

## Article

# Synthesis, Structural Characterization and Catalytic Evaluation of Anionic Phosphinoferrocene Amidosulfonate Ligands

Jiří Schulz, Filip Horký, Ivana Císařová and Petr Štěpnička \*

Department of Inorganic Chemistry, Faculty of Science, Charles University, Hlavova 2030, 128 40 Prague, Czech Republic; jiri.schulz@natur.cuni.cz (J.S.); Filip.blud@seznam.cz (F.H.); ivana.cisarova@natur.cuni.cz (I.C.)

\* Correspondence: petr.stepnicka@natur.cuni.cz; Tel.: +420-221-951-260

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**Abstract:** Triethylammonium salts of phosphinoferrocene amidosulfonates with electron-rich dialkylphosphino substituents,  $R_2PfcCONHCH_2SO_3(HNEt_3)$  (**4a–c**), where *fc* = ferrocene-1,1'-diyl, and *R* = *i*-Pr (**a**), cyclohexyl (Cy; **b**), and *t*-butyl (**c**), were synthesized from the corresponding phosphinocarboxylic acids-borane adducts,  $R_2PfcCO_2H \cdot BH_3$  (**1a–c**), via esters  $R_2PfcCO_2C_6F_5 \cdot BH_3$  (**2a–c**) and adducts  $R_2PfcCONHCH_2SO_3(HNEt_3) \cdot BH_3$  (**3a–c**). Compound **4b** was shown to react with  $[Pd(\mu-Cl)(\eta-C_3H_5)]_2$  and  $AgClO_4$  to afford the zwitterionic complex  $[Pd(\eta^3-C_3H_5)(Cy_2PfcCONHCH_2SO_3-\kappa^2O,P)]$  (**5b**), in which the amidosulfonate ligand coordinates as a chelating donor making use of its phosphine moiety and amide oxygen. The structures of **3b**·CH<sub>2</sub>Cl<sub>2</sub>, **4b** and **5b**·CH<sub>2</sub>Cl<sub>2</sub> were determined by single-crystal X-ray diffraction analysis. Compounds **4a–c** and their known diphenylphosphino analogue,  $Ph_2PfcCONHCH_2SO_3(HNEt_3)$  (**4d**), were studied as supporting ligands in Pd-catalyzed cyanation of aryl bromides with  $K_4[Fe(CN)_6]$  and in Suzuki–Miyaura biaryl cross-coupling performed in aqueous reaction media under mild reaction conditions. In the former reaction, the best results were achieved with a catalyst generated from  $[PdCl_2(cod)]$  (*cod* =  $\eta^2:\eta^2$ -cycloocta-1,5-diene) and 2 equiv. of the least electron-rich ligand **4d** in dioxane–water as a solvent. In contrast, the biaryl coupling was advantageously performed with a catalyst resulting from palladium(II) acetate and ligand **4a** (1 equiv.) in the same solvent.

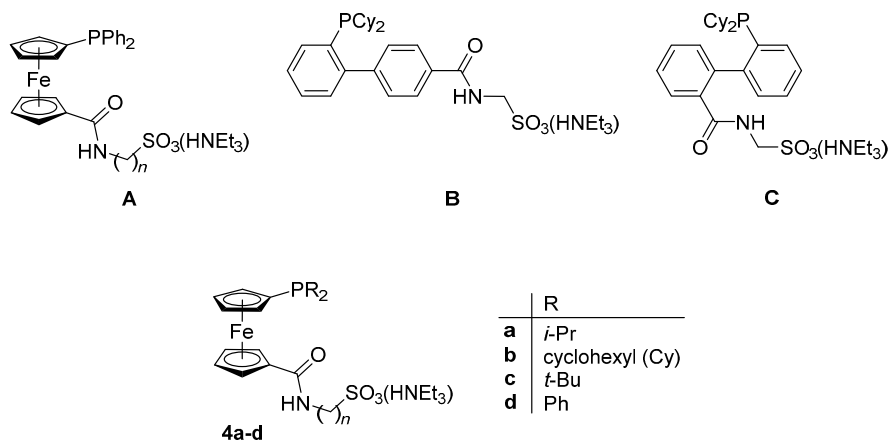
**Keywords:** ferrocene ligands; phosphines; sulfonates; aqueous catalysis; Suzuki–Miyaura reaction; cyanation; palladium

## 1. Introduction

Sulfonation of phosphines represents an efficient and time-tested approach toward hydrophilic ligands. Introduction of a single sulfonate moiety into a molecule of a phosphine donor usually increases polarity and hydrophilicity to such an extent that the resulting derivatives can be used as donors to prepare highly hydrophilic coordination compounds as well as supporting ligands for transition metal-catalyzed reactions performed in aqueous and water-organic biphasic media [1–3]. Phosphinosulfonate Donors including the archetypal and widely used trisodium tris(sulfonatophenyl)phosphine (TPPTS) [4–6] are typically obtained by direct sulfonation of the parent phosphines, which somewhat limits the scope of the accessible compounds, mainly due to problems associated with a high reactivity of the sulfonation agents and their compatibility with other functional groups.

We have recently demonstrated that phosphinosulfonate donors can also be accessed via amidation of phosphinocarboxylic acids with  $\omega$ -aminosulfonic acids [7]. This synthetic approach, which inherently leads to a simultaneous incorporation of the polar amide linking group, is modular

and allows the synthesis of libraries of donors with modified structures and also eliminates some limitations of the direct-sulfonation approach. So far, we have utilized this method to prepare a series of phosphinoferrocene amidosulfonates differing in the length of the aliphatic spacer between the amide and sulfonate groups, compounds **A** ( $n = 1-3$ ) [7], and a pair of isomeric phosphinobiphenyl donors **B** and **C** [8,9] (Scheme 1). These compounds were successfully tested as supporting ligands in Pd-catalyzed cyanation of aryl bromides and in Suzuki–Miyaura cross-coupling [7–9].



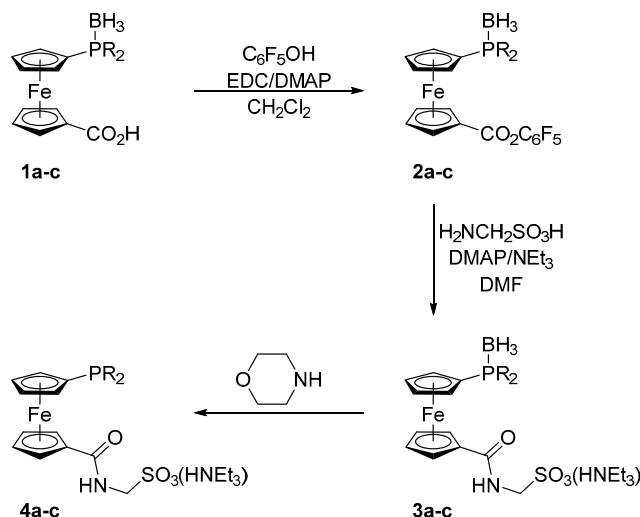
**Scheme 1.** Examples of phosphino-amidosulfonate donors.

Having recently established a reliable synthetic route to new (dialkylphosphino)ferrocenecarboxylic acids in their stable, phosphine-protected form (viz. compounds **1a–c**) [10], we decided to use these compounds further in the preparation of phosphinoferrocene amidosulfonate donors with varied, electron-rich phosphine substituents, compounds **4a–c** (Scheme 1). The synthesis, structural characterization and an evaluation of these compounds as supporting ligands in Pd-catalyzed cyanation of aryl bromides to the corresponding nitriles [11,12] and Suzuki–Miyaura cross-coupling of aryl bromides with arylboronic acids [13–17] performed in aqueous reaction media are reported in this contribution.

## 2. Results and Discussion

### 2.1. Synthesis of the Ligands

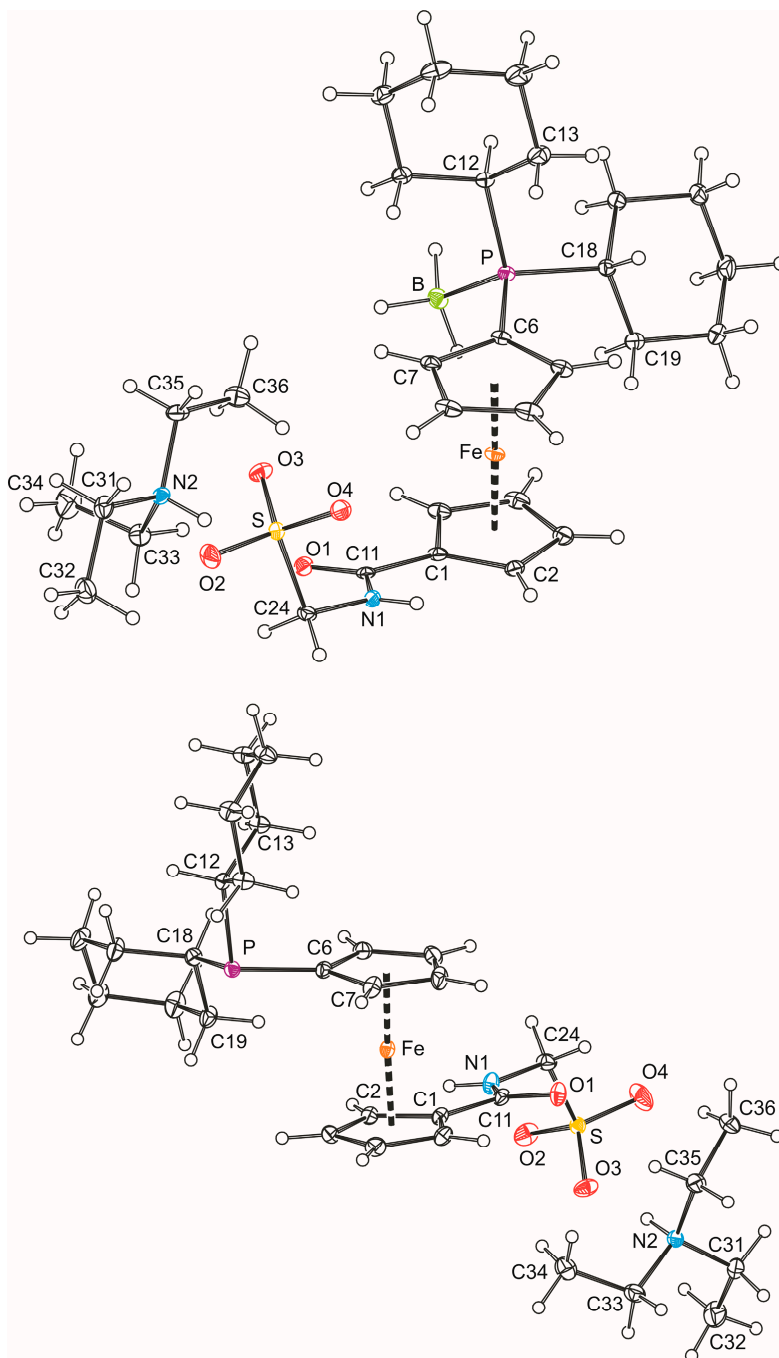
Compounds **1a–c** were prepared in analogy to the amidosulfonate donors **A–C** mentioned in the Introduction except that their oxidation-sensitive phosphine moieties were protected in the form of BH<sub>3</sub> adducts [18] during the synthesis (Scheme 2). In the first step, phosphinocarboxylic acid-borane adducts **1a–c** were reacted with pentafluorophenol in the presence of 1-ethyl-3-[3-(dimethylamino)propyl]carbodiimide (EDC) and 4-(dimethylamino)pyridine (DMAP) to afford the corresponding esters **2a–c**. These active esters were, in turn, reacted with aminomethanesulfonic acid in a mixture of *N,N*-dimethylformamide (DMF) and triethylamine to give the target ligands in their P-protected form, compound **3a–c**. In the last step, the borane protecting group was removed by heating these borane adducts in neat morpholine (65 °C/16 h) and the resulting free phosphines **4a–c** were isolated by column chromatography using a NEt<sub>3</sub>-pretreated silica gel column to avoid cation exchange. The target ligands **4a–c** as well as all reaction intermediates were characterized by NMR and IR spectroscopy, electrospray ionization (ESI) mass spectrometry and by elemental analysis.



**Scheme 2.** Synthesis of ligands **4a–c**. Legend: R = *i*-Pr (**a**), cyclohexyl (Cy; **b**), and *t*-Bu (**c**); EDC = 1-ethyl-3-[3-(dimethylamino)propyl]carbodiimide, DMAP = 4-(dimethylamino)pyridine, and DMF = *N,N*-dimethylformamide.

