High Enantioselectivity in Rhodium-Catalyzed Allylic Alkylation of 1-Substituted 2-Propenyl Acetates

Tamio Hayashi*, Atsushi Okada, Toshimasa Suzuka, and Motoi Kawatsura

Department of Chemistry, Graduate School of Science, Kyoto University, Sakyo, Kyoto 606-8502, Japan

Supporting Data

General. All manipulations were carried out under a nitrogen atmosphere. Nitrogen gas was dried by passage through P₂O₅. Chemical shifts are reported in δ ppm referenced to an internal tetramethylsilane standard for ¹H NMR and chloroform-*d* (δ 77.0) for ¹³C NMR, and to an external 85% H₃PO₄ standard for ³¹P NMR.

Materials. Rhodium complexes, Rh(2,4-pentanedionato)(C₂H₄)₂ (**3a**, Rh(acac)(C₂H₄)₂),¹ Rh(2,2,6,6-tetramethyl-3,5-heptanedionato)(C₂H₄)₂ (**3b**, Rh(dpm)(C₂H₄)₂),² Rh(1,1,1,5,5,5-hexafluoro-2,4-pentanedionato)(C₂H₄)₂ (**3c**, Rh(hfac)(C₂H₄)₂),³ and Rh(1,3-diphenyl-1,3-propanedionato)(C₂H₄)₂ (**3d**, Rh(dbm)(C₂H₄)₂)⁴ were prepared according to the reported procedures. Phosphino-oxazoline ligands ((*S*)-2-[2-(diphenylphosphino)phenyl]-4-isopropylloxazoline (**2a**, (*S*)-*i*-Pr-phox),⁵ (*S,R*)-2-[4-(isopropyl)oxazol-2-yl]-2'-diphenylphosphino-1,1'-binaphthyl (**2b**, (*S,R*)-axial-phox),⁶ (*S,S*)-2-[4-(isopropyl)oxazol-2-yl]-2'-diphenylphosphino-1,1'-binaphthyl (**2c**, (*S,S*)-axial-phox)⁶ were prepared according to the reported procedures. THF, dioxane, and toluene were dried over sodium benzophenone ketyl and distilled prior to use.

Rhodium-Catalyzed Asymmetric Allylic Alkylation of 1-Phenyl-2-propenyl Acetate (*dl*-1) with Dimethyl Malonate. The experimental conditions and results are summarized in Table 1. A typical procedure is given for the reaction with Rh(dpm)(C₂H₄)₂ and Cs₂CO₃ in toluene (entry 12). To a solution of Rh(dpm)(C₂H₄)₂ (**3b**) (6.8 mg, 0.02 mmol), phosphino-oxazoline ligand (*S,R*)-axial-phox (**2b**) (11.0 mg, 0.02 mmol), and cesium carbonate (521 mg, 1.60 mmol) in toluene (2.0 mL) was added 1-phenyl-2-propenyl acetate (**1**) (70.5 mg, 0.40 mmol) and dimethyl malonate (211 mg, 1.60 mmol), and the mixture was stirred at 40 °C for 12 h. Water (1 mL) was added and the mixture was extracted with ether. The combined extracts were washed with aqueous sodium chloride and dried over anhydrous magnesium sulfate. The solvent was evaporated and the residue was chromatographed on silica gel PTLC (hexane/ethyl acetate = 5/1) to give 93.4 mg (94% yield) of a mixture of dimethyl 1-phenyl-2-propenylmalonate (**4**)⁷ and dimethyl 3-phenyl-2-propenylmalonate (**5**).⁷ The regioselectivity was determined to be **4**/**5** = 98/2 by ¹H NMR analysis of the crude mixture. The enantiomeric purity was determined to be 97% ee by HPLC analysis with CHIRALCEL OJ (220 nm, hexane/2-propanol = 93/7, flow rate = 0.5 mL/min)

