Assessing the Activity of Lewis Bases Organocatalysts in Halonium-Induced Carbocyclization Reactions


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\(^1\)H NMR and \(^{13}\)C NMR were recorded on a Bruker AV 300 instrument. All signals were expressed as ppm (\(\delta\)) and internally referenced to residual protio solvent signals. Coupling constants (\(J\)) are reported in Hz and refer to apparent peak multiplicities. Mass spectrometry analyses (direct introduction by chemical ionization with ammoniac or electrospray) were performed at the Ecole Nationale Supérieure de Chimie de Paris. High resolution mass spectra were performed at the University Pierre and Marie Curie (Paris) and at the Institute of Molecular Sciences (University of Bordeaux).

Catalysts 5m, 5p and 5n, 5q were prepared according the procedures A and B respectively and spectra data are in accordance with those from the literature.\(^1,2\)

Compounds 3, 6, 8 and 12 were prepared according to described procedures and spectra data are in accordance with those from the literature.\(^3\)

Cyclized products 4, 7, 9 and 13 were synthesized according the procedure D and spectra data are in accordance with those from the literature.\(^3\)

Compound 16 was prepared according the described procedure and spectra data are in accordance with those from the literature.\(^4\)

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\(^3\) Sanz, R.; Martínez, A.; García-García, P.; Fernández-Rodríguez, M. A.; Rashid, M.; Rodriguez, F. Chem. Commun., 2010, 46, 7427.

General procedure A for the preparation of selenide derivatives

In an argon purged screw cap tube were introduced the desired phosphine, phosphite or phosphoramidite derivative (1 equiv.), selenium powder (1 equiv) and CHCl₃ (0.1M). The resulting mixture was heated to reflux overnight, concentrated in vacuo and filtered over silica gel in dichloromethane to afford the pure selenide as a white to yellow foam.

General procedure B for the preparation of sulfides derivatives

In an argon purged screw cap tube were introduced the desired phosphine, phosphite or phosphoramidite derivative (1 equiv.), sulfur powder (1 equiv.) and toluene (0.1M). The resulting mixture was heated to reflux overnight, concentrated in vacuo and filtered over silica gel in dichloromethane to afford the pure sulfide as a white to yellow foam.

General procedure C for phosphite preparation

The chlorophosphite derivative was prepared by heating to reflux the corresponding binol (1 equiv.) in PCl₃ (10 equiv.) during 16 hours. The pure product was isolated by distillation of PCl₃ and dissolved in toluene (0.5M). In parallel the phenolate derivative was obtained by deprotonation with NaH (1 equiv.) of the 2,6-diphenylphenol (1 equiv.) in THF (1M). Both of the solutions were mixed and stirred during 4 hours before filtration on a pad of silica. After evaporation of the volatiles under reduced pressure, the crude mixture was purified by flash chromatography to afford the pure phosphite.

Typical procedure D for halocarbocyclization catalyzed by a Lewis base

N-Iodosuccinimide or N-bromosuccinimide (0.24 mmol) was added to a solution of the corresponding starting o-(alkynyl)styrene (0.2 mmol) with triphenylphosphite selenide (10 mol%) in dichloromethane (0.1M). The resulting mixture was stirred at room temperature during 2 hours and quenched by addition of saturated aq Na₂S₂O₃ (2 mL). The layers were separated and the aqueous layer was extracted with CH₂Cl₂ (3 × 1 mL). The combined organic layers were dried (MgSO₄), filtered and the solvents were removed under reduced pressure. The residue was purified by flash chromatography on silica gel using petroleum ether as eluent.
1-(2-methylprop-1-en-1-yl)-2-(2’-methoxyphenylethynyl)benzene (10)

![Chemical structure](image)

