

Unfolding the frontal chemistry: a facile selective hydrogenation of 7-methylidene-6,8-dioxabicyclo[3.2.1]octanes, 2:2 ensembles of ketones and acetylene

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(*1R*,3R,*5S**)-1,5-Bis(4-phenylphenyl)-3,7-dimethyl-6,8-dioxabicyclo[3.2.1]octane **2b**, a 2:1 mixture of two diastereomers: yield 831 mg (93%), colorless oil. Found (%): C 86.09; H 7.12. Calc. for C₃₂H₃₀O₂ (%): C 86.06; H 7.17. (*1R*,3R*,5S*,7R**)-1,5-Bis(4-phenylphenyl)-3,7-dimethyl-6,8-dioxabicyclo[3.2.1]octane (major isomer): yield: 545 mg (61%), colorless solid, mp 133 °C. IR (film, v/cm⁻¹): 3057, 3030, 2954, 2925, 2869, 1600, 1488, 1455, 1448, 1401, 1378, 1368, 1349, 1320, 1266, 1244, 1180, 1160, 1132, 1115, 1106, 1092, 1075, 1030, 1015, 1008, 996, 979, 954, 937, 895, 848, 833, 788, 759, 729, 697, 660, 638, 571, 515. ¹H NMR, δ: 7.75–7.71 (m, 2H), 7.65–7.60 (m, 2H), 7.61–7.57 (m, 2H), 7.57–7.53 (m, 4H), 7.43–7.39 (m, 6H), 7.37–7.30 (m, 2H) [Ph], 4.07 (qd, ³J 6.5 Hz, ⁴J 1.7 Hz, 1H, H-7), 2.62–2.51 (m, 1H, H-3), 2.46 (dd, ²J 13.9 Hz, ³J 5.8 Hz, 1H, H-2_{eq}), 2.24 (dd, ²J 13.3 Hz, ³J 5.8 Hz, 1H, H-4_{eq}), 1.65 (dd, ²J 13.3 Hz, ³J 10.8 Hz, 1H, H-4_{ax}), 1.58 (dd, ²J 13.9 Hz, ³J 12.0 Hz, 1H, H-2_{ax}), 1.46 (d, ²J 6.5 Hz, 3H, C⁷Me), 1.06 (d, ³J 6.6 Hz, 3H, C³Me). ¹³C NMR, δ: 141.3, 141.2, 141.1, 140.9, 140.6, 140.1, 129.0, 128.9, 127.5, 127.4, 127.3, 127.2, 127.1, 125.9, 125.3 (24C, Ph), 107.2 (C⁵), 85.1 (C¹), 82.3 (C⁷), 43.6 (C⁴), 38.0 (C²), 25.4 (C³), 22.2 (C³Me), 13.4 (C⁷Me).

(*1R*,3R*,5S*,7S**)-1,5-Bis(4-phenylphenyl)-3,7-dimethyl-6,8-dioxabicyclo[3.2.1]octane (minor isomer): yield 259 mg (29%), colorless solid, mp 132 °C. IR (film, v/cm⁻¹): 3057, 3030, 2952, 2926, 2868, 1600, 1487, 1448, 1399, 1378, 1366, 1329, 1308, 1242, 1181, 1142, 1127, 1106, 1094, 1076, 1062, 1039, 1029, 1007, 998, 983, 942, 936, 911, 851, 834, 787, 762, 730, 697, 666, 562, 510. ¹H NMR, δ: 7.77–7.71 (m, 2H), 7.64–7.52 (m, 2H), 7.49–7.43 (m, 2H), 7.65–7.55 (m, 6H), 7.49–7.39 (m, 4H), 7.37–7.30 (m, 2H) [Ph], 4.60 (q, ³J 6.3 Hz, 1H, H-7), 2.54–2.42 (m, 1H, H-3), 2.29 (dd, ²J 13.6 Hz, ³J 5.1 Hz, 1H, H-2_{eq}), 2.19 (dd, ²J 13.2 Hz, ³J 5.3 Hz, 1H, H-4_{eq}), 1.66 (dd, ²J 13.2 Hz, ³J 11.3 Hz, 1H, H-4_{ax}), 1.54 (dd, ²J 13.6 Hz, ³J 12.2 Hz, 1H, H-2_{ax}), 1.05 (d, ²J 6.7 Hz, 3H, C³Me), 0.83 (d, ³J 6.3 Hz, 3H, C⁷Me). ¹³C NMR, δ: 141.3, 141.1, 140.9, 140.8, 128.9, 127.5, 127.4, 126.0, 125.6, 140.9, 140.0, 127.4, 127.2, 127.1, 127.0 (24C, Ph), 107.5 (C⁵), 86.1 (C¹), 79.4 (C⁷), 44.7 (C²), 43.9 (C⁴), 25.4 (C³), 21.6 (C³Me), 20.6 (C⁷Me).

