cis-3,3-(Ethylenedioxy)-7α-hydroxy-9α-(2-hydroxyethyl)-2-oxaoctal-5-ene (26). To a solution of 171 mg (0.822 mmol) of the dilactone **24** in 1.9 mL of ethylene glycol was added 130 mL of dry benzene. The mixture was vigorously stirred with 1.93 g of anhydrous magnesium sulfate, 112 mg of Dowex 50W×8 (H^+ form), and 19 mg of *p*-toluenesulfonic acid. Reflux under a Dean-Stark separator, with vigorous stirring, was continued for 1.5 h. After filtration of the solid, the filtrate was washed with 20 mL of 4:3:3 saturated sodium bicarbonate/saturated sodium chloride/water. The organic layer was dried over anhydrous sodium sulfate. Evaporation of the solvent gave 199 mg of ethylene ortho ester **25**: mp 198-202 °C; IR (Nujol) 1725, 1650 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.43 (d, 1 H, J = 11.7 Hz), 3.57 (d, 1 H, J = 11.7 Hz), 3.89-4.08 (m, 4 H), 4.85 (quntet, 1 H, J = 2.7 Hz), 5.90 (dd, 1 H, J = 9.8 and 4.4 Hz), 6.03 (dd, 1 H, J = 9.8 and 5.4 Hz); MS, *m/e* 252 (M^+).

To a solution of 199 mg of **25** in 3 mL of dry THF cooled to 0 °C was added 96 mg (2.5 mmol) of lithium aluminum hydride, and the whole mixture was allowed to stir at room temperature for 50 mim. After addition of sodium sulfate·$10H_2O$ was complete, the reaction mixture was filtered off and the filtrate was evaporated in vacuo to give the crude diol **26**, which was purified by chromatography on silica gel. Elution with dichloromethane-methanol (20:1) gave 185 mg (88%) of diol **26**: mp 86-87 °C; IR (Nujol) 3220, 1655 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.97-4.14 (m, 4 H), 4.31 (m, 1 H), 5.73 (d, 1 H, J = 10.3 Hz), 5.80 (d, 1 H, J = 10.3 Hz); MS *m/e* 256 (M^+). Anal. Calcd for $C_{13}H_{20}O_5$: C, 60.92; H, 7.89. Found: C, 60.64; H, 7.64.

cis-3,3-(Ethylenedioxy)-7α-hydroxy-9α-[2-[(_o_-nitrophenyl)seleno]ethyl]-2-oxaoctal-5-ene (27). To a solution of 57 mg (0.223 mmol) of diol **26** in 2 mL of dry THF was added 50 mg (0.22 mmol) of *o*-nitrophenyl selenocyanate and 65 μL (0.26 mmol) of tri-*n*-butylphosphine under an argon atmosphere. The whole mixture was stirred at room temperature for 1 h. The solvent was evaporated under reduced pressure to give the crude selenides. Purification of product by chromatography on alumina using benzene-ethyl acetate (1:1) afforded 22 mg (22%) of the selenide **27** and 11 mg (11%) of the selenide **28**, respectively. **27**: IR (neat) 3450, 1590, 1510 cm^{-1}; MS, *m/e* 443, 441, 439, 438, 437, 435 (M^+); UV (EtOH) 255 nm. **28**: IR (neat) 3450, 1590, 1566, 1510 cm^{-1}; MS, *m/e* 443, 441, 439, 438, 437, 435 (M^+); UV (EtOH) 255 nm.

cis-9α-Ethenyl-3,3-(ethylenedioxy)-7α-hydroxy-2-oxaoctal-5-ene (29). A solution of 16 mg (0.036 mmol) of the selenide **27** in 0.5 mL of THF was treated with a 30% hydrogen peroxide (50 μL) solution at room temperature for 18 h. After removal of the solvent, the residue was purified by chromatography on alumina. Elution with dichloromethane-methanol (50:1) gave 8 mg (93%) of the vinyl alcohol **29**: mp 129-133 °C; IR (melt) 3470, 1640 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.04 (dd, 1 H, J = 14.2 and 5.6 Hz), 2.35 (dd, 1 H, J = 14.2 and 5.6 Hz), 2.64 (m, 1 H, $w_{1/2}$ = 20 Hz), 3.54 (d, 1 H, J = 11.7 Hz), 3.62 (d, 1 H, J = 11.7 Hz), 3.97, 4.18 (m, 4 H), 4.20 (m, 1 H, $w_{1/2}$ = 24 Hz), 5.19 (dd, 1 H, J = 17.6 and 1.0 Hz), 5.21 (dd, 1 H, J = 10.8 and 1.0 Hz), 5.82 (br, 2 H), 5.87 (dd, 1 H, J = 17.6 and 10.8 Hz); MS, *m/e* 238 (M^+).

