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High-Yield Double Cyclopropanation of Benzene

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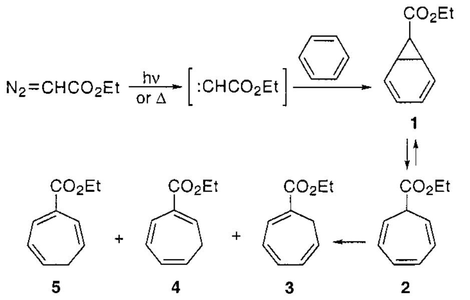
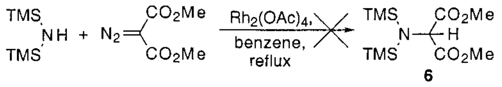
Introduction

The thermal or photochemical reaction of ethyl diazoacetate with benzene to give (via norcaradiene **1**) a mixture of isomeric cycloheptatrienes (**2**−**5**) (eq 1) is the prototypical example of the Büchner reaction, a reaction that has been known for over 100 years.[1] The daunting complexity of the product mixtures was reduced or eliminated with the advent of metal catalysts, at first copper-based, then in the early 1980s $Rh_2(OAc)_4$, which, along with its analogues, has become the catalyst of choice for this reaction.[2] Subsequently, $Rh_2(OAc)_4$-catalyzed cyclopropanations of aromatics, especially intramolecular cyclopropanations, have enjoyed a certain popularity due to the regio- and stereoselectivity which can now be achieved.[3] The related sequential cyclopropanation−Cope rearrangement methodology that has been applied fruitfully to a variety of synthetic challenges includes examples of Büchner-type cyclopropanations of benzenes, pyrroles, and furans.[4]



[1]

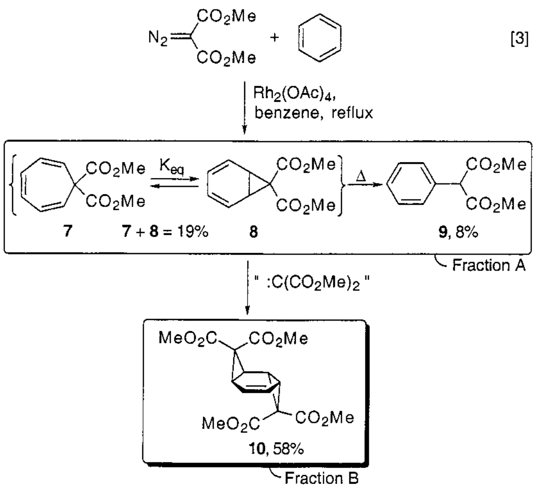
While investigating a completely different facet of Rh-stabilized carbenoid chemistry, namely carbenoid N−H insertion, we had occasion to try the $Rh_2(OAc)_4$-catalyzed reaction of dimethyl diazomalonate, $(MeOOC)_2C{=}N_2$ ("DDM"), with hexamethyldisilazane (HMDS) in refluxing benzene. We expected this reaction to lead to **6** via insertion of the DDM-derived carbenoid into the N−H bond of HMDS (eq 2). Surprisingly, silica gel column chromatographic workup afforded two fractions, A and B, neither of which contained trimethylsilyl groups. The reaction was repeated in the absence of HMDS and the identical products were obtained. Therefore, HMDS was superfluous; all products resulted from a Büchner reaction of DDM with the solvent, benzene. The details of this reaction are reported herein.



[2]

Results and Discussion

Fraction A was identified as a mixture of **7**, **8**, and **9** (eq 3), based on comparison with reported ^1H NMR spectra.[5−7] Compounds **7** and **8** have been shown to be in rapid equilibrium, with $K_{eq} = 0.30$ at the temperature of refluxing benzene and $K_{eq} = 0.31$ at room temperature.[6] The ratio of [**7** + **8**] to **9** depended somewhat on the duration of reflux and was in the range [**7** + **8**]/**9** = 2.3−3.0 for reflux times of 4−8 h. These products are unremarkable, inasmuch as they have been reported before for thermal and photochemical cases of the Büchner reaction of DDM with benzene.[8]



[3]

By contrast, fraction B was indeed remarkable. It was identified as bis-cyclopropanation product **10** by ^1H and ^{13}C NMR, mass spectrometry, elemental analysis, IR, and

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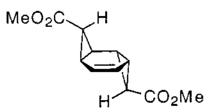
ultimately, X-ray crystallography. Compound **10** is the major product of this reaction, being formed in 58% yield.

