Synthetic Photochemistry. 65.[1] Synthesis of Hexacyclo[6.4.2.0^{2,7}.0^{3,11}.0^{6,10}.0^{9,12}]tetradecane

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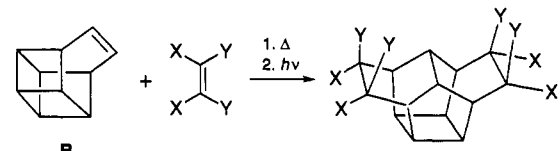
Since the peroxy bond (RO—OR') is one of the most weak covalent bonds for homolysis,[2] it suffers a restriction in syntheses. However, it is true that the dialkyl peroxides have no absorption maximum in wavelengths longer than 300 nm, and under photochemical conditions, it could be inert during the reaction, preventing the generation of alkoxyl radicals. Herein, we applied an acetone-sensitized intramolecular [2 + 2] π photocycloaddition to a molecule possessing a peroxy ester group to furnish a symmetrical cage compound, hexacyclo[6.4.2.0^{2,7}.0^{3,11}.0^{6,10}.0^{9,12}]tetradecane (**1**).[3] Although derivatives (**A**) having this skeleton were synthesized by thermal reaction of basketene (**B**) and electron-withdrawing olefins followed by photocylization,[4] the unsubstituted compound **1** has not been synthesized (Scheme 1).

A decade ago, we observed[5] a stereoselective formation of the Diels–Alder adducts **2** from bicyclo[3.2.2]nona-3,6-dien-2-one (**3**), obtained from tropone (**4a**) and ethene (**5**),[6] with various cyclic dienes including cyclohexadiene (**6**). Their nearly-confronted two C=C bonds seem to be promising starting compounds for cage derivatives; *e.g.*, the [2 + 2] π cycloaddition of **2a**, from **3** and **6**, might give a cage compound (**C**).

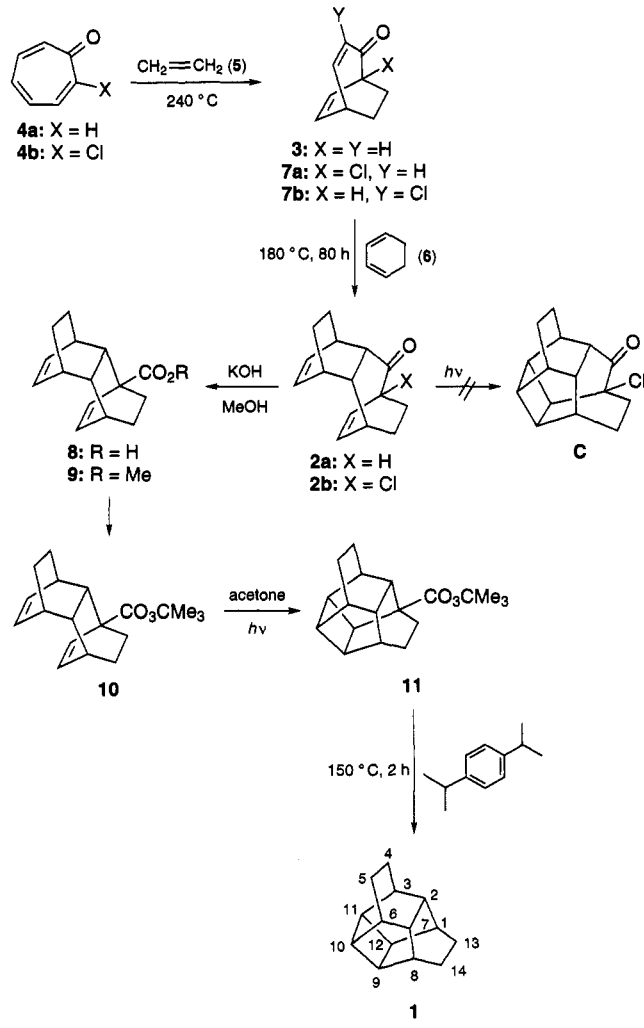
The Diels–Alder adduct **2b** was prepared from cyclohexa-1,3-diene (**6**) from 1-chlorobicyclo[3.2.2]nona-3,6-dien-2-one (**7a**),[6] obtained as a major product from 2-chlorotropone (**4b**) and **5**, in an 85% yield. Photocyclization of **2b** under copper(I) trifluoromethanesulfonate-sensitized conditions caused no reaction; 95% of the starting material was recovered, and the remaining mass was intractable. Since the β,γ-unsaturated carbonyl function of bicyclo[3.2.2]nona-3,6-dien-2-ones is known to cause a [1,3] sigmatropic rearrangement[7] to give hydroindenone derivative,[8] it is desirable to remove the β,γ-unsaturated carbonyl function at this stage. Thus, Favorski rearrangement of **2b** afforded *endo-syn*-tetracyclo[6.2.2.2^{3,6}.0^{2,7}]tetradeca-4,9-diene-1-carboxylic acid (**8**). According to a proposal of Osawa *et al.*,[9] this

