REVISED
1/02/03

Supporting Information

Unusual, Strained Heterocycles: 3-Alkylidene-2-methyleneoxetanes from Morita-

Baylis-Hillman-type Adducts

Isamir Martinez, Alexander E. Andrews, Joseph D. Emch⁺, Albert J. Ndakala,
Jun Wang, and Amy R. Howell*

Department of Chemistry, The University of Connecticut, Storrs, Connecticut

06269-3060

amy.howell@uconn.edu

General Experimental. ¹H NMR and ¹³C spectra were obtained using a Bruker Avance DRX-400 NMR spectrometer. Chemical shifts are reported in units of parts per million (ppm). IR was performed in a Nicolet 60SX FT-IR spectrometer. GC/MS spectra were obtained on a Hewlett-Packard 5890 gas chromatograph equipped with a HP-1 methyl silicon column and detected on a low-resolution 5970 series mass selective detector. High resolution mass spectra were obtained on a JEOL JMS-AX505HA instrument at the University of Notre Dame, Indiana. Column chromatography was performed using Scientific Adsorbents silica gel, 40 microns flash silica. Thin layer chromatography was performed on silica gel (EM Science Silica Gel 60 F₂₅₄) glass plates, and the compounds were visualized by UV, 5% phosphomolybdic acid in ethanol or 0.5% aqueous solution of KMnO₄.

THF was distilled from a dark blue solution of sodium benzophenone ketyl. Deuterated chloroform and toluene were dried over 3 molecular sieves.

Dichloromethane was freshly distilled from calcium hydride. Reagents were purchased from Aldrich and Acros. Bulk solvents were purchased from J. T. Baker or Fisher. Hydrocinnamaldehyde and isobutyraldehyde were purchased from Aldrich and distilled before use. Dimethyltitanocene¹ and $\text{MgBr}_2 \cdot \text{Et}_2\text{O}$ ² were prepared using literature procedures. Compounds **7c**,³ **7d**,³ **7i**,⁴ **9c**,³ and **9d**³ were prepared using literature procedures with minor modifications.

Methyl 3-hydroxy-2-methylene-4,4-diphenylbutyrate (7b). A solution of methyl acrylate (5.80 g, 67.8 mmol), diphenylacetaldehyde **6b** (13.3 g, 67.8 mmol) and DABCO (0.829 g, 6.8 mmol) was stirred at rt for 7 d. The reaction was diluted with Et_2O (400 mL) and washed with 2 M HCl (100 mL) and saturated aqueous NaHCO_3 (100 mL). The organic extracts were combined, dried (MgSO_4) and evaporated under reduced pressure. Purification by flash chromatography on silica gel (petroleum ether/ EtOAc 9:1) afforded **8b** as a solid (16.1 g, 84%): mp 99-100°C; IR (CDCl_3) 3502, 3028, 1714, 1495, 1450, 1195, 1151, cm^{-1} ; ^1H NMR (CDCl_3) δ 7.26 (m, 10 H), 6.13 (s, 1H), 5.62 (s, 1H), 5.20 (dd, $J = 8.1, 7.4$ Hz, 1H), 4.35 (d, $J = 8.2$ Hz, 1H), 3.70 (s, 3H), 2.56 (d, $J = 7.2$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 166.9, 141.8, 140.7, 140.6, 129.2, 128.6, 128.5, 128.5, 127.3, 126.8, 126.6, 74.2, 57.1, 51.9; MS (EI) m/z 264 ($\text{M}^+ - \text{H}_2\text{O}$), 205, 167 (100), 152, 115, 91, 83, 55; HRMS (FAB) calcd for $\text{C}_{18}\text{H}_{19}\text{O}_3$ ($\text{M}^+ + \text{H}$) m/z 283.1334. Found: 283.1359.