cis-9α-Ethenyl-3,3-(ethylenedioxy)-7α-hydroxy-2-oxa-5α,6α-oxirenodecalin (4). To a solution of 7 mg (0.029 mmol) of the vinyl alcohol **29** in 0.5 mL of dichloromethane was added 8 mg (0.05 mmol) of *m*-chloroperbenzoic acid, and the resulting mixture was stirred at room temperature for 1.5 h. After addition of sodium sulfite followed by filtration, the organic layer was washed with saturated sodium bicarbonate solution and then brine. The solvent, dried over anhydrous sodium sulfate, was evaporated in vacuo to give the crude product, which was chromatographed on alumina. Elution with dichloromethane-methanol (50:1) gave 4.0 mg, 54%) of epoxide **4**: mp 131-132 °C; IR ($CHCl_3$) 3550 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.27-1.92 (5 H), 2.18-2.30 (m, 2 H), 3.37-3.43 (m, 2 H), 3.49 (d, 1 H, J = 12.2 Hz), 3.67 (d, 1 H, J = 12.2 Hz), 4.00-4.16 (m, 4 H), 5.14 (dd, 1 H, J = 10.7 and 1.0 Hz), 5.20 (dd, 1 H, J = 17.6 and 1.0 Hz), 5.88 (dd, 1 H, J = 17.6 and 10.7 Hz); MS, *m/e* 253 ($M^+ - 1$). the ^{1}H NMR, IR, and mass spectra were identical with those of authentic sample **4** kindly provided by Professor S. Danishefsky.

Acknowledgment. We express our thanks to Professor Danishefsky for his generous gift of authentic sample **4**. This work was supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture, Japan.

Registry No. (±)-**1**, 59598-29-7; (±)-**2**, 59598-30-0; (±)-**4**, 59955-20-3; (±)-**5**, 93603-11-3; (±)-**6**, 93531-06-7; (±)-**7**, 74207-04-8; (±)-**8**, 74320-39-1; (±)-**9**, 93531-07-8; (±)-**10**, 93531-08-9; (±)-**11**, 93603-12-4; (±)-**12**, 93531-09-0; (±)-**13**, 93531-10-3; **14**, 93531-11-4; **16**, 93531-12-5; **21**, 93531-13-6; **22**, 93531-14-7; (±)-**23**, 93531-15-8; (±)-**24**, 93531-16-9; (±)-**25**, 93531-17-0; (±)-**26**, 93531-18-1; (±)-**27**, 93531-19-2; **28**, 93531-20-5; (±)-**29**, 93531-21-6; β-bromovinyl ethyl ether, 18519-95-4; *o*-nitrophenyl selenocyanate, 51694-22-5.

Notes

Synthesis and Crystal Structure of an Oxidizable Polycyclic Metacyclophane Derived from Hexacyclen and Hexafluorobenzene

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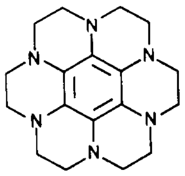
Benzoquinone reacts with 1,4,7,10,13,16-hexaazacyclooctadecane (hexacyclen) to produce as yet uncharacterized species which are intensely colored and are undoubtedly the result of redox reactions.[2] In an attempt to identify the species responsible for these properties, we sought to prepare I, a compound referred to as the "wheel"



I

by Breslow[3] and of general interest because of its potential

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[1] (a) University of Minnesota. (b) 3M Company, St. Paul, MN 55144.

[2] Presented in preliminary form by J. E. Richman and M. R. Asirvatham at the Second Symposium on Macrocyclic Compounds, Provo, Utah, August 14-16, 1978.

