Synthesis of Benzannelated Bisdehydro[14]-, -[16]-, -[18]-, and -[20]annulenes[1]

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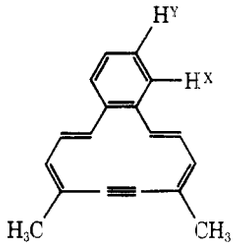
A new synthetic route to benzannelated bisdehydroannulenes is described, which led to the bisdehydrobenz[14]-annulenes 14 and **2**, the bisdehydrobenz[16]annulenes **25** and **26**, and the bisdehydrobenz[18]annulenes **35** and **36**, as well as the bisdehydrobenz[20]annulene **41**. The electronic and ^{1}H NMR spectra of the various benzannelated bisdehydroannulenes are discussed.

Macrocyclic annulenes containing an annelated benzene ring are an interesting class of compound, since the effect of each π system on the other can be studied. In particular, it has been calculated that in such substances the π-bond orders for the benzene rings depend characteristically on the number of π electrons in the annulene rings.[2] Until now, the only known representatives were the dimethylmonodehydrobenz[12]annulene **1** (no particular conformation implied)[3] and



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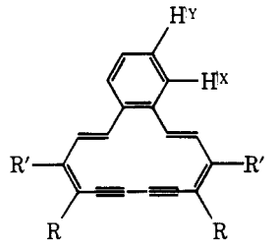
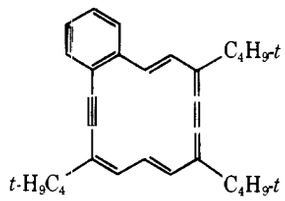


2, R = CH_3; R′ = H
3, R, R′ = $-(CH_2)_4-$



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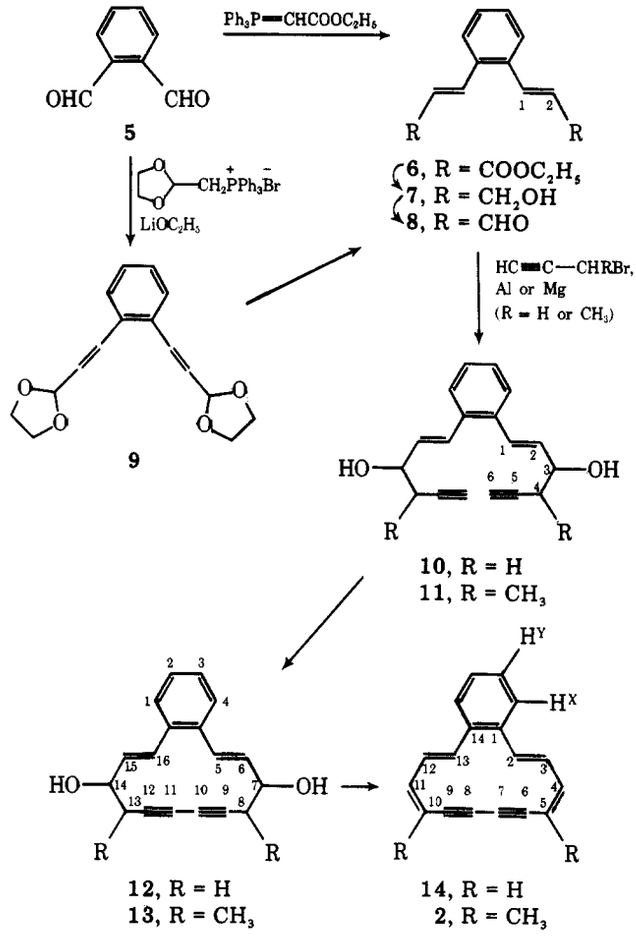
the alkylated bisdehydrobenz[14]annulenes **2**,[4] **3**,[4] and **4**.[5,6] Unfortunately, the dehydrobenzannulenes **1**, **2**, and **3** synthesized in our laboratories were obtained only in poor yield, and the methods used necessitated the presence of alkyl groups in the final products. We have now developed a greatly improved synthesis of bisdehydrobenzannulenes, which often proceeds in satisfactory yield, and appears to be of general applicability. In this paper we describe the use of this new synthesis for the preparation of the unsubstituted bisdehydrobenz[14]annulene **14**, -[16]annulene **25**, -[18]annulene **35**, and -[20]annulene **41**, as well as the dimethyl derivatives **2**, **26**, and **36** in the 14-, 16-, and 18-membered ring series, respectively.[7] The dimethyl derivatives were prepared in addition to the unsubstituted ones, since they were required as models for comparison with annulenoannulenes containing the same alkylation pattern.[8]

The synthesis of the bisdehydrobenz[14]annulene **14** (Scheme I) illustrates the method. Wittig reaction of *o*-phthalaldehyde (**5**) with 2 molar equiv of carbethoxymethylenetriphenylphosphorane[9] in boiling methylene chloride yielded 79% of the di-trans ester **6**. This substance was then converted to the dialdehyde **8** in 51% overall yield by reduction to the diol **7** with diisobutylaluminum hydride, followed by oxidation with manganese dioxide.[10] Alternatively, the transformation of **5** to **8** could be effected in ~50% yield by Wittig reaction of **5** with 1,3-dioxolan-2-ylmethyltriphenyl-

Scheme I



phosphonium bromide[11] and lithium ethoxide to give the bisacetal **9** (stereoisomeric mixture), followed by hydrolysis with hydrochloric acid.

Grignard reaction of the dialdehyde **8** with an excess of the aluminum derivative of propargyl bromide[12] led to a stereoisomeric mixture of the diols **10** in 92% yield. This mixture in aqueous ethanol, benzene, and hydrochloric acid was subjected to oxidative coupling with oxygen in the presence of cuprous chloride and ammonium chloride at 60 °C ("Glaser conditions"). The resulting crude stereoisomeric macrocyclic diols **12** (68% yield) were then treated with 2 molar equiv of methanesulfonyl chloride and triethylamine[13] to give the corresponding dimethanesulfonates, which were subjected to elimination with 2 molar equiv of 1,5-diazabicyclo[4.3.0]-non-5-ene (DBN). This procedure furnished 65% of the desired bisdehydrobenz[14]annulene **14** (40% overall yield from the dialdehyde **8**) as relatively stable, golden yellow needles. Alternatively, the bisdehydrobenz[14]annulene **14** could be obtained directly from the diols **12** in 25% yield by dehydration

with phosphorus oxychloride and pyridine in dimethoxyethane.

The dimethylbisdehydrobenz[14]annulene **2** was obtained analogously (Scheme I). Grignard reaction of the dialdehyde **8** with an excess of the magnesium derivative of 3-bromo-1-butyne[12,14] gave a mixture of the stereoisomeric diols **11.** In this case, the oxidative coupling was carried out with anhydrous cupric acetate[15] in pyridine at 50 °C.[16] The resulting diols **13** were then converted to the corresponding dimethanesulfonates, which were subjected to elimination with DBN. The dimethylbisdehydrobenz[14]annulene **2,** obtained in 37% yield from the dialdehyde **8,** proved to be identical with that obtained previously.[4] The presently described synthesis of **2** is greatly superior to the previous one,[4] since the double bonds adjacent to the benzene ring are introduced stereospecifically in the required trans configuration, and the oxidative coupling of terminal diacetylenes of type **10** and **11** containing hydroxyl groups usually proceeds in much better yield than when the coupling is carried out with hydrocarbons using normal dilutions.[17]

The intermediate required for the synthesis of the bisdehydrobenz[16]annulenes **25** and **26** (Scheme II) was the dialdehyde **18,** a vinylog of the above described dialdehyde **8.** Substance **18** could be obtained by two routes. The preferred one used the diol **7** as starting material, which on oxidation with a limited amount of manganese dioxide gave the monoaldehyde **15** in 56% yield. Reaction of **15** with the salt obtained from triethyl phosphonoacetate and sodium hydride[19] led to the ester **16,** which on reduction with diisobutylaluminum hydride to **17** and subsequent oxidation with manganese dioxide gave 51% (based on **15**) of the dialdehyde **18.**