In addition, solid-state structures of **3b**·CH<sub>2</sub>Cl<sub>2</sub> and **4b** were determined by single-crystal X-ray diffraction analysis. Views of the molecular structures are shown in Figure 1 and the relevant structural parameters for the phosphinoferrocene amidosulfonate anions are presented in Table 1. The ferrocene units in both structures adopt their usual geometry with similar Fe–C distances (cf. Fe–C(1–10): 2.036(2)–2.066(2) Å for **3b**·CH<sub>2</sub>Cl<sub>2</sub> and 2.032(2)–2.070(1) Å for **4b**) and tilt angles not exceeding 5°. The substituents attached in the positions 1 and 1' are diverted from each other, so that the ferrocene cyclopentadienyls assume conformations near to anticlinal eclipsed (compare  $\tau$  angles with the ideal value of 144° [19]). Generally, the individual geometric parameters compare well with the values reported previously for compound **4d** [7] and acid **1b** [10]. In the pair, the structures of the anions differ mainly by the orientation of their CH<sub>2</sub>SO<sub>3</sub> pendant groups. In the structure of **3b**·CH<sub>2</sub>Cl<sub>2</sub>, this moiety extends above the amide plane toward the ferrocene unit, whereas in **4b**, it is directed away from the ferrocene moiety (compare the dihedral angles C11–N1–C24–S of –88.5(2)° and 105.3(1)° in **3b**·CH<sub>2</sub>Cl<sub>2</sub> and **4b**, respectively). Slight differences are observed also in the overall molecular conformation (compare angles  $\tau$  and  $\phi$  in Table 1) and in the lengths of the P–C bonds, which are longer in the free phosphine **4b** than in the corresponding BH<sub>3</sub> adduct **3b**·CH<sub>2</sub>Cl<sub>2</sub> [**3b**·CH<sub>2</sub>Cl<sub>2</sub>: P–C6 1.798(2) Å, P–C12 1.843(2) Å, and P–C18 1.840(2) Å; **4b**: P–C6 1.825(1) Å, P–C12 1.873(1) Å, and P–C18 1.862(1) Å]. The cyclohexyl substituents assume chair conformations, which is clearly indicated by the ring puckering parameter  $\theta$  being 0.0(2)° [2.2(2)] and 178.0(2)° [175.3(2)°] for the rings C(12–17) and C(18–23) in **3b**·CH<sub>2</sub>Cl<sub>2</sub> [**4b**], respectively (N.B. ideal chair requires  $\theta = 0/180^\circ$ , see ref. [20]). In all rings, the P–C bonds occupy equatorial positions.

Despite their obvious structural similarity, compounds **3b**·CH<sub>2</sub>Cl<sub>2</sub> and **4b** constitute different solid-state assemblies in their crystals (Figure 2). The amidosulfonate anions in the structure of **3b**·CH<sub>2</sub>Cl<sub>2</sub> interact with their inversion-related counterparts through a pair of N1–H1N···O4 hydrogen bonds (N1···O4 = 2.811(2) Å) to form a closed dimeric motif, which further binds two adjacent Et<sub>3</sub>NH<sup>+</sup> cations via N2–H2N···O1 hydrogen bonds involving the amide oxygen (N2···O1 = 2.794(2) Å). A similar central unit formed from a pair of inversion-related amidosulfonate anions is found also in the structure of **4b** (N1···O2 = and 2.813(2) Å) and this dimeric moiety even interacts with a pair of the triethylammonium cations though via hydrogen bonds toward the sulfonate oxygen O3 (N2–H2N···O3 = 2.717(2) Å).



**Figure 1.** PLATON plots of the molecular structures of **3b**·CH<sub>2</sub>Cl<sub>2</sub> (**top**) and **4b** (**bottom**). The displacement ellipsoids are scaled to the 30% probability level. Note: all rings are numbered consecutively and, hence, only the labels of the pivotal and the adjacent atom are shown to avoid complicating the Figure. The molecule of solvent is also omitted.

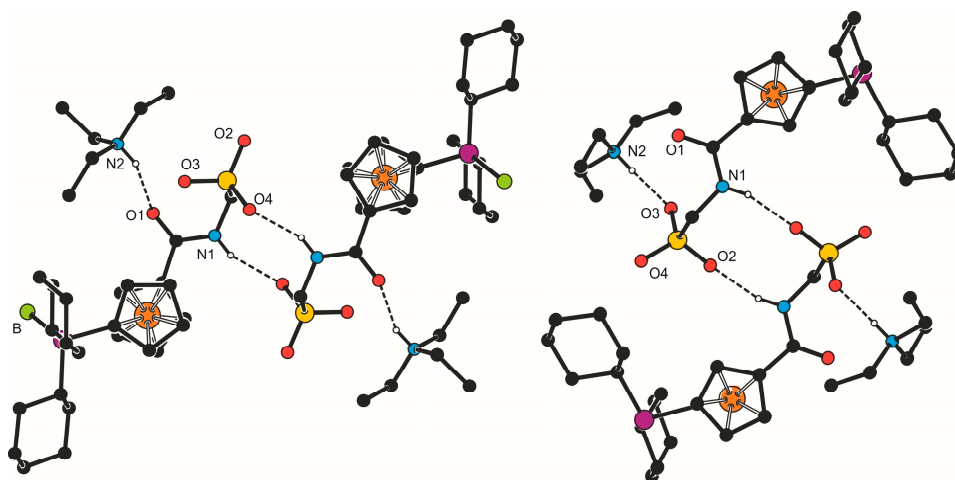


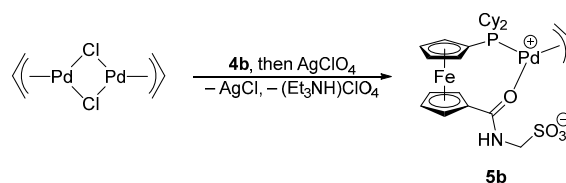
Figure 2. Simplified packing diagrams for **3b**·CH<sub>2</sub>Cl<sub>2</sub> (left) and **4b** (right).

Table 1. Selected distances and angles for the anions in the structures of **3b**·CH<sub>2</sub>Cl<sub>2</sub> and **4b** (in Å and deg)<sup>a</sup>.

Parameter	<b>3b</b> ·CH <sub>2</sub> Cl <sub>2</sub>	<b>4b</b>
Fe–Cg1	1.6506(8)	1.6452(7)
Fe–Cg2	1.6490(8)	1.6490(8)
∠Cp1, Cp2	4.8(1)	4.50(9)
τ	−130.3(1)	146.1(1)
P–C6	1.798(2)	1.825(1)
P–B	1.931(2)	n.a.
C1–C11	1.483(2)	1.477(2)
C11–O1	1.239(2)	1.230(2)
C11–N1	1.346(2)	1.353(2)
O–C11–N1	123.0(1)	122.6(1)
φ	11.9(2)	5.9(2)
N1–C24	1.443(2)	1.434(2)
C24–S	1.804(2)	1.791(2)
S–O2	1.453(1)	1.445(1)
S–O3	1.454(1)	1.458(1)
S–O4	1.460(1)	1.442(1)
N1–C24–S	112.3(1)	115.0(1)
C24–S–O <sup>b</sup>	104.59(7)–106.20(7)	103.06(8)–107.16(7)
O2–S–O3	114.07(7)	110.89(7)
O2–S–O4	113.27(8)	114.73(8)
O3–S–O4	112.16(7)	113.57(8)

<sup>a</sup> Definition of the parameters: Cp1 and Cp2 are the cyclopentadienyl rings C(1–5) and C(6–10), respectively. Cg1 and Cg2 are the respective centroids. τ denotes the dihedral angle C1–Cg1–Cg2–Cg, and φ is the angle subtended by the planes of the ring Cp1 and the amide group [C11, O1 N]. n.a. = not applicable. <sup>b</sup> The range of C24–S–O(2,3,4) angles.

The reaction of [Pd(μ-Cl)(η-C<sub>3</sub>H<sub>5</sub>)<sub>2</sub>] with ligand **4b** chosen as a representative and then with silver(I) perchlorate proceeded under cleavage of the chloride bridges in the dimeric Pd(II) precursor and removal of the Pd-bound chloride to afford the zwitterionic (η<sup>3</sup>-C<sub>3</sub>H<sub>5</sub>)Pd(II) complex **5b** wherein the phosphinosulfonate anion Cy<sub>2</sub>PfcCONHCH<sub>2</sub>SO<sub>3</sub><sup>−</sup> coordinates through its phosphine substituent and the amide oxygen, forming an O,P-chelate ring (Scheme 3). The coordination of the phosphine group in **5b** was manifested through a shift of the <sup>31</sup>P NMR resonance to a lower field (the <sup>31</sup>P NMR coordination shift, Δ<sub>P</sub> = δ<sub>P</sub>(complex) − δ<sub>P</sub>(free ligand), was 36.0 ppm), whereas the shift of the amide C=O vibration in the IR spectrum by 65 cm<sup>−1</sup> to lower energies suggested that the amide oxygen is involved in coordination to the (η<sup>3</sup>-C<sub>3</sub>H<sub>5</sub>)Pd fragment rather than the anionic sulfonate moiety [7].

Scheme 3. Synthesis of complex **5b**.

The formulation of **5b** was unequivocally corroborated by X-ray diffraction analysis on the stoichiometric solvate **5b**·CH<sub>2</sub>Cl<sub>2</sub>. A view of the complex molecule is shown in Figure 3, and the selected geometric parameters are given in Table 2. The allyl moiety {C31, C32, C33} in the structure of **5b** is rotated by 69.7(4)° with respect to the plane defined by the palladium atom and the remaining ligating atoms P and O1, so that the carbon atom C32 in the *meso* position is diverted from the ferrocene ligand [21]. The individual Pd–C(allyl) distances decrease gradually from C31 to C33, reflecting the *trans*-influence of the donor atoms located opposite the allyl moiety (P > O) [22,23].

Table 2. Selected distances and angles for **5b**·CH<sub>2</sub>Cl<sub>2</sub> (in Å and deg)<sup>a</sup>.

Pd–P	2.3161(7)	P–Pd–O1	105.07(5)
Pd–O1	2.131(2)	C31–Pd–C33	67.1(1)
Pd–C31	2.225(3)	P–Pd–C33	97.00(9)
Pd–C32	2.140(3)	O1–Pd–C31	91.1(1)
Pd–C33	2.082(3)	C31–C32–C33	121.4(3)
Fe–Cg1	1.650(1)	∠Cp1,Cp2	6.5(2)
Fe–Cg2	1.652(1)	τ	−65.1(2)
C1–C11	1.467(3)	O1–C11–N	120.6(2)
C11–O	1.249(3)	φ	15.3(3)
C11–N	1.342(3)	C11–N–C24	123.2(2)
N–C24	1.436(4)	N–C24–S	112.5(2)
C24–S	1.793(3)	C24–S–O <sup>b</sup>	103.0(2)–106.8(2)
S–O2	1.442(3)	O2–S–O3	111.1(2)
S–O3	1.460(2)	O2–S–O4	116.9(2)
S–O4	1.443(3)	O3–S–O4	111.8(2)
C6–P	1.813(3)	C6–P–C12	104.6(1)
P–C12	1.844(3)	C6–P–C18	101.2(1)
P–C18	1.854(3)	C12–P–C18	104.9(1)

<sup>a</sup> Definition of the parameters: Cp1 and Cp2 are the cyclopentadienyl rings C(1–5) and C(6–10), respectively. Cg1 and Cg2 denote their respective centroids. τ stands for the dihedral angle C1–Cg1–Cg2–Cg, and φ is the angle subtended by the planes of the ring Cp1 and the amide moiety {C11, O1 N}. <sup>b</sup> The range of C24–S–O(2,3,4) angles.

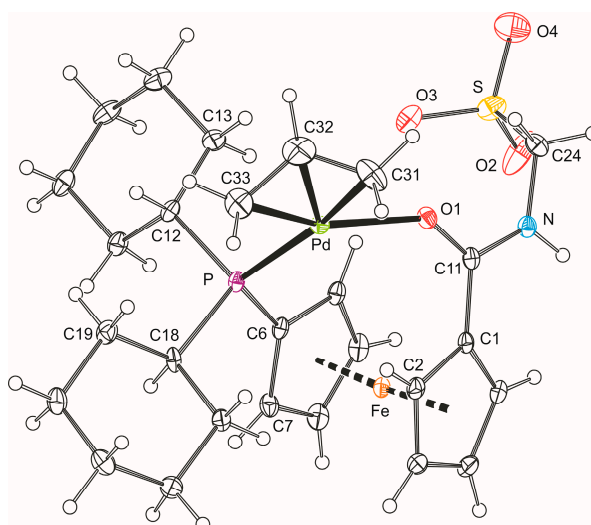


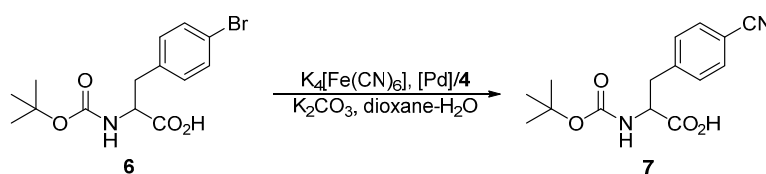
Figure 3. PLATON plot of the complex molecule in the structure of **5b**·CH<sub>2</sub>Cl<sub>2</sub> showing displacement ellipsoids at the 30% probability level.

Apparently because of chelate coordination, the 1,1'-disubstituted ferrocene unit is less open than in the structure of **4b**, adopting a near synclinal eclipsed conformation as evidenced by the torsion angle C1–Cg1–Cg2–C6 ( $\tau$ ) of  $-65.1(2)^\circ$  (cf. the ideal value:  $72^\circ$ ). The ferrocene moiety is somewhat tilted (dihedral angle:  $6.5(2)^\circ$ ) with the C1 and C10 atoms that reside above each other in the ferrocene unit forming the shortest bonds toward the central iron atom (N.B. the individual Fe–C bonds span the range 2.011(2)–2.074(2) Å). More importantly, the distortion propagates to the amide unit, which appears twisted by  $15.3(3)^\circ$  with respect to its parent cyclopentadienyl ring Cp1 and the pivotal atom C11 is displaced from the Cp1 plane inward of the ferrocene unit by as much as 0.214(2) Å. All this aids in bringing the amide oxygen O1 into a position suitable for chelate ring formation. The CH<sub>2</sub>SO<sub>3</sub> arm is oriented above the amide unit and to the side of the ferrocene unit so that the angle subtended by the C24–S bond and the axis of the ferrocene unit (Cg1...Cg2) is  $21.75(6)^\circ$ . In contrast, the phosphine phosphorus lies in the plane of its bonding cyclopentadienyl ring (perpendicular distance from the Cp2 plane is only 0.047(1) Å). However, because of the proximity of one of the cyclohexyl substituents, the C7–C6–P angle is  $3.6^\circ$  less acute than the C10–C6–P angle opening to the less sterically encumbered side of the ferrocene moiety (N.B. the difference between the C2–C1–C11 and C5–C1–C11 angles is only  $2.0^\circ$ ).

