3,3'-Diaryl-BINOL phosphoric acids as enantioselective extractants of benzyllic primary amines
Verkuijl, B.J.V.; de Vries, J.G.; Feringa, B.L.

Published in:
Chirality

DOI:
10.1002/chir.20834

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2011

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Download date: 09-01-2021
Supporting Information

The phosphoric acids used in the study were prepared according to the reaction scheme depicted in Figure 1.

**Preparation of (S)-2,2'-dimethoxy-1,1'-binaphthyl.**

(S)-BINOL (50 g, 0.18 mol) was dissolved in acetone (1 L). K$_2$CO$_3$ (823 g, 0.6 mol) was added and the suspension was stirred for 15 min. Me$_2$SO$_4$ (50 g, 67.6 mL, 0.40 mol) was added dropwise. The reaction mixture was stirred overnight and filtered. The solvent was evaporated *in vacuo*, giving (S)-2,2'-dimethoxy-1,1'-binaphthyl (52 g, 92%) as a white powder. $[\alpha]_D^{20} = -564.0$ (c 1.00, CHCl$_3$). M.p. 195-199 °C. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 7.96 (d, $J = 9.00$ Hz, 2H), 7.85 (d, $J = 8.12$ Hz, 2H), 7.45 (d, $J = 9.03$ Hz, 2H), 7.30 (m, 2H), 7.19 (m, 2H), 7.09 (dd, $J = 8.52$, 0.59 Hz, 2H), 3.75 (s, 6H). $^{13}$C NMR (50 MHz, CDCl$_3$): $\delta$ ppm 155.2, 134.2, 129.6, 129.4, 128.1, 126.5, 125.5, 123.7, 119.8, 114.5, 57.1; MS(EI+): 314 [M$^+$].
Preparation of (S)-3,3'-dibromo-2,2'-dimethoxy-1,1'-binaphthyl.

(S)-2,2'-Dimethoxy-1,1'-binaphthyl (25.0 g, 79.5 mmol) was suspended in Et₂O dried over sodium (0.7 L) and the mixture was mechanically stirred under a nitrogen atmosphere at rt. TMEDA (38 mL), dried over Na₂SO₄, was added followed by dropwise addition of n-BuLi (2.5 M in hexanes, 140 mL, 0.35 mol, 4.4 eq.). The reaction mixture was stirred overnight and turned from a white suspension into a light brown suspension. The conversion was examined by quenching a sample with Br₂ showing full conversion. The reaction mixture was cooled to -80 °C and Br₂ (35 mL, 0.69 mol) was added dropwise over a period of 1h. The reaction mixture was stirred for one more hour at -80 °C and allowed to warm to -10 °C. A saturated aqueous solution of Na₂SO₃ (400 mL) was added dropwise and the reaction mixture was stirred overnight at rt. The layers were separated and the aqueous phase was subsequently extracted with EtOAc and DCM. The combined organic layers were dried with brine and Na₂SO₄, filtered and the solvent was removed *in vacuo*. The crude product was filtered over silica (eluent: EtOAc:Pentane 1:1) and triturated in ether. The obtained solid was dried for 16h in a vacuum oven at T = 40 °C giving (S)-3,3'-dibromo-2,2'-dimethoxy-1,1'-binaphthyl (22.6 g, 60 %) as an off-white powder. [α]D²⁰ = -121.0 (c 1.00, CHCl₃). M.p. 157-159 °C. ¹H NMR (400 MHz, CDCl₃) δ ppm 8.27 (s, 2H), 7.82 (d, J = 8.15 Hz, 2H), 7.42 (m, 2H), 7.27 (m, 2H), 7.08 (d, J = 8.50 Hz, 2H), 3.51 (s, 6H). ¹³C NMR (50 MHz, CDCl₃): δ ppm 133.3, 133.2, 131.7, 127.3, 127.1, 126.1, 126.0, 117.7, 61.3; MS(EI+): 472 [M⁺].
General procedure for the preparation of (S)-3,3'-diaryl-2,2'-dimethoxy-1,1'-binaphthyls.

