Fluorous-Silica-Supported Perfluoro-Tagged Palladium Complexes Catalyze *Suzuki* Couplings in Water

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Different Pd-complexes (see **2a**–**d** and **3**) with and without perfluoroalkyl tags were deposited on fluorous reversed-phase silica **1** and unmodified silica gel. These supported complexes were successfully used as precatalysts for the *Suzuki* reaction in H_2O. H_2O-Soluble aryl bromides were easily converted to the corresponding biphenyls. Although none of the complexes is H_2O-soluble, the active catalyst is most likely homogeneously dissolved. Nevertheless, the Pd-leaching into the product was low.

Introduction. – In catalytic chemistry, there is an increasing requirement to optimize reactions in terms of environmental and process safety as well as in terms of economic viability. Important aspects are the reduction of waste, straightforward isolation of products, recycling of catalysts, and the use of environmentally benign reaction media [1]. Water is in these regards a suitable solvent, since it is cheap, nonflammable and nontoxic. However, it is important to remove products and catalyst efficiently to allow for easy disposal of H_2O.

Solid-supported catalysts have become valuable tools for simplified product isolation and catalyst recycling. For immobilization, catalysts can be linked covalently to different supports, such as polymer resins or inorganic solids. Polar catalysts can be adsorbed on silica gel [2], or immobilized in a thin layer of H_2O [3], ethylene glycol [4], or ionic liquids [5][6] on a silica support. The reaction is carried out in an apolar organic solvent. These applications usually require suitable derivatization of the catalyst with polar functionalities. The system can be reversed in such a way that a lipophilic catalyst is physisorbed on reversed-phase silica gel [7] or fluorous reversed-phase silica gel (FRPSG) [8][9] and applied to reactions in polar solvents.

In this context, we reported the use of fluorous reversed-phase silica gel (FRPSG) as solid support for the noncovalent immobilization of perfluoro-tagged Pd-catalysts [8]. These supported Pd-complexes were applied to *Suzuki* couplings and to *Sonogashira* reactions. The FRPSG-supported catalyst was removed by simple decantation or filtration, and the catalyst could be reused several times without significant loss of efficiency. The same strategy was used in a solventless approach by *Biffis et al.* for the immobilization of dirhodium(II) perfluorocarboxylates as catalyst for the alcoholysis of silanes [9]. Attempts of *Pozzi et al.* to immobilize perfluoro-tagged [Co^{III}(salen)] complexes on FRPSG did not lead to active catalysts [10]. In a similiar context, *Gladysz et al.* employed the thermomorphic behavior of certain perfluoro-tagged compounds together with *Teflon* shavings as solid-support material

[11–13]. In combinatorial chemistry, FRPSG has been used as a solid support for multistep organic synthesis [14]. FRPSG has found numerous applications as material for solid-phase extractions and chromatography [15][16].

While, in our previous experiments in 1,2-dimethoxyethane (=glyme), the Pd-leaching was already low [8], we thought that it could be further reduced by the use of H_2O as the reaction solvent, because of the pronounced hydrophobicity of perfluoro-tagged compounds. But this hydrophobicity also presents a challenge, since FRPSG is usually not wetted by H_2O as demonstrated by the high contact angle (*Fig. 1*) [17], and the question was whether the reaction could occur at all. Herein, we report the first application of a precatalyst supported on FRPSG in H_2O as the sole reaction solvent, and data suggesting a homogeneous nature of the actual catalytic species.

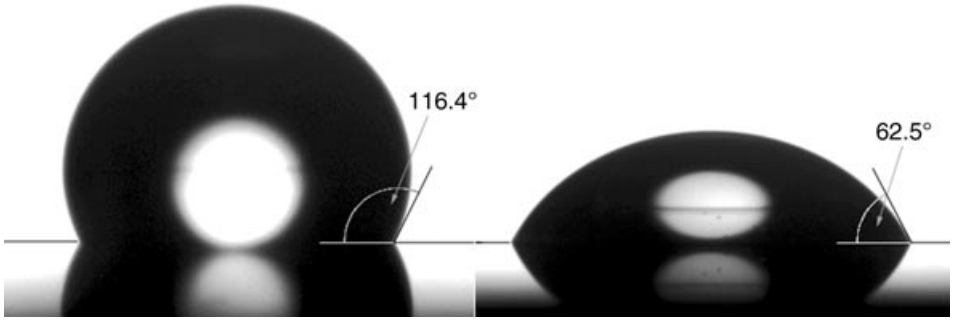
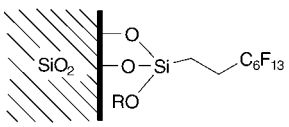