Scheme 1



conversion should even improve the intramolecular [2 + 2] photocyclization; two reactive double bonds in **8** are parallel in each other. However, irradiations of its methyl ester (**9**) under various conditions, including those under copper(I) trifluoromethanesulfonate-sensitized photoreaction,[10] were unsuccessful. Finally, an acetone-sensitized photocyclization of a *tert*-butyl perester derivative (**10**), which was prepared in an attempt to simplify the functional groups in the molecule *via* a consecutive treatment of **8** with thionyl chloride and *tert*-butyl hydroperoxide, yielded a colorless oily compound (**11**) as a sole product in a 76% yield. Its ^{1}H NMR spectrum showed no olefinic proton signal, and the ^{13}C NMR spectrum showed, indeed, fourteen lines of signals for skeletal carbon signals, in addition to the carboxyl carbon signal at δ 174.7 and two signals ascribable to the *tert*-butyl group. Interestingly, **11** was positive to the KI-starch test, and the elemental analysis assured the retention of the perester group.

Scheme 2



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(1) Part 64: Hatsui, T.; Wang, J.-J.; Takeshita, H. *Bull. Chem. Soc. Jpn.* **1994**, *67*, (9), in press.

(2) The bond dissociation energy of H_2O_2 at 0 K is given as 49.5 ± 0.5 kcal/mol. Cf., *Lange's Handbook of Chemistry*, 13th ed., Dean, J. A., Ed.; McGraw Hill Book Co.: New York, 1985; pp 3–131.

(3) After completion of this work, an elegant synthesis of a bis-homo analog, hexacyclo[6.6.2.0^{2,7}.0^{3,12}.0^{6,11}.0^{9,14}]hexadeca-4,15-diene, appeared: Chen, T.-C.; Yang, M.-S.; Lin, C.-T. *J. Org. Chem.* **1994**, *59*, 661.

(4) LeGoff, L.; Oka, S. *J. Am. Chem. Soc.* **1969**, *91*, 5665.

(5) Takeshita, H.; Hatsui, T.; Shimooda, I.; Mametsuka, H. *Bull. Chem. Soc. Jpn.* **1982**, *55*, 2291.

(6) Uyehara, T.; Kitahara, Y. *Chem. Ind. (London)* **1971**, 354.

(7) Li, Z.-H.; Mori, A.; Kato, N.; Takeshita, H. *Bull. Chem. Soc. Jpn.* **1991**, *64*, 2778.

(8) Houk, K. N. *Chem. Rev.* **1976**, *76*, 1.

(9) Osawa, E.; Aigami, K.; Inamoto, Y. *J. Org. Chem.* **1977**, *42*, 2621.

