Synthesis, Structural and Conformational Analysis of Methanohomo[15]annulene and Methanohomo[19]annulene

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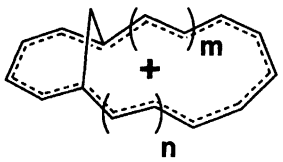
Methanohomo[15]annulene and methanohomo[19]annulene were synthesized by the Wittig reactions of 1,3-bis(triphenylphosphonio)propane dibromide with 1,6-bis(2-formylvinyl)- and 1,6-bis(4-formyl-1,3-butadienyl)-1,3,5-cycloheptatriene, respectively. Conformational properties of these homoannulenes are discussed. Attempts to convert these homoannulenes into the corresponding 14π- and 18π-methanoannulenyl cations were unsuccessful.

In 1970, Vogel et al. reproted the synthesis of bicyclo[5.4.1]dodeca-2,5,7,9,11-pentaene (methanohomo[11]annulene) (**3a**)[1] by the Wittig reaction of 1,3,5-cycloheptatriene-1,6-dicarbaldehyde (**1a**) with 1,3-bis(triphenylphosphonio)propane dibromide (**2**)[2] and its conversion to the corresponding methano[11]annulenyl cation **4a**, a 10π aromatic system (Scheme 1 and Chart 1).[3] The availability of the vinylogous dicarbaldehydes **1b**—**e**, prepared by successive homologations of **1a** in connection with our studies of methanobisdehydroannulenes[4] and methanothiaannulenes,[5] led us to attempt the synthesis of the higher homologs of **3a** and their conversion to the corresponding peripherally conjugated cations in order to compare their properties systematically.

Results and Discussion

Synthesis. The double Wittig reaction of 1,6-bis(2-formylvinyl)-1,3,5-cycloheptatriene (**1c**)[4] with 1,3-bis(triphenylphosphonio)propane dibromide (**2**)[2] using ethanolic lithium ethoxide in *N,N*-dimethylformamide (DMF) afforded the desired methanohomo[15]annulene **3c**, although the yield was as low as 6% (Scheme 1). Similarly the Wittig reaction of 1,6-bis(4-formyl-1,3-butadienyl)-1,3,5-cycloheptatriene (**1e**) with **2** afforded the methanohomo[19]annulene **3e** in 3% yield. However, no desired products were obtained by the Wittig reaction of the unsymmetrical dicarbaldehydes, 1-formyl-6-(2-formylvinyl)-1,3,5-cycloheptatriene (**1b**) and 1-(2-formylvinyl)-6-(4-formyl-1,3-butadienyl)-1,3,5-cycloheptatriene (**1d**), with the bisphosphonium salt **2** under the same conditions as for the preparations of **3c** and **3e** or under slightly modified conditions (see Experimental).

Compounds **3c** and **3e** were thermally unstable especially in solution; **3c** rapidly decomposed in $CDCl_3$ above ca. 60°C and **3e** was less stable than **3c** and gradually decomposed even at 26°C in $CDCl_3$.



4a : m=n=0

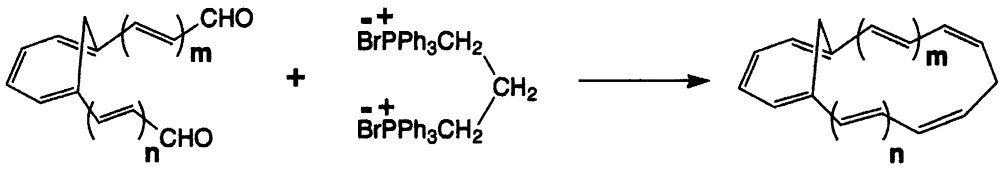
Chart 1.