Fig. 1. *Photographs of solvent drops on the perfluorinated silicium dioxide surface of a silicon wafer, demonstrating the large difference in polarity:* left: *water drop with a contact angle of 116.4°, and* right: *1,2-dimethoxyethane drop with a contact angle of 62.5°*. Due to the lower interfacial energy, 1,2-dimethoxyethane can wet FRPSG much better than H_2O [17].

Results and Discussion. – The FRPSG **1** and the perfluoro-tagged Pd-complexes **2a–d** were prepared by our reported procedures [14][18]. For the immobilization of the complexes, FRPSG **1** was shaken with a solution of perfluoro-tagged bis(triarylphosphine)palladium complexes **2a–d** in Et_2O, and the solvent was evaporated. The thus immobilized precatalyst is an air-stable, free-flowing powder. These catalyst-loaded FRPSGs were employed in different *Suzuki* cross-coupling reactions in H_2O.



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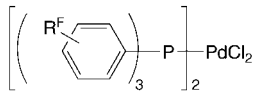


2a $R^F = 4\text{-}C_8F_{17}CH_2CH_2$
2b $R^F = 3\text{-}C_8F_{17}CH_2CH_2$
2c $R^F = 4\text{-}C_8F_{17}$
2d $R^F = 4\text{-}C_7F_{15}CH_2O$
3 $R^F = H$

Initially, between 0.001 mol-% and 1 mol-% of **2a** on FRPSG was tested as precatalyst for the *Suzuki* coupling of phenylboronic acid and *p*-bromomandelic acid (=4-bromo-α-hydroxybenzeneacetic acid) in H_2O (see *Scheme 1* and *Table 1*). The product was separated by filtration, and the supported catalyst was reused up to five times. For the higher catalyst loadings (*Entries 1* and *2*), nearly complete conversion was observed in the first run. Up to the sixth run, the conversion decreased only to 87% and 76%, respectively. With the lower catalyst loadings (*Entries 3* and *4*), the conversion was low in the first run but increased significantly in the second run. It must be noted, however, that the yields deviate more from the average in the first runs than in the following runs. This might be due to insufficient wetting of the support during the first run. The conversions remained on a fairly high level with 0.01 mol-% of catalyst. Only with 0.001 mol-% of catalyst, the conversions decreased from the third to the sixth run, still leading to cumulated turn-over numbers (TON) of more than 200000.

Scheme 1. Suzuki *Reactions Performed with 0.01–1 mol-% of* **2a** *Immobilized on Support* **1**

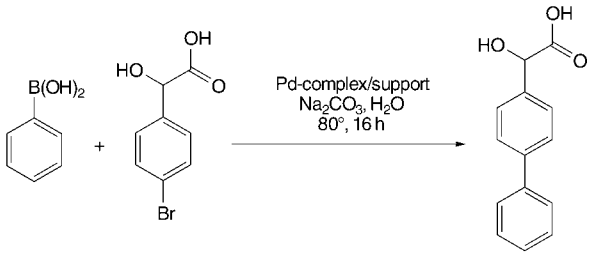


Table 1. Suzuki *Reactions with Complexes* **2a–d** *and* **3**. Yields are determined by HPLC and are the average of at least two independent experiments. TON = turn-over number.

