New Binaphthyl-based C_3-symmetric Chiral Hemilabile Monophosphite Ligands: Synthesis and Characterization of Their Platinum Complexes

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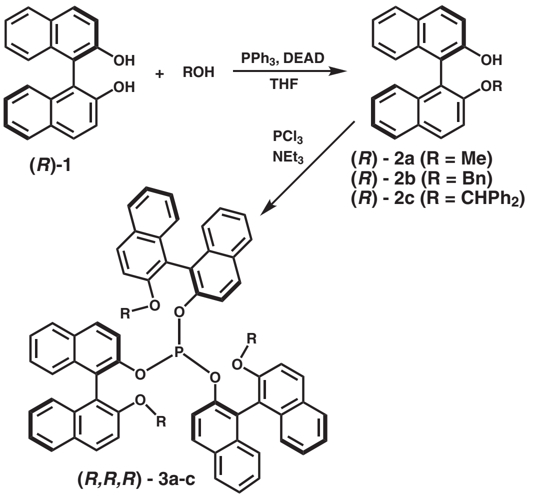
In this paper, we report an easy and highly efficient methodology for the synthesis of novel binaphthyl-based chiral monophosphites with C_3-symmetry. The preparation of the respective platinum complexes and their characterization by suitable in situ NMR spectroscopic studies confirmed the noteworthy hemilabile potential of the new phosphite ligands.

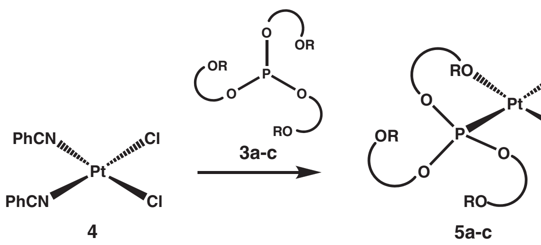
Molecular symmetry and chirality are found to be of great significance in both natural and synthetic perspectives. As it is well known, ligand properties can significantly influence transition-metal complexes to a wide range of activities.[1] In this context, 2,2′-binaphthol (BINOL) has generated particular interest because its versatile backbone can be modified, providing ligands with fitting functionalities, accurate elements of symmetry, and substituents capable of differentiating the available space in the vicinity of the metal centre.[2] The design and synthesis of chiral phosphorus ligands containing P-donor atoms is still a challenging goal since they have played a prominent role in asymmetric catalysis.[3] Over several decades, attention was almost exclusively focused on bidentate chelating P-donor ligands. However, since 2000 the growing interest in their chiral monodentate counterparts has significantly been boosted by the improvement of numerous asymmetric catalytic processes based on metal complexes containing this kind of ligand.[4] Moreover, ligands holding at least two different functional groups (often called hemilabile) found notable use in asymmetric catalysis due to enhanced selectivity introduced by an increasing dynamic behavior on the metal–ligand molecular bonding.[1] Integration of molecular symmetry into ligands is also one of the guiding principles behind catalyst design, as their mode of action is thought to be simplified by the reduction of the number of possible intermediates or transition states. Although C_2-symmetric ligands have been the center of attention, C_3-symmetry have attracted particular interest in recent times due to potential use in several chemical endeavors, such as asymmetric catalysis, molecular recognition, and nanoarchitecture.[5]

Herein we report an expedient method for the synthesis of a set of chiral C_3-symmetric bulky tris[(*R*)-2′-alkoxy-1,1′-binaphthyl-2-yl] phosphites. The phosphite ligands were prepared, according to Scheme 1. First, the monoetherification of (*R*)-BINOL (**1**) with different alcohols (MeOH, BnOH, and Ph_2CHOH) took place, in agreement with some modifications of the Mitsunobu reaction.[6] To a stirring solution of (*R*)-**1** (99% ee, 2.5 g, 8.7 mmol), triphenylphosphine (PPh_3) (2.28 g, 8.7 mmol) and the respective alcohol (20 mmol) in dry THF (50 mL) was added diethyl azodicarboxylate (DEAD) (40% in toluene, 3.8 mL, 17 mmol) dropwise, at 0 °C. After stirring for 48 h at room temperature, the solvent was evaporated under reduced pressure and the monoalkyl ethers **2a**–**2c** were isolated by silica gel column chromatography, using dichloromethane/*n*-hexane (1:1) as eluent and recrystallized from toluene/*n*-hexane, with yields of 84, 87, and 63%, respectively. The protection of (*R*)-**1** with primary alcohols was easier than with a secondary alcohol, due to higher steric hindrance of the latter.[7]



Scheme 1. Synthesis of C_3-symmetric chiral monophosphites **3a**–**3c**.

