

1 **Dimerization of Pyramidalized 3,4,8,9-Tetramethyltetracyclo [4.4.0.03,9.04,8]dec-1(6)-ene to a**  
2 **Hydrocarbon Featuring Four Cyclohexane Rings in Boat Conformations\*\***  
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41 **ABSTRACT**

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43 The synthesis, chemical trapping, and dimerization of a highly pyramidalized alkene is reported. Its  
44 dimer is a unique nonacycle featuring three planar cyclobutane rings, four cyclopentane rings, and four  
45 cyclohexane rings in boat conformations. The X-ray diffraction analysis showed a H–H distance  
46 between the flagpole hydrogen atoms of 1.999 Å and a separation of 2.619 Å between the two flagpole  
47 carbon atoms. The three cyclobutane rings of the dimer were thermally stable

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57 Pyramidalized alkenes are compounds containing carbon–carbon double bonds in which one or both of  
58 the sp<sup>2</sup>-carbon atoms do not lie in the same plane as the attached atoms.[1] We have reported the  
59 generation, trapping, and dimerization of several highly pyramidalized alkenes and the first  
60 crosscoupling of two different pyramidalized alkenes leading to a tetrasecododecahedradiene  
61 derivative.[1c, 2, 3] Herein, we report the generation of 4 (Scheme 1), a novel highly pyramidalized  
62 alkene, its trapping with 1,3-diphenylisobenzofuran, and its dimerization to a unique polycyclic  
63 hydrocarbon, 7, which features three planar cyclobutane rings, four cyclopentane rings, and four  
64 cyclohexane rings in a boat conformations.

65 Theoretical calculations using B3LYP/6-31G(d) showed us that the alkene 4 should be an accessible  
66 target.[4] Its calculated pyramidalization angle ( $F=47.58$ ),[5] carbon–carbon double bond length (1.360  
67 Å), heat of hydrogenation (-63.7 kcalmol<sup>-1</sup>), HOMO–LUMO gap (5.64 eV), and predicted <sup>13</sup>C NMR  
68 chemical shift ( $d=148.4$  ppm) were in line with the values calculated for previously synthesized highly  
69 pyramidalized alkenes.[1c, 6]

70 It is known that vicinal diiodo compounds are suitable precursors of highly pyramidalized alkenes, so  
71 the generation of 4 was envisioned from the diiodo derivative 3 (Scheme 1), whose preparation from the  
72 known anhydride 1[7] was carried out in just two steps. Saponification of 1 gave the dicarboxylic acid 2  
73 in 70% yield. The diiodo compound 3 was obtained in 27%yield by using a iododecarboxylation  
74 procedure recently reported by Gandelman and co-workers.[8] Previous attempts to carry out the  
75 iododecarboxylation of 2 using iodosobenzene diacetate or lead tetraacetate gave even lower yields of 3.  
76 Reaction of 3 with tert-butyllithium in THF at -67°C in the presence of 1,3-diphenylisobenzofuran  
77 furnished the expected Diels–Alder adduct 5 in 37%yield. Finally, reaction of 3 with a large excess of  
78 molten sodium in 1,4-dioxane at reflux for 4 hours gave a mixture of three products (GC/MS): the  
79 reduced product 6, the expected dimer 7, and the dihydrodimer 8. From this mixture, 6 was isolated by  
80 sublimation (100 °C at 1 Torr), 7 was obtained by crystallization from n-pentane, and 8 was obtained  
81 from the mother liquors. X-Ray diffraction analysis unequivocally established the structures of 7 and  
82 8.[9]

83 The X-ray diffraction analysis of 7 revealed several interesting features. Firstly, 7 has three planar  
84 cyclobutanes, two of them with four eclipsed methyl groups. While the central cyclobutane is not a fully  
85 perfect square, as it has two newly formed carbon–carbon bonds being slightly shorter than the other  
86 two bonds, the other two cyclobutanes are nearly perfect squares (see Figure 1). Secondly, the  
87 compound has four cyclopentane rings in a “frozen” envelope conformation. Finally, the structure  
88 features four cyclohexane rings in a boat conformation. Although there are several precedents of  
89 cyclohexane rings in boat conformations,[10] most of the known examples lack the typical H–H  
90 flagpole interaction of the boat conformation (e.g. camphor and other norbornane derivatives).[11] Some  
91 notable exceptions with frozen boat cyclohexanes, featuring a H–H flagpole interaction, are the  
92 asteranes, such as tetracyclo [3.3.1.0<sub>2,8</sub>.0<sub>4,6</sub>]nonane (triassterane; 9)[12] tricyclo[3.1.1.1<sub>2,4</sub>]octane  
93 (diasterane; 10),[12d, 13] and pentacyclo[6.4.0.0<sub>2,7</sub>.0<sub>4,11</sub>.0<sub>5,10</sub>]dodecane (tetraasterane; 11),[12a,d,  
94 14, 15] and tetracyclo[5.3.1.1<sub>2,6</sub>.0<sub>4,9</sub>]dodecane (iceane; 12),[16] a polycyclic compound featuring two  
95 chair and three boat cyclohexane rings (Figure 2). Interestingly, the cyclobutane rings of these  
96 polycyclic compounds can be either planar, as in 7 and 11, or puckered as in 10.