2-(1-Hydroxy-3-phenylpropyl)acrylic acid (8a). A solution of methyl acrylate (12.4 g, 0.144 mol), hydrocinnamaldehyde **6a** (14.4 g, 0.107 mol) and DABCO (1.63 g, 14.5 mmol) was stirred at rt for 10 d. The crude reaction mixture was dissolved in MeOH (45 mL) and 2 M KOH (125 mL) and stirred at rt for 24 h. MeOH was removed *in vacuo*, and the aqueous mixture was acidified with 2 M HCl (160 mL) and then

saturated with NaCl. The mixture was then diluted with Et₂O (200 mL). The organic layer was separated, and the aqueous layer was extracted with Et₂O (3 x 150 mL). The combined organic extracts were dried (MgSO₄), filtered and concentrated. Purification by flash chromatography on silica gel (petroleum ether/EtOAc 9:1 to 4:1 to 5:2) provided a white solid (16.3 g, 74%). Recrystallization from toluene/hexane provided **8a** as white prisms: mp 79-80 °C; IR(neat) 3062, 3027, 2925, 1693, 1627, 1496, 1454, 1418, 1040, 1177, 1148, 1065, 1040, 956 cm⁻¹; ¹H NMR (CDCl₃) δ 7.31 (dd, *J* = 14.9, 7.5 Hz, 2H), 7.23 (m, 3H), 6.45 (s, 1H), 5.98 (s, 1H), 4.49 (dd, *J* = 7.4, 5.5 Hz, 1H), 2.86 (ddd, *J* = 20.6, 9.0, 6.3 Hz, 1H), 2.74 (m, 1H), 2.05 (m, 2H); ¹³C NMR (CDCl₃) δ 171.2, 141.5, 141.4, 128.4, 127.9, 126.0, 70.8, 37.5, 32.0; MS (EI) *m/z* 206 (M⁺), 188, 173, 160, 143, 129, 128, 105, 91 (100), 83, 77, 65, 51; Anal. Calcd for C₁₂H₁₄O₃: C, 69.88; H, 6.84. Found: C, 69.73; H, 7.08.

3-Hydroxy-2-methylene-4,4-diphenylbutyric acid (8b). Ester **7b** (0.25 g, 0.89 mmol) was dissolved in MeOH (2 mL) and 2 M KOH (1 mL) and stirred at rt for 24 h. MeOH was removed *in vacuo*, and the aqueous mixture was acidified with 2 M HCl to pH 2. The mixture was then diluted with Et₂O (5 mL). The organic layer was separated and the aqueous layer extracted with Et₂O (3 x 10 mL). The combined organic extracts were dried (MgSO₄), filtered and concentrated. Purification by flash chromatography on silica gel (petroleum ether/EtOAc/AcOH 74.5:25:0.5) provided **8b** as a white solid (0.21 g, 88%): ¹H NMR (CDCl₃) δ 7.31 (m, 10 H), 6.29 (s, 1H), 5.71 (s, 1H), 5.23 (d, *J* = 8.0 Hz, 1H), 4.38 (d, *J* = 8.0 Hz, 1H).

2-(Hydroxyphenylmethyl)acrylic acid (8g). Prepared by the procedure described for **8a** and used without further purification:⁵ ¹H NMR (CDCl₃) δ 7.23 (m, 5H), 6.37 (s, 1H), 5.84 (s, 1H), 5.46 (s, 1H).

2-(Hydroxy-*p*-tolylmethyl)acrylic acid (8h). Prepared by the procedure described for **8a**. Purification by flash chromatography on silica gel (petroleum ether/EtOAc 1:1) provided **8h** as an off white (0.36 g, 73%):⁶ ¹H NMR (CDCl₃) δ 7.20 (m, 5H), 6.47 (s, 1H), 5.97 (s, 1H), 5.54 (s, 1H), 2.34 (s, 3H).

3-Hydroxy-3-(2-nitrophenyl)-2-methylenepropionic acid (8i). Prepared from **7i** according to the procedure described for **8a**. Purification by flash chromatography on silica gel (petroleum ether/EtOAc/AcOH 79.5:20:0.5) provided **8i** as a yellow solid (8.2g, 92%): ¹H NMR (CDCl₃) δ 8.25 (d, *J* = 8.3 Hz, 1H), 7.86 (d, *J* = 7.8 Hz, 1H), 7.77 (app t, *J* = 7.6 Hz, 1H), 7.59 (app t, *J* = 8.2 Hz, 1H), 6.58 (s, 1H), 5.76 (s, 1H).