Next, the coupling reactions of **2a**–**2c** with PCl_3, in the presence of triethylamine (NEt_3) as base and also as reaction solvent were carried on. In a typical procedure, the desired ether **2a**–**2c** (3.45 mmol) was azeotropically dried with toluene and dissolved in dry triethylamine (9 mL). To this solution, at 0 °C and under nitrogen inert atmosphere, a solution of PCl_3 (0.10 mL, 1.15 mmol) was slowly added. After stirring at 0 °C for 3 h, the solvent was evaporated under reduced pressure, the residue was dissolved in dichloromethane/*n*-hexane (1:1) and the final product was isolated and purified by silica gel column chromatography using dichloromethane/*n*-hexane (1:1) as eluent, followed by recrystallization in ethyl ether/*n*-hexane, always under nitrogen atmosphere. The ligands tris[(*R*)-2′-methoxy-1,1′-binaphthyl-2-yl] phosphite (**3a**), tris[(*R*)-2′-benzyloxy-1,1′-binaphthyl-2-yl] phosphite (**3b**), and tris[(*R*)-2′-diphenylmethoxy-1,1′-binaphthyl-2-yl] phosphite (**3c**) were obtained with 83, 81, and 77% yields, respectively and all of them were properly characterized.[8]



Scheme 2. Synthesis of platinum complexes **5a**–**5c**.

Furthermore, to investigate the coordination ability of the new monophosphites as potential heterobidentate P,O ligands, a typical platinum(II) complex using **3a** as model has been synthesized, through the benzonitrile substitution method. A degassed solution of $PtCl_2(PhCN)_2$ (**4**) (23.6 mg, 0.05 mmol) in benzene (5 mL) was heated to reflux under argon. When a bright yellow homogeneous solution was formed, **3a** (46.4 mg, 0.05 mmol) in benzene (2 mL) was added. The mixture was heated for 1 h. Half of the solvent was evaporated and *n*-hexane (1 mL) was added. An off-white precipitated was formed and crystallized from an *n*-hexane/chloroform mixture.

The target complex **5a** was isolated as a white powder-like solid material, with yield of 78% (47 mg).[9] The in situ coordination studies for **3a**–**3c**, carried out in $CDCl_3$ at room temperature, revealed that platinum–phosphite complexes **5a**–**5c**, Scheme 2, containing only one bulky ligand were formed even at higher ligand to platinum ratio. For example, the twofold excess of **3a** to the platinum precursor **4** resulted in a ca. 1/1 mixture of the starting ligand **3a** and the complex **5a**.

Due to the different reactivity of the ligands towards substitution, in situ conversions of 97, 80, and 12% were obtained by NMR for **5a**, **5b**,[10] and **5c**,[11] respectively. The direct platinum–phosphorus bonds in all complexes have been proven by the ^{1}J (^{195}Pt, ^{31}P) coupling constants of diagnostic value, appearing as platinum satellites. The large coupling constants (close to 6 kHz) are typical of four-coordinated platinum–phosphite complexes with square-planar geometry possessing a chloro ligand trans to phosphorus.[12]

In conclusion, we have successfully developed a proficient route to obtain chiral bulky monophosphites with C_3-symmetry, whose potential hemilability was attested through the characterization of the respective platinum complexes. In order to investigate the performance of these hemilabile monophosphite ligands in asymmetric catalysis, several studies are currently underway, namely in platinum- and rhodium-catalyzed carbonylation reactions. The phosphites have already revealed remarkable results regarding active and selective catalytic systems, specifically in the rhodium-catalyzed hydroformylation of sterically hindered olefins, like *trans*-1-phenyl-1-propene and Δ^4-steroids. Indeed, the new hemilabile ligands reported here possess high potential to promote further important asymmetric catalytic reactions, for which the presence of a monodentate phosphite along with a hard O–R ether group might be crucial on behalf of dynamic metal–ligand molecular interaction modulation.

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8 Tris[(*R*)-2′-methoxy-1,1′-binaphthyl-2-yl] phosphite (**3a**) Yield: 83% (0.887 g); mp: 153–155 °C; $[\alpha]_D^{25}$ +30 (*c* 1.0, toluene); ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.45 (s, 9H), 6.34 (d, $J = 8.8$ Hz, 3H), 6.84 (d, $J = 8.4$ Hz, 3H), 7.01 (d, $J = 8.4$ Hz, 3H), 7.05 (t, $J = 7.8$ Hz, 3H), 7.15 (t, $J = 7.8$ Hz, 3H), 7.18–7.27 (m, 9H), 7.31 (t, $J = 7.4$ Hz, 3H), 7.75 (d, $J = 8.4$ Hz, 3H), 7.82 (d, $J = 8.4$ Hz, 3H), 7.89 (d, $J = 9.2$ Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 56.22, 113.79, 118.46, 120.63, 120.73, 123.42, 124.30, 125.41, 125.77, 126.01, 126.27, 127.71, 127.79, 128.66, 129.01, 129.69, 130.26, 133.65, 133.85, 147.48, 154.98; ^{31}P NMR (161 MHz, $CDCl_3$): δ 131.51. HRMS (ESI) (*m*/*z*): calcd for $C_{63}H_{45}O_6PNa$ $[M + Na]^+$, 951.2846; found, 951.2828.