In the crystal, the molecules of complex **5b** associate into dimers via hydrogen bonds between their amide NH groups and sulfonate oxygen O2 in a proximal molecule, N–H1N...O2 (N1...O2 = 2.779(3) Å, angle at H1N =  $155^\circ$ ). Additional soft C–H...O<sub>3</sub>S interactions interconnect these dimers into a three-dimensional array.

## 2.2. Catalytic Experiments

The series of phosphinoferrocene amidosulfonates **4a–d** bearing different substituents at the phosphorus atom, which can be regarded as the primary coordination site for the catalytically active soft metal ions, was firstly evaluated in Pd-catalyzed cyanation of aryl bromides leading to the corresponding nitriles [11,12] using potassium hexacyanoferrate(II) as a practically non-toxic and environmentally benign cyanide source [24]. In particular, we chose the cyanation of N-Boc protected 4-bromophenylalanine **6** (Scheme 4) performed in dioxane–water (1:1) mixture at  $100^\circ\text{C}$  in the presence of potassium carbonate as a base. The results collected in Table 3 indicate that the yield of the coupling product **7** depends strongly on the Pd source. At a Pd loading of 2 mol. % and with the model ligand **4d**, the best catalyst performance resulted from [PdCl<sub>2</sub>(cod)] (cod =  $\eta^2:\eta^2$ -cycloocta-1,5-diene) and 2 equiv. of the phosphine ligand, which reached full conversion of **6** to **7** within 3 h. An analogous catalyst prepared at a 1:1 [PdCl<sub>2</sub>(cod)]:**4d** molar ratio ensued in only 30% conversion. Similar catalysts resulting from **4d** and palladium(II) acetate, which is commonly used as a Pd-precursor in cross-coupling reactions [25] and even afforded very good yields of the coupling products in similar cyanation reactions [7,26], performed considerably worse (conversions <5%). Poor results were also obtained when [Pd( $\mu$ -Cl)( $\eta$ -C<sub>3</sub>H<sub>5</sub>)]<sub>2</sub> was employed as the Pd source, whereas the reaction performed in the presence of [PdCl<sub>2</sub>(cod)] (2 mol. %) without any supporting ligand did not proceed in any appreciable extent. Notably, the yields of the coupling product **7** markedly decreased when the supporting ligand **4d**, used during the screening experiments, was replaced with its more electron-rich dialkylphosphino analogues **4a–c** (see Table 3).



**Scheme 4.** Pd-catalyzed cyanation of N-protected (4-bromophenyl)alanine **6**.

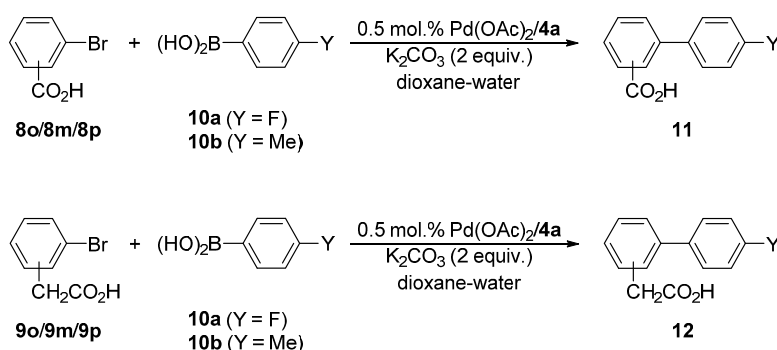


**Table 3.** Summary of the catalytic results in Pd-catalyzed cyanation of substrate **6** <sup>a</sup>.

Entry	Pd Source (Loading)	Ligand (Amount)	NMR Yield of <b>7</b> [%]
1	[PdCl <sub>2</sub> (cod)] (2 mol. %)	<b>4d</b> (4 mol. %)	100 (95 <sup>c</sup> )
2	[PdCl <sub>2</sub> (cod)] (2 mol. %)	<b>4d</b> (2 mol. %)	30
3	Pd(OAc) <sub>2</sub> (2 mol. %)	<b>4d</b> (4 mol. %)	<5%
4	Pd(OAc) <sub>2</sub> (2 mol. %)	<b>4d</b> (2 mol. %)	<5%
5	[Pd(μ-Cl)(η-C <sub>3</sub> H <sub>5</sub> ) <sub>2</sub> ] (2 mol. %) <sup>b</sup>	<b>4d</b> (2 mol. %)	<5%
6	[PdCl <sub>2</sub> (cod)] (2 mol. %)	none	0
7	[PdCl <sub>2</sub> (cod)] (2 mol. %)	<b>4a</b> (2 mol. %)	6
8	[PdCl <sub>2</sub> (cod)] (2 mol. %)	<b>4b</b> (2 mol. %)	14
9	[PdCl <sub>2</sub> (cod)] (2 mol. %)	<b>4c</b> (2 mol. %)	12

<sup>a</sup> Conditions: Substrate **6** (0.50 mmol), K<sub>2</sub>CO<sub>3</sub> (1 mmol) and K<sub>4</sub>[Fe(CN)<sub>6</sub>] (0.25 mmol) were reacted in the presence of in situ generated catalysts in dioxane–water (1:1, 4 mL) at 100 °C for 3 h. <sup>b</sup> 2 mol. % of Pd. <sup>c</sup> Isolated yield.

Next, we turned to Suzuki–Miyaura biaryl coupling, which is one of the most widely utilized cross-coupling reactions [14–17]. We chose the reactions of bromobenzoic (**8o/8m/8p**) and (bromophenyl)acetic (**9o/9m/9p**) acids with 4-fluorophenyl (**10a**) and 4-tolylboronic (**10b**) acids (Scheme 5) that can be advantageously performed in aqueous solvents, and used the most stable and accessible ligand **4d** for the initial screening experiments. The reaction conditions were optimized for the coupling of **9p** and **10a** yielding biphenyl **12pa**, which can be easily monitored by <sup>1</sup>H and <sup>19</sup>F NMR spectroscopy. The results are summarized in Table 4.

**Scheme 5.** Pd-catalyzed Suzuki–Miyaura cross-coupling of aromatic acids **8/9** with boronic acids **10a** and **10b**.

The first reaction tests were aimed at finding a suitable solvent (Table 4, entries 1–5). When performed in water at 40 °C and with a catalyst formed from [PdCl<sub>2</sub>(cod)] and **4d** (1:2 ratio, 1 mol. %), the model reaction produced the coupling product **12pa** in a decent 60% yield after 2 h and a 72% yield after 6 h. Better results were obtained in ethanol and, in particular, an ethanol–water 1:1 mixture, where the yield was 81% after 6 h. Reaction in pure dioxane proceeded to only a negligible extent (10% yield after 6 h), presumably for solubility reasons. However, the addition of water to the system markedly improved the reaction outcome. Thus, the yields of **12pa** achieved in a 1:1 dioxane–water mixture were 82% after 2 h and quantitative after 6 h at 40 °C.



**Table 4.** Summary of the optimization experiments for the model coupling of **8p** and **10a**.

Entry	Pd Source (Loading)	Ligand	Solvent	NMR Yield of <b>12pa</b> [%] after	
				2 h	6 h
1	[PdCl <sub>2</sub> (cod)] (1 mol. %)	<b>4d</b> (2 mol. %)	water	60	72
2	[PdCl <sub>2</sub> (cod)] (1 mol. %)	<b>4d</b> (2 mol. %)	ethanol	72	75
3	[PdCl <sub>2</sub> (cod)] (1 mol. %)	<b>4d</b> (2 mol. %)	ethanol–water (1:1)	72	81
4	[PdCl <sub>2</sub> (cod)] (1 mol. %)	<b>4d</b> (2 mol. %)	dioxane	0	10
5	[PdCl <sub>2</sub> (cod)] (1 mol. %)	<b>4d</b> (2 mol. %)	dioxane–water (1:1)	82	quant.
6	[PdCl <sub>2</sub> (cod)] (1 mol. %)	<b>4d</b> (1 mol. %)	dioxane–water (1:1)	41	n.a.
7	Pd(OAc) <sub>2</sub> (1 mol. %)	<b>4d</b> (2 mol. %)	dioxane–water (1:1)	78	n.a.
8	Pd(OAc) <sub>2</sub> (1 mol. %)	<b>4d</b> (1 mol. %)	dioxane–water (1:1)	85	n.a.
9	[Pd(μ-Cl)(η-C <sub>3</sub> H <sub>5</sub> ) <sub>2</sub> ] (1 mol. %) <sup>b</sup>	<b>4d</b> (1 mol. %)	dioxane–water (1:1)	0	n.a.
10	Pd(OAc) <sub>2</sub> (1 mol. %)	none	dioxane–water (1:1)	56	n.a.
11	Pd(OAc) <sub>2</sub> (0.5 mol. %)	<b>4a</b> (0.5 mol. %)	dioxane–water (1:1)	79	98
12	Pd(OAc) <sub>2</sub> (0.5 mol. %)	<b>4b</b> (0.5 mol. %)	dioxane–water (1:1)	74	88
13	Pd(OAc) <sub>2</sub> (0.5 mol. %)	<b>4c</b> (0.5 mol. %)	dioxane–water (1:1)	43	67
14	Pd(OAc) <sub>2</sub> (0.5 mol. %)	<b>4d</b> (0.5 mol. %)	dioxane–water (1:1)	85	89

<sup>a</sup> Conditions: substrates **8p** (1.0 mmol) and **10a** (1.15 mmol) were reacted in the presence of in situ generated catalysts and K<sub>2</sub>CO<sub>3</sub> (2.0 mmol) in 4 mL of the respective solvent at 40 °C. n.a. = not available. <sup>b</sup> 1 mol. % of Pd.

Evaluation of different Pd(II) precursors performed next (Table 4, entries 5–13) revealed that the best yield of the coupling product (85%) is obtained with a catalyst resulting in situ from palladium(II) acetate and 1 equiv. of the amidosulfonate ligand **4d**. Addition of another equivalent of **4d** slightly reduced the yield of **12pa**. A different trend was noted for [PdCl<sub>2</sub>(cod)] in which case the catalyst obtained after the addition of 2 equiv. of **4d** achieved a higher yield than the analogous catalyst after the addition of only 1 equiv. of the supporting ligand. The catalyst generated from [Pd(μ-Cl)(η-C<sub>3</sub>H<sub>5</sub>)<sub>2</sub>] and **4d** (1 equiv. per Pd atom) proved to be inactive. It is also noteworthy that unsupported palladium(II) acetate also catalyzed the reaction but the yield was substantially lower than for both tested Pd(OAc)<sub>2</sub>/**4d** catalysts.

In the last step, we have compared catalysts resulting from palladium(II) acetate and different ligands **4**. For this purpose, the metal loading was reduced to 0.5 mol. % and the reaction was monitored after 2 h and 6 h to check whether the catalysts retain their activity. In the case of the Pd(OAc)<sub>2</sub>/**4d** catalyst, the yields achieved after 2 and 6 h were 85% and 89%, respectively. Analogous catalyst resulting from **4b** showed a similar yield after 6 h (namely 88%) but a significantly lower yield after 2 h (only 74%), which may suggest a slower catalyst activation and/or slower reaction rate [6]. A similar situation was noted in the case of ligand **4a** possessing diisopropylphosphino substituent, except that the yield of **12pa** after 6 h was the highest among the catalysts tested (nearly quantitative). In contrast, catalysts resulting from the most bulky and electron-rich ligand **4c** acquired the lowest conversions in the entire series, presumably due to rapid deactivation [10]. Based on these results, the Pd(OAc)<sub>2</sub>/**4a** catalyst (0.5 mol. % Pd) was chosen for the following reaction scope tests, which were limited to aryl bromides because the reaction with (4-chlorophenyl)acetic acid and **10a** did not yield any coupling product (0.5 mol. % Pd(OAc)<sub>2</sub>/**4a**, dioxane–water, 40 or 80 °C/6 h).

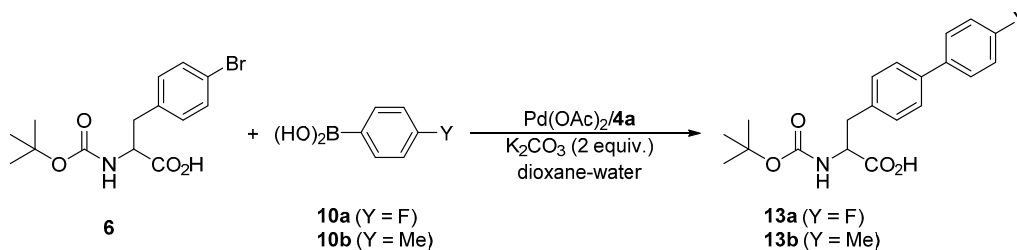
The results collected in Table 5 reveal several trends. First of all, both 2-bromobenzoic and (2-bromophenyl)acetic acid reacted only sluggishly with arylboronic acids **10a/b**, which can be ascribed to a steric hindrance. All other isomeric aryl bromide substrates reacted well, achieving very good to practically complete conversions. In all cases, the reactions with **10a** bearing the electron-withdrawing substituent proceeded with higher conversions than those with **10b**. The differences in pairs of the analogous reactions involving **10a** and **10b** were considerably larger for *ortho*- and *para*-substituted aryl bromides than for their *meta*-substituted counterparts, which in turn points to a dominant electronic influence (*I*- and *M*-effect).