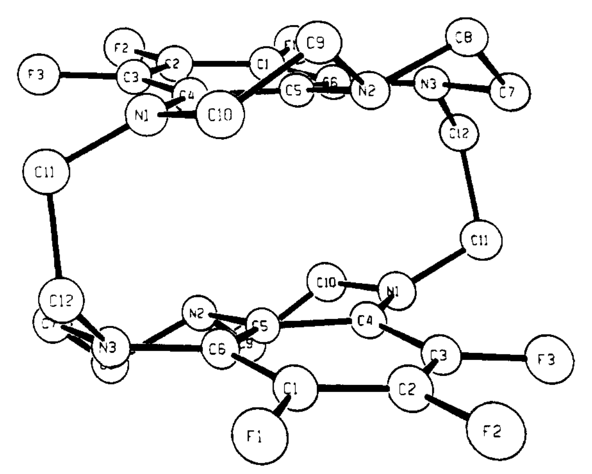
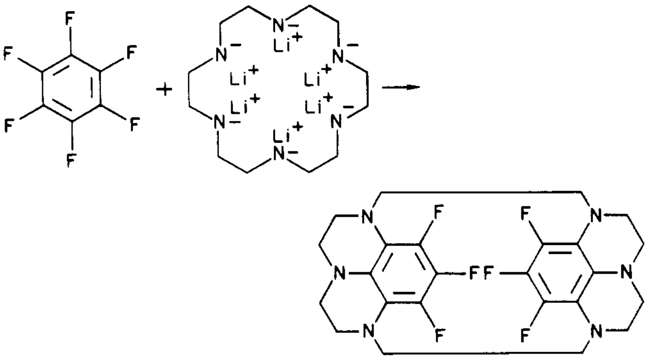
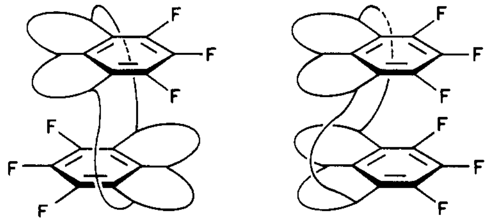


Figure 1. Numbering scheme and geometry of II showing the crown nature of the hexacyclen portion of the molecule. The molecule contains a center of symmetry located at the center of this crown cavity, thus the top and bottom portions of this figure are related as x,y,z and $1 - x, -y, 1 - z$.

for forming "antiaromatic" cyclic $4n\ \pi$ dication systems. The synthetic route we chose involved refluxing equimolar amounts of lithiated hexacyclen and hexafluorobenzene in tetrahydrofuran solution. A low yield of glistening crystals, identified as $C_{24}H_{24}N_6F_6$ (II),[4] was produced with no evidence for formation of I as a stable isolable species. Crystals of II are stable in air but react with trifluoroacetic acid to form a colorless solid which turns purple when exposed to air. The structure and properties of II itself thus become important to our understanding of the redox reactions of hexacyclen derivatives. Elemental and spectroscopic analyses confirm that II contains two 1,2,3-trifluoroaryl rings per molecule. An X-ray crystal structure analysis was carried out to determine which of two possible stereoisomers, IIa or IIb, applied.



II



IIa IIb

A clear plate-like crystal (0.34 × 0.19 × 0.96 mm) of II was grown from chlorobenzene, and, from a full three-dimensional X-ray structure analysis, it was found that II exists in the form shown above, as IIa. The molecule, Figures 1 and 2, has inversion symmetry, with the two halves related as x,y,z and $1 - x, -y, 1 - z$. The bridging C(11)–C(12) bond length is 1.537 (4) Å, indicating that the cyclophane is not highly strained. In addition the sums of the angles about the nitrogens show that N(1) is nearly planar (356°), N(2) is nearly tetrahedral (334°), and N(3) is intermediate between extremes (349°). The aromatic rings are coplanar with a van der Waals separation of 3.4 Å, and they pack in a head-to-tail arrangement within the crown cavity such that the fluorines extend outside of the cavity. The closest intermolecular F–F contact is between F(1) on the x,y,z portion of the molecule and F(1) on a neighboring molecule at $1 - x, -y, -z$. The only other nonbonded distances shorter than 3.5 Å are intramolecular contracts occurring between C(5) and C(5)′ (3.431 (4)) and C(5) and C(4)′ (3.468 (3) Å). The aromatic rings are coplanar to within ±0.04 Å with N(2) 0.25 Å from the best plane of the ring, F(1) 0.12 Å away, and the other substituents less than 0.1 Å from the plane.

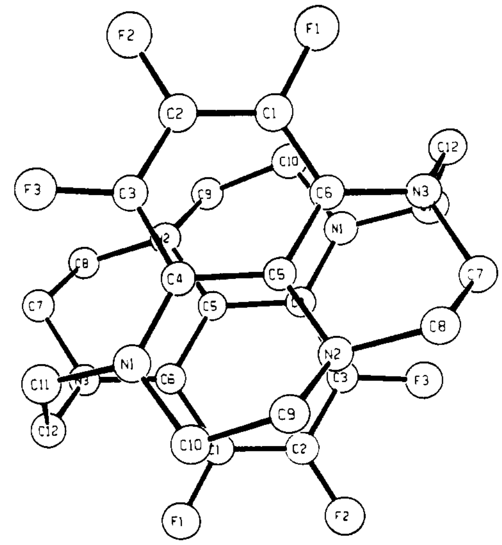


Figure 2. View of II along the normal to the aromatic rings. The head-to-tail arrangement of the trifluorophenyl rings is apparent, as is their coplanarity. The π systems of the two rings are not directly overlapping, even though their interplanar separation is only 3.4 Å, rather the rings are slipped relative to one another with close intermolecular contracts between C(5) and C(4)′ (3.468 (3) Å) and C(5) and C(5)′ (3.431 (4) Å).