Compound 10 was prepared according to a general procedure from the literature.1

**1H-NMR (300 MHz, CDCl₃)** δ 1.87 (d, J = 1.2 Hz, 3H); 1.99 (d, J = 1.4 Hz, 3H); 3.93 (s, 3H); 6.67 (m, 1H); 6.90-6.97 (m, 2H); 7.13-7.21 (m, 1H); 7.24-7.33 (m, 3H); 7.46 (dd, J = 7.5, 1.7 Hz, 1H); 7.54-7.57 (m, 1H). **13C NMR (150 MHz, CDCl₃)** δ = 19.8, 27.0, 56.0, 90.0, 93.0, 110.9, 113.1, 120.6, 123.1, 124.4, 125.9, 127.7, 129.1, 129.7, 132.2, 133.5, 136.5, 140.6, 160.1. **HRMS (EI)** m/z calcd for C₁⁹H₁₈O (M⁺) 262.1358, found 262.1350.

3-iodo-2-(2’-methoxyphenyl)-1-(prop-1-en-2-yl)-1H-indene (11)

![Chemical structure](image)

This product was prepared according to general procedure D.

**1H-NMR (300 MHz, CDCl₃)** δ 1.17 (dd, J = 1.3, 0.8 Hz, 3H); 3.82 (s, 3H); 4.86-4.87 (m, 1H); 4.88 (s, 1H); 5.02 (dd, J = 1.5, 0.6 Hz, 1H); 6.95-6.98 (m, 1H); 7.00-7.06 (m, 1H); 7.27-7.42 (m, 6H). **13C NMR (75 MHz, CDCl₃)** δ 17.4, 55.4, 61.9, 96.5, 111.2, 115.4, 120.4, 122.7, 123.0, 125.6, 126.4, 127.4, 129.7, 131.5, 143.1, 144.6, 146.1, 152.3, 156.9. **HRMS (EI)** m/z calcd for C₁⁹H₁₇IO (M⁺) 388.0324, found 388.0333.

N-cinnamyl-N-(4-methoxyphenyl)-4-methylbenzenesulfonamide (15)

![Chemical structure](image)

The tosylated p-anisidine (500 mg, 1.8 mmol, 1 equiv.) was dissolved in distilled DMF (15 mL), and the reaction mixture was cooled to 0°C Then, NaH (86.4 mg, 2.16 mmol, 1.2 equiv.) was added portionwise. After 1 hour of stirring at room temperature, previously dissolved cinnamylbromide (426 mg, 2.16 mmol, 1.2 equiv., in 5 mL of DMF) was added dropwise.
The reaction mixture was allowed to stir at room temperature during 16 hours and then it was poured into water and extracted 3 times with ethyl acetate. The combined organic layers were washed with water 3 times before drying over MgSO₄, filtration and concentration under reduced pressure. The residue was purified by flash chromatography using petroleum ether / ethyl acetate 90/10 as eluent to afford the pure product 15 with 89% (630 mg). Spectral data were in accordance with those from the literature.

3-iodo-6-methoxy-4-phenyl-1-tosyl-1,2,3,4-tetrahydroquinoline (17)

15 (39 mg, 0.1 mmol, 1 equiv.) was dissolved in a mixture of DCE/HFIP (9:1, 0.1 M), then SP(OPh)₃ (3.42 mg, 0.01 mmol, 0.1 equiv) and DIDMH (45.6 mg, 0.12 mmol, 1.2 equiv.) were subsequently added and the mixture was allowed to stir at room temperature for 10 minutes before quenching with an aqueous saturated Na₂S₂O₃ solution and extraction with dichloromethane. The organic phases were dried over MgSO₄, filtered and concentrated under reduced pressure. The crude product was purified by flash chromatography with petroleum ether /ethyl acetate as eluent to give 17 as a white solid, [42 mg, 80%].

**1H NMR (300 MHz, CDCl₃)** δ 7.79 (d, J = 9.1 Hz, 1H), 7.56 (d, J = 8.2 Hz, 2H), 7.31 (d, J = 8.2 Hz, 2H), 7.20 (t, J = 7.3 Hz, 1H), 7.11 (t, J = 7.3 Hz, 2H), 6.79 (dd, J = 9.1, 2.7 Hz, 1H), 6.43 (d, J = 8.4 Hz, 2H), 6.09 (d, J = 2.7 Hz, 1H), 4.85 (dd, J = 13.0, 2.7 Hz, 1H), 4.17 (d, J = 9.8 Hz, 1H), 4.04 – 3.77 (m, 2H), 3.61 (s, 3H), 2.47 (s, 3H).

