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September 2014: The paragraphs above replace the section "Handling and Disposal of Hazardous Chemicals" in the originally published version of this article. The statements above do not supersede any specific hazard caution notes and safety instructions included in the procedure.

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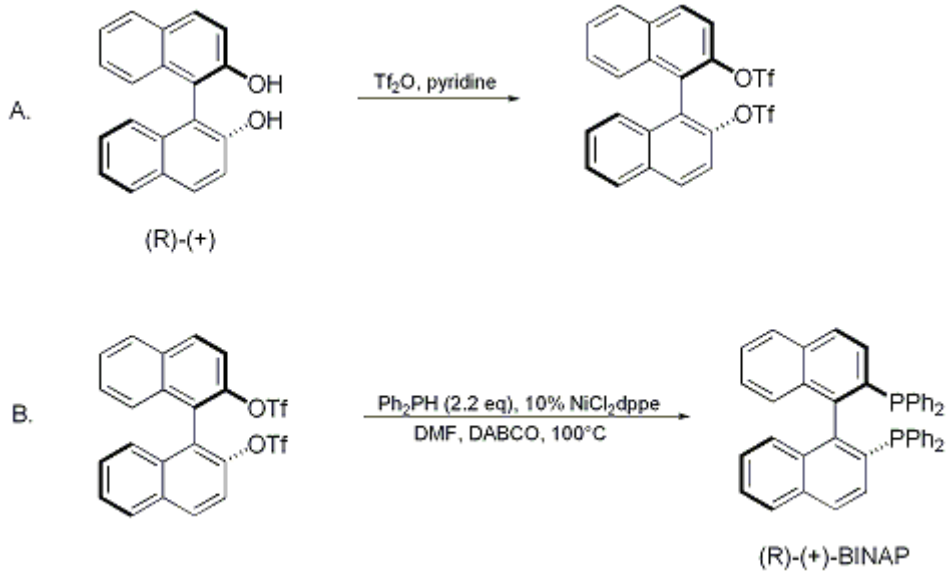
(R)-(+)- AND (S)-(−)-2,2'-BIS(DIPHENYLPHOSPHINO)-1,1'-BINAPHTHYL (BINAP)

[Phosphine, [1,1'-binaphthalene]-2,2'-diylbis[diphenyl-, (R)- and (S)]



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Checked by Rachel van Rijn and Amos B. Smith, III.

1. Procedure

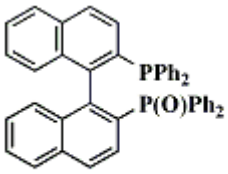
A. Preparation of ditriflate of 1,1'-bi-2-naphthol.[2] An oven-dried, 100-mL, single-necked flask, equipped with a magnetic stirring bar, is charged with (R)-(+)-1,1'-bi-2-naphthol (8.5 g, >99% ee, 30 mmol) (Note 1). Dry methylene chloride (60 mL) is added followed by dry pyridine (7.2 mL, 90 mmol) and triflic anhydride (20.0 g, 70 mmol) at 5–10°C (bath temperature) under a nitrogen (N_2) atmosphere (Note 2) and (Note 3). After the addition, the reaction solution is stirred at room temperature overnight (17 hr) (Note 4). Hexane (60 mL) is then added, and the resulting mixture is filtered under reduced pressure through a pad of silica gel [50 g of silica gel (230–400 mesh) in a 150-mL sintered glass funnel]. The silica gel is washed with a 1:1 mixture of hexane and CH_2Cl_2 (200 mL). The resulting filtrate is concentrated under vacuum to provide the ditriflate as a white solid (15.4 g, 94% yield, 99.6 area% by LC at 220 nm, mp 72–75°C) (Note 5), (Note 6).