3-Methylene-4-phenylethyloxetan-2-one (9a). Anhydrous Na₂CO₃ (10.0 g, 94.4 mmol) was added to a stirred solution of **8a** (2.0 g, 9.7 mmol) in CH₂Cl₂ (50 mL). After 15 min, 2-nitrobenzenesulfonyl chloride (3.23 g, 14.6 mmol) was added and the mixture left to stir at rt for 2 d. The mixture was diluted with CH₂Cl₂ (100 mL) and water (45 mL) and stirred for 15 min. The organic layer was separated and the aqueous layer extracted with CH₂Cl₂ (3 x 15 mL). The combined organic extracts were dried (Na₂SO₄), filtered and concentrated. Purification by flash chromatography on silica gel (petroleum ether/EtOAc 95:5) provided **8a** as a colorless oil (1.41 g, 77%): IR (neat) 3062, 3028, 2945, 2863, 1815, 1603, 1496, 1454, 1409, 1206, 1083, 1001, 944 cm⁻¹; ¹H NMR (CDCl₃) δ 7.33 (m, 2H), 7.23 (m, 3H), 5.90 (dd, *J* = 2.0, 2.0 Hz, 1H), 5.32 (ddd, *J* = 2.0, 2.0, 0.49 Hz, 1H), 4.97 (m, 1H), 2.82 (m, 2H), 2.18 (m, 2H); ¹³C NMR (CDCl₃) δ 163.4,

146.1, 140.0, 128.6, 128.4, 126.4, 115.2, 78.6, 35.0, 30.9; MS (EI) m/z 188 (M^+), 187 (M^+-1), 170, 142, 129, 117, 105, 91 (100), 84, 77, 65, 56; Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43. Found: C, 76.60; H, 6.30.

4-Benzhydryl-3-methylenioxetan-2-one (9b). Prepared from **8b** by the procedure described for **9a**. Purification by flash chromatography on silica gel (petroleum ether/EtOAc 92.5:7.5) provided **9b** as a white solid (0.28 g, 51%): mp 82-83 °C; IR (neat) 3090, 3027, 2923, 1821, 1495, 1450, 1083 cm^{-1} ; ^1H NMR ($CDCl_3$) δ 7.25 (m, 10H), 5.74 (dd, $J = 2.0, 1.4$ Hz, 1H), 5.53 (ddd, $J = 9.6, 2.0, 1.4$ Hz, 1H), 4.72 (dd, $J = 2.0, 1.4$ Hz, 1H), 4.20 (d, $J = 9.6$ Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 163.1, 144.9, 139.5, 139.1, 129.0, 128.8, 128.7, 128.3, 127.7, 127.3, 117.0, 80.0, 54.5; MS (EI) m/z 250 (M^+), 167(100), 165, 152, 102, 77, 51; HRMS (FAB) calcd $C_{17}H_{15}O_2$ ($M^+ + H$) m/z 251.1072. Found: 251.1075.

3-Benzylidene-4-methyloxetan-2-one (9e). DIBALH (22.4 mL, 1 M in hexanes) was added slowly to a stirred suspension of 4-methylmorpholine *N*-oxide (NMO) (2.7 g, 23 mmol) in THF (150 mL) at rt over a period of 30-45 min. After obtaining a clear solution, the reaction mixture was stirred for an additional hour. Ethyl phenylpropionate (2.4 g, 14.0 mmol) was then added slowly over 15 min. The resulting yellow solution was stirred for 1 h, followed by the addition of acetaldehyde (0.74 g, 16.8 mmol) over 15 min at 0 °C. The reaction was allowed to warm to rt and stir overnight. The bright yellow-green reaction mixture was quenched with cold 1 M HCl (60 mL) and extracted with Et_2O (3 x 300 mL). The organic extracts were combined, dried ($MgSO_4$) and concentrated *in vacuo*. The yellow residue was dissolved in EtOH (15 mL), and 2 M KOH (57 mL) was added. The resulting solution was stirred at rt for 48 h. EtOH was

removed *in vacuo* and the aqueous mixture acidified with 2 M HCl (100 mL). The mixture was then diluted with Et₂O (200 mL). The organic layer was separated, and the aqueous layer was extracted with Et₂O (3 x 150 mL). The combined organic extracts were dried (MgSO₄), filtered and concentrated to afford **8e**. ¹H NMR (DMSO) δ 7.26 (m, 5H), 6.59 (d, *J* = 1.3 Hz, 1H), 4.42 (qd, *J* = 6.5, 1.3 Hz, 1H), 1.22 (d, *J* = 6.4, Hz, 3H).

