

Supporting Information

**5,5'-Diamino-BIPHEP Ligands Bearing Small
Selector Units for Non-Covalent Binding of
Chiral Analytes in Solution**

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Table of Contents

1. Synthetic Procedures.....	4
1.1. General Remarks	4
1.2. Ligand and Complex Preparation	5
1.2.1. 5,5'-Dinitro-2,2'-biphenol.....	5
1.2.2. 5,5'-Dinitro-(1,1'-biphenyl)-2,2'-diyl bis(trifluoromethanesulfonate).....	6
1.2.3. 5,5'-Diamino-(1,1'-biphenyl)-2,2'-diyl bis(trifluoromethanesulfonate)	7
1.2.4. 5,5'-Bis[(<i>tert</i> -butoxycarbonyl)amino]-(1,1'-biphenyl)-2,2'-diyl bis(trifluoromethanesulfonate).....	8
1.2.5. Diphenylphosphine oxide.....	9
1.2.6. 5,5'-Bis[(<i>tert</i> -butoxycarbonyl)amino]-(1,1'-biphenyl)-2,2'-diyl-bis(diphenylphosphine oxide)	10
1.2.7. 5,5'-Diamino-(1,1'-biphenyl)-2,2'-diyl bis(diphenylphosphine oxide).....	11
1.2.8. 5,5'-Bis(3,5-dichlorobenzoylamino)-BIPHEP(O)	12
1.2.9. 5,5'-Bis[(3,5-dichlorobenzoylaminoacetyl)amino]-BIPHEP(O)	13
1.2.10. 5,5'-Bis(3,5-Dichlorophenylureylene)-BIPHEP(O).....	14
1.2.11. 5,5'-Bis(3,5-dichlorobenzoylamino)-BIPHEP	15
1.2.12. [(X)Rh(COD)](BF ₄)	16
1.3. Phenylalanine Derivatives	17
1.3.1. Compound 9	17
1.3.2. Compound 10	18
1.3.3. Compound 11	18
1.3.4. Compound 12	19
2. NMR Interaction Studies	20
2.1. Complex 6 / (<i>S</i>)-Amidoester 7	20
2.2. Complex 6 / (<i>S</i>)-Amidoester 8	21
2.3. Complex 6 / (<i>S</i>)-Diamide 9.....	22
2.4. Complex 6 / (<i>S</i>)-Diamide 10.....	23
2.5. Complex 6 / (<i>S</i>)-Diamide 11.....	24

2.6.	Complex 6 / (<i>S</i>)-Diamide 12.....	25
2.7.	Complex 6 / (<i>S</i>)-Diamide 13.....	26
2.8.	Complex 6 / (<i>S</i>)-Diamide 13 (50% <i>ee</i>).....	28
2.9.	Complex 6 / (<i>S</i>)-Diamide 13 (25 and 75 % <i>ee</i>).....	29
2.10.	Complex 6 / <i>rac</i> -Diamide 13.....	30
2.11.	Linear Correlation of Splitting and Enantiomeric Excess of Analyte (Complex 6 / Ac-Phe-NHMe)	31
2.12.	[(BIPHEP)Rh(COD)](BF ₄) / (<i>S</i>)-Diamide 13.....	32
2.13.	5,5'-Bis(3,5-dichlorobenzoylamino)-BIPHEP/ (<i>S</i>)-Diamide 13	33
3.	NMR-spectra.....	34
3.1.	Cf. 1.1.1.....	34
3.2.	Cf. 1.1.2.....	35
3.3.	Cf. 1.1.3.....	37
3.4.	Cf. 1.1.4.....	39
3.5.	Cf. 1.1.6.....	41
3.6.	Cf. 1.1.7.....	43
3.7.	Cf. 1.1.8.....	45
3.8.	Cf. 1.1.9.....	47
3.9.	Cf. 1.1.10.....	49
3.10.	Cf. 1.1.11.....	51
3.11.	Cf. 1.1.12.....	53

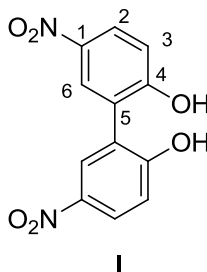
1. Synthetic Procedures

1.1. General Remarks

Syntheses with air sensitive reactants were carried out under an argon atmosphere (Ar 5.0) under exclusion of air. All glassware was heated prior to use and standard Schlenk techniques were applied. THF, toluene, diethyl ether, acetonitrile and DCM were dried in an MB SPS-800 system and stored under argon. NMR-spectra were recorded on Bruker Avance 600, 500, 400 and 300 MHz spectrometers. Chemical shifts are reported in ppm, coupling constants J in Hz and peak multiplicity is defined by s (singlet), d (doublet), t (triplet) and m (multiplet). Broad signals are labeled as such (b). The solvent residual signals were used for calibration.^[1] Assignment of all signals was done by means of two-dimensional experiments (^1H - ^1H -COSY, ^1H - ^{13}C -HSQC-ME and ^1H - ^{13}C -HMBC). Mass spectra were recorded on a JEOL JMS-700 Magnetic Sector, Bruker ApexQe hybrid 9.4 T FT-ICR, or a Finnigan MAT TSQ 700 spectrometer. Infrared spectra were recorded on a Thermo Scientific Nicolet 6700 ATR-FT-IR spectrometer. X-Ray crystallographic analysis was done on a Bruker Smart CCD or a Bruker APEX diffractometer. All chemicals were obtained from Aldrich, Acros, TCI or Alfa Aesar unless otherwise stated and used without further purification.

1.2. Ligand and Complex Preparation

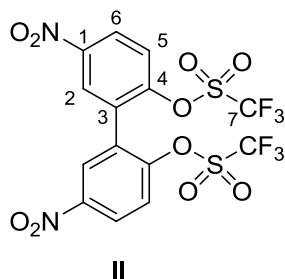
1.2.1. 5,5'-Dinitro-2,2'-biphenol



This compound was synthesized according to a procedure described in literature^[2] with modified workup. *Ortho*-biphenol (37.8 g, 203 mmol, 1.0 eq.) was dissolved in acetic acid (120 mL) and cooled to 0°C under vigorous stirring. A solution of HNO₃ (28.3 mL, 65 %, 412 mmol, 2.03 eq.) in acetic acid (20 mL) was added very carefully as quickly as possible via a dropping funnel. The reaction mixture was stirred for additional 45 min at 0°C and subsequently all solid products were collected over fritted glass. The crude product was washed with water (2x 20 mL) and dried under reduced pressure at 60°C. The crude product was suspended in acetonitrile (350 mL), heated to reflux and slowly cooled to room temperature overnight. The solid was collected over fritted glass and dried under reduced pressure.

Beige solid, 8.98 g (16%), ¹H-NMR (DMSO-d₆, 500.13 MHz, 300 K): δ = 7.11 (d, ³J_{H-H} = 8.6 Hz, 2H, H³), 8.11-8.17 (m, 4H, H^{2,6}), 11.25 (bs, 2H, OH); ¹³C{¹H}-NMR (DMSO-d₆, 125.76 MHz, 300 K): δ = 116.1 (2C, C³), 123.8 (2C, C⁵), 125.5 (2C, C^{2/6}), 127.4 (2C, C^{2/6}), 139.3 (2C, C¹), 161.5 (2C, C⁴); HR-MS (EI⁺): m/z calc. for ([M]⁺, [C₁₂H₈O₆N₂]⁺): 276.0377, found: 276.0363.

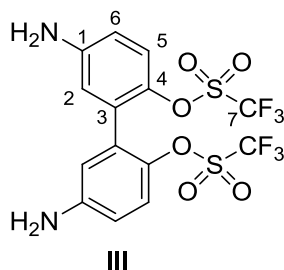
1.2.2. 5,5'-Dinitro-(1,1'-biphenyl)-2,2'-diyl bis(trifluoromethanesulfonate)



Compound I (14.5 g, 52.5 mmol, 1.0 eq.) was suspended in anhydrous DCM (300 mL) and anhydrous pyridine (12.6 mL, 157 mmol, 3.0 eq.) was added. The reaction mixture was cooled to 0°C and Tf₂O (26.5 mL, 157 mmol, 3.0 eq.) was slowly added. Stirring was continued over night. Subsequently, all volatiles were removed under reduced pressure and the resulting crude mixture was partitioned between EtOAc (500 mL) and hydrochloric acid (1M, 500 mL). The organic phase was washed with sat. NaHCO₃ solution (400 mL) and brine (400 mL) and dried over Na₂SO₄. All volatiles were removed under reduced pressure.

Beige solid, 24.1 g (85%), ¹H-NMR (CDCl₃, 500.13 MHz, 300 K): δ = 7.70 (d, ³J_{H-H} = 9.1 Hz, 2H, H⁵), 8.43 (d, ⁴J_{H-H} = 2.7 Hz, 2H, H²), 8.52 (dd, ³J_{H-H} = 9.1 Hz, ⁴J_{H-H} = 2.7 Hz, 2H, H⁶); ¹³C{¹H}-NMR (CDCl₃, 125.76 MHz, 300 K): δ = 118.3 (q, ¹J_{C-F} = 320.7 Hz, 2C, C⁷), 123.4 (2C, C⁵), 127.2 (2C, C⁶), 127.9 (2C, C²), 129.2 (2C, C³), 147.1 (2C, C⁴), 150.3 (2C, C¹); ¹⁹F-NMR (CDCl₃, 470.59 MHz, 300 K): δ = -73.4; HR-MS (EI⁺): m/z calc. for ([M]⁺, [C₁₄H₆O₁₀N₂F₆S₂]⁺): 539.9363, found: 539.9387.

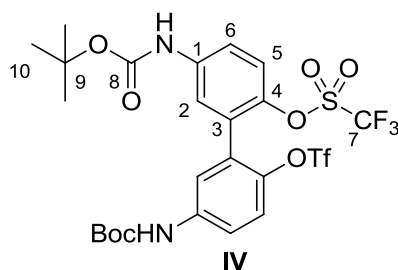
1.2.3. 5,5'-Diamino-(1,1'-biphenyl)-2,2'-diyl bis(trifluoromethanesulfonate)



Compound II (22.0 g, 40.7 mmol, 1.0 eq.) was suspended in EtOH (220 mL) and powdered iron (17.1 g, 305 mmol, 7.5 eq.) was added. The reaction mixture was warmed to 60°C and hydrochloric acid (37%, 60.9 mL, 742 mmol, 18.2 eq.) was added portion wise within 20 min. Stirring was continued for 3 h under reflux conditions. Subsequently, all volatiles were removed under reduced pressure. The crude mixture was partitioned between H₂O (100 mL) and DCM (100 mL) and adjusted to pH = 6 with aqueous NaOH solution (half concentrated). The aqueous phase was absorbed with excess Na₂SO₄ and the resulting residue was extracted with DCM (2 L). The organic phase was dried over Na₂SO₄ and concentrated under reduced pressure. The resulting crude product was re-dissolved in DCM and passed through silica in a fritted glass funnel (elution with 2 L DCM). All volatiles were removed under reduced pressure.

White solid, 16.4 g (84 %), ¹H-NMR (DMSO-d₆, 500.13 MHz, 300 K): δ = 5.65 (bs, 4H, NH₂), 6.55 (d, ⁴J_{H-H} = 2.8 Hz, 2H, H²), 6.65 (dd, ³J_{H-H} = 8.9 Hz, ⁴J_{H-H} = 2.8 Hz, 2H, H⁶), 7.11 (d, ³J_{H-H} = 8.9 Hz, 2H, H⁵); ¹³C{¹H}-NMR (DMSO-d₆, 75.47 MHz, 300 K): δ = 114.4 (2C, C⁶), 115.7 (2C, C²), 117.9 (q, ¹J_{C-F} = 320.7 Hz, 2C, C⁷), 121.9 (2C, C⁵), 129.9 (2C, C³), 136.2 (2C, C¹), 149.1 (2C, C⁴); ¹⁹F-NMR (DMSO-d₆, 470.59 MHz, 300 K): δ = -74.3; HR-MS (EI⁺): m/z calc. for ([M]⁺, [C₁₄H₁₀O₆N₂F₆S₂]⁺): 479.9879, found: 479.9889; IR (FT-ATR) : ν (cm⁻¹) = 3492, 3402, 1627, 1587, 1488, 1443, 1405, 1391, 1347, 1302, 1247, 1221, 1133, 1026, 934, 860, 812, 773, 726.

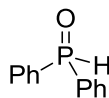
1.2.4. 5,5'-Bis[(*tert*-butoxycarbonyl)amino]-(1,1'-biphenyl)-2,2'-diyl bis(trifluoromethanesulfonate)



Compound **III** (15.4 g, 32.1 mmol, 1.0 eq.) and Boc₂O (70.0 g, 321 mmol, 10 eq.) were dissolved in THF (100 mL) and stirred at 50°C over night. Complete conversion was confirmed by NMR analysis of a small sample. Otherwise, stirring had to be continued at 50°C. Subsequently, the reaction mixture was cooled to 0°C and *N,N*-dimethylethylenediamine (70.0 mL, 641 mmol, 20 eq.) was carefully added. The reaction mixture was stirred at 50°C over night. All volatiles were removed under reduced pressure and the remaining residue was partitioned between sat. aq. NH₄Cl solution (300 mL) and EtOAc (300 mL). The organic phase was washed with sat. aq. NH₄Cl solution until the aqueous phase reached pH = 6-7. It was then washed with brine (300 mL) and dried over Na₂SO₄. All volatiles were removed under reduced pressure. The crude product was loaded on a fritted glass funnel, washed with *n*-pentane (170 mL, in small portions), and subsequently dried under reduced pressure.

White solid, 18.3 g (84%); ¹H-NMR (DMSO-d₆, 600.25 MHz, 300 K): δ = 1.48 (s, 18H, H¹⁰), 7.51 (d, ³J_{H-H} = 8.9 Hz, 2H, H⁵), 7.65 (m, 2H, H²), 7.68 (m, 2H, H⁶), 9.86 (s, 2H, NH); ¹³C{¹H}-NMR (DMSO-d₆, 150.93 MHz, 300 K): δ = 28.0 (6C, C¹⁰), 80.0 (2C, C⁹), 117.8 (q, ¹J_{C-F} = 320.5 Hz, 2C, C⁷), 119.8 (2C, C⁶), 120.6 (2C, C²), 122.4 (2C, C⁵), 129.1 (2C, C³), 140.2 (2C, C^{1/8}), 140.3 (2C, C^{1/4/8}), 152.7 (2C, C^{1/4/8}); ¹⁹F-NMR (DMSO-d₆, 470.59 MHz, 300 K): δ = -74.1; HR-MS (EI⁺): m/z calc. for ([M]⁺, [C₂₄H₂₆O₁₀N₂F₆S₂]⁺): 680.0928, found: 680.0927; IR (FT-ATR): ν (cm⁻¹) = 3305, 1702, 1612, 1590, 1537, 1500, 1479, 1423, 1409, 1393, 1371, 1308, 1271, 1247, 1212, 1151, 1131, 1101, 1065, 1027, 881, 865, 832, 777, 758, 735, 696.

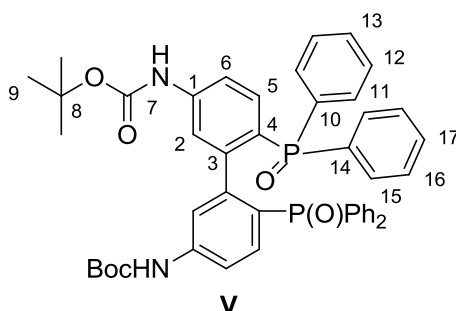
1.2.5. Diphenylphosphine oxide



This is a known compound. It was prepared using a literature known procedure with modifications.^[3-5] Powdered K_2CO_3 (1.25 g, 9.06 mmol, 2.0 eq.) was suspended in ACN (5 mL) and $\text{Ph}_2\text{P}(\text{Cl})$ (1.00 g, 4.53 mmol, 1.0 eq.) was added. The reaction mixture was cooled with a water bath and H_2O (434 μL , 24.1 mmol, 5.3 eq.) was added dropwise. Stirring was continued for 4 h at room temperature. Subsequently, the reaction mixture was partitioned between DCM (40 mL) and H_2O (40 mL). The organic phase was separated and the aqueous phase extracted with DCM (40 mL). The combined organic phases were washed with sat. aq. NaHCO_3 solution (3x 40 mL) and dried over Na_2SO_4 . All volatiles were removed under reduced pressure. The resulting oil was dissolved in Et_2O , concentrated and cooled to -18°C over night upon which crystallisation was initiated.

White crystalline solid, 655 mg (72%); $^1\text{H-NMR}$ (CDCl_3 , 300.51 MHz, 300 K): $\delta = 7.47\text{-}7.62$ (m, 6H, H^{Ar}), $7.67\text{-}7.75$ (m, 4H, H^{Ar}), 8.09 (d, $^1J_{\text{H-P}} = 481.4$ Hz, 1H, P-H); $^{31}\text{P}\{^1\text{H}\}\text{-NMR}$ (CDCl_3 , 121.65 MHz, 300 K): $\delta = 21.7$ (s, P-H).

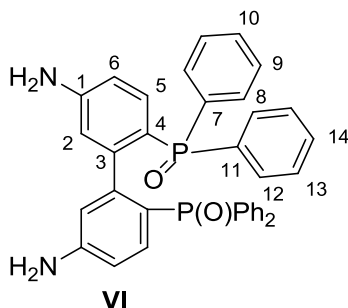
1.2.6. 5,5'-Bis[(*tert*-butoxycarbonyl)amino]-(1,1'-biphenyl)-2,2'-diyl-bis(diphenylphosphine oxide)



Compound **IV** (4.00 g, 5.88 mmol, 1.0 eq.), dppb (426 mg, 999 μ mol, 0.17 eq.), Pd₂(dba)₃ (377 mg, 411 μ mol, 0.07 eq.) and HP(O)Ph₂ (2.38 g, 11.8 mmol, 2.0 eq.) were dissolved in anhydrous, degassed DMSO (15 mL). Anhydrous Hünigs base (5.12 mL, 29.4 mmol, 5.0 eq.) was added and the resulting reaction mixture was stirred at 110°C over night. NMR analysis of a small sample showed predominant formation of mono cross-coupled product. Thus, dppb (276 mg, 647 μ mol, 0.11 eq.), Pd₂(dba)₃ (269 mg, 294 μ mol, 0.05 eq.) and HP(O)Ph₂ (1.19 g, 5.88 mmol, 1.0 eq.) were added and the reaction mixture was stirred over night. NMR analysis of a small sample now showed predominant formation of **V**. Subsequently, the reaction mixture was diluted with DCM (200 mL) and washed with H₂O (150 mL) and brine (2x 150 mL). The organic phase was dried over Na₂SO₄ and all volatiles were removed under reduced pressure. The crude product was purified by flash column chromatography (silica, hexanes:EtOAc 2:1 -> EtOAc -> hexanes:2-propanol 10:1 -> hexanes:2-propanol 6:1, R_f (hexanes:2-propanol 4:1) = 0.59).

Off-white solid, 1.21 g (26%); ¹H-NMR (DMSO-d₆, 500.13 MHz, 300 K): δ = 1.43 (s, 18H, H⁹), 6.97 (dd, ³J_{H-P} = 13.1 Hz, ³J_{H-H} = 8.6 Hz, 2H, H⁵), 7.03 (m, 2H, H²), 7.15 (m, ³J_{H-H} = 8.6 Hz, 2H, H⁶), 7.32-7.37 (m, 4H, H^{11/12/13/15/16/17}), 7.40-7.48 (m, 6H, H^{11/12/13/15/16/17}), 7.50-7.61 (m, 10H, H^{11/12/13/15/16/17}), 9.38 (s, 2H, NH); ¹³C{¹H}-NMR (DMSO-d₆, 125.76 MHz, 300 K): δ = 28.0 (6C, C⁹), 79.4 (2C, C⁸), 116.0 (d, ³J_{C-P} = 12.1 Hz, 2C, C⁶), 120.7 (d, ³J_{C-P} = 11.0 Hz, 2C, C²), 123.6 (d, ¹J_{C-P} = 107.5 Hz, 2C, C⁴), 127.9 (d, ^{2/3}J_{C-P} = 11.6 Hz, 4C, C^{11/12/15/16}), 128.2 (d, ^{2/3}J_{C-P} = 11.0 Hz, 4C, C^{11/12/15/16}), 131.0 (2C, C^{13/17}), 131.2 (2C, C^{13/17}), 131.4 (d, ^{2/3}J_{C-P} = 8.7 Hz, 4C, C^{11/12/15/16}), 131.8 (d, ³J_{C-P} = 9.8 Hz, 4C, C^{11/12/15/16}), 133.6 (d, ²J_{C-P} = 12.7 Hz, 2C, C⁵), 134.4 (d, ¹J_{C-P} = 103.5 Hz, 2C, C^{10/14}), 134.8 (d, ¹J_{C-P} = 101.1 Hz, 2C, C^{10/14}), 141.0 (b, 2C, C¹), 145.3 (b, 2C, C³), 152.2 (2C, C⁷); ³¹P{¹H}-NMR (DMSO-d₆, 121.65 MHz, 300 K): δ = 26.2; HR-MS (ESI⁺): m/z calc. for ([M+H]⁺, [C₄₆H₄₇O₆N₂P₂]⁺): 785.2904, found: 785.2908; IR (FT-ATR): ν (cm⁻¹) = 2976, 1720, 1580, 1526, 1485, 1437, 1414, 1391, 1366, 1315, 1275, 1232, 1154, 1115, 1072, 1048, 1027, 998, 876, 839, 745, 720, 693.