**Table 5.** Summary of the reaction scope tests <sup>a</sup>.

Entry	Aryl Bromide	Boronic Acid	Product	NMR Yield [%]	Isolated Yield [%]
1	<b>8o</b>	<b>10a</b>	<b>11oa</b>	19	n.d.
2	<b>8m</b>	<b>10a</b>	<b>11ma</b>	89	67
3	<b>8p</b>	<b>10a</b>	<b>11pa</b>	92	77
4	<b>8o</b>	<b>10b</b>	<b>11ob</b>	24	n.d.
5	<b>8m</b>	<b>10b</b>	<b>11mb</b>	88	77
6	<b>8p</b>	<b>10b</b>	<b>11pb</b>	84	64
7	<b>9o</b>	<b>10a</b>	<b>12oa</b>	<5	n.d.
8	<b>9m</b>	<b>10a</b>	<b>12ma</b>	97	78
9	<b>9p</b>	<b>10a</b>	<b>12pa</b>	98	78
10	<b>9o</b>	<b>10b</b>	<b>12ob</b>	12	n.d.
11	<b>9m</b>	<b>10b</b>	<b>12mb</b>	93	90
12	<b>9p</b>	<b>10b</b>	<b>12pb</b>	80	71

<sup>a</sup> Conditions: the respective substrates **8/9** (1.0 mmol) and **10** (1.15 mmol) were reacted in the presence of a catalyst generated from palladium(II) acetate (0.5 mol.%) and ligand **4a** (1 equiv. with respect to Pd) and K<sub>2</sub>CO<sub>3</sub> (2.0 mmol) as the base in 4 mL of dioxane–water (1:1) at 40 °C. n.d. = not determined.

Attempted coupling of 4-bromophenyl alanine substrate **6** with **10a** and **10b** (Scheme 6) under similar conditions proceeded satisfactorily, producing the biphenyl amino acids **13a** and **13b**, respectively, in approximately 90% yields (Table 6). Unfortunately, these products could not be separated from unreacted **6a** either by chromatography or crystallization due to a similar retention characteristic and reluctance to crystallize, respectively. Upon increasing the amount of the catalyst to 1 mol. %, the reaction achieved complete conversions within 6 h at 40 °C, which in turn allowed for the isolation of the pure products **13** in good yields. Notably, NMR analysis of the crude reaction mixtures revealed that the Boc-protecting group is stable under the reaction conditions, which is indeed manifested in the good yields.

**Scheme 6.** Pd-catalyzed Suzuki–Miyaura biaryl coupling involving substrate **6**.**Table 6.** Reactions of **10a/b** with amino acid **6** <sup>a</sup>.

Entry	Boronic Acid	Product	Pd Loading	NMR Yield [%]	Isolated Yield [%]
1	<b>10a</b>	<b>13a</b>	0.5 mol. %	88	n.d.
2	<b>10b</b>	<b>13b</b>	0.5 mol. %	91	n.d.
3	<b>10a</b>	<b>13a</b>	1.0 mol. %	100	76
4	<b>10b</b>	<b>13b</b>	1.0 mol. %	100	83

<sup>a</sup> Conditions: compound **6** (1.0 mmol) and **10a** or **10b** (1.15 mmol) were reacted in the presence of a catalyst generated from palladium(II) acetate (0.5 or 1.0 mol. %) and ligand **4a** (1 equiv.) and K<sub>2</sub>CO<sub>3</sub> (2.0 mmol) as the base in 4 mL of dioxane–water (1:1) at 40 °C for 6 h. n.d. = not determined.

### 3. Experimental

#### 3.1. Materials and Methods

Compounds **1a–c** [10] and **4d** [7] were prepared according to the literature methods. Anhydrous dichloromethane was obtained from a PureSolv MD5 Solvent Purification System (Innovative

Technology Inc., Amesbury, MA, USA). Triethylamine and dioxane were distilled from sodium metal. Other chemicals (Alfa-Aesar or Sigma-Aldrich, Ward Hill, MA, USA; Saint Louis, MO, USA), anhydrous *N,N*-dimethylformamide over molecular sieves (Sigma-Aldrich), anhydrous ethanol (Penta, Prague, Czech Republic) and all solvents (reagent grade from Lach-Ner, Neratovice, Czech Republic) used for workup, column chromatography and crystallizations were without any additional purification.

NMR spectra were recorded at 298 K on a Varian Unity Inova 400 spectrometer ( $^1\text{H}$ , 399.95 MHz;  $^{13}\text{C}$ , 100.58 MHz; and  $^{31}\text{P}$ , 161.90 MHz) or a Bruker AVANCE III 400 spectrometer ( $^1\text{H}$ , 400.13 MHz;  $^{13}\text{C}\{^1\text{H}\}$ , 100.62 MHz;  $^{19}\text{F}$ , 376.46 MHz; and  $^{31}\text{P}$ , 161.97 MHz). Chemical shifts ( $\delta$ /ppm) are given relative to internal tetramethylsilane ( $^1\text{H}$  and  $^{13}\text{C}$  NMR), to external 85% aqueous  $\text{H}_3\text{PO}_4$  ( $^{31}\text{P}$  NMR), and to external neat  $\text{CFCl}_3$  ( $^{19}\text{F}$  NMR), respectively. In addition to the standard notation of NMR signals, vt and vq are used to distinguish virtual triplets and quartets arising from the C=O and phosphine-substituted cyclopentadienyl rings, respectively. Conventional low-resolution electrospray ionization mass spectra (ESI MS) were recorded with an Esquire 3000 (Bruker). High-resolution (HR) analyses were performed with a compact Q-TOF (Bruker Daltonik) instrument. The samples were dissolved in HPLC-grade methanol. Infrared spectra were collected in Nujol mulls on a FTIR Thermo Fisher Nicolet 760 instrument in the range 400–4000  $\text{cm}^{-1}$ .

### 3.2. General Procedure for the Synthesis of Esters $\text{H}_3\text{B}\cdot\text{R}_2\text{PfcCO}_2\text{C}_6\text{F}_5$ (**2a–c**)

The respective acids  $\text{H}_3\text{B}\cdot\text{R}_2\text{PfcCO}_2\text{H}$  (**1a–c**, 5.0 mmol), 1-ethyl-3-[3-(dimethylamino)propyl]-carbodiimide hydrochloride (1.15 g, 6.0 mmol), pentafluorophenol (1.10 g, 6.0 mmol) and 4-(dimethylamino)pyridine (122 mg, 1.0 mmol) were dissolved in dichloromethane (50 mL). After stirring overnight, brine (50 mL) was added to the reaction mixture and stirring was continued for another 10 min. Then, the organic layer was separated and washed with brine (50 mL). The combined aqueous phases were back-extracted with dichloromethane (20 mL). The combined organic layers were dried over anhydrous  $\text{MgSO}_4$  and evaporated to dryness. The crude product was purified by flash column chromatography over silica gel as described below.

#### 3.2.1. Preparation of $i\text{Pr}_2\text{PfcCO}_2\text{C}_6\text{F}_5\cdot\text{BH}_3$ (**2a**)

Ester **2a** was synthesized from acid **1a** (1.80 g, 5.0 mmol) following the general procedure and isolated as an orange solid. Ethyl acetate-hexane (1:8) was used during the chromatography. Only the first band from the product was collected. Yield: 2.46 g (94%).

$^1\text{H}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  0.15–1.10 (br m, 3 H,  $\text{BH}_3$ ), 1.16 (dd,  $^3J_{\text{HH}} = 7.1$  Hz,  $^3J_{\text{PH}} = 2.7$  Hz, 6 H,  $\text{CHMe}_2$ ), 1.19 (dd,  $^3J_{\text{HH}} = 7.1$  Hz,  $^3J_{\text{PH}} = 3.5$  Hz, 6 H,  $\text{CHMe}_2$ ), 2.16 (d of sept,  $^2J_{\text{PH}} = 10.1$  Hz,  $^3J_{\text{HH}} = 7.1$  Hz, 2 H,  $\text{CHMe}_2$ ), 4.52 (vq,  $J' = 1.8$  Hz, 2 H, fc), 4.61 (d of vt,  $J' \approx 0.9$ , 1.9 Hz, 2 H, fc), 4.80 (vt,  $J' = 2.0$  Hz, 2 H, fc), 5.06 (vt,  $J' = 2.0$  Hz, 2 H, fc).  $^{13}\text{C}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  17.16 (s, 2 C,  $\text{CHMe}_2$ ), 17.47 (d,  $^2J_{\text{PC}} = 2$  Hz, 2 C,  $\text{CHMe}_2$ ), 22.58 (d,  $^1J_{\text{PC}} = 35$  Hz, 2 C,  $\text{CHMe}_2$ ), 68.05 (s,  $\text{C}_{\text{ipso}}\text{-CO}$  of fc), 70.65 (d,  $^1J_{\text{PC}} = 53$  Hz,  $\text{C}_{\text{ipso}}\text{-P}$  of fc), 72.32 (s, 2 C, CH of fc), 73.44 (d,  $J_{\text{PC}} = 7$  Hz, 2 C, CH of fc), 73.59 (d,  $J_{\text{PC}} = 6$  Hz, 2 C, CH of fc), 75.43 (s, 2 C, CH of fc), 125.16 (s,  $\text{C}_{\text{ipso}}$  of  $\text{C}_6\text{F}_5$ ), 137.96 (dm,  $^1J_{\text{FC}} = 253$  Hz,  $\text{C}_{\text{meta}}$  of  $\text{C}_6\text{F}_5$ ), 139.45 (dm,  $^1J_{\text{FC}} = 253$  Hz,  $\text{C}_{\text{para}}$  of  $\text{C}_6\text{F}_5$ ), 141.48 (dm,  $^1J_{\text{FC}} = 250$  Hz,  $\text{C}_{\text{ortho}}$  of  $\text{C}_6\text{F}_5$ ), 167.45 (s, C=O).  $^{19}\text{F}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta = -162.60$  (m,  $\text{F}_{\text{meta}}$  of  $\text{C}_6\text{F}_5$ ),  $-158.34$  (t,  $^3J_{\text{FF}} = 22$  Hz,  $\text{F}_{\text{para}}$  of  $\text{C}_6\text{F}_5$ ),  $-153.08$  (m,  $\text{F}_{\text{ortho}}$  of  $\text{C}_6\text{F}_5$ ) ppm.  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  31.9 (br d). IR (Nujol): 2373 m, 2342 m, 1768 s, 1522 s, 1305 w, 1261 (s), 1203 w, 1169 w, 1142 w, 1072 s, 1058 m, 1023 m, 1011 m, 974 m, 885 m, 870 w, 852 w, 833 w, 753 w, 639 w, 611 w, 531 w, 505 w  $\text{cm}^{-1}$ . MS (ESI+):  $m/z$  549.1 ( $[\text{M} + \text{Na}]^+$ ), 565.1 ( $[\text{M} + \text{K}]^+$ ). Anal. Calc. for  $\text{C}_{23}\text{H}_{25}\text{BF}_5\text{FeO}_2\text{P}$  (526.06): C 52.51, H 4.79%. Found: C 52.50, H 4.69%.

### 3.2.2. Preparation of $\text{Cy}_2\text{PfcCO}_2\text{C}_6\text{F}_5\cdot\text{BH}_3$ (**2b**)

Ester **2b** was obtained from acid **1b** (2.20 g, 5.0 mmol) as described above and isolated as an orange solid. Ethyl acetate-hexane (1:10) was used during the chromatography. Only the first band from the product was collected. Yield: 2.54 g (84%).

