Is the Intermediate in the Reaction of 3-Bromo-6,7-benzobicyclo[3.2.1]octa-2,6-diene with Potassium *tert*-Butoxide an Allene or an Alkyne?

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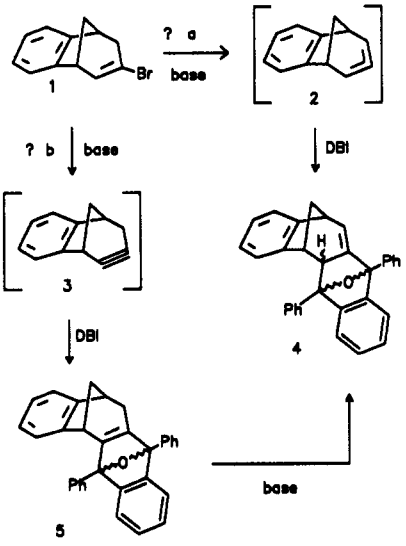
Introduction

The incorporation of an allene unit into a cyclic system creates an interesting moiety for stereoselective transformations.[1] An allene unit in a nine-membered ring is relatively strain free;[2] however, an allene unit in a six- or seven-membered ring is bent and twisted away from the optimum geometry,[3] and ab initio MCSCF calculations support these experimental findings.[4] The highly-strained allene **2** was suggested as an intermediate in the base-catalyzed elimination of HBr from **1** to give the 1,3-diphenylbenzoisofuran (DBI) trapping product **4**[5] (Scheme I); however, this mechanism is now in question.

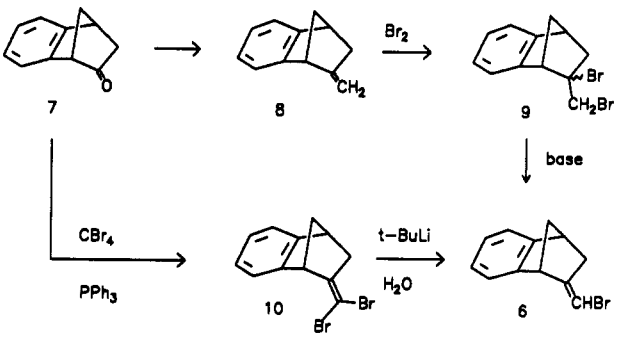
Results and Discussion

An alternate mechanism for the formation of **4** requires the dehydrobromination of **1** to yield the bicyclic alkyne **3** which undergoes cycloaddition with DBI. The base-promoted isomerization of the double bonds in **5** would give the observed adducts **4**. In order to distinguish between the two mechanisms, generation of the alkyne **3** by alternate procedures and subsequent trapping with DBI was investigated. The intermediate alkyne **3** can be generated by the base-induced rearrangement[6] of the bromomethylene compound **6**. As shown in Scheme II, compound **6** was synthesized by two independent routes. Addition of bromine to the methylene compound[7] **8** followed by KOH-promoted elimination results in the formation of **6**.[8] Conversion of **7**[9] to the dibromomethylene compound **10** followed by reaction with t-BuLi at −100 °C and quenching by water also gave **6**.[8]

Scheme I



Scheme II



When **6** (0.042 mol) was heated for 6 h with potassium *tert*-butoxide (0.042 mol) and 1,3-diphenylbenzoisofuran (0.042 mol) in THF, a mixture of two products was obtained. During chromatography over either SiO_2 or Al_2O_3 these products isomerize[10] to give **11** and **12**. On the basis of the ^1H and ^{13}C NMR the structures could not be assigned unequivocally, and the structure of **11** was determined by X-ray diffraction.[11] The most likely pathway for the formation of **11** and **12** involves the formation of the highly reactive alkyne **3**, followed by trapping with DBI to give **5a** and **5b**, respectively. This mixture isomerizes on the chromatographic column to give the corresponding ketones **11** and **12**, respectively.

Repetition of this reaction with 2 mol of potassium *tert*-butoxide, under identical conditions, afforded a completely

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(1) (a) Johnson, R. P. *Chem. Rev.* **1989**, *89*, 1111–1124. (b) Thies, R. W. *Isr. J. Chem.* **1985**, *26*, 191–195. (c) Schuster, H. F.; Coppola, G. M. *Allenes in Organic Synthesis*; John Wiley: New York, 1984. (d) Landor, S. R., Ed. *The Chemistry of the Allene*; Academic Press: New York, 1982. (e) Patai, S., Ed. *The Chemistry of Ketenes, Allenes and Related Compounds*; Wiley: New York, 1980; Parts 1 and 2.