97 According to a seminal paper by Hassel and Ottar,[17] the boat conformer of the cyclohexane ring with  
98 fixed C–C–C angles of 109.5° would have a distance between the flagpole hydrogen atoms of 1.8–1.83 Å  
99 and a separation of 2.57 Å would be expected between the flagpole carbon atoms. These distances  
100 should induce severe steric congestion given the van der Waals radius of hydrogen and carbon, 1.1–1.2  
101 Å and 1.7–1.8 Å, respectively.[18] In fact, Sauers has found, using density functional calculations at the  
102 B3LYP/6-311++G(2d,p) level of theory, that the boat conformer of cyclohexane suffers from significant  
103 distortions from pure sp<sup>3</sup> hybridization, thus relieving the flagpole H–H interaction at an interatomic

104 separation of 2.353 Å and with a distance of 2.736 Å between the two flagpole carbon atoms.[11a] In  
105 this work, for the boat conformer of cyclohexane, we have found smaller distances using MP2/6-  
106 31G(d): 2.289 Å and 2.710 Å for the flagpole H–H and C–C interatomic distances, respectively.[4]

107 However, in the polycyclic compounds shown in Scheme 1 the ability of the boat cyclohexanes to  
108 relieve the flagpole H–H interaction is severely limited. Thus, the X-ray diffraction analysis of 7  
109 revealed a distance between the flagpole hydrogen atoms of only 1.999 Å and a separation of 2.619 Å  
110 between the flagpole carbon atoms. We have optimized the structure of 7 at the MP2/6-31G(d) level of  
111 theory and found distances of 2.042 Å and 2.668 Å for the flagpole H–H and C–C distances,  
112 respectively, and they are in reasonable agreement with the experimental values. At this level, these  
113 distances are shorter than the corresponding values found in 9, 11, and 12, but longer than those of 10  
114 (Table 1).[4]

115 Regarding the X-ray diffraction analysis of 8 two features are worthy of comment. Firstly, values  
116 between 1.93 and 2.03 Å were found for the distance between the flagpole hydrogen atoms, while an  
117 average value of 2.64 Å was found between the flagpole carbon atoms, very similar to the values found  
118 for 7. These values are also very similar in the X-ray diffraction structures found for 1, 3, and 5.[9]  
119 Secondly, the exocyclic intercage C–C bond length of 8 is 1.539(3) Å, the normal length for a C–C single  
120 bond, midway between the very short intercage C–C bond found in tetrahedranyltetrahedrane and  
121 bicubyl derivatives, which feature significantly shorter distances (around 1.44–1.46 Å),[19] and that of  
122 the 1-(1-adamantyl)adamantine (1.578(2) Å).[20]

123 Previously, we had observed that several cyclobutane dimers of highly pyramidalized alkenes underwent  
124 an exothermic [2+2] retrocycloaddition process to their corresponding diene isomers.[1, 3d] However,  
125 the three cyclobutane rings in 7 were thermally stable. In fact, the only process that was observed when  
126 a sample of 7 was heated up to 500°C was the melting process at 380°C. MP2/6-311++G(d,p)//MP2/6-  
127 31G(d) calculations carried out on 7 and its three theoretical diene isomers, 13, 14, and 15, predicted  
128 endothermic processes for all the ring-opening reactions, with the transformation of 7 into 13 being  
129 more endothermic, 17.8 kcal/mol, than the opening to 14 or 15, 11.5 and 11.4 kcal/mol, respectively,  
130 thus probably reflecting the increase in the strain in 13 as a consequence of the approaching of the  
131 eclipsed methyl groups (Scheme 2).[4]

132 In summary, we have presented here the synthesis, chemical trapping, and dimerization of a highly  
133 pyramidalized alkene. Its dimer features three planar cyclobutane rings and four cyclohexane rings in  
134 boat conformations. X-ray structural studies and theoretical calculations showed that the distances  
135 between the flagpole hydrogen atoms and the flagpole carbon atoms are smaller than the sum of the van  
136 der Waals radius of the involved atoms. Finally, in spite of the three cyclobutane rings, and in sharp  
137 contrast with the behavior of previously described dimers of highly pyramidalized alkenes, the  
138 nonacycle 7 is thermally stable.

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141 **Keywords:** ab initio calculations · dimerization · hydrocarbons · polycycles · strained molecules

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145 **EXPERIMENTAL SECTION**

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147 3,4,8,9-Tetramethyltetracyclo[4.4.0.03,9.04,8]decane-1,6-dicarboxylic acid (2): A solution of the  
148 anhydride 1 (270 mg, 1.03 mmol) in 1n NaOH (10 mL) was heated to reflux for 18 h. The suspension  
149 was allowed to cool down to room temperature, was acidified with 6n HCl, and extracted with EtOAc (3  
150  $\square$  50 mL). The organic phase was dried over anhydrous Na<sub>2</sub>SO<sub>4</sub> and concentrated under reduced  
151 pressure to give 2 (203 mg, 70% yield) as a colorless solid, m.p. 209–2108C. <sup>1</sup>H NMR (400 MHz,  
152 [D<sub>6</sub>]DMSO):  $\delta$ =0.92 (s, 12H, 3(4,8,9)-CH<sub>3</sub>), 0.98 [d, J=11.6 Hz, 4H, 2(5,7,10)-Ha], 1.97 ppm [d,  
153 J=11.6 Hz, 4H, 2(5,7,10)-Hb]; <sup>13</sup>C NMR (100.6 MHz, CD<sub>3</sub>OD):  $\delta$ = 15.7 [CH<sub>3</sub>, 3(4,8,9)-CH<sub>3</sub>], 43.5  
154 [CH<sub>2</sub>, 2(5,7,10)-CH<sub>2</sub>], 46.4 [C, 3(4,8,9)-C], 53.7 [C, 1(6)-C], 179.1 ppm (C, CO<sub>2</sub>H); IR (KBr):  
155  $\nu$ =3000–2400 (2953, 2921, 2867, 2673, 2570), 1717, 1429, 1299, 1218, 1176, 1116, 1061, 1030, 1013,  
156 877, 771, 720 cm<sup>-1</sup>; GC/MS (70 eV): m/z (%): 260 [(M - H<sub>2</sub>O)<sup>+</sup>, 5], 232 (51), 187 (100), 173 (73),  
157 163 (19), 159 (15), 145 (34), 131 (23), 119 (37), 105 (17), 91 (36), 82 (37), 77 (31), 67 (17); Accurate  
158 mass [ESI( )]: m/z calcd for C<sub>16</sub>H<sub>21</sub>O<sub>4</sub> : 277.1445 [M - H] ; found: 277.1448.