Anhydrous Na₂CO₃ (10.0 g, 94.4 mmol) was added to a solution of **8e** (2.0 g, 9.7 mmol) in CH₂Cl₂ (200 mL). After 15 min, 2-nitrobenzenesulfonyl chloride (3.23 g, 14.6 mmol) was added and the mixture left to stir at rt for 2 d. The mixture was diluted with CH₂Cl₂ (100 mL) and water (45 mL) and stirred for 15 min. The organic layer was separated and the aqueous layer extracted with CH₂Cl₂ (3 x 15 mL). The combined organic extracts were dried (Na₂SO₄), filtered and concentrated. Purification by flash chromatography on silica gel (petroleum ether/EtOAc 98:2) provided **9e** as a yellowish oil (1.29 g, 55%): IR (neat) 3067, 2980, 1790, 1687 cm⁻¹; ¹H NMR (CDCl₃) δ 7.95 (m, 2H), 7.42 (m, 3H), 6.51 (s, 1H), 5.09 (m, 1H), 1.64 (d, *J* = 6.2 Hz, 3H); ¹³C NMR (CDCl₃) δ 163.0, 136.7, 133.2, 132.9, 130.6, 130.2, 128.9, 74.1, 19.5; MS (EI) *m/z* 174 (M⁺)(100), 159, 131, 115, 102, 77, 51; Anal. Calcd for C₁₁H₁₀O₂: C, 75.84; H, 5.79. Found: C, 75.44; H, 5.70.

3-Benzylidene-4-isopropylloxetan-2-one (9f). Prepared by the procedure described for compound **9e**. Purification by flash chromatography on silica gel (petroleum ether/EtOAc 97.5:2.5) provided **9f** as a white solid (2.0, 35%): mp 54 °C; IR (neat) 3067, 2925, 1776, 1682, 1128, 1060, 938, 870, 847, 726, 688 cm⁻¹; ¹H NMR (CDCl₃) δ 7.95 (m, 2H), 7.35 (m, 3H), 6.57 (s, 1H), 4.71 (d, *J* = 6.5 Hz, 1H), 2.12 (app o,

$J = 6.7$ Hz, 1H), 1.11 (d, $J = 6.7$ Hz, 3H), 1.09 (d, $J = 6.7$ Hz, 3H). ^{13}C NMR (CDCl_3) δ 163.1, 134.5, 133.7, 133.0, 130.6, 130.3, 128.9, 81.9, 31.9, 17.4, 17.3; MS (EI) m/z 202 (M^+), 201, 159 (100), 131, 115, 103, 77, 51; Anal. Calcd for $\text{C}_{13}\text{H}_{14}\text{O}_2$: C, 77.20; H, 6.98. Found: C, 77.55; H, 7.21.

3-Methylene-4-(2-nitrophenyl)oxetan-2-one (9i). Prepared from **8i** by the procedure described for **9a**. Purification by flash chromatography on silica gel (petroleum ether/EtOAc/Et₃N 94.5:5.0:0.5) provided **9i** as a beige solid (42 mg, 46%): mp (135 °C dec); IR (neat) 1825, 1526, 1495, 1346, 1075, 741, 700 cm^{-1} ; ^1H NMR (CDCl_3) δ 8.24 (d, $J = 8.1$ Hz, 1H), 7.86 (d, $J = 7.6$ Hz, 1H), 7.77 (m, 1H), 7.59 (m, 1H), 6.57 (s, 1H), 6.00 (s, 1H), 5.75 (s, 1H); ^{13}C NMR (CDCl_3) 163.0, 145.8, 134.9, 132.8, 129.7, 127.1, 125.4, 118.3, 76.3; MS (EI) m/z 160 ($\text{M}^+ - \text{HCO}_2$), 121, 104, 92, 77, 65, 51; Anal. Calcd for: $\text{C}_{10}\text{H}_7\text{NO}_4$, C, 58.54; H, 3.44; N, 6.83. Found: C, 58.87; H, 3.63, N, 6.47.