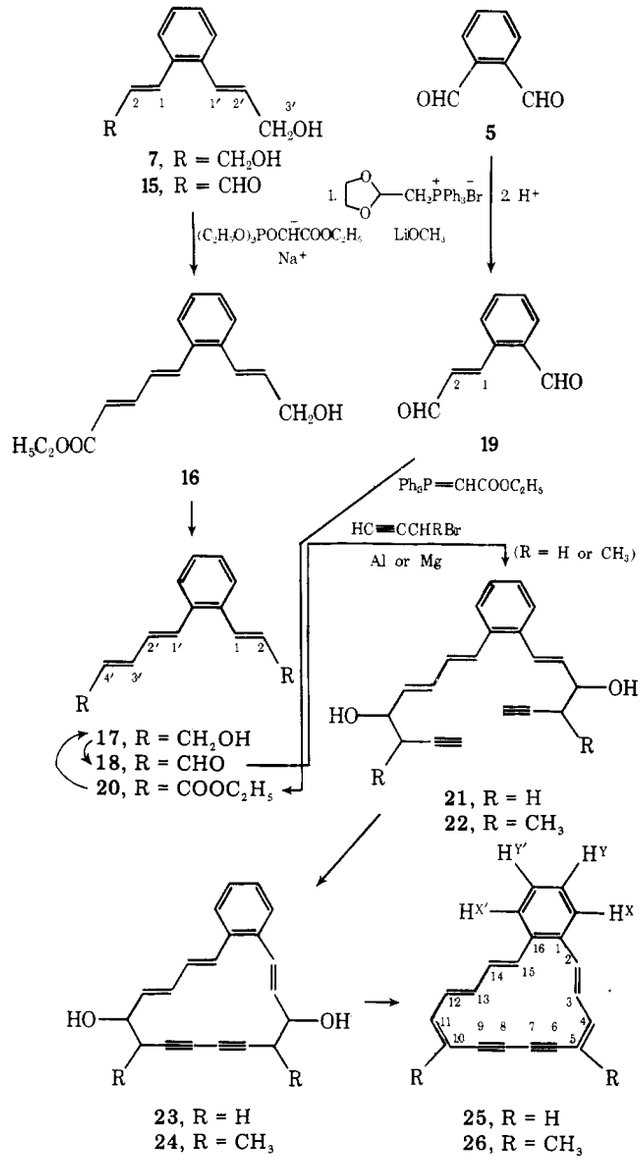
The second route to **18** involved Wittig reaction of *o*-phthalaldehyde (**5**) with 1 molar equiv of 1,3-dioxolan-2-ylmethyltriphenylphosphonium bromide[11] and lithium methoxide, followed by hydrolysis with hydrochloric acid, to give the monovinylog **19** in 18% yield. Treatment of **19** with 2 molar equiv of carbethoxymethylenetriphenylphosphorane[9] then led to 80% of the diester **20,** which could be converted to the dialdehyde **18** via the diol **17** in 62% yield by reduction with diisobutylaluminum hydride and subsequent oxidation with manganese dioxide.

The conversion of the dialdehyde **18** to the bisdehydrobenz[16]annulene **25** (by the sequence **18** → **21** → **23** → **25;** overall yield 53%) and to the dimethylbisdehydrobenz[16]annulene **26** (by the sequence **18** → **22** → **24** → **26;** overall yield 18%) was carried out essentially as described for the corresponding bisdehydrobenz[14]annulenes **14** and **2,** except that both **21** and **22** were oxidatively coupled by means of cupric acetate monohydrate in dimethylformamide at 50–60 °C. The annulenes **25** and **26** formed red needles, mp 98–99 and 133–134 °C, respectively.

Several methods were investigated for the synthesis of the dialdehyde **30,** the intermediate required for the preparation of the bisdehydrobenz[18]annulenes **35** and **36** (Scheme III). The most convenient one involved the Wittig reaction of *o*-phthalaldehyde (**5**) with 2 molar equiv of the ylide **27.**[20] The resulting diester **28,** obtained as a stereoisomeric mixture in 82% yield, was then reduced with diisobutylaluminum hydride to the diols **29.** Oxidation with manganese dioxide and subsequent isomerization with iodine led to the all-trans dialdehyde **30** in 34% yield (based on **28**). The subsequent steps paralleled the ones used for the syntheses of the benzannelated bisdehydro[14]- and bisdehydro[16]annulenes. The bisdehydrobenz[18]annulene **35** (dark red needles) and the dimethylbisdehydrobenz[18]annulene **36** (orange needles, mp 214–216 °C) were obtained thereby in 21 and 11% yield, respectively, based on **30.**

The dialdehyde **39,** required for the synthesis of the bis-

Scheme II

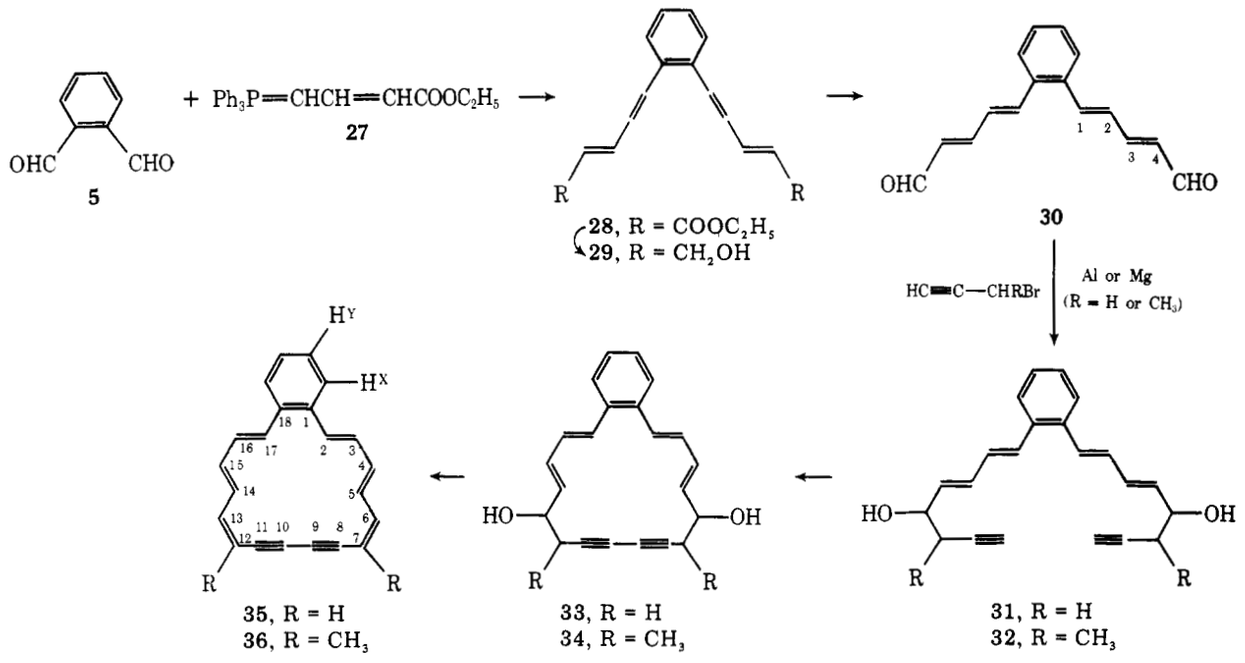


dehydrobenz[20]annulene **41** (Scheme IV), was prepared in 64% yield by the Wittig reaction of the dialdehyde **18** with 2 molar equiv of carbethoxymethylenetriphenylphosphorane[9] followed by reduction of the resulting diester **37** with diisobutylaluminum hydride and oxidation of the diol **38** with manganese dioxide. The usual reaction sequence (Scheme IV) then gave the bisdehydrobenz[20]annulene **41** in 20% overell yield (based on **39**) as purple-brown crystals.

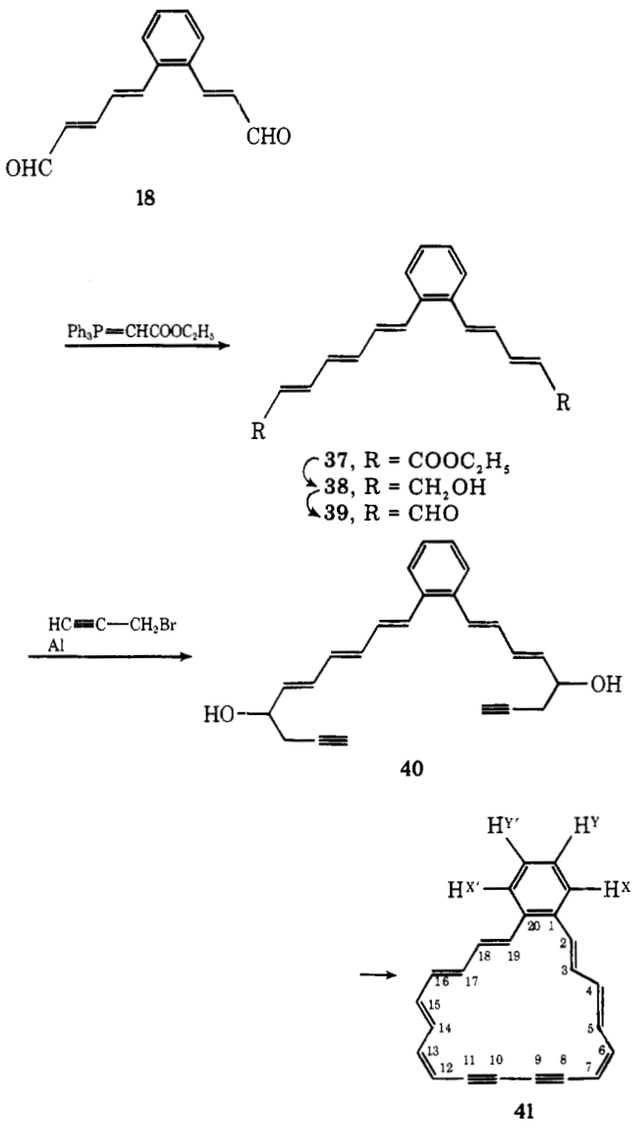
The electronic spectra of the various bisdehydrobenzannulenes were complex (see Experimental Section). The main maxima are given in Table I, as well as those of the nonannelated and unsubstituted bis- or trisdehydroannulenes.[21] It is evident that in the benzannelated compounds the same alternation in the wavelengths of the main maxima of $(4n + 2)$ and $4n$ π systems occurs, as has already been observed for the monocyclic annulenes[22a] and dehydroannulenes.[22b] For each ring size, fusion of the benzene ring results in an appreciable bathochromic shift (4–16 nm), but the introduction of the methyl groups into the benzannulenes causes only a very small bathochromic shift (1–3 nm).[23]