(*1R*,3R*,5S**)-1,5-Bis(3-methoxyphenyl)-3,7-dimethyl-6,8-dioxabicyclo[3.2.1]octane **2c**, a 2:1 mixture of two diastereomers: yield 463 mg (65%), colorless oil. Found (%): C 74.76; H 7.15. Calc. for C₂₂H₂₆O₄ (%): C 74.55; H 7.39. (*1R*,3R*,5S*,7R**)-1,5-Bis(3-methoxyphenyl)-3,7-dimethyl-6,8-dioxabicyclo[3.2.1]octane (major isomer): yield 269 mg (38%), colorless oil. IR (film, v/cm⁻¹): 3079, 3033, 2992, 2954, 2939, 2870, 2835, 1612, 1604, 1586, 1488, 1464, 1454, 1434, 1378, 1368, 1349, 1323, 1290, 1267, 1226, 1213, 1180, 1151, 1131, 1117, 1089, 1050, 1024, 1011, 981, 957, 946, 913, 900, 869, 838, 784, 764, 732, 698, 669, 656, 567, 552, 500, 463. ¹H NMR, δ: 7.35–7.26 (m, 2H), 7.24–7.23 (m, 1H), 7.21–7.19 (m, 1H), 7.09–7.04 (m, 2H), 6.89–6.85 (m, 1H), 6.83–6.79 (m, 1H) [Ph], 3.97 (qd, ³J 6.7 Hz, ⁴J 1.1 Hz, 1H, H-7), 3.83 (s, 3H), 3.79 (s, 3H) [OMe], 2.57–2.43 (m, 1H, H-3), 2.38 (dd, ²J 13.9 Hz, ³J 5.7 Hz, 1H, H-2_{eq}), 2.15 (dd, ²J 13.1 Hz, ³J 5.9 Hz, 1H, H-4_{eq}), 1.56 (dd, ²J 13.1 Hz, ³J 10.9 Hz, 1H, H-4_{ax}), 1.51 (dd, ²J 13.9 Hz, ³J 11.9 Hz, 1H, H-2_{ax}) 1.42 (d, ²J 6.5 Hz, 3H, C⁷Me), 1.02 (d, ³J 6.6 Hz, 3H, C³Me). ¹³C NMR, δ: 159.8, 159.7, 143.6, 142.8, 129.5, 129.4, 117.8, 117.1, 114.0, 112.7, 111.0,

110.9 (12C, Ph), 107.0 (C⁵), 85.0 (C¹), 82.0 (C⁷), 55.4, 55.3 (2C, OMe), 43.7 (C⁴), 38.0 (C²), 25.4 (C³), 22.1 (C³Me), 13.4 (C⁷Me). (*1R**,*3R**,*5S**,*7S**)-1,5-Bis(3-methoxyphenyl)-3,7-dimethyl-6,8-dioxabicyclo[3.2.1]octane (minor isomer): yield 113 mg (16%), colorless oil. IR (film, ν/cm^{-1}): 3079, 3033, 2992, 2953, 2929, 2870, 2835, 1612, 1604, 1586, 1490, 1464, 1453, 1434, 1377, 1367, 1350, 1321, 1289, 1266, 1220, 1211, 1180, 1151, 1127, 1090, 1050, 1022, 1009, 997, 984, 946, 917, 903, 870, 838, 782, 764, 700, 669, 567. ¹H NMR, δ : 7.31–7.19 (m, 4H), 7.08–7.04 (m, 1H), 6.98–6.96 (m, 1H), 6.90–6.86 (m, 1H), 6.80–6.76 (m, 1H) [Ph], 4.51 (q, ³J 6.2 Hz, 1H, H-7), 3.83 (s, 3H), 3.79 (s, 3H) [OMe], 2.44–2.35 (m, 1H, H-3), 2.21 (dd, ²J 13.8 Hz, ³J 5.4 Hz, 1H, H-2_{eq}), 2.11 (dd, ²J 13.0 Hz, ³J 5.0 Hz, 1H, H-4_{eq}), 1.58–1.50 (m, 2H, H-4_{ax}, H-2_{ax}), 1.00 (d, ³J 6.8 Hz, 3H, C³Me), 0.77 (d, ³J 6.3 Hz, 3H, C⁷Me). ¹³C NMR, δ : 159.7, 159.6, 143.6, 143.4, 129.3, 117.9, 117.6, 113.8, 112.2, 111.4, 111.3 (12C, Ph), 107.4 (C⁵), 86.0 (C¹), 79.3 (C⁷), 55.4, 55.3 (OMe), 44.6 (C²), 44.0 (C⁴), 25.4 (C³), 21.6 (C³Me), 20.3 (C⁷Me).