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160 1,6-Diiodo-3,4,8,9-tetramethyltetracyclo[4.4.0.03,9.04,8]decane ( 3): 1,3-Diiodo-5,5-dimethylhydantoin  
161 (7.17 g, 18.9 mmol) was added to a solution of the diacid 2 (2.10 g, 7.54 mmol). The resulting orange  
162 solution was irradiated (2  $\square$  60W tungsten bulb) at reflux for 24 h. The suspension was cooled to room  
163 temperature and washed with 10% aqueous NaHSO<sub>3</sub> (50 mL). The aqueous layer was extracted with  
164 CH<sub>2</sub>Cl<sub>2</sub> (25 mL) and the combined organic layers were washed with saturated aqueous solution of  
165 NaHCO<sub>3</sub> (2  $\square$  25 mL), dried over Na<sub>2</sub>SO<sub>4</sub>, filtered, and concentrated under vacuum to obtain 1.4 g of a  
166 mixture of starting 2, 3 and the corresponding iodoacid. Purification by column chromatography (silica  
167 gel, n-hexane) gave 3 as a colorless solid (900 mg, 27% yield), m.p. 234–2358C. <sup>1</sup>H NMR (400 MHz,  
168 CDCl<sub>3</sub>):  $\delta$ =0.92 (s, 12H, 3(4,8,9)-CH<sub>3</sub>), 1.62 [d, J=12.0 Hz, 4H, 2(5,7,10)-Ha], 2.69 ppm [d, J=12.0 Hz,  
169 4H, 2(5,7,10)-Hb]; <sup>13</sup>C NMR (100.6 MHz, CDCl<sub>3</sub>):  $\delta$ =14.3 [CH<sub>3</sub>, 3(4,8,9)-CH<sub>3</sub>], 47.0 [C, 3(4,8,9)-C],  
170 48.7 [C, 1(6)-C], 53.7 ppm [CH<sub>2</sub>, 2(5,7,10)-CH<sub>2</sub>]; IR (KBr):  $\nu$ = 2923, 2859, 1717, 1448, 1384, 1369,  
171 1298, 1270, 1208, 1187, 1102, 935, 820, 790, 708, 654 cm<sup>-1</sup>; GC/MS (70 eV): m/z (%): 442 (MC<sup>+</sup>, 2),  
172 315 (46), 187 (100), 173 (46), 159 (13), 145 (34), 131 (16), 119 (23), 105 (11), 91 (20), 77 (12); Anal  
173 calcd for C<sub>14</sub>H<sub>20</sub>I<sub>2</sub> : C 38.94%; H 4.49%; calcd for C<sub>14</sub>H<sub>20</sub>I<sub>2</sub>·0.1 hexane: C: 38.91%, H 4.79%; found  
174 C: 38.94,H 4.49%.