A literature procedure of Chong et al.\textsuperscript{1} was followed for the Suzuki coupling used for this synthesis. (S)-3,3'-Dibromo-2,2'-dimethoxy-1,1'-binaphthyl (typically 500 mg) and Pd(PPh\textsubscript{3})\textsubscript{4} (0.1 eq.) were dissolved in DME (2.5 mL). The reaction mixture was flushed three times with Ar. The aryl boronic acid (3.5 eq.) was added, followed by an aqueous 2 M Na\textsubscript{2}CO\textsubscript{3} (0.56 mL) solution. The reaction mixture was flushed three more times with Ar and stirred for 16h at 95 °C. TLC revealed full conversion. The reaction mixture was filtered over Celite and the solvent of the filtrate was evaporated \textit{in vacuo}. The crude product was dissolved in DCM, washed with sat. NH\textsubscript{4}Cl (aq), water and brine and dried over Na\textsubscript{2}SO\textsubscript{4}. The solvent was evaporated \textit{in vacuo}. The crude product was dissolved in DCM (100 mL) and the solution was cooled in an ice-bath. A solution of BBr\textsubscript{3} (10 eq.) in DCM (10 mL) was added dropwise. The reaction mixture was allowed to warm to room temperature and stirred for 16h. \textsuperscript{1}H-NMR analysis revealed complete conversion. The resulting mixture was cooled in an ice bath and ice water was added dropwise. The reaction mixture was stirred for 1h and sat. aqueous NaHCO\textsubscript{3} solution was added dropwise. The layers were separated, the organic layer was washed with water and brine and dried over Na\textsubscript{2}SO\textsubscript{4}. The solvent was evaporated \textit{in vacuo}. The crude product was purified using silica gel chromatography (eluent: pentane, 5 v-% EtOAc) yielding the (S)-3,3'-diaryl-2,2'-hydroxy-1,1'-binaphthyl.
(S)-3,3'-Bis(3,5-ditrifluoromethyl)phenyl-2,2'-dihydroxy-1,1'-binaphthyl

The product was obtained as a white powder (23.4 g, 85%). \([\alpha]_D^{20} = -35.4\) (c 1.00, CHCl₃). M.p. 97-99 °C. \(^1\)H NMR (400 MHz, CHCl₃): \(\delta\) 8.24-8.20 (m, 4H), 8.12-8.09 (m, 2H), 7.99 (d, \(J = 7.75\) Hz, 2H), 7.92-7.89 (m, 2H), 7.47 (m, 2H), 7.41 (m, 2H), 7.22 (d, \(J = 7.94\) Hz, 2H), 5.35 (d, \(J = 0.52\) Hz, 2H). \(^13\)C NMR (50 MHz, CDCl₃): \(\delta\) 144.1, 144.0, 139.0, 123.6, 131.1, 131.9, 131.5, 131.3, 130.2, 128.8, 127.68, 127.3, 126.8, 126.1, 122.9, 120.7. MS (EI+): 710 [M⁺]. Anal. Calcd for C₃₆H₁₈F₁₂O₂: C, 60.86; H, 2.55; Found: C, 60.74 H, 2.57.