Tris[(*R*)-2′-benzyloxy-1,1′-binaphthyl-2-yl] phosphite (**3b**) Yield: 81% (1.076 g); mp: 113–115 °C; $[\alpha]_D^{25}$ +15 (*c* 1.0, toluene); ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.73 (s, 6H), 6.20 (d, $J = 8.8$ Hz, 3H), 6.79 (d, $J = 6.4$ Hz, 6H), 6.88 (d, $J = 8.4$ Hz, 3H), 6.99–7.17 (m, 24H), 7.23 (t, $J = 7.6$ Hz, 3H), 7.32 (t, $J = 7.4$ Hz, 3H), 7.71–7.77 (m, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 70.39, 115.27, 119.15, 120.03, 120.13, 122.47, 123.24, 123.90, 125.19, 125.50, 125.61, 125.90, 126.40, 126.80, 127.33, 127.42, 127.69, 128.331, 128.88, 129.20, 129.94, 133.30, 133.55, 137.07, 147.05, 147.07, 153.80; ^{31}P NMR (161 MHz, $CDCl_3$): δ 132.60. HRMS (ESI) (*m*/*z*): calcd for $C_{81}H_{58}O_6P$ $[M + H]^+$, 1157.3996; found, 1157.3932.

Tris[(*R*)-2′-diphenylmethoxy-1,1′-binaphthyl-2-yl] phosphite (**3c**) Yield: 77% (1.226 g); mp: 142–144 °C; $[\alpha]_D^{25}$ −20 (*c* 1.0, toluene); ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.05 (s, 3H), 6.17 (d, $J = 9.2$ Hz, 3H), 6.74 (d, $J = 8.4$ Hz, 3H), 6.80–6.97 (m, 27H), 7.01 (t, $J = 7.2$ Hz, 6H), 7.10–7.15 (m, 9H), 7.19 (d, $J = 9.2$ Hz, 6H), 7.30 (t, $J = 7.4$ Hz, 3H), 7.64–7.71 (m, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 81.88, 116.73, 120.42, 120.53, 123.55, 124.12, 125.73, 126.03, 126.08, 126.32, 126.34, 126.39, 126.42, 126.47, 126.50, 126.68, 126.73, 127.10, 127.22, 127.53, 127.57, 127.68, 128.02, 128.09, 128.20, 128.29, 128.42, 128.75, 129.15, 129.20, 130.28, 133.61, 134.03, 141.47, 141.52, 147.45, 147.48, 153.16; ^{31}P NMR (161 MHz, $CDCl_3$): δ 134.20. HRMS (ESI) (*m*/*z*): calcd for $C_{99}H_{70}O_6P$ $[M + H]^+$, 1386.4938; found, 1386.4909.

9 **5a**: ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.47 (s, 6H), 3.80 (s, 3H), 6.38 (d, $J = 8.6$ Hz, 2H), 6.44 (d, $J = 8.6$ Hz, 1H), 6.76–6.85 (m, 3H), 6.95–7.96 (m, 30H); ^{31}P NMR (161 MHz, $CDCl_3$): δ 39.0, $^{1}J(^{195}\mathrm{Pt},^{31}\mathrm{P}) = 5861$ Hz. Anal. Calcd for $C_{63}H_{45}O_6PPtCl_2$: C, 63.32; H, 3.80%. Found: C, 63.07; H, 3.94%.

10 Selected NMR data obtained for **5b** by in situ studies: ^{31}P NMR (161 MHz, $CDCl_3$): δ 39.2, $^{1}J(^{195}\mathrm{Pt},^{31}\mathrm{P}) = 5844$ Hz. ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.74 ("AB-quartet," 2H), 5.08 ("AB-quartet," 1H).

11 Selected NMR data obtained for **5c** by in situ studies: ^{31}P NMR (161 MHz, $CDCl_3$): δ 50.9, $^{1}J(^{195}\mathrm{Pt},^{31}\mathrm{P}) = 5359$ Hz.

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