175 12,13,14,17-Tetramethyl-2,9-diphenyl-19-oxaheptacyclo-[10.3.2.12,9.110,13.01,10.03,8.014,17]  
176 nonadec-3,5,7-triene (5). A solution of tert-butyllithium (1.6m in pentane, 0.61 mL, 0.97 mmol) was  
177 slowly added, under stirring, to a cold ( - 678C) solution of 3 (252 mg, 0.6 mmol) and 1,3-  
178 diphenylisobenzofuran (186 mg, 0.68 mmol) in anhydrous THF (10 mL). The reaction mixture was kept  
179 at this temperature for 30 min and then it was allowed to warm to room temperature. Methanol (5 mL)  
180 and water (10 mL) were added dropwise and the mixture was extracted with diethyl ether (3  $\square$  50 mL).  
181 The combined organic extracts were dried over Na<sub>2</sub>SO<sub>4</sub>, filtered, and concentrated in vacuo to dryness  
182 to give a yellow oil. Purification by column chromatography (EtOAc/n-hexane mixtures) gave 5 (96 mg,  
183 37% yield) as a pale yellow solid, m.p. 182–1838C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>):  $\delta$ =0.42 [d, J=11.5  
184 Hz, 2H, 11(16)-Ha], 0.80 (s, 6H) and 0.85 (s, 6H) [C<sub>12</sub>(17)-CH<sub>3</sub> and C<sub>13</sub>(14)-CH<sub>3</sub>], 0.94 [dd, J=11.0  
185 Hz, J'=2.5 Hz, 2H, 15(18)-Hb], 1.06 [d, J=11.0 Hz, 2H, 15(18)-Ha], 1.51 [dd, J=11.5 Hz, J'=2.5 Hz, 2H,  
186 11(16)-Hb], 7.15 [m, 2H, 5(6)-H], 7.32 [m, 2H, 4(7)-H], 7.37 (tt, 2H, J=7.5 Hz, J'=1.5 Hz, Ar-Hpara),  
187 7.49 (broad t, J=7.5 Hz, 4H, Ar-Hmeta), 7.78 ppm (d, J=8.0 Hz, J'=1.5 Hz, 4H, Ar-Hortho); <sup>13</sup>C NMR  
188 (125.7 MHz, CDCl<sub>3</sub>):  $\delta$ =15.6 (CH<sub>3</sub>) and 15.8 (CH<sub>3</sub>) [C<sub>12</sub>(17)-CH<sub>3</sub> and C<sub>13</sub>(14)-CH<sub>3</sub>], 39.2 [CH<sub>2</sub>,  
189 C<sub>11</sub>(16)], 41.0 [CH<sub>2</sub>, C<sub>15</sub>(18)], 44.6 [C, C<sub>12</sub>(17)], 45.4 [C, C<sub>13</sub>(14)], 55.3 [C, C<sub>1</sub>(10)], 88.8 [C, C<sub>2</sub>(9)],  
190 119.6 [CH, C<sub>4</sub>(7)], 125.0 (CH, Cortho-C<sub>6</sub>H<sub>5</sub>), 126.1 [CH, C<sub>5</sub>(6)], 127.0 (CH, Cpara-C<sub>6</sub>H<sub>5</sub>), 128.2 (CH,  
191 Cmeta-C<sub>6</sub>H<sub>5</sub>), 138.3 (C, Cipso-C<sub>6</sub>H<sub>5</sub>), 146.7 ppm [C, C<sub>3</sub>(8)]; IR (KBr):  $\nu$ =3061, 3024, 2943, 2913,  
192 2860, 1597, 1457, 1446, 1370, 1342, 1302, 1272, 1217, 1178, 1155, 1119, 1021, 1001, 975, 936, 839,

193 745, 712, 698, 674 cm<sup>-1</sup>; GC/MS (70 eV): m/z (%): 458 (MC+, 1), 353 (36), 270 (100), 241 (13), 193  
194 (5), 165 (8), 105 (5), 77 (4); Accurate mass [ESI(+)]: m/z calcd for C<sub>34</sub>H<sub>35</sub>O: 459.2682 [M+H]<sup>+</sup>;  
195 found: 459.2680; Anal calcd for C<sub>34</sub>H<sub>34</sub>O: C 89.04%; H 7.47%; calcd for C<sub>34</sub>H<sub>34</sub>O·0.05CH<sub>2</sub>Cl<sub>2</sub> : C:  
196 88.35%, H 7.43%; found C: 88.10, H 7.63%.