(2) (a) Blomquist, A. T.; Burger, R. E., Jr.; Liu, L. H.; Bohrer, J. C.; Sucsy, A. C.; Kleis, J. *J. Am. Chem. Soc.* **1951**, *73*, 5510–5512. (b) Skattebol, L.; Solomon, S. *Org. Synth.* **1969**, *49*, 35.

(3) (a) Balci, M.; Jones, W. M. *J. Am. Chem. Soc.* **1980**, *102*, 7607–7608. (b) Balci, M.; Jones, W. M. *J. Am. Chem. Soc.* **1981**, *103*, 2874–2876.

(4) Schmidt, M. W.; Angus, R. O., Jr.; Johnson, R. P. *J. Am. Chem. Soc.* **1982**, *104*, 6838–6839.

(5) Balci, M.; Harmandar, M. *Tetrahedron Lett.* **1984**, *25*, 237–240.

(6) For a similar rearrangement see: (a) Erickson, K. L.; Wolinksy, J. *J. Am. Chem. Soc.* **1965**, *87*, 1142–1143. (b) Erickson, K. L. *J. Org. Chem.* **1973**, *38*, 1463–1469.

(7) Scully, F.; Grutzner, J.; Morrison, H. *J. Am. Chem. Soc.* **1973**, *95*, 5100–5102.

(8) NMR spectral studies (^1H- and ^{13}C-NMR) indicated the presence of expected cis and trans isomers in a 1:4 ratio. All attempts to separate them failed. For further reactions the isomeric mixture was used. In the second method using the dibromomethylene compound, an isomeric mixture of **6** was also obtained; however, the ratio of isomers was in this case reversed.

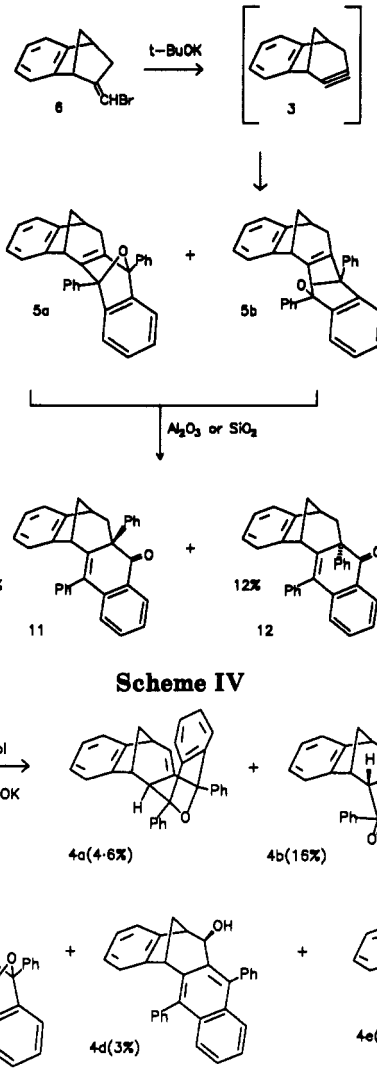
(9) Sandman, D. J.; Mislow, K.; Giddings, W. P.; Dirlam, J.; Hanson, G. C. *J. Am. Chem. Soc.* **1968**, *90*, 4877–4884.

(10) For similar isomerization see: (a) Komatsu, K.; Aonuma, S.; Jinbu, Y.; Tsuji, R.; Hirosawa, C.; Takeuchi, K. *J. Org. Chem.* **1991**, *56*, 195–202. (b) Wittig, G.; Weinlich, J.; Wilson, E. R. *Chem. Ber.* **1965**, *98*, 458–470.

(11) Watson, W. H.; Balci, M.; Kashyap, R. P.; Krawiec, M.; Taskensenligtil, Y. *Acta Crystallogr.* manuscript submitted. The author has deposited atomic coordinates for **11** with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

0022-3263/93/1958-3216$04.00/0

Scheme III



Scheme IV

different reaction mixture consisting of **4a–e**. This is the same reaction mixture as obtained previously[5] when **1** was reacted with potassium *tert*-butoxide in the presence of DBI. These two experiments indicate clearly that the alkyne initially reacts with DBI to give the syn and anti isomers **5a** and **5b** which form completely the allene-like adducts **4a–e** in the presence of excess base.