1.2.7. 5,5'-Diamino-(1,1'-biphenyl)-2,2'-diyl bis(diphenylphosphine oxide)

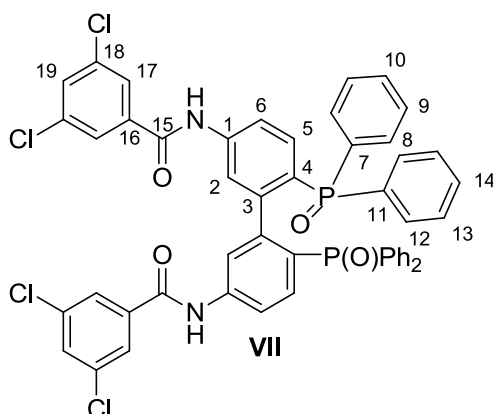


Compound **V** (843 mg, 1.07 mmol, 1.0 eq.) was suspended in 2-propanol (4 mL) and hydrogen chloride (5M in 2-propanol, 10.7 mL, 53.7 mmol, 50.0 eq.) was added. The reaction mixture was stirred over night. Subsequently, all volatiles were removed under reduced pressure and the residue was re-suspended in 2-propanol (2 mL). EtOAc (20 mL) was added and the product precipitated. The supernatant solution was removed via filter canula and the hydrogen chloride salt of the product ($M \cdot 2HCl$) was dried *in vacuo*.

Isolation of the free amine: The hydrogen chloride salt was partitioned between DCM and H_2O . The aqueous phase was adjusted to pH = 8-9 with Na_2CO_3 under vigorous stirring. The organic phase was separated and the aqueous phase extracted with DCM four times. The organic phases were dried over Na_2SO_4 and all volatiles were removed under reduced pressure.

White solid, 654 mg ($M \cdot 2HCl$, 93 %), NMR analysis was performed with the free amine: **1H -NMR** (DMSO- d_6 , 500.13 MHz, 300 K): δ = 5.23 (bs, 4H, NH_2), 5.98 (m, 2H, H^2), 6.23 (m, 2H, H^6), 6.67 (dd, $^3J_{H-P}$ = 13.4 Hz, $^3J_{H-H}$ = 8.5 Hz, 2H, H^5), 7.29-7.39 (m, 6H, $H^{8/9/10/12/13/14}$), 7.46-7.64 (m, 14H, $H^{8/9/10/12/13/14}$); **$^{13}C\{^1H\}$ -NMR** (DMSO- d_6 , 125.76 MHz, 300 K): δ = 111.2 (d, $^3J_{C-P}$ = 13.6 Hz, 2C, C^6), 115.5 (d, $^1J_{C-P}$ = 114.5 Hz, 2C, C^4), 117.1 (d, $^3J_{C-P}$ = 10.7 Hz, 2C, C^2), 127.6 (d, $^{2/3}J_{C-P}$ = 11.8 Hz, 4C, $C^{8/9/12/13}$), 128.2 (d, $^{2/3}J_{C-P}$ = 11.5 Hz, 4C, $C^{8/9/12/13}$), 130.4 (d, $^4J_{C-P}$ = 2.2 Hz, 2C, $C^{10/14}$), 130.9 (d, $^4J_{C-P}$ = 2.0 Hz, 2C, $C^{10/14}$), 131.3 (d, $^{2/3}J_{C-P}$ = 9.1 Hz, 4C, $C^{8/9/12/13}$), 131.6 (d, $^{2/3}J_{C-P}$ = 9.4 Hz, 4C, $C^{8/9/12/13}$), 134.6 (d, $^2J_{C-P}$ = 13.6 Hz, 2C, C^5), 135.7 (d, $^1J_{C-P}$ = 102.7 Hz, 2C, $C^{7/11}$), 136.5 (d, $^1J_{C-P}$ = 102.0 Hz, 2C, $C^{7/11}$), 146.1 (m, 2C, C^3), 150.0 (2C, C^1); **$^{31}P\{^1H\}$ -NMR** (DMSO- d_6 , 202.46 MHz, 295 K): δ = 26.1; **HR-MS** (ESI $^+$): m/z calc. for ($[M+H]^+$, $[C_{36}H_{31}N_2O_2P_2]^+$): 585.1855, found: 585.1860; **IR** (FT-ATR): ν (cm^{-1}) = 2563, 1590, 1526, 1483, 1436, 1314, 1246, 1161, 1116, 1026, 997, 883, 828, 742, 722, 692.

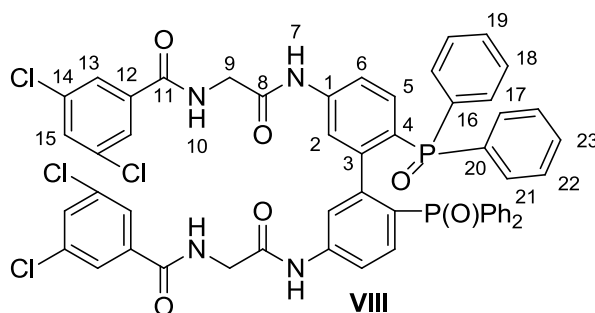
1.2.8. 5,5'-Bis(3,5-dichlorobenzoylamino)-BIPHEP(O)



Compound **VI** (300 mg, 0.513 mmol, 1.0 eq.) was dissolved in anhydrous DCM (4 mL) and anhydrous pyridine (250 μ L, 3.08 mmol, 6.0 eq.) was added. Subsequently, the reaction mixture was cooled to 0°C and 3,5-dichlorobenzoylchloride (269 mg, 1.28 mmol, 2.5 eq.) was added. Stirring was continued for 1 h at room temperature. The reaction mixture was diluted with DCM (100 mL) and washed with hydrochloric acid (1M, 100 mL), brine (100 mL) and aqueous sodium hydroxide solution (1M, 2x 100 mL). The organic phase was dried over Na_2SO_4 and all volatiles were removed under reduced pressure.

White solid, 440 mg (92%), $^1\text{H-NMR}$ (DMSO- d_6 , 500.13 MHz, 300 K): δ = 7.13 (m, 2H, H^5), 7.27 (m, 2H, H^2), 7.37 (m, 4H, $\text{H}^{8/9/10/12/13/14}$), 7.43-7.48 (m, 8H, $\text{H}^{8/9/10/12/13/14}$), 7.58-7.68 (m, 10H, $\text{H}^{6,8/9/10/12/13/14}$), 7.88 (d, $^4J_{\text{H-H}} = 1.9$ Hz, 4H, H^{17}), 7.91 (t, $^4J_{\text{H-H}} = 1.9$ Hz, 2H, H^{19}), 10.37 (bs, 2H, NH); $^{13}\text{C}\{^1\text{H}\}\text{-NMR}$ (DMSO- d_6 , 125.77 MHz, 300 K): δ = 118.2 (d, $^3J_{\text{C-P}} = 11.4$ Hz, 2C, C^6), 123.1 (d, $^3J_{\text{C-P}} = 11.0$ Hz, 2C, C^2), 126.3 (d, $^1J_{\text{C-P}} = 105.0$ Hz, 2C, C^4), 126.5 (4C, C^{17}), 128.0 (d, $^{2/3}J_{\text{C-P}} = 11.7$ Hz, 4C, $\text{C}^{8/9/12/13}$), 128.4 (d, $^{2/3}J_{\text{C-P}} = 11.5$ Hz, 4C, $\text{C}^{8/9/12/13}$), 131.2 (6C, $\text{C}^{10,14,19}$), 131.4 (d, $^{2/3}J_{\text{C-P}} = 9.3$ Hz, 4C, $\text{C}^{8/9/12/13}$), 131.9 (d, $^{2/3}J_{\text{C-P}} = 9.4$ Hz, 4C, $\text{C}^{8/9/12/13}$), 133.7 (d, $^1J_{\text{C-P}} = 103.1$ Hz, 2C, $\text{C}^{7/11}$), 133.9 (d, $^2J_{\text{C-P}} = 13.1$ Hz, 2C, C^5), 134.4 (4C, C^{18}), 134.7 (d, $^1J_{\text{C-P}} = 102.0$ Hz, 2C, $\text{C}^{7/11}$), 137.7 (2C, C^{16}), 140.0 (d, $^4J_{\text{C-P}} = 2.6$ Hz, 2C, C^1), 144.6 (b, 2C, C^3), 162.6 (2C, C^{15}); $^{31}\text{P}\{^1\text{H}\}\text{-NMR}$ (DMSO- d_6 , 202.47 MHz, 300 K): δ = 25.8; **HR-MS** (ESI $^+$): m/z calc. for $([\text{M}+\text{H}]^+, [\text{C}_{50}\text{H}_{35}^{35}\text{Cl}_4\text{N}_2\text{O}_4\text{P}_2]^+)$: 929.0821, found: 929.0845; **IR** (FT-ATR): ν (cm^{-1}) = 3075, 1677, 1566, 1517, 1437, 1416, 1368, 1311, 1259, 1166, 1115, 1067, 1028, 998, 869, 828, 805, 747, 721, 693, 654.

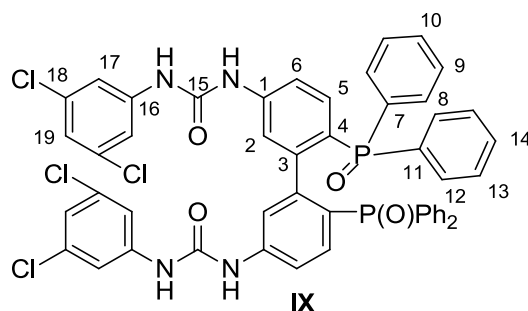
1.2.9. 5,5'-Bis[(3,5-dichlorobenzoylaminoacetyl)amino]-BIPHEP(O)



Compound **VI·2HCl** (600 mg, 913 μmol , 1.0 eq.) was suspended in anhydrous DCM (5 mL) and NaHCO_3 (767 mg, 9.13 mmol, 10.0 eq.) was added. In a second schlenk flask, *N*-3,5-dichlorobenzoyl glycine (453 mg, 1.83 mmol, 2.0 eq.) was suspended in anhydrous DCM (5 mL), EEDQ (451 mg, 1.83 mmol, 2.0 eq.) was added and the mixture was stirred until a homogeneous, colorless solution had formed (approx. 10 min). This solution was subsequently added to the amine. At intervals of two hours, four further solutions of activated acid were prepared as described above and added to the reaction mixture. The reaction mixture was then diluted with DCM (50 mL) and washed with hydrochloric acid (3M, 2x 50 mL), sat. aq. NaHCO_3 (2x 50 mL) and brine (50 mL). The organic phase was dried over Na_2SO_4 and all volatiles were removed under reduced pressure. The crude product was purified by flash column chromatography (silica, DCM \rightarrow MeOH:DCM 3:100 \rightarrow MeOH:DCM 10:100, R_f (MeOH:DCM 10:100) = 0.43).

Beige solid, 569 mg (60%), $^1\text{H-NMR}$ (DMSO- d_6 , 600.25 MHz, 300 K) δ = 4.00 (d, $^3J_{\text{H-H}} = 5.5$ Hz, 4H, H^9), 7.03 (m, 2H, H^2), 7.05 (m, $^3J_{\text{H-P}} = 13.2$ Hz, $^3J_{\text{H-H}} = 8.6$ Hz, 2H, H^5), 7.36 (m, 4H, $\text{H}^{17/18/19/21/22/23}$), 7.40-7.44 (m, 4H, $\text{H}^{6,17/18/19/21/22/23}$), 7.48 (m, 4H, $\text{H}^{17/18/19/21/22/23}$), 7.53 (m, 2H, $\text{H}^{17/18/19/21/22/23}$), 7.57-7.64 (m, 8H, $\text{H}^{17/18/19/21/22/23}$), 7.87 (t, $^4J_{\text{H-H}} = 1.7$ Hz, 2H, H^{15}), 7.92 (d, $^4J_{\text{H-H}} = 1.7$ Hz, 4H, H^{13}), 9.12 (bt, 2H, H^{10}), 10.04 (s, 2H, H^7); $^{13}\text{C}\{^1\text{H}\}$ -NMR (DMSO- d_6 , 150.95 MHz, 300 K): δ = 43.4 (2C, C^9), 117.3 (d, $^3J_{\text{C-P}} = 12.5$ Hz, 2C, C^6), 122.1 (d, $^3J_{\text{C-P}} = 10.0$ Hz, 2C, C^2), 125.4 (d, $^1J_{\text{C-P}} = 106.5$ Hz, 2C, C^4), 126.3 (4C, C^{13}), 128.1 (d, $^{2/3}J_{\text{C-P}} = 11.7$ Hz, 4C, $\text{C}^{17/18/21/22}$), 128.5 (d, $^{2/3}J_{\text{C-P}} = 11.5$ Hz, 4C, $\text{C}^{17/18/21/22}$), 131.0 (2C, C^{15}), 131.3 (2C, $\text{C}^{19/23}$), 131.4 (d, $^{2/3}J_{\text{C-P}} = 9.0$ Hz, 4C, $\text{C}^{17/18/21/22}$), 131.5 (2C, $\text{C}^{19/23}$), 132.0 (d, $^{2/3}J_{\text{C-P}} = 9.5$ Hz, 4C, $\text{C}^{17/18/21/22}$), 133.9 (d, $^2J_{\text{C-P}} = 13.5$ Hz, 2C, C^5), 133.9 (d, $^1J_{\text{C-P}} = 103.0$ Hz, 2C, $\text{C}^{16/20}$), 134.5 (4C, C^{14}), 134.6 (d, $^1J_{\text{C-P}} = 101.7$ Hz, 2C, $\text{C}^{16/20}$), 137.2 (2C, C^{12}), 140.2 (2C, C^1), 144.9 (m, 2C, C^3), 164.1 (2C, C^{11}), 167.6 (2C, C^8); $^{31}\text{P}\{^1\text{H}\}$ -NMR (DMSO- d_6 , 243.00 MHz, 300 K): δ = 28.7; **HR-MS** (ESI $^+$): m/z calc. for $([\text{M}+\text{H}]^+)$, $[\text{C}_{54}\text{H}_{41}^{35}\text{Cl}_4\text{N}_4\text{O}_6\text{P}_2]^+$: 1043.1250, found: 1043.1265; **IR** (FT-ATR): ν (cm^{-1}) = 3241, 3055, 2873, 1653, 1583, 1565, 1517, 1508, 1436, 1415, 1374, 1303, 1288, 1231, 1173, 1114, 1069, 1027, 1010, 997, 866, 828, 802, 692, 666.

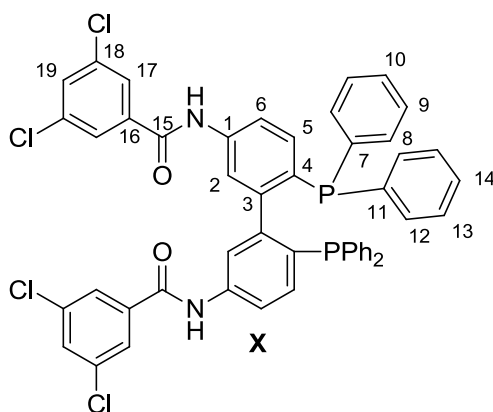
1.2.10.5,5'-Bis(3,5-Dichlorophenylureylene)-BIPHEP(O)



Compound **VI** (335 mg, 573 μmol , 1.0 eq.) was dissolved in anhydrous DCM (5 mL) and a solution of 3,5-dichlorophenyl isocyanate (323 mg, 1.72 mmol, 3.0 eq.) in anhydrous DCM (4 mL) was added dropwise. The resulting reaction mixture was stirred over night at room temperature. Subsequently, the precipitate formed during reaction progress was removed via filtration over celite. All volatiles were removed under reduced pressure and the crude product was purified by flash column chromatography (neutral alumina, hexanes:2-propanol 20:1 \rightarrow 2:1, R_f (hexanes:2-propanol 4:1) = 0.48).

White solid, 284 mg (52%), $^1\text{H-NMR}$ (DMSO- d_6 , 600.25 MHz, 300 K): δ = 7.01 (m, 2H, H^5), 7.15-7.19 (m, 6H, $\text{H}^{2,6,19}$), 7.37 (m, 4H, $\text{H}^{8/9/12/13}$), 7.41-7.49 (m, 8H, $\text{H}^{8/9/10/12/13/14}$), 7.49 (d, $^4J_{\text{H-H}} = 1.8$ Hz, 4H, H^{17}), 7.58-7.65 (m, 8H, $\text{H}^{8/9/10/12/13/14}$), 8.93 (s, 2H, NH), 9.07 (s, 2H, NH); $^{13}\text{C}\{^1\text{H}\}\text{-NMR}$ (DMSO- d_6 , 150.95 MHz, 300 K): δ = 116.3 (d, $^3J_{\text{C-P}} = 12.5$ Hz, 2C, $\text{C}^{2/6}$), 116.4 (4C, C^{17}), 121.1 (2C, C^{19}), 121.6 (d, $^3J_{\text{C-P}} = 9.2$ Hz, 2C, $\text{C}^{2/6}$), 123.6 (d, $^1J_{\text{C-P}} = 107.2$ Hz, 2C, C^4), 128.0 (d, $^{2/3}J_{\text{C-P}} = 11.7$ Hz, 4C, $\text{C}^{8/9/12/13}$), 128.4 (d, $^{2/3}J_{\text{C-P}} = 11.7$ Hz, 4C, $\text{C}^{8/9/12/13}$), 131.1 (2C, $\text{C}^{10/14}$), 131.3 (2C, $\text{C}^{10/14}$), 131.3 (d, $^{2/3}J_{\text{C-P}} = 8.8$ Hz, 4C, $\text{C}^{8/9/12/13}$), 131.7 (d, $^{2/3}J_{\text{C-P}} = 9.6$ Hz, 4C, $\text{C}^{8/9/12/13}$), 134.0 (d, $^1J_{\text{C-P}} = 103.4$ Hz, 2C, $\text{C}^{7/11}$), 134.1 (d, $^2J_{\text{C-P}} = 12.3$ Hz, 2C, C^5), 134.1 (4C, C^{18}), 134.7 (d, $^1J_{\text{C-P}} = 102.7$ Hz, 2C, $\text{C}^{7/11}$), 140.7 (d, $^4J_{\text{C-P}} = 2.1$ Hz, 2C, C^1), 142.0 (2C, C^{16}), 145.1 (b, 2C, C^3), 151.5 (2C, C^{15}); $^{31}\text{P}\{^1\text{H}\}\text{-NMR}$ (DMSO- d_6 , 202.47 MHz, 300 K): δ = 26.1; **HR-MS** (ESI $^+$): m/z calc. for $([\text{M}+\text{H}]^+)$, $[\text{C}_{50}\text{H}_{37}^{35}\text{Cl}_4\text{N}_4\text{O}_4\text{P}_2]^+$: 959.1039, found: 959.1043; **IR** (FT-ATR): ν (cm^{-1}) = 3057, 1715, 1578, 1524, 1447, 1436, 1410, 1373, 1300, 1270, 1240, 1182, 1113, 1047, 1027, 992, 933, 836, 786, 737, 716, 693, 668.

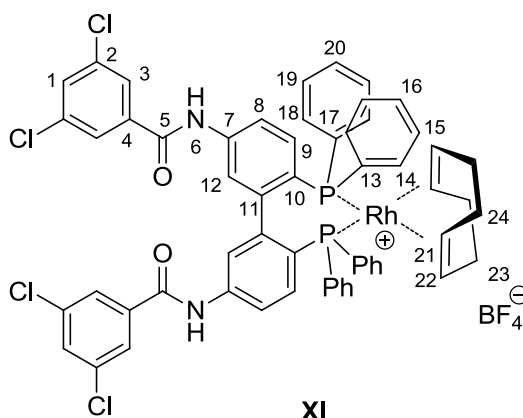
1.2.11.5,5'-Bis(3,5-dichlorobenzoylamino)-BIPHEP



Compound **VII** (429 mg, 461 μmol) was dissolved in PhSiH_3 (3.0 mL) and heated to 120°C for 3 d. Subsequently, all volatiles were removed under reduced pressure and the crude product was purified by flash column chromatography (silica, hexanes:EtOAc 10:1 \rightarrow 2:1, R_f (hexanes:EtOAc 2:1) = 0.85) followed by precipitation from $\text{Et}_2\text{O}/n$ -pentane.