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198 3,4,8,9-Tetramethyltetracyclo[4.4.0.0.3,9.0.4,8]decane (6), 4,5,6,7,12,-13,16,17-  
199 ctamethylnonacyclo[8.4.4.12,5.16,9.0.1,10.0.2,9.0.4,7.0.12,17.0.13,16]-eicosane (7), and 3,4,8,9-  
200 tetramethyl-1-[3,4,8,9-tetramethyltetracyclo[4.4.0.0.3,9.0.4,8]dec-1-yl]-tetracyclo[4.4.0.0.3,9.0.4,8]decane  
201 (8). Finely cut sodium (0.49 g, 21.5 mmol) was added to boiling anhydrous 1,4-dioxane (25 mL) and the  
202 mixture was heated with stirring under an argon atmosphere until the metal melted. Then, solid 3 (0.95  
203 g, 2.15 mmol) was added and the mixture was heated under reflux for 4 h. The reaction mixture was  
204 cooled to room temperature and filtered through Celite<sup>®</sup>. The solid residue was washed with diethyl  
205 ether and n-pentane, and the combined filtrate and washings were concentrated under reduced pressure  
206 to give a solid white residue (151 mg, approx. 35% yield). GC/MS spectrometry showed the presence of  
207 three main components with the following retention times, m/z of the molecular ions and relative areas  
208 (12.3 min, 190, 20.8%; 24.2 min, 376, 11.5%; 25.1 min, 378, 45.6%). By sublimation (100 °C/1 atm),  
209 pure tetracycle 6 was obtained (19 mg, 5% yield), m.p. 189–190 °C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>):  
210 δ=0.56 [d, J=11.0 Hz, 4H, 2(5,7,10)-Ha], 0.93 (s, 12H, 3(4,8,9)-CH<sub>3</sub>), 1.70 [d, J=11.0 Hz, 4H,  
211 2(5,7,10)-Hb], 2.24 ppm [s, 2H, 1(6)-H]; <sup>13</sup>C NMR (100.6 MHz, CDCl<sub>3</sub>): δ=15.8 (CH<sub>3</sub>), 32.9 (CH),  
212 38.1 (CH<sub>2</sub>), 45.3 ppm (C); IR (KBr): ν=3447, 2946, 2864, 1458, 1381, 1369, 1323, 1116, 1096, 1028,  
213 927 cm<sup>-1</sup>; GC/MS (70 eV):m/z (%): 190 (MC+, 43), 120 (100), 119 (30), 108 (31), 107 (34), 105 (51),  
214 95 (16), 93 (39), 91 (34), 77 (19). By recrystallization of the remaining mixture from n-pentane, pure  
215 dimer 7 (36 mg, 9% yield) was isolated by filtration, m.p. >300 °C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ=0.64  
216 [d, J=13.5 Hz, 8H, 3(8,11,14,15,18,19,20)-Ha], 0.91 (s, 24H, 4(5,6,7,12,13,16,17)-CH<sub>3</sub>), 1.97 ppm [d,  
217 J=13.5 Hz, 8H, 3(8,11,14,15,18,19,20)-Hb]; <sup>13</sup>C NMR (100.6 MHz, CDCl<sub>3</sub>): δ=15.8 (CH<sub>3</sub>), 38.9  
218 (CH<sub>2</sub>), 45.3 [C, 4(5,6,7,12,13,16,17)-C], 47.0 ppm [C, 1(2,9,10)-C]; IR (KBr): ν= 2945, 2860, 1699,  
219 1445, 1382, 1297, 1215, 1115 cm<sup>-1</sup>; GC/MS (70 eV): m/z (%): 376 (MC+, 12), 190 (24), 189 (17), 188  
220 (69), 187 (100), 186 (55), 185 (15), 173 (71), 171 (34), 145 (21), 131 (16), 119 (42), 105 (17), 91 (19),  
221 79 (15); Anal calcd for C<sub>28</sub>H<sub>40</sub> : C 89.29%; H 10.71%; found C: 89.07, H 10.71%. The solid remaining  
222 after concentration of the mother liquors was washed with dichloromethane to give the pure  
223 dihydrodimer 8 (37 mg, 9% yield), m.p. 199–200 °C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ=0.62 [d, J=11.6  
224 Hz, 4H, 2(2',10,10')-Ha], 0.69 [dd, J=11.2 Hz, J'=2.8 Hz, 4H, 5(5',7,7')-Ha], 0.91 (s, 12H) and 0.93 (s,  
225 12H) [3(3',9,9')-CH<sub>3</sub>, and 4(4',8,8')-CH<sub>3</sub>], 1.62 [d, J=11.2 Hz, 4H, 2(2',10,10')-Hb], 1.71 [dd, J=11.2  
226 Hz, J'=1.4 Hz, 4H, 5(5',7,7')-Hb], 2.31 ppm [m, 2H, 6(6')-H]; <sup>13</sup>C NMR (100.6 MHz, CDCl<sub>3</sub>): δ=  
227 15.8 (CH<sub>3</sub>), 16.1 (CH<sub>3</sub>), 36.9 [CH, 6(6')-C], 39.2 [CH<sub>2</sub>, 2(2',10,10')-C], 39.4 [CH<sub>2</sub>, 5(5',7,7')-C], 44.8  
228 (C), and 45.3 (C) [3(3',9,9')-C and 4(4',8,8')-C], 47.5 ppm [C, 1(1')-C]; IR (KBr): ν=2943, 2861, 1457,  
229 1381, 1371, 1324, 1258, 1224, 1095, 1061, 1033, 799 cm<sup>-1</sup>; GC/MS (70 eV): m/z (%): 378 (MC+, 21),  
230 296 (49), 214 (18), 189 (65), 188 (68), 187 (20), 173 (33), 133 (21), 120 (25), 119 (100), 107 (50), 105  
231 (29), 95 (54), 93 (16), 91 (34), 80 (19), 67 (20); Anal calcd for C<sub>28</sub>H<sub>42</sub>: C 88.82%; H 11.18%; calcd for  
232 C<sub>28</sub>H<sub>42</sub>·0.1CH<sub>2</sub>Cl<sub>2</sub> : C 87.18%; H 10.99%; found C: 87.43, H 11.11%.

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235 [1] a) W. T. Borden, *Chem. Rev.* 1989, 89, 1095 – 1109; b) H. Hopf, *Classics in Hydrocarbon*  
236 *Chemistry: Syntheses, Concepts, Perspectives*, Wiley-VCH, Weinheim, 2000, pp. 122 – 137; c)  
237 S. Vázquez, P. Camps, *Tetrahedron* 2005, 61, 5147 – 5208; d) A. Nicolaides in *Strained*  
238 *Hydrocarbons* (Ed: H. Dodziuk), Wiley-VCH, Weinheim, 2009, pp. 112 – 121; e) S. P. Gavrish,  
239 *J. Comput. Chem.* 2012, 33, 2173 – 2179.

240 [2] For recent examples: a) P. Camps, M. R. Muñoz, S. Vázquez, *Tetrahedron* 2006, 62, 7645 –  
241 7652; b) P. Camps, G. Colet, S. Delgado, M. R. Muñoz, M. A. Pericás, L. Solà, S. Vázquez,  
242 *Tetrahedron* 2007, 63, 4669 – 4679.

243 [3] For recent works by other groups: a) F. A. Theophanous, A. J. Tasiopoulos, A. Nicolaides, X.  
244 Zhou, W. T. G. Johnson, W. T. Borden, *Org. Lett.* 2006, 8, 3001 – 3004; b) M. A. Forman, C.  
245 Moran, J. P. Herres, J. Stairs, E. Chopko, A. Pozzessere, M. Kerrigan, C. Kelly, L. Lowchyj, K.  
246 Salandria, A. Gallo, E. Loutzenhiser, *J. Org. Chem.* 2007, 72, 2996 – 3005; c) M. Pillekamp, W.  
247 Alachraf, I. M. Oppel, G. Dyker, *J. Org. Chem.* 2009, 74, 8355 – 8358; d) S. Ioannou, H.  
248 Krassos, A. V. Nicolaides, *Tetrahedron* 2013, 69, 8064 – 8068.