The identical product distribution from the two different reactions, (i) base-promoted reaction of **1** in the presence of DBI and (ii) base-promoted reaction of **6** in the presence of DBI, implies that the intermediates must have the same structure. Since the allene intermediate cannot be generated from the base-promoted reaction of **6**, we conclude that the intermediate is the alkyne **3**. We believe this clearly implicates the alkyne as the reactive intermediate in the formation of the cycloadducts **4a–d** and **4e** by the base-promoted reaction of **1**. The alkyne **3** is calculated to be 11 kcal/mol (MOPAC[12]) and 16 kcal/mol (PCMODEL[13]) more stable than the allene **2**.

Experimental Section

All melting points are uncorrected. $CDCl_3$ was the solvent for all NMR specta.

2-Methylenebenzonorbornene (8).[7] A solution of 1.6 M n-BuLi in hexane (3.86 mL, 42.2 mmol) was added dropwise to a stirred solution of PH_3PCH_3I (3.84 g, 9.50 mmol) in THF (100 mL) over 10 min at 0 °C under nitrogen. After the solution was stirred for 1 h at rt, 1 g (6.32 mmol) of **7** in THF (15 mL) was added dropwise over the course of 0.5 h. The reaction mixture was stirred under nitrogen for an additional 2 h at rt. At this time the yellow color of the solution changed slowly to deep red-brown. A major part of the THF was removed under reduced pressure and the residue extracted with ether. The ether extracts were washed with water and dried over $CaCl_2$. After the solvent was removed, the crude product was chromatographed over silica gel (30 g) with petroleum ether yielding 0.470 g (47%) of **8** as a colorless liquid: ^1H NMR (250 MHz) δ 7.23 (m, 2H), 7.10 (m, 2H), 5.13 (br s, 1H), 4.73 (br s, 1H), 3.74 (br s, 1H), 3.47 (m, 1H), 2.56 (dm, J = 14.4 Hz, 1H), 2.0 (dm, J = 8.6 Hz, 1H), 1.96 (dm, J = 14.4 Hz, 1H), 1.83 (dt, J = 8.6, 1.4 Hz, 1H); ^{13}C NMR (63 MHz) δ 151.23, 148.11, 146.65, 126.34, 126.22, 121.36, 121.11, 104.81, 53.53, 51.31, 44.16, 36.03.

2-(Dibromomethylene)benzonorbornene (10). Anhydrous benzene (750 mL) was placed in a three-necked flask fitted with a condenser, a drying tube, and N_2 inlet tube. After the benzene was saturated with nitrogen for 10 min, triphenylphosphine (59.6 g, 0.227 mol), CBr_4 (37.8 g, 0.113 mol), and ketone **7** (7.2 g, 45.5 mmol) in benzene (20 mL) were added in the above order. The reaction mixture was stirred and refluxed for 17 h. The initial yellow solution turned gray. After the reaction mixture was cooled to rt, the insoluble materials were separated by filtration. The filtrate was evaporated, and the residue was treated with water (30 mL) and extracted with CH_2Cl_2 (2 × 150 mL). The organic layer was washed with water, dried over $CaCl_2$, and evaporated to give the crude product which was chromatographed over silica gel with petroleum ether. The oily viscous residue was crystallized from CCl_4 to give compound **10** (7.7 g, 53%): colorless crystals, mp 56–57 °C; ^1H NMR (60 MHz) δ 6.85–7.32 (m, 4H), 4.05 (m, 1H), 3.50 (m, 1H), 2.50 (dd, J = 15.0, 4.0 Hz, 1H), 1.90 (br s, 2H), 1.85 (dm, J = 15.0 Hz, 1H); ^{13}C NMR (75 MHz) δ 148.74, 147.63, 143.18, 126.47, 126.27, 121.50, 121.38, 77.84, 53.88, 51.11, 44.21, 41.32; MS (EI) m/z 316/314/312 (M^+), 235/233 (M^+ – Br), 153 (M^+ – 2Br). Anal. Calcd for $C_{12}H_{10}Br_2$: C, 45.89; H, 3.20. Found: C, 45.62; H, 3.24.