Structural Analysis of 3c and 3e. The olefinic proton region of the ^{1}H NMR spectrum of **3c** was composed of six signals suggesting a symmetric C_S structure (Fig. 1a). The spectrum was easily analyzed unambiguously and the coupling constant data (see Experimental) revealed that the diene moiety (C^2—C^5) between the cycloheptatriene ring and the peripheral methylene group had 2-*E*,4-*Z* configuration with the *s-trans* C^3–C^4 single bond as shown in the structural formula (Chart 2). The ^{1}H NMR spectrum of **3e** also indicated a symmetric structure giving eight signals for the olefinic protons (Fig. 1b). The signals ascribed to H^4/H^{12} and H^5/H^{11} were too close to be analyzed on the first-order basis and the analysis was relied on computer simulation using the LAOCN3 program.[6] which revealed $\Delta\delta_{4,5}=0.03$ ppm and $J_{4,5}=10.5$ Hz indicating that the C^4=C^5 bond had *Z* configuration. Thus the ^{1}H spectrum was analyzed as given in the Experimental section and the structure of **3e** was determined as shown in the formula (Chart 2).

The geometries of these compounds are the same as those found in the corresponding methanothiaannulenes **5c** and **5e** (Chart 3).[5] Since the configuration of the butadienyl moieties of the dicarbaldehyde **1e** has been established to be *E,E*,[4] configurational isomerization had occurred during the Wittig reaction affording **3e**. A similar change in configuration during a synthetic reaction has been observed in the preparations of bisdehydro[15]annulenone[7] and bisdehydrotribenzo[14]annulene.[8]

Conformational Analysis of Methanohomoannulenes. In order to consider the conformation of the methanohomoannulenes, molecular mechanics calculations using the MM3 program with the 1989 force field[9] were carried out for **3a**, **3c**, and **3e**. The calculated geometries of the most stable conformations are given in Fig. 2.

For the methanohomo[11]annulene **3a**, the syn conformation, in which the peripheral methylene group is tilted to the same side as the methano bridge as shown in Fig. 2a, was calculated to be more stable

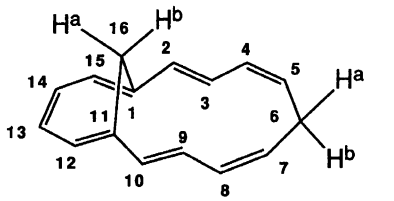


1a : m=n=0
1b : m=1, n=0
1c : m=n=1
1d : m=2, n=1
1e : m=n=2

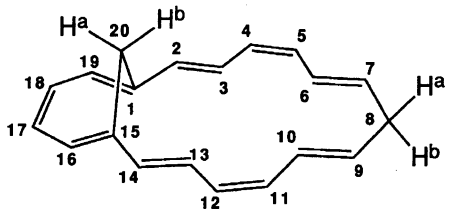
2

3a : m=n=0
3b : m=1, n=0
3c : m=n=1
3d : m=2, n=1
3e : m=n=2

Scheme 1.



3c



3e

Chart 2.