**13C NMR (75 MHz, CDCl₃)** δ 157.4, 144.3, 142.0, 136.7, 133.5, 130.1, 128.8, 128.6, 128.4, 127.5, 127.4, 126.9, 115.0, 113.0, 55.6, 55.3, 55.1, 28.8, 21.7. **HRMS (ESI)** m/z calcd for C₂₃H₂₂INO₃SNa (M + Na⁺) 542.0257 found 542.0253.
Scheme 1. Lewis base-catalyzed enantioselective iodocarbocyclization of 1,5-enyne 3.

Scheme 2. Iodocarbocyclization of 15 in the presence of chiral phosphorus-containing Lewis bases. Yields were determined using acenaphthene as an internal standard.
(11bS)-4-(piperidin-1-yl)dinaphtho[2,1-d:1',2'-f][1,3,2]dioxaphosphepine 4-selenide (18)

![Chemical structure of compound 18]

Compound 18 was obtained according the procedure A starting from PipPhos® (200 mg, 0.5 mmol), Se (39.5 mg, 0.5 mmol) in chloroform (5 mL) with 76% yield (181 mg). 

**1H NMR (300 MHz, CDCl₃)** δ 8.07 (d, J = 8.9 Hz, 1H), 8.01 (d, J = 8.9 Hz, 1H), 7.97 (d, J = 8.5 Hz, 2H), 7.67 (dd, J = 8.5, 1.2 Hz, 1H), 7.56 – 7.42 (m, 4H), 7.39 – 7.23 (m, 3H), 3.41 – 3.06 (m, 4H), 1.66 – 1.37 (m, 6H).

**13C NMR (75 MHz, CDCl₃)** δ 149.0, 148.8, 147.1, 147.0, 142.5, 132.5, 131.9, 131.4, 130.8, 130.6, 128.5, 128.4, 127.3, 127.1, 126.7, 126.4, 125.6, 125.6, 122.0, 121.0, 48.1, 26.1, 26.0, 24.3. 

**31P NMR (121 MHz, CDCl₃)** δ 85.7 (d, J = 967 Hz).

[α]D₂₀ = -420 (c = 0.39, CHCl₃). m.p. 248-253 °C. 

**HRMS (FD) m/z** calcd for C₂₅H₂₂NO₂PSe (M⁺) 475.0580 found 475.0582.

(11bS)-4-(piperidin-1-yl)dinaphtho[2,1-d:1',2'-f][1,3,2]dioxaphosphepine 4-sulfide (19)

![Chemical structure of compound 19]

Compound 19 was obtained according the procedure B starting from PipPhos® (400 mg, 1 mmol), S₈ (32 mg, 0.125 mmol) in toluene (5 mL) with 24% yield (105 mg). 

**1H NMR (300 MHz, CDCl₃)** δ 7.97 – 7.85 (m, 4H), 7.52 (dd, J = 8.8, 1.1 Hz, 1H), 7.46 – 7.30 (m, 4H), 7.30 – 7.13 (m, 3H), 3.29 – 2.90 (m, 4H), 1.63 – 1.32 (m, 6H).

**13C NMR (75 MHz, CDCl₃)** δ 149.0 (Cq), 147.1 (Cq), 132.4 (Cq), 131.9 (Cq), 131.4 (Cq), 130.8 (CH), 130.6 (CH), 128.5 (CH), 128.4 (CH), 127.3 (CH), 127.1 (CH), 126.6 (CH), 126.4 (CH), 125.6 (CH), 125.5 (CH), 121.9 (CH), 121.1 (CH), 47.7(2CH₂), 26.2 (CH₂), 26.1 (CH₂), 24.3 (CH₂). 