White solid, 292 mg (70%); $^1\text{H-NMR}$ (DMSO- d_6 , 600.25 MHz, 300 K): δ = 7.02 (bm, 2H, H^5), 7.13 (m, 4H, $\text{H}^{8/9/12/13}$), 7.17 (m, 4H, $\text{H}^{8/9/12/13}$), 7.27-7.36 (m, 12H, $\text{H}^{8/9/10/12/13/14}$), 7.51 (bm, 2H, H^2), 7.70 (bm, 2H, H^6), 7.87 (bt, 2H, H^{19}), 7.88 (bd, 4H, H^{17}), 10.41 (s, 2H, NH); $^{13}\text{C}\{^1\text{H}\}$ -NMR (DMSO- d_6 , 125.77 MHz, 300 K): δ = 119.6 (2C, C^6), 122.0 (m, 2C, C^2), 126.5 (4C, C^{17}), 128.3 (2C, $\text{C}^{10/14}$), 128.5 (dd, $J_{\text{C-P}} = 2.7$ Hz, 4C, $\text{C}^{8/9/12/13}$), 128.5 (2C, $\text{C}^{10/14}$), 128.5 (dd, $J_{\text{C-P}} = 3.2$ Hz, 4C, $\text{C}^{8/9/12/13}$), 130.9 (dd, $J_{\text{C-P}} = 4.7$ Hz, $J_{\text{C-P}} = 3.1$ Hz, 2C, C^3), 131.0 (2C, C^{19}), 132.8 (dd, $J_{\text{C-P}} = 10.5$ Hz, 4C, $\text{C}^{8/9/12/13}$), 133.2 (dd, $J_{\text{C-P}} = 10.1$ Hz, 4C, $\text{C}^{8/9/12/13}$), 134.2 (b, 2C, C^5), 134.3 (4C, C^{18}), 137.0 (dd, $J_{\text{C-P}} = 6.9$ Hz, $J_{\text{C-P}} = 5.0$ Hz, 2C, $\text{C}^{7/11}$), 137.6 (dd, $J_{\text{C-P}} = 7.8$ Hz, $J_{\text{C-P}} = 6.0$ Hz, 2C, $\text{C}^{7/11}$), 137.9 (2C, C^{16}), 139.0 (2C, C^1), 147.6 (dd, $J_{\text{C-P}} = 19.2$ Hz, 2C, C^4), 162.7 (2C, C^{15}); $^{31}\text{P}\{^1\text{H}\}$ -NMR (DMSO- d_6 , 202.47 MHz, 300 K): δ = -16.8; HR-MS (ESI $^+$): m/z calc. for $([\text{M}+\text{H}]^+, [\text{C}_{50}\text{H}_{35}^{35}\text{Cl}_4\text{N}_2\text{O}_2\text{P}_2]^+)$: 897.0922, found: 897.0945; IR (FT-ATR): ν (cm^{-1}) = 3069, 1652, 1564, 1510, 1432, 1408, 1371, 1306, 1240, 1092, 1027, 998, 961, 866, 827, 804, 740, 693, 668.

1.2.12. [(X)Rh(COD)](BF₄)



A solution of compound **X** (89.6 mg, 0.10 mmol, 1.0 eq.) in degassed anhydrous DCM (2 mL) was slowly added to [Rh(COD)₂](BF₄) (40.6 mg, 0.10 mmol, 1.0 eq.) dissolved in degassed anhydrous DCM (3 mL). The resulting reaction mixture was stirred at room temperature for 1 h. Subsequently, all volatiles were removed under reduced pressure. The crude product was dissolved in a minimum amount of degassed anhydrous DCM and precipitated with degassed anhydrous *n*-pentane followed by separation of the supernatant solution via filter canula. This washing procedure was repeated twice.

Bright yellow-orange solid, 105 mg (88%); ¹H-NMR (CDCl₃, 500.13 MHz, 300 K): δ = 2.03-2.23 (m, 4H, H^{23/24}), 2.52-2.59 (m, 2H, H^{23/24}), 2.63-2.73 (m, 2H, H^{23/24}), 4.57 (m, 2H, H^{21/22}), 4.76 (m, 2H, H^{21/22}), 6.67 (m, 2H, H¹²), 7.26-7.35 (m, 6H, H^{14/15,16}), 7.38-7.43 (m, 6H, H^{9,18/19}), 7.48 (t, ⁴J_{H-H} = 1.8 Hz, 2H, H¹), 7.49-7.52 (m, 6H, H^{18/19,20}), 7.64 (m, 4H, H^{14/15}), 7.89 (dd, ³J_{H-H} = 8.9 Hz, ⁴J_{H-H} = 1.9 Hz, 2H, H⁸), 7.91 (d, ⁴J_{H-H} = 1.8 Hz, 4H, H³), 8.80 (s, 2H, NH, H⁶); ¹³C{¹H}-NMR (CDCl₃, 150.93 MHz, 300 K): δ = 27.7 (2C, C^{23/24}), 33.5 (2C, C^{23/24}), 98.0 (m, 2C, C^{21/22}), 101.7 (m, 2C, C^{21/22}), 119.4 (2C, C⁸), 123.4 (dd, J_{C-P} = 26.4, J_{C-P} = 22.9 Hz, 2C, C¹⁰), 126.3 (4C, C³), 127.2 (dd, J_{C-P} = 6.5 Hz, 2C, C¹²), 127.5 (dd, J_{C-P} = 23.1 Hz, J_{C-P} = 19.5 Hz, 2C, C¹⁷), 128.8 (dd, J_{C-P} = 4.4 Hz, 4C, C^{18/19}), 129.1 (dd, J_{C-P} = 5.1 Hz, 4C, C^{14/15}), 129.9 (dd, J_{C-P} = 25.7 Hz, J_{C-P} = 24.2 Hz, 2C, C¹³), 131.2 (2C, C²⁰), 131.5 (dd, J_{C-P} = 4.0 Hz, 2C, C⁹), 131.8 (2C, C¹⁶), 131.9 (2C, C¹), 133.8 (dd, J_{C-P} = 4.3 Hz, 4C, C^{18/19}), 135.7 (4C, C²), 136.3 (dd, J_{C-P} = 6.6 Hz, 4C, C^{14/15}), 136.9 (2C, C⁴), 141.1 (2C, C⁷), 144.5 (dd, J_{C-P} = 6.5 Hz, 2C, C¹¹), 163.3 (2C, C⁵); ³¹P{¹H}-NMR (CDCl₃, 202.46 MHz, 300 K): δ = 23.7 (d, ¹J_{P-Rh} = 145.1 Hz); HR-MS (ESI⁺): m/z calc. for ([M-(BF₄)])⁺, [C₅₈H₄₆N₂O₂P₂Rh³⁵Cl₄]⁺: 1107.0838, found 1107.0846; IR (FT-ATR): ν (cm⁻¹) 3331, 3074, 1678, 1565, 1515, 1478, 1435, 1376, 1306, 1254, 1237, 1053, 996, 867, 803, 741, 669.

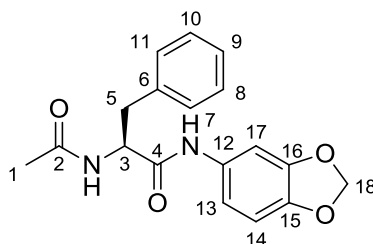
1.3. Phenylalanine Derivatives

(*S*)-Ac-Phe-OMe, (*S*)-Piperonyloyl-Phe-OMe^[6] and Ac-Phe-NHMe^[7] are known compounds and were prepared according to published protocols.

General procedure for the amide bond formation reaction of N-substituted (S)-phenylalanine with 3,4-(methylenedioxy)aniline:

EEDQ (1.05 eq.) was added to a solution of *N*-substituted (*S*)-phenylalanine derivative (1.00 eq.) in anhydrous THF. The resulting solution was stirred for 20 min at room temperature and subsequently 3,4-(methylenedioxy)aniline (1.00 eq.) was added. The reaction mixture was stirred for 2 h at room temperature. It then was diluted with DCM and washed with hydrochloric acid (3M) twice, aqueous diluted NaHCO₃ solution twice and H₂O. The organic phase was dried over Na₂SO₄ and all volatiles were removed under reduced pressure.

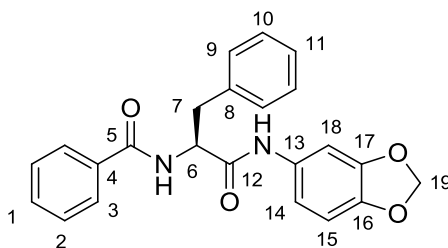
1.3.1. Compound 9



The reaction was performed according to the general procedure (2.39 mmol scale). The crude product was purified by flash column chromatography (silica, hexanes:EtOAc 1:1 -> 1:5, R_f (hexanes:EtOAc 1:1) = 0.35).

White solid, 187 mg (24%); ¹H-NMR (DMSO-d₆, 300.18 MHz, 300 K): δ = 1.79 (s, 3H, H¹), 2.77-3.03 (m, 2H, H⁵), 4.60 (m, 1H, H³), 5.97 (m, 2H, H¹⁸), 6.84 (d, ³J_{H-H} = 8.4 Hz, 1H, H¹⁴), 6.94 (dd, ³J_{H-H} = 8.4 Hz, ⁴J_{H-H} = 2.0 Hz, 1H, H¹³), 7.19 (m, 1H, H^{7/8/9/10/11}), 7.24-7.30 (m, 5H, H^{7,8,9,10,11,17}), 8.27 (d, ³J_{H-H} = 8.2 Hz, 1H, NH), 9.99 (s, 1H, NH); ¹³C{¹H}-NMR (DMSO-d₆, 75.49 MHz, 300 K): δ = 22.4 (C¹), 37.9 (C⁵), 54.8 (C³), 101.0 (C¹⁸), 101.5 (C^{7/8/10/11}), 108.0 (C¹⁴), 112.2 (C¹³), 126.4 (C⁹), 128.1 (2C, C^{7/8/10/11}), 129.2 (2C, C^{7/8/10/11}), 133.2 (C¹²), 137.7 (C⁶), 143.0 (C^{15/16}), 147.0 (C^{15/16}), 169.2 (C²), 170.0 (C⁴); HR-MS (ESI⁺): m/z calc. for ([2M+Na]⁺, [C₃₆H₃₆N₄O₈Na]⁺): 675.2425, found 675.2432.

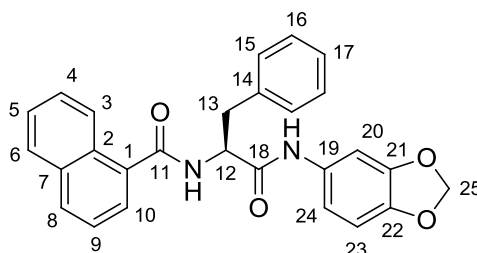
1.3.2. Compound 10



The reaction was performed according to the general procedure (1.85 mmol scale). The crude product was purified by flash column chromatography (neutral alumina, DCM:EtOH 100:1, R_f (DCM:EtOH 100:1) = 0.35).

White solid, 337 mg (47%); $^1\text{H-NMR}$ (DMSO- d_6 , 400.33 MHz, 300 K): δ = 3.05-3.17 (m, 2H, H⁷), 4.82 (m, 1H, H⁶), 5.98 (m, 2H, H¹⁹), 6.86 (d, $^3J_{\text{H-H}}$ = 8.4 Hz, 1H, H¹⁵), 6.99 (dd, $^3J_{\text{H-H}}$ = 8.4 Hz, $^4J_{\text{H-H}}$ = 2.0 Hz, 1H, H¹⁴), 7.18 (m, 1H, H¹¹), 7.28 (m, 2H, H^{9/10}), 7.31 (d, $^4J_{\text{H-H}}$ = 2.0 Hz, 1H, H¹⁸), 7.40 (m, 2H, H^{9/10}), 7.44 (m, 2H, H^{2/3}), 7.52 (m, 1H, H¹), 7.83 (m, 2H, H^{2/3}), 8.70 (d, $^3J_{\text{H-H}}$ = 8.1 Hz, 1H, NH), 10.10 (s, 1H, NH); $^{13}\text{C}\{^1\text{H}\}\text{-NMR}$ (DMSO- d_6 , 100.67 MHz, 300 K): δ = 37.2 (C⁷), 55.7 (C⁶), 100.9 (C¹⁹), 101.5 (C¹⁸), 108.0 (C¹⁵), 112.2 (C¹⁴), 126.3 (C¹¹), 127.4 (2C, C^{2/3}), 128.1 (2C, C^{9/10}), 128.2 (2C, C^{2/3}), 129.2 (2C, C^{9/10}), 131.3 (C¹), 133.2 (C¹³), 133.9 (C⁴), 138.1 (C⁸), 143.0 (C^{16/17}), 147.0 (C^{16/17}), 166.4 (C⁵), 170.0 (C¹²); **HR-MS (ESI⁺)**: m/z calc. for ([2M+H]⁺, [C₄₆H₄₁N₄O₈]⁺): 777.2919, found 777.2941.

1.3.3. Compound 11

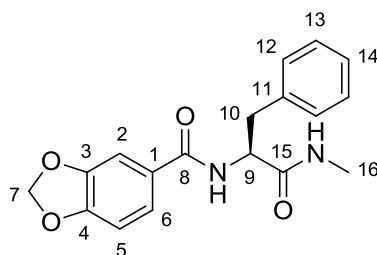


The reaction was performed according to the general procedure (1.57 mmol scale). The crude product was purified by flash column chromatography (silica, hexanes:EtOAc 2:1 -> EtOAc, R_f (hexanes:EtOAc 2:1) = 0.55).

White solid, 406 mg (59%); $^1\text{H-NMR}$ (DMSO- d_6 , 400.33 MHz, 300 K): δ = 2.98-3.21 (m, 2H, H¹³), 4.97 (m, 1H, H¹²), 6.00 (m, 2H, H²⁵), 6.89 (d, $^3J_{\text{H-H}}$ = 8.4 Hz, 1H, H²³), 7.04 (dd, $^3J_{\text{H-H}}$ = 8.4 Hz, $^4J_{\text{H-H}}$ = 2.0 Hz, 1H, H²⁴), 7.26 (m, 1H, H¹⁷), 7.30-7.36 (m, 3H, H^{15/16,20}), 7.39-7.43 (m, 2H, H^{15/16}), 7.43-7.48 (m, 2H, H^{4/5/9/10}), 7.49-7.54 (m, 2H, H^{3/4/5/6/8/9/10}), 7.86 (m, $^3J_{\text{H-H}}$ = 8.4 Hz, 1H, H^{3/6/8/10}), 7.94 (m, $^3J_{\text{H-H}}$ = 8.0 Hz,

1H, H^{3/6/8/10}), 7.98 (m, ³J_{H-H} = 8.0 Hz, 1H, H^{3/6/8/10}), 8.84 (d, ³J_{H-H} = 8.2 Hz, 1H, NH), 10.16 (s, 1H, NH); ¹³C{¹H}-NMR (DMSO-d₆, 100.67 MHz, 300 K): δ = 37.4 (C¹³), 55.4 (C¹²), 101.0 (C²⁵), 101.5 (C²⁰), 108.1 (C²³), 112.2 (C²⁴), 124.8 (C^{3/4/5/6/8/9/10}), 125.2 (C^{4/5/9/10}), 125.4 (C^{3/6/8/10}), 126.1 (C^{3/4/5/6/8/9/10}), 126.4 (C¹⁷), 126.5 (C^{4/5/9/10}), 128.0 (C^{3/6/8/10}), 128.1 (2C, C^{15/16}), 129.3 (2C, C^{15/16}), 129.7 (C^{1/2/7}), 129.7 (C^{3/6/8/10}), 133.0 (C^{1/2/7}), 133.3 (C¹⁹), 134.4 (C^{1/2/7}), 138.0 (C¹⁴), 143.0 (C^{21/22}), 147.1 (C^{21/22}), 168.6 (C¹), 169.9 (C¹⁸); **HR-MS (ESI⁺)**: m/z calc. for ([2M+Na]⁺, [C₅₄H₄₄N₄O₈Na]⁺): 899.3051, found 899.3038.

1.3.4. Compound 12



N-Piperonylphenylalanine methyl ester (300 mg, 917 μmol, 1.0 eq.) was dissolved in a solution of MeNH₂ in anhydrous EtOH (33%, 3.4 mL, 30 eq.). The reaction mixture was stirred for 2 h at room temperature upon which a white solid precipitated. All volatiles were removed under reduced pressure.

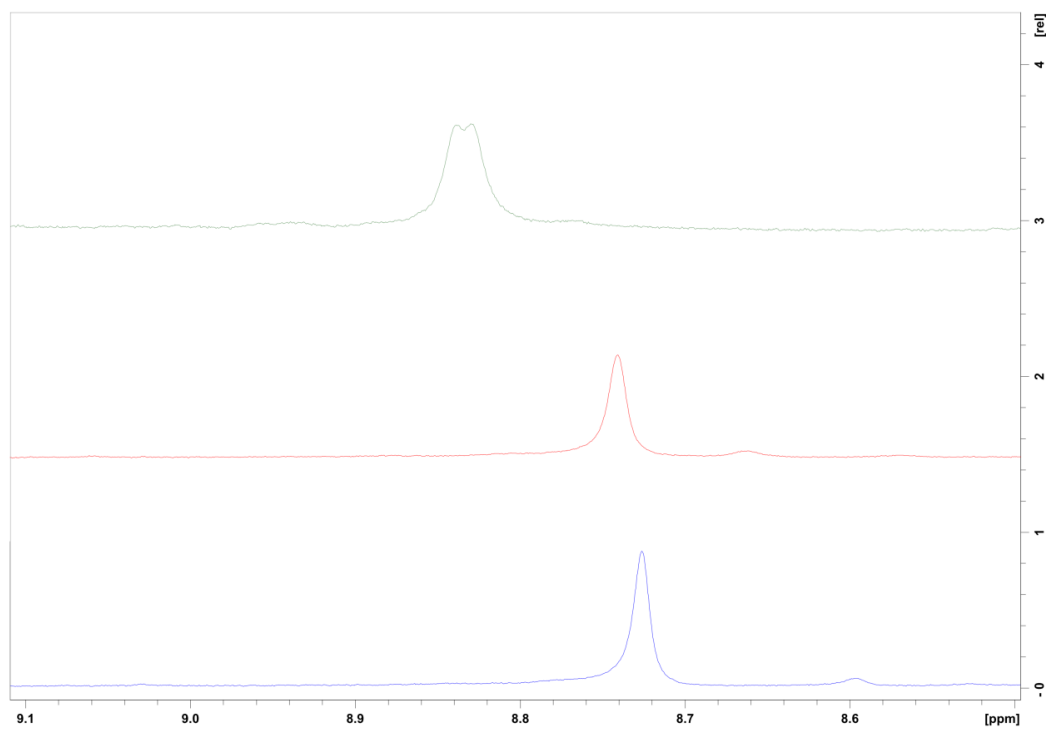
White solid, 299 mg (quantitative yield); ¹H-NMR (CDCl₃, 400.33 MHz, 300 K): δ = 2.74 (d, ³J_{H-H} = 4.3 Hz, 3H, H¹⁶), 3.09-3.28 (m, 2H, H¹⁰), 4.82 (bm, 1H, H⁹), 6.02 (s, 2H, H⁷), 6.80 (d, ³J_{H-H} = 8.0 Hz, 1H, H⁵), 7.20-7.32 (m, 7H, H^{2,6,12,13,14}), NH protons of the amide groups were not observed; ¹³C{¹H}-NMR (CDCl₃, 100.67 MHz, 300 K): δ = 26.5 (C¹⁶), 38.7 (C¹⁰), 55.5 (C⁹), 101.9 (C⁷), 107.9 (C^{2/14}), 108.2 (C⁵), 122.2 (C^{2/14}), 127.3 (C⁶), 127.7 (C¹), 128.9 (2C, C^{12/13}), 129.5 (2C, C^{12/13}), 136.8 (C¹¹), 148.2 (C^{3/4}), 151.0 (C^{3/4}), 167.0 (C⁸), 171.9 (C¹⁵); **HR-MS (ESI⁺)**: m/z calc. for ([2M+H]⁺, [C₃₆H₃₇N₄O₈]⁺): 653.2606, found 653.2582.

2. NMR Interaction Studies

Interaction studies were performed in anhydrous, degassed CDCl_3 using J-Young tubes at room temperature. The concentration of rhodium complex **6** was kept constant (6.7 mM) for all experiments. Spectra with varying equivalents of phenylalanine derivatives are depicted below.

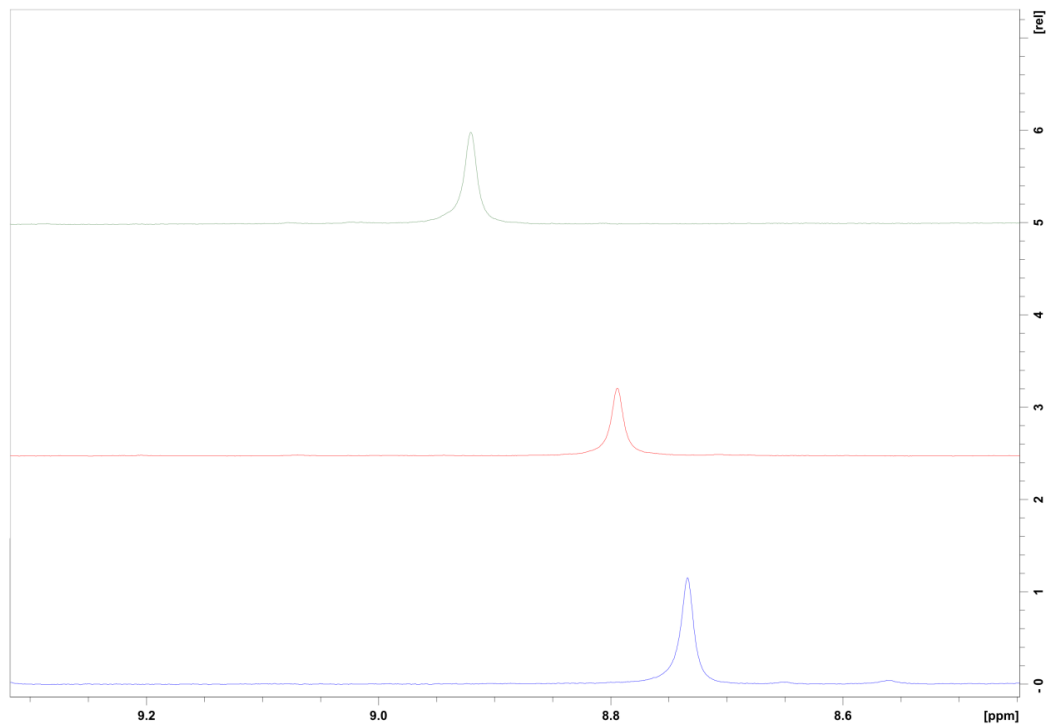
2.1. Complex **6** / (*S*)-Amidoester **7**

^1H -NMR spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide *NH* – region of the complex is depicted.