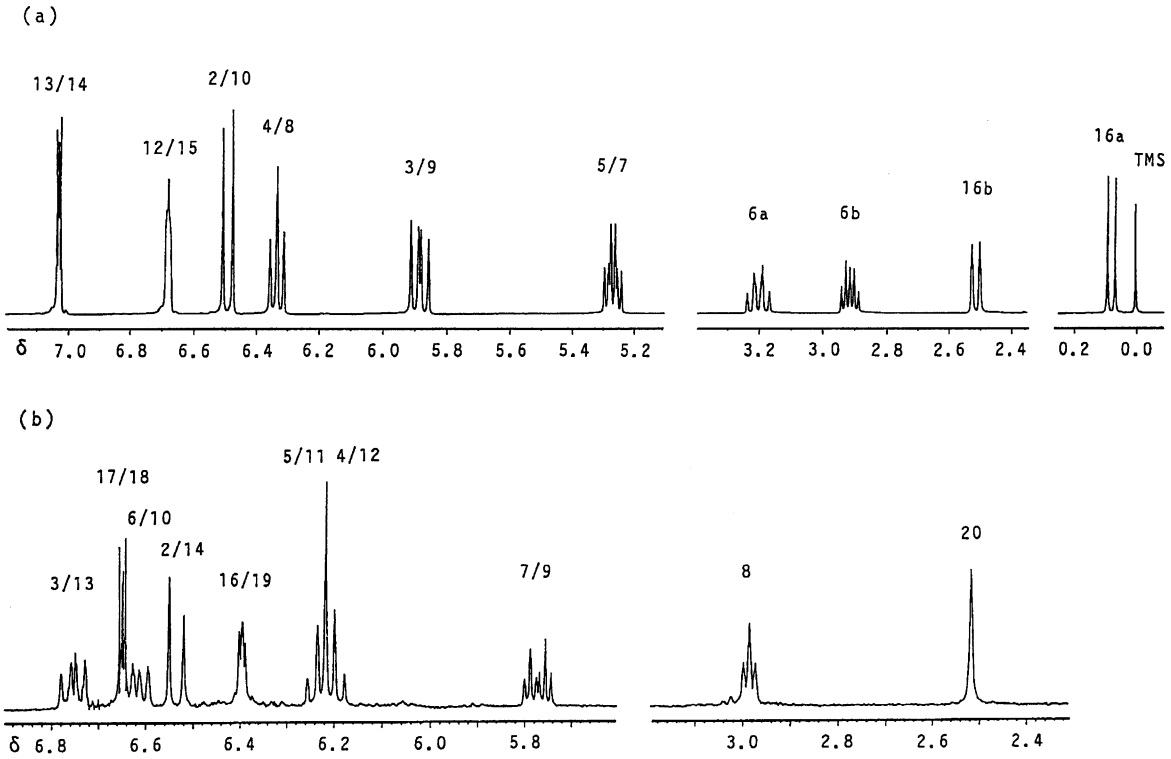
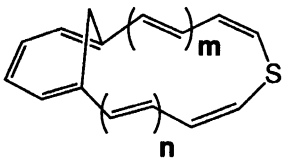


Fig. 1. The ^{1}H NMR spectra (500 MHz, $CDCl_3$, 26°C) of (a) **3c** and (b) **3e**.



5a : m=n=0
5c : m=n=1
5e : m=n=2

Chart 3.

than an anti conformation. The result is consistent with the discussion developed by Vogel on the basis of the UV spectra.[10] The calculated steric energy difference between the syn and anti conformations was 1.24 kcal mol^{-1}. The MM3 calculations do not consider the resonance stabilization energy, and when this term is properly taken into account, the energy difference will be even larger because the syn form has a higher planarity of the π system than the anti form. The calculated geometry is very similar to that of the corresponding methano[11]annulenone, bicyclo-[5.4.1]dodeca-2,5,7,9,11-pentaen-4-one, determined by X-ray crystallography.[11]

Similar syn conformations were found to be the most stable for both methanohomo[15]annulene **3c** (Fig. 2b) and methanohomo[19]annulene **3e** (Fig. 2c).

In the ^{1}H NMR spectrum of **3c** at 26°C, the methylene protons of the methano bridge (16-CH_2) are magnetically nonequivalent, consistent with a nonplanar conformation. One of the protons appears at as high as δ=0.08 as a sharp doublet while the other proton appears at δ=2.51 as a somewhat broad doublet due to the long-range couplings with H^{12} and H^{15} (Fig. 1a). Therefore the lower-field proton is assigned to H^{16b} which is anti to the four-carbon bridge. The protons of the peripheral methylene group (6-CH_2) are also nonequivalent, affording their signals at δ=3.20 and 2.91. Irradiation of the signal at δ=5.88 assigned to H^3 and H^9 enhanced the intensity of both the H^{16b} signal at δ=2.51 and the H^{6a} signal at δ=3.20, indicating that these protons are very close in space to H^3 and H^9. These NOE results are quite consistent with the optimized geometry of **3c** shown in Fig. 2b. The dihedral angles of H^{6a} and H^{6b} to H^5 obtained from this geometry are 155.4° and 41.4°, respectively. According to the modified Karplus type relation for cycloalkenes,[12] the coupling constants of $J_{5.6a}$=9.4 Hz and $J_{5.6b}$=6.0 Hz are calculated, which are in good agreement with the experimental values of 10.6 and 6.8 Hz, respectively.