The ^{1}H NMR spectra of the various bisdehydrobenz[14]-, -[16]-, and -[18]annulenes, given in the Experimental Section, confirm the assigned structures and indicated conformations. We have already discussed[4,8] that the spectra show the macrocyclic rings in the dimethylbisdehydrobenz[14]annulene **2**

Scheme III



Scheme IV



and -[18]annulene **36** to be diatropic, and in the dimethylbisdehydrobenz[16]annulene **26** to be paratropic, although the ring currents have been reduced by fusion of the benzene rings.[24] Examination of the ^{1}H NMR spectra of the corresponding nonalkylated bisdehydrobenzannulenes **14, 35,** and **25** indicates that the two methyl groups, as expected, cause little effect, although generally the macrocyclic ring currents of the nonalkylated compounds appear to be slightly greater than those of the dimethyl series.

The ^{1}H NMR spectrum of the bisdehydrobenz[20]annulene **41** exhibited a 5 H low-field and a 9 H high-field band due to the olefinic protons, showing the 20-membered ring to be paratropic (although the magnitude of the ring current was again less than in a nonbenzannelated bisdehydro[20]annulene[22c]). This observation, together with the method of synthesis, also indicates **41** to possess the indicated configuration, although a definite conformation could not be assigned in this case.

It is also of interest to examine the effect on the ^{1}H NMR resonances of the benzene ring caused by annelation of the macrocyclic π systems. In the model system **42**,[4] the H^X protons resonate at τ 2.47 and the H^Y protons at τ 2.78 (in $CDCl_3$), the assumption being made that H^X is more affected than H^Y by the unsaturated substituents. Compared with this model, it is clear from Table II that fusion of 14- and 18-membered rings ($4n + 2$ series) causes a downfield shift of the benzenoid proton resonances, this effect being greater for H^X than for H^Y. Conversely, fusion of 12-, 16-, and 20-membered rings ($4n$ series) causes an upfield shift of the benzene resonances; undoubtedly the effect is again greater for H^X (and $H^{X'}$) than H^Y (and $H^{Y'}$), resulting in these resonances appearing as relatively narrow bands. These observations must arise from the

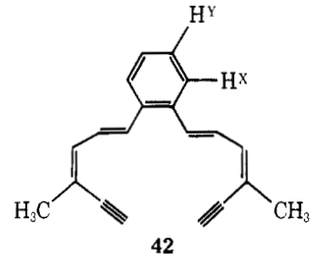


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Table I. Main Electronic Absorption Maxima of the Bisdehydrobenzannulenes 2, 14, 25, 26, 35, 36, and 41, and of Nonannelated Analogues, in Ether or 2,2,4-Trimethylpentane (nm; ϵ Values in Parentheses)

Ring size	Bisdehydro-benzannulene	Dimethylbisdehydro-benzannulene	Bisdehydro- or trisdehydro-annulene[a]	
[14]	**14**, 317 (49 100)	**2**, 318 (54 000)	1,7-	304 (83 000)
			1,8-	310 (210 000)
[16]	**25**, 297 (61 400)	**26**, 298 (81 500)	1,3-	281 (55 000)
			1,9-	283 (54 000)
[18]	**35**, 339 (68 700)	**36**, 342 (64 600)	1,7,13-I-	335 (190 000)
			1,7,13-II-	331 (166 000)
[20]	**41**, 324 (95 300)		1,11-	319 (109 000)

[a] See ref 22b.

Table II. Benzenoid ^{1}H NMR Chemical Shifts of Benzannelated Dehydroannulenes at 100 MHz in $CDCl_3$ (τ Values; Internal Standard, Me_4Si)

Registry no.	Dehydrobenzannulene	H^X ($H^{X'}$)	H^Y ($H^{Y'}$)
52421-94-0	Model system **42**[a]	2.47	2.78
59035-73-3	Dimethylmonodehydro[12]-, **1**[b]	2.92	2.92
61650-35-9	Bisdehydro[14]-, **14**[c]	1.69	2.50
61650-36-0	Dimethylbisdehydro[14]-, **2**[a]	1.75	2.49
61650-37-1	Bisdehydro[16]-, **25**	2.8–3.3	
61650-38-2	Dimethylbisdehydro[16]-, **26**	2.9–3.2	
61675-26-1	Bisdehydro[18]-, **35**[c]	1.90	2.49
61650-39-3	Dimethylbisdehydro[18]-, **36**	1.94	2.58
61650-40-6	Bisdehydro[20]-, **41**	2.8–3.2	

[a] Reference 4. [b] Reference 3. [c] The specific assignments of the H^X and H^Y resonances in these compounds were confirmed by long-range coupling observed between H^X and the α protons in the annulene ring (H. Günther, private communication).

predominance of the deshielding of the dehydro[4*n* + 2]-annulenes and shielding of the dehydro[4*n*]annulenes over the ring current of the fused benzene ring.

It was clearly of interest to investigate the benzene π-bond order of the dehydrobenzannulenes described in this paper, in view of the work of Günther et al.,[2] and several of these substances were sent to Professor Günther (University of Cologne) for this purpose. Unfortunately, in the demethyl series, the 16- and 20-membered ring compounds **25** and **41** decomposed during transit, whereas the 14- and 18-membered ring compounds **14** and **35** were essentially unchanged. This shows that "aromatic" macrocyclic (4*n* + 2) systems are more stable than "antiaromatic" 4*n* systems![25] The results obtained with **14** and **35**, as well as with the dimethylbisdehydrobenz-[16]annulene **26** (which proved to be considerably more stable than the demethyl analogue **25**), will be reported subsequently.

Experimental Section

General Procedures. Melting points were determined on a Kofler hot stage apparatus and are uncorrected. Infrared spectra were measured on a Unicam SP 200 spectrophotometer or on a Perkin-Elmer 177 grating spectrophotometer (s = strong, m = medium, w = weak); only significant maxima are reported. Electronic spectra were determined on a Unicam SP 800 or a Unicam SP 1800 spectrophotometer (sh = shoulder). ^{1}H NMR spectrum were recorded as $CDCl_3$ solutions on a Varian T-60 (60 MHz), a Varian HA-100 (100 MHz), or a Perkin-Elmer R34 (220 MHz) spectrometer, tetramethylsilane being used as internal standard. Assignments were clarified by the use of decoupling experiments where necessary. Mass spectra were determined on an AEI MS-12 or (for accurate mass measurements) on an AEI MS-902 spectrometer, both operating at 70 eV. Alumina for column chromatography refers to Woelm activity III and silica to Woelm activity II. Compounds were preadsorbed from ether or dichloromethane solution onto the adsorbent before column chromatography on the same adsorbent. Benzene, dimethylformamide (DMF), and 1,5-diazabicyclo[5.4.0]non-5-ene (DBN) were stored over 4 Å molecular sieves for a prolonged period before use. Petrol (light petroleum, bp 40–60 °C) was distilled from P_4O_{10} before use. Tetrahydrofuran (THF) was refluxed over $LiAlH_4$ and distilled under argon before use. 1,2-Dimethoxyethane (DME) was distilled from $LiAlH_4$ before use. Reactions were carried out under prepurified nitrogen and organic extracts were dried over magnesium sulfate before solvent removal.

1,2-Bis(2-ethoxycarbonylethenyl)benzene (6).[10] A solution of *o*-phthalaldehyde (**5**, 24.8 g, 0.185 mol) in dichloromethane (200 mL) was added dropwise over 1 h to a stirred solution of carbethoxymethylenetriphenylphosphorane[9] (129 g, 0.37 mol) in dichloromethane (1 L). The solution was then boiled under reflux for 19 h, acetone (25 mL) was added, and boiling was continued for a further 1 h. The solvents were removed under reduced pressure and the residue was extracted with ether (7 × 150 mL). Evaporation of the ether, removal of triphenylphosphine oxide by filtration as it precipitated, and crystallization from methanol yielded the trans,trans diester **6** (40.1 g, 79%) as prisms: mp 78–79 °C (lit.[26] mp 81 °C); IR ($CHCl_3$) 1710 s (COOEt), 1640 s (C=C), 975 cm^{-1} m (trans HC=CH); ^{1}H NMR (60 MHz) τ 1.93 (d, $J_{1,2}$ = 16 Hz, H-1), 2.3–2.7 (m, benzenoid H), 3.63 (d, $J_{2,1}$ = 16 Hz, H-2), 5.68 (q, $CO_2CH_2CH_3$), 8.64 (t, $CO_2CH_2CH_3$).