The use of $Rh_2(O_2CCF_3)_4$ instead of $Rh_2(OAc)_4$ as the catalyst led to a vastly different product distribution: [**7** + **8**], 64%; **9**, 32%; **10**, 4%. The low yield of double-cyclopropanation product **10** obtained with $Rh_2(O_2CCF_3)_4$ is comparable to other carbenoid reactions with aromatics, in which double-cyclopropanation is almost never found. Despite the long history of the Büchner reaction, double cyclopropanation has been reported in only the following few instances of which we are aware: (a) the copper−bronze-catalyzed reaction of methyl diazoacetate with benzene, which gave **11** in 3% yield;[9] (b) the solvent-free thermal reaction of naphthalene with excess DDM, which gave **12** in 5−15% yield;[10] (c) the thermal addition of ethyl diazoacetate to naphthalene and two symmetrical dimethylnaphthalenes, which gave **13a** and **13b** in 14−17% yield (**13a**/**13b** = 2.6),[11] **13c** in 11% yield,[12] and **13d** in 19% yield;[13] (d) the CuCl-catalyzed reaction of diazomethane with *N*-carbomethoxypyrrole, which gave **14a** in 12% yield and a trace of **14b**, and the CuBr-catalyzed reaction of ethyl diazoacetate with *N*-carbomethoxypyrrole, which gave **14c** in 5% yield;[14] and (e) the $Rh_2(OAc)_4$-catalyzed reaction of diethyl (*Z*)-2-methoxy-4-diazo-2-pentenedioate with *N*-carbomethoxypyrrole, which gave **14d** in 33% yield.[15] The formation of diadduct **15** from $CuSO_4$-catalyzed addition of methyl diazoacetate to anthracene has been mentioned, but a yield was not given.[16] Cases (d) and (e) are included here, even though *N*-carbomethoxypyrrole is known to be anomalous in its reactivity toward carbenoids, resembling more a diene than a typical aromatic.[14] Therefore, carbenoid double cyclopropanation of an aromatic substrate is a rarity, and a 58% yield of such a product is unprecedented.



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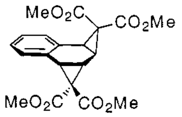

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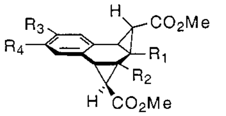
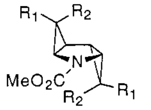
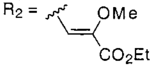
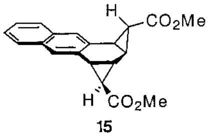


13a, $R_1=R_2=R_3=R_4=H$
b, $R_1=R_2=R_3=R_4=H$ (cyclopropanes *cis*)
c, $R_1=R_4=CH_3$; $R_2=R_3=H$
d, $R_1=R_2=H$; $R_3=R_4=CH_3$



14a $R_1 = R_2 = H$
b $R_1 = R_2 = H$ (cyclopropanes *cis*)
c $R_1 = CO_2Et$, $R_2 = H$
d $R_1 = CO_2Et$, $R_2 =$