**31P NMR (121 MHz, C₆D₆)** δ 82.0. [α]D₂₀ = -449 (c = 0.39, CHCl₃). m.p. 236-240 °C.
Compound 20 was obtained according the procedure A starting from the corresponding phosphoramidite \(^5\) (100 mg, 0.2 mmol), Se (16 mg, 0.2 mmol) in chloroforme (2mL) with 68% yield (80 mg). \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 8.14 (d, \(J = 8.9\) Hz, 1H), 8.01 (d, \(J = 8.2\) Hz, 1H), 7.89 (d, \(J = 8.2\) Hz, 1H), 7.85 – 7.77 (m, 2H), 7.60 – 7.14 (m, 16H), 6.95 (m, 1H), 4.82 – 4.65 (m, 2H), 3.78 – 3.59 (m, 2H). \(^{13}\)C NMR (75 MHz, CDCl\(_3\)) \(\delta\) 149.1 (Cq), 147.0 (Cq), 136.6 (2Cq), 136.6 (2Cq), 132.4 (Cq), 132.3 (Cq), 132.1 (Cq), 131.4 (Cq), 130.9 (2CH), 128.8 (4CH), 128.6 (4CH), 128.3 (2CH), 127.9 (2CH), 127.2 (CH), 127.1 (CH), 126.7 (CH), 126.5 (CH), 125.7 (2CH), 122.1 (CH), 120.5 (CH), 50.3 (2CH\(_2\)). \(^{31}\)P NMR (121 MHz, CDCl\(_3\)) \(\delta\) 88.3 (d, \(J = 977\) Hz).

Compound 21 was obtained according the procedure A starting from the corresponding phosphoramidite \(^6\) (217 mg, 0.5 mmol), Se (39.5 mg, 0.5 mmol) in chloroforme (5mL) with 46% yield (118 mg). \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 8.08 (d, \(J = 8.9\) Hz, 1H), 7.50 (d, \(J = 9.2\) Hz, 1H), 7.42 – 7.18 (m, 9H), 4.91 – 4.56 (m, 1H), 3.88 (t, \(J = 9.2\) Hz, 1H), 1.62 (d, \(J = 6.8\) Hz, 3H). \(^{13}\)C NMR (75 MHz, CDCl\(_3\)) \(\delta\) 147.9 (Cq), 147.7 (Cq), 146.6 (Cq), 146.5 (Cq), 143.6 (Cq), 143.5 (Cq), 132.4 (Cq), 132.0 (Cq), 131.5 (Cq), 130.9 (CH), 130.6 (CH), 128.6 (2CH), 128.4 (CH), 127.4 (CH), 127.2 (CH), 127.0 (CH), 126.7 (CH), 126.5 (CH), 125.9 (2CH), 125.7 (CH), 125.6 (CH), 122.3 (CH), 121.6 (CH), 121.0 (CH), 53.12 (CH), 25.3 (CH\(_3\))). \(^{31}\)P NMR (121 MHz, CDCl\(_3\)) \(\delta\) 82.1 (d, \(J = 972\) Hz). m.p. 218-220 °C


Compound 23 was obtained according the procedure A starting from the corresponding phosphoramidite \(^7\) (116 mg, 0.2 mmol), Se (16 mg, 0.2 mmol) in chloroform (2 mL) with 75% yield (99 mg). \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 7.71 – 7.62 (m, 2H), 7.57 (ddd, \(J = 5.7, 3.2, 1.0\) Hz, 4H), 7.46 – 7.32 (m, 6H), 7.32 – 7.23 (m, 8H), 5.73 (d, \(J = 7.9\) Hz, 1H), 5.22 (d, \(J = 7.9\) Hz, 1H), 3.44 – 3.19 (m, 2H), 3.18 – 3.04 (m, 2H), 1.75 – 1.36 (m, 6H), 0.72 (s, 3H), 0.61 (s, 3H). \(^{13}\)C NMR (75 MHz, CDCl\(_3\)) \(\delta\) 142.7 (2Cq), 130.3 (2CH), 128.6 (CH), 128.2 (CH), 128.1 (3CH), 127.9 (2CH), 127.7 (2CH), 127.5 (CH), 127.3 (3CH), 127.1 (3CH), 127.1 (3CH), 113.9 (2Cq), 92.2 (Cq), 86.8 (Cq), 79.4 (CH), 78.4 (CH), 46.9 (2CH\(_2\)), 26.7 (2CH\(_2\)), 26.0 (CH\(_2\)), 25.9 (CH\(_2\)), 24.5 (CH\(_2\)). \(^{31}\)P NMR (121 MHz, CDCl\(_3\)) \(\delta\) 58.8 (d, \(J = 933\) Hz). m.p. 226-231 °C HRMS (FD) m/z calcd for C\(_{36}\)H\(_{38}\)NO\(_4\)PSe (M\(^+\)) 655.1731 found 655.1732.