$t_R(S) = 33.9$ min (major), $t_R(R) = 39.8$ min (minor).; **4**; ^1H NMR (CDCl_3) δ 3.49 (s, 3H), 3.74 (s, 3H), 3.87 (d, $J = 11.0$ Hz, 1H), 4.11 (dd, $J = 11.0, 8.3$ Hz, 1H), 5.09 (d, $J = 10.2$ Hz, 1H), 5.12 (d, $J = 17.1$ Hz, 1H), 5.99 (ddd, $J = 17.1, 10.2, 8.3$ Hz, 1H), 7.19-7.32 (m, 5H). ^{13}C NMR (CDCl_3) δ 49.7, 52.4, 52.5, 57.3, 116.6, 127.1, 127.8, 128.6, 137.7, 139.8, 167.8, 168.1.; $[\alpha]^{20}_{\text{D}} -34.9$ (c 1.01, CHCl_3) for a mixture of (*S*)-**4** of 97% ee and **5** in a ratio of 98 to 2.

Rhodium-Catalyzed Asymmetric Allylic Alkylation of 1-Substituted 2-Propenyl Acetates 7. The reaction was carried out in the same manner as that of **1**. The data for the products **8** are shown below. **Dimethyl 1-(4-methylphenyl)-2-propenylmalonate (8a)**; ⁸ purified by PTLC (hexane/ethyl acetate = 5/1) (97% yield).; ^1H NMR (CDCl_3) δ 2.30 (s, 3H), 3.50 (s, 3H), 3.73 (s, 3H), 3.84 (d, $J = 11.0$ Hz, 1H), 4.07 (dd, $J = 11.0, 8.2$ Hz, 1H), 5.06 (d, $J = 10.9$ Hz, 1H), 5.10 (d, $J = 17.1$ Hz, 1H), 5.97 (ddd, $J = 17.1, 10.9, 8.2$ Hz, 1H), 7.08-7.10 (m, 4H). ^{13}C NMR (CDCl_3) δ 21.0, 49.3, 52.4, 52.6, 57.4, 116.4, 126.1, 127.7, 129.3, 136.9, 138.0, 167.9, 168.3.; $[\alpha]^{20}_{\text{D}} -35.8$ (c 1.02, CHCl_3) for a mixture of **8a** of 94% ee and **9a** in a ratio of 88 to 12.; HPLC (CHIRALCEL OD-H, 220 nm, hexane/2-propanol = 200/1, flow rate = 0.5 mL/min) $t_R = 22.9$ min (minor), $t_R = 24.9$ min (major). **Dimethyl 1-(4-trifluoromethylphenyl)-2-propenylmalonate (8b)**; ⁹ purified by PTLC (hexane/ethyl acetate = 5/1) (97% yield).; ^1H NMR (CDCl_3) δ 3.51 (s, 6H), 3.87 (d, $J = 11.0$ Hz, 1H), 4.17 (dd, $J = 11.0, 8.3$ Hz, 1H), 5.12 (d, $J = 10.2$ Hz, 1H), 5.13 (d, $J = 17.1$ Hz, 1H), 5.96 (ddd, $J = 17.1, 10.2, 8.3$ Hz, 1H), 7.35 (d, $J = 8.1$ Hz, 2H), 7.56 (d, $J = 8.1$ Hz, 2H). ^{13}C NMR (CDCl_3) δ 49.4, 52.6, 52.7, 56.9, 117.5, 124.0 (q, $J = 271.9$ Hz), 125.6 (q, $J = 3.8$ Hz), 128.3, 129.4 (q, $J = 32.6$ Hz), 136.9, 144.1, 167.5, 167.8.; $[\alpha]^{20}_{\text{D}} -41.1$ (c 1.00, CHCl_3) for 97% ee.; HPLC (CHIRALCEL OD-H, 220 nm, hexane/2-propanol = 200/1, flow rate = 0.5 mL/min) $t_R = 24.6$ min (minor), $t_R = 25.8$ min (major). **Dimethyl 1-(4-chlorophenyl)-2-propenylmalonate (8c)**; ⁸ purified by PTLC (hexane/ethyl acetate = 5/1) (93% yield).; ^1H NMR (CDCl_3) δ 3.52 (s, 3H), 3.74 (s, 3H), 3.82 (d, $J = 11.0$ Hz, 1H), 4.09 (dd, $J = 11.0, 8.2$ Hz, 1H), 5.10 (d, $J = 10.4$ Hz, 1H), 5.11 (d, $J = 17.1$ Hz, 1H), 5.95 (ddd, $J = 17.1, 10.4, 8.2$ Hz, 1H), 7.17 (d, $J = 8.4$ Hz, 2H), 7.27 (d, $J = 8.4$ Hz, 2H). ^{13}C NMR (CDCl_3) δ 48.9, 52.5, 52.6, 57.1, 117.0, 128.8, 129.3, 132.9, 137.2, 138.4, 167.6, 167.9.; $[\alpha]^{20}_{\text{D}} -41.8$ (c 1.00, CHCl_3) for 95% ee.; HPLC (CHIRALCEL OD-H, 220 nm, hexane/2-propanol = 200/1, flow rate = 0.5 mL/min) $t_R = 26.3$ min (minor), $t_R = 28.3$ min (major). **Dimethyl 1-(1-naphthyl)-2-propenylmalonate (8d)**; ⁷ purified by PTLC (hexane/ethyl acetate = 5/1) (94% yield).; ^1H NMR (CDCl_3) δ 3.38 (s, 3H), 3.78 (s, 3H), 4.16 (d, $J = 10.7$ Hz, 1H), 5.03 (dd, $J = 10.7, 8.1$ Hz, 1H), 5.10 (d, $J = 10.2$ Hz, 1H), 5.16 (d, $J = 17.1$ Hz, 1H), 6.08 (ddd, $J = 17.1, 10.2, 8.1$ Hz, 1H), 7.35-7.59 (m, 4H), 7.74 (d, $J = 8.3$ Hz, 1H). 7.84 (d, $J = 8.1$ Hz, 1H). 8.24 (d, $J = 8.7$ Hz, 1H). ^{13}C NMR (CDCl_3) δ 44.1, 52.4, 52.6, 57.0, 117.1, 123.3, 124.3, 125.2, 125.6, 126.2,