0022-3263/94/1959-6490$04.50/0

Subsequently, a *p*-diisopropylbenzene solution of **11** was heated[11] in a sealed tube for 2 h, and collecting the volatile material in vacuo furnished colorless crystals (**1**) in a 50% yield. The mass spectrum of **1** showed a strong molecular ion peak, suggesting it to be a cage molecule, and its ^{1}H NMR spectrum revealed only five separate signals with a relative peak area of 4:4:4:4:2. Together with an appearance of only four ^{13}C NMR signals in the sp^3-carbon region, the formation of **1** is thus confirmed. Interestingly, as a measure for the s-character of covalent hydrogens, the $^1J_{C-H}$ values observed in the ^{13}C NMR spectra are frequently discussed.[12] In the above ^{13}C NMR spectrum of **1**, the cyclobutyl hydrogens revealed the largest s-character of 29.3% from the splitting, J = 146.7 Hz. The protons of the carbons on the mirror plane of the symmetry showed J = 144.7 Hz, i.e., s-character = 28.9%. Comparisons of $^1J_{C-H}$ values with several related cage compounds, J = 160 Hz for cubane,[13] J = 148 Hz for pentaprismane,[14] and J = 140 to 149 Hz for homopentaprismane,[15] recorded in the literature provided supporting evidence for the depicted structure, **1**.

Experimental Section

1-Chlorobicyclo[3.2.2]nona-3,6-dien-2-one (7a) and 3-Chlorobicyclo[3.2.2]nona-3,6-dien-2-one (7b). Being modified from Uyehara's procedure,[6] to a toluene solution (100 mL) of **4b** (5.47 g; 38.9 mmol) in an autoclave was added **5** at 30 atm and heated at 240 °C for 2 h. After cooling the vessel to room temperature, the mixture was distilled in vacuo to remove the solvent and the residue thus obtained was chromatographed on a silica-gel column to give **7a** (3.17 g, 48%): colorless crystals; mp 55–60.0 °C; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.92 (m, 2H), 2.40 (dd, J = 8.8, 6.2 Hz, 2H), 3.40 (m, 1H), 5.95 (d, J = 11.3 Hz, 1H), 6.08 (d, J = 8.8 Hz, 1H), 6.55 (dd, J = 8.8, 7.7 Hz, 1H), 7.08 (dd, J = 11.3, 8.8 Hz, 1H); ^{13}C NMR (67.5 MHz, $CDCl_3$) δ 25.8, 33.6, 35.6, 77.3, 127.9, 132.8, 137.3, 152.8, 189.0; IR (KBr) 1682, 1650 and 708 cm^{-1}; MS *m/e* 146 (6), 133 (100), 115 (27), 105 (53), 91 (23), 77 (45), 55 (35); UV λ^{MeOH}_{max} = 226 nm (ϵ = 7300). Anal. Calcd for C_9H_9OCl: C, 64.10; H, 5.38. Found: C, 64.33; H, 5.14. Also obtained was its isomer **7b** (1.77 g, 27%): colorless crystals, mp 35–36 °C; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.74 (m, 1H), 1.86 (m, 1H), 1.95–2.06 (m, 2H), 3.47 (m, 1H), 3.79 (ddd, J = 7.7, 6.5, 1.1 Hz, 1H), 6.10 (t, J = 7.7 Hz, 1H), 6.59 (t, J = 7.7 Hz, 1H), 7.38 (d, J = 9.5 Hz, 1H); ^{13}C NMR (67.5 MHz, $CDCl_3$) δ 20.4, 26.0, 36.5, 50.9, 126.2, 132.4, 138.5, 149.6, 190.8; IR (KBr) 3050, 1683, 1635, 721 cm^{-1}; MS *m/e*, 170 (5), 168 (18), 140 (10), 133 (37), 112 (38), 105 (100), 91 (8), 78 (91), 63 (8), 52 (42). Anal. Calcd for C_9H_9OCl: C, 64.10; H, 5.38. Found: C, 64.11; H, 5.27.