Compound 24 was prepared following the procedure C starting from (S)-BINOL (1.14 g, 4 mmol), PCl\(_3\) (3.5 mL, 40 mmol), toluene (8 mL), 2,6-diphenylphenol (984 mg, 4 mmol), NaH (160 mg, 4 mmol, 60% in mineral oil) and THF (4 mL). the pure product was obtained with 38% (850 mg). \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 7.86 – 7.75 (m, 3H), 7.65 – 7.42 (m, 10H), 7.42 – 7.28 (m, 4H), 7.28 – 7.09 (m, 6H), 6.75 (d, \(J = 8.7\) Hz, 1H), 5.82 (d, \(J = 8.7\) Hz, 1H). \(^{13}\)C NMR (75 MHz, CDCl\(_3\)) \(\delta\) 147.9, 146.6, 146.1, 145.9, 138.5, 136.1, 136.0, 132.6, 132.3, 131.5, 131.0, 130.7, 130.1, 130.0, 129.6, 129.4, 129.0, 128.9, 128.8, 128.5, 128.2, 128.1, 127.7, 127.4, 127.0, 126.1, 125.7, 125.3, 125.0, 124.7, 124.3, 123.9, 122.0, 121.8, 121.6. \(^{31}\)P NMR (121 MHz, CDCl\(_3\)) \(\delta\) 145.3. \([\alpha]_D^{20} = -186\) (c = 0.47, CHCl\(_3\)). m.p. 98-101 °C

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(11bS)-4-((1,1':3',1''-terphenyl]-2'-yloxy)dinaphtho[2,1-d:1',2'-f][1,3,2]dioxaphosphepine 4-selenide (25)

Compound 25 was obtained according the procedure A starting from phosphite 24 (200 mg, 0.36 mmol), Se (28.8 mg, 0.36 mmol) in toluene (5 mL) with 73% yield (168 mg). \(^1\text{H NMR (300 MHz, CDCl}_3\) \(\delta \) 7.88 (t, \(J = 8.0\) Hz, 2H), 7.77 (d, \(J = 8.9\) Hz, 1H), 7.64 – 7.52 (m, 4H), 7.52 – 7.39 (m, 6H), 7.37 (s, \(J = 1.8\) Hz, 3H), 7.31 – 7.18 (m, 7H), 7.16 (dd, \(J = 8.9, 1.3\) Hz, 1H), 6.15 (dd, \(J = 8.9, 1.3\) Hz, 1H). \(^{31}\text{P NMR (121 MHz, CDCl}_3\) \(\delta \) 75.8. \([\alpha]D^{20} = -24\) (c = 1.03, CHCl\(_3\)) m.p. 150-153 °C HRMS (FD) \(m/z\) calcd for C\(_{38}\)H\(_{25}\)O\(_3\)PSe (M\(^+\)) 636.0733 found 636.0753.