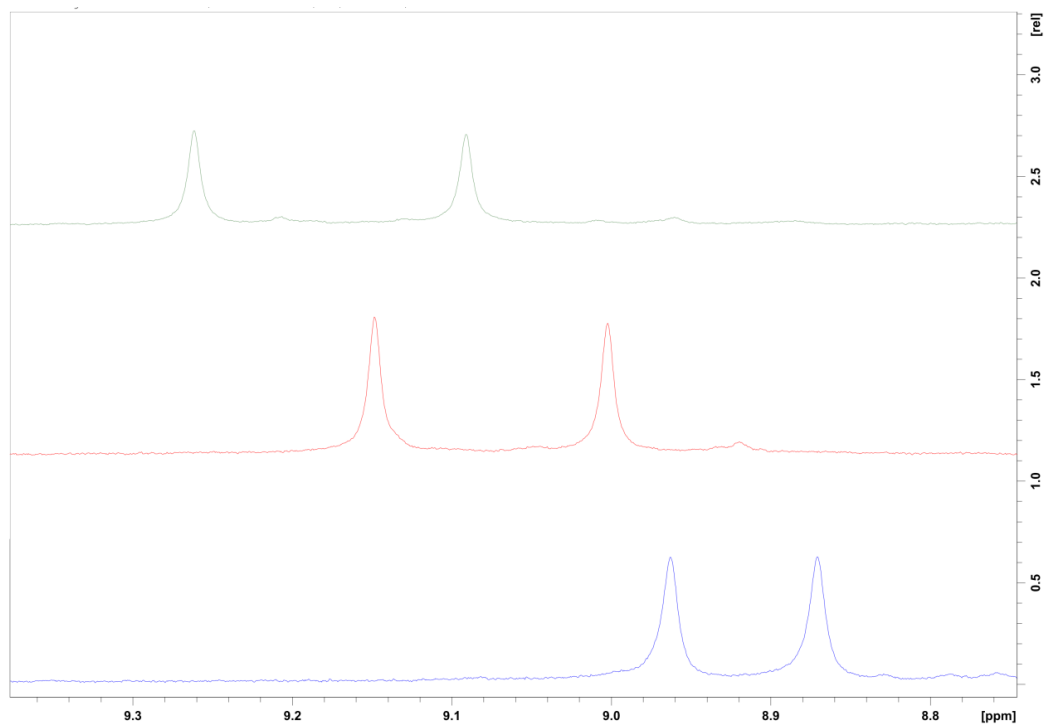
2.2. Complex 6 / (S)-Amidoester 8

$^1\text{H-NMR}$ spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide NH – region of the complex is depicted.



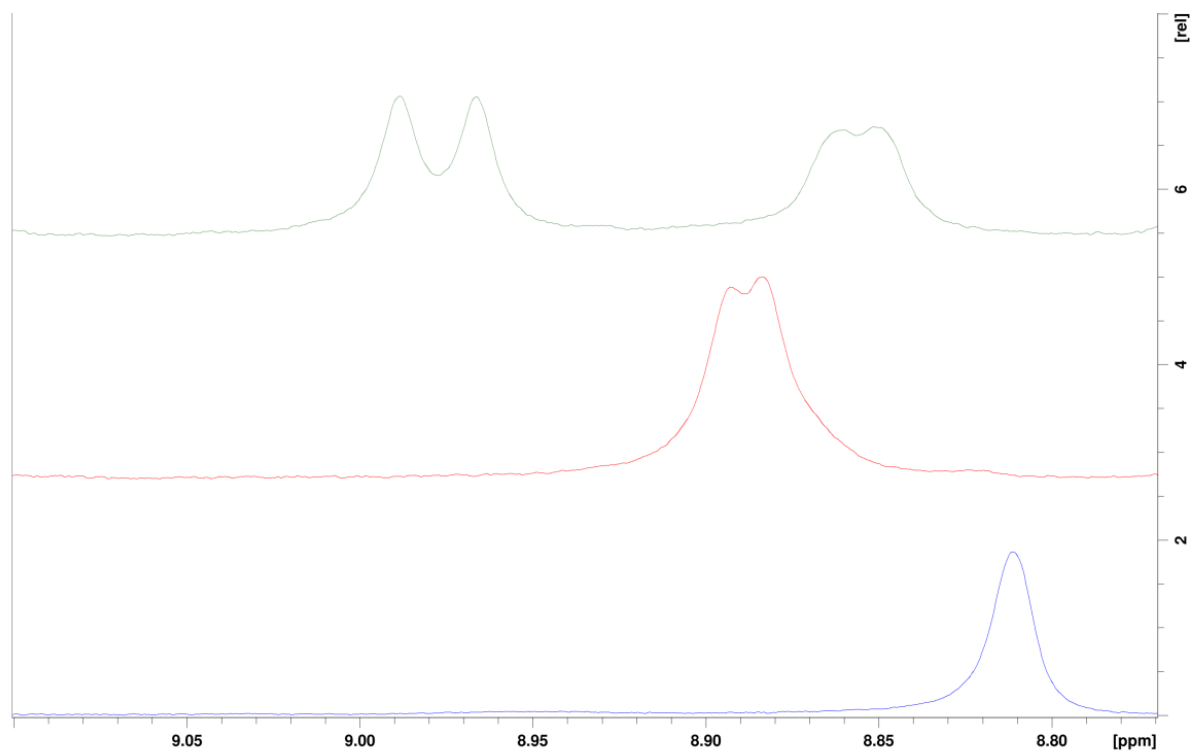
2.3. Complex 6 / (S)-Diamide 9

$^1\text{H-NMR}$ spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide NH – region of the complex is depicted.

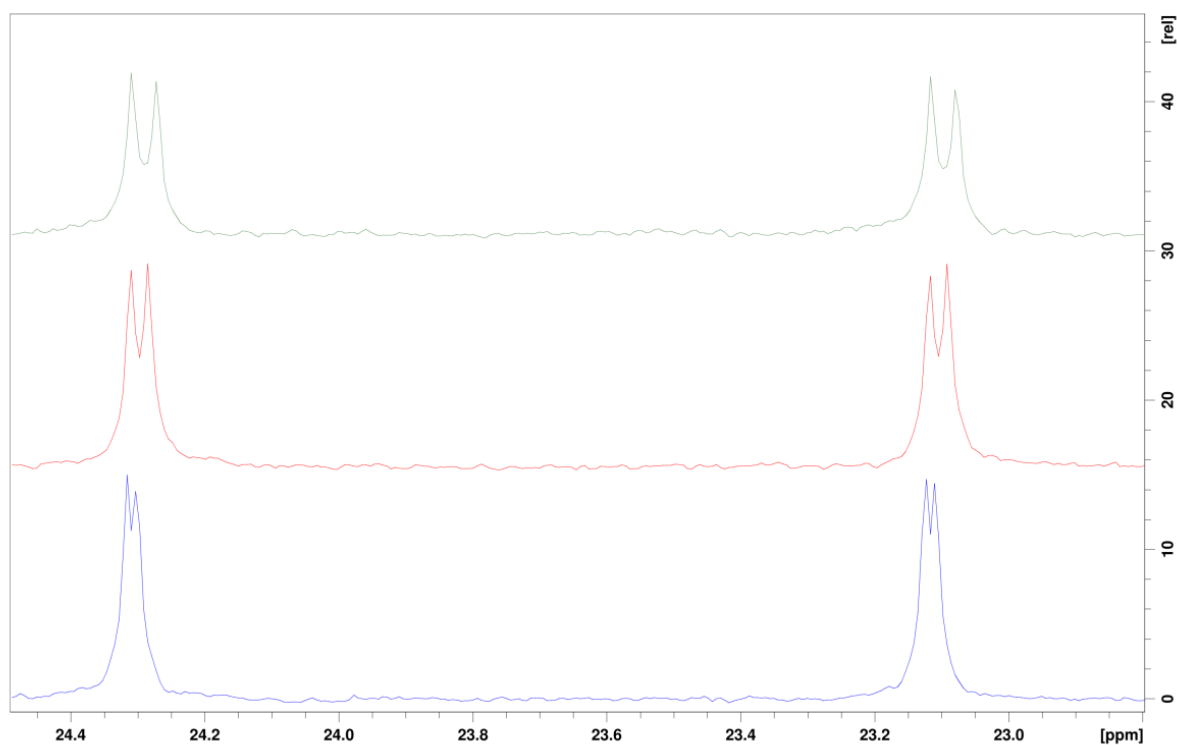


2.4. Complex 6 / (S)-Diamide 10

^1H -NMR spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide NH – region of the complex is depicted. The signal at 8.86 ppm in the green spectrum does not correspond to the NH protons.

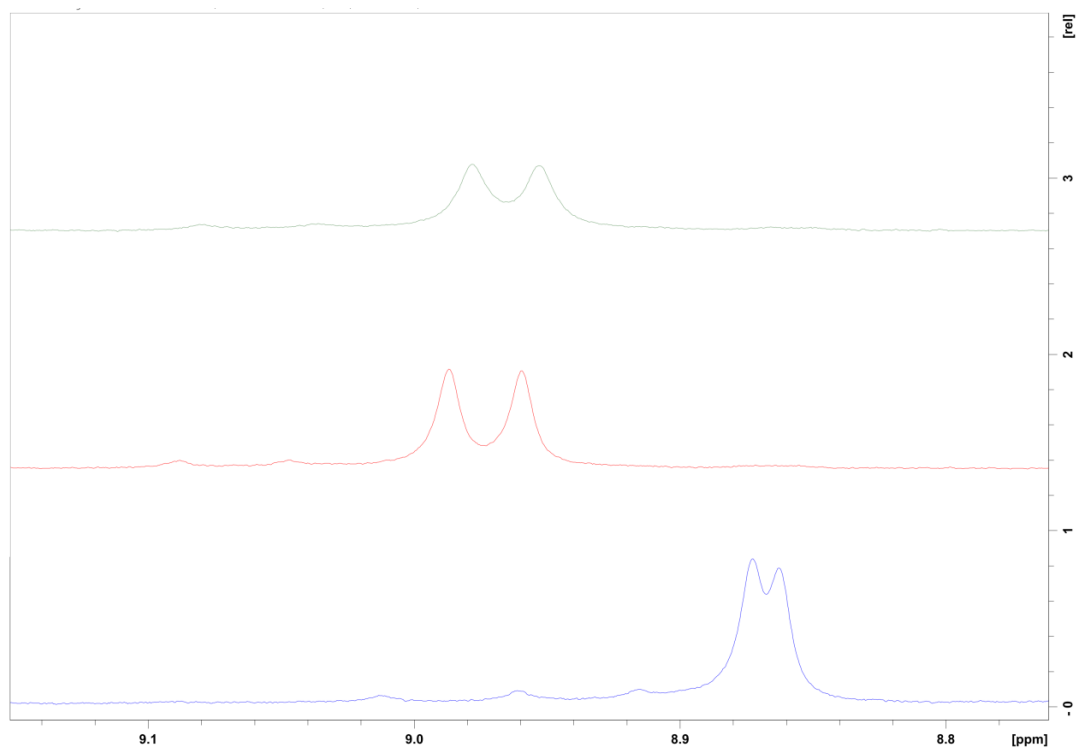


$^{31}\text{P}\{^1\text{H}\}$ -NMR with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The $^1J_{\text{P-Rh}}$ doublet is depicted.

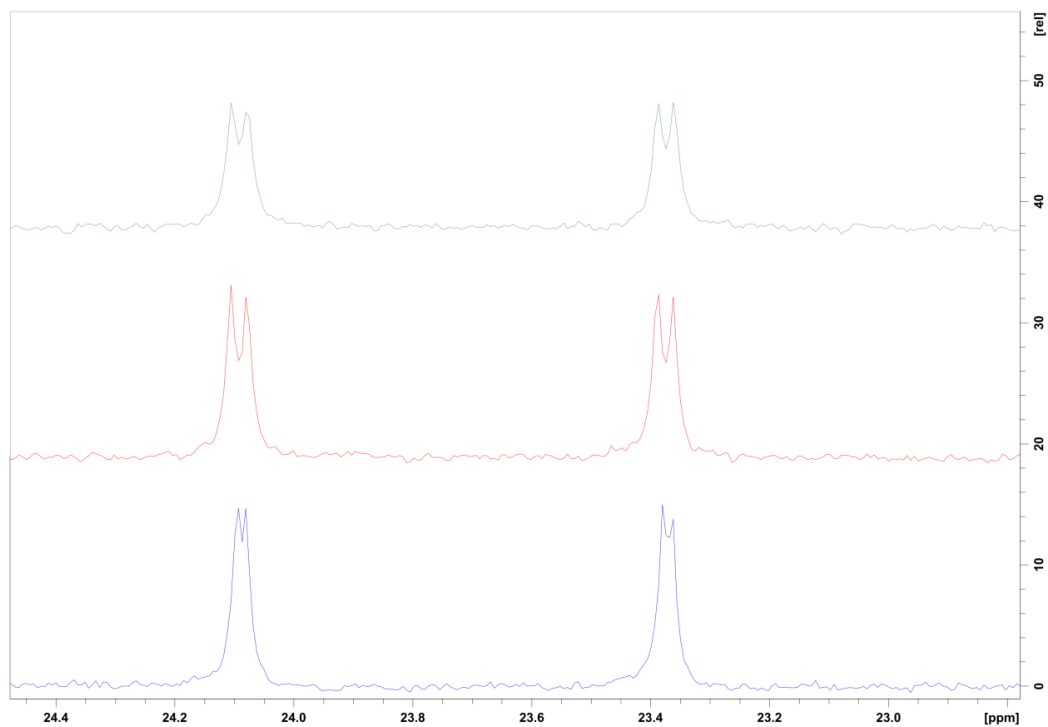


2.5. Complex 6 / (S)-Diamide 11

^1H -NMR spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide NH – region of the complex is depicted.

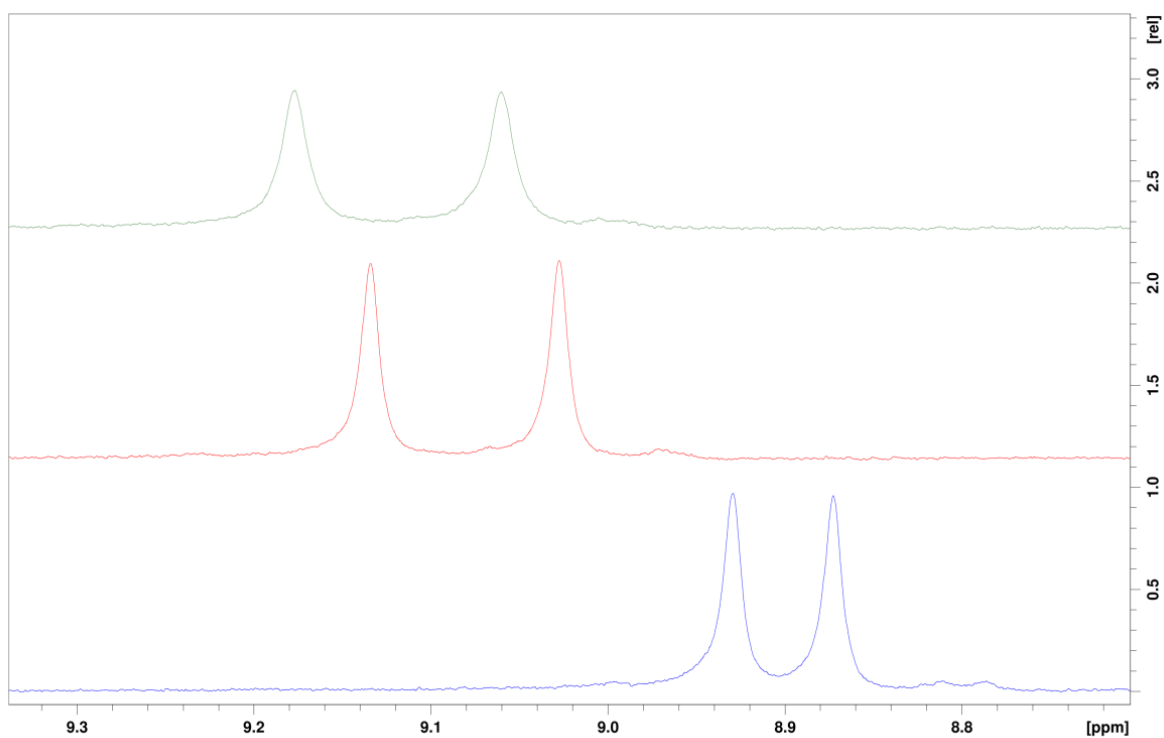


$^{31}\text{P}\{^1\text{H}\}$ -NMR with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The $^1J_{\text{P-RH}}$ doublet is depicted.

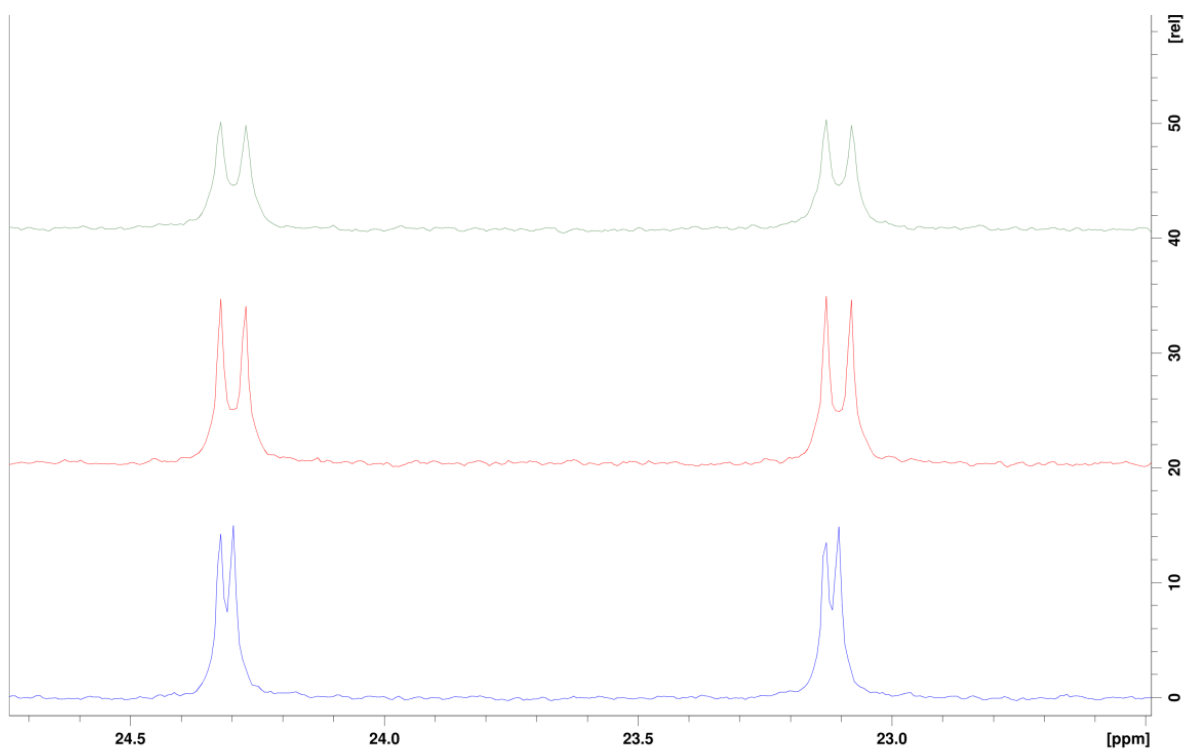


2.6. Complex 6 / (S)-Diamide 12

^1H -NMR spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide NH – region of the complex is depicted.