No change in the lineshape of the ^{1}H NMR spectrum of **3c** was observed between 61 and −52°C, although small shifts of the peak positions were observed. This suggests that the molecular skeleton of **3c** is very rigid. As the sample decomposed rapidly above ca. 60°C, further elevation of the temperature to check the line broadening due to conformational change was abandoned. The free energy of activation of far higher than 16 kcal mol^{-1} is estimated for the conformational change.

In compound **3e**, the two protons of the methylene groups (8-CH_2 and 20-CH_2) are magnetically equivalent at 26°C, indicating that rapid interchange between the conformation shown in Fig. 2c and its mirror-image conformation formed by flipping of the methylene groups is taking place at this temperature. On lowering the temperature, the singlet due to the methano-bridge protons broadened and split into two peaks below ca. −50°C. At −85°C two broad peaks were observed at δ=1.54 and 3.37, suggesting that conformational change become slow though not yet completely frozen. Observation of the spectrum at further lower temperatures was not possible. The free energy of activation for the conformational change, i.e. the flipping of the methano bridge, was estimated to be ca. 9.6 kcal mol^{-1} at −50°C. This value is compared with 9.2 kcal mol^{-1} observed for the corresponding methanothia-[19]annulene **5e**.[5] The slightly smaller energy barrier for **5e** than for **3e** may be ascribed to the longer bond length of C–S than C–C.

The signal for the peripheral methylene protons appeared as a triplet at 26°C and no significant change in the lineshape was observed even at the lowest temperature of −85°C. This indicates that the chemical shift difference between the diastereotopic protons is very small either because the intrinsic chemical shift difference in the frozen conformation is very small or because this part of the molecule is still rapidly flipping at this temperature.

Attempts to Prepare the Annulenyl Cations. Vogel et al. prepared the 1,6-methano[11]annulenyl cation **4a** by abstracting a hydride ion from **3a** with triphenylmethyl tetrafluoroborate ($Ph_3C^+BF_4^-$) in dichloromethane and isolated its tetrafluoroborate salt as orange-yellow stable crystals.[1,3] As **4a** was a stable 10π aromatic system, its structure has been extensively discussed on the basis of various spectroscopic studies[13] as well as X-ray crystallographic analysis.[14]

Therefore preparation of higher homologs of **4a**, the 1,6-methano[15]- and -[19]annulenyl cations (**4c** and **4e**), from the corresponding methanohomoannulenes seemed very interesting.

Reaction of $Ph_3C^+BF_4^-$ with **3c** in CH_2Cl_2 resulted in immediate formation of yellow solids. The solids were insoluble in CD_3CN but slowly dissolved in $CDCl_3$ or CCl_4 forming a green solution, ^{1}H NMR spectrum of which, however, gave no definite signals indicative of the formation of the desired cationic species **4c**. It was therefore concluded that the solids were not the desired salt. The ^{1}H NMR spectrum of the solution obtained by admixing a solution of **3c** in $CDCl_3$ with a solution of $Ph_3C^+BF_4^-$ in $CDCl_3$ or in CD_3CN gave only uninterpretable broad humps and no signals ascribable to **4c** or triphenylmethane (the methine proton would appear