B. Preparation of (R)-(+)-BINAP .[3] An oven-dried, 250-mL, single-necked flask, equipped with a magnetic stirring bar, is charged with [1,2-bis(diphenylphosphino)ethane]nickel(II) chloride] ($NiCl_2$dppe, 1.1 g, 2 mmol). The flask is purged with N_2 (using a vacuum and nitrogen manifold) and anhydrous dimethylformamide (DMF, 40 mL) is added via a syringe, followed by diphenylphosphine (2.0 mL, 12 mmol) at room temperature (Note 7). The resulting dark red solution is heated at 100°C for 30 min. A solution of the chiral ditriflate of binaphthol (11.0 g, 20 mmol) and 1,4-diazabicyclo[2.2.2] octane (DABCO, 9.0 g, 80 mmol) in anhydrous, degassed DMF (60 mL) (Note 8) is transferred in one portion to the reaction flask via cannula, and the resulting dark green solution is kept at 100°C. Three additional portions of diphenylphosphine (3 × 2 mL) are added by syringe after 1 hr, 3 hr, and 7 hr. The reaction is heated at 100°C until the ditriflate of binaphthol is completely consumed (2ndash;3 days) (Note 6). The dark brown solution is cooled to −15 ∼ −20°C with an ice/acetone bath and stirred for 2 hr. The product is filtered, and the solid is washed with methanol (2 × 20 mL) and dried under vacuum. The isolated product (9.6 g, 77%) is a white to off-white crystalline compound with a chemical purity of ∼97 area% (HPLC, 220 nm) containing ∼1% of the monooxide of BINAP (Note 6), (Note 9), (Note 10),

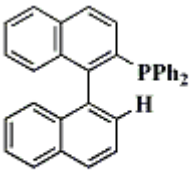
(Note 11).[4]

2. Notes

1. Both enantiomers of 1,1'-bi-2-naphthol are available from Aldrich Chemical Company, Inc.
2. Methylene chloride and pyridine were purchased from Aldrich Chemical Company, Inc. and dried over activated 4 Å molecular sieves.
3. Triflic anhydride was purchased from Aldrich Chemical Company, Inc. and used without purification.
4. The reaction is complete in 2 hr, but may be run overnight.
5. The spectral properties of the ditriflate of binaphthol are as follows: ^{1}H NMR (500 MHz, $CDCl_3$) δ: 7.27 (d, 2 H, J = 8.5), 7.42 (ddd, 2 H, J = 1.1, 6.8, 8.2), 7.59 (ddd, 2 H, J = 1.0, 7.0, 8.1), 7.63 (d, 2 H, J = 9.1), 8.02 (d, 2 H, J = 8.2), 8.15 (d, 2 H, J = 9.1) ; ^{13}C NMR (125 MHz, $CDCl_3$) δ: 118.3, 119.4, 123.6, 126.8, 127.4, 128.1, 128.5, 132.1, 132.5, 133.2, 145.5 .
6. Conditions for the LC assay were as follows: Zorbax Rx-C_8 column, 4.6 mm × 25 cm, room temperature, 1.50 mL/min, linear gradient, 60% CH_3CN/water to 90% CH_3CN/water in 20 min, then hold at 90% CH_3CN/water for 5 min; water contained 0.1% H_3PO_4; UV detection at 220 nm. Typical retention times are 1.75 min (DMF), 2.32 min (Ph_2POH), 5.53 min (dppe), 6.42 min (Ph_2PH), 7.73 min (BINAPO, dioxide of BINAP), 8.55 min [Ar(OTf)-ArP(O)Ph_2], 11.69 min (ditriflate of binaphthol), 14.54 min (monooxide of BINAP), 16.00 min Ar(H)-ArPPh_2, 20.99 min (BINAP); typical LC (area %) at the end of the reaction are DMF (49%), dppe (1.4%) BINAPO (0.6%), ditriflate of bi-2-naphthol (0.5%), monooxide of BINAP (4%), Ar(H)-ArPPh_2 (0.9%) and BINAP (36%).
7. $NiCl_2$dppe, DMF (anhydrous grade) and DABCO were obtained from Aldrich Chemical Company, Inc. , and used without further purification. $NiCl_2$dppe can also be obtained from Strem Chemicals Inc. Diphenylphoshine (DPP) was obtained in an ampoule from Strem Chemicals Inc. When not handled properly, DPP [^{31}P NMR; (200 MHz, $CDCl_3$) δ: −40 ppm] is rapidly oxidized to diphenylphoshine oxide [^{31}P NMR; (200 MHz, $CDCl_3$) δ: 22 ppm]. DPP was transferred directly from the ampoule to a Schlenk flask under an inert atmosphere. Its purity was checked by ^{31}P NMR to ensure that it was free of oxidation products.
8. This solution was degassed via vacuum and nitrogen 3–6 times. Exclusion of air from the reaction is critical to minimize formation of phosphine oxide by-products.
9. Recrystallization of the mother liquor after the first crop was obtained yielded a product with a lower purity.
10. Two impurities were identified as