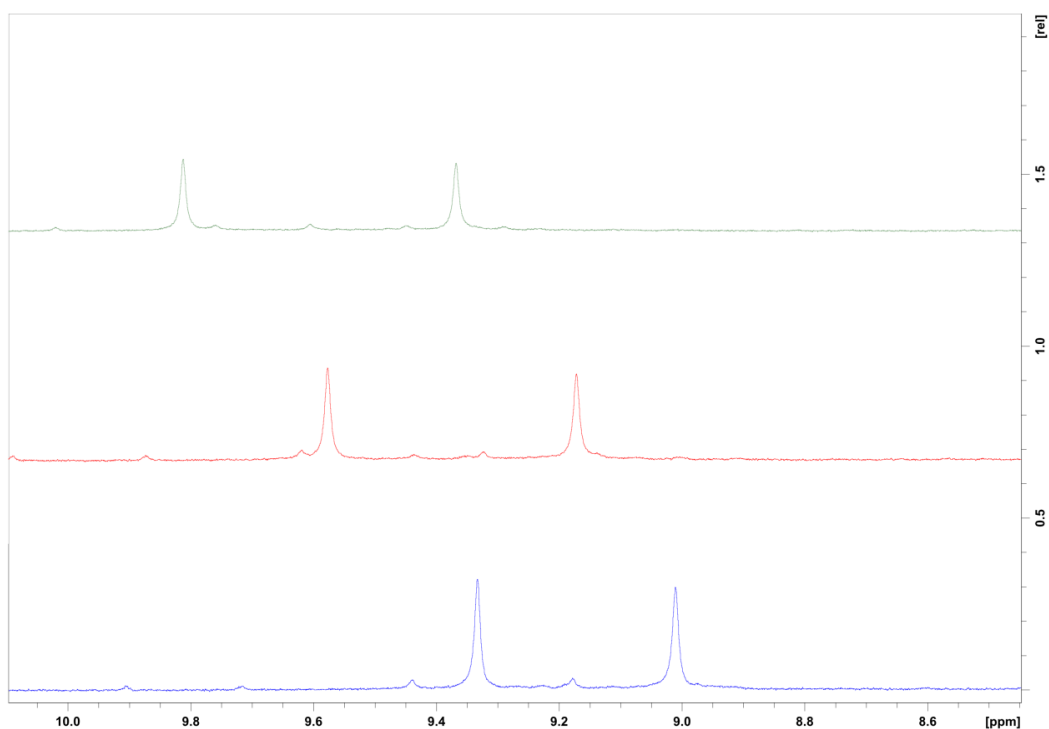


$^{31}\text{P}\{^1\text{H}\}$ -NMR with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The $^1J_{\text{P-Rh}}$ doublet is depicted.

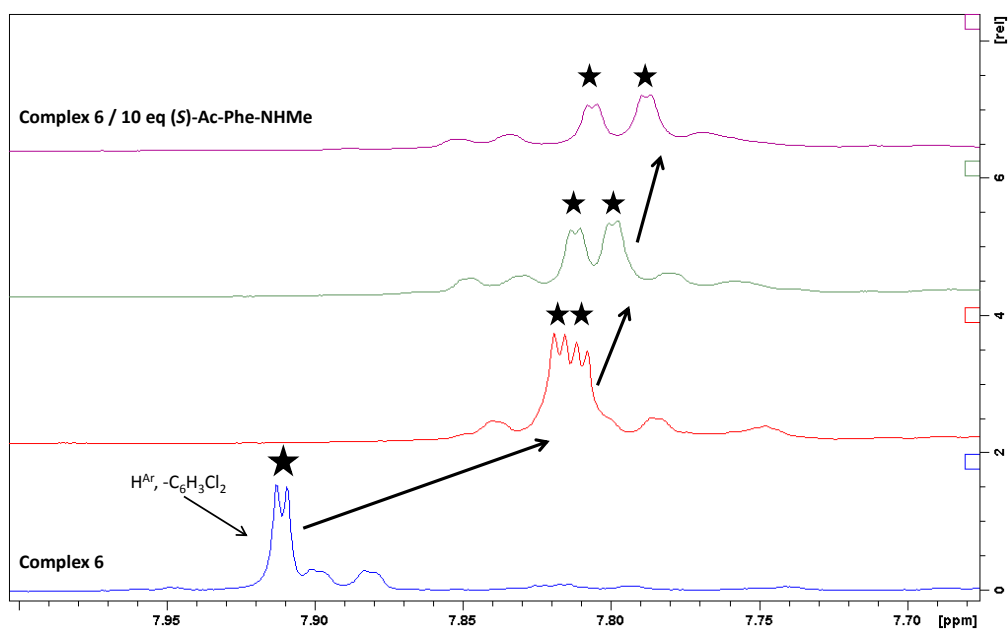


2.7. Complex 6 / (S)-Diamide 13

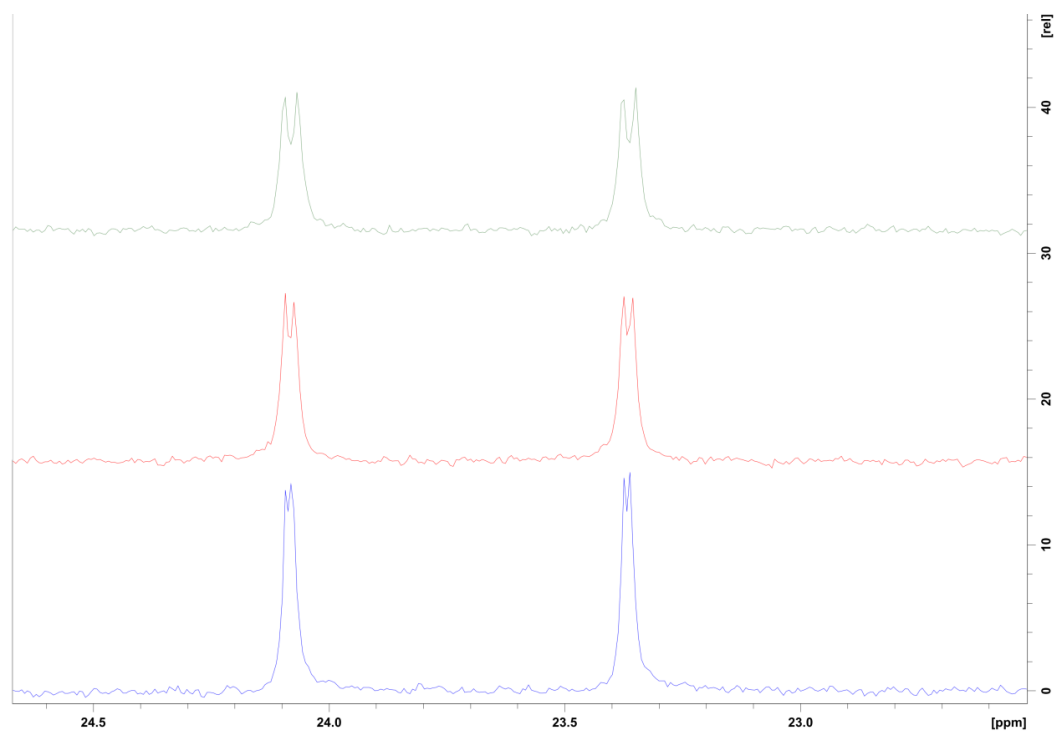
$^1\text{H-NMR}$ spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide NH – region of the complex is depicted.



$^1\text{H-NMR}$ spectra with various equivalents of phenylalanine derivative (0 eq – blue, 2 eq – red, 5 eq – green and 10 eq – purple). The doublet of the two equivalent protons of the $-\text{C}_6\text{H}_3\text{Cl}_2$ moiety is depicted.

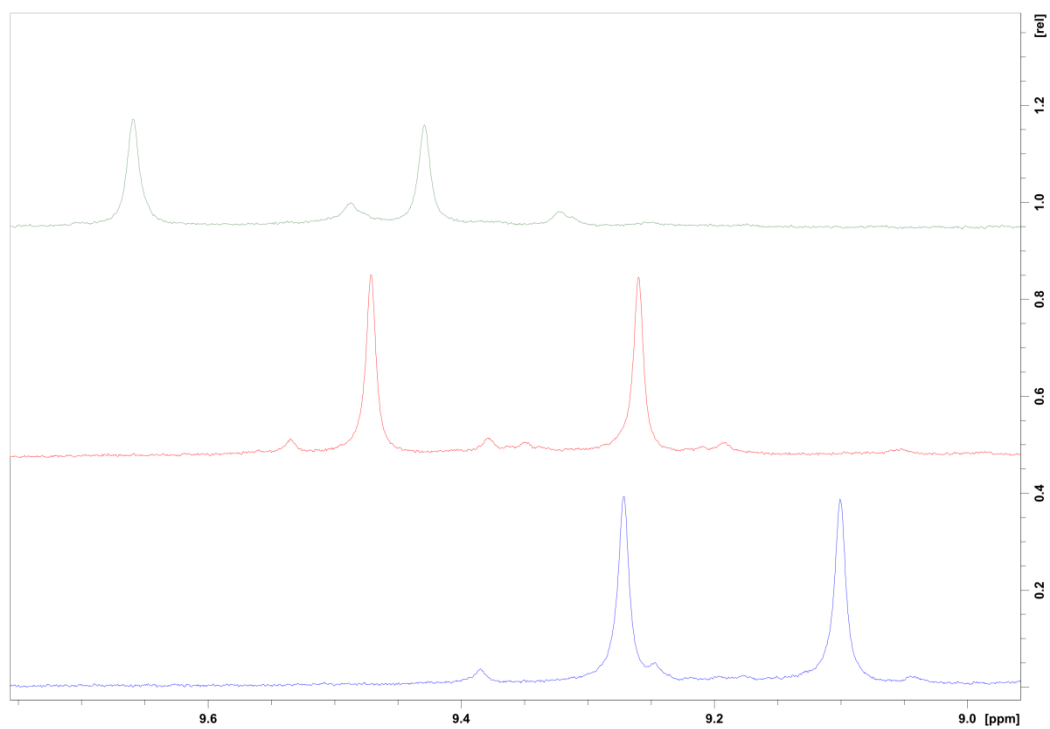


$^{31}\text{P}\{^1\text{H}\}$ -NMR with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The $^1J_{\text{P-RH}}$ doublet is depicted.



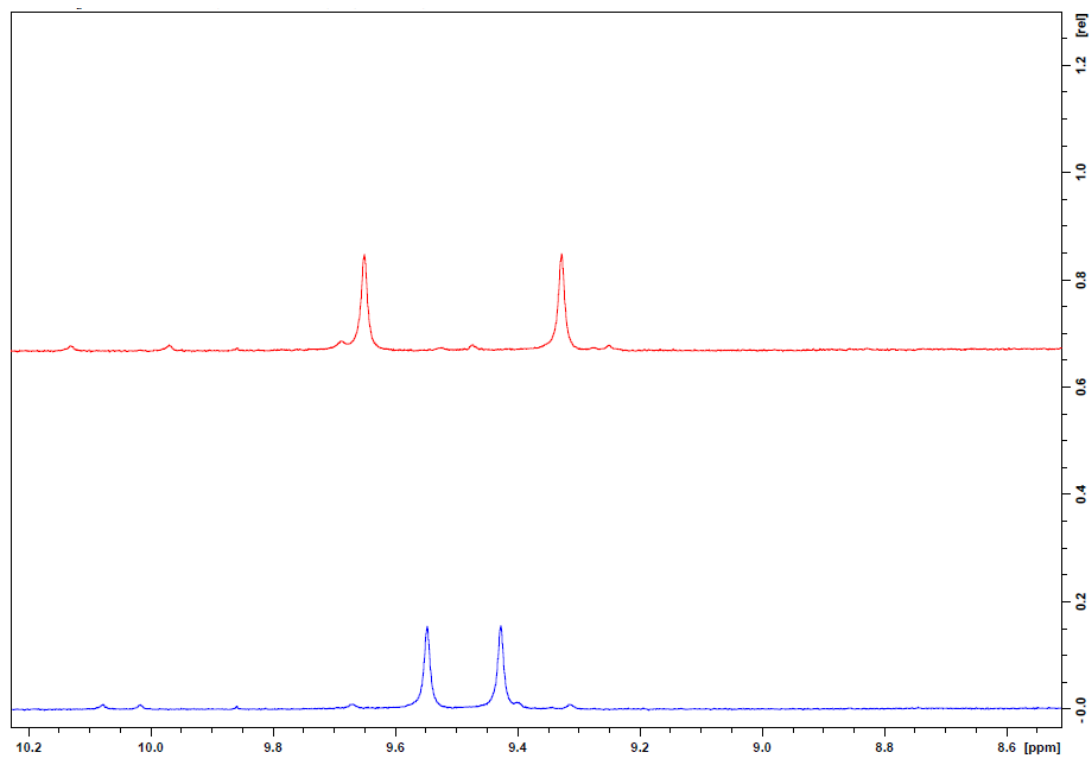
2.8. Complex 6 / (*S*)-Diamide 13 (50% *ee*)

¹H-NMR spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide NH – region of the complex is depicted.



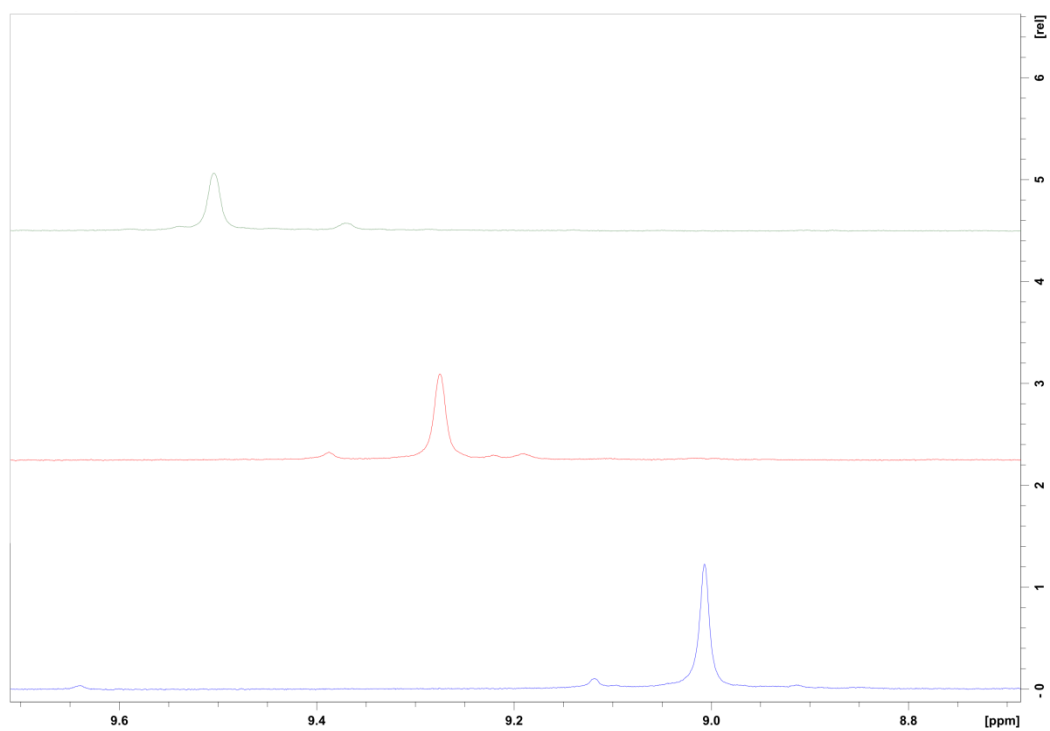
2.9. Complex 6 / (*S*)-Diamide 13 (25 and 75 % *ee*)

^1H -NMR spectra with 10 equivalents of phenylalanine derivative (25 % *ee* – blue, 75 % *ee* – red). The amide *NH* – region of the complex is depicted.

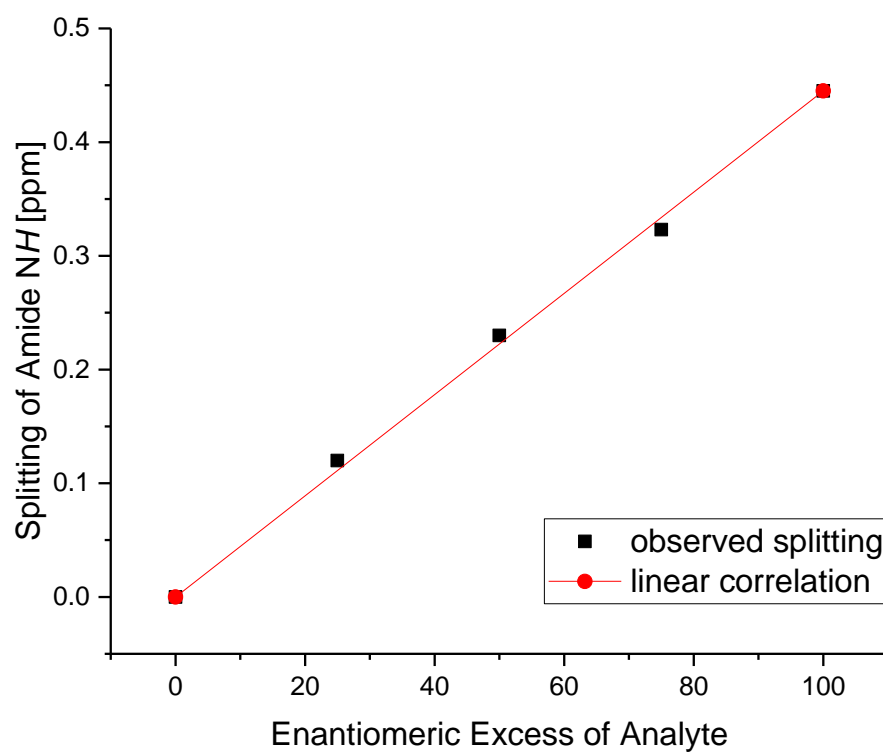


2.10. Complex 6 / *rac*-Diamide 13

^1H -NMR spectra with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The amide *NH* – region of the complex is depicted.

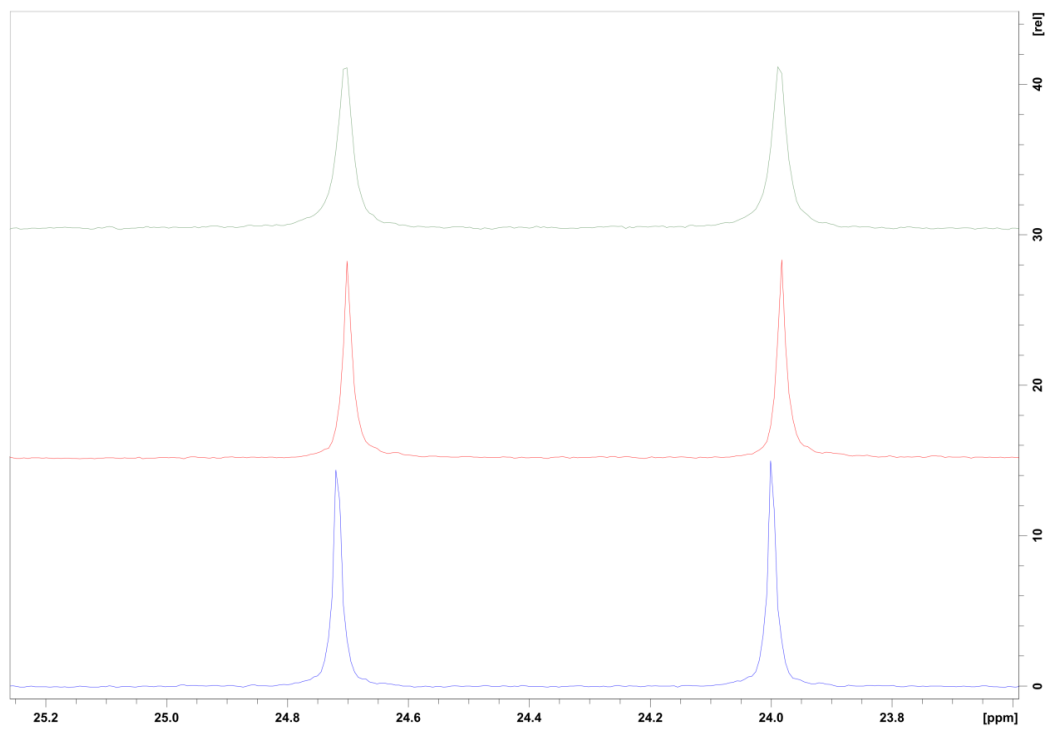


2.11. Linear Correlation of Splitting and Enantiomeric Excess of Analyte (Complex 6 / Ac-Phe-NHMe)



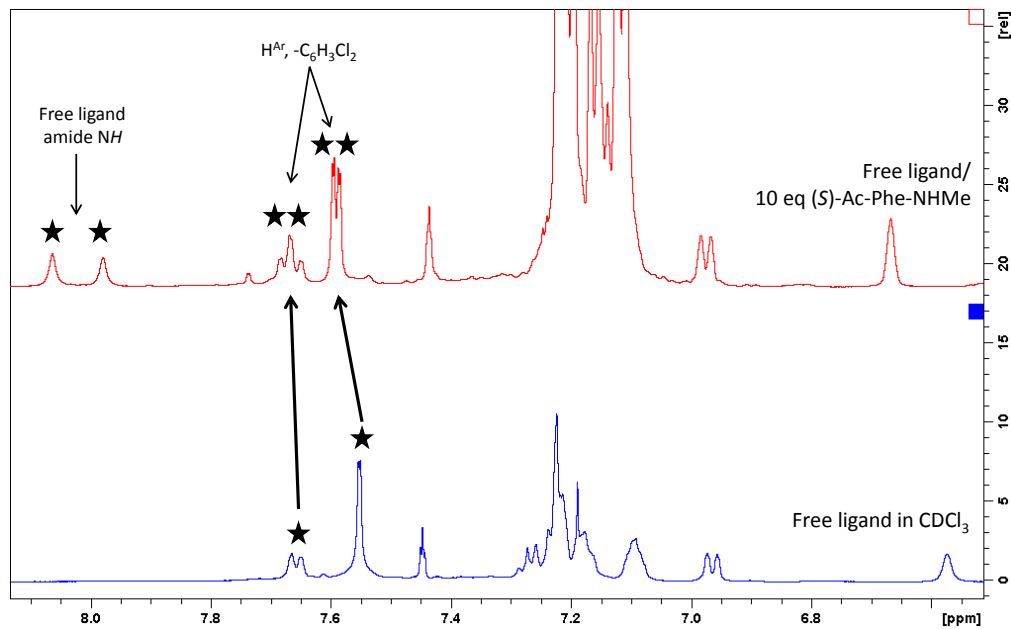
2.12. $[(\text{BIPHEP})\text{Rh}(\text{COD})](\text{BF}_4)$ / (*S*)-Diamide 13

$^{31}\text{P}\{^1\text{H}\}$ -NMR with various equivalents of phenylalanine derivative (2 eq – blue, 5 eq – red and 10 eq – green). The $^1J_{\text{P-Rh}}$ doublet is depicted.