$^1\text{H}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  0.15–1.05 (br m, 3 H,  $\text{BH}_3$ ), 1.10–1.40 (m, 10 H, Cy), 1.65–1.73 (m, 2 H, Cy), 1.75–2.01 (m, 10 H, Cy), 4.49 (vt,  $J' = 1.8$  Hz, 2 H, fc), 4.60 (d of vt,  $J' \approx 0.9$ , 1.8 Hz, 2 H, fc), 4.78 (vt,  $J' = 2.0$  Hz, 2 H, fc), 5.04 (vt,  $J' = 2.0$  Hz, 2 H, fc).  $^{13}\text{C}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  25.89 (d,  $J_{\text{PC}} = 1$  Hz, 2 C,  $\text{CH}_2$  of Cy), 26.77 (d,  $J_{\text{PC}} = 2$  Hz, 2 C,  $\text{CH}_2$  of Cy), 26.88 (d,  $J_{\text{PC}} = 1$  Hz, 2 C,  $\text{CH}_2$  of Cy), 26.95 (s, 2 C,  $\text{CH}_2$  of Cy), 27.27 (d,  $J_{\text{PC}} = 2$  Hz, 2 C,  $\text{CH}_2$  of Cy), 32.33 (d,  $J_{\text{PC}} = 34$  Hz, 2 C, CH of Cy), 68.03 (s,  $\text{C}_{\text{ipso}}\text{-CO}$  of fc), 71.31 (d,  $J_{\text{PC}} = 53$  Hz,  $\text{C}_{\text{ipso}}\text{-P}$  of fc), 72.34 (s, 2 C, CH of fc), 73.42 (d,  $J_{\text{PC}} = 6$  Hz, 2 C, CH of fc), 73.58 (d,  $J_{\text{PC}} = 7$  Hz, 2 C, CH of fc), 75.39 (s, 2 C, CH of fc), 125.18 (m,  $\text{C}_{\text{ipso}}$  of  $\text{C}_6\text{F}_5$ ), 137.95 (dm,  $J_{\text{FC}} = 252$  Hz,  $\text{C}_{\text{meta}}$  of  $\text{C}_6\text{F}_5$ ), 139.44 (dm,  $J_{\text{FC}} = 253$  Hz,  $\text{C}_{\text{para}}$  of  $\text{C}_6\text{F}_5$ ), 141.38 (dm,  $J_{\text{FC}} = 251$  Hz,  $\text{C}_{\text{ortho}}$  of  $\text{C}_6\text{F}_5$ ), 167.46 (s, C=O).  $^{19}\text{F}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta = -162.62$  (m,  $\text{F}_{\text{meta}}$  of  $\text{C}_6\text{F}_5$ ),  $-158.33$  (t,  $J_{\text{FF}} = 22$  Hz,  $\text{F}_{\text{para}}$  of  $\text{C}_6\text{F}_5$ ),  $-153.10$  (m,  $\text{F}_{\text{ortho}}$  of  $\text{C}_6\text{F}_5$ ) ppm.  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  24.3 (br d). IR (Nujol): 2373 m, 2342 m, 1768 s, 1522 s, 1305 w, 1261 m, 1203 w, 1169 w, 1142 w, 1072 s, 1058 m, 1023 m, 1011 s, 974 m, 885 m, 870 w, 852 w, 833 w, 753 w, 639 w, 611 w, 531 w, 505 w  $\text{cm}^{-1}$ . MS (ESI+):  $m/z$  629.2 ( $[\text{M} + \text{Na}]^+$ ), 645.1 ( $[\text{M} + \text{K}]^+$ ). Anal. Calc. for  $\text{C}_{29}\text{H}_{33}\text{BF}_5\text{FeO}_2\text{P}$  (606.18): C 57.50, H 5.50%. Found: C 57.46, H 5.49%.

### 3.2.3. Preparation of $\text{H}_3\text{B}\cdot t\text{Bu}_2\text{PfcCO}_2\text{C}_6\text{F}_5$ (**2c**)

Ester **2c** was synthesized from **1c** (1.94 g, 5.0 mmol) by using the general procedure and isolated as an orange solid. Ethyl acetate-hexane (1:8) was used during the column chromatography. Only the first band from the product was collected. Yield: 2.06 g (93%).

$^1\text{H}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  0.20–1.20 (br m, 3 H,  $\text{BH}_3$ ), 1.30 (d,  $J_{\text{PH}} = 12.9$  Hz, 18 H,  $\text{CMe}_3$ ), 4.62–4.65 (m, 4 H, fc), 4.80 (vt,  $J' = 2.0$  Hz, 2 H, fc), 5.03 (vt,  $J' = 2.0$  Hz, 2 H, fc).  $^{13}\text{C}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  28.64 (d,  $J_{\text{PC}} = 2$  Hz, 6 C,  $\text{CMe}_3$ ), 33.42 (d,  $J_{\text{PC}} = 27$  Hz, 2 C,  $\text{CMe}_3$ ), 67.95 (s,  $\text{C}_{\text{ipso}}\text{-CO}$  of fc), 72.46 (s, 2 C, CH of fc), 72.76 (d,  $J_{\text{PC}} = 48$  Hz,  $\text{C}_{\text{ipso}}\text{-P}$  of fc), 73.51 (d,  $J_{\text{PC}} = 6$  Hz, 2 C, CH of fc), 74.91 (d,  $J_{\text{PC}} = 6$  Hz, 2 C, CH of fc), 75.92 (s, 2 C, CH of fc), 125.18 (m,  $\text{C}_{\text{ipso}}$  of  $\text{C}_6\text{F}_5$ ), 137.92 (dm,  $J_{\text{FC}} = 252$  Hz,  $\text{C}_{\text{meta}}$  of  $\text{C}_6\text{F}_5$ ), 139.44 (dm,  $J_{\text{FC}} = 253$  Hz,  $\text{C}_{\text{para}}$  of  $\text{C}_6\text{F}_5$ ), 143.37 (dm,  $J_{\text{FC}} = 251$  Hz,  $\text{C}_{\text{ortho}}$  of  $\text{C}_6\text{F}_5$ ), 167.45 (s, C=O).  $^{19}\text{F}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta = -162.60$  (m,  $\text{F}_{\text{meta}}$  of  $\text{C}_6\text{F}_5$ ),  $-158.35$  (t,  $J_{\text{FF}} = 22$  Hz,  $\text{F}_{\text{para}}$  of  $\text{C}_6\text{F}_5$ ),  $-153.01$  (m,  $\text{F}_{\text{ortho}}$  of  $\text{C}_6\text{F}_5$ ) ppm.  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  45.5 (br d). IR (Nujol): 2391 m, 2363 m, 2344 m, 1752 s, 1521 s, 1304 w, 1267 s, 1162 w, 1144 w, 1080 s, 1057 w, 1026 m, 1006 w, 995 m, 980 w, 910 w, 895 m, 874 w, 852 w, 833 m, 815 w, 755 w, 647 w, 626 w, 573 w, 531 w, 514 w  $\text{cm}^{-1}$ . MS (ESI+):  $m/z$  577.2 ( $[\text{M} + \text{Na}]^+$ ), 593.1 ( $[\text{M} + \text{K}]^+$ ). Anal. Calc. for  $\text{C}_{25}\text{H}_{29}\text{BF}_5\text{FeO}_2\text{P}$  (554.11): C 54.19, H 5.28%. Found: C 54.18, H 5.22%.

### 3.3. General Procedure for the Synthesis of Amides $\text{R}_2\text{PfcCONHCH}_2\text{SO}_3(\text{HNEt}_3)\cdot\text{BH}_3$ (**3a–c**)

The respective ester **1** (3.0 mmol), aminomethanesulfonic acid (0.51 g, 4.5 mmol) and 4-(dimethylamino)pyridine (122 mg, 1.0 mmol) were dissolved in a mixture of *N,N*-dimethylformamide (10 mL) and triethylamine (2 mL). After stirring overnight, the solvents were evaporated under vacuum and the residual DMF was removed by trituration with diethyl ether (50 mL). The crude product was purified by flash column chromatography over silica gel. The column was packed in  $\text{CH}_2\text{Cl}_2\text{--MeOH--Et}_3\text{N}$  (100:5:5) and the product was eluted with  $\text{CH}_2\text{Cl}_2\text{--MeOH}$  (100:5). The first orange band was collected and evaporated. The solid residue was triturated with diethyl ether ( $3 \times 20$  mL) to remove residual triethylamine and, finally, dried under vacuum.

### 3.3.1. Preparation of $i\text{Pr}_2\text{PfcCONHCH}_2\text{SO}_3(\text{HNEt}_3)\cdot\text{BH}_3$ (**3a**)

Amide **3a** was synthesized from ester **2a** (1.58 g, 3.0 mmol) following the general procedure described above and isolated as an orange crystalline solid after crystallization from hot ethyl acetate. Yield: 1.32 g (79%).

$^1\text{H}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  0.10–1.10 (br m, 3 H,  $\text{BH}_3$ ), 1.11 (dd,  $^3J_{\text{HH}} = 7.1$  Hz,  $^3J_{\text{PH}} = 1.4$  Hz, 6 H,  $\text{CHMe}_2$ ), 1.15 (d,  $^3J_{\text{HH}} = 7.1$  Hz, 6 H,  $\text{CHMe}_2$ ), 1.31 (t,  $^3J_{\text{HH}} = 7.3$  Hz, 9 H,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 2.13 (d of sept,  $^2J_{\text{PH}} = 10.1$  Hz,  $^3J_{\text{HH}} = 7.1$  Hz, 2 H,  $\text{CHMe}_2$ ), 3.10 (q,  $^3J_{\text{HH}} = 7.3$  Hz, 6 H,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 4.40 (vq,  $J' = 1.7$  Hz, 2 H, fc), 4.43 (d,  $^3J_{\text{HH}} = 6.6$  Hz, 2 H,  $\text{CH}_2\text{N}$ ), 4.50 (vt,  $J' = 2.0$  Hz, 2 H, fc), 4.65 (d of vt,  $J' \approx 0.9$ , 1.9 Hz, 2 H, fc), 4.83 (vt,  $J' = 2.0$  Hz, 2 H, fc), 6.92 (t,  $^3J_{\text{HH}} = 6.5$  Hz, 1 H, NH).  $^{13}\text{C}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  8.85 (s, 3 C,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 17.30 (s, 2 C,  $\text{CHMe}_2$ ), 17.62 (d,  $^2J_{\text{PC}} = 2$  Hz, 2 C,  $\text{CHMe}_2$ ), 22.82 (d,  $^1J_{\text{PC}} = 35$  Hz, 2 C,  $\text{CHMe}_2$ ), 46.46 (s, 3 C,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 56.05 (s,  $\text{CH}_2\text{N}$ ), 69.36 (d,  $^1J_{\text{PC}} = 55$  Hz,  $\text{C}_{\text{ipso-P}}$  of fc), 70.09 (s, 2 C, CH of fc), 73.35 (s, 2 C, CH of fc), 73.59 (s, 2 C, CH of fc), 73.66 (d,  $J_{\text{PC}} = 1$  Hz, 2 C, CH of fc), 76.96 (s,  $\text{C}_{\text{ipso-CO}}$  of fc), 169.54 (s, C=O).  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  31.6 (br d). IR (Nujol): 3312 m, 2376 w, 2360 m, 2332 m, 1654 s, 1533 s, 1499 m, 1366 m, 1313 w, 1285 w, 1245 m, 1216 m, 1165 s, 1070 m, 1035 m, 1012 m, 980 m, 899 w, 888 w, 868 w, 852 w, 840 m, 831 m, 812 w, 797 w, 754 m, 692 w, 667 w, 632 w, 615 m, 585 w, 535 w, 515  $\text{cm}^{-1}$ . MS (ESI+):  $m/z$  555.2 ( $[\text{M} + \text{H}]^+$ ), 656.4 ( $[\text{M} + \text{HNEt}_3]^+$ ); MS (ESI−):  $m/z$  451.9 ( $[\text{M} - \text{HNEt}_3]^+$ ). Anal. Calc. for  $\text{C}_{24}\text{H}_{44}\text{BFeN}_2\text{O}_4\text{PS}$  (554.30): C 52.00, H 8.00, N 5.06%. Found: C 51.90, H 8.03, N 4.93%.

### 3.3.2. Preparation of $\text{Cy}_2\text{PfcCONHCH}_2\text{SO}_3(\text{HNEt}_3)\cdot\text{BH}_3$ (**3b**)

Amide **3b** was synthesized from **2b** (1.82 g, 3.0 mmol) according to the general procedure and was isolated as an orange crystalline solid after crystallization from hot ethyl acetate. Yield: 1.67 g (88%).

$^1\text{H}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  0.04–1.04 (br m, 3 H,  $\text{BH}_3$ ), 1.08–1.38 (m, 10 H, Cy), 1.31 (t,  $^3J_{\text{HH}} = 7.3$  Hz, 9 H,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 1.64–1.71 (m, 2 H, Cy), 1.74–1.99 (m, 10 H, Cy), 3.11 (q,  $^3J_{\text{HH}} = 7.3$  Hz, 6 H,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 4.37 (vq,  $J' = 1.8$  Hz, 2 H, fc), 4.42 (d,  $^3J_{\text{HH}} = 6.6$  Hz, 2 H,  $\text{CH}_2\text{N}$ ), 4.47 (vt,  $J' = 2.0$  Hz, 2 H, fc), 4.64 (d of vt,  $J' \approx 0.9$ , 1.8 Hz, 2 H, fc), 4.80 (vt,  $J' = 1.9$  Hz, 2 H, fc), 6.85 (t,  $^3J_{\text{HH}} = 6.6$  Hz, 1 H, NH).  $^{13}\text{C}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  8.87 (s, 3 C,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 26.39 (d,  $J_{\text{PC}} = 2$  Hz, 2 C,  $\text{CH}_2$  of Cy), 27.15–27.30 (m, 6 C,  $\text{CH}_2$  of Cy), 27.57 (d,  $J_{\text{PC}} = 2$  Hz, 2 C,  $\text{CH}_2$  of Cy), 32.49 (d,  $^1J_{\text{PC}} = 35$  Hz, 2 C, CH of Cy), 46.50 (s, 3 C,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 56.02 (s,  $\text{CH}_2\text{N}$ ), 69.99 (d,  $^1J_{\text{PC}} = 55$  Hz,  $\text{C}_{\text{ipso-P}}$  of fc), 70.04 (s, 2 C, CH of fc), 73.35 (s, 2 C, CH of fc), 73.48 (d,  $J_{\text{PC}} = 7$  Hz, 2 C, CH of fc), 73.70 (d,  $J_{\text{PC}} = 7$  Hz, 2 C, CH of fc), 76.98 (s,  $\text{C}_{\text{ipso-CO}}$  of fc), 169.44 (s, C=O).  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  24.1 (br d). IR (Nujol): 3531 m, 3456 m, 3337 m, 2378 m, 2334 m, 1648 s, 1523 m, 1296 w, 1253 w, 1211 m, 1168 s, 1053 m, 890 w, 853 w, 826 w, 765 w, 635 w, 616 w, 528 w, 506  $\text{cm}^{-1}$ . MS (ESI+):  $m/z$  635.2 ( $[\text{M} + \text{H}]^+$ ), 736.5 ( $[\text{M} + \text{HNEt}_3]^+$ ); MS (ESI−):  $m/z$  532.0 ( $[\text{M} - \text{HNEt}_3]^+$ ). Anal. Calc. for  $\text{C}_{30}\text{H}_{52}\text{BFeN}_2\text{O}_4\text{PS}$  (634.43): C 56.79, H 8.26, N 4.42%. Found: C 56.64, H 8.31, N 4.29%.