1,2-Bis(3-hydroxy-1-propenyl)benzene (7).[10] A solution of diisobutylaluminum hydride (50 mL) in dry benzene (100 mL) was added dropwise over 1 h to a stirred solution of the diester **6** (17.0 g) in benzene (600 mL) at ambient temperature (water bath cooling). The mixture was allowed to stand overnight, and methanol (300 mL) was then added. The mixture was filtered, the solid was washed well with methanol, and the solvents were evaporated. Crystallization from methanol yielded the diol **7** (7.67 g, 65%) as prisms: mp 91–91.5 °C; IR ($CHCl_3$) 3330 s (broad, OH), 965 cm^{-1} s (trans HC=CH); ^{1}H NMR (60 MHz) τ 2.4–3.0 (m, benzenoid H), 3.05 (d, $J_{1,2}$ = 16 Hz, H-1), 3.80 (dt, $J_{2,1}$ = 16, J_{2,CH_2} = 6 Hz, H-2), 5.65 [d(b), $J_{CH_2,2}$ = 6 Hz, CH_2], 8.10 [s(b), OH].

Anal. Calcd for $C_{12}H_{14}O_2$: C, 75.76; H, 7.42. Found: C, 75.55; H, 7.35.

1,2-Bis(2-formylethenyl)benzene (8). A. From the Diol 7.[10] The diol **7** (7.5 g) in dichloromethane (1.1 L) was stirred with activated manganese dioxide[27] (75 g) at ambient temperature for 23 h. The mixture was filtered through Celite, and the solid was washed well with dichloromethane. Evaporation of the solvent and crystallization from ethyl acetate gave the dialdehyde **8** (5.84 g, 79%): mp 115–116 °C; IR ($CHCl_3$) 1680 s (C=O), 970 cm^{-1} m (trans HC=CH); ^{1}H NMR (60 MHz) τ 0.25 (d, $J_{CHO,2}$ = 8 Hz, CHO), 2.10 (d, $J_{1,2}$ = 16 Hz, H-1), 2.15–2.7 (benzenoid H), 3.37 (dd, $J_{2,1}$ = 16, $J_{2,CHO}$ = 8 Hz, H-2).

Anal. Calcd for $C_{12}H_{10}O_2$: C, 77.40; H, 5.41. Found: C, 77.03; H, 5.47.

B. From *o*-Phthalaldehyde (5) via the Bisacetal 9. A solution of lithium ethoxide, prepared by dissolving lithium (210 mg, 30 mg-atoms) in dry ethanol (50 mL), was added dropwise during 4 h to a stirred solution of 1,3-dioxolan-2-ylmethyltriphenylphosphonium bromide[11] (12.9 g, 30 mmol) and *o*-phthalaldehyde (**5**, 1.34 g, 10 mmol) in dry DMF (100 mL) at 80–90 °C (bath) under a reflux condenser. After a further 1 h, the reaction mixture was cooled and poured into brine (600 mL). The resultant mixture was extracted with ether (3 × 200 mL), and the combined extracts were washed with brine. Drying and evaporation led to the crude bisacetal **9**, the complex ^{1}H NMR spectrum of which indicated it to be a stereoisomeric mixture. The crude material was hydrolyzed by solution in tetrahydrofuran (50 mL) and addition of 10% hydrochloric acid (50 mL). After being allowed to stand for 3 h at ambient temperature, the solution was extracted with chloroform, and the extracts were washed with sodium bicarbonate solution and water, dried, and evaporated. The residue was chromatographed on a column of silica (75 g) with 30% ethyl acetate–petrol as eluent. Crystallization from ethyl acetate gave the dialdehyde **8** (0.95 g, 51% based on **5**), identical with that prepared by method A.

1,2-Bis(3-hydroxy-1-hexen-5-ynyl)benzene (10). A solution of propargyl bromide (2.04 g, 17 mmol) in dry ether (15 mL) was added dropwise over 15 min to a stirred mixture of small pieces of aluminum foil (0.31 g, 12 mg-atoms), mercuric chloride (70 mg), and dry ether (5 mL) under reflux. The mixture was boiled under reflux for 5 h, cooled to −30 °C, and stirred rapidly while a solution of the dialdehyde **8** (0.85 g, 4.5 mmol) in DME (25 mL) was added over 5 min. The mixture was allowed to warm to 0 °C over 15 min, ice and water were added, and the aqueous layer was extracted with ether. The residue after solvent removal, dissolved in the minimum of chloroform, was chromatographed on a column of silicic acid (3 × 3 cm). Elution with 2% ethanol–chloroform yielded the diol **10** (stereoisomeric mixture, 1.10 g, 92%) as a colorless oil: mass spectrum *m/e* 266 (M^+); IR (film) 3375 m (OH), 3300 m (C≡CH), 2130 w (C≡C), 975 cm^{-1} m (trans HC=CH); ^{1}H NMR (60 MHz) τ 2.78 (m, benzenoid H), 3.05 (d, $J_{1,2}$ = 16 Hz, H-1), 3.85 (dd, $J_{2,1}$ = 16, $J_{2,3}$ = 6 Hz, H-2), 5.56 (m, H-3), 7.02 [s(b), OH], 7.48 (dd, $J_{4,3}$ = 6, $J_{4,6}$ = 2 Hz, H-4), 7.90 (t, $J_{6,4}$ = 2 Hz, H-6).

9,10,11,12-Tetradehydro-7,8,13,14-tetrahydrobenzocyclotetradecene-7,14-diol (12). A solution of the diol **10** (4.0 g, 15 mmol) in ethanol (30 mL) was added to a stirred mixture of cuprous chloride (65 g), ammonium chloride (110 g), water (400 mL), and concentrated hydrochloric acid (6 mL) at 60 °C. After 5 min, benzene (240 mL) and ethanol (110 mL) were added, and the mixture was stirred for 2 h while a vigorous stream of oxygen was bubbled into the mixture. The volume was maintained by the periodic addition of benzene–ethanol (5:1). The mixture was then cooled to ambient temperature and sufficient 4 N hydrochloric acid was added to effect dissolution of the salts. The aqueous layer was extracted with ether (3 × 250 mL), and the combined organic phases were dried and evaporated. Trituration of the residue with chloroform afforded the diol **12** (stereoisomeric mixture, 2.72 g, 68%) as a nearly colorless solid: mp >130 °C dec; IR (Nujol) 3300 s (OH), 2275 w (C≡C), 970 s and 960 cm^{-1} m (trans HC=CH); ^{1}H NMR (60 MHz) τ 2.4–3.2 (m, benzenoid H, H-5, H-16), 3.7–4.4 (m, H-6, H-15), 5.2–5.7 (m, H-7, H-14), 7.2–7.7 (m, H-8, H-13). The diol **12** was used in subsequent reactions without further purification.

6,8-Bisdehydrobenz[14]annulene (9,10,11,12-Tetradehydrobenzocyclotetradecene, 14). A. Methanesulfonate Method. A solution of triethylamine (0.67 g, 6.7 mmol) in DME (1.5 mL) was added dropwise over 5 min to a stirred, ice-cooled solution of the diol **12** (0.80 g, 3.0 mmol) and methanesulfonyl chloride (0.73 g, 6.4 mmol) in DME (18 mL). After 20 min at 0 °C, the precipitated salts were removed by filtration and a solution of DBN (0.93 g, 7.5 mmol) in DME (1.5 mL) was added dropwise over 5 min to the ice-cooled stirred filtrate. After a further 5 min, the ice bath was removed and the mixture stirred for 45 min at ambient temperature. The reaction mixture was then poured onto water and extracted with benzene. The residue, after solvent removal, was chromatographed on a column of alumina (5 × 3 cm) with benzene as eluent. Crystallization from hexane led to the benz[14]annulene **14** (0.45 g, 65%) as golden yellow needles: mp >165 °C dec; MS *m/e* 228 (M^+); UV (Et_2O) λ_{max} 262 nm (ϵ 8500), 276 sh (11 000), 317 (49 100), 380 (4000), 398 (3950), 416 sh (2600); IR ($CHCl_3$) 2180 w (C≡C), 985 cm^{-1} m (trans HC=CH); ^{1}H NMR (100 MHz) τ 1.69 (m, H^X), 2.40 (dd, $J_{3,2}$ = $J_{12,13}$ = 16, $J_{3,4}$ = $J_{12,11}$ = 7 Hz, H-3, H-12), 2.50 (m, H^Y), 2.71 (dd, $J_{4,5}$ = $J_{11,10}$ = 11, $J_{4,3}$ = $J_{11,12}$ = 7 Hz, H-4, H-11), 3.58 (d, $J_{5,4}$ = $J_{10,11}$ = 11 Hz, H-5, H-10), 5.44 (d, $J_{2,3}$ = $J_{13,12}$ = 16 Hz, H-2, H-13).