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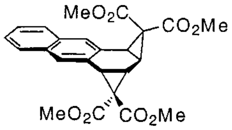
The yield of **10** may be increased, if desired. When fraction A, viz. a mixture of [**7** + **8**] and **9**, was treated with DDM and $Rh_2(OAc)_4$ in refluxing CCl_4 for 4 h, **10** was produced. Integration of ^1H NMR peaks versus an internal standard revealed that the **10** produced came from [**7** + **8**], and within experimental error, none came from **9**. More DDM was added to this sample, and it was refluxed for an additional 3 h, which gave a product mixture consisting of **9**, **10**, and products of self-reaction of DDM, with [**7** + **8**] barely discernible by NMR. Additionally, as a control, the ratio of [**7** + **8**] to **9** did not change when fraction A was refluxed in CCl_4 for 4 h in the presence of $Rh_2(OAc)_4$ but without DDM. This means that in principle one could increase the yield of **10** by converting the [**7** + **8**] present in fraction A to **10** by reacting fraction A with DDM and $Rh_2(OAc)_4$ in refluxing CCl_4, although we have not undertaken that optimization.

The relatively high yield and easy isolation suggested that **10** might be made in larger amounts. In fact, we have scaled up the reaction, reducing the amount of catalyst from 0.85 mol % to 0.45 mol % to lower the cost, and have obtained over 1.5 g of **10** in a single run (44% yield).

Tricyclic structures such as **10** have been termed "bis-σ-homobenzenes" and have been synthesized by a variety of routes.[17] These syntheses are multistep and afford the bis-σ-homoaromatic in low overall yield. Direct, one-pot double cyclopropanation of benzene usually fails, as discussed. We believe it is accurate to state that *the reaction of eq 3 represents the most convenient and most efficient synthesis to date of any bis-σ-homoaromatic.*

The $Rh_2(OAc)_4$/DDM methodology was investigated with other aromatic substrates. Naphthalene (liquid, as solvent) gave **12** in 31% yield. Anthracene (in CCl_4, DDM/anthracene = 1.8:1) gave **16** in 20% yield, based on anthracene reacted. Toluene led to an intractable mixture of isomeric products. Linstrumelle, et al. found thermal and photochemical Büchner reactions of DDM with toluene also gave mixtures of isomers.[7] Anisole gave **17** cleanly in 70% isolated yield, with no sign of double cyclopropanation, which is reminiscent of the behavior of 2-diazo-1,3-indanedione with anisole.[18]



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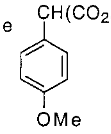

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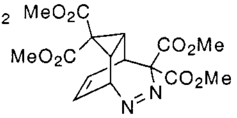

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It is reasonable to state that, mechanistically, diadduct **10** results from a competition between norcaradiene **8**

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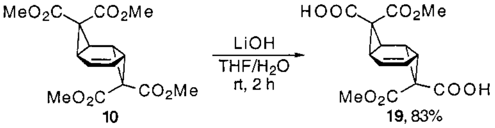
and benzene for available Rh-carbenoid. The yield of **10** is startling when one considers that **8** is at an enormous statistical disadvantage versus benzene, the solvent. One way to explain the atypically high yield of **10** is to posit that **8**, as a diene, is simply so much more reactive than benzene that it may compensate for its statistical disadvantage. To test this idea qualitatively, an equimolar mixture of benzene and 1,3-cyclohexadiene (a model for **8**) was reacted with a deficiency of DDM and $Rh_2(OAc)_4$. Within the limits of NMR detection, no products of reaction of DDM with benzene were found. Therefore, the diene is probably at least 100 times more reactive than benzene, and this increase in reactivity may also apply to **8** vs benzene. However, using reasonable assumptions, we estimate a reactivity ratio of ca. 550 would be required to account for the observed yield of **10**. It is interesting to note that although the use of $Rh_2(O_2CCF_3)_4$ in the reaction of eq 3 had a large effect on the yield of **10**, repeating the benzene−1,3-cyclohexadiene competition using $Rh_2(O_2CCF_3)_4$ had almost no effect on that outcome. If **8** *is* 550 times more reactive than benzene toward carbenoids, one may ask why **10** was not produced in good yield in the many previously reported Büchner reactions of benzene. A plausible answer is that the much more reactive carbenes used previously were unselective, reacting statistically, leading to monocyclopropanation products exclusively. In the present instance, the lower reactivity of the DDM−$Rh_2(OAc)_4$ pair[19] allowed a selective reaction to occur. According to the general mechanism for carbenoid cyclopropanation proposed by Doyle et al.,[20] the Rh-carbenoid reversibly forms a π-complex with the substrate, which was an alkene in the cases treated originally by Doyle et al., but in the present case is either benzene or diene **8** (or possibly triene **7**). If the equilibrium constant for π-complex formation were greater for diene **8** than for benzene, this would constitute another factor tending to favor reaction of the carbenoid with **8** in preference to benzene. However, such equilibrium constants are not known. Although complexes of rhodium(II) carboxylates with a wide variety of Lewis bases have been studied,[21] it would be inadvisable to extrapolate those results to the question of complexes of $Rh(O_2CCH_3)_4Rh{=}C(COOCH_3)_2$. A less attractive rationale for the high yield of **10** is to suggest **8** is efficiently trapped by DDM by a 1,3-dipolar cycloaddition to form **18**,[22] which subsequently loses N_2 and rearranges to **10**. However, we have no evidence for the existence of **18**.