### 3.3.3. Preparation of $t\text{Bu}_2\text{PfcCONHCH}_2\text{SO}_3(\text{HNEt}_3)\cdot\text{BH}_3$ (**3c**)

Amide **3c** was synthesized from **2c** (1.66 g, 3.0 mmol) according to the general procedure and isolated as an orange solid. The compound decomposes upon attempted crystallization. Yield: 1.62 g (92%).

$^1\text{H}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  0.15–1.15 (br m, 3 H,  $\text{BH}_3$ ), 1.27 (d,  $^3J_{\text{PH}} = 12.8$  Hz, 18 H,  $\text{CMe}_3$ ), 1.31 (t,  $^3J_{\text{HH}} = 7.3$  Hz, 9 H,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 3.10 (q,  $^3J_{\text{HH}} = 7.3$  Hz, 6 H,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 4.43 (d,  $^3J_{\text{HH}} = 6.6$  Hz, 2 H,  $\text{CH}_2\text{N}$ ), 4.48 (vt,  $J' = 2.0$  Hz, 2 H, fc), 4.50 (vq,  $J' = 1.7$  Hz, 2 H, fc), 4.69 (d of vt,  $J' \approx 0.9$ , 1.9 Hz, 2 H, fc), 4.80 (vt,  $J' = 2.0$  Hz, 2 H, fc), 6.91 (t,  $^3J_{\text{HH}} = 6.5$  Hz, 1 H, NH).  $^{13}\text{C}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  8.86 (s, 3 C,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 28.84 (d,  $^2J_{\text{PC}} = 2$  Hz, 6 C,  $\text{CMe}_3$ ), 33.60 (d,  $^1J_{\text{PC}} = 28$  Hz, 2 C,  $\text{CMe}_3$ ), 46.44 (s, 3 C,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 56.03 (s,  $\text{CH}_2\text{N}$ ), 70.23 (s, 2 C, CH of fc), 71.66 (d,  $^1J_{\text{PC}} = 49$  Hz,  $\text{C}_{\text{ipso-P}}$  of fc), 73.49 (d,  $J_{\text{PC}} = 6$  Hz, 2 C, CH of fc), 73.85 (s, 2 C, CH of fc), 75.16 (d,  $J_{\text{PC}} = 7$  Hz, 2 C, CH of fc), 76.93 (s,  $\text{C}_{\text{ipso-CO}}$  of fc), 169.42 (s, C=O).  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  45.1 (br m). IR (Nujol): 3296 m,

2382 m, 2363 m, 2343 m, 1656 s, 1517 m, 1498 m, 1316 w, 1299 w, 1251 w, 1211 m, 1161 s, 1068 w, 1039 s, 1014 m, 983 m, 895 w, 858 w, 838 w, 814 w, 751 w, 647 w, 613 w, 598 w, 516 w  $\text{cm}^{-1}$ . MS (ESI+):  $m/z$  684.4 ( $[\text{M} + \text{HNEt}_3]^+$ ), 605.3 ( $[\text{M} + \text{Na}]^+$ ); MS (ESI−):  $m/z$  479.9 ( $[\text{M} - \text{HNEt}_3]^+$ ). Anal. Calc. for  $\text{C}_{26}\text{H}_{48}\text{BFeN}_2\text{O}_4\text{PS} \cdot 0.1\text{CH}_2\text{Cl}_2$  (590.84): C 53.05, H 8.22, N 4.74%. Found: C 52.98, H 7.88, N 4.49%.

### 3.4. General Procedure for Deprotection of Borane Adducts 3

A Schlenk flask was charged with a borane adduct **3** (1.5 mmol) and freshly distilled morpholine (10 mL). The reaction mixture was thoroughly degassed by five freeze–pump–thaw cycles and then heated at 65 °C for 16 h. Next, the morpholine was removed under vacuum and the crude product was purified by flash column chromatography over silica gel. The chromatographic column was packed in  $\text{CH}_2\text{Cl}_2$ –MeOH– $\text{Et}_3\text{N}$  (100:5:5) and the product was eluted with  $\text{CH}_2\text{Cl}_2$ –MeOH (100:5). The first orange band was collected and evaporated. The residue was triturated with diethyl ether (3 × 20 mL) to remove residual triethylamine.

#### 3.4.1. Preparation of $i\text{Pr}_2\text{PfcCONHCH}_2\text{SO}_3(\text{HNEt}_3)$ (**4a**)

Amide **4a** was prepared from **3a** (0.831 g, 1.5 mmol) as outlined above and isolated as an orange crystalline solid after crystallization from hot ethyl acetate. Yield: 0.657 g (81%).

$^1\text{H}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  1.05 (dd,  $^3J_{\text{HH}} = 7.0$  Hz,  $^3J_{\text{PH}} = 2.1$  Hz, 6 H,  $\text{CHMe}_2$ ), 1.08 (dd,  $^3J_{\text{HH}} = 7.0$  Hz,  $^3J_{\text{PH}} = 4.2$  Hz, 6 H,  $\text{CHMe}_2$ ), 1.32 (t,  $^3J_{\text{HH}} = 7.3$  Hz, 9 H,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 1.91 (d of sept,  $^2J_{\text{PH}} = 2.0$  Hz,  $^3J_{\text{HH}} = 7.3$  Hz, 2 H,  $\text{CHMe}_2$ ), 3.12 (q,  $^3J_{\text{HH}} = 7.3$  Hz, 6 H,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 4.25 (vq,  $J' = 1.6$  Hz, 2 H, fc), 4.31 (vt,  $J' = 1.9$  Hz, 2 H, fc), 4.41 (d,  $^3J_{\text{HH}} = 6.5$  Hz, 2 H,  $\text{CH}_2\text{N}$ ), 4.47 (vt,  $J' = 1.8$  Hz, 2 H, fc), 4.68 (vt,  $J' = 1.9$  Hz, 2 H, fc), 6.77 (t,  $^3J_{\text{HH}} = 5.8$  Hz, 1 H, NH).  $^{13}\text{C}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  8.90 (s, 3 C,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 20.03 (d,  $^2J_{\text{PC}} = 11$  Hz, 2 C,  $\text{CHMe}_2$ ), 20.25 (d,  $^2J_{\text{PC}} = 15$  Hz, 2 C,  $\text{CHMe}_2$ ), 23.76 (d,  $^1J_{\text{PC}} = 12$  Hz, 2 C,  $\text{CHMe}_2$ ), 46.61 (s, 2 C,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 56.08 (s,  $\text{CH}_2\text{N}$ ), 69.66 (s, 2 C, CH of fc), 72.21 (d,  $J_{\text{PC}} = 2$  Hz, 2 C, CH of fc), 72.75 (s, 2 C, CH of fc), 73.13 (d,  $J_{\text{PC}} = 10$  Hz, 2 C, CH of fc), 76.28 (s,  $\text{C}_{\text{ipso}}\text{-CO}$  of fc), 76.28 (d,  $^1J_{\text{PC}} = 10$  Hz,  $\text{C}_{\text{ipso}}\text{-P}$  of fc), 170.09 (s, C=O).  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  − 0.1 (s). IR (Nujol): 3509 s, 3448 s, 3285 s, 1659 s, 1637 s, 1540 s, 1342 w, 1315 m, 1286 m, 1243 m, 1209 m, 1157 s, 1073 w, 1038 s, 964 w, 893 w, 834 m, 769 w, 658 w, 635 w, 616 m, 595 w, 541 w, 525 w, 517 w  $\text{cm}^{-1}$ . MS (ESI+):  $m/z$  440.0 ( $[\text{M} + \text{H} - \text{NEt}_3]^+$ ), 541.2 ( $[\text{M} + \text{H}]^+$ ); MS (ESI−):  $m/z$  437.9 ( $[\text{M} - \text{HNEt}_3]^+$ ). Anal. Calc. for  $\text{C}_{24}\text{H}_{41}\text{BFeN}_2\text{O}_4\text{PS}$  (540.47): C 53.33, H 7.65, N 5.18%. Found: C 53.07, H 7.69, 5.24%.

#### 3.4.2. Preparation of $\text{Cy}_2\text{PfcCONHCH}_2\text{SO}_3(\text{HNEt}_3)$ (**4b**)

Amide **4b** was synthesized from **3b** (0.952 g, 1.5 mmol) by following the general procedure and isolated as an orange crystalline solid after crystallization from hot ethyl acetate. Yield: 0.78 g (84%).

$^1\text{H}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  0.96–1.37 (m, 10 H, Cy), 1.32 (t,  $^3J_{\text{HH}} = 7.3$  Hz, 9 H,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 1.61–1.82 (m, 10 H, Cy), 1.86–1.95 (m, 2 H, Cy), 3.12 (q,  $^3J_{\text{HH}} = 7.3$  Hz, 6 H,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 4.22 (vq,  $J' = 1.6$  Hz, 2 H, fc), 4.29 (vt,  $J' = 1.9$  Hz, 2 H, fc), 4.42 (d,  $^3J_{\text{HH}} = 6.5$  Hz, 2 H,  $\text{CH}_2\text{N}$ ), 4.46 (vt,  $J' = 1.8$  Hz, 2 H, fc), 4.67 (vt,  $J' = 1.9$  Hz, 2 H, fc), 6.86 (t,  $^3J_{\text{HH}} = 6.3$  Hz, 1 H, NH).  $^{13}\text{C}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  8.91 (s, 3 C,  $\text{CH}_3$  of  $\text{Et}_3\text{NH}^+$ ), 26.87 (d,  $J_{\text{PC}} = 1$  Hz, 2 C,  $\text{CH}_2$  of Cy), 27.65 (d,  $J_{\text{PC}} = 9$  Hz, 2 C,  $\text{CH}_2$  of Cy), 27.78 (d,  $J_{\text{PC}} = 11$  Hz, 2 C,  $\text{CH}_2$  of Cy), 30.48 (d,  $J_{\text{PC}} = 2$  Hz, 2 C,  $\text{CH}_2$  of Cy), 30.60 (s, 2 C,  $\text{CH}_2$  of Cy), 33.73 (d,  $J_{\text{PC}} = 12$  Hz, 2 C, CH of Cy), 46.63 (s, 3 C,  $\text{CH}_2$  of  $\text{Et}_3\text{NH}^+$ ), 56.09 (s,  $\text{CH}_2\text{N}$ ), 69.67 (s, 2 C, CH of fc), 72.16 (d,  $J_{\text{PC}} = 3$  Hz, 2 C, CH of fc), 72.76 (d,  $J_{\text{PC}} = 1$  Hz, 2 C, CH of fc), 73.32 (d,  $J_{\text{PC}} = 10$  Hz, 2 C, CH of fc), 76.23 (s,  $\text{C}_{\text{ipso}}\text{-CO}$  of fc), 170.21 (s, C=O). One ferrocene resonance ( $\text{C}_{\text{ipso}}\text{-P}$ ) was not identified, presumably due to overlaps.  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  − 8.3 (s). IR (Nujol): 3309 s, 1653 s, 1533 s, 1314 m, 1284 m, 1247 w, 1217 m, 1169 s, 1077 w, 1044 s, 966 w, 891 w, 847 w, 831 w, 771 w, 613 m, 547 w, 533 w, 516 w  $\text{cm}^{-1}$ . MS (ESI+):  $m/z$  621.3 ( $[\text{M} + \text{H}]^+$ ); MS (ESI−):  $m/z$  518.0 ( $[\text{M} - \text{HNEt}_3]^+$ ). Anal. Calc. for  $\text{C}_{30}\text{H}_{49}\text{BFeN}_2\text{O}_4\text{PS}$  (620.59): C 58.06, H 7.96, N 4.52%. Found: C 57.81, H 7.82, N 4.50%.

### 3.4.3. Preparation of *t*Bu<sub>2</sub>PfcCONHCH<sub>2</sub>SO<sub>3</sub>(HNEt<sub>3</sub>) (**4c**)

Amide **4c** was synthesized from **3c** (0.874 g, 1.5 mmol) as described above and isolated as an orange solid. Yield: 0.605 g (71%).

