofuran was cooled to −78 °C, and a solution of *n*-butyllithium in *n*-hexane (4.20 mL, 2.35 M, 9.89 mmol) was added dropwise. The cooling bath was removed, and the mixture was stirred for 1 h while warming up. The resulting red solution was cooled to −78 °C, and iodine (1.20 g, 4.72 mmol) was added in one portion. The reaction mixture was stirred for 1 h, while it warmed up after removal of the cooling bath. CuCl (467 mg, 4.72 mmol) was then added at ambient temperature in one portion, and the mixture was stirred for an additional 1 h. After that, 50 mL of sat. Na_2SO_3 solution was added, and the aqueous phase was extracted with Et_2O (3 × 15 mL). The combined organic phases were washed with 30 mL of sat. NaCl solution and dried over $MgSO_4$, and the solvents were removed under reduced pressure. The residue was purified by column chromatography on silica gel (65 g, column 3 × 21 cm), eluting with pentane, and subsequent recrystallization from pentane/ethyl acetate to give 670 mg (67%) of *syn*-**2** as colorless crystals, m.p. >250 °C (decomp.). UV (0.131 mg/10 mL of hexane): λ = 210 nm (end absorption, ε(210) = 634), 234 (shoulder, ε = 341). ^{1}H NMR (600 MHz, $CDCl_3$): δ = 0.38 (m_c, 8H, CH_2), 0.50 (m_c, 4H, CH_2), 0.56 (m_c, 16H, CH_2), 0.81 (m_c, 4H, CH_2), 1.08 (tt, 4H, J = 5.6, J = 8.6 Hz, CH), 1.16 ppm (tt, 4H, J = 5.5, J = 8.5 Hz, CH). ^{13}C NMR (125 MHz, $CDCl_3$, attached-proton test (APT)): δ = 3.1 (−, 4 C, cPr-C), 4.5 (−, 4 C, cPr-C), 6.6 (−, 4 C, cPr-C), 6.9 (−, 4 C, cPr-C), 10.1 (+, 4 C, cPr-C), 10.9 (+, 4 C, cPr-C), 55.6 [C_{quat}, 4 C, C-1(6), C-2(5)], 142.6 ppm [C_{quat}, 4 C, C-3(4,7,8)].

3: A solution of *syn*-**2** (117 mg) in 50 mL of pentane was irradiated in a 50-mL photochemical reactor with a quartz cooling sleeve with a 450-W medium-pressure mercury lamp and external and internal cooling at 20 °C for 3 h. After evaporation of the solvent and column chromatography on silica gel (10 g, R_f = 0.67) 56 mg (48%) of **3** was isolated[18] as colorless crystals, m.p. >300 °C (decomp.). ^{1}H NMR (600 MHz, $CDCl_3$): δ = 0.88 (tt, J = 5.64, 8.57, 8H, CH, M part of an AA′BB′M system), 0.61 (m_c, 16H, CH_2), 0.39 ppm (m_c, 16H, CH_2). ^{13}C NMR (125 MHz, $CDCl_3$, APT): 3.6 (−), 8.8 (+), 56.0 ppm (C_{quat}). MS (EI, 70 eV): 424 (100), 383 (49), 355 (47), 327 (27), 299 (42), 269 (65), 257 (66), 243 (73), 229 (70), 205 (65), 179 (59), 165 (69), 141 (54), 129 (65), 105 (52), 91 (98), 79 (60), 55 (50), 41 (58).

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[14] The DSC curves of *syn*- and *anti*-**2** actually display significant differences. While the curve of *anti*-**2** shows an exotherme at 225 °C, the latter probably corresponding to the rearrangement of *anti*-**2** into **4**, that of *syn*-**2** displays a more substantial exotherme at 178 °C in addition to a small exotherme at 222 °C. This may be taken to indicate that *syn*-**2** first isomerizes to another isomer—possibly octacyclopropylsemibullvalene—which in turn rearranges to **4**.
[15] For the cyclic voltammetry of **3**, an Autolab potentiostat with a three-electrode cell was used (glassy carbon disc working electrode, platinum wire auxiliary electrode, AgCl reference electrode). All measurements were carried out at room temperature in a 1:1 mixture of benzene and acetonitrile, using nPr$_4$NBF$_4$ as the auxiliary electrolyte. Ferrocene/ferrocenium redox couple was used as an external standard. Sweep rates of 0.01 mV to 1 V s^{-1} were employed, but within this range no corresponding reduction wave was observed.
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