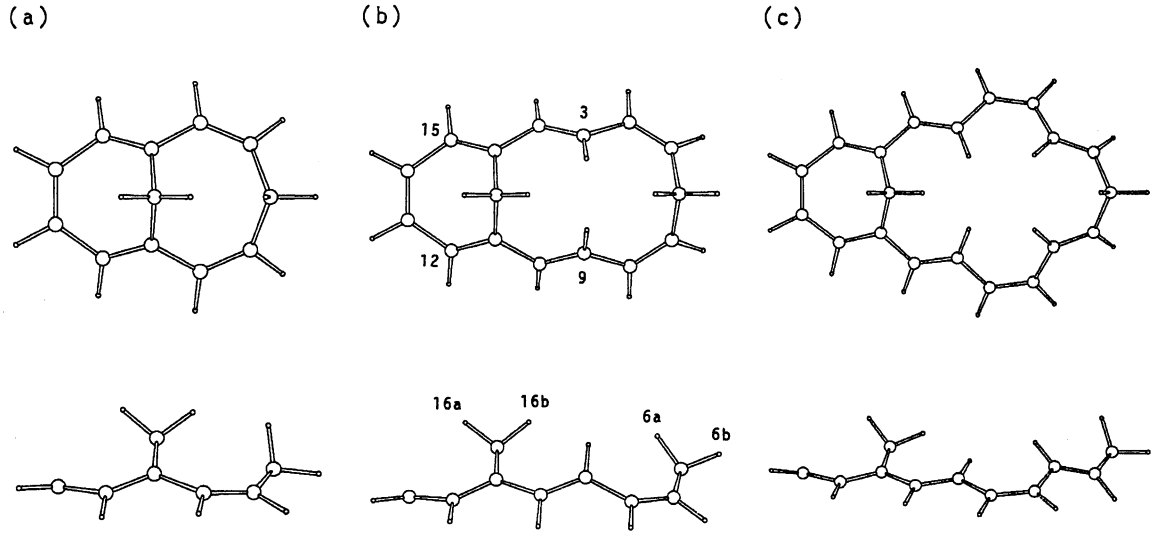


Fig. 2. The MM3-optimized geometries of the most stable conformation of (a) **3a**, (b) **3c**, and (c) **3e**. The top (upper) and side (lower) views.

at δ=ca. 5.6) were detected. This suggests that the hydride abstraction from **3c** did not occur at all, simply resulting in decomposition of **3c** presumably because of the instability of **3c**. These results discouraged us to attempt the preparation of **4e** from the even less stable **3e**.

Experimental

Melting points were determined on a hot-stage apparatus and are uncorrected. IR spectra were measured on a Hitachi 260-50 spectrophotometer as KBr disks and only significant peaks are reported. Electronic spectra were determined on a Hitachi 220A spectrophotometer (sh=shoulder). ^{1}H and ^{13}C NMR spectra were obtained on a Bruker AM-500 spectrometer at 500.1 and 125.7 MHz, respectively, in $CDCl_3$ solutions with tetramethylsilane as an internal standard. Mass spectra were recorded with a JMS D-300 spectrometer at 75 eV using a direct inlet system. Alumina (Merck, activity II-III) was used for column chromatography. Reactions were followed by TLC with aluminium sheets precoated with Merck silica gel F_{254}.

Bicyclo[9.4.1]hexadeca-2,4,7,9,11,13,15-heptaene (Methanohomo[15]annulene) (3c). A lithium ethoxide solution prepared from lithium (123 mg, 17.6 mmol) in dry ethanol (35 cm^3) was added dropwise during 2 h under argon to a stirred solution of 1,6-bis(2-formylvinyl)-1,3,5-cycloheptatriene (**1c**)[4] (800 mg, 4.00 mmol) and 1,3-bis(triphenylphosphonio)propane dibromide (**2**)[2] (6.39 g, 8.80 mmol) in *N*,*N*-dimethylformamide (DMF) (210 cm^3) at 60°C. After being stirred for further 30 min at 60°C, the mixture was cooled to room temperature, poured onto water, and extracted with benzene. The extracts were washed with brine and dried over anhydrous sodium sulfate. The residue obtained after removal of the solvent was chromatographed on alumina (3.8×10 cm). The fractions eluted with hexane afforded the methanohomo[15]annulene **3c** (50 mg, 6.0%). It formed yellow needles, mp 125—126°C, from hexane. Found: C, 92.04; H, 7.72%. Calcd for $C_{16}H_{16}$: C, 92.26; H, 7.74%. MS *m*/*z* 208 (M$^+$, 100%). IR 1000, 980, 960 (*E*-C=C), 730, and 690 cm^{-1} (*Z*-C=C). UV (THF) 282 (ε 62600) and 354 nm (5210). ^{1}H NMR (26°C) δ=7.028 (2H, m, H^{13} and H^{14}), 6.661 (2H, m, H^{12} and H^{15}), 6.490 (2H, d, *J*=15.6 Hz, H^2 and H^{10}), 6.332 (2H, t, *J*=11.0 Hz, H^4 and H^8), 5.883 (2H, dd, *J*=15.6 and 11.5 Hz, H^3 and H^9), 5.267 (2H, td, *J*=10.4 and 6.8 Hz, H^5 and H^7), 3.201 (1H, dt, *J*=13.0 and 10.6 Hz, H^{6a}), 2.911 (1H, dt, *J*=13.0 and 6.8 Hz, H^{6b}), 2.511 (1H, d, *J*=12.5 Hz, H^{16b}), and 0.078 (1H, d, *J*=12.5 Hz, H^{16a}). ^{13}C NMR δ=130.17t, 128.86t, 128.25t, 126.32t, 125.28q, 124.49t, 117.63t, 26.17s, and 26.12s.