2-(Bromomethylene)benzonorbornene (6). (a) Via Bromination and Dehydrobromination of 8. To a solution of **8** (700 mg, 4.48 mmol) in 20 mL of CCl_4 was added dropwise bromine (718 mg, 4.48 mmol) in 6 mL of CCl_4 at room temperature until the color persisted. Stirring was continued at rt for 15 min after the addition of bromine. The reaction mixture was washed with aqueous $NaHSO_3$ and water. The organic layer was dried over $MgSO_4$, and after filtration, the solvent was removed to give crude dibromide (1.23 g, 86%).

The crude dibromide was dissolved in a solution of 0.7 g of KOH in 20 mL of 95% ethanol, and the resulting solution was refluxed for 3 h. Water was added, and the aqueous mixture was extracted with ether. The ether extracts were washed with water and dried over $MgSO_4$. The ether was removed, and the residue (0.89 g) was subjected to preparative thin-layer chromatography (silica gel–petroleum ether) to give 230 mg (21%) of a 70/30 mixture of cis/trans isomers of **6** (colorless liquid) accompanied by 280 mg (19%) of the Wagner–Meerwein rearranged product. Data for the cis isomer of **6**: ^1H (250 MHz) δ 7.05–7.31 (m, 4H), 5.69 (br s, 1H), 4.21 (br s, 1H), 3.57 (m, 1H), 2.57 (dm, J = 14.7 Hz, 1H), 1.98 (m, 2H), 1.82 (dt, J = 8.6, 1.4 Hz, 1H); ^{13}C NMR (63 MHz) δ 147.81, 147.44, 144.74, 126.67, 126.53, 121.69, 121.59, 95.4, 51.42, 50.37, 44.64, 37.47. Data for trans isomer of **6**: ^1H NMR (250 MHz) δ 6.97–7.15 (m, 4H), 6.08 (t, J = 2.1 Hz, 1H), 3.73 (br s, 1H), 3.40 (m, 1H), 2.44 (ddd, J = 15.8, 3.8, 2.6 Hz, 1H), 1.96 (dm, J = 8.6 Hz, 1H), 1.89 (dm, J = 15.8 Hz, 1H), 1.77 (dt, J = 8.6, 1.4 Hz, 1H); ^{13}C NMR (63 MHz) δ 148.70, 148.24, 144.91, 126.68, 126.62, 121.60, 121.53, 97.21, 53.29, 52.12, 43.53, 38.30.

(b) Via Reaction of Dibromomethylene Compound 10 with t-BuLi and H_2O. To a stirred 0.05 M solution of **10** (1.0 g, 3.18 mmol) in dry THF (63.6 mL) at −100 °C was added slowly a solution of 0.85 M t-BuLi in pentane (4.12 mL, 3.5 mmol) under nitrogen. The solution was stirred at −100 °C for 10 min and then quenched with wet THF (3 mL). The mixture was slowly warmed to rt. After a major part of the THF was removed, the

(12) MOPAC, QCPE 455 (Version 6.0), University of Indiana, Bloomington, IN.
(13) PCMODEL, Molecular Modeling Software, Serena Software, Bloomington, IN.

mixture was treated with water (25 mL) and extracted with ether (50 mL × 3). The combined ether layers were washed with water, dried over $MgSO_4$, and filtered. The solvent was removed, and the oily residue (0.81 g) was chromatographed over silica gel with petroleum ether to afford 0.65 g (86%) of a 20/80 mixture of cis/trans isomers of **6**.