An interesting feature of this molecule is that the thermal parameters determined at room temperature for the individual atoms of the structure are unusually low (B_{av} for the fluorines is 4.0, for the carbons, 2.8, and for the hydrogens, 3.8), indicative of a rigid structure. A rigid framework is also suggested from CPK models of the molecule in which interconversion of IIa and IIb is not possible due to extremely limited conformational mobility.

We have thus confirmed that II is a rigid polycyclic metacyclophane which undergoes reaction with strong acids to form easily oxidized products. The oxidation of II is related to the reaction of hexacyclen with benzoquinone—a process that absorbs multiple equivalents of oxygen.

Experimental Section

Preparation of II.[4] A 50-mL flask with a magnetic stir bar and N_2 atmosphere was charged with 0.68 g (2.63 mmol) of 1,4,7,10,13,16-hexaazacyclooctadecane (available as $3H_2SO_4$ salt from Aldrich Chemical Co.)[5] and 20 mL of anhydrous THF. This

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[3] Breslow, R. *Pure Appl Chem.* **1982**, *54*, 927.

[4] Compound II is 6,7,8,23,24,25-hexafluoro-1,4,11,14,17,20-hexaazaheptacyclo$[18.6.2.2^{4,11}.0^{5,10}.0^{9,14}.0^{17,22}.0^{21,26}]$triaconta-5,7,9,21,23,25-hexaene.

[5] Atkins, T. J.; Richman, J. E.; Oettle, W. F. *Org. Synth.* **1978** *58*, 86.

solution was cooled to −78 °C and treated with 10.5 mL of 1.6 M n-butyllithium/hexane. The resulting mixture was allowed to warm to room temperature and then was cooled to −78 °C and treated with 0.53 g (2.85 mmol) of hexafluorobenzene. This mixture was refluxed overnight and then was cooled and poured into 100 mL of water. After stirring 10 min, the initial pale green slurry turned yellow and was filtered, giving 0.90 g of crude solids. Extraction of these solids for 3 h in a Soxhlet extractor with dichloromethane gave 82 mg of semisolid residue which was slurried in minimal chloroform and filtered, giving 20–25 mg of glistening crystals of II which were recrystallized from 0.5 mL of boiling chlorobenzene. Crystals of II do not melt but turn black above 300 °C.

Anal. Calcd for $C_{24}H_{24}N_6F_6$: C, 56.47; H, 4.74; N, 16.46; F, 22.33; M_r 510.50. Found: C, 56.53; H, 4.80; N, 16.32; F, 22.16. IR (KBr): 2930, 2880, 2800, 1615, 1490 (st), 1440, 1373, 1357, 1329, 1287 (w), 1255, 1240, 1231, 1217, 1182, 1137 (st), 1073, 1051, 1025, 991 915, 893, 825 and 774 cm^{-1}. MS: M^+ at m/e 510 with metastable peaks corresponding to the transitions for M − CH_3 and M − F. UV (CH_3CN): λ_{max} 241 nm (ϵ 4.97 × 10^4), shoulder at 320 nm. ^{19}F NMR (C_6H_5Cl solvent at 100 °C, external CF_3CO_2Na/D_2O assigned −77.0 ppm): −162.9 (d, J = 23 Hz) and −175.2 ppm (t, J = 23 Hz).

Crystal Data: Pccn, a = 14.514 (3) Å, b = 15.205 (2) Å, c = 9.403 (3) Å, $V = 2075 Å^3$, Z = 8, M_r 510, $C_{24}H_{24}N_6F_6$, ρ_c = 1.63 g/cc. Data were collected on an Enraf-Nonius CAD-4 diffractometer and the structure was solved by using conventional direct methods, Fourier syntheses, and full-matrix least-squares refinements, available in the Enraf-Nonius structure determination package.[6] R = 0.034, R_w = 0.045 for 1751 independent diffracted intensities ($I > 3.0\sigma(I)$), with $2 < \theta < 75°$ (Cu Kα radiation), at room temperature. Anisotropic thermal parameters were employed for all 18 independent non-hydrogen positions. All the hydrogens were located on difference electron density maps. Their positions were refined in the final least-squares cycles, and their thermal parameters were refined isotropically.