Propa-1,2-dienylbenzene (10g). Anhydrous Na_2CO_3 (10.0 g, 94.4 mmol) was added to a solution of **8g** (2.0 g, 9.7 mmol) in CH_2Cl_2 (125 mL). After 15 min, 2-nitrobenzenesulfonyl chloride (3.23 g, 14.6 mmol) was added and the mixture left to stir at rt for 2 d. The mixture was diluted with CH_2Cl_2 (100 mL) and water (45 mL) and stirred for 15 min. The organic layer was separated and the aqueous layer extracted with CH_2Cl_2 (3 x 15 mL). The combined organic extracts were dried (Na_2SO_4), filtered and concentrated. Purification by flash chromatography on silica gel (petroleum ether) provided **10g** as a clear oil (0.16 g, 28%): ^1H NMR (CDCl_3) δ 7.25 (m, 5H), 6.17 (t, $J = 6.8$ Hz, 1H), 5.15 (d, $J = 6.8$ Hz, 2H).

1-Methyl-4-propa-1,2-dienylbenzene (10h). Prepared from compound **8h** by the procedure described above. Purification by flash chromatography on silica gel (petroleum ether) provided **10h** as a colorless oil (88 mg, 34%):⁸ ¹H NMR (CDCl₃) δ 7.19 (d, J = 8.0 Hz, 2H), 7.11 (d, J = 7.9 Hz, 2H), 6.14 (t, J = 6.8 Hz, 1H), 5.20 (d, 2H), 2.33 (s, 3H).

General procedure for the methylenation of α -alkylidene- β -lactones.

Method A. A solution of dimethyltitanocene (0.5 M in toluene, 1.5-2 equiv) and α -alkylidene- β -lactones (1 equiv) was stirred in the dark at 80 °C under N₂. The progress of the reaction was followed until the disappearance of the starting material by ¹H NMR (reaction time varies from 3-5 h). The cooled reaction mixture was added to petroleum ether (10 volumes) and stirred for 1 h. The yellow precipitate that formed was filtered through a pad of celite using petroleum ether until the filtrate was colorless. The filtrate was concentrated *in vacuo* and the residue purified by flash chromatography on deactivated silica gel.

Method B. A solution of dimethyltitanocene (0.25 M in toluene, 4-5 equiv) and α -alkylidene- β -lactones (1 equiv) was stirred in the dark at 75 °C under N₂. The progress of the reaction was followed until the disappearance of the starting material by ¹H NMR (reaction time varies from 2-3 h). The cooled reaction mixture was added to petroleum ether (10 volumes) and stirred for 1 h. The yellow precipitate that formed was filtered through a pad of celite using petroleum ether until the filtrate was colorless. The filtrate was concentrated *in vacuo* and the residue purified by flash chromatography on deactivated silica gel.

2,3-Dimethylene-4-phenethyloxetane (11a). Prepared from compound **9a** by Method A. Purification by flash chromatography on silica gel (petroleum ether/triethylamine 99.5:0.5) afforded **11a** as a pale yellow oil (75 mg, 35%): IR (neat) 3062, 3027, 2944, 1816, 1737, 1659, 1496, 1454, 1226, 1144, 1118, 1009, 902 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 7.29 (m, 2H), 7.21 (m, 3H), 5.22 (m, 2H), 4.85 (s, 1H), 4.19 (d, $J = 3.9$ Hz, 1H), 4.17 (d, $J = 3.9$ Hz, 1H), 2.82 (m, 1H), 2.72 (m, 1H), 2.17 (m, 1H), 2.10 (m, 1H); ^{13}C NMR (100 MHz, CDCl_3) δ 162.8, 144.7, 141.0, 128.5, 128.4, 126.1, 103.5, 86.9, 78.4, 36.0, 30.4; MS (EI) m/z 187 ($\text{M}^+ + \text{H}$), 186 (M^+), 171, 143, 128, 115, 103, 91 (100), 77, 65, 51; HRMS (EI) calcd for $\text{C}_{13}\text{H}_{14}\text{O}$ (M^+) m/z 186.1045. Found: 186.1038.