(S)-3,3'-Bis-2-phenyl-2,2'-dihydroxy-1,1'-binaphthyl

The product was obtained as a white powder (0.20 g, 45%). \([\alpha]_D^{20} = -71.8\) (c 1.00, CHCl₃); M.p. 203-205 °C; \(^1\)H NMR (400 MHz, CDCl₃): \(\delta\) 8.03 (d, \(J = 0.60\) Hz, 2H), 7.93 (d, \(J = 8.09\) Hz, 2H), 7.74 (dd, \(J = 7.22, 1.10\) Hz, 4H), 7.50 (m, 4H), 7.41 (m, 4H), 7.32 (m, 2H), 7.29-7.21 (m, 2H), 5.47-5.26 (s, 2H). \(^13\)C NMR (50 MHz, CDCl₃): \(\delta\) 112.6, 124.5, 124.6, 127.6, 128.0, 128.7, 128.8, 129.7, 129.8, 130.9, 131.6, 133.2, 137.7, 150.4. MS: 438.2 [M⁺]; Anal. Calcd for C₃₂H₂₂O₂: C, 87.65; H, 5.06 Found: C, 87.18 H, 5.14.
The product was obtained as a white powder (1.38 g, 43 %). [α]D20 = +65.4 (c 1.00, CHCl3). M.p. 219-222 °C. 1H NMR (400 MHz, CDCl3): δ 8.12-8.09 (s, 2H), 7.96 (d, J = 7.95 Hz, 2H), 7.85 (d, J = 8.08 Hz, 4H), 7.74 (d, J = 8.11 Hz, 4H), 7.68 (d, J = 8.23 Hz, 4H), 7.48 (t, J = 7.64 Hz, 4H), 7.45-7.32 (m, 2H), 7.29-7.24 (m, 6H), 5.44-5.41 (s, 2H). 13C NMR (50 MHz, CDCl3): δ ppm 112.6, 124.5, 124.7, 127.4, 127.5, 127.7, 128.8, 129.1, 129.8, 130.3, 130.5, 131.7, 133.2, 136.7, 140.9, 141.0, 150.5. MS: 590 [M+]; Anal. Calcd for C44H30O2: C, 89.46; H, 5.12; Found: C, 89.38; H, 5.12.

**General procedure for the preparation of (S)-3,3′-Diaryl-2,2′-dihydroxy-1,1′-binaphthyls.**

A modified literature procedure of Akiyama et al.2 was followed for the phosphoric acid synthesis. The (S)-3,3′-diaryl-2,2′-hydroxy-1,1′-binaphthyl (typically 50 mg) was dissolved in pyridine (1 mL) and POCl3 (2.0 eq.) was added at rt. The reaction mixture was stirred overnight. TLC revealed full conversion. The reaction mixture was cooled in an ice-bath and water (1 mL) was added carefully. The reaction mixture was stirred for 30 min at rt. and DCM (30 mL) was added. Subsequently, 1 M HCl (aq., 30 mL) was added and the layers were separated. The solvent of the organic phase was evaporated in
vacuo and the product was purified by chromatography using C18RP-silica and a 
water/MeOH gradient. The fractions containing pure product were collected and the 
solvent was evaporated in vacuo. The product was stripped with toluene and dried 16 h in 
a vacuum oven at 40 °C.

(S)-3,3′-bis(3,5-Ditrifluoromethyl)phenyl)-2,2′-diyl hydrogenphosphate-1,1′-binaphthyl 
(PA1)

![Chemical Structure](image)

The product was obtained as a white powder\(^2\) (1.2 g, 37 %). \([\alpha]_D^{20} = +238 \text{ (c 1.00, CHCl}_3\). M.p. 174-180 °C (dec). \(^1^H\) NMR (400 MHz, CDCl\(_3\)): δ 8.91 (s, 1H), 8.12 – 7.85 
(m, 8H), 7.57 (m, 4H), 7.45 – 7.29 (m, 4H). \(^1^C\) NMR (50 MHz, CDCl\(_3\)): δ 143.5, 138.6, 
132.3, 132.0, 131.4, 131.4, 131.1, 129.9, 128.7, 127.6, 127.1, 126.8, 123.1, 122.5, 121.5. 
\(^3^1^P\) NMR (189 MHz, CDCl\(_3\)): δ 6.0 ppm (s). \(^1^9^F\) NMR (376 MHz, CDCl\(_3\)): δ -62.6 (s). 
HRMS (EI\(^+\)) calcd for C\(_{36}\)H\(_{15}\)F\(_{12}\)O\(_4\)P: m/z 773.0751; found 773.0750. IR(DCM) 3522, 
1622, 1597, 1502, 1474, 1462, 1427, 1377, 1358, 1335, 1281, 1236, 1182, 1140, 1036, 
989 cm\(^{-1}\).
(S)-2,2'-Diyl hydrogen phosphate-1,1'-binaphthyl (PA2)