Acknowledgment. J.E.R. is indebted to Margaret R. Asirvatham for work which preceeded this.[2] This research was supported by the donors of the Petroleum Research Fund, administered by the American Chemical Society.

Registry No. II, 92643-59-9; 1,4,7,10,13,16-hexaazacyclooctadecane, 296-35-5; hexafluorobenzene, 392-56-3.

Supplementary Material Available: Structure factor tables, temperature factors, and atomic positional parameters (3 pages). Ordering information is given on any current masthead page.

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[6] Frenz, B. A. "Enraf-Nonius Structure Determination Package" (Molecular Structure Corporation, 3rd ed., 1978), College Station, TX.

Synthesis of (±)-Lineatin by 2 + 2 Cycloaddition of Dichloroketene with a Cyclic Allyl Ether

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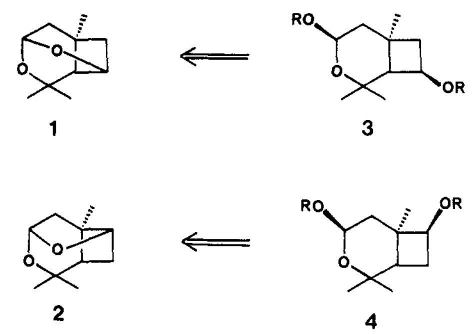
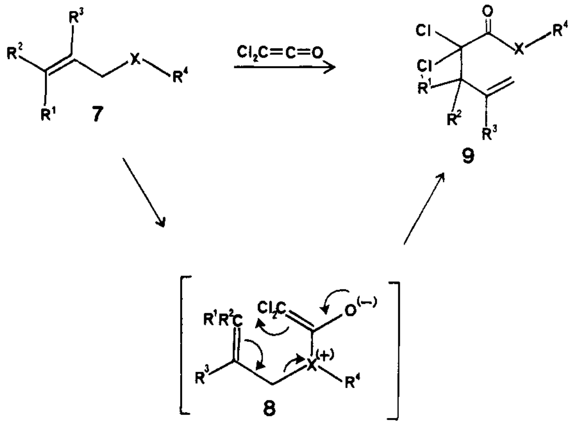
Received May 30, 1984

Lineatin (3,3,7-trimethyl-2,9-dioxatricyclo[3.3.1.0^{4,7}]nonane, **1**) has been shown to be an aggregation pheromone for the bark beetle *Trypodendron lineatum* (Oliver), an economically important forest pest which is responsible for significant damage to fallen and cut timber.[1] The unusual tricyclic acetal structure of **1** has attracted synthetic interest and there have been a number of syntheses reported.[2-8]

Scheme I



Scheme II



Our recent efforts have been directed at development of a relatively simple synthetic scheme for the production of multigram amounts of the pheromone without the coproduction of isolineatin (3,3,7-trimethyl-2,9-dioxatricyclo[4.2.1.0^{4,7}]nonane, **2**) which has been a coproduct in several previous syntheses. Disconnection of the intramolecular ketal (Scheme I) makes it apparent that a selective synthesis of **1** would require a protocol for the production of a functionalized cyclobutane precursor with the correct regiochemistry (**3** rather than **4**).

One approach would be to utilize the well-known regioselectivity of dichloroketene cycloadditions with unsymmetric trisubstituted alkenes.[9] Initially, this approach was frustrated by the extreme reluctance of dichloroketene to participate in 2 + 2 cycloaddition reactions with the required alkene substrates. Less than 5% yield of the desired cycloadduct **6** could be isolated from the reaction of **5** with dichloroketene.[3] Compound **5** was eventually abandoned as a precursor to lineatin in part due to the extreme acid sensitivity of cycloadduct **6**.

Recent reports[10,11] emphasize that the reaction of dichloroketene with allyl ethers and allyl sulfides typically

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[2] (a) Mori, K.; Sasaki, M. Tetrahedron Lett. 1979, 1329; (b) Tetrahedron 1980, 36, 2197.

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[4] (a) Mori, K.; Uematsu, T.; Minobe, M.; Yanagi, K. Tetrahedron Lett. 1982, 23, 1921; (b) Tetrahedron 1983, 39, 1735.

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[7] White, J. D.; Avery, M. A.; Carter, J. P. J. Am. Chem. Soc. 1982, 104, 5486.

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[10] (a) Malherbe, R.; Bellus, D. Helv. Chim. Acta 1978, 61, 3096. (b) Malherbe, R.; Rist, G.; Bellus, D. J. Org. Chem. 1983, 48, 860.

[11] Rosini, G.; Spineti, G. G.; Foresti, E.; Pradella, G. J. Org. Chem. 1981, 46, 2228.