<sup>1</sup>H NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ 1.18 (d, <sup>3</sup>J<sub>PH</sub> = 11.2 Hz, 18 H, CMe<sub>3</sub>), 1.32 (t, <sup>3</sup>J<sub>HH</sub> = 6.0 Hz, 9 H, CH<sub>3</sub> of Et<sub>3</sub>NH<sup>+</sup>), 3.12 (q, <sup>3</sup>J<sub>HH</sub> = 6.4 Hz, 6 H, CH<sub>2</sub> of Et<sub>3</sub>NH<sup>+</sup>), 4.32–4.45 (m, 4 H, fc), 4.42 (d, <sup>3</sup>J<sub>HH</sub> = 6.5 Hz, 2 H, CH<sub>2</sub>N), 4.54 (vt, *J'* = 1.8 Hz, 2 H, fc), 4.71 (vt, *J'* = 1.9 Hz, 2 H, fc), 6.76 (t, <sup>3</sup>J<sub>HH</sub> = 5.4 Hz, 1 H, NH). <sup>13</sup>C{<sup>1</sup>H} NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ 8.92 (s, 3 C, CH<sub>3</sub> of Et<sub>3</sub>NH<sup>+</sup>), 30.92 (d, <sup>2</sup>J<sub>PC</sub> = 13 Hz, 6 C, CMe<sub>3</sub>), 33.00 (d, <sup>1</sup>J<sub>PC</sub> = 20 Hz, 2 C, CMe<sub>3</sub>), 46.58 (s, 3 C, CH<sub>2</sub> of Et<sub>3</sub>NH<sup>+</sup>), 56.10 (s, CH<sub>2</sub>N), 69.72 (s, 2 C, CH of fc), 72.17 (d, *J*<sub>PC</sub> = 3 Hz, 2 C, CH of fc), 73.34 (s, 2 C, CH of fc), 74.65 (d, *J*<sub>PC</sub> = 12 Hz, 2 C, CH of fc), 76.11 (s, C<sub>ipso</sub>-CO of fc), 170.00 (s, C=O). One ferrocene resonance (C<sub>ipso</sub>-P) was not identified, presumably due to overlaps. <sup>31</sup>P{<sup>1</sup>H} NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ 27.3 (s). IR (Nujol): 3448 s, 3324 s, 1644 s, 1541 s, 1317 m, 1292 m, 1186 s, 1072 w, 1039 s, 936 w, 896 w, 837 m, 812 m, 756 w, 734 w, 617 m, 522 m cm<sup>-1</sup>. MS (ESI<sup>+</sup>): *m/z* 468.1 ([M + H – NEt<sub>3</sub>]<sup>+</sup>), 569.2 ([M + H]<sup>+</sup>); MS (ESI<sup>–</sup>): *m/z* 465.9 ([M – HNEt<sub>3</sub>]<sup>+</sup>). Anal. Calc. for C<sub>26</sub>H<sub>45</sub>FeN<sub>2</sub>O<sub>4</sub>PS·0.3CH<sub>2</sub>Cl<sub>2</sub> (594.00): C 53.18, H 7.74, N 4.72%. Found: C 53.16, H 7.75, N 4.53%.

### 3.4.4. Preparation of [Pd(Cy<sub>2</sub>PfcCONHCH<sub>2</sub>SO<sub>3</sub>-κ<sup>2</sup>O,P)(η<sup>3</sup>-C<sub>3</sub>H<sub>5</sub>)] (**5b**)

Solid [Pd(μ-Cl)(η<sup>3</sup>-C<sub>3</sub>H<sub>5</sub>)]<sub>2</sub> (18.3 mg, 0.05 mmol) was added to a solution of **4b** (62.1 mg, 0.1 mmol) in dichloromethane (5 mL). After stirring for 30 min, a solution of AgClO<sub>4</sub> (21.0 mg, 0.1 mmol) in benzene (1 mL) was added causing immediate precipitation of AgCl. The resulting mixture was stirred for 1 h and filtered through a syringe filter (PTFE, 0.45 μm pore size). The filtrate was evaporated under vacuum to afford a crude product, which was purified by two subsequent crystallizations by liquid-phase diffusion of diethyl ether into a chloroform solution of the complex to fully remove triethylammonium perchlorate. Yield after two crystallizations: 41 mg (62%).

<sup>1</sup>H NMR (CDCl<sub>3</sub>): δ 1.11–1.44 (m, 11 H, Cy), 1.67–2.09 (m, 11 H, Cy), 4.41 (br m, 2 H, fc), 4.53 (br m, 2 H, fc), 4.60 (br d, <sup>3</sup>J<sub>HH</sub> = 5.4 Hz, 2 H, CH<sub>2</sub>N), 4.76 (br m, 2 H, fc), 4.87 (br m, 2 H, fc), 5.67 (quint, <sup>3</sup>J<sub>HH</sub> = 9.9 Hz, 1 H, CH of C<sub>3</sub>H<sub>5</sub>), 7.14 (br s, 1 H, NH). <sup>31</sup>P{<sup>1</sup>H} NMR (CDCl<sub>3</sub>): δ 27.7 (s). IR (Nujol): 3240 s, 1588 s, 1566 s, 1329 w, 1297 m, 1258 m, 1249 w, 1226 w, 1204 s, 1175 s, 1091 s, 1039 s, 1007 m, 976 w, 959 w, 937 w, 921 w, 846 m, 836 w, 771 w, 743 m, 619 m, 604 w, 594 w, 548 w, 529 w, 500 w. MS (ESI<sup>+</sup>): *m/z* 688.1 ([M + Na]<sup>+</sup>). Anal. Calc. for C<sub>27</sub>H<sub>38</sub>FeNO<sub>4</sub>PPdS (665.86): C 48.70, H 5.75, N 2.10%. Found: C 48.52, H 5.68, N 2.04%.

## 3.5. Catalytic Tests in Pd-Catalyzed Cyanation

A solution of ligand (2, 4 or 8 mol. % with respect to the aryl bromide **6**) in dry dichloromethane (3 mL) was added to the respective palladium source (2 or 4 mol. %) placed in the reaction vessel; the obtained mixture was stirred for 5 min and then evaporated under vacuum. Anhydrous potassium hexacyanoferrate(II) (184 mg, 0.5 mmol), potassium carbonate (138 mg, 1.0 mmol) and **6** (172 mg, 0.5 mmol) were added to the pre-formed catalyst. The flask was equipped with a magnetic stirring bar, flushed with argon, and sealed with a septum. Solvent (1,4-dioxane/water, 1:1; 4 mL) was introduced, the septum was replaced with a glass stopper, and the reaction flask was transferred to an oil bath maintained at 100 °C. After stirring for 3 h, the reaction mixture was cooled to room temperature and diluted with water (10 mL), ethyl acetate (5 mL) and 3 M HCl (3 mL). The organic layer was separated and washed with brine (10 mL). The aqueous layer was back-extracted with ethyl acetate (3 × 5 mL). The combined organic layers were dried over anhydrous magnesium sulfate and evaporated under reduced pressure. The conversion was determined by integration of <sup>1</sup>H NMR spectrum.

Characterization data for the coupling product **7**. <sup>1</sup>H NMR (CDCl<sub>3</sub>): δ 1.35 (s, 9 H, CH<sub>3</sub>), 2.95–3.38 (m, 2 H, CH<sub>2</sub>), 4.25–5.10 (m, 2 H, CH and NH), 7.32 and 7.60 (2 × d, *J*<sub>HH</sub> = 8.0 Hz, 2 H, C<sub>6</sub>H<sub>4</sub>). The NMR data are in accordance with the literature [27].



### 3.6. Catalytic Tests in Pd-Catalyzed Suzuki–Miyaura Cross-Coupling

The procedure was modified from ref. [28]. Thus, palladium(II) acetate (1.0 or 0.5 mol. %) and the respective ligand **4** (1 or 2 equiv. with respect to Pd) were placed into a Schlenk tube and dissolved in dichloromethane (2 mL) under argon. The mixture was stirred for 5 min and then evaporated under vacuum. Next, aryl halide (1.00 mmol), boronic acid (1.15 mmol) and K<sub>2</sub>CO<sub>3</sub> (2.00 mmol) were added to the Schlenk tube and the reaction vessel was filled with argon and sealed with a rubber septum. Degassed water (2 mL) and dioxane (2 mL) were introduced and the reaction flask was placed into a preheated oil bath (40 °C). After stirring for 6 h, the reaction was terminated by cooling on ice and the simultaneous addition of 3 M aqueous HCl (3 mL), water (7 mL) and ethyl acetate (10 mL). The aqueous layer was separated and extracted with ethyl acetate (3 × 15 mL). The organic layers were combined, washed with brine (30 mL), dried over MgSO<sub>4</sub> and evaporated under reduced pressure. Conversion was determined by <sup>1</sup>H NMR spectroscopy.

If appropriate, the coupling products were isolated as follows. K<sub>2</sub>CO<sub>3</sub> (ca. 300 mg) was added to the crude product and the mixture was dissolved in water (10 mL). Brine (10 mL) and NaCl (ca. 300 mg) were added to the solution and the resulting precipitate was filtered. The collected precipitate was dissolved in boiling water (100 mL) and filtered immediately by suction to remove the by-product resulting from self-coupling of aryl boronic acids. The filtrate was cooled to laboratory temperature and acidified with dilute hydrochloric acid until pH 3–4 was reached whereupon a white precipitate formed. The separated product was filtered off, washed with distilled water (20 mL) and then taken up with ethyl acetate (30 mL). The solution was dried over MgSO<sub>4</sub> and evaporated under reduced pressure to afford pure coupling product, which was analyzed by <sup>1</sup>H NMR spectroscopy. Characterization data of the coupling products were as follows.

2-(4-Fluorophenyl)benzoic acid (**11oa**). <sup>1</sup>H NMR (CDCl<sub>3</sub>): δ 7.13–7.01 (m, 2 H), 7.31–7.25 (m, 2 H), 7.33 (dd, *J* = 7.8, 1.1 Hz, 1H), 7.43 (td, *J* = 7.6, 1.4 Hz, 1H), 7.57 (td, *J* = 7.6, 1.4 Hz), 7.96 (dd, *J* = 7.8, 1.1 Hz, 1H), (all aromatics). The collected data correspond to those in the literature; see ref. [29].

3-(4-Fluorophenyl)benzoic acid (**11ma**). <sup>1</sup>H NMR (dms-*d*<sub>6</sub>): δ 7.28–8.17 (m, 8 H, aromatics), 13.16 (br s, 1 H, CO<sub>2</sub>H). The NMR data are in line with those in the literature (see ref. [27]).

4-(4-Fluorophenyl)benzoic acid (**11pa**). <sup>1</sup>H NMR (dms-*d*<sub>6</sub>): δ 7.30–7.37 (m, 2 H, aromatics), 7.75–7.83 (m, 4 H, aromatics), 7.98–8.04 (m, 2 H, aromatics), 13.02 (br s, 1 H, CO<sub>2</sub>H). The data are in accordance with those in the literature; see ref. [27].

2-(4-Tolyl)benzoic acid (**11ob**). <sup>1</sup>H NMR (CDCl<sub>3</sub>): δ 2.38 (s, 3 H, CH<sub>3</sub>), 7.26–7.14 (m, 4 H, aromatics), 7.35 (dd, *J* = 7.7, 0.9 Hz, 1 H, aromatics), 7.39 (td, *J* = 7.6, 1.4 Hz, 1 H, aromatics), 7.53 (td, *J* = 7.6, 1.4 Hz, 1 H, aromatics), 7.92 (dd, *J* = 7.8, 1.1 Hz, 1 H, aromatics). The analytical data are in agreement with those in the literature, see ref. [28].

3-(4-Tolyl)benzoic acid (**11mb**). <sup>1</sup>H NMR (dms-*d*<sub>6</sub>): δ 2.35 (s, 3 H, CH<sub>3</sub>), 7.27–8.19 (m, 8 H, aromatics). The NMR data are in agreement with those in the literature; see ref. [27].

4-(4-Tolyl)benzoic acid (**11pb**). <sup>1</sup>H NMR (CDCl<sub>3</sub>): δ 2.42 (s, 3 H, CH<sub>3</sub>), 7.27–7.32 (m, 2 H, aromatics), 7.52–7.57 (m, 2 H, aromatics), 7.66–7.71 (m, 2 H, aromatics), 8.13–8.18 (m, 2 H, aromatics). These data correspond with those in the literature; see ref. [27].

2-(4-Fluorophenyl)phenylacetic acid (**12oa**). <sup>1</sup>H NMR (dms-*d*<sub>6</sub>): δ 3.50 (s, 2 H, CH<sub>2</sub>), 7.21–7.38 (m, 8 H, aromatics), 12.27 (br s, 1 H, CO<sub>2</sub>H). <sup>13</sup>C{<sup>1</sup>H} NMR (dms-*d*<sub>6</sub>): δ 38.49 (s, CH<sub>2</sub>), 115.06 (d, <sup>2</sup>*J*<sub>CF</sub> = 21 Hz, 2 C, aromatic CH), 126.91 (s, CH), 127.45 (s, CH), 129.76 (s, aromatic CH), 130.79 (s, CH), 130.83 (d, <sup>3</sup>*J*<sub>CF</sub> = 7.9 Hz, 2 C, aromatic CH), 132.53 (s, aromatic C), 137.06 (d, <sup>4</sup>*J*<sub>CF</sub> = 3 Hz, aromatic C), 140.76 (s, aromatic C), 161.42 (d, <sup>1</sup>*J*<sub>CF</sub> = 244 Hz, aromatic C), 172.67 (s, CO<sub>2</sub>H). HRMS (ESI<sup>−</sup>) calc. for C<sub>14</sub>H<sub>10</sub>FO<sub>2</sub> ([M − H]<sup>−</sup>): 229.0665, found 229.0670.