1-Chlorotetracyclo[7.2.2.2^{4,7}.0^{3,8}]pentadeca-5,10-dien-2-one (2b). A xylene solution (20 mL) of **7a** (1250 mg; 7.42 mmol) and **6** (3 mL) was heated in a sealed tube at 150 °C for 80 h. The mixture was then heated in vacuo to remove the volatile material. The residue thus obtained was chromatographed on silica gel to obtain **2b** (923 mg, 84.9%): colorless prisms; mp 132–133 °C; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.08–1.92 (m, 6H), 2.32 (m, 3H), 2.52 (m, 2H), 2.87 (dd, J = 9.2, 2.9 Hz, 1H), 3.38 (br s, 1H), 5.52 (d, J = 9.2 Hz, 1H), 6.02 (t, J = 7.0 Hz, 1H), 6.19 (t, J = 7.0 Hz, 1H), 6.23 (dd, J = 9.2, 8.1 Hz, 1H); ^{13}C NMR (67.5 MHz, $CDCl_3$) δ 21.8, 26.2, 28.4, 33.6, 33.8, 36.8, 37.9, 48.0, 53.1, 73.7, 127.8, 131.7, 132.5, 134.9, 194.7; IR (KBr) 3042, 1706, 702 cm^{-1}; MS *m/e* 250, 248 (M$^+$, 3 and 37), 168 (37), 150 (5), 133 (51), 114 (23), 91 (24), 79 (100), 65 (7), 51 (11). Anal. Calcd for $C_{15}H_{17}OCl$: C, 72.43; H, 6.89. Found: C, 72.67; H, 6.94.

More polar fractions contained the recovered **6** (412 mg, 33.0%).

Attempted Intramolecular Photocyclization of 2b. To an anhydrous THF solution (2 mL) of **2b** (20 mg; 0.08 mmol) was added a benzene solution of $Cu(OSO_2CF_3)$ (20 mg) and the mixture was externally irradiated, while being cooled with running water, by means of a 100-W low-pressure Hg lamp for 40 h. No characterizable compound was detected except for the recovered material **2b** (19 mg, 95%).

Tetracyclo[6.2.2.2^{3,6}.0^{2,7}]tetradeca-4,9-dien-1-oic Acid (8). To a MeOH solution (10 mL) of **2b** (226 mg; 0.91 mmol) was added KOH (2.5 g) in H_2O (5 mL) and the mixture was refluxed for 12 h. The mixture was acidified with dilute HCl and extracted with ether. After being dried over $MgSO_4$, the organic layer was heated to evaporate a volatile material, and the residue thus obtained was chromatographed on a silica-gel column to give **8** (189 mg, 88%): colorless prisms; mp 162–163 °C; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.11 (m, 1H), 1.18 (dt, J = 11.4, 3.3 Hz, 1H), 1.24–1.34 (m, 2H), 1.50 (m, 2H), 1.63 (m, 2H), 1.90 (m, 1H), 2.09 (dt, J = 9.5, 2.2 Hz, 1H), 2.32–2.44 (m, 3H), 5.78 (m, 2H), 5.87 (dd, J = 8.4, 6.9 Hz, 1H), 6.10 (d, J = 8.4 Hz, 1H), 10.8 (br, 1H); ^{13}C NMR (67.5 MHz, $CDCl_3$) δ 26.6, 26.8, 27.0, 31.6, 32.4, 35.0, 35.6, 43.2, 46.3, 47.7, 128.9, 131.5, 132.1, 132.4, 182.1; IR (KBr) 3200–2800, 3048, 1696 cm^{-1}; MS *m/e* (%) 230 (M$^+$, 90), 185 (100), 157 (11), 143 (19), 129 (44), 117 (32), 105 (59), 91 (83), 77 (63). Anal. Calcd for $C_{15}H_{18}O_2$: C, 78.23; H, 7.88. Found: C, 78.24; H, 8.14.