2.13. 5,5'-Bis(3,5-dichlorobenzoylamino)-BIPHEP/ (S)-Diamide 13

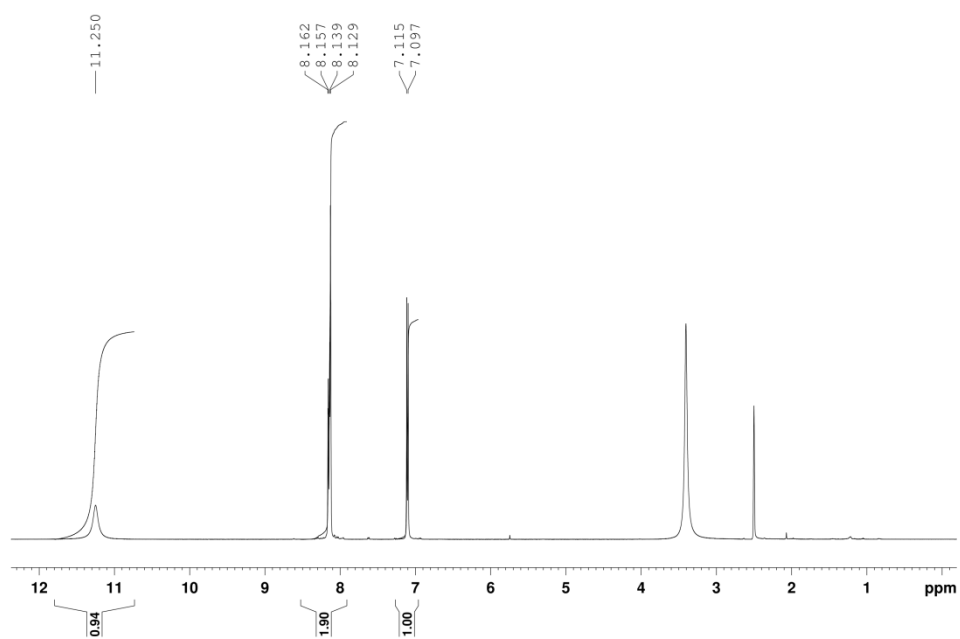
$^1\text{H-NMR}$ spectra of the free ligand in CDCl_3 . The aromatic region is depicted. Blue: Free ligand. Red: Ligand with 10 eq. (S)-Ac-Phe-NHMe.