127.7, 128.9, 131.3, 136.1, 137.6, 167.8, 168.4.; $[\alpha]^{20}_{\text{D}} -27.0$ (c 1.00, CHCl_3) for a mixture of **8d** of 95% ee and **9d** in a ratio of 61 to 39.; HPLC (CHIRALCEL OJ, 254 nm, hexane/2-propanol = 93/7, flow rate = 0.5 mL/min) $t_{\text{R}} = 30.4$ min (major), $t_{\text{R}} = 39.1$ min (minor). **Dimethyl 1-(2-phenylethyl)-2-propenylmalonate (8e)**; ¹⁰ purified by PTLC (hexane/ethyl acetate = 5/1) (81% yield).; ¹H NMR (CDCl_3) δ 1.62 (dtd, $J = 13.3, 10.4, 4.8$ Hz, 1H), 1.80 (m, $J = 13.3, 10.3, 6.7, 3.3$ Hz, 1H), 2.51 (ddd, $J = 13.8, 10.4, 6.7$ Hz, 1H), 2.69 (ddd, $J = 13.8, 10.5, 4.8$ Hz, 1H), 2.82 (m, $J = 9.5, 3.3$ Hz, 1H), 3.42 (d, $J = 8.6$ Hz, 1H), 3.68 (s, 3H), 3.71 (s, 3H), 5.15 (d, $J = 17.0$ Hz, 1H), 5.16 (d, $J = 10.3$ Hz, 1H), 5.71 (ddd, $J = 17.0, 10.3, 9.7$ Hz, 1H), 7.12-7.31 (m, 5H). ¹³C NMR (CDCl_3) δ 33.3, 34.0, 35.7, 43.9, 52.2, 52.4, 56.8, 118.1, 125.8, 128.3, 128.4, 137.6, 141.7, 168.4, 168.6.; $[\alpha]^{20}_{\text{D}} -8.4$ (c 1.01, CHCl_3) for a mixture of **8e** of 90% ee and **9e** in a ratio of 86 to 14.; HPLC (CHIRALCEL OD-H, 220 nm, hexane/2-propanol = 200/1, flow rate = 0.5 mL/min) $t_{\text{R}} = 31.1$ min (minor), $t_{\text{R}} = 32.9$ min (major).