(*1R**,*3R**,*5S**)-3,7-Dimethyl-1,5-di(naphthalen-2-yl)-6,8-dioxabicyclo[3.2.1]octane **2d** (a mixture of two diastereomers in a 3:1 molar ratio): yield 686 mg (87%), colorless oil. Found (%): C 86.12; H 6.83. Calc. for C₂₈H₂₆O₂ (%): C 85.25; H 6.64. (*1R**,*3R**,*5S**,*7R**)-3,7-Dimethyl-1,5-di(naphthalen-2-yl)-6,8-dioxabicyclo[3.2.1]octane (major isomer): yield 466 mg (59%), colorless oil. IR (film, ν/cm^{-1}): 3059, 3024, 2954, 2925, 2869, 1602, 1507, 1472, 1456, 1437, 1378, 1370, 1351, 1317, 1291, 1273, 1258, 1231, 1221, 1193, 1142, 1127, 1116, 1090, 1073, 1028, 1009, 982, 961, 944, 932, 907, 863, 856, 820, 807, 791, 772, 763, 734, 674, 649, 630, 586, 569, 550, 477. ¹H NMR, δ : 8.15 (s, 1H), 7.95 (s, 1H), 7.90–7.88, 7.85–7.77, 7.67–7.65, 7.50–7.43 (m, 12H) [Naphth], 4.15 (q, ³J 6.2 Hz, 1H, H-7), 2.69–2.53 (m, 2H, H-3, H-2_{eq}), 2.29 (dd, ²J 13.3 Hz, ³J 5.3 Hz, 1H, H-4_{eq}), 1.75 (dd, ²J 13.3 Hz, ³J 10.7 Hz, 1H, H-4_{ax}), 1.66 (dd, ²J 13.6 Hz, ³J 11.9 Hz, 1H, H-2_{ax}), 1.50 (d, ³J 6.3 Hz, 3H, C⁷Me), 1.09 (d, ³J 6.0 Hz, 3H, C³Me). ¹³C NMR, δ : 139.4, 138.5, 133.4, 133.3, 133.2, 132.9, 128.6, 128.3, 128.3, 128.2, 127.8, 127.7, 126.3, 126.2, 126.2, 124.3, 123.8, 123.0 (20C, Naphth), 107.5 (C⁵), 85.3 (C¹), 82.4 (C⁷), 43.6 (C⁴), 38.0 (C²), 25.5 (C³), 22.2 (C³Me), 13.5 (C⁷Me). (*1R**,*3R**,*5S**,*7S**)-3,7-Dimethyl-1,5-di(naphthalen-2-yl)-6,8-dioxabicyclo[3.2.1]octane (minor isomer): yield 142 mg (18%), colorless oil. IR (film, ν/cm^{-1}): 3057, 3024, 2973, 2953, 2926, 2868, 2839, 1603, 1508, 1472, 1454, 1438, 1367, 1355, 1324, 1307, 1290, 1272, 1259, 1230, 1221, 1193, 1140, 1133, 1122, 1097, 1062, 1040, 1027, 1009, 985, 960, 945, 933, 907, 864, 856, 839, 819, 808, 794, 769, 745, 734, 680, 649, 630, 621, 573, 477. ¹H NMR, δ : 8.16 (s, 1H), 7.95 (s, 1H), 7.93–7.88, 7.86–7.79, 7.51–7.40 (m, 12H) [Naphth], 4.69 (q, ³J 6.1 Hz, 1H, H-7), 2.59–2.47 (m, 1H, H-3), 2.38 (dd, ²J 13.6 Hz, ³J 4.8 Hz, 1H, H-2_{eq}), 2.26 (dd, ²J 13.2 Hz, ³J 5.2 Hz, 1H, H-4_{eq}), 1.77 (dd, ²J 13.2 Hz, ³J 11.5 Hz, 1H, H-4_{ax}), 1.58 (dd, ²J 13.6 Hz, ³J 12.2 Hz, 1H, H-2_{ax}), 1.06 (d, ³J 6.5 Hz, 3H, C³Me), 0.81 (d, ³J 6.2 Hz, 3H, C⁷Me). ¹³C NMR, δ : 139.3, 139.1, 133.4, 133.3, 133.2, 132.6, 128.6, 128.3, 128.1, 128.0, 127.8, 127.7, 126.3, 126.2, 126.0, 124.5, 124.0, 123.8, 123.6 (20C, Naphth), 107.9 (C⁵), 86.4 (C¹), 79.4 (C⁷), 44.8 (C²), 44.0 (C⁴), 25.5 (C³), 21.7 (C³Me), 20.6 (C⁷Me).