Entry	Catalyst/Support	Catalyst loading [mol-%]	Yield [%]	TON
1	**2a**/FRPSG	1.0	98 (98, 95, 90, 83, 87)	551
2	**2a**/FRPSG	0.1	99 (91, 88, 79, 80, 76)	5130
3	**2a**/FRPSG	0.01	6 (74, 86, 86, 85, 70)	40600
4	**2a**/FRPSG	0.001	27 (71, 54, 37, 22, 7)	217000
5	**2b**/FRPSG	0.1	88 (62, 83, 84, 86, 82)	4850
6	**2c**/FRPSG	0.1	94 (76, 83, 82, 74, 73)	4820
7	**2d**/FRPSG	0.1	85 (90, 89, 88, 85, 75)	5120
8	**3**/silica gel	0.1	52 (95, 95, 91, 85, 77)	4950

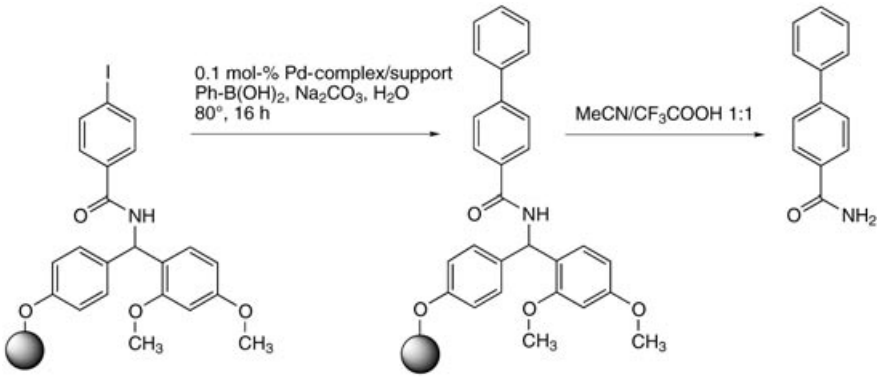
To examine the influence of the perfluoro tags and the support, Pd-complexes **2b–d** and **3** on FRPSG **1** were used as precatalysts. Like in complex **2a**, in **2b** an ethylene spacer isolates the aryl ring from the electron-withdrawing perfluoroalkyl chain. In **2c** the perfluoro tag is directly attached to the phenyl ring, while, in **2d**, an electron-donating CH_2O spacer is employed. In these experiments, the loading of the support was 10 mg of complex per g FRPSG, and the catalyst loading was 0.1 mol-%. In the first run, the yields obtained with **2b–d** were slightly lower than with **2a**, but in recycling experiments, all four complexes behaved similarly, giving cumulated TONs in the range of 5000 (*Table 1*, *Entries 5–7*). Thus, neither the spacer between the perfluoroalkyl chain and the phenyl ring nor the point of attachment of the perfluoro tag exerts a

detectable influence on the catalyst performance. To our surprise, complex **2a** on FRPSG and the nontagged complex **3** on normal silica gel behaved quite similiarly (*Table 1*, *Entries 2* and *8*).

To assess the catalyst leaching, the coupling of phenylboronic acid and *p*-bromomandelic acid was carried out with 0.1 mol-% of **2a** on FRPSG **1** and 0.1 mol-% of **3** on unmodified silica gel. After reaction, the support was filtered off and washed with H_2O. The combined filtrates were evaporated, and the Pd-content was determined by inductively coupled plasma (ICP) MS. For **2a** on FRPSG, the amount of Pd in the crude product was 2.2 ppm, corresponding to 0.8% of the Pd, whereas, for **3** on silica gel, we observed 14.0 ppm in the crude product, corresponding to 7.4% of the Pd.

Despite the low leaching of Pd, the question still remained whether the catalytic process proceeded in a heterogeneous or a homogeneous fashion. To shed more light on this problem, we carried out a three-phase test (*cf. Ley* and co-workers [19]) in which a solid-phase-bound aryl iodide was subjected to the reaction conditions (*Scheme 2*). If the catalyst is truly immobilized, the spatial separation from the iodide prevents any conversion, while a soluble catalyst can reach the substrate by diffusion, and thus, effect conversion. We carried out the experiment with complex **2a** supported on FRPSG **1** in the presence and in the absence of bromomandelic acid as a soluble substrate. Similarly, control experiments were carried out with complex **3** on unmodified silica gel. In all four experiments, over 80% conversion of the solid-phase-bound iodide was observed. These results suggest that the catalyst is operating by a homogeneous mechanism and does not depend on a soluble aryl halide for generation of the active species from the precatalyst.