2-Benzhydryl-3,4-dimethyleneoxetane (11b). Prepared from compound **9b** by Method B. Purification by flash chromatography on silica gel (petroleum ether/triethylamine 99.5:0.5) afforded **11b** as a clear oil (54 mg, 55%): IR (neat) 3061, 3028, 2924, 1660, 1495, 1452, 903 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 7.28 (m, 10H), 5.85 (dt, $J = 9.8, 2.0$ Hz, 1H), 5.09 (m, 1H), 4.34 (d, $J = 9.8$ Hz, 1H), 4.23 (s, 1H), 4.17 (m, 2H); ^{13}C NMR (100 MHz, CDCl_3) δ 162.7, 143.2, 140.4., 139.7, 128.9, 128.6, 128.6, 128.2, 127.2, 126.8, 105.3, 88.0, 78.6, 55.2; MS (EI) m/z 248 (M^+), 167, 152, 141 (100), 115, 91, 77, 51; HRMS (FAB) calcd for $\text{C}_{18}\text{H}_{17}\text{O}$ ($\text{M}^+ + \text{H}$) m/z 249.1279. Found: 249.1261.

2-Isopropyl-3-iodomethylene-4-methyleneoxetane (11c). Prepared from compound **9c** by Method B. Purification by flash chromatography on silica gel (petroleum ether/triethylamine 99.5:0.5) afforded **11c** as a pale yellow oil (0.14 g, 70%): IR (film) 3068, 2956, 2922, 2853, 1684, 1641, 1465, 1386, 1256, 1221, 1166, 951, 909,

801 cm^{-1} , ^1H NMR (400 MHz, CDCl_3) δ 6.14 (s, 1H), 4.87 (dd, $J = 6.7, 1.5$ Hz, 1H), 4.84 (d, $J = 3.8$ Hz, 1H), 4.18 (d, $J = 3.8$ Hz, 1H), 2.02 (app o, $J = 6.8$, 1H), 1.0 (d, $J = 6.7$ Hz, 3H), 0.98 (d, $J = 6.8$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 162.4, 145.3, 93.9, 82.0, 66.4, 32.1, 17.0, 16.6. MS (EI) m/z 250 (M^+) (100), 235, 95, 79, 51; HRMS (FAB) calcd for $\text{C}_8\text{H}_{12}\text{IO}$ ($\text{M}^+ + \text{H}$) m/z 250.9933. Found: 250.9952.

2-*tert*-Butyl-3-iodomethylene-4-methyleneoxetane (11d) Prepared from compound **9d** by Method A. Purification by flash chromatography on silica gel (petroleum ether/triethylamine 99.5:0.5) afforded **11d** (0.060 g, 75%) as a pale yellow oil: ^1H NMR (CDCl_3) δ 6.13 (s, 1H), 4.83 (d, $J = 0.89$ Hz, 1H), 4.79 (s, 1H), 4.18 (d, $J = 0.89$ Hz, 1H), 0.97 (s, 9H); ^{13}C NMR (CDCl_3) δ 162.4, 144.5, 96.4, 81.7, 66.4, 34.4, 24.0; MS (EI) m/z 264 (M^+), 249, 206, 137, 122, 109, 95, 79, 67, 51 (100); HRMS (FAB) calcd for $\text{C}_9\text{H}_{14}\text{IO}$ ($\text{M}^+ + \text{H}$) 265.0090. Found: 265.0092.

3-Benzylidene-2-methyl-4-methyleneoxetane (11e). Prepared from compound **9e** by Method B. Purification by flash chromatography on silica gel (petroleum ether/triethylamine 99.5:0.5) afforded **11e** as a clear oil (56 mg, 28%): IR (neat) 2972, 2923, 1806, 1650, 1491, 1449, 1176, 967 cm^{-1} ; ^1H NMR (CDCl_3) δ 7.44 (m, 2H), 7.30 (m, 2H), 7.28 (m, 1H), 6.18 (s, 1H), 5.36 (qd, $J = 6.3, 1.7$ Hz, 1H), 4.57 (d, $J = 3.9$ Hz, 1H), 4.30 (dd, $J = 3.9, 1.1$ Hz, 1H), 1.58 (d, $J = 6.3$ Hz, 3H); ^{13}C NMR (CDCl_3) 162.0, 138.0, 134.9, 128.4, 128.3, 128.0, 122.1, 83.0, 82.3, 20.3; MS (EI) m/z 172 (M^+), 157, 129 (100), 115, 102, 77, 51; HRMS (FAB) calcd for $\text{C}_{12}\text{H}_{13}\text{O}$ ($\text{M}^+ + \text{H}$) m/z 173.0966. Found: 173.0965.