Reaction of 2-(Bromomethylene)benzonorborenene 6 with Potassium *tert*-Butoxide (1 Equiv) in the Presence of Diphenylisobenzofuran. To a stirred solution of **6** (1.0 g, 4.25 mmol) and diphenylisobenzofuran (1.13 g, 4.22 mmol) in dry freshly distilled THF (20 mL) was added 0.52 g (4.64 mmol, 10% excess) of potassium *tert*-butoxide. The reaction mixture was refluxed for 6 h under nitrogen. After the mixture was cooled to rt, a major part of the THF was removed and 30 mL of H_2O was added. The aqueous layer was extracted with ether (4 × 20 mL) and CH_2Cl_2 (2 × 25 mL). The combined organic layers were washed with water, dried over $MgSO_4$, and filtered. The filtrate was treated with maleic anhydride until the yellow color disappeared. After removal of the solvent, the oily residue (3 g) was chromatographed over alumina (150 g, grade IV, neutral). Elution with petroleum ether–toluene (8:2) gave as the first fraction the exo ketone **11** (197 mg, 11%): white crystals, mp 237–238 °C (recrystallized from ether); ^{1}H NMR (200 MHz) δ 7.81–7.48 (m, 7H), 7.38–6.90 (m, 9H), 6.60 (dd, 1H), 6.49 (d, 1H), 4.35 (d, J = 4.0 Hz, 1H), 3.30 (dd, 1H), 3.12 (dd, J = 12.8 Hz, 1H), 2.68 (dd, J = 12.8 Hz, 1H), 2.18 (d, J = 11.2 Hz, 1H), 1.83 (ddt, J = 11.2 Hz, 1H); ^{13}C NMR (50 MHz) δ 201.09, 150.56, 146.11, 143.65, 140.69, 139.92, 138.20, 134.75, 133.37, 131.50, 130.38, 129.26, 129.22, 128.85 (2×), 128.74, 127.80, 127.19, 127.12 (2×), 126.91 (2×), 126.75, 126.28, 126.14, 123.02, 122.09, 55.71, 44.33, 38.48, 37.12, 35.09; MS (EI) m/z 424 (M^+). Anal. Calcd for $C_{32}H_{24}O$: C, 90.53, H, 5.69. Found: C, 90.48, H, 5.72.

Continued elution with the same solvent mixture afforded the endo isomer **12** as the second fraction (213 mg, 12%): white crystals, mp 194–195 °C (recrystallized from ether–pentane); ^{1}H NMR (200 MHz) δ 7.73–7.48 (m, 5H), 7.36–7.06 (m, 5H), 6.96–6.61 (m, 8H), 3.95 (d, J = 4.5 Hz, 1H), 3.35 (m, 1H), 3.20 (dt, J = 15.2 Hz, 1H), 2.64 (dd, J = 15.2, 3.2 Hz, 1H), 2.35 (ddt, J = 10.4 Hz, 1H), 1.92 (d, J = 10.4 Hz, 1H); ^{13}C NMR (50 MHz) δ 201.10, 145.98, 143.63, 142.89, 139.71, 138.97, 138.35, 133.50, 132.88, 130.46, 129.92, 129.22, 128.92, 128.68, 127.52, 127.30 (2×), 127.19, 127.05, 126.78 (2×), 126.33 (2×), 126.12, 125.81, 123.87, 123.19, 55.58, 46.41, 46.07, 40.16, 38.35; MS (EI) m/z 424 (M^+). Anal. Calcd for $C_{32}H_{24}O$: C, 90.53, H, 5.69. Found: C, 90.42; H, 5.65.

Further elution with petroleum ether–ether (9:1) yielded **4e** (120 mg, 16%) as the last fraction. The spectral data matched those reported in the literature.[5]

Reaction of 2-(Bromomethylene)benzonorbornene 6 with Potassium *tert*-Butoxide (2 Equiv) in the Presence of Diphenylisobenzofuran. To a stirred solution of **6** (1.3 g, 5.53 mmol) and diphenylisobenzofuran (1.49 g, 5.51 mmol) in dry THF (30 mL) was added 1.25 g (11.17 mmol, 10% excess) of potassium *tert*-butoxide. The reaction mixture was refluxed for 6 h under nitrogen and worked up in the same way as described above. The crude product (3.8 g) was chromatographed over alumina (300 g). Five products (**4a–e**) were isolated after repeated column chromatography with petroleum ether–toluene (8:2, 7:3).

The first component was identified as the syn-exo isomer **4c** (42 mg, 1.8%): colorless crystals, mp 211 °C from CH_2Cl_2–pentane; ^{1}H NMR (400 MHz) δ 7.40–7.77 (m, 9H), 7.10–7.25 (m, 9H), 6.17 (dd, J = 7.7, 2.3 Hz, 1H), 3.34 (dd, J = 7.7, 4.0 Hz, 1H), 3.13 (d, J = 3.3 Hz, 1H), 2.75 (d, J = 2.3 Hz, 1H), 1.98 (dt, J = 9.7, 4.0 Hz, 1H), 1.49 (d, J = 9.7 Hz, 1H); ^{13}C NMR (100 MHz) δ 150.81, 150.17, 147.64, 143.68, 138.73, 136.61, 135.94, 128.62 (2×), 128.46 (2×), 127.50, 127.35, 126.74, 126.59, 126.56, 126.35, 126.12, 125.81 (2×), 125.73 (2×), 122.43, 121.87, 120.57, 116.72, 89.45, 89.38, 52.23, 41.35, 40.81, 39.15; MS (EI) m/z 424 (M^+). Anal. Calcd for $C_{32}H_{24}O$: C, 90.53; H, 5.69. Found: C, 90.35; H, 5.45.