Scheme 2. *Three-Phase Test: Behavior of a Solid-Phase-Bound Aryl Iodide under* Suzuki *Coupling Conditions.* Upon cleavage from the support, the conversion was determined by HPLC.



The assumption of a homogeneous catalyst is supported further by the finding that the reaction continues after filtration of the reaction mixture and leads to the same conversions (*Fig. 2*). Upon completion of the reaction and cooling to room temperature, the Pd-species are possibly recaptured by the solid phase, which would be in accordance with the low Pd-leaching. Such a 'release and capture' mechanism has been invoked recently for a catalyst based on Pd-containing perovskites [19]. But it is also conceivable that the support acts as a reservoir, and only a small fraction of active

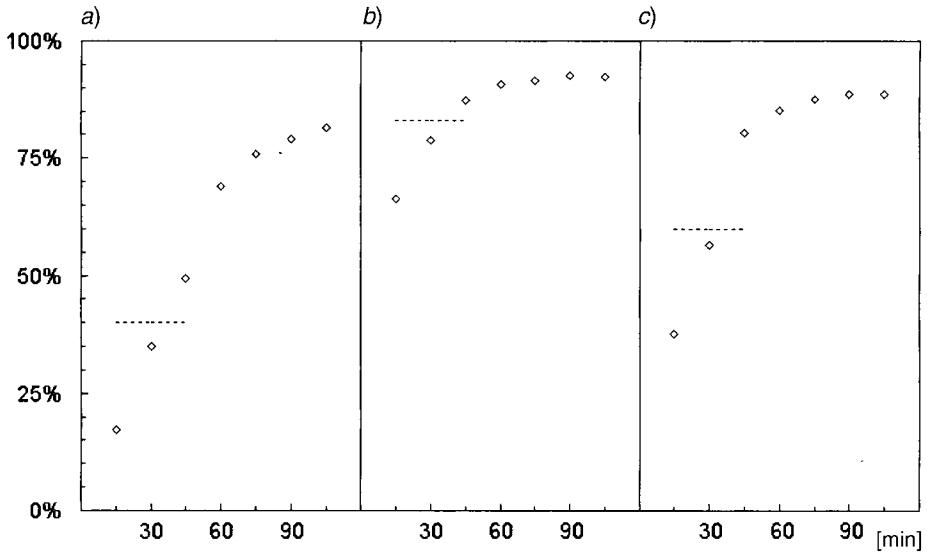


Fig. 2. *Formation of phenylmandelic acid* vs. *reaction time.* Reaction conditions: 0.1 mol-% **2a**/FRPSG, Na_2CO_3, H_2O, 80°, 16 h. *a*) Fresh catalyst, *b*) reused catalyst, *c*) second reuse. The dashed line denotes the filtration of the reaction mixture.

catalyst is released into the solution. That very small catalyst amounts can lead to high conversion, was already shown above (*Table 1*, *Entry 4*).

Furthermore, Pd-complex **2a** was evaluated in the *Suzuki* coupling of different substrates (see *Scheme 3* and *Table 2*). The reaction proceeded well with a range of H_2O-soluble substrates, and the catalyst could be recycled. Only in the case of 2-bromobenzoic acid, the yield was low and recycling of the catalyst was not successful (*Table 2*, *Entry 4*). This is probably due to steric hindrance of the *o*-carboxyl group. On the other hand, in the boronic acid, small *o*-substituents were well tolerated, as the comparison of (4-methoxyphenyl)boronic acid (*Table 2*, *Entries 8* and *9*) and (2-methoxyphenyl)boronic acid (*Table 2*, *Entries 10* and *11*) shows. In the coupling of 4-bromophenylacetic acid with (4-formylphenyl)boronic acid, less than 5% conversion was observed in the first run (not shown). Upon recycling of the catalyst, slightly increased activity was observed, with 15% conversion of the bromide. With less H_2O-soluble substrates like 4-bromoacetophenone or 4-bromobutylbenzene, no significant consumption of boronic acid could be observed. It is possible that, in these cases, the