Compound **10** is thermally stable, having been recovered unchanged after heating at 200−260 °C for 40 min. The ready availability of **10** herein reported would obviously be of greater importance if **10** could be functionalized easily and selectively. As one step in that direction, we have found mild hydrolysis cleaved two of the four ester groups of **10**, affording exclusively the exo,-exo diacid **19** in 83% yield (eq 4). Proof of the stereochemistry of **19** was nontrivial and required X-ray crystallography (see the Supporting Information), confirming, as expected, that only the sterically more accessible exo ester groups of **10** were hydrolyzed, and revealed that **19** possesses crystallographic C_2 symmetry. Differential scanning calorimetry (DSC) of **19** up to 500 °C revealed no processes other than loss of water of hydration and melting; i.e., decarboxylation apparently does not occur within the time frame of the DSC experiment. Also, tetraester **10** may be reduced nonselectively to tetraol **20** (eq 5).



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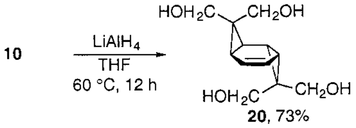
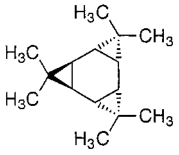


[5]

Only one other nonheteroatom σ-homobenzene has been examined crystallographically: **21**.[23,24] As far as we are aware, *the present crystallographic results are the first for bis-σ-homobenzenes*. At first glance, **21** would appear to be an interesting compound with which to compare the structures of **10** and **19**. However, the presence in **21** of neighboring cis cyclopropanes bearing geminal methyls causes distortions not present in **10** and **19**. For example, the central six-membered ring of **21** is bent, boatlike, at a dihedral angle of 163°. But, in **10** and **19**, the six carbons derived from benzene are planar, despite this ring's containing four formally tetrahedral carbons. The root mean square (rms) deviation of these atoms from the best plane through them is 0.004 Å, which is in the neighborhood of the esd's of the fractional coordinates of the atoms. The six endocyclic C−C−C angles in this "planar cyclohexene" average 120.0 ± 2.1° for **10** and **19**. Heteroatom-containing tris-σ-homoaromatics have "planar cyclohexane" rings.[24] These curious planar entities have been discussed recently by Dodziuk.[25] The cyclo-



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propanes of **10** and **19** are better described as isosceles than equilateral triangles. The average length of the "nonfused" cyclopropane C−C bonds in **10** and **19**, 1.530 Å, is in the uppermost quartile of the sample of 888 cyclopropane C−C bond lengths surveyed by Allen et al.[26] The remaining cyclopropane C−C bonds, those common to the cyclohexene ring, average 1.491 Å, which is in the lowest quartile of the same dataset. Similar values are observed for cyclopropane-1,1-dicarboxylic acid.[27] The angles between the plane of the cyclopropane ring and the best plane through the planar cyclohexene ring are 109.0(1)°and 110.5(1)° for **10** and 109.2(1)° for **19**. In **21**, the unique cyclopropane makes a dihedral angle of 110.1° with its half of the six-membered ring.[23] Because **19** crystallized as a dihydrate, the usual carboxylic acid dimer H-bonds[28] were replaced by a H-bond network including waters of crystallization.