The second component was the anti-endo isomer **4b** (380 mg, 16%): colorless crystals; mp 176 °C from hexane; ^{1}H (400 MHz) δ 6.62–7.81 (m, 18H), 5.74 (ddd, J = 5.2, 2.7, 0.9 Hz), 3.85 (dd, J = 5.2, 3.9 Hz, 1H), 3.61 (t, J = 2.7 Hz, 1H), 3.41 (t, J = 4.8 Hz, 1H), 2.29 (ddt, J = 10.9, 4.8, 0.9 Hz, 1H), 2.22 (d, J = 10.3 Hz, 1H); ^{13}C NMR (100 MHz) δ 147.45, 144.19, 142.02, 138.15, 137.52, 135.39, 134.81, 128.72 (3×), 128.47 (2×), 128.41 (2×), 127.89, 127.41, 127.19, 126.34 (2×), 124.65, 124.21, 122.82, 122.75, 122.55, 119.35, 117.13, 90.09, 89.30, 51.80, 44.08, 42.33, 42.23; MS (EI) m/z 424 (M^+). Anal. Calcd for $C_{32}H_{24}O$: C, 90.53; H, 5.69. Found: C, 90.61; H, 5.75.

The third fraction yielded the anti-exo isomer **4a** (110 mg, 4.6%): colorless crystals, mp 231–232 °C from chloroform–hexane; ^{1}H NMR (400 MHz) δ 6.98–7.80 (m, 18H), 6.03 (dd, J = 7.5, 2.9 Hz, 1H), 3.45 (d, J = 2.9 Hz, 1H), 3.28 (d, J = 3.6 Hz, 1H), 3.13 (dd, J = 7.5, 4.0 Hz, 1H), 1.71 (dt, J = 10.3, 3.8 Hz, 1H), 1.14 (d, J = 10.0 Hz, 1H); ^{13}C NMR (100 MHz) δ 149.82, 149.73, 147.29, 144.25, 143.71, 136.67, 133.99, 129.18, 129.15, 128.88, 128.71, 128.57, 128.55, 128.45, 128.42, 128.20, 128.02, 127.77, 127.56, 126.76, 126.36, 126.04, 122.66, 121.50, 121.48, 117.80, 91.06, 90.41, 51.02, 40.81, 39.17, 38.41; MS (EI) m/z 424 (M^+). Anal. Calcd for $C_{32}H_{24}O$: C, 90.53; H, 5.69. Found: C, 90.26; H, 5.37.

The fourth component was identified as alcohol **4d** (75 mg, 3%): colorless crystals, mp 220 °C from chloroform–hexane; ^{1}H NMR (400 MHz) δ 6.98–7.70 (m, 18H), 4.85 (d, J = 2.0, 0.9 Hz, 1H), 4.13 (d, J = 4.5, 1H), 3.40 (dd, J = 4.5, 2.0 Hz, 1H), 2.64 (d, J = 11.0 Hz, 1H), 2.34 (ddt, J = 11.0, 4.5, 0.9 Hz, 1H), 2.15 (br s, 1H, OH); ^{13}C NMR (100 MHz) δ 151.43, 142.70, 141.20, 139.49, 138.39, 138.33, 134.84, 132.90, 132.22, 132.14, 131.18, 130.65, 130.45, 129.75, 129.27, 128.79, 128.69, 128.26, 127.79, 127.39, 126.73, 126.69, 126.48, 126.06, 125.93, 124.91, 124.42, 122.49, 68.66, 47.32, 43.65, 37.01; MS (EI) m/z 424 (M^+). Anal. Calcd for $C_{32}H_{24}O$: C, 90.53; H, 5.69. Found: C, 90.47; H, 5.58.

Lastly, 100 mg (10.5%) of the symmetric ketone **4e** was isolated.

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Supplementary Material Available: Infrared and mass spectral data for compounds **4a–d**, **6**, **8**, **11**, and **12** (1 page). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.