(*1R**,*2R**,*3R**,*4S**,*5S**,*7R**)-2,3,4,7-Tetramethyl-1,5-diphenyl-6,8-dioxabicyclo[3.2.1]octane **2e**: yield 548 mg (85%), colorless solid, mp 112 °C. Found (%): C 81.55; H 8.43. Calc. for C₂₂H₂₆O₂ (%): C 81.95; H 8.13. IR (film, ν/cm^{-1}): 3090, 3061, 3030, 3002, 2973, 2931, 2904, 2878, 1604, 1496, 1467, 1449, 1380, 1341, 1310, 1270, 1234, 1172, 1145, 1131, 1088, 1069, 1045, 1033, 1015, 998, 987, 971, 943, 932, 912, 894, 812, 756, 734, 699, 682, 669, 651, 628, 618, 558, 537, 520, 503. ¹H NMR, δ : 7.57–7.51 (m, 2H), 7.45–7.39 (m, 2H), 7.34–7.27 (m, 4H), 7.26–7.19 (m, 2H) [Ph], 4.42 (qd, ³J 6.9 Hz, ⁴J 1.6 Hz, 1H, H-7), 1.95–1.87 (m, 1H, H-2), 1.87–1.79 (m, 1H, H-4), 1.80–1.72 (m, 1H, H-3), 1.80 (d, ³J 6.9 Hz, 3H, C⁷Me), 1.06 (d, ³J 6.0 Hz, 3H, C³Me), 0.85 (d, ³J 7.2 Hz, 3H, C²Me), 0.74 (d, ³J 6.5 Hz, 3H, C⁴Me). ¹³C NMR, δ : 141.5, 141.0, 128.1, 128.0, 127.8, 127.5, 126.1, 125.9 (12C) [Ph], 108.8 (C⁵), 86.9 (C¹), 79.7 (C⁷), 47.9 (C²), 46.7 (C⁴), 39.9 (C³), 18.1 (C³Me), 17.0 (C⁷Me), 14.5 (C⁴Me), 14.3 (C²Me).

(1*R**,2*R**,3*R**,4*S**,5*S**,7*R**)-2,3,4,7-Tetramethyl-1,5-di-*p*-tolyl-6,8-dioxabicyclo[3.2.1]octane **2f**: yield 554 mg (79%), colorless solid, mp 104 °C. Found (%): C 82.36; H 8.48. Calc. for C₂₄H₃₀O₂ (%): C 82.24; H 8.63. IR (film, v/cm⁻¹): 3089, 2971, 2924, 2879, 1716, 1647, 1617, 1514, 1457, 1380, 1347, 1308, 1267, 1236, 1176, 1131, 1085, 1017, 940, 910, 808, 732, 652, 594, 527. ¹H NMR, δ: 7.43–7.39 (m, 2H), 7.32–7.27 (m, 2H), 7.13–7.07 (m, 4H) [Ph], 4.39 (qd, ³*J* 6.6 Hz, ⁴*J* 1.2 Hz, 1H, H-7), 2.29 (m, 6H, C^{*i*}Me₂), 1.95–1.69 (m, 3H, H-2, H-3, H-4), 1.77 (d, ³*J* 6.6 Hz, 3H, C⁷Me), 1.05 (d, ³*J* 6.1 Hz, 3H, C³Me), 0.84 (d, ³*J* 7.2 Hz, 3H, C²Me), 0.75 (d, ³*J* 6.5 Hz, 3H, C⁴Me). ¹³C NMR, δ: 138.6, 138.2, 137.3, 136.9, 128.7, 128.6, 126.0, 125.8 (12C, Ph), 108.7 (C⁵), 86.7 (C¹), 79.8 (C⁷), 47.9 (C²), 46.5 (C⁴), 39.9 (C³), 21.3, 21.2 (2C^{*i*}Me), 18.1 (C³Me), 16.9 (C⁷Me), 14.6 (C⁴Me), 14.3 (C²Me).