(11bS)-4-((1,1':3',1''-terphenyl]-2'-yloxy)-2,6-diphenyldinaphtho[2,1-d:1',2'-f][1,3,2]dioxaphosphepine 4-selenide (26)

Compound 26 was obtained according the procedure A starting from the corresponding phosphite (114 mg, 0.16 mmol), Se (15 mg, 0.16 mmol) in toluene (2 mL) with 69% yield (86 mg). \(^1\text{H NMR (300 MHz, CDCl}_3\) \(\delta \) 8.20 – 8.07 (m, 2H), 7.87 (dd, \(J = 8.8, 6.9\) Hz, 4H), 7.74 – 7.54 (m, 4H), 7.51 – 7.29 (m, 4H), 7.29 – 7.17 (m, 13H), 7.07 (d, \(J = 8.6\) Hz, 2H), 7.02 – 6.81 (m, 4H). \(^{13}\text{C NMR (75 MHz, CDCl}_3\) \(\delta \) 138.1, 137.8, 137.1, 136.0, 134.3, 134.2, 132.6, 132.1, 132.0, 131.6, 131.2, 130.8, 130.6, 130.0, 129.1, 128.9, 128.4, 128.2, 127.9, 127.6, 127.5, 127.2, 126.9, 126.4, 125.8, 123.4. \(^{31}\text{P NMR (121 MHz, CDCl}_3\) \(\delta \) 65.2 (d, \(J = 1073\) Hz). \([\alpha]D^{20} = -64\) (c = 0.32, CHCl\(_3\)). m.p. 163-168 °C
(11bR)-4-(bis((R)-1-phenylethyl)amino)dinaphtho[2,1-d:1’,2’-f][1,3,2]dioxaphosphepine 4-sulfide (27)

Compound 27 was obtained according the procedure B starting from the corresponding phosphoramidite8 (216 mg, 0.4 mmol), S₈ (13 mg, 0.4 mmol) in toluene (4mL) with 51% yield (118 mg). ¹H NMR (300 MHz, CDCl₃) δ 8.04 (d, J = 8.9 Hz, 1H), 7.93 (d, J = 8.2 Hz, 1H), 7.82 (d, J = 8.2 Hz, 1H), 7.70 (d, J = 8.9 Hz, 1H), 7.62 (dd, J = 8.8, 1.2 Hz, 1H), 7.48 – 7.38 (m, 2H), 7.31 – 7.05 (m, 9H), 7.05 – 6.89 (m, 6H), 5.23 – 4.87 (m, 2H), 1.74 (d, J = 7.1 Hz, 6H). ¹³C NMR (75 MHz, CDCl₃) δ 148.9 (Cq), 148.7 (Cq), 146.4 (Cq), 146.3 (Cq), 141.8 (Cq), 132.6 (Cq), 131.9 (Cq), 131.3 (Cq), 130.6 (CH), 130.2 (CH), 128.5 (CH), 128.1 (CH), 127.9 (4CH), 127.7 (4CH), 127.4 (CH), 127.2 (CH), 126.9 (2CH), 126.3 (CH), 126.2 (CH), 125.5 (CH), 125.3 (CH), 122.3 (CH), 121.0 (Cq), 120.8 (CH), 55.4 (CH), 55.4 (CH), 19.5 (2CH₃). [α]D²⁰ = -146 (c = 0.5, CHCl₃) m.p. 185-189 °C HRMS (FD) m/z calcd for C₃₆H₃₀NO₂PS (M⁺) 571.1735 found 571.1740.

(3aR,8aR)-4,4,8,8-tetra([1,1'-biphenyl]-4-yl)-6-(dibenzylandino)-2,2-dimethyltetrahydro-[1,3]dioxolo[4,5-e][1,3,2]dioxaphosphepine 6-sulfide (28)