249 [4] Gaussian09 (Revision A.1): M. J. Frisch et al., see the Supporting Information for details about  
250 the calculations.

251 [5] For a definition of the pyramidalization angle, see: W. V. Volland, E. R. Davidson, W. T.  
252 Borden, *J. Am. Chem. Soc.* 1979, 101, 533 – 537. For fullerenes and related compounds,  
253 pyramidalizations are typically reported as POAV angles. The POAV angle of 4 is 17.98. For a  
254 definition of the POAV angle, see: a) R. C. Haddon, *J. Phys. Chem.* 1987, 91, 3719 – 3720; b)  
255 R. C. Haddon, *J. Am. Chem. Soc.* 1990, 112, 3385 – 3389; c) R. C. Haddon, *J. Phys. Chem. A*  
256 2001, 105, 4164 – 4165.

257 [6] a) P. Camps, M. Font-Bardia, N. Múñdez, F. Pérez, X. Pujol, X. Solans, S. Vázquez, M.  
258 Vilalta, *Tetrahedron* 1998, 54, 4679 – 4696; b) S. Vázquez, *J. Chem. Soc. Perkin Trans. 2*  
259 2002, 2100 – 2103.

260 [7] W. B. Avila, R. A. Silva, *J. Chem. Soc. Chem. Commun.* 1970, 94 – 95.

261 [8] K. Kulbitski, G. Nisnevich, M. Gandelman, *Adv. Synth. Catal.* 2011, 353, 1438 – 1442.



262 [9] a) Crystal structure analysis of 7: a translucent colorless prismatic specimen of 7, approximate  
263 dimensions 0.071 mm × 0.093 mm × 0.109 mm, was used for the X-ray crystallographic  
264 analysis. The X-ray intensity data were measured on a D8 Venture system equipped with a  
265 Multilayer monochromator and a Mo microfocus ( $\lambda=0.71073 \text{ \AA}$ ). A total of 1473 frames were  
266 collected. The total exposure time was 4.09 h. The frames were integrated with the Bruker  
267 SAINT software package using a narrow-frame algorithm. The integration of the data using a  
268 monoclinic unit cell yielded a total of 34804 reflections to a maximum  $2\theta$  angle of 28.578 (0.74  
269 resolution), of which 2683 were independent (average redundancy 12.972, completeness=  
270 100.0%,  $R_{int}=5.79\%$ ) and 2224 (82.89%) were greater than  $2\sigma(F_2)$ . The final cell constants of  
271  $a=6.978(6)$ ,  $b=11.110(10)$ ,  $c=14.848(13) \text{ \AA}$ ,  $\beta=113.90(4)^\circ$ , volume= $1052.4(16) \text{ \AA}^3$ , are based  
272 upon the refinement of the XYZ-centroids of 87 reflections above  $2\sigma(I)$  with  
273  $7.3488 < 2\theta < 54.878$ . Data were corrected for absorption effects using the multi-scan method  
274 (SADABS). The ratio of minimum to maximum apparent transmission was 0.955. The structure  
275 was solved and refined using the Bruker SHELXTL Software Package, with  $Z=2$  for the formula  
276 unit,  $C_{28}H_{40}$ . The final anisotropic full-matrix least-squares refinement on  $F_2$  with 155 variables  
277 converged at  $R_1=5.13\%$ , for the observed data and  $wR_2=14.36\%$  for all data. The goodness-of-  
278 fit was 1.065. The largest peak in the final difference electron density synthesis was 0.571  
279  $e \text{ \AA}^{-3}$  and the largest hole was  $-0.444 e \text{ \AA}^{-3}$  with an RMS deviation of  $0.068 e \text{ \AA}^{-3}$ . On  
280 the basis of the final model, the calculated density was  $1.188 \text{ g cm}^{-3}$  and  $F(000), 416 e^{-}$ . 8 H  
281 atoms were located from a difference synthesis and refined with an isotropic temperature factor  
282 equal to 1.2 times the equivalent temperature factor of the atom which are linked and 12 H atoms  
283 were computed and refined, using a riding model, with an isotropic temperature factor equal to  
284 1.2 times the equivalent temperature factor of the atom which are linked; b) crystal structure  
285 analysis of 8: a colorless Prism-like specimen of 8, approximate dimensions 0.090 mm × 0.209  
286 mm × 0.623 mm, was used for the X-ray crystallographic analysis. The X-ray intensity data  
287 were measured on a D8 Venture system equipped with a multilayer monochromator and a Mo  
288 microfocus ( $\lambda=0.71073 \text{ \AA}$ ). A total of 1064 frames were collected. The total exposure time was  
289 17.73 h. The frames were integrated with the Bruker SAINT software package using a narrow-