Rh(acac)(C₂H₄)₂ with (S)-i-Pr-phox in THF; ³¹P NMR (THF) δ 51.7 (d, $J = 206.8$ Hz). ¹H NMR (toluene-*d*₈) δ 0.59 (d, $J = 6.8$ Hz, 3H), 0.96 (d, $J = 7.1$ Hz, 3H), 1.83 (s, 3H), 2.25 (s, 3H), 3.38 (dsep, $J = 3.0, 6.9$ Hz, 1H), 3.86 (dd, $J = 10.0, 8.6$ Hz, 1H), 4.08 (dd, $J = 8.6, 4.4$ Hz, 1H), 5.58 (ddd, $J = 10.0, 4.4, 3.0$ Hz, 1H), 5.63 (s, 1H), 7.18 (t, $J = 7.5$ Hz, 1H), 7.25 (d, $J = 7.5$ Hz, 1H), 7.27-7.30 (m, 3H), 7.34-7.41 (m, 3H), 7.50 (t, $J = 8.0$ Hz, 1H), 8.01-8.07 (m, 2H), 8.10-8.17 (m, 3H).

Rh(acac)((S)-i-Pr-phox) with 1 in THF; ³¹P NMR (THF) δ 46.6 (d, $J = 143.6$ Hz, major isomer); δ 40.7 (d, $J = 148.6$ Hz, minor isomer).

References

- (1) Cramer, R. *Inorg. Synth.* **1974**, *15*, 15.
- (2) Jesse, A. C.; Gijben, H. P.; Stufkens, D. J.; Vrieze, K. *Inorg. Chim. Acta* **1978**, *31*, 203.
- (3) Aneja, R.; Golding, B. T.; Pierpoint, C. *J. Chem. Soc., Dalton Trans.* **1984**, 219.
- (4) Ingrosso, G.; Porri, L.; Pantini, G.; Racanelli, P. *J. Organomet. Chem.* **1975**, *84*, 75.
- (5) (a) Sprinz, J.; Helmchen, G. *Tetrahedron Lett.* **1993**, *34*, 1769. (b) Matt, P.; Pfaltz, A. *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 566. (c) Dawson, G. J.; Frost, C. G.; Williams, J. M. J. *Tetrahedron Lett.* **1993**, *34*, 3149.
- (6) (a) Ogasawara, M.; Yoshida, K.; Kamei, H.; Kato, K.; Uozumi, Y.; Hayashi, T. *Tetrahedron Asymmetry* **1998**, *9*, 1779. (b) Imai, Y.; Zhang, W.; Kida, T.; Nakatsuji, Y.; Ikeda, I. *Tetrahedron Lett.* **1998**, *39*, 4343. (c) Selvakumar, K.; Valentini, M.; Wörle, M.; Pregosin, P. S.; Albinati, A. *Organometallics* **1999**, *18*, 1207.
- (7) Trost, B. M.; Hachiya, I. *J. Am. Chem. Soc.* **1998**, *120*, 1104.
- (8) You, S.-L.; Zhu, X.-Z.; Luo, Y.-M.; Hou, X.-L.; Dai, L.-X. *J. Am. Chem. Soc.* **2001**, *123*, 7471.
- (9) Lehmann, J.; Lloyd-Jones, G. C. *Tetrahedron* **1995**, *51*, 8863.
- (10) Bartels, B.; Helmchen, G. *Chem. Commun.* **1999**, 741.