Methyl Tetracyclo[6.2.2.2^{3,6}.0^{2,7}]tetradeca-4,9-dien-1-oate (9). An ether solution (12 mL) of **8** (45 mg; 0.20 mmol) was treated with ethereal CH_2N_2 to give **9** (38 mg, 81%): colorless crystals, mp 34–35 °C; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.08–1.22 (m, 4H), 1.48 (m, 2H), 1.60 (m, 1H), 1.85 (m, 1H), 2.06 (dt, J = 9.5, 2.2 Hz, 1H), 2.22 (br s, 1H), 2.35 (m, 3H), 3.78 (s, 3H), 5.75 (t, J = 5.5 Hz, 1H), 5.76 (t, J = 5.5 Hz, 1H), 5.84 (dd, J = 8.4, 6.9 Hz, 1H), 6.13 (d, J = 8.4 Hz, 1H); ^{13}C NMR (67.5 MHz, $CDCl_3$) δ 26.6, 26.8, 27.0, 31.4, 32.5, 34.9, 35.5, 43.2, 46.4, 47.8, 51.7, 129.5, 131.4, 131.99, 132.03, 176.2; MS *m/e* (%) 244 (M$^+$, 51), 213 (12), 185 (100), 184 (31), 137 (24), 105 (21), 91 (26), 80 (53), 77 (23); IR (neat) 3044, 1732 cm^{-1}; HRMS calcd for $C_{16}H_{20}O_2$ 244.1463, found 244.1426.

Attempted Intramolecular Photocyclization of 9. An acetone solution (2 mL) of **9** (20 mg; 0.082 mmol) was irradiated with or without $Cu(OSO_2CF_3)$ (20 mg) by means of a low-pressure Hg lamp for 18 h. The TLC analysis of the reaction mixture revealed no formation of any characterizable compound.

1-(*tert*-Butyldioxycarbonyl)tetracyclo[6.2.2.2^{3,6}.0^{2,7}]tetradeca-4,9-diene (10). A mixture of **8** (170 mg; 0.74 mmol) and $SOCl_2$ (350 mg) in anhydrous benzene solution (10 mL) was heated at 80 °C for 8 h. After evaporating the volatile material, the residue thus obtained was treated with t-BuOOH (75 mg) to give **10** (51 mg, 28%): a colorless oil; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.08–1.34 (m, 3H), 1.36 (s, 9H), 1.50 (m, 2H), 1.55–1.66 (m, 2H), 1.92 (ddd, J = 11.7, 9.5, 4.0 Hz, 1H), 2.12 (dt, J = 9.5, 2.2 Hz, 1H), 2.3–2.44 (m, 4H), 5.79 (m, 2H), 5.91 (dd, J = 8.4, 6.6 Hz, 1H), 6.64 (d, J = 8.4 Hz, 1H); ^{13}C NMR (67.5 MHz, $CDCl_3$) δ 26.2 (3C), 26.5, 26.7, 26.9, 31.6, 32.4, 34.9, 35.3, 43.1, 46.6, 47.8, 83.3, 128.3, 131.4, 132.0, 132.7, 172.4; MS *m/e* (%) 229 [(M − 73)$^+$, 49], 213 (35), 186 (100), 143 (77), 119 (97), 77 (75), 58 (67); IR ($CHCl_3$) 3050, 1768 cm^{-1}.

The polar fractions contained the recovered **8** (50 mg; 29%).