The availability on a larger scale of thermally stable, C_2-symmetric bis-σ-homoaromatics **10**, **12**, and **16** in one easy step and **19** and **20** in two easy steps will stimulate a variety of imaginative uses of these intriguing compounds, we suspect.

Experimental Section

5,5,8,8-Tetracarbomethoxytricyclo[5.1.0.0^{4,6}]oct-2-ene, 10. (a) To a solution of 335 mg (2.12 mmol) dimethyl diazomalonate in 15 mL of benzene was added 8 mg (0.02 mmol) of $Rh_2(OAc)_4$, and the resulting green mixture was brought to reflux. After 4 h, TLC indicated the diazo compound had been consumed, and heating was stopped. After cooling and filtration, solvent was removed at the rotary evaporator and the residue subjected to column chromatography on silica gel (60−200 mesh; EtOAc/hexanes 1:2 (v/v)). Fraction A (121 mg) was a mixture of [**7** + **8**] and **9**. For [**7** + **8**]: ^{1}H NMR (250 MHz, $CDCl_3$) δ 6.47 (m, 2H), 6.38 (m, 2H), 5.04 (dd, J = 7.4, 0.8 Hz, 2H), 3.69 (s, 6H); ^{13}C NMR (63 MHz, $CDCl_3$, proton chemical shift correlation from 2D H−C correlation experiment given in italics) δ 169.3 (quat), 128.9 (*6.47*), 126.2 (*6.38*), 100.04 (*5.04*), 51.4 (quat), 53.1 (*3.69*). For **9**: ^{1}H NMR (250 MHz, $CDCl_3$) δ 7.37 (m, 5H), 4.65 (s, 1H), 3.75 (s, 6H); ^{13}C NMR (63 MHz, $CDCl_3$, proton chemical shift correlation from 2D H−C correlation experiment given in italics) δ 168.7 (quat), 132.7 (quat), 129.3 (*7.37*), 128.8 (*7.37*), 128.4 (*7.37*), 57.7 (*4.65*), 52.9 (*3.75*).

Fraction B was an oil that later solidified to afford 208 mg (58%) **10**: mp 122−123 °C; ^{1}H NMR (250 MHz, $CDCl_3$) δ 5.71 (m, 2H, (H2, H3)), 3.75 (s, 6H), 3.74 (s, 6H), 2.50 (d with unresolved splitting, J = 9.5 Hz, 2H, (H6, H7)), 2.02 (dd with unresolved splitting, J = 9.5, 3.1 Hz, 2H, (H1, H4)); ^{13}C NMR (63 MHz, $CDCl_3$, proton chemical shift correlation from 2D H−C correlation experiment given in italics) δ 169.2 (quat), 166.0 (quat), 122.8 (CH, *5.71*), 52.9 (CH_3, *3.74*), 52.6 (CH_3, *3.75*), 42.3 (quat), 25.6 (CH, *2.50*), 24.9 (CH, *2.02*); EI-MS, *m/e* (rel intensity) 338 (M, 0.2), 320 (0.8), 306 (1.2), 274 (45), 247 (39), 219 (44), 215 (49), 208 (25), 187 (44), 170 (20), 129 (23), 105 (31), 89 (40), 59 (100); IR 1729, 1253 cm^{-1}. Anal. Calcd for $C_{16}H_{18}O_8$: C, 56.80; H, 5.36. Found: C, 56.71; H 5.42. A crystal 0.80 × 0.40 × 0.20 mm was selected for X-ray crystallography with 0.71073 Å radiation: monoclinic a = 8.290(4) Å, b = 21.670(8) Å, c = 10.051(5) Å, β = 113.16(3)°; $P2_1/n$; Z = 4; 3120 reflections were collected, 2920 independent (R_{int} = 0.0268), $0 \le h \le 9$, $-22 \le k \le 25$, $-11 \le l \le 11$. Full-matrix least-squares refinement on F^2, data-to-parameter ratio = 13.3, gave goodness-of-fit 1.025, R1 = 0.0460, wR2 = 0.1151 ($I > 2\sigma(I)$), R1 = 0.0617, wR2 = 0.1912 (all data).