Anal. Calcd for $C_{18}H_{12}$: C, 94.70; H, 5.30. Found: C, 94.59; H, 5.30.

B. Phosphorus Oxychloride Method. A stirred solution of the diol **12** (0.16 g, 0.6 mmol) and pyridine (0.25 g, 3.2 mmol) in DME (6 mL) was cooled to −30 °C and phosphorus oxychloride (30 drops) was added. The cooling bath was removed after 15 min, and the mixture was stirred at ambient temperature for 19 h. It was then poured onto water and extracted with ether, and the extracts were washed with water. The residue after solvent removal was chromatographed on a column of alumina (3 × 2 cm) with pentane as eluent. Early fractions afforded, after crystallization from hexane, the benz[14]annulene **14** (34 mg, 25%) as golden yellow needles, identical with that prepared by method A.

5,10-Dimethyl-6,8-bisdehydrobenz[14]annulene (8,13-Dimethyl-9,10,11,12-tetradehydrobenzocyclotetradecene, 2). A small portion of a solution of 3-bromo-1-butyne[14] (1.2 g, 9.1 mmol) in dry ether (5 mL) was added to a stirred mixture of magnesium (0.21 g, 8.6 mg-atoms) and mercuric chloride (10 mg) in dry ether (20 mL). When the mixture had become cloudy (~5 min), it was cooled in an ice bath, and the remainder of the bromide solution was added over 2 min. After 2 h at 0 °C, the mixture was cooled to −30 °C, and a solution of the dialdehyde **8** (0.20 g, 1.1 mmol) in THF (10 mL) was added in a thin stream. The resultant mixture was allowed to warm to 0 °C over 15 min, and saturated aqueous ammonium chloride was then added. Extraction with ether, followed by solvent removal, gave the crude diol **11** (stereoisomeric mixture) as an oil (0.38 g).

A solution of crude **11** (0.38 g) in pyridine (20 mL) was added dropwise over 2 h to a stirred solution of anhydrous cupric acetate[15] (4.0 g) in pyridine (100 mL) and dry ether (30 mL) at 50 °C. After a further 1 h at 50 °C, the solution was cooled and the solvents were evaporated. Water was added to the residue, the mixture was extracted with ether, and the organic extract was washed with water. Solvent removal yielded the crude diol **13** (stereoisomeric mixture) as a light brown froth (0.33 g).

A solution of triethylamine (0.22 g, 2.2 mmol) in THF (3 mL) was added over 2 min to a stirred, ice-cooled solution of the crude diol **13** (0.33 g) and methanesulfonyl chloride (0.25 g, 2.1 mmol) in THF (15 mL). After 1.5 h, the salts were separated by filtration, and a solution of DBN (1.3 g, 10.5 mmol) in THF (8 mL) was added dropwise over 10 min to the stirred filtrate with ice cooling. The ice bath was then removed, and the mixture was stirred at ambient temperature for 3 h. The mixture was then poured onto water and extracted with ether, and the extract was washed with water. The residue, after solvent removal, was chromatographed on a column of alumina (6 × 4 cm) with 10% ether–petrol as eluent. Crystallization from dichloromethane–petrol gave the benz[14]annulene **2** (102 mg, 37% based on **8**) as orange needles, mp 176–177 °C (lit.[4] mp 174–175 °C). The electronic and ^{1}H NMR spectra were identical with those reported previously.[4]

Anal. Calcd for $C_{20}H_{16}$: C, 93.71; H, 6.29. Found: C, 93.49; H, 6.34.

1-(2-Formylethenyl)-2-(3′-hydroxy-1′-propenyl)benzene (15). A solution of the diol **7** (4.3 g, 23 mmol) in dichloromethane (100 mL) was stirred with activated manganese dioxide[27] (16 g) for 15 h. A further quantity (10 g) of manganese dioxide was added, and the mixture was then stirred and heated under reflux for 3 h. The solid was separated by filtration and washed well with dichloromethane. The combined filtrates were dried ($MgSO_4$), concentrated to ~10 mL, and applied to a column of silica gel (10 × 4 cm). Elution with dichloromethane afforded the monoaldehyde **15** (2.35 g, 56%) as a pale yellow gum, homogeneous by TLC examination: MS *m/e* 188 (M^+), 170 ($M^+ - H_2O$), 159 ($M^+ - CHO$), 158 ($M^+ - CH_2O$), 157 ($M^+ - CH_2OH$); IR (film) 3410 m (OH), 1672 (C=O), 968 cm^{-1} m (trans HC=CH); ^{1}H NMR (100 MHz) τ 0.34 (d, $J_{CHO,2}$ = 7 Hz, CHO), 2.16 (d, $J_{1,2}$ = 16 Hz, H-1), 2.38–2.80 (m, benzenoid H), 3.03 (dt, $J_{1',2'}$ = 16, $J_{1',3'}$ = 2 Hz, H-1′), 3.38 (dd, $J_{2,1}$ = 16, $J_{2,CHO}$ = 7 Hz, H-2), 3.76 (dd, $J_{2',1'}$ = 16, $J_{2',3'}$ = 6 Hz, H-2′), 5.61 (dd, $J_{3',2'}$ = 6, $J_{3',1'}$ = 2 Hz, H-3′), 7.22 [s(b), OH]. The amount of manganese dioxide needed depends on its activity, and the reaction can be conveniently followed by TLC examination.

1-(2-Formylethenyl)-2-(4′-formyl-1′,3′-butadienyl)benzene (18) from 15. A stirred mixture of the salt obtained from triethyl phosphonoacetate (4.5 g, 20 mmol) and sodium hydride (0.79 g of a 57% mineral oil dispersion rendered oil free by washing with pentane; 19 mmol) in dry benzene (50 mL) was treated dropwise over 15 min with a solution of the monoaldehyde **15** (2.3 g, 12 mmol) in dry benzene (10 mL) at ambient temperature. After a further 30 min, the mixture was poured onto water and extracted with ether, and the extracts were washed with water. Solvent removal resulted in the crude ester **16** (3.64 g) as a viscous, pale yellow gum.

A solution of diisobutylaluminum hydride (4.4 g, 31 mmol) in dry benzene (22 mL) was added dropwise over 20 min to an ice-cooled stirred solution of the crude ester **16** (3.64 g) in dry benzene (50 mL). The ice bath was then removed and the solution was stirred at ambient temperature for 30 min before being recooled in an ice bath. Methanol (5 mL) was added cautiously and the resultant mixture was poured onto ice-cold 2 N hydrochloric acid (150 mL) and extracted with ether. The extracts were washed successively with 2 N hydrochloric acid, saturated sodium bicarbonate solution, and water. Solvent removal gave the crude diol **17** (2.46 g) as a yellow gum.

A solution of the crude diol **17** (2.46 g) in dichloromethane (80 mL) was stirred with activated manganese dioxide[27] (29 g) for 4 h. The solid was separated by filtration and washed well with dichloromethane. Evaporation of the combined filtrates afforded the dialdehyde **18** as a yellow solid (1.33 g, 51% based on **15**), homogeneous by TLC examination. Crystallization from 95% ethanol gave yellow prisms: mp 124–126 °C; MS *m/e* 212 (M^+); UV (EtOH) λ_{max} 288 nm (ϵ 37 900), 333 (38 600); IR (KBr) 1667 s (C=O), 983 m and 972 cm^{-1} w (trans HC=CH); ^1H NMR (100 MHz) τ 0.22 (d, $J_{CHO,4'}$ = 8 Hz, CHO next to H-4'), 0.33 (d, $J_{CHO,2}$ = 8 Hz, CHO next to H-2), 2.21 (d, $J_{1,2}$ = 16 Hz, H-1), 2.05–3.32 (m, benzenoid H, H-1', H-2', H-3'), 3.33 (dd, $J_{2,1}$ = 16, $J_{2,CHO}$ = 8 Hz, H-2), 3.67 (dd, $J_{4',3'}$ = 16, $J_{4',CHO}$ = 8 Hz, H-4').

Anal. Calcd for $C_{14}H_{12}O_2$: C, 79.23; H, 5.70. Found: C, 78.76; H, 5.78.