1-(*tert*-Butyldioxycarbonyl)hexacyclo[6.4.2.0^{2,7}.0^{3,11}.0^{6,10}.0^{9,12}]tetradecane (11). An acetone solution (10 mL) of **10** (51 mg; 0.17 mmol) in a quartz vessel was irradiated by means of a 100-W low-pressure Hg lamp. Silica-gel column chromatography of the mixture gave, prior to elution of the recovered **10** (11 mg; 21%), **11** (31 mg, 76%): a colorless oil; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.29 (s, 9H), 1.43–1.55 (m, 4H), 1.55–1.70 (m, 3H), 1.72–1.82 (m, 2H), 1.89 (dt, J = 11.7, 2.9 Hz, 1H), 2.04 (dd, J = 11.7, 4.0 Hz, 1H), 2.15 (m, 1H), 2.50 (m, 2H), 2.62 (m, 2H), 2.98 (m, 1H); ^{13}C NMR (67.5 MHz, $CDCl_3$) δ 18.61, 18.63, 18.9, 23.8, 26.2 (3C), 32.5, 34.6, 35.0, 39.3, 39.4, 39.8, 40.7, 41.2, 44.2, 48.9, 83.2, 174.7; MS *m/e* (%) 229 (M − 73$^+$ = $C_{14}H_{17}CO_2$,

(10) Evers, J. Th.; Mackor, A. *Tetrahedron Lett.* **1978**, 821. Raychandhuli, S. R.; Ghosh, S.; Salomon, R. G. *J. Am. Chem. Soc.* **1982**, *104*, 6841.
(11) Langhals, H.; Rückardt, C. *Chem. Ber.* **1975**, *108*, 2156.
(12) Muller, N.; Pritchard, D. E. *J. Chem. Phys.* **1959**, *31*, 1471. Stothers, J. B. *Carbon-13 NMR Spectroscopy*; Academic Press: New York, 1972; p 331.
(13) (a) Eaton, P. E.; Or, Y. S.; Branca, S. J.; Cole, T. W., Jr. *J. Am. Chem. Soc.* **1964**, *86*, 962. (b) Della, E. W.; Hine, P. T.; Patney, H. K. *J. Org. Chem.* **1977**, *42*, 2940.
(14) Eaton, P. E.; Or, Y. S.; Branca, S. J.; Shanker, B. K. R. *Tetrahedron*, **1986**, *42*, 1621.
(15) Eaton, P. E.; Cassar, L.; Hudson, R. A.; Huang, D. R. *J. Org. Chem.* **1976**, *41*, 1445.

7), 213 (40), 185 (100), 143 (9), 129 (18), 117 (21), 105 (26), 91 (50), 79 (34), 58 (20); IR (neat) 1765 cm^{-1}. Anal. Calcd for $C_{19}H_{26}O_3$: C, 75.46; H, 8.67. Found: C, 75.85; H, 8.46.

Hexacyclo[6.4.2.0^{2,7}.0^{3,11}.0^{6,10}.0^{9,12}]tetradecane (1). A mixture of **11** (30 mg; 0.10 mmol) and *p*-diisopropylbenzene (47 mg) was sealed in vacuo and heated in an autoclave at 150 °C for 2 h. The mixture was then chromatographed on a silica-gel column with pentane and the eluted materials were condensed by purging with a dry N_2 gas to give **1** (9.2 mg, 50%): colorless crystals; mp 91–92 °C (in a sealed tube); ^1H NMR (270 MHz, $CDCl_3$) δ 1.38 (br s, 4H), 1.49 (m, 4H), 1.75 (dm, J = 12.8 Hz, 4H), 2.03 (t, J = 1.8 Hz, 2H), 2.49 (br s, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.2 (J_{C-H} = 127.6 Hz, 4C), 34.7 (J_{C-H} = 133.0 Hz, 4C), 40.2 (J_{C-H} = 146.7 Hz, 4C), 41.4 (J_{C-H} = 144.7 Hz, 2C); MS *m/e* (%) 186 (M^+, 96), 158 (16), 143 (12), 129 (47), 117 (50), 104 (44), 91 (96), 80 (100), 65 (15), 51 (19); IR (KBr) 2924 cm^{-1}. Anal. Calcd for $C_{14}H_{18}$: C, 90.26; H, 9.74. Found: C, 90.45; H, 9.57.