290 frame algorithm. The integration of the data using a monoclinic unit cell yielded a total of 40995  
291 reflections to a maximum  $q$  angle of 28.338 (0.75 resolution), of which 5377 were  
292 independent (average redundancy 7.587, completeness=98.8%,  $R_{int}$ =5.79%,  $R_{sig}$ =3.37%) and  
293 5037 (93.23%) were greater than  $2s(F_2)$ . The final cell constants of  $a=22.792(3)$ ,  $b=7.8099(8)$ ,  
294  $c=12.4331(15)$ ,  $\beta=100.517(4)^\circ$ , volume=2176.0(4) Å<sup>3</sup>, are based upon the refinement of the  
295 XYZ-centroids of 143 reflections above  $2\theta$  with  $7.1428 < 2\theta < 52.438$ . Data were corrected  
296 for absorption effects using the multi-scan method (SADABS). The ratio of minimum to  
297 maximum apparent transmission was 0.775. The structure was solved and refined using the  
298 Bruker SHELXTL Software Package, with  $Z=4$  for the formula unit, C<sub>28</sub>H<sub>42</sub>. The final  
299 anisotropic full-matrix least-squares refinement on  $F_2$  with 322 variables converged at  
300  $R_1=8.25\%$ , for the observed data and  $wR_2=21.75\%$  for all data. The goodness-of-fit was 1.071.  
301 The largest peak in the final difference electron density synthesis was 0.426 e Å<sup>-3</sup> and the  
302 largest hole was -0.428 e Å<sup>-3</sup> with an RMS deviation of 0.099 e Å<sup>-3</sup>. On the basis of the  
303 final model, the calculated density was 1.156 g cm<sup>-3</sup> and  $F(000)$ , 840e<sup>-</sup>. 22 H atoms were  
304 located from a difference synthesis and refined with an isotropic temperature factor equal to 1.2  
305 times the equivalent temperature factor of the atom which are linked and 20 H atoms were  
306 computed and refined, using a riding model, with an isotropic temperature factor equal to 1.2  
307 times the equivalent temperature factor of the atom which are linked; c) the structures of 1, 3 and  
308 5 were also established by X-Ray diffraction analysis. See supporting information for details.  
309 CCDC 994900, 994901, 994902, 994903 and 994904 contain the supplementary  
310 crystallographic data for this paper. These data can be obtained free of charge from The  
311 Cambridge Crystallographic Data Centre via [www.ccdc.cam.ac.uk/data\\_request/cif](http://www.ccdc.cam.ac.uk/data_request/cif).

312 [10] M. Balasubramanian, Chem. Rev. 1962, 62, 591 – 598.

313 [11] a) R. R. Sauers, J. Chem. Educ. 2000, 77, 332 – 332; b) K. Kakhiani, U. Lourderaj, W. Hu, D.  
314 Birney, W. L. Hase, J. Phys. Chem. A 2009, 113, 4570 – 4580.

315 [12] a) U. Biethan, U. v. Gizycki, H. Musso, Tetrahedron Lett. 1965, 6, 1477 – 1482; b) H. Musso, U.  
316 Biethan, Chem. Ber. 1967, 100, 119 – 131; c) H. Musso, H. Klusacek, Chem. Ber. 1970, 103,

317 3076 – 3086; d) B. Ahlquist, A. Almenningen, B. Benterud, M. Traetteberg, P. Bakken, W.  
318 L ttke, Chem. Ber. 1992, 125, 1217 – 1225.

319 [13] A. Otterbach, H. Musso, Angew. Chem. 1987, 99, 588 – 590; Angew. Chem. Int. Ed. Engl.  
320 1987, 26, 554 – 555.

321 [14] a) H.-M. Hutmacher, H.-G. Fritz, H. Musso, Angew. Chem. 1975, 87, 174 – 175; Angew.  
322 Chem. Int. Ed. Engl. 1975, 14, 180 – 181; b) H.-G. Fritz, H.-M. Hutmacher, H. Musso, G.  
323 Ahlgren, B. K rnermark, R. Karlsson, Chem. Ber. 1976, 109, 3781 – 3792; c) G. Kaiser, H.  
324 Musso, Chem. Ber. 1985, 118, 2266 – 2281.

325 [15] Several double tetraasteranes are also known: a) V. T. Hoffmann, H. Musso, Angew. Chem.  
326 1987, 99, 1036 – 1037; Angew. Chem. Int. Ed. Engl. 1987, 26, 1006 – 1007; b) V. T. Hoffmann,  
327 H. Musso, Chem. Ber. 1991, 124, 103 – 109.

328 [16] a) C. A. Cupas, L. Hodakowski, J. Am. Chem. Soc. 1974, 96, 4668 – 4669; b) D. P. G. Hamon,  
329 G. F. Taylor, Tetrahedron Lett. 1974, 15, 155 – 158; c) D. P. G. Hamon, G. F. Taylor, Aust. J.  
330 Chem. 1976, 29, 1721 – 1734.

331 [17] O. Hassel, B. Ottar, Acta Chem. Scand. 1947, 1, 929 – 943.

332 [18] a) R. Chauvin, J. Phys. Chem. 1992, 96, 9194 – 9197; b) R. S. Rowland, R. Taylor, J. Phys.  
333 Chem. 1996, 100, 7384 – 7391.

334 [19] a) R. Gilardi, M. Maggini, P. E. Eaton, J. Am. Chem. Soc. 1988, 110, 7232 – 7234; b) M.  
335 Tanaka, A. Sekiguchi, Angew. Chem. 2005, 117, 5971 – 5973; Angew. Chem. Int. Ed. 2005, 44,  
336 5821 – 5823.

337 [20] R. A. Alden, J. Kraut, T. G. Traylor, J. Am. Chem. Soc. 1968, 90, 74 – 82.