3-Benzylidene-2-isopropyl-4-methyleneoxetane (11f). Prepared from compound **9f** by Method B. Purification by flash chromatography on silica gel

(petroleum ether/EtOAc/triethylamine 98:1:1) afforded **11f** as a clear oil (0.11 g, 60 %): IR (CDCl₃) 2964, 2928, 1801, 1655, 1494, 1468, 1387, 1246, 1171, 968 cm⁻¹; ¹H NMR (CDCl₃) δ 7.43 (m, 2H), 7.36 (m, 2H), 7.27 (m, 1H), 6.25 (s, 1H), 4.97 (d, *J* = 6.2 Hz, 1H), 4.97 (d, *J* = 6.3 Hz, 1H), 4.51 (d, *J* = 3.8 Hz, 1H), 4.25 (d, *J* = 3.8 Hz, 1H), 2.10 (m, 1H), 1.07 (d, *J* = 3.4 Hz, 3H), 1.06 (d, *J* = 3.6 Hz, 3H); ¹³C NMR (CDCl₃) δ 162.1, 136.0, 135.1, 128.5, 128.4, 128.0, 122.7, 90.8, 81.5, 32.4, 17.0, 17.0; MS (EI) *m/z* 201 (*M*⁺ + 1), 159 (100), 131, 103, 77, 51; HRMS (FAB) calcd for C₁₄H₁₇O (*M*⁺ + H) *m/z* 201.1279. Found: 201.1261.

3-Methylene-4-phenethyl-1,5-dioxaspiro[3.2]hexane (12). A solution of dimethyldioxirane (0.35 M in CH₂Cl₂, 1.0 equiv) was added dropwise to a solution of **11a** in dry CH₂Cl₂ at -78 °C. The reaction mixture was stirred for 1 h and then concentrated. A yellow oil (53 mg, 98%) was obtained as a mixture of diastereomers (60:40). IR (CDCl₃) 3085, 3061, 3027, 2929, 2860, 1820, 1719, 1603, 1496, 1454, 1383, 1211, 1114 cm⁻¹; Major diastereomer: ¹H NMR (CDCl₃) δ 7.31 (m, 2H), 7.21 (m, 3H), 5.21 (ddd, *J* = 9.4, 4.6, 2.1 Hz, 1H), 5.13 (dd, *J* = 2.2, 2.2 Hz, 1H), 5.08 (dd, *J* = 2.0, 2.0 Hz, 1H), 3.15 (d, *J* = 3.6 Hz, 1H), 2.98 (d, *J* = 3.7 Hz, 1H), 2.81 (m, 2H), 2.18 (m, 2H); ¹³C NMR (CDCl₃) δ 147.9, 140.9, 128.5, 128.5, 126.1, 107.4, 91.1, 83.2, 52.1, 36.7, 30.7. Minor diastereomer: ¹H NMR (CDCl₃) δ 7.31 (m, 2H), 7.21 (m, 3H), 5.14 (dd, *J* = 2.1, 2.1 Hz, 1H), 5.09 (dd, *J* = 1.9, 1.9 Hz, 1H), 5.04 (ddd, *J* = 9.5, 4.8, 2.2 Hz, 1H), 3.16 (d, *J* = 3.7 Hz, 1H), 3.02 (d, *J* = 3.7 Hz, 1H), 2.81 (m, 2H), 2.18 (m, 2H); ¹³C NMR (CDCl₃) δ 148.1, 141.0, 128.5, 128.5, 126.1, 107.3, 90.4, 82.2, 52.2, 36.9, 30.4; HRMS (FAB) calcd for C₁₅H₁₅O₂ (*M*⁺ + H) *m/z*: 203.1073. Found: 203.1079.