Compound 28 was obtained according the procedure B starting from the corresponding phosphoramidite (300 mg, 0.31 mmol), S₈ (9.7 mg, 0.31 mmol) in toluene (3 mL) with 60% yield (186 mg). ¹H NMR (300 MHz, CDCl₃) δ 7.93 (d, J = 8.5 Hz, 2H), 7.83 – 7.62 (m, 10H), 7.62 – 7.28 (m, 34H), 5.97 (d, J = 8.0 Hz, 1H), 5.28 (d, J = 8.0 Hz, 1H), 4.52 – 4.35 (m, 2H), 4.27 – 4.00 (m, 2H), 0.93 (s, 3H), 0.69 (s, 3H). ¹³C NMR (75 MHz, CDCl₃) δ 143.6 (Cq), 142.1 (Cq), 140.7 (Cq), 140.4 (Cq), 139.8 (Cq), 139.7 (Cq), 139.4 (Cq), 137.3 (Cq), 130.7 (CH), 129.3 (CH), 128.8 (CH), 128.4 (CH), 128.4 (CH), 127.6 (CH), 127.5 (CH), 127.4 (CH), 127.1 (CH), 126.8 (CH), 126.6 (CH), 125.9 (CH), 125.8 (CH), 113.8 (Cq), 91.4 (Cq), 91.3 (Cq), 87.9 (Cq), 87.0 (Cq), 79.9 (CH), 78.3 (CH), 77.3 (CH), 49.3 (CH₂), 49.2 (CH₂), 27.1 (CH₃), 26.8 (CH₃). ³¹P NMR (121 MHz, CDCl₃) δ 63.1. [α]D²⁰ = -112 (c = 1.02, CHCl₃). m.p. 138-140 °C MS (ESI) m/z: 1050.7 MNa⁺.

3-iodo-2-(2’-methoxyphenyl)-1-(prop-1-en-2-yl)-1H-indene
3-iodo-6-methoxy-4-phenyl-1-tosyl-1,2,3,4-tetrahydroquinoline
(11hS)-4-(piperidin-1-yl)dinaphtho[2,1-d:1',2'-d'][1,3,2]dioxaphosphepine 4-selenide
(11bS)-4-(piperidin-1-yl)dinaphtho[2,1-d:1',2'-f][1,3,2]dioxaphosphepine 4-sulfide
(11bR)-4-(dibenzylamino)dinaphtho[2,1-d:1',2'-f][1,3,2]dioxaphosphepine 4-selenide

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(11bS)-4-(((R)-1-phenylethyl)amino)dinaphtho[2,1-d:1’,2’-f][1,3,2]dioxaphosphepine 4-selenide
(3aR,8aR)-2,2-dimethyl-4,4,8,8-tetraphenyl-6-(piperidin-1-yl)tetrahydro-[1,3]dioxolo[4,5-e][1,3,2]dioxaphosphepine 6-selenide
(11bS)-4-((1',1''-terphenyl)-2'-yloxy)dinaphtho[2,1-d:1',2'-f][1,3,2]dioxaphosphepine
(11bS)-4-((1,1':3',1''-terphenyl)-2'-yloxy)dinaphtho[2,1-d:1',2'-f][1,3,2]dioxaphosphepine 4-selenide
(11bS)-4-([1,1’:3’,1’’-terphenyl]-2'-yloxy)-2,6-diphenyldinaphtho[2,1-d:1’,2’-f][1,3,2]dioxaphosphepine 4-selenide
(11bS)-4-((1,1′:3′,1′′-terphenyl)-2′-yloxy)-2,6-diphenylidaphtho[2,1-d:1′,2′-f][1,3,2]dioxaphosphepine 4-selenide

![NMR spectrum of the compound](image)

**1H NMR**

- δ 7.61, 7.64, 7.68, 7.71 ppm
- δ 7.81, 7.83 ppm
- δ 7.92, 7.95, 8.02, 8.05 ppm

**13C NMR**

- δ 119.0, 120.77, 121.00 ppm
- δ 122.32, 125.28, 125.52 ppm
- δ 126.17, 126.27, 126.90 ppm
- δ 127.17, 127.42, 127.70 ppm
- δ 127.93, 128.05, 128.45 ppm
- δ 130.19, 130.62, 131.30 ppm
- δ 131.92, 132.56, 141.75 ppm
- δ 141.78, 146.25, 146.37 ppm
- δ 148.74, 148.94 ppm
(3aR,8aR)-4,4,8,8-tetra([1,1'-biphenyl]-4-yl)-6-(dibenzylnimino)-2,2-dimethyltetrahydro-
[1,3]dioxolo[4,5-e][1,3,2]dioxaphosphepine 6-sulfide