Bicyclo[13.4.1]icosa-2,4,6,9,11,13,15,17,19-nonaene (Methanohomo[19]annulene) (3e). A lithium ethoxide solution prepared from lithium (275 mg, 39.8 mmol) in dry ethanol (80 cm^3) was added dropwise during 2 h under argon to a stirred solution of 1,6-bis(4-formyl-1,3-butadienyl)-1,3,5-cycloheptatriene (**1e**)[4] (2.00 g, 7.95 mmol) and the bisphosphonium salt **2**[2] (14.4 g, 20.0 mmol) in DMF (615 cm^3) at 60°C. After being stirred for 30 min at 60°C, the mixture was worked-up as for the isolation of **3c**. The dark brown liquid obtained after removal of the solvent was chromatographed on alumina (3.8×13 cm). The fractions eluted with hexane afforded the methanohomo[19]annulene **3e** (73 mg, 3.6%). It formed orange needles, mp 118—120°C (decomp), from hexane. Found: C, 92.02; H, 7.39%. Calcd for $C_{20}H_{20}$: C, 92.31; H, 7.69%. MS *m*/*z* 260 (M$^+$, 100%). IR 1000, 980 (*E*-C=C), 735, and 690 cm^{-1} (*Z*-C=C). UV (THF) 322 (ε 35400), 338 (40700), and 425 nm (5100). ^{1}H NMR (26°C) δ=6.753 (2H, dd, *J*=15.1 and 10.4 Hz, H^3 and H^{13}), 6.647 (2H, m, H^{17} and H^{18}), 6.617 (2H, dd, *J*=15.9 and 9.3 Hz, H^6 and H^{10}), 6.533 (2H, d, *J*=15.2 Hz, H^2 and H^{14}), 6.394 (2H, m, H^{16} and H^{19}), 6.23 (2H, m, H^5 and H^{11}), 6.20 (2H, m, H^4 and H^{12}), 5.770 (2H, dt, *J*=15.9 and 6.3 Hz, H^7 and H^9), 2.983 (2H, t, *J*=6.3 Hz, 8-CH_2), and 2.516 (2H, s, 20-CH_2). ^{13}C NMR δ=134.26t, 132.63q, 130.41t, 130.24t, 129.74t, 129.00t, 128.79t, 128.01t, 124.09t, 31.03s, and 26.33s.

Attempted Synthesis of Methanohomo[13]annulene 3b and Methanohomo[17]annulene 3d. A lithium ethoxide solution prepared from lithium (120 mg, 17.2 mmol) in

dry ethanol (40 cm^3) and a solution of 1-formyl-6-(2-formylvinyl)-1,3,5-cycloheptatriene (**1b**)[4] (500 mg, 2.87 mmol) in DMF (40 cm^3) were simultaneously added dropwise during 2 h under argon to a stirred suspension of **2**[2] (6.24 g, 8.61 mmol) in DMF (130 cm^3) at 60°C. After stirring for 1 h at 60°C, the mixture was worked-up as for the isolation of **3c**. However, the desired product **3b** was not detected at all despite of careful examinations of the eluates of the column chromatography.

A similar procedure with 1-(2-formylvinyl)-6-(4-formyl-1,3-butadienyl)-1,3,5-cycloheptatriene (**1d**)[4] also failed to give the desired methanohomoannulene **3d**.

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