Scheme 3. Suzuki *Reactions with Different Substrates in the Presence of 0.1 mol-%* **2a** *on Support* **1**

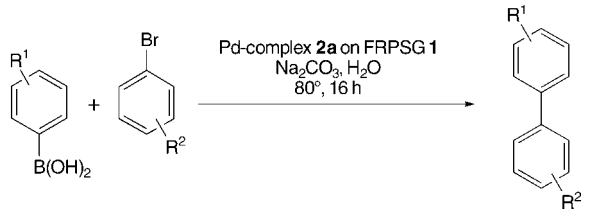


Table 2. Suzuki *Reactions with Different Substrates in the Presence of 0.1 mol-%* **2a** *on Support* **1** (*Scheme 3*)

Entry	R^1	R^2	Yield [%]
1	H	4-CH(OH)CO_2H	100 (94, 93)
2	H	4-CO_2H	100 (97, 93)
3	H	3-CO_2H	99 (93, 90)
4	H	2-CO_2H	30 (6, 8)
5	H	4-CH_2CO_2H	100 (82, 88)
6	H	4-$CONHCH_2CO_2$H	94 (98)
7	H	3-$CONHCH_2CO_2$H	76 (97)
8	4-MeO	4-CH(OH)CO_2H	99 (88, 99)
9	4-MeO	4-CH_2CO_2H	89 (99)
10	2-MeO	4-CH(OH)CO_2H	98 (99, 99)
11	2-MeO	4-CH_2CO_2H	78 (95)

hydrophobic substrate covers the solid support and mechanically prevents the contact between the solution and the precatalyst.

Conclusions. – In summary, we could demonstrate that perfluoro-tagged Pd-complexes immobilized on FRPSG **1** are useful as precatalysts for the *Suzuki* reaction in H_2O, despite their pronounced hydrophobicity. There is conclusive evidence that the actual catalysis proceeds *via* a homogeneously dissolved Pd-species. H_2O-Soluble substrates were easily converted to the corresponding biphenyls. The supported complexes were separated by simple filtration and could be reused several times. With low catalyst loadings, TONs as high as 200000 were achieved.

Financial support from *Fluka*, Buchs (CH), is gratefully acknowledged.

Experimental Part

General. All reagents and solvents were obtained from either *Fluka* or *Aldrich* and were used without further purification. HPLC: *Agilent-1100* system with binary pump, sample changer, column oven, and diode-array detector. M.p.: *IA9000* apparatus from *Electrothermal Engineering Ltd.*; uncorrected. NMR Spectra: chemical shifts δ in ppm rel. to $SiMe_4$ (=0 ppm) for ^{1}H- and rel. to $CHCl_3$ (=77 ppm) for ^{13}C. MS: *Finnigan MAT8200* (EI), *MAT312* (CI), and *TSQ7000* (ESI) spectrometer; APCI = atmospheric-pressure chemical ionization, ICP = inductively coupled plasma; in *m*/*z* (rel. %).

Typical Procedure for Recycling Experiments. To FRPSG-supported catalyst (100 mg) under Ar, an aq. stock soln. of the substrates (3 ml, containing 0.3 mmol of 4-bromomandelic acid, 0.33 mmol of phenylboronic acid, and 0.6 mmol of Na_2CO_3) was added. The mixture was shaken at 80° for 16 h. An aliquot (20 µl) of the soln. was withdrawn, and the yield was measured by HPLC analysis. The mixture was cooled to 20° and filtered. The FRPSG was washed with 1M HCl in MeOH/H_2O 11:1 (2 × 1 ml), MeOH (2 × 1 ml), and H_2O (2 × 1 ml). The immobilized catalyst was reused as such in further experiments. All manipulations were carried out automatically (*Automated Synthesis Workstation ASW 2000*, *Chemspeed Ltd.*, Augst, Switzerland). HPLC analysis: *C-18* column (*Zorbax SB*, 3 µm, 4.6 × 50 mm); isocratic eluent H_2O/MeCN/HCOOH 70:30:0.2 (*v*/*v*); detection at 210 nm; conversions calculated from the ratio of the peak areas of 4-bromomandelic acid and 4-phenylmandelic acid corrected for the extinction coefficients.