(b) The reaction was repeated with $Rh_2(O_2CCF_3)_4$ instead of $Rh_2(OAc)_4$. DDM (315 mg, 1.99 mmol) was dissolved in 15 mL of benzene, and 7 mg (0.01 mmol) of $Rh_2(O_2CCF_3)_4$ was added. The mixture was refluxed until TLC showed no DDM present, about 1 h. Evaporation of the solvent and NMR analysis of the residue indicated the following products: [**7** + **8**], 64%; **9**, 32%, **10**, 4%.

Benzo-5,5,8,8-tetracarbomethoxytricyclo[5.1.0.0^{4,6}]oct-2-ene, 12. A mixture of 6.891 g (53.76 mmol) naphthalene and 0.413 g (2.61 mmol) dimethyl diazomalonate was heated in an 86 °C oil bath until the mixture had liquefied. To this was added 11 mg (0.025 mmol) $Rh_2(OAc)_4$. The reaction was heated and stirred for 5 h, at which time TLC indicated no dimethyl diazomalonate remained. Excess naphthalene was sublimed, and the residue was subjected to silica gel chromatography using 1:3 (v/v) EtOAc/hexanes as eluent. Two fractions were collected: A, 176 mg; B, 155 mg. Fraction A was a mixture of benzo-[*b*]-7,7-dicarbomethoxybicyclo[4.1.0]hept-2-ene, the monocyclopropanation product analogous to [**7** + **8**] that was identified by comparison with published spectra,[10] dimethyl 1-naphthylmalonate, and dimethyl 2-naphthylmalonate. Fraction B was diadduct **12**: 30.6% yield; mp 159−60 °C; ^{1}H NMR (250 MHz, $CDCl_3$) δ 7.24−7.15 (m, 4H), 3.77 (s, 6H), 3.42 (s, 6H), 2.73 (appar. AB quartet, J = 9.8 Hz, 4H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 169.0 (quat), 165.8 (quat), 130.5, 128.6 (quat), 127.7, 52.9, 41.8 (quat), 29.9, 26.7.

Naphtho(*b*)-5,5,8,8-tetracarbomethoxytricyclo[5.1.0.0^{4,6}]-oct-2-ene, 16. A suspension of 1.12 g (6.29 mmol) of anthracene in 30 mL of CCl_4 was heated at reflux until the anthracene dissolved. To this solution was added 12 mg (0.027 mmol) of $Rh_2(OAc)_4$ and 1.78 g (11.3 mmol) of dimethyl diazomalonate. The reaction mixture was refluxed for 5.5 h, at which time TLC indicated no diazomalonate remaining. Solvent was removed at the rotary evaporator, and the residue was purified by silica gel column chromatography, using a step-gradient from pure hexanes to 1:2 (v/v) EtOAc/hexanes, in which anthracene (0.613 g) was recovered. Two other fractions were collected: A, 95 mg and B, 261 mg. Fraction A was naphtho[*b*]-7,7-dicarbomethoxybicyclo-[4.1.0]hept-2-ene, the monocyclopropanation product analogous to [**7** + **8**]: 8.3% yield; ^{1}H NMR (250 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.82−7.76 (m, 2H), 7.56 (s, 1H), 7.45−7.41 (m, 2H), 6.67 (d, J = 9.8 Hz, 1H), 6.25 (m, 1H), 3.82 (s, 3H), 3.25 (d, J = 8.5 Hz, 1H), 3.33 (s, 3H), 3.02 (m, 1H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 171.8, 165.3, 133.5, 133.1, 129.6, 129.1, 128.4, 128.1, 127.6, 126.6, 126.3, 126.2, 123.3, 53.4, 52.4, 34.5, 33.8, 31.0. Fraction B was diadduct **16**: 20.8% yield; mp 229−230 °C; ^{1}H NMR (250 MHz, $CDCl_3$) δ 5.04. 7.74−7.70 (m, 4H), 7.43−7.39 (m, 2H), 3.79 (s, 6H), 3.36 (s, 6H), 2.85 (AB quartet, J = 9.5 Hz, 4H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 169.2, 166.0, 133.1, 129.9, 127.6, 126.7, 126.3, 53.2, 52.6, 41.8, 30.8, 26.8. Anal. Calcd for $C_{24}H_{22}O_8$: C, 65.75; H, 5.06. Found: C, 65.81; H, 5.04. Both yields take into account recovered anthracene.