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342 **Legends to figures**

343

344 **Scheme 1.** Synthesis, trapping, and dimerization of alkene 4. a) aq. NaOH, reflux, then conc HCl, 70%  
345 yield; b) 1,3-diiodo-5,5-dimethylhydantoin, 1,2-dichloroethane, 27% yield; c) Na, 1,4-dioxane, reflux, 4  
346 h; d) tBuLi, 1,3-diphenylisobenzofuran, THF, 678C, 37% yield.

347

348 **Figure 1.** Crystal structure (ORTEP) of 7. Thermal ellipsoids shown at 50% probability. Selected  
349 distances [ ] and angles [8]: C2–C8 1.5844(19), C7–C8 1.5841(19), C4–C5 1.589(2), C4–C5a  
350 1.542(2), C8–C9 1.5376(19), C4–C9 1.543(2); C3-C2-C10 109.44(11), C3-C2-C8 105.41(11), C10-C2-  
351 C8 90.01(10), C2-C3-C4 99.61(11), H3a-C3-H3b 110.1 (15), C5a-C4-C5 90.05(11), C3-C4-C5  
352 109.78(12), C4a-C5-C12 122.30(13), C12-C5-C13 101.86(12), C4a-C5-C4 89.95(11).

353

354 **Figure 2.** Known polycyclic compounds featuring boat cyclohexane rings.

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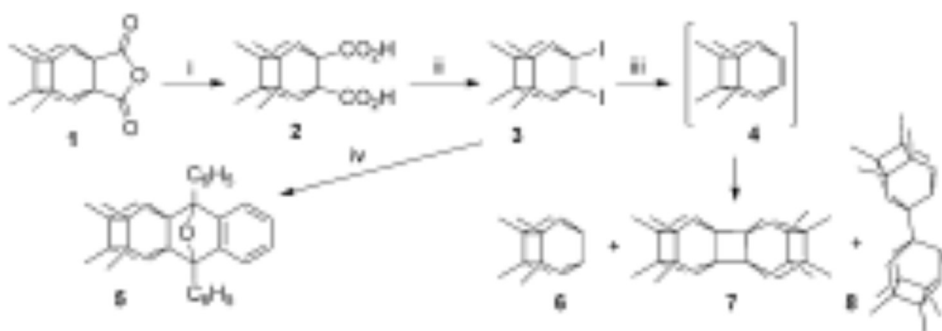
356 **Scheme 2.** Hypothetical [2+2] cycloreversion of 7 into the dienes 13, 14, and 15.

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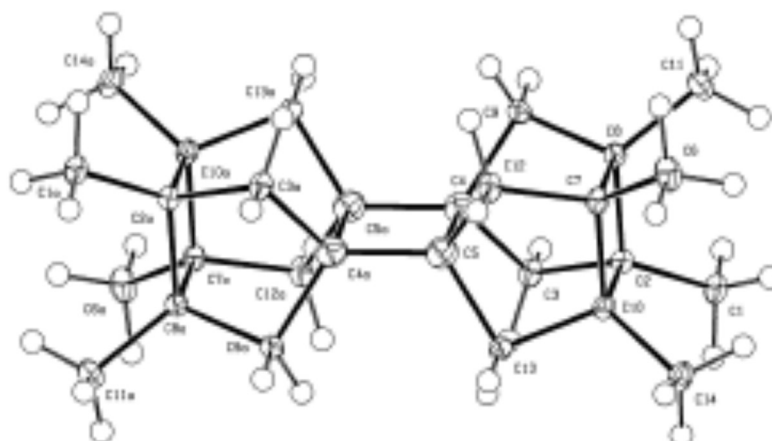
**SCHEME 1.**



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FIGURE 1



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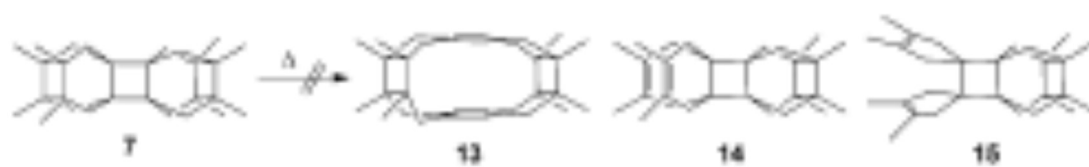
FIGURE 2



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### SCHEME 2



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382 **Table 1.** H–H and C–C distances between the flagpole hydrogen atoms and the flagpole carbon atoms in  
 383 boat cyclohexane and hydrocarbons 6–7 and 9–12.  
 384

Compound	H–H distance [Å]		C–C distance [Å]	
	B3LYP/ 6-31G(d)	MP2/ 6-31G(d)	B3LYP/ 6-31G(d)	MP2/ 6-31G(d)
Cyclohexane	2.349	2.289	2.739	2.710
<b>6</b>	2.035	2.027	2.655	2.639
7 <sup>[a]</sup>	2.054	2.042	2.684	2.668
9 <sup>[b]</sup>	3.252	3.238	2.990	2.979
10	1.861	1.856	2.625	2.610
11	2.505	2.488	2.814	2.800
12	2.126	2.120	2.668	2.652

[a] The H–H and the C–C distances in the crystal structure of **7** were 1.999(2) Å and 2.619(1) Å, respectively. [b] The C–C distance obtained for **9** by gas-phase electron diffraction was 2.973(6).<sup>[234]</sup>

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