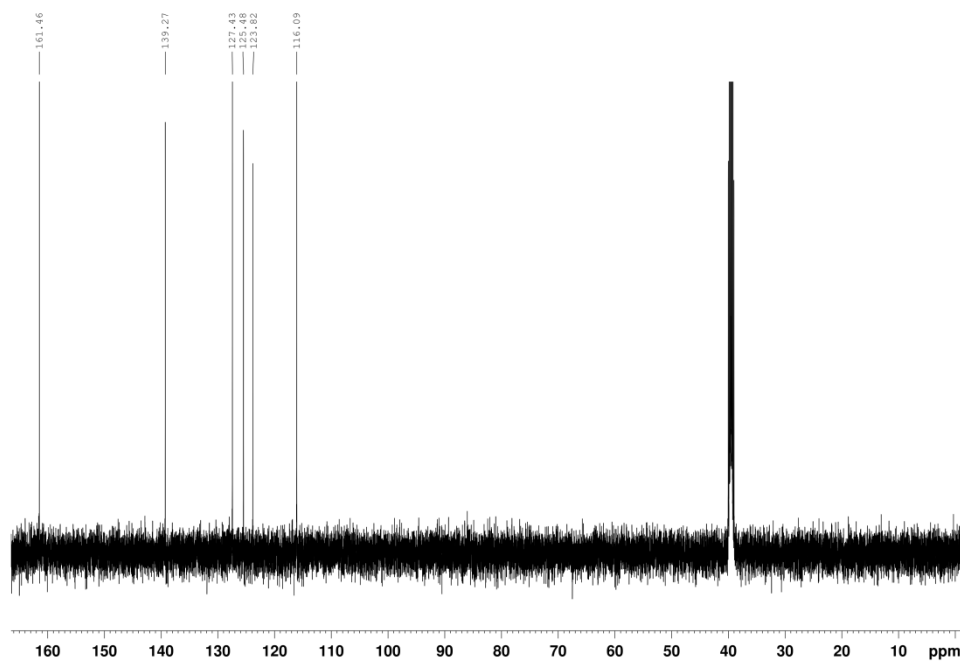
3. NMR-spectra

3.1.Cf. 1.1.1

^1H -NMR

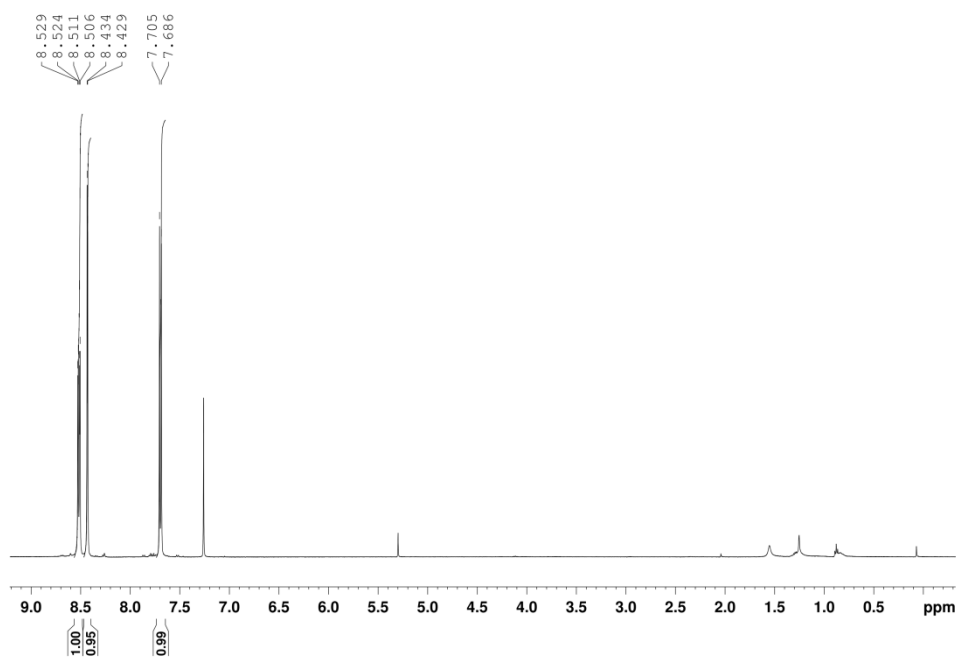


$^{13}\text{C}\{^1\text{H}\}$ -NMR

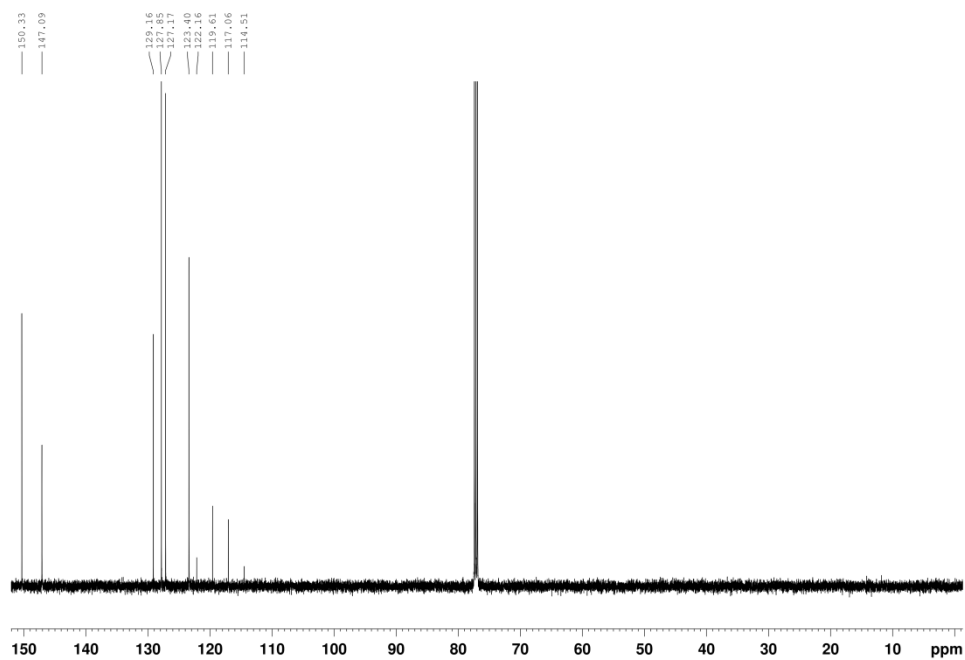


3.2.Cf. 1.1.2

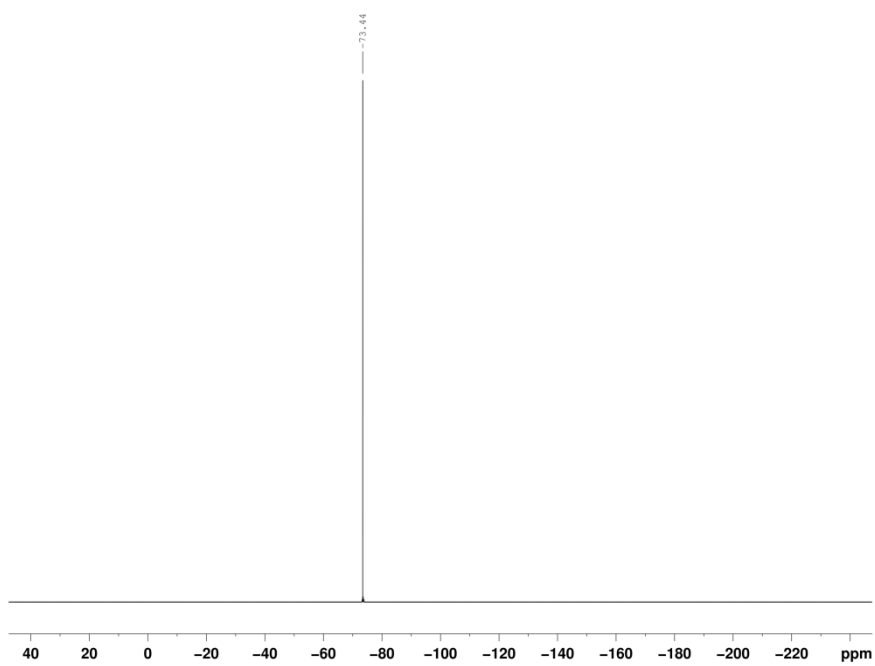
$^1\text{H-NMR}$



$^{13}\text{C}\{^1\text{H}\}\text{-NMR}$

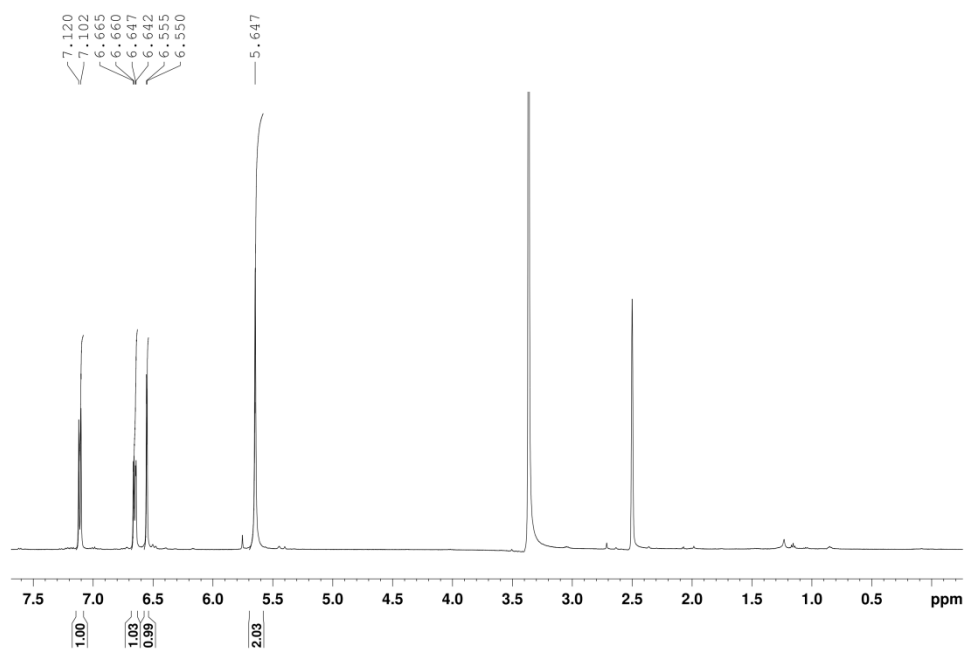


^{19}F -NMR

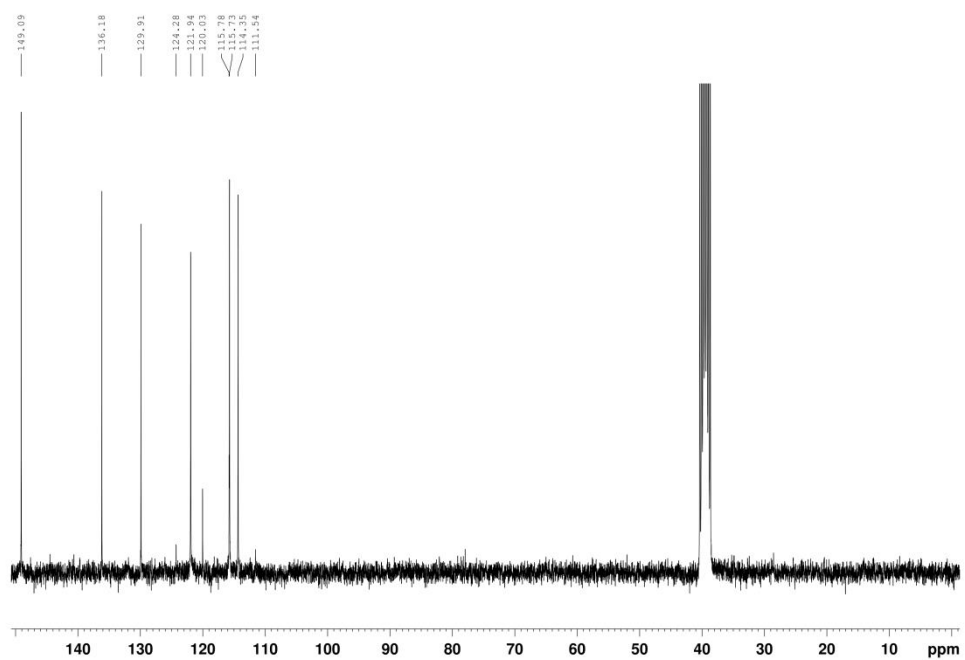


3.3.Cf. 1.1.3

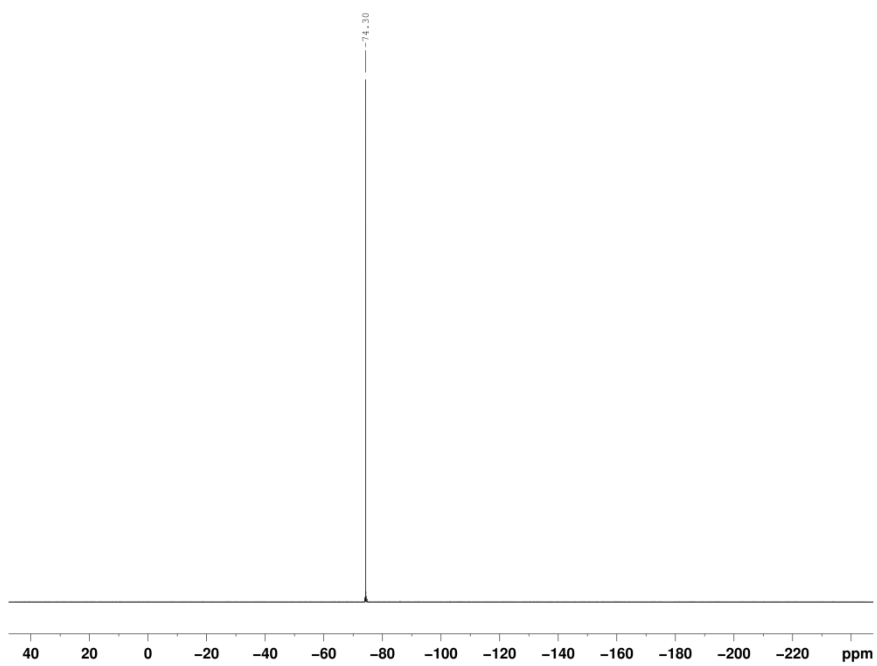
$^1\text{H-NMR}$



$^{13}\text{C}\{^1\text{H}\}\text{-NMR}$

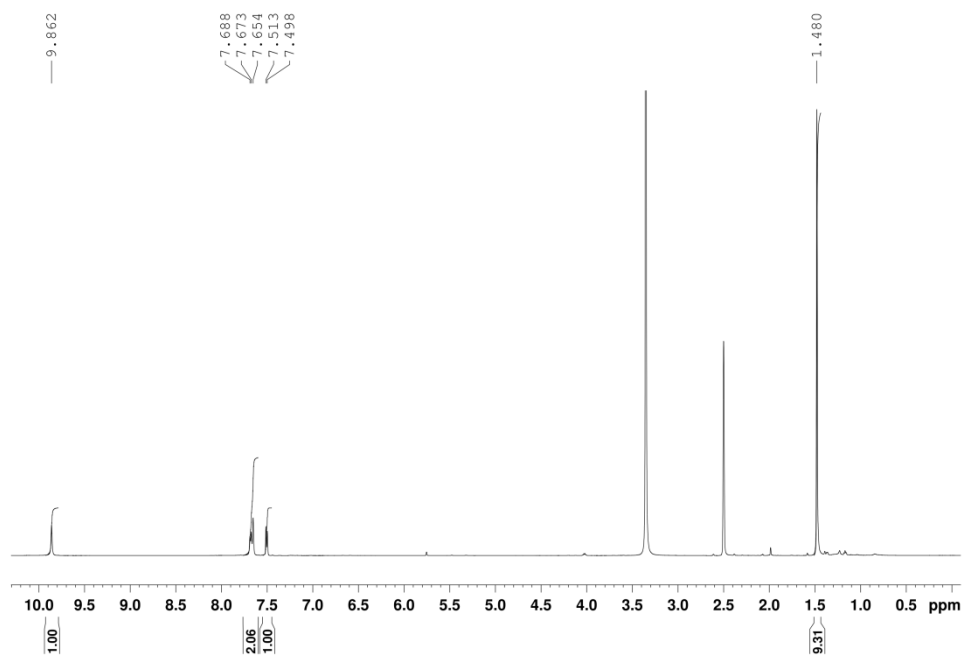


^{19}F -NMR

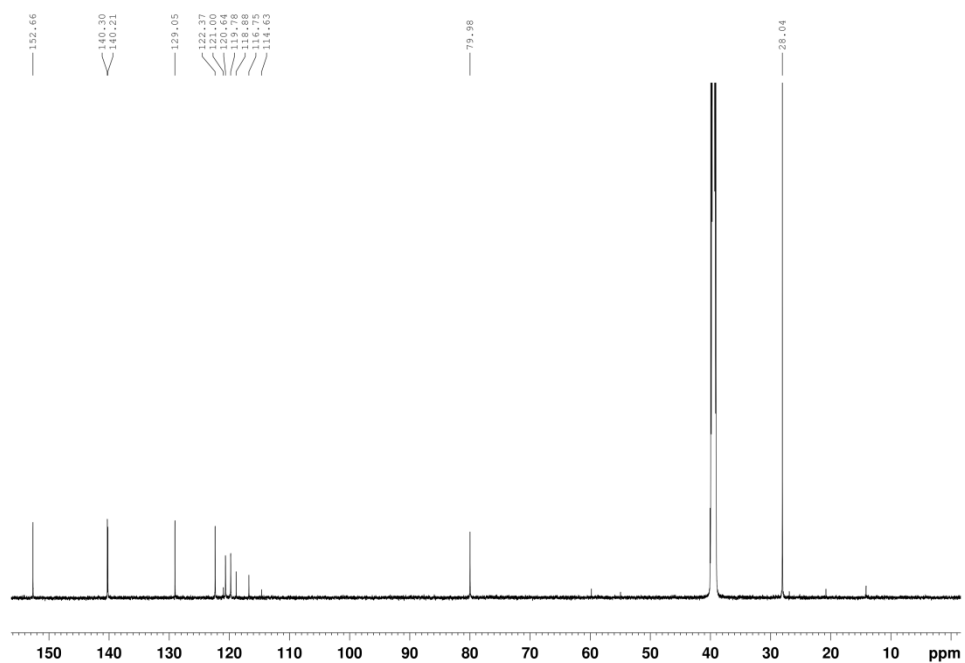


3.4.Cf. 1.1.4

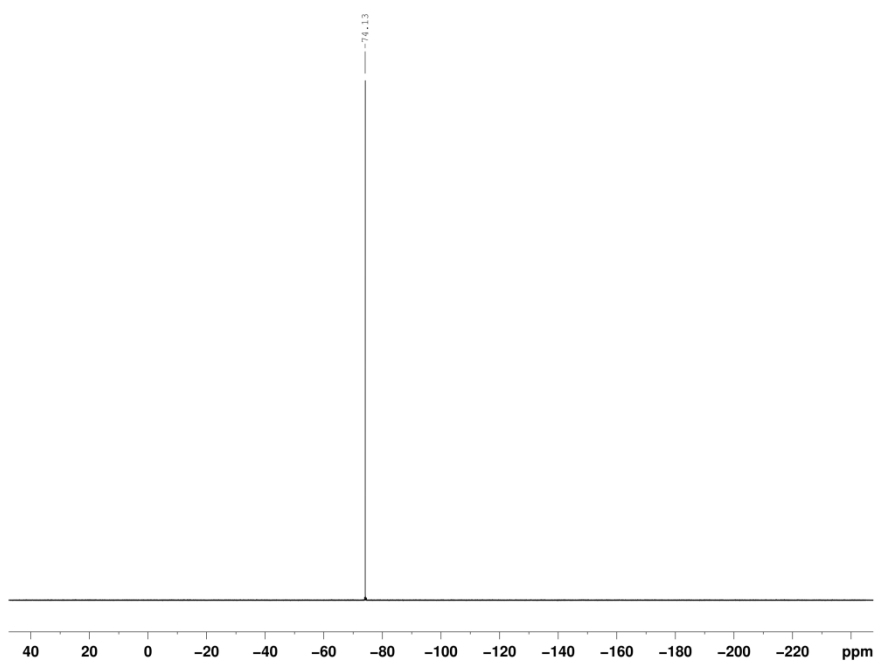
$^1\text{H-NMR}$



$^{13}\text{C}\{^1\text{H}\}\text{-NMR}$

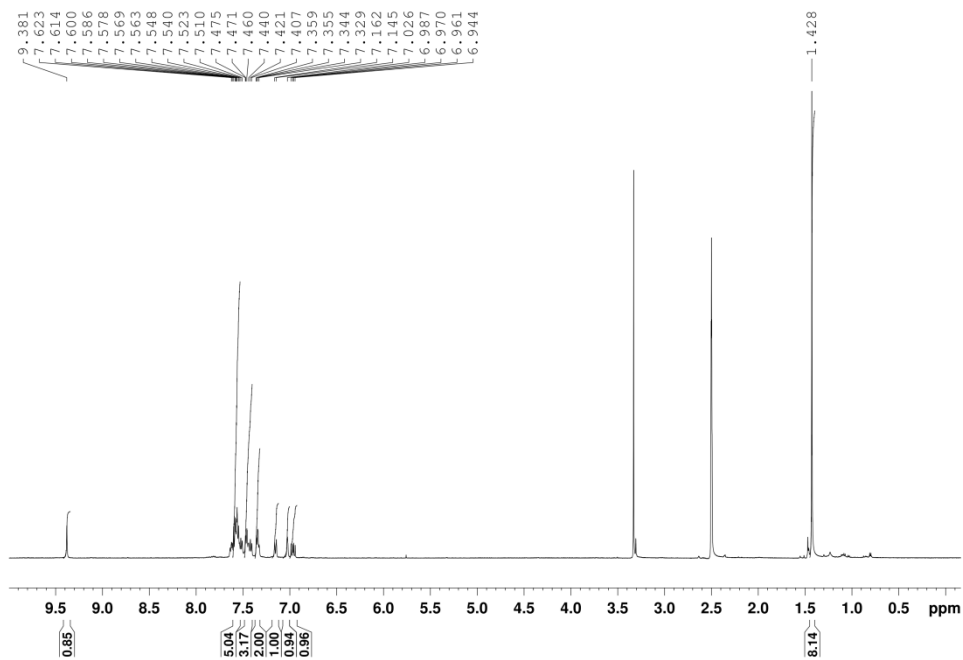


^{19}F -NMR

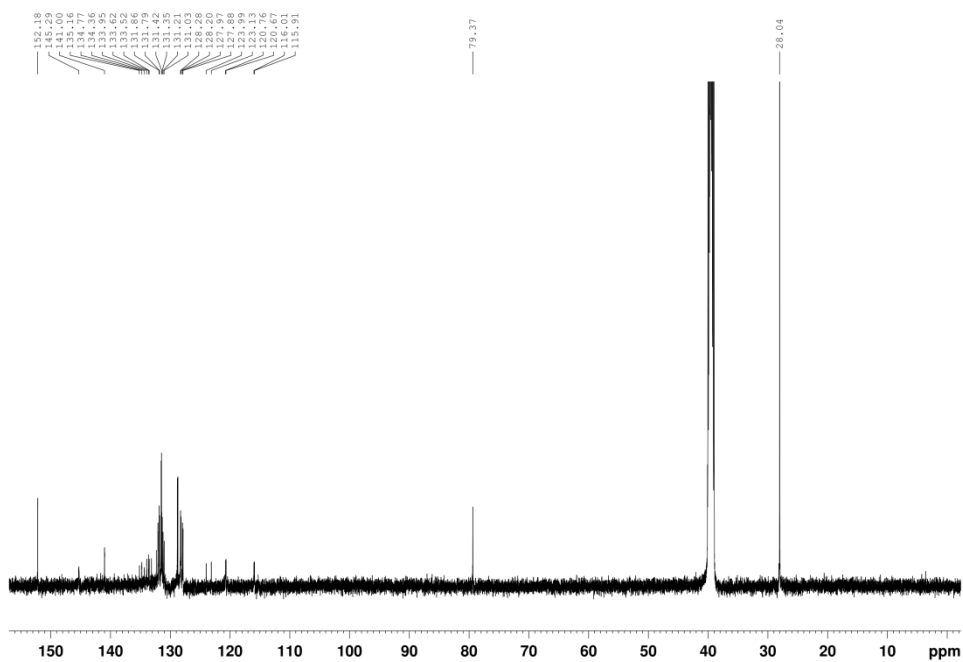


3.5.Cf. 1.1.6

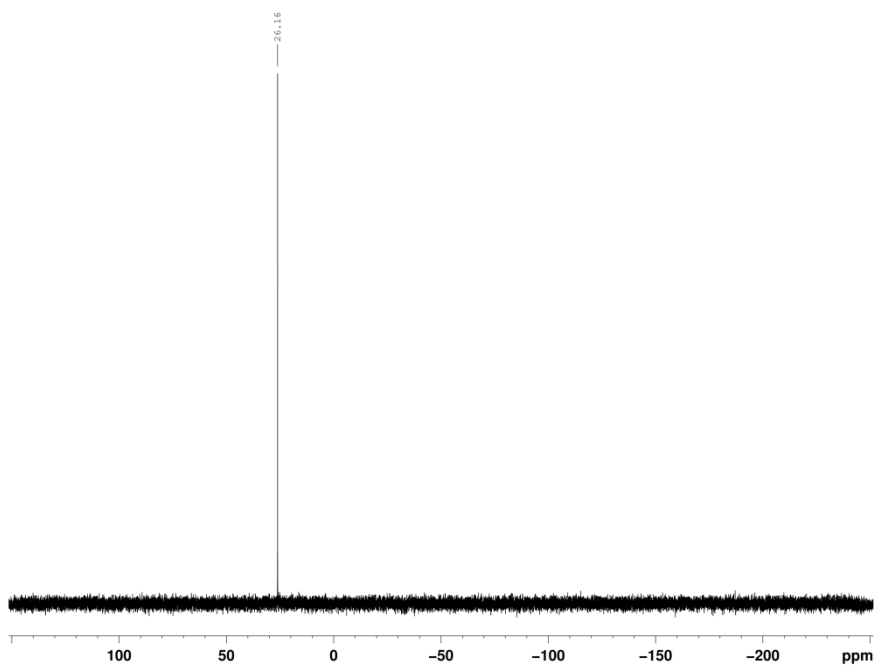
$^1\text{H-NMR}$



$^{13}\text{C}\{^1\text{H}\}\text{-NMR}$

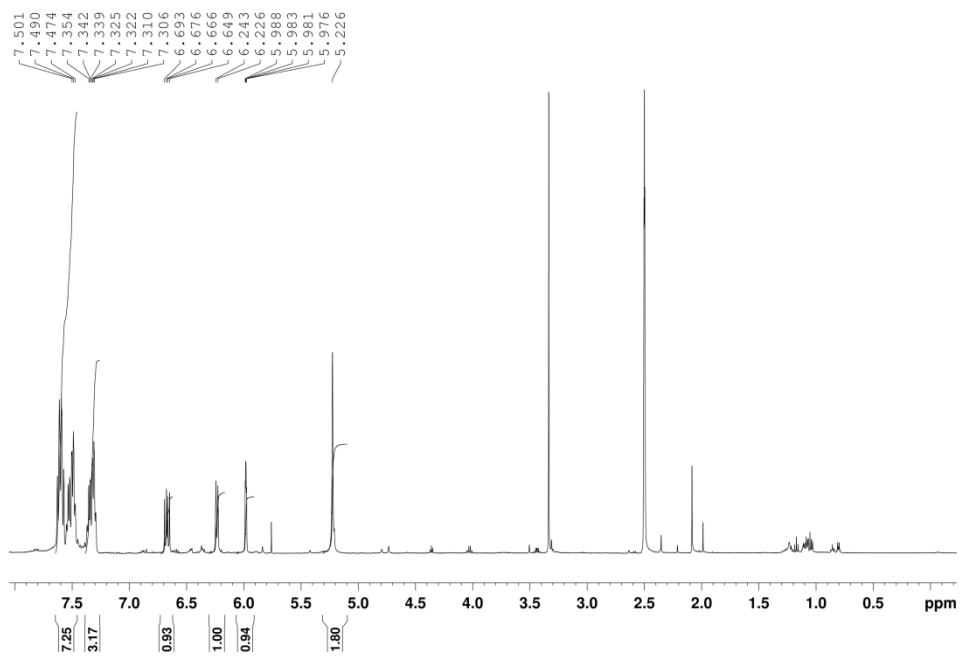


$^{31}\text{P}\{^1\text{H}\}$ -NMR

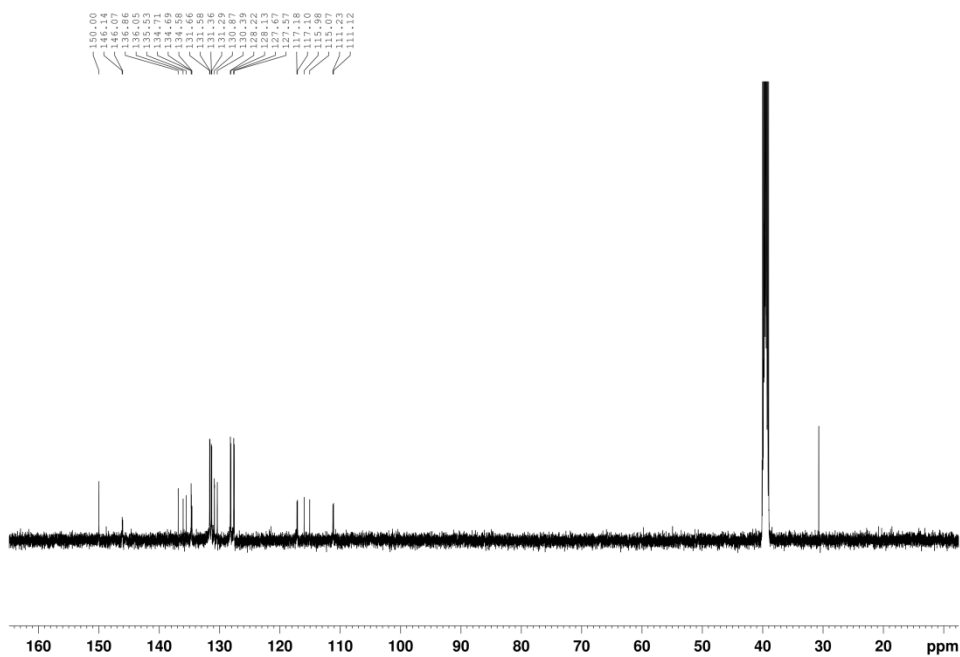


3.6.Cf. 1.1.7

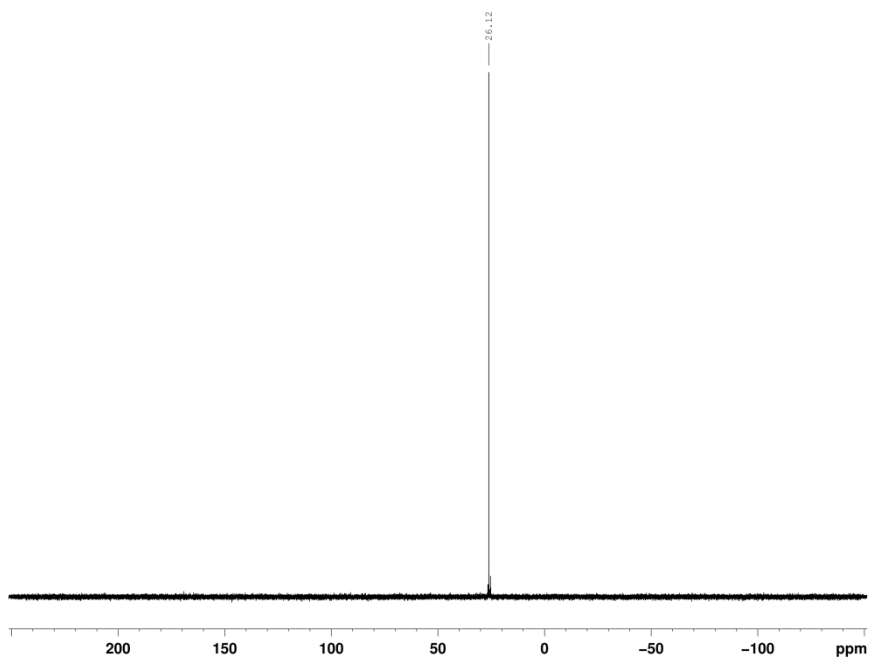
$^1\text{H-NMR}$



$^{13}\text{C}\{^1\text{H}\}\text{-NMR}$

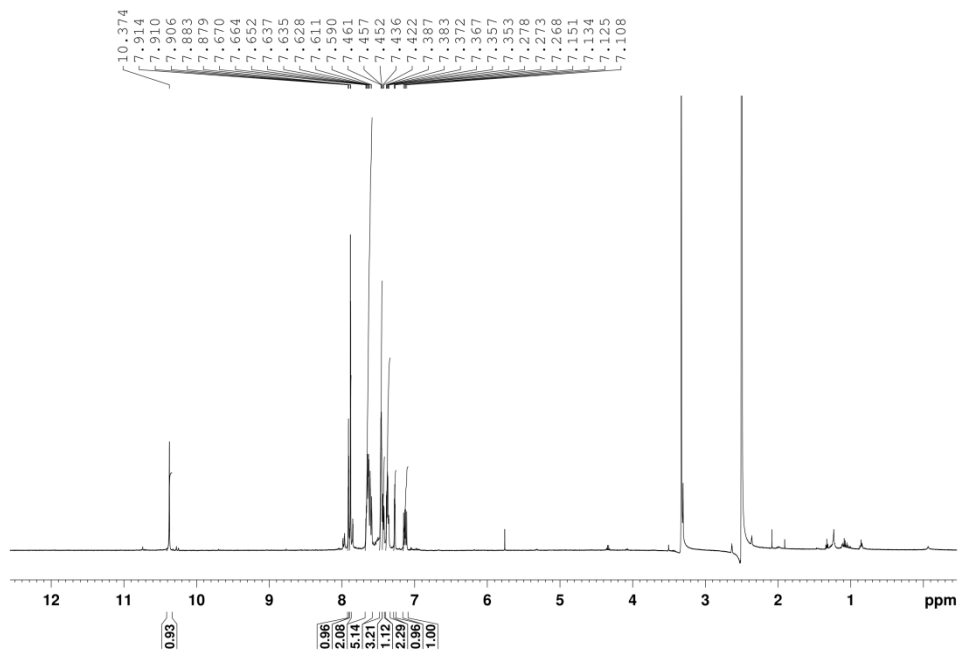


$^{31}\text{P}\{^1\text{H}\}$ -NMR

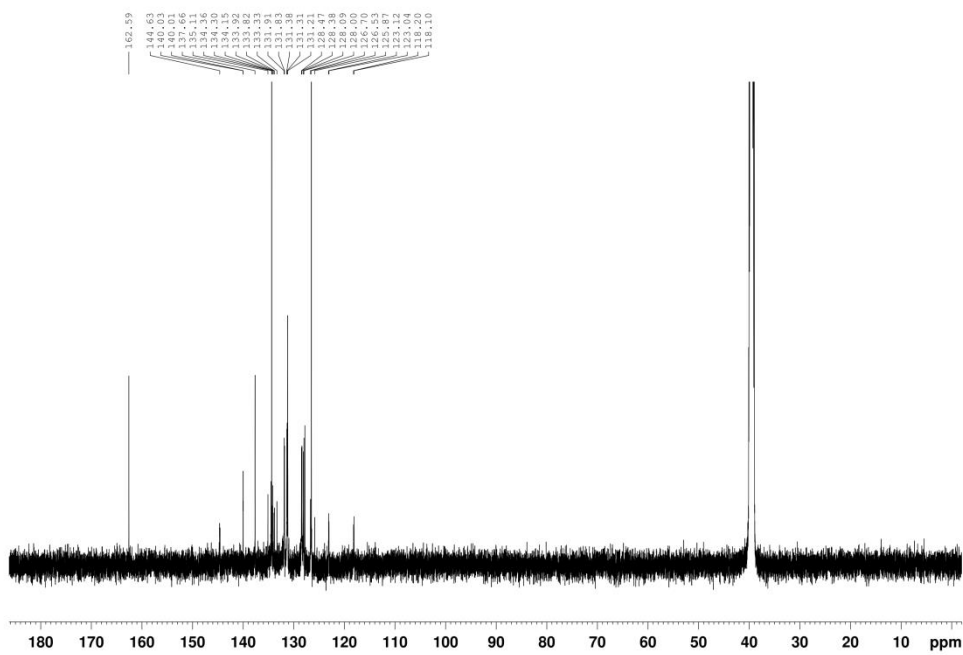


3.7.Cf. 1.1.8

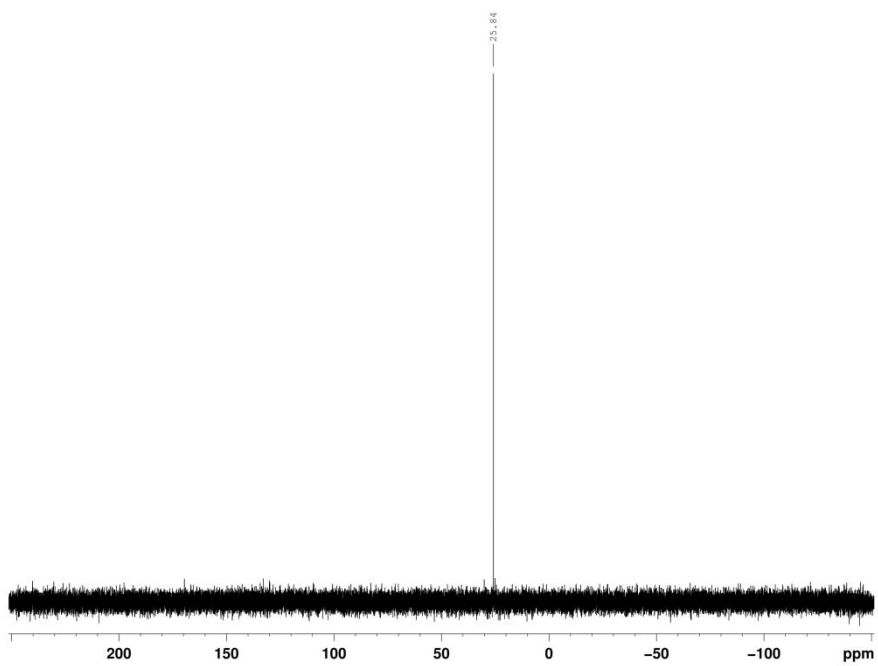
$^1\text{H-NMR}$



$^{13}\text{C}\{^1\text{H}\}\text{-NMR}$

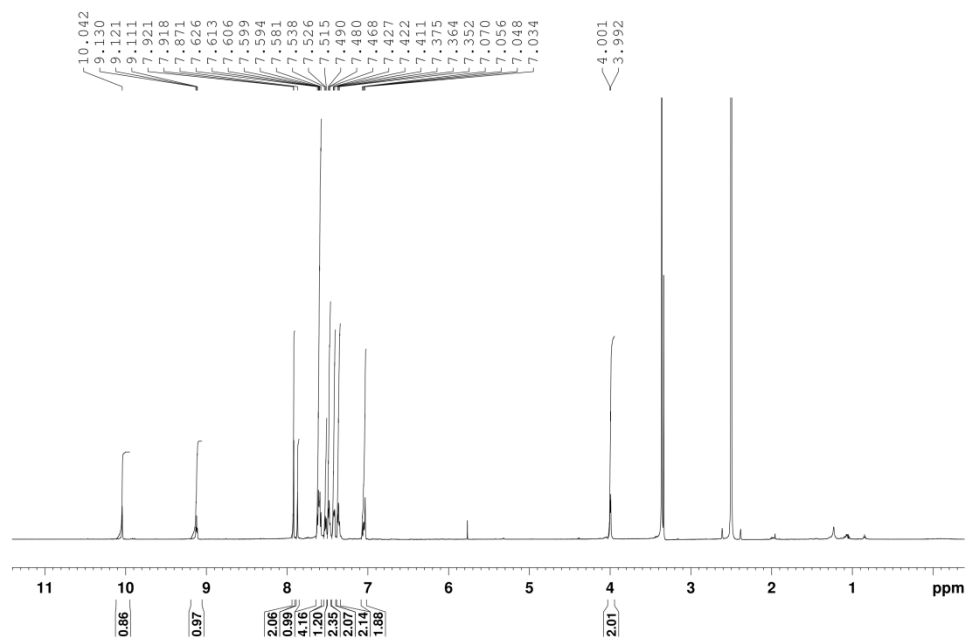


$^{31}\text{P}\{^1\text{H}\}$ -NMR

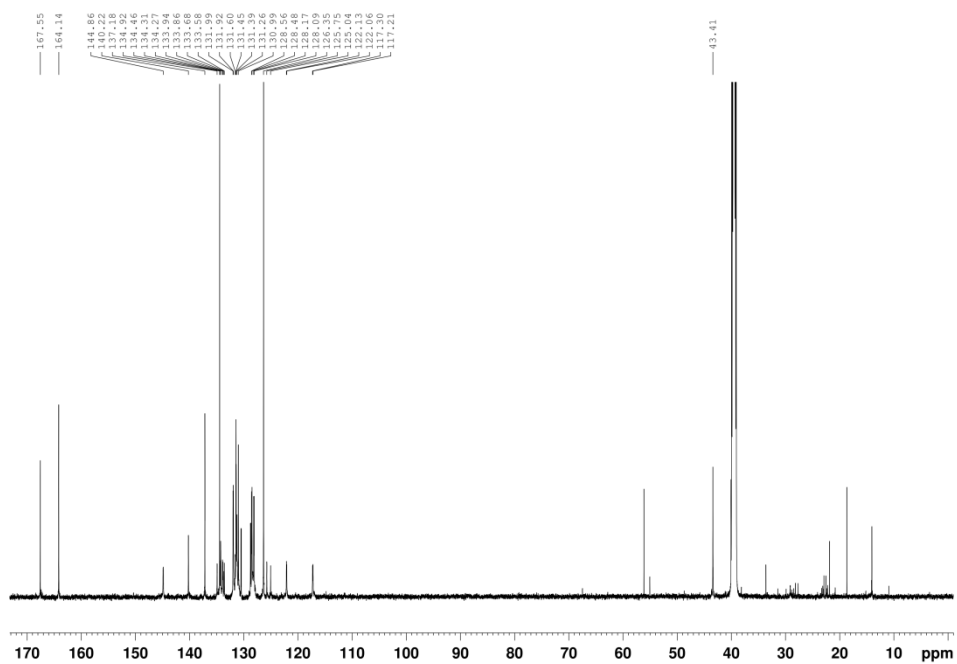


3.8.Cf. 1.1.9