Tricyclo[5.1.0.0^{4,6}]oct-2-ene-5,5,8,8-tetracarboxylic Acid *endo,endo*-Dimethyl Ester, 19. To a solution of 218 mg (0.644 mmol) of tetraester **10** in 11 mL of H_2O/THF (4:7 (v/v)) was added 95 mg (2.26 mmol) of $LiOH\cdot H_2O$. The mixture was stirred at room temperature for 2 h, and 3 M HCl was added to pH = 3. After the inside of the flask was scratched with a glass rod, precipitation began and was allowed to continue for 0.5 h at ice-bath temperature. The solid **19** was filtered and air-dried: 166 mg (83.0%); mp 201−202 °C; ^{1}H NMR (250 MHz, acetone-d_6) δ 6.3−4.9 (br s), 5.68 (app t, J = 2.1 Hz, 2H) 3.68 (s, 6H), 2.42 (d, J = 9.3 Hz, 2H), 1.94 (br d, J = 9.4 Hz, 2H); ^{13}C NMR (63 MHz, acetone-d_6) δ 170.2, 166.8, 123.5, 52.6, 43.0, 26.2, 25.4. Anal. Calcd for $C_{14}H_{14}O_8$: C, 54.20; H, 4.55. Found: C, 54.10; H, 4.54. A crystal 0.38 × 0.32 × 0.08 mm was selected for X-ray crystallography with 0.71073 Å radiation: monoclinic a = 15.133(7) Å, b = 10.569(5) Å, c = 10.436(4) Å, β = 105.32(3)°; $C2/c$; Z = 4; 1482 reflections were collected, 1426 independent (R_{int} = 0.0132), $0 \le h \le 18$, $0 \le k \le 12$, $-12 \le l \le 11$. Full-matrix least-squares refinement on F^2, data-to-parameter ratio = 11.7, gave goodness-of-fit 1.074, R1 = 0.0425, wR2 = 0.0922 ($I > 2\sigma(I)$), R1 = 0.0670, wR2 = 0.1038 (all data). The structure revealed the compound had crystallized as a dihydrate, viz. $C_{14}H_{14}O_8\cdot 2H_2O$.

5,5,8,8-Tetrakis(hydroxymethyl)tricyclo[5.1.0.0^{4,6}]oct-2-ene, 20. To a mixture of 0.45 g $LiAlH_4$ (12 mmol) in 7 mL of dry THF was added a solution of 0.35 g **10** (1.0 mmol) in 5 mL of dry THF dropwise under a N_2 atmosphere. The reaction was

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warmed to 60 °C for 12 h. The reaction was cooled, and to it were added sequentially 0.45 mL of water, 0.45 mL of 15% aqueous NaOH, and 1.30 mL of water. The mixture was filtered and the filtrate evaporated to give a pale yellow oil. When triturated with 1:8 MeOH/EtOAc, the oil solidified affording 0.17 g (73%) of **20** as a colorless solid: mp 159−161 °C; ^{1}H NMR (400 MHz, DMSO-d_6 + D_2O) δ 5.60 (m, 2H) 3.70 (AB quartet, J = 11.2 Hz, $\Delta\nu$ = 15.4 Hz, 4H), 3.33 (AB quartet, J = 11.2, $\Delta\nu$ = 22.5 Hz, 4H), 1.29 (d, J = 8.6 Hz, 2H), 1.02 (d with unresolved splitting, J = 8.6 Hz, 2H); ^{13}C NMR (100 MHz, DMSO-d_6): 123.3, 65.1, 57.7, 36.2, 19.7, 18.2. Anal. Calcd for $C_{12}H_{18}O_4$: C, 63.70; H,8.02. Found: C, 63.43; H, 8.17.