***o*-Formylcinnamaldehyde (19).** A solution of lithium methoxide, prepared by dissolving lithium (0.43 g, 62 mg-atoms) in absolute methanol (190 mL), was added dropwise over 3 h to a stirred solution of *o*-phthalaldehyde (**5**, 7.5 g, 56 mmol) and 1,3-dioxolan-2-ylmethyltriphenylphosphonium bromide[11] (26.4 g, 62 mmol) in dry DMF (300 mL) at 80–85 °C (bath) under a reflux condenser. After a further 30 min, the reaction mixture was cooled and poured onto water. The mixture was extracted with ether and the extracts were washed with water. Removal of solvent gave a dark, oily residue which was dissolved in THF (150 mL) and stirred with 10% hydrochloric acid (100 mL) for 1 h. The mixture was poured onto water and extracted with ether. The extracts were washed with saturated sodium bicarbonate solution and then with water. The semisolid mass remaining after solvent removal was extracted with ether (5 × 25 mL), and the combined extracts were evaporated. The dark, oily residue was then chromatographed on a column of silica gel (10 × 4 cm) with 35% ethyl acetate–pentane as eluent. The second compound eluted was the impure dialdehyde **19** which was rechromatographed as before. Crystallization from ethyl acetate–cyclohexane yielded pure **19** (1.58 g, 18%) as yellow needles: mp 62–63 °C; MS *m/e* 160 (M^+); IR ($CHCl_3$) 1690 s and 1670 s (C=O), 980 cm^{-1} s (trans HC=CH); ^1H NMR (60 MHz) τ −0.28 (s, CHO), 0.15 (d, $J_{CHO,2}$ = 8 Hz, unsaturated CHO), 1.40 (d, $J_{1,2}$ = 16 Hz, H-1), 1.8–2.5 (m, benzenoid H), 3.32 (dd, $J_{2,1}$ = 16, $J_{2,CHO}$ = 8 Hz, H-2).

Anal. Calcd for $C_{10}H_8O_2$: C, 74.99; H, 5.03. Found: C, 74.76; H, 4.98.

1-(Formylethenyl)-2-(4'-formyl-1',3'-butadienyl)benzene (18) from 19. A stirred solution of the dialdehyde **19** (1.55 g, 9.7 mmol) and carbethoxymethylenetriphenylphosphorane[9] (6.75 g, 19 mmol) in dichloromethane (70 mL) was heated under reflux for 19 h. The mixture was cooled, the solvents were evaporated, and the residue was extracted with ether (5 × 15 mL). The ether was evaporated and the residue was chromatographed on a column of silica gel (90 g) with 30% ethyl acetate–petrol as eluent. Early fractions afforded the diester **20** (2.3 g, 80%) as a yellow gum: ^1H NMR (60 MHz) τ 1.35 (d, $J_{1,2}$ = 16 Hz, H-1), 2.1–2.7 (m, benzenoid H, H-1', H-3'), 2.98 (dd, $J_{2',1'}$ = 16, $J_{2',3'}$ = 11 Hz, H-2'), 3.70 (d, $J_{4',3'}$ = 16 Hz, H-4'), 4.03 (d, $J_{2,1}$ = 16 Hz, H-2), 5.70 and 5.80 (each q, $CO_2CH_2CH_3$), 8.67 and 8.70 (each t, $CO_2CH_2CH_3$).

A solution of diisobutylaluminum hydride (4.58 g, 32 mmol) in dry benzene (23 mL) was added over 30 min to a stirred solution of the diester **20** (2.2 g, 7.3 mmol) in dry benzene (80 mL). The solution was stirred for 2 h, methanol (70 mL) was then added cautiously, and stirring was continued for a further 30 min. Filtration and evaporation led to the crude diol **17** (1.57 g) as a pale yellow solid.

A solution of the crude diol **17** (1.57 g) in dichloromethane (150 mL) was stirred with activated manganese dioxide[27] (14 g) for 4 h. Filtration through Celite, thorough washing with dichloromethane, evaporation, and crystallization from ethyl acetate afforded the dialdehyde **18** (0.97 g, 62% based on **20**) as yellow prisms, identical with that described above.

6,8-Bisdehydrobenz[16]annulene (9,10,11,12-Tetradehydrobenzocyclohexadecene, 25). The dialdehyde **18** (475 mg, 2.24 mmol) was allowed to react with the product obtained from propargyl bromide (1.19 g, 10 mmol), aluminum foil (180 mg, 6.67 mg-atoms), and mercuric chloride (40 mg), exactly as described above for the synthesis of **10**. This procedure led to the crude diol **21** (650 mg) as a nearly colorless oil: ^1H NMR (60 MHz) τ 2.3–4.4 (m, benzenoid and olefinic H), 5.55 (m, methine H), 7.2–7.6 (m, methylene and hydroxyl H), 7.90 (t, C≡CH).

A solution of the crude diol **21** (150 mg) in DMF (25 mL) was added dropwise over 1 h to a stirred solution of cupric acetate monohydrate (2.8 g) in DMF (100 mL) at 50–55 °C. After a further 1 h, the solution was cooled, poured onto a mixture of brine (150 mL) and 1 N hydrochloric acid (50 mL), and extracted well with ether. The ether extracts were washed well with water, and the solvent was evaporated. Chromatography on a short column of silicic acid (6 g), with 2% ethanol–chloroform as eluent, gave the crude macrocyclic diol **23** (110 mg) as a colorless solid: ^1H NMR (60 MHz) τ 2.3–4.5 (m, benzenoid and olefinic H), 5.55 (m, methine H), 7.0–7.6 (m, methylene H).

The crude diol **23** (250 mg, 0.86 mmol) was allowed to react with methanesulfonyl chloride (220 mg, 1.9 mmol) and triethylamine (200 mg, 2 mmol) in DME (11 mL) at 0 °C, followed by treatment of the filtrate with DBN (260 mg, 2.1 mmol) in DME (1.5 mL), exactly as described above for the conversion of **12** to **14**. The resulting product was chromatographed on a column of alumina (4 × 2 cm) with benzene as eluent. Crystallization from hexane gave the benz[16]annulene **25** (157 mg, 53% based on **18**) as brick-red needles: mp 98–99 °C; UV (Et_2O) λ_{max} 267 nm sh (ϵ 17 100), 280 sh (36 500), 297 (61 400), 305 sh (59 100), 442 (700); IR ($CHCl_3$) 2200 w (C≡C), 990 cm^{-1} s (trans HC=CH); ^1H NMR (100 MHz) τ 0.14 (dd, $J_{3,2}$ = 16, $J_{3,4}$ = 11 Hz, H-3), 0.20 (dd, $J_{13,12}$ = 16, $J_{13,14}$ = 11 Hz, H-13), 0.82 (d, $J_{15,14}$ = 16 Hz, H-15), 2.8–3.3 (m, H^X, $H^{X'}$, H^Y, $H^{Y'}$), 3.6–4.0 (m, H-2, H-4, H-11, H-14), 4.35 (dd, $J_{12,13}$ = 16, $J_{12,11}$ = 6 Hz, H-12), 4.94 and 4.98 (each d, $J_{5,4}$ = $J_{10,11}$ = 11 Hz, H-5, H-10).

Anal. Calcd for $C_{20}H_{14}$: C, 94.45; H, 5.55. Found: C, 94.39; H, 5.69.

5,10-Dimethyl-6,8-bisdehydrobenz[16]annulene (8,13-Dimethyl-9,10,11,12-tetradehydrobenzocyclohexadecene, 26). The dialdehyde **18** (400 mg, 1.89 mmol) was allowed to react with the product obtained from 3-bromo-1-butyne[14] (1.5 g, 11.4 mmol), magnesium (270 mg, 11.1 mg-atoms), and mercuric chloride (20 mg), exactly as described above for the synthesis of **11**. This procedure yielded the crude diol **22** (580 mg) as a yellow oil.

A solution of crude **22** (580 mg) in DMF (20 mL) was added dropwise over 2 h to a stirred solution of cupric acetate monohydrate (10 g) in DMF (200 mL) at 60 °C. After a further 2 h, the solution was cooled, poured onto water (1 L), and extracted with ether. The ether extracts were washed well with water, and the solvent was evaporated. The resulting crude macrocyclic diol **24** (490 mg) was obtained as a yellow powder.

The crude diol **24** (490 mg, 1.5 mmol) was allowed to react with methanesulfonyl chloride (430 mg, 3.8 mmol) and triethylamine (480 mg, 4.8 mmol), followed by treatment of the filtrate with DBN (1.4 g, 11.3 mmol), exactly as described above for the conversion of **13** to **2**. Chromatography of the product on a column of alumina (8 × 4 cm), elution with petrol, and crystallization from this solvent gave the benz[16]annulene **26** (95 mg, 18% based on **18**) as red needles: mp 133–134 °C; MS *m/e* 282.142 (M^+, calcd 282.141); UV (Et_2O) λ_{max} 265 nm sh (ϵ 18 600), 278 sh (40 100), 298 (81 500), 308 sh (77 500), 426 (4300); IR (KBr) 2180 w (C≡C), 978 s and 974 cm^{-1} s (trans HC=CH); ^1H NMR (220 MHz) τ 0.55 (dd, $J_{3,2}$ = 16, $J_{3,4}$ = 10 Hz, H-3), 0.58 (dd, $J_{13,12}$ = 15, $J_{13,14}$ = 11 Hz, H-13), 1.10 (d, $J_{15,14}$ = 15 Hz, H-15), 2.9–3.2 (m, H^X, $H^{X'}$, H^Y, $H^{Y'}$), 3.80 (dd, $J_{14,15}$ = 15, $J_{14,13}$ = 11 Hz, H-14), 3.89 (d, $J_{2,3}$ = 16 Hz, H-2), 3.93 (d, $J_{4,3}$ = 10 Hz, H-4), 4.06 (d, $J_{11,12}$ = 6 Hz, H-11), 4.27 (dd, $J_{12,13}$ = 15, $J_{12,11}$ = 6 Hz, H-12), 8.30 [s(b), CH_3-5, CH_3-10].