General Procedure (*G. P.*) *for Preparative Experiments: 4-Phenylmandelic Acid* (=*α-Hydroxy[1,1′-biphenyl]-4-acetic Acid*): A 13-ml glass reactor was charged with FRPSG-supported catalyst (100 mg), solid 4-bromomandelic acid (69 mg, 0.3 mmol), and phenylboronic acid (40 mg, 0.33 mmol). Under Ar, 2M aq. Na_2CO_3 (3 ml, 0.6 mmol) was added. The mixture was shaken at 80° for 16 h. Aliquots (20 µl) of the soln. were withdrawn at the beginning of the reaction and after 16 h, and the conversion was estimated by HPLC. The mixture was cooled to 20° and filtered. The FRPSG was washed with H_2O (4 × 1 ml). The immobilized catalyst

was reused as such in further experiments. Up to this point, all manipulations were carried out automatically by *Chemspeed ASW 2000*. The aq. product soln. was acidified with conc. HCl soln. (1 ml) and extracted with Et_2O (3×5 ml) and the combined extract evaporated to give the product. An anal. sample was crystallized from AcOEt. M.p. 199° ([20]: 202–204°). ^{1}H-NMR ((D_6)DMSO, 400 MHz): 7.62–7.66 (*m*, 4 arom. H); 7.50 (*m*(*AA′BB′*), $J_{app} = 8.2$, 2 arom. H); 7.45 (‘*t*’, $J_{app} = 7.7$, 2 arom. H); 7.35 (‘*t*’, $J_{app} = 7.5$, 1 arom. H); 5.08 (*s*, CH). ^{13}C-NMR ((D_6)DMSO, 100.6 MHz): 174.0; 139.8; 139.5; 139.3; 128.9; 127.4; 127.2; 126.6; 126.4; 72.1. EI-MS: 228 (52, M^+), 183 (100, $[M - CO_2H]^+$), 155 (41).

[1,1′-Biphenyl]-4-carboxylic Acid. According to the *G. P.*, but with a different workup procedure: Upon completion of the reaction, the mixture was filtered and the FRPSG washed with 1M HCl in MeOH/H_2O 11:1 (2×1 ml), MeOH (2×1 ml), and H_2O (2×1 ml). The combined filtrate was diluted with sat. aq. NaCl soln. (30 ml) and extracted with Et_2O (3×20 ml). The combined extracts were evaporated to give the product. An anal. sample was crystallized from MeOH. M.p. 223–226° (dec.) ([21]: 226–228°). ^{1}H-NMR ((D_6)DMSO, 400 MHz): 8.01 (*m*(*AA′BB′*), $J_{app} = 8.2$, 2 arom. H); 7.79 (*m*(*AA′BB′*), $J_{app} = 8.2$, 2 arom. H); 7.72 (*m*(*AA′BB′*), $J_{app} = 7.3$, 2 arom. H); 7.49 (‘*t*’, $J_{app} = 7.5$, 2 arom. H); 7.41 (‘*t*’, $J_{app} = 7.3$, 1 arom. H). ^{13}C-NMR ((D_6)DMSO, 100.6 MHz): 167.0; 144.2; 139.0; 129.9; 129.6; 129.0; 128.2; 126.9; 126.7. EI-MS : 198 (100, M^+), 181 (63, $[M - OH]^+$).