Monooxide of BINAP



Ar(H)-ArPPh$_2$

11. The submitters' isolated BINAP had $[\alpha]^{20}_{D}$ +219°, 99% ee, mp 237-238°C (lit ref.[5] $[\alpha]^{20}_{D}$ +217°, 98.4% ee). Other physical properties of BINAP are as follows: IR cm^{-1}: 3050 (s), 3010 (s), 1480 (m), 1450 (s), 1310 (m), 1180 (m), 1110 (m), 1090 (m) ; ^{1}H NMR (500 MHz, $CDCl_3$) δ: 6.83 (d, 2 H, J = 8.4), 6.91 (ddd, 2 H, J = 1.2, 8.2, 6.9), 7.04-7.18 (m, 20 H), 7.34 (ddd, 2 H, J = 1.1, 6.9, 8.0), 7.46 (ddd, 2 H, J = 2.6, 8.5), 7.83 (d, 2 H, J = 8.2), 7.89 (d, 2 H, J = 8.5) ; ^{13}C NMR (125 MHz, $CDCl_3$) δ: 125.7, 126.5, 127.5, 127.7, 128.0, 128.1, 128.4, 130.5, 132.8, 132.9, 133.0, 133.2, 133.4, 133.5, 134.1, 134.2, 134.3, 135.5, 135.6, 137.4, 137.5, 138.0, 145.1, 145.4 ; ^{31}P NMR (101 MHz, CDCl) δ: −14.9 ppm ; HRMS (FAB, m-nitrobenzyl alcohol): m/z 623.2074 [$(M+H)^+$; calcd for $C_{44}H_{32}P_2$: 623.2058].

Waste Disposal Information

All toxic materials were disposed of in accordance with "Prudent Practices in the Laboratory"; National Academy Press; Washington, DC, 1995.

3. Discussion

Both enantiomers of BINAP are very useful ligands for various catalytic asymmetric reactions.[6] [7] [8] However, the scarce supply and high cost of BINAP somewhat limit their wide application. A previously reported synthesis of BINAP was not easy to scale up because of potentially hazardous conditions (320°C with HBr evolution), and low overall yield.[9] [5] This procedure presents a short and efficient process to chiral BINAP from readily available chiral 1,1'-bi-2-naphthol.

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Appendix
Chemical Abstracts Nomenclature (Collective Index Number); (Registry Number)

(R)-(+)-2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl[(R)-BINAP]:
Phosphine, [1,1'-binaphthalene]-2,2'-diylbis[diphenyl-, (R)- (10); (76189-55-4)

(S)-(−)-2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl [(S)-BINAP]:
Phosphine, [1,1'-binaphthalene]-2,2'-diylbis[diphenyl-, (3)- (10); (76189-56-5)

1,1'-Bi-2-naphthol ditriflate:
Methanesulfonic acid, trifluoro-, [1,1'-binaphthalene]-2,2'-diyl ester, (±)- (12); (128575-34-8)

(R)-(+)-1,1'-Bi-2-naphthol:
[1,1'-Binaphthalene]-2,2'-diol, (R)-(+)- (8);
[1,1'-Binaphthalene]-2,2'-diol, (R)- (9); (18531-94-7)

Triflic anhydride:
Methanesulfonic acid, trifluoro-, anhydride (8,9); (358-23-6)

[1,2-Bis(diphenylphosphino)ethane]nickel(II) chloride: CANCER SUSPECT AGENT:
Nickel, dichloro[ethylenebis[diphenylphosphine]]- (8);
Nickel, dichloro[1,2-ethanediylbis[diphenylphosphine]-P,P']- (SP-4-2)- (9); (14647-23-5)

Diphenylphosphine: PYROPHORIC:
Phosphine, diphenyl- (8,9); (829-85-6)

1,4-Diazabicyclo[2.2.2]octane (DABCO) (8,9); (280-57-9)