1,2-Bis(4-formyl-1,3-butadienyl)benzene (30). A solution of *o*-phthalaldehyde (**5**, 8.97 g, 0.067 mol) in dichloromethane (50 mL) was added dropwise over 30 min to a vigorously stirred solution of the ylide **27**[20] (50 g, 0.134 mmol) in dichloromethane (400 mL), which was boiled under reflux. After a further 2 h of refluxing, the solution was cooled and stirred for 20 h at ambient temperature. The residue after solvent removal was extracted with ether (5 × 75 mL), and the extracts were evaporated. Chromatography of the resultant red oil on a column of silica gel (12 × 6 cm) with 30% ethyl acetate–pentane as eluent afforded the diester **28** (stereoisomeric mixture, 18.0 g, 82%) as a yellow oil: ^1H NMR (60 mhz) τ 2.2–4.4 (m, benzenoid and olefinic H), 5.79 and 5.85 (each q, $CO_2CH_2CH_3$), 8.72 and 8.78 (each t, $CO_2CH_2CH_3$).

A solution of diisobutylaluminum hydride (15.62 g, 0.11 mol) in dry benzene (78 mL) was added dropwise over 30 min to a stirred solution of the stereoisomeric diester **28** (8.1 g, 0.025 mol, dried by azeotropic distillation with benzene) in dry benzene (300 mL). The solution was stirred for a further 18 h, and methanol (250 mL) was then added

cautiously, followed by concentrated sulfuric acid (10 drops). The mixture was stirred for 15 min, filtered, and evaporated. This procedure yielded the crude stereoisomeric diol **29** (6.0 g) as a yellow oil: ^{1}H NMR (60 MHz) τ 2.4–4.4 (m, benzenoid and olefinic H), 5.88 (m, CH_2), 7.50 (m, OH).

The crude diol **29** (14.0 g) in dichloromethane (1.1 L) was stirred with activated manganese dioxide[27] (128 g) for 23 h. The mixture was filtered through Celite, and the solid was washed well with dichloromethane. The combined filtrates were concentrated to ~500 mL, a crystal of iodine was added, and the solution was allowed to stand at ambient temperature for 18 h. The solution was then washed with dilute sodium thiosulfate solution, dried, and evaporated. Crystallization from dichloromethane–petrol afforded the all-trans dialdehyde **30** (4.7 g, 34% based on **28**) as bright yellow blades: mp 159–160 °C; MS *m/e* 238 (M^+); UV (Et_2O) λ_{max} 297 nm (ϵ 47 600), 340 (42 500); IR ($CHCl_3$) 1680 s (C=O), 1620 s (C=C), 990 cm^{-1} s (trans HC=CH); ^{1}H NMR (60 MHz) τ 0.30 (d, $J_{CHO,4}$ = 8 Hz, CHO), 2.2–3.3 (m, benzenoid H, H-1, H-2, H-3), 3.52 (dd, $J_{4,3}$ = 16; $J_{4,CHO}$ = 8 Hz, H-4).

Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.64; H, 5.92. Found: C, 80.49; H, 5.97.

8,10-Bisdehydrobenz[18]annulene (11,12,13,14-Tetradehydrobenzocyclooctadecene, 35). The dialdehyde **30** (1.6 g, 6.72 mmol) was allowed to react with the product obtained from propargyl bromide (3.6 g, 30 mmol), aluminum foil (540 mg, 20 mg-atoms), and mercuric chloride (120 mg), exactly as described above for the synthesis of **10.** Chromatography of the product on a column of silicic acid (5 × 4 cm) and elution with chloroform gave the diol **31** (2.1 g, 98%) as a pale yellow solid: ^{1}H NMR τ 2.4–4.4 (m, benzenoid and olefinic H), 5.58 (m, methine H), 7.3–7.7 (m, methylene and hydroxyl H), 7.90 (t, C≡CH).

A solution of the diol **31** (318 mg, 1 mmol) in DMF (50 mL) was added dropwise over 1 h to a stirred solution of cupric acetate monohydrate (6.0 g) in DMF (250 mL) at 55 °C. After a further 1 h, the solution was cooled, poured onto brine (600 mL), and extracted with ether. The ether extracts were washed well with water, and the solvent was evaporated. Chromatography on a column of silicic acid (3 × 2 cm) and elution with chloroform afforded the macrocyclic diol **33** (115 mg, 36%) as a nearly colorless solid.

The diol **33** (240 mg, 0.76 mmol) was allowed to react with methanesulfonyl chloride (180 mg, 1.6 mmol) and triethylamine (170 mg, 1.7 mmol) at 0 °C, followed by treatment of the filtrate with DBN (210 mg, 1.7 mmol), exactly as described above for the conversion of **12** to **14.** The resulting product was chromatographed on a column of alumina (5 × 3 cm) with benzene as eluent. Crystallization from benzene–hexane yielded the benz[18]annulene **35** (126 mg, 59%) as long, dark red needles: mp >200 °C dec; MS *m/e* 280.125 (M^+, calcd 280.125); UV (Et_2O) λ_{max} 298 nm sh (ϵ 18 500), 339 (68 700), 410 sh (7600); IR ($CHCl_3$) 2200 w (C≡C), 985 s and 970 cm^{-1} m (trans HC=CH); ^{1}H NMR (100 MHz) τ 1.90 (m, H^X), 2.49 (m, H^Y), 2.5–2.9 (m, H-3, H-6, H-13, H-16), 3.06 (dd, $J_{4,5}$ = $J_{15,14}$ = 16, $J_{4,3}$ = $J_{15,16}$ = 8 Hz, H-4, H-15), 3.83 (d, $J_{7,6}$ = $J_{12,13}$ = 10 Hz, H-7, H-12), 4.80 (d, $J_{2,3}$ = $J_{17,16}$ = 16 Hz, H-2, H-17), 4.90 (dd, $J_{5,4}$ = $J_{14,15}$ = 16 Hz, $J_{5,6}$ = $J_{14,13}$ = 11 Hz, H-5, H-14).

7,12-Dimethyl-8,10-bisdehydrobenz[18]annulene (10,15-Dimethyl-11,12,13,14-tetradehydrobenzocyclooctadecene, 36). The dialdehyde **30** (400 mg, 1.68 mmol) was allowed to react with the product obtained from 3-bromo-1-butyne[14] (1.8 g, 13.6 mmol), magnesium (320 mg, 13.2 mg-atoms), and mercuric chloride (50 mg), exactly as described above for the synthesis of **11.** The resulting crude diol **32** (580 mg) was a yellow gum.

A solution of the crude diol **32** (580 mg) in pyridine (20 mL) was added dropwise over 3 h to a stirred solution of anhydrous cupric acetate[15] (4.0 g) in pyridine (160 mL) and ether (40 mL) at 50 °C. After a further 30 min, the solution was cooled and the solvent was evaporated. Water was added to the residue, the mixture was extracted with ether, and the extracts were washed with water. Evaporation of the solvent led to the crude macrocyclic diol **34** (270 mg) as a brown froth.

The crude diol **34** (270 mg) was allowed to react with methanesulfonyl chloride (390 mg, 3.4 mmol) and triethylamine (340 mg, 3.4 mmol), and the filtrate was then treated with DBN (1.2 g, 9.7 mmol), exactly as described above for the conversion of **13** to **2.** Chromatography of the product on a column of alumina (6 × 4 cm), elution with 10% ether–petrol, and crystallization from dichloromethane–petrol gave the benz[18]annulene **36** (57 mg, 11% based on **30**) as orange prisms or needles: mp 214–216 °C; MS *m/e* 308 (M^+); UV (Et_2O) λ_{max} 283 nm sh (ϵ 13 300), 298 sh (18 300), 342 (64 600), 408 sh (9600); ^{1}H NMR (100 MHz) τ 1.94 (m, M^X), 2.58 (m, H^Y), 2.76 (dd, $J_{3,2}$ = $J_{16,17}$ = 16, $J_{3,4}$ = $J_{16,15}$ = 7 Hz, H-3, H-16), 2.83 (d, $J_{6,5}$ = $J_{13,14}$ = 11 Hz, H-6, H-13), 3.15 (dd, $J_{4,5}$ = $J_{15,14}$ = 16, $J_{4,3}$ = $J_{15,16}$ = 7 Hz, H-4, H-15), 4.77 (d, $J_{2,3}$ = $J_{17,16}$ = 16 Hz, H-2, H-17), 5.06 (dd, $J_{5,4}$ = $J_{14,15}$ = 16, $J_{5,6}$ = $J_{14,13}$ = 11 Hz, H-5, H-14), 7.72 (s, CH_3).