[1,1′-Biphenyl]-3-carboxylic Acid. According to the *G. P.* M.p. 168° ([22]: 169–170°). ^{1}H-NMR ((D_6)DMSO, 400 MHz): 13.0 (br., OH); 8.17 (*t*, $J = 1.7$ Hz, 1 arom. H); 7.89–7.95 (*m*, 2 arom. H); 7.69 (*m*(*AA′BB′*), $J_{app} = 7.3$, 2 arom. H); 7.59 (*t*, $J = 7.7$, 1 arom. H); 7.49 (‘*t*’, $J_{app} = 7.7$, 2 arom. H); 7.40 (‘*t*’, $J_{app} = 7.3$, 1 arom. H). ^{13}C-NMR ((D_6)DMSO, 100.6 MHz): 167.1; 140.5; 139.2; 131.4; 131.0; 129.3; 129.0; 128.2; 127.8; 127.2; 126.7. EI-MS: 198 (100, M^+), 181 (29, $[M - OH]^+$), 152 (34).

[1,1′Biphenyl]-4-acetic Acid. According to the *G. P.* M.p. 165° ([20]: 161–162°). ^{1}H-NMR ($CDCl_3$, 400 MHz): 7.54–7.59 (*m*, 4 arom. H); 7.42 (‘*t*’, $J_{app} = 8.0$, 2 arom. H); 7.31–7.37 (*m*, 3 arom. H); 3.69 (*s*, CH_2). ^{13}C-NMR ($CDCl_3$, 100.6 MHz): 177.4; 140.8; 140.5; 132.4; 129.9; 128.9; 127.5; 127.4; 127.2; 40.7. EI-MS: 212 (53, M^+), 167 (100, $[M - CHO_2]^+$).

4-Phenylhippuric Acid. (= N-*([1,1′-Biphenyl]-4-ylcarbonyl)glycine*). According to the *G. P.*, but extraction with AcOEt instead of Et_2O. M.p. 218–219° (dec.) ([23]: 211°). ^{1}H-NMR ((D_6)DMSO, CD_3OD, 500 MHz): 7.94 (*m*(*AA′BB′*), $J_{app} = 8.6$, 2 arom. H); 7.75 (*m*(*AA′BB′*), $J_{app} = 8.6$, 2 arom. H); 7.70 (*m*, $J_{app} = 8.2$, 2 arom. H); 7.46 (‘*t*’, $J_{app} = 7.6$, 2 arom. H); 7.38 (*m*, 1 arom. H); 3.95 (*s*, CH_2). ^{13}C-NMR ((D_6)DMSO, CD_3OD, 125.7 MHz): 171.6; 166.7; 143.5; 139.6; 132.9; 131.7; 129.3; 128.2; 127.1; 126.8; 41.3. EI-MS: 255 (15, M^+), 211 (51, $[M - CO_2]^+$), 181 (100, $C_{13}H_9O^+$), 152 (44).

3-Phenylhippuric Acid (= N-*([1,1′-Biphenyl]-3-ylcarbonyl)glycine*). According to the *G. P.*, but extraction with AcOEt instead of Et_2O. M.p. 212–213° ([24]: 219°). ^{1}H-NMR (CD_3OD, 500 MHz): 8.12 (*t*, $J = 1.9$, 1 arom. H); 7.83 (*ddd*, $J = 7.7$, 1.8, 1.1, 1 arom. H); 7.80 (*ddd*, $J = 7.8$, 1.9, 1.1, 1 arom. H); 7.65–7.67 (*m*, 2 arom. H); 7.54 (*t*, $J = 7.8$, 1 arom. H); 7.45 (‘*t*’, $J_{app} = 7.9$, 2 arom. H); 7.34 (‘*t*’, $J_{app} = 7.4$, 1 arom. H); 4.12 (*s*, CH_2). ^{13}C-NMR (CD_3OD, 125.7 MHz): 173.2; 170.4; 142.9; 141.5; 135.7; 131.4; 130.2; 130.0; 128.8; 128.1; 127.2; 127.0; 25.6. EI-MS: 255 (27, M^+), 211 (37, $[M - CO_2]^+$), 181 (100, $C_{13}H_9O^+$), 152 (58).