![Structure of PA2](image)

The product was obtained as a white powder\(^2\) (0.40 g, 90 %). \([\alpha]_D^{20} = +457 \text{ (c 1.00, CHCl}_3)\). M.p. 232-235 °C (dec). \(^1\)H NMR (200 MHz, CDCl\(_3\)): \(\delta\) 8.69 (d, \(J = 5.45\) Hz, 1H), 8.04 (t, \(J = 8.13\) Hz, 1H), 7.87 (d, \(J = 8.47\) Hz, 4H), 7.55 (d, \(J = 8.84\) Hz, 2H), 7.41 (dd, \(J = 13.43, 7.14\) Hz, 4H), 7.32-7.20 (m, 1H); \(^1^3\)C NMR (50 MHz, CDCl\(_3\)): \(\delta\) 142.4, 132.6, 131.6, 130.9, 128.6, 127.3, 126.5, 125.4, 122.1, 121.6; MS(EI\(^+\)): 348 [M\(^+\)], HRMS (EI\(^+\)) calcd for C\(_{20}\)H\(_{14}\)O\(_4\)P: \(m/z\) 349.0630; found 349.0624.

(S)-3,3'-Diphenyl-2,2'-diyl hydrogen phosphate-1,1'-binaphthyl (PA3)

![Structure of PA3](image)

The product was obtained as a white powder\(^1\) (0.12 g, 48 %). \([\alpha]_D^{20} = +337 \text{ (c 1.00, CHCl}_3)\). M.p. 194-197 °C (dec). \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 8.56 – 8.32 (m, 1H), 7.99 (s, 2H), 7.95 (d, \(J = 8.2\) Hz, 2H), 7.58 (d, \(J = 7.2\) Hz, 4H), 7.53 – 7.45 (m, 2H), 7.38 (d, \(J = 8.3\) Hz, 2H), 7.34 – 7.27 (m, 2H), 7.27 – 7.20 (m, 4H), 7.17 (d, \(J = 7.3\) Hz, 2H). \(^1^3\)C NMR (50 MHz, CDCl\(_3\)): \(\delta\) 144.9, 144.7, 137.0, 134.3, 132.2, 131.8, 131.5, 128.6, 128.4, 127.8, 127.3, 126.7, 126.2, 122.6 ppm. \(^3^1\)P NMR (189 MHz, CDCl\(_3\)): \(\delta\) 4.2 ppm (s). MS: 500 [M\(^+\)], HRMS (EI\(^+\)) calcd for C\(_{21}\)H\(_{14}\)O\(_4\)PNa: \(m/z\) 523.1075 found: 523.1048.
(S)-3,3'-Bis-2-(4-Phenyl)-phenyl-2,2'-diyl hydrogen phosphate-1,1'-binaphthyl (PA4)

The product was obtained as a white powder (0.13 g, 59 %). \([\alpha]_{D}^{20} = +357 \text{ (c 1.00, CHCl}_3\text{)}.\) M.p. 220-223 °C (dec). \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 8.02 (s, 2H), 7.96 (d, J = 8.1 Hz, 2H), 7.61 (d, J = 8.1 Hz, 4H), 7.51 (t, J = 7.0 Hz, 2H), 7.46 – 7.28 (m, 12H), 7.17 (d, J = 3.6 Hz, 6H). \(^{13}\)C NMR (50 MHz, CDCl\(_3\)): \(\delta\) 144.8, 144.6, 141.0, 140.7, 135.8 133.9, 133.8, 132.1, 131.8, 131.6, 130.3, 128.7, 127.4, 127.2, 126.8 126.7 126.3, 122.6. \(^{31}\)P NMR (162 MHz, CDCl\(_3\)): \(\delta\) ppm 5.02 (s). MS: 652 [M\(^+\)]; HRMS (EI\(^+\)) calcd for C\(_{44}\)H\(_{36}\)O\(_4\)PNa: \(m/z\) 653.1882 found: 653.1876.
LITERATURE CITED