Anal. Calcd for $C_{24}H_{20}$: C, 93.46; H, 6.54. Found: C, 93.12; H, 6.47.

1-(4-Formyl-1,3-butadienyl)-2-(6′-formyl-1′,3′,5′-hexatrienyl)benzene (39). A solution of the dialdehyde **18** (510 mg, 2.4 mmol) in dichloromethane (15 mL) was added dropwise over 15 min to a stirred solution of carbethoxymethylenetriphenylphosphorane[9] (1.7 g, 4.9 mmol) in dichloromethane (20 mL). The solution was then boiled under reflux for 5 h and cooled, and the solvent was evaporated. The residue was extracted with ether (4 × 10 mL), and the solvent was evaporated. Chromatography of the residue on a column of silica gel (5 × 3 cm) with 30% ethyl acetate–pentane as eluent gave the diester **37** (790 mg, 93%) as a bright yellow oil: ^{1}H NMR (60 MHz) τ 2.0–4.3 (m, benzenoid and olefinic H), 5.76 (q, $CO_2CH_2CH_3$), 8.68 (t, $CO_2CH_2CH_3$).

A solution of diisobutylaluminum hydride (1.42 g, 10 mmol) in dry benzene (8 mL) was added dropwise over 15 min to a stirred solution of the diester **37** (790 mg, 2.2 mmol) in dry benzene (25 mL). After a further 1 h, methanol (25 mL) was added cautiously and stirring was continued for 15 min. The mixture was filtered, the solid was washed with methanol, and the solvent was evaporated. The resulting crude diol **38** (550 mg, 91%) was a pale yellow solid.

The crude diol **38** (550 mg) in dichloromethane (65 mL) was stirred with activated manganese dioxide[27] (5 g) for 2 h. The mixture was filtered through Celite, and the solid was washed well with dichloromethane. Evaporation and crystallization from ethyl acetate–cyclohexane gave the dialdehyde **39** (405 mg, 75%; 64% based on **18**) as yellow-orange needles: MS *m/e* 264.114 (M^+, calcd 264.115); IR ($CHCl_3$) 1670 s (C=O), 1620 m (C=C), 995 cm^{-1} m (trans HC=CH); ^{1}H NMR (60 MHz) τ 0.34 (d, J = 8 Hz, CHO), 0.41 (d, J = 8 Hz, CHO), 2.2–4.0 (m, benzenoid and olefinic H).

8,10-Bisdehydrobenz[20]annulene (11,12,13,14-Tetradehydrobenzocycloeicosene, 41). The dialdehyde **39** (360 mg, 1.4 mmol) was allowed to react with the product obtained from propargyl bromide (740 mg, 6.2 mmol), aluminum foil (110 mg, 4.1 mg-atoms), and mercuric chloride (25 mg), exactly as described above for the synthesis of **10.** The resulting crude diol **40** (430 mg) was obtained as a yellow glass: ^{1}H NMR τ 2.2–4.4 (m, benzenoid and olefinic H), 5.61 (m, methine H), 7.2–7.7 (m, methylene and hydroxyl H), 7.90 (t, C≡CH).

A solution of the crude diol **40** (320 mg) in DMF (90 mL) was added dropwise over 2 h to a stirred solution of cupric acetate monohydrate (8.4 g) in DMF (300 mL) at 60 °C. After a further 45 min, the solution was cooled, poured onto a mixture of brine (350 mL), 10% hydrochloric acid (200 mL), and ice, and extracted with ether. The extract was washed with water (7 × 50 mL) and sodium bicarbonate solution, and was then evaporated. The resulting crude macrocyclic diol (225 mg, pale yellow solid) was allowed to react with methanesulfonyl chloride (170 mg, 1.5 mmol) and triethylamine (160 mg, 1.6 mmol) at 0 °C, followed by treatment of the filtrate with DBN (200 mg, 1.6 mmol), exactly as described above for the conversion of **12** to **14.** Chromatography of the product on a column of alumina (4 × 2 cm), elution with benzene, and crystallization from benzene–hexane yielded the benz[20]annulene **41** (61 mg, 20% based on **39**) as dark purple brown prisms: mp >120 °C dec; MS *m/e* 306.141 (M^+, calcd 306.141); UV (Et_2O) λ_{max} 301 nm sh (ϵ 53 200), 324 (95 300), 334 (93 400), 434 (2100), with absorption >550 nm; ^{1}H NMR (100 MHz) τ 1.0–1.8 (m, 5 H, inner olefinic H), 2.8–3.2 (m, 4 H, benzenoid H), 3.5–4.2 (m, 7 H, outer olefinic H except H-7, H-12), 4.95 [d(b), 2 H, $J_{7,6}$ = $J_{12,13}$ = 11 Hz, H-7, H-12].

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Registry No.—**5,** 643-79-8; **6,** 28839-73-8; **7,** 61650-41-7; **8,** 61650-42-8; **9,** 61650-43-9; **10,** 61650-44-0; **11,** 61650-45-1; **12,** 61650-46-2; **13,** 61650-47-3; **15,** 61650-48-4; **16,** 61650-49-5; **17,** 61650-50-8; **18,** 61650-51-9; **19,** 61650-52-0; **20,** 61650-53-1; **21,** 61650-54-2; **22,** 61650-55-3; **23,** 61650-56-4; **24,** 61650-57-5; **27,** 51544-70-8; **28,** 61650-58-6; **29,** 61650-59-7; **30,** 61650-60-0; **31,** 61650-61-1; **32,** 61650-62-2; **33,** 61650-63-3; **34,** 61650-64-4; **37,** 61675-25-0; **38,** 61650-65-5; **39,** 61650-66-6; **40,** 61650-67-7; carbethoxymethylenetriphenylphosphorane, 1099-45-2; 1,3-dioxolan-2-ylmethyltriphenylphosphonium bromide, 52509-14-5; propargyl bromide, 106-96-7; methanesulfonyl chloride, 124-63-0; 3-bromo-1-butyne, 18668-72-9; triethyl phosphonoacetate, 867-13-0.

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Acid-Catalyzed Cyclialkylation of Benzene with Isoprene

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The acid-catalyzed reaction of isoprene with benzene forms a more complex mixture of reaction products than previously observed from alkylbenzenes. The formation of identified products is rationalized through existing carbonium ion theory. These products include 1,1-dimethylindan, the majority of the possible tetramethylhydrindacenes, both hexamethyltrindans, and two isopentyltetramethylhydrindacenes. Synthesis through independent routes provided standards for identification of products and study of intermediates.

The acid-catalyzed cyclialkylation of benzenoid hydrocarbons is well known.[2a] Such reaction with isoprene is a convenient and direct route to substituted 1,1-dimethylindans and tetramethylhydrindacenes. While an array of products are observed with mono- and dialkylbenzenes, the reaction can provide a reasonably clean product or product mixture from which several pure hydrocarbons have been isolated.[2b-e] Hydrocarbons **1**, **2**, and **7** were readily isolated in the current work and appear as major peaks in the GC trace shown in Figure 1.

Cyclialkylation products have been considered to have potential as high-energy fuels[2d,3a] and source materials in medicine[3b] and perfumery.[4] Acetylated and nitrated derivatives show musk properties.[4] Acetylation also yields ketones active as preemergence herbicides.[5]

The cyclialkylation of benzene with isoprene is not a useful reaction for the preparation of 1,1-dimethylindan (**1**)[6] in quantity, since this is rapidly converted to the hydrindacenes as shown in Scheme I. Schmerling[2b] first observed that the yield of **2** exceeds that of **1**.

Despite the low yields of **1** and **2**, we decided to use the cyclialkylation reaction for their preparation and a concomitant study of the cyclialkylation process in which **1** is regarded as an isolable but reacting intermediate.

A trial cyclialkylation reaction (procedure A) gave the expected low yields of **1** (3.5%) and **2** (9–10%). A second run (procedure A) in which the amounts of reagents were increased 20-fold showed a decreased yield of **1**, which results from the increased time necessary for addition of isoprene, and consequent conversion of **1** to other products.

The preparation of **1** in larger quantity was required to determine its role as an intermediate. Since increasing the scale of the preparation was unsatisfactory, we carried out numerous successive small runs (procedure B) involving rapid mixing of reagents, quenching, and workup of the reaction mixture. By this means we were able to accumulate a substantial quantity of **1**.[6] The other products from this preparation were thus also available for study. Distillation of the product mixture afforded the crystalline tetramethylhydrindacene **2** and the crystalline *as*-hexamethyltrindan **7**. Preparative GC was used to isolate **6**,[7a] **9**,[7b] and *tert*-butylbenzene (**11**).[7b] Their structures, along with those of **2** and **7**, were established by spectroscopic studies.

It is assumed that **9** is derived by an isopentenylation of **6**