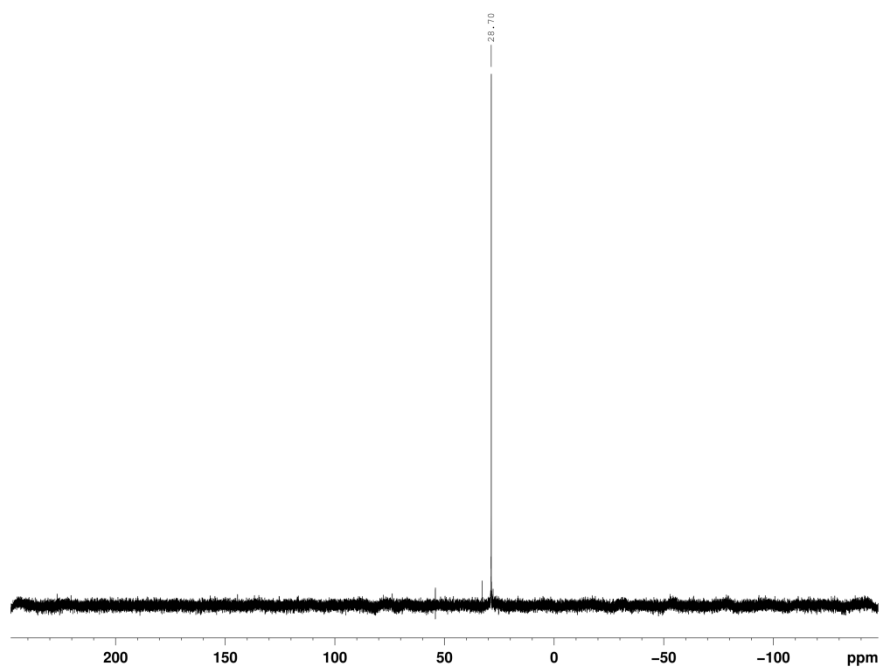
$^1\text{H-NMR}$



$^{13}\text{C}\{^1\text{H}\}\text{-NMR}$

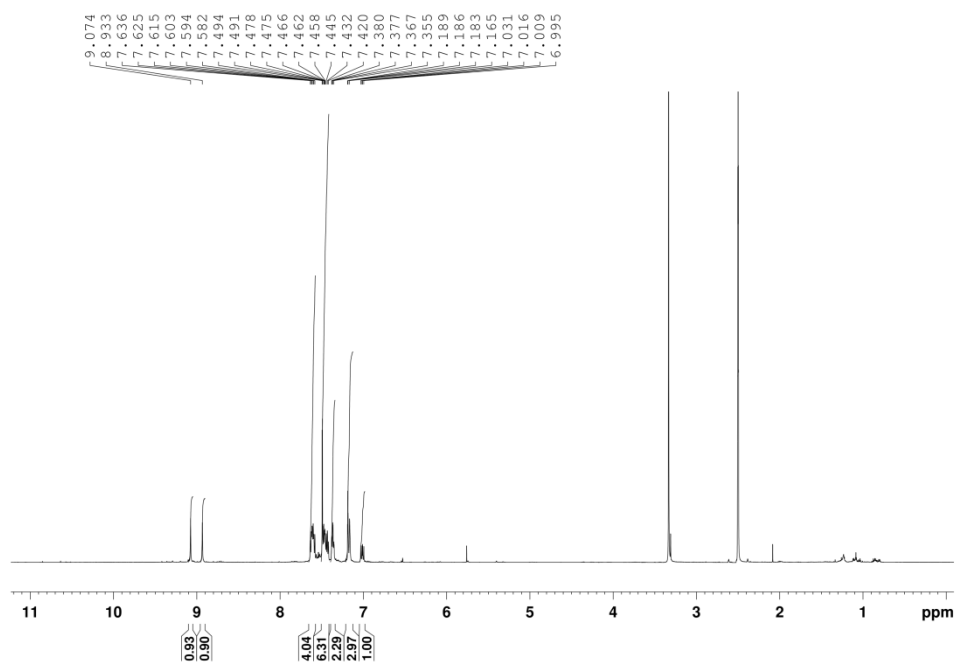


$^{31}\text{P}\{^1\text{H}\}$ -NMR

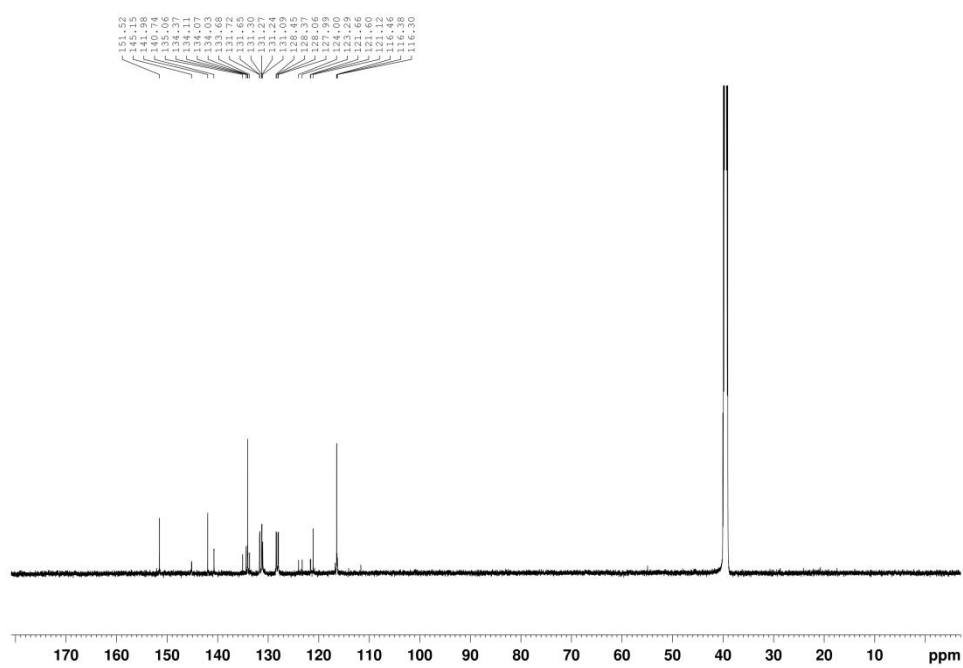


3.9.Cf. 1.1.10

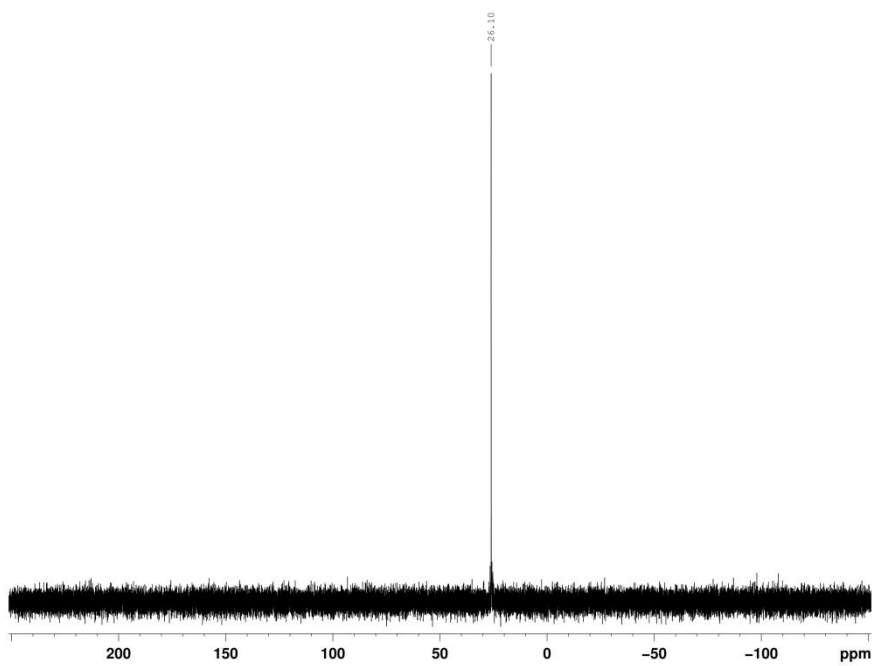
$^1\text{H-NMR}$



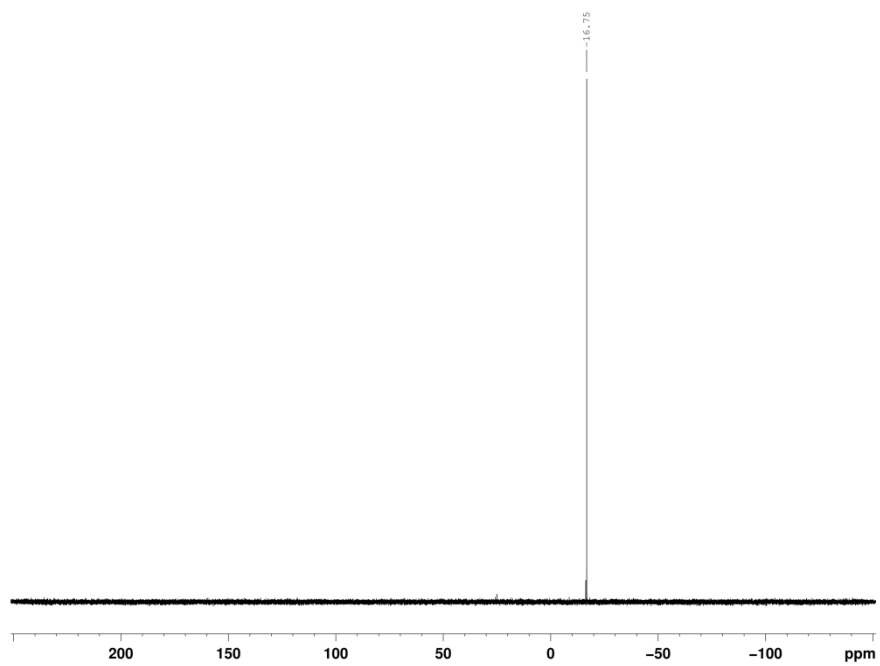
$^{13}\text{C}\{^1\text{H}\}\text{-NMR}$



$^{31}\text{P}\{^1\text{H}\}$ -NMR

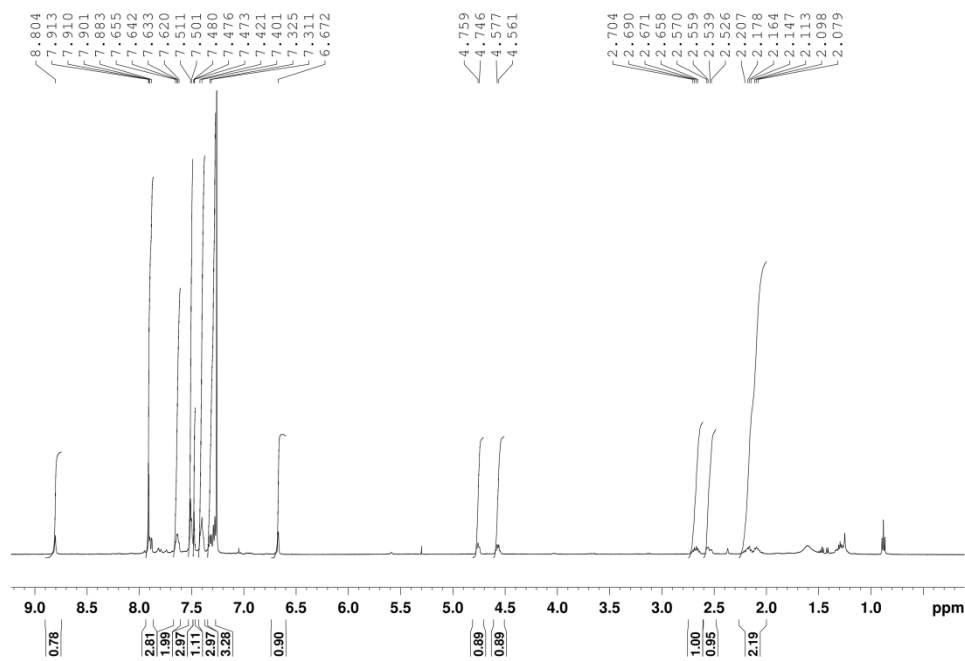


$^{31}\text{P}\{^1\text{H}\}$ -NMR

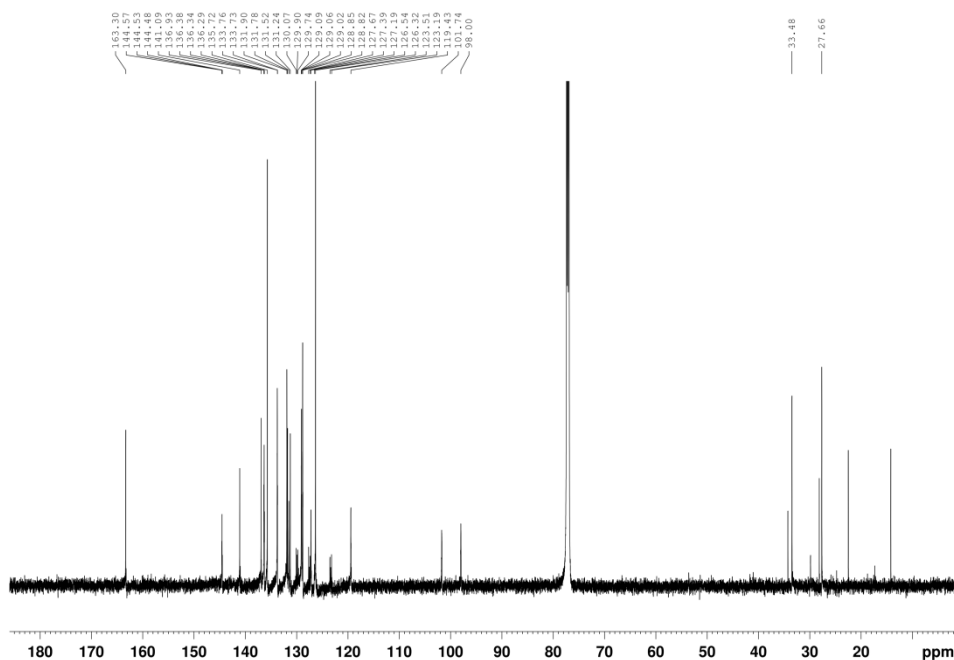


3.11. Cf. 1.1.12

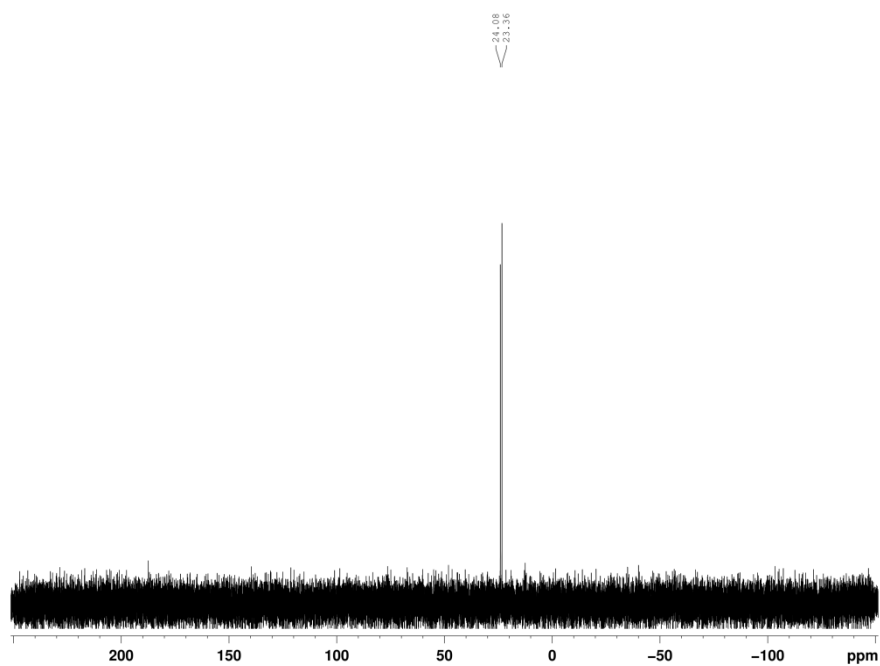
^1H -NMR (NMR spectrum contains trace amounts of residual *n*-pentane)



$^{13}\text{C}\{^1\text{H}\}$ -NMR (NMR spectrum contains trace amounts of residual *n*-pentane)



$^{31}\text{P}\{^1\text{H}\}$ -NMR



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- [1] G. R. Fulmer, A. J. M. Miller, N. H. Sherden, H. E. Gottlieb, A. Nudelman, B. M. Stoltz, J. E. Bercaw, K. I. Goldberg, *Organometallics* **2010**, *29*, 2176.
 - [2] O. Diels, A. Bibergeil, *Ber. dt. chem. Ges.* **1902**, *35*, 302.
 - [3] N. A. Bondarenko, A. V. Kharlamov, A. G. Vendilo, *Russ. Chem. Bull.* **2009**, *58*, 1872.
 - [4] A. A. Bobrikova, M. P. Koroteev, A. M. Koroteev, Y. V. Nelyubina, E. E. Nifant'ev, *Russ. Chem. Bull.* **2008**, *57*, 2021.
 - [5] D. Camp, P. C. Healy, I. D. Jenkins, B. W. Skelton, A. H. White, *J. Chem. Soc., Perkin Trans. 1* **1991**, 1323.
 - [6] Z. Fu, J. He, A. Tong, Y. Xie, Y. Wei, *Synthesis* **2013**, *45*, 2843.
 - [7] T. H. Applewhite, C. Niemann, *J. Am. Chem. Soc.* **1959**, *81*, 2208.