4-Methylene-1-phenylhex-5-yn-3-ol (14). *n*-BuLi (2.2 M, 1.77 mL, 2.2 mmol) was added dropwise to a solution of diisopropylamine (0.64 mL, 4.54 mmol) in dry THF (5 mL) at 0 °C under nitrogen. The solution was then stirred 15 min at rt, and added to a solution of **11a** (0.25 g, 1.34 mmol) in THF (2 mL) at 0 °C under nitrogen. Stirring was continued for 20 min. The solution was quenched with water (5 mL), diluted with Et₂O (5 mL), and the layers separated. The aqueous layer was extracted with Et₂O (3 x 10 mL). The combined organic extracts were dried (Na₂SO₄) and concentrated. Purification by flash chromatography on silica gel (petroleum ether/EtOAc 85:15) gave **14** (0.18 g, 56%) as a pale yellow oil: IR (film) 3650-3350, 3300, 3080, 2900, 2350, 1470, 1350, 1080, 950 cm⁻¹; ¹H NMR (CDCl₃) δ 7.37-7.16 (m, 5H), 5.58 (m, 2H), 4.14 (m, 1H), 2.99 (s, 1H), 2.73 (m, 2H), 2.02 (m, 2H), 1.77 (bs, 1H); ¹³C NMR (CDCl₃) δ 141.6, 133.8, 128.4, 128.5, 125.9, 122.8, 81.1, 79.5, 73.7, 37.3, 31.6; MS (EI) *m/z* 186 (M⁺), 167, 148, 115, 105, 91(100), 77, 66, 51; HRMS (EI) calcd for C₁₃H₁₄O (M⁺) 186.1045. Found: 186.1053.

3-Bromomethyl-6-phenylhex-3-en-2-one (16). Anhydrous MgBr₂·Et₂O (0.031g, 0.12 mmol) was added to a solution of the diene **11a** (0.035 g, 0.19 mmol) in dry CH₂Cl₂ (5 mL). The suspension was stirred at rt under N₂ for 10 h. The reaction mixture was diluted with CH₂Cl₂ (20 mL), followed by the addition of brine, and stirred for 10 min. The layers were separated, and the aqueous layer was extracted with CH₂Cl₂ (3 x 10 mL). The combined organic extracts were dried (Na₂SO₄) and concentrated. Purification by flash chromatography on silica gel (petroleum ether/EtOAc 95:5) provided **16** (0.035g, 69%) as a pale yellow oil.⁹ ¹H NMR (CDCl₃) δ 7.28 (m, 5H), 6.82 (t, *J* = 7.4 Hz, 1H), 4.13 (s, 2H), 2.88 (m, 2H), 2.70 (m, 2H), 2.33 (s, 3H).

⁺*Dedicated to the memory of Joseph D. Emch*

¹ Dollinger, L. M.; Ndakala, A. J.; Hashemzadeh, M.; Wang, G.; Wang, Y.; Martinez, I.; Arcari, J. T.; Galluzzo, D. J.; Howell, A. R.; Rheingold, A. L.; Figuero, J. S. *J. Org. Chem.* **1999**, *64*, 7074-7080.

² Montgomery, J.; Overman, L. E. *J. Org. Chem.* **1993**, *58*, 6476-6479.

³ Zhang, C.; Lu, X. *Synthesis* **1996**, 586-589.

⁴ Familoni, O. B.; Kaye, P. T.; Klass, P. J. *J. Chem. Soc., Chem. Commun.* **1998**, 23, 2563-2564.

⁵ Drewes, S. E.; Emslie, N. D.; Field, J. S.; Khan, A. A.; Ramesar, N. *Tetrahedron: Asymmetry* **1992**, *3*, 255-260.

⁶ Rosa, J. N.; Carlos, A. M.; Santos, A. G. *Tetrahedron* **2001**, *57*, 4189-4194.

⁷ Ma, S.; Zhang, A. *J. Org. Chem.* **1998**, *63*, 9601-9604.

⁸ Becker, J. Y. *J. Organomet. Chem.* **1976**, *118*, 247-252.

⁹ Iwamura, T.; Fujita, M.; Kawakita, T.; Kinoshita, S.; Watanabe, S.-I.; Kataoka, T. *Tetrahedron* **2001**, *57*, 8455-8462.