Competition Experiments. (a) A mixture of 5.0 mL of benzene (56 mmol), 5.0 mL of 1,3-cyclohexadiene (53 mmol), 0.69 g of DDM (4.4 mmol), and 12 mg of $Rh_2(OAc)_4$ (0.027 mmol) was refluxed until TLC showed no DDM remaining, about 1.5 h. NMR analysis of the residue after evaporation of solvents showed no products of reaction of DDM with benzene (**7**−**10**). The only product formed (aside from minute amounts of unidentified sideproducts) was 7,7-dicarbomethoxybicyclo[4.1.0]-hept-2-ene: ^{1}H NMR (250 MHz, $CDCl_3$) δ 5.93−5.67 (m, 2H), 3.72 (s, 3H), 3.71 (s, 3H), 2.21−1.59 (m, 6H); ^{13}C NMR (63 MHz, $CDCl_3$) δ 170.1, 167.7, 127.8, 121.8, 52.6, 52.5, 40.8, 26.6, 24.5, 20.5, 16.0.

(b) The benzene/cyclohexadiene competition described above was repeated using $Rh_2(O_2CCF_3)_4$ instead of $Rh_2(OAc)_4$ (1.93 g of 1,3-cyclohexadiene (24.1 mmol), 1.88 g of benzene (24.1 mmol), 0.44 g of DDM (2.8 mmol), and 7 mg of $Rh_2(O_2CCF_3)_4$ (0.01 mmol)). After 1.5 h reflux, DDM was consumed. NMR of the residue after removal of volatiles was almost identical to that obtained in the $Rh_2(OAc)_4$ competition, the only difference being a slightly higher level of unidentified side products.

Reaction of Dimethyl Diazomalonate with Benzene Derivatives. (a) Toluene. To a mixture of 0.99 g of DDM (6.3 mmol) in 15 mL of toluene was added 13 mg of $Rh_2(OAc)_4$ (0.029 mmol), and the resultant mixture was heated at 80 °C for 3 h. After evaporation of solvent, silica gel column chromatography (THF/hexane 1:2 (v/v)) gave three fractions. However, NMR spectroscopy revealed each fraction to be composed of a mixture of several (most likely isomeric) compounds.

(b) Anisole. To a mixture of 0.51 g (3.2 mmol) of DDM and 15 mL of anisole was added 10 mg of $Rh_2(OAc)_4$ (0.023 mmol), and the resultant mixture heated to 80 °C for 4 h. At this time, TLC showed no DDM present. Excess anisole was removed by vacuum distillation and the residue purified by column chromatography on silica gel (EtOAc/hexanes 1:5(v/v)), to afford 0.53 g (70%) of dimethyl *p*-methoxyphenylmalonate: mp 44−45 °C (lit.[29] mp 44−47 °C); ^{1}H NMR (250 MHz, $CDCl_3$) δ 7.35−7.31 (m, 2H), 6.92−6.88 (m, 2H), 4.61 (s, 1H), 3.80 (s, 3H), 3.75 (s, 6H); ^{13}C NMR (63 MHz, $CDCl_3$) δ 169.0, 159.7, 130.5, 124.8, 114.3, 56.9, 55.4, 52.9.

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Supporting Information Available: Crystallographic data for **10** and **19**·$2H_2O$ and ^{1}H and ^{13}C NMR spectra of fraction A of the reaction that led to **12** and of the reaction that led to **16**. This material is available free of charge via the Internet at http://pubs.acs.org.

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