3-(4-Fluorophenyl)phenylacetic acid (**12ma**).  $^1\text{H}$  NMR (dmso- $d_6$ ):  $\delta$  3.65 (s, 2 H,  $\text{CH}_2$ ), 2.24–2.33 (m, 3 H, aromatics), 7.37–7.43 (m, 1 H, aromatics), 7.50–7.55 (m, 2 H, aromatics), 7.65–7.71 (m, 2 H, aromatics), 12.35 (br s, 1 H,  $\text{CO}_2\text{H}$ ).  $^{13}\text{C}\{^1\text{H}\}$  NMR (dmso- $d_6$ ):  $\delta$  40.61 (s,  $\text{CH}_2$ ), 115.68 (d,  $^2J_{\text{CF}} = 21$  Hz, 2 C aromatic CH), 124.88 (s, aromatic CH), 127.79 (s, aromatic CH), 128.56 (s, aromatic CH), 128.60 (d,  $^3J_{\text{CF}} = 7.9$  Hz, 2 C aromatic CH) 128.83 (s, aromatic CH) 135.72 (s, aromatic C), 136.50 (d,  $^4J_{\text{CF}} = 3$  Hz, aromatic C), 139.04 (s, aromatic C), 161.82 (d,  $^1J_{\text{CF}} = 244$  Hz, aromatic C), 172.62 (s,  $\text{CO}_2\text{H}$ ). HRMS (ESI $^-$ ) calc. for  $\text{C}_{14}\text{H}_{10}\text{FO}_2$  ( $[\text{M} - \text{H}]^-$ ): 229.0665, found 229.0669.

4-(4-Fluorophenyl)phenylacetic acid (**12pa**).  $^1\text{H}$  NMR (dmso- $d_6$ ):  $\delta$  3.61 (s, 2 H,  $\text{CH}_2$ ), 7.24–7.74 (m, 8 H, aromatics), 12.38 (br s, 1 H,  $\text{CO}_2\text{H}$ ). The data are in accordance with those in the literature; see ref. [30].

2-(4-Tolyl)phenylacetic acid (**12ob**).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  2.39 (s, 3 H,  $\text{CH}_3$ ), 3.59 (s, 2 H,  $\text{CH}_2$ ), 7.25–7.55 (m, 8 H, aromatics). The NMR parameters are in agreement with those in the literature; see ref. [31].

3-(4-Tolyl)phenylacetic acid (**12mb**).  $^1\text{H}$  NMR (dmso- $d_6$ ):  $\delta$  2.34 (s, 3 H,  $\text{CH}_3$ ), 3.64 (s, 2 H,  $\text{CH}_2$ ), 7.20–7.56 (m, 8 H, aromatics), 12.35 (br s, 1 H,  $\text{CO}_2\text{H}$ ).  $^{13}\text{C}\{^1\text{H}\}$  NMR (dmso- $d_6$ ):  $\delta$  20.67 (s,  $\text{CH}_3$ ), 40.66 (s,  $\text{CH}_2$ ), 124.68 (s, aromatic CH), 126.45 (s, 2 C, aromatic CH), 127.56 (s, aromatic CH), 128.17 (s, aromatic CH), 128.78 (s, aromatic CH), 129.51 (s, 2 C, aromatic CH), 135.62 (s, aromatic C), 136.72 (s, aromatic C), 137.15 (s, aromatic C), 140.013 (s, aromatic C), 172.69 (s,  $\text{CO}_2\text{H}$ ). HRMS (ESI $^-$ ) calc. for  $\text{C}_{15}\text{H}_{13}\text{O}_2$  ( $[\text{M} - \text{H}]^-$ ): 225.0916, found 225.0957.

4-(4-Tolyl)phenylacetic acid (**12pb**).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ ):  $\delta$  2.39 (s, 3 H,  $\text{CH}_3$ ), 3.59 (s, 2 H,  $\text{CH}_2$ ), 7.25–7.55 (m, 8 H, aromatics). The data correspond with those in the literature (ref. [27]).

*Rac*-2-[[*tert*-butyloxy)carbonyl]amino]-3-(4'-fluorobiphenyl-4-yl)propionic acid (**13a**).  $^1\text{H}$  NMR (dmso- $d_6$ ):  $\delta$  1.32 (s, 9 H,  $\text{CMe}_3$ ), 2.83–2.89 (m, 1 H,  $\text{CH}_2$ ), 3.03–3.08 (m, 1 H,  $\text{CH}_2$ ), 4.01–4.15 (m, 1 H, CH), 7.16–7.09 (m, 1 H), 7.13 (d,  $^3J_{\text{HH}} = 8.3$  Hz, 1 H, NH), 7.24–7.30 (m, 2 H, aromatics), 7.33 (d,  $J = 8.1$  Hz, 2 H, aromatics), 7.56 (d,  $J = 8.2$  Hz, 2 H, aromatics), 12.65 (br s, 1 H,  $\text{CO}_2\text{H}$ ). The data are in accordance with those reported in ref. [32].

*Rac*-2-[[*tert*-butyloxy)carbonyl]amino]-3-(4'-methylbiphenyl-4-yl)propionic acid (**13b**).  $^1\text{H}$  NMR (dmso- $d_6$ ):  $\delta$  1.32 (s, 9 H,  $\text{CMe}_3$ ), 2.33 (s, 3 H,  $\text{CH}_3$ ), 2.76–3.08 (m, 2 H,  $\text{CH}_2$ ), 4.01–4.16 (m, 1 H, CH), 7.12 (d,  $^3J_{\text{HH}} = 8.3$  Hz, 1 H, NH), 7.24–7.26 (m, 2 H, aromatics), 7.30–7.32 (m, 2 H, aromatics), 7.51–7.56 (m, 4 H, aromatics), 12.63 (br s, 1 H,  $\text{CO}_2\text{H}$ ). The analytical data are in agreement with those in the literature (see ref. [8]).

### 3.7. X-ray Crystallography

The crystals of **3b**· $\text{CH}_2\text{Cl}_2$  (orange prism,  $0.17 \times 0.20 \times 0.25$  mm<sup>3</sup>) and **4b** (orange plate,  $0.07 \times 0.17 \times 0.23$  mm<sup>3</sup>) were grown from dichloromethane–hexane and ethyl acetate–heptane, respectively. Full-set diffraction data for both compounds ( $\pm h \pm k \pm l$ ,  $\theta_{\text{max}} = 27.5^\circ$ ) were collected on a Bruker D8 VENTURE Kappa Duo PHOTON100 diffractometer equipped with  $\text{I}\mu\text{S}$  micro-focus sealed tube (MoK $\alpha$  radiation,  $\lambda = 0.71073$  Å) and a Cryostream cooling device (Oxford Cryosystems) at 150(2) K.

Selected crystallographic data for **3b**· $\text{CH}_2\text{Cl}_2$ :  $\text{C}_{31}\text{H}_{54}\text{BCl}_2\text{FeN}_2\text{O}_4\text{PS}\cdot\text{CH}_2\text{Cl}_2$  ( $M = 719.35$  g mol $^{-1}$ ), triclinic, space group  $P - 1$  (no. 2);  $a = 8.3583(3)$  Å,  $b = 11.0812(4)$  Å,  $c = 20.6164(8)$  Å,  $\alpha = 99.276(1)^\circ$ ,  $\beta = 100.551(1)^\circ$ ,  $\gamma = 102.947(1)^\circ$ ;  $V = 1788.3(1)$  Å<sup>3</sup>,  $Z = 2$ ,  $D_{\text{calc}} = 1.336$  g mL $^{-1}$ ,  $F(000) = 764$ ,  $\mu(\text{MoK}\alpha) = 0.711$  mm $^{-1}$ . A total of 37,660 diffractions were collected, of which were 8211 unique ( $R_{\text{int}} = 2.93\%$ ) and 7117 observed according to the  $I_o > 2\sigma(I_o)$  criterion.

Selected crystallographic data for **4b**:  $\text{C}_{30}\text{H}_{49}\text{FeN}_2\text{O}_4\text{PS}$  ( $M = 620.59$  g mol $^{-1}$ ), monoclinic, space group  $P2_1/c$  (no. 14);  $a = 17.3904(6)$  Å,  $b = 9.1114(3)$  Å,  $c = 19.7014(7)$  Å,  $\beta = 97.552(1)^\circ$ ;  $V = 3094.6(2)$  Å<sup>3</sup>,  $Z = 4$ ,  $D_{\text{calc}} = 1.332$  g mL $^{-1}$ ,  $F(000) = 1328$ ,  $\mu(\text{MoK}\alpha) = 0.643$  mm $^{-1}$ . A total of 82,146 diffractions were collected, of which were 7125 unique ( $R_{\text{int}} = 4.12\%$ ) and 3275 observed according to the  $I_o > 2\sigma(I_o)$  criterion.

The structures of **3b**·CH<sub>2</sub>Cl<sub>2</sub> and **4b** were solved by direct methods (XT2014 [33]) and refined by unrestricted least-squares against  $F^2$  (SHELXL-97 [34] or SHELXL-2014 [35]). All non-hydrogen atoms were refined with anisotropic displacement parameters. The amide hydrogens H1N were identified on an electron density map and refined as riding atom with  $U_{\text{iso}}(\text{H1N})$  set to  $1.2U_{\text{eq}}(\text{N})$ . Hydrogen atoms in the CH<sub>n</sub> groups were included in their theoretical positions using the standard HFIX instructions in SHELXL-2014 and refined as riding atoms. A recent version of the PLATON program [36] was used to perform all geometric calculations and prepare the structural diagrams.

In the case of **3b**·CH<sub>2</sub>Cl<sub>2</sub>, the refinement converged ( $\Delta/\sigma \leq 0.002$ , 391 parameters) to  $R = 2.96\%$  and  $wR = 7.02\%$  for the observed diffractions and to  $R = 3.84\%$  and  $wR = 7.54\%$  for all diffractions. Extremes on the final difference electron density map were:  $\Delta\rho_{\text{max}} = 0.72$ ,  $\Delta\rho_{\text{min}} = -0.79 \text{ e } \text{\AA}^{-3}$ . CCDC deposition number: 1545049.

For **4b**, the refinement converged ( $\Delta/\sigma \leq 0.002$ , 355 parameters) to  $R = 2.68\%$  and  $wR = 6.53\%$  for the observed diffractions and to  $R = 3.31\%$  and  $wR = 6.83\%$  for all diffractions. Extremes on the final difference electron density map were:  $\Delta\rho_{\text{max}} = 0.36$ ,  $\Delta\rho_{\text{min}} = -0.36 \text{ e } \text{\AA}^{-3}$ . CCDC deposition number: 1545048.

An orange, bar-like crystal of **5b**·CH<sub>2</sub>Cl<sub>2</sub> with approximate dimensions of  $0.14 \times 0.25 \times 0.36 \text{ mm}^3$  was obtained by recrystallization of the complex from dichloromethane–diethyl ether. Full-diffraction data ( $\pm h \pm k \pm l$ ,  $\theta_{\text{max}} = 27.56^\circ$ ) were collected at 150(2) K with a Nonius Kappa CCD diffractometer equipped with a Bruker APEX-II image plate detector and a Cryostream cooling device (Oxford Cryosystems) using MoK $\alpha$  radiation ( $\lambda = 0.71073 \text{ \AA}$ ). A total of 26,856 diffractions were collected, of which 7049 were independent ( $R_{\text{int}} = 2.98\%$ ) and 5970 observed according to the  $I_o > 2\sigma(I_o)$  criterion. Selected crystallographic data: C<sub>27</sub>H<sub>38</sub>FeNO<sub>4</sub>PPdS·CH<sub>2</sub>Cl<sub>2</sub> ( $M = 750.79 \text{ g mol}^{-1}$ ), monoclinic, space group  $P2_1/c$  (no. 13);  $a = 17.257(1) \text{ \AA}$ ,  $b = 10.4304(6) \text{ \AA}$ ,  $c = 17.2618(8) \text{ \AA}$ ,  $\beta = 100.882(2)^\circ$ ;  $V = 3051.2(3) \text{ \AA}^3$ ,  $Z = 4$ ,  $D_{\text{calc}} = 1.634 \text{ g mL}^{-1}$ ,  $F(000) = 1535$ ,  $\mu(\text{MoK}\alpha) = 1.395 \text{ mm}^{-1}$ .

The structure was solved and refined as described above for **3b**·CH<sub>2</sub>Cl<sub>2</sub> and **4b**. The refinement converged ( $\Delta/\sigma \leq 0.002$ , 352 parameters) to  $R = 3.30\%$  and  $wR = 7.74\%$  for the observed diffractions and to  $R = 4.26\%$  and  $wR = 8.22\%$  for all diffractions. The final difference electron density map showed peaks of no chemical significance ( $\Delta\rho_{\text{max}} = 1.51$ ,  $\Delta\rho_{\text{min}} = -0.75 \text{ e } \text{\AA}^{-3}$ ). CCDC deposition number: 1544852.

#### 4. Conclusions

In summary, several new phosphinoferrocene amidosulfonate donors with different dialkylphosphino substituents were synthesized and characterized. Together with their diphenylphosphino-substituted counterpart, these compounds were used as a ligand in Pd-mediated cyanation of aryl bromides and Suzuki–Miyaura cross-coupling of bromo-substituted benzoic and phenylacetic acids with boronic acids to the corresponding biphenyls. The testing reactions—aimed mainly at comparing different ligands and catalysts resulting thereof, rather than at obtaining the highest yields—revealed differences between the two types of reactions. Namely, ligand **4d** bearing the least electron-donating phosphine moiety and [PdCl<sub>2</sub>(cod)] as a palladium source provided the best results in the cyanation reaction, while the biaryl coupling reactions provided the best yields with a catalyst resulting from the electron-rich donor **4a** and palladium(II) acetate. In a wider perspective, the collected results confirm that careful optimization of the catalytic system and reaction conditions is needed in each particular case to obtain good results in Pd-catalyzed C–C bond forming reactions.

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