4-(4-Methoxyphenyl)mandelic Acid (= *α-Hydroxy-4′-methoxy[1,1′-biphenyl]-4-acetic Acid*). According to the *G. P.*, but workup as described above for [1,1′-biphenyl]-4-carboxylic acid. ^{1}H-NMR (CD_3OD, 400 MHz; * = overlapping): 7.55* (*m*(*AA′BB′*), $J_{app} = 8.6$, 2 arom. H); 7.53* (*m*(*AA′BB′*), $J_{app} = 9.0$, 2 arom. H); 7.46 (*m*(*AA′BB′*), $J_{app} = 8.2$, 2 arom. H); 6.97 (*m*(*AA′BB′*), $J_{app} = 9.0$, 2 arom. H); 5.21 (*s*, CH); 3.81 (*s*, MeO). ^{13}C-NMR (CD_3OD, 100.6 MHz): 174.9; 160.9; 142.2; 138.7; 134.3; 129.0; 127.6; 115.3; 74.1; 55.8. APCI-MS (neg.): 257 (100, $[M - H]^-$), 213 (14, $[M - CO_2H]^-$).

4-(4-Methoxyphenyl)phenylacetic Acid (= *4′-Methoxy[1,1′-biphenyl]-4-acetic Acid*). According to the *G. P.*, but workup as described above for [1,1′-biphenyl]-4-carboxylic acid. ^{1}H-NMR (CD_3OD, 400 MHz): 7.49–7.53 (*m*, 4 arom. H); 7.32 (*m*(*AA′BB′*), $J_{app} = 8.2$, 2 arom. H); 6.97 (*m*(*AA′BB′*), $J_{app} = 9.0$, 2 arom. H); 3.81 (*s*, MeO); 3.60 (*s*, CH_2). ^{13}C-NMR (CD_3OD, 100.6 MHz): 176.0; 160.7; 140.7; 134.7; 134.6; 130.8; 128.9; 127.6; 115.3; 55.8; 41.9. EI-MS: 242 (80, M^+), 197 (100, $[M - CO_2H]^+$), 182 (15), 154 (31).

4-(2-Methoxyphenyl)mandelic Acid (= *α-Hydroxy-2′-methoxy[1,1′-biphenyl]-4-acetic Acid*). According to the *G. P.* ^{1}H-NMR (CD_3OD, 400 MHz): 7.44–7.48 (*m*(*AA′BB′*), 4 arom. H); 7.24–7.31 (*m*, 2 arom. H); 7.04 (*d*, $J = 8.2$, 1 arom. H); 6.98 (*t*, $J = 7.5$, 1 arom. H); 5.15 (*s*, C*H*OH); 3.76 (*s*, MeO). ^{13}C-NMR (CD_3OD, 100.6 MHz): 176.4; 158.0; 140.0; 139.4; 131.7; 131.6; 130.5; 129.9; 127.4; 121.9; 112.7; 74.2; 56.0. APCI-MS (neg.): 257 (100, $[M - H]^-$), 213 (44, $[M - CO_2H]^-$).

4-(2-Methoxyphenyl)phenylacetic Acid (= *2′-Methoxy[1,1′-biphenyl]-4-acetic Acid*). According to the *G. P.* ^{1}H-NMR (CD_3OD, 500 MHz; * = overlapped): 7.40 (*m*(*AA′BB′*), $J_{app} = 8.5$, 2 arom. H); 7.22–7.29* (*m*, 2 arom. H); 7.25* (*m*(*AA′BB′*), $J_{app} = 7.8$, 2 arom. H); 7.01 (*dd*, $J = 8.2$, 1.0, 1 arom. H); 6.97 (*td*, $J = 7.5$, 1.1,

1 arom. H); 3.73 (*s*, MeO); 3.63 (*s*, CH_2). ^{13}C-NMR (CD_3OD, 125.7 MHz): 175.7; 158.0; 138.8; 134.5; 132.4; 131.6; 130.6; 129.9; 129.7; 121.9; 112.6; 56.0; 41.7. EI-MS: 242 (100, M^+), 197 (94, $[M-CO_2H]^+$), 181(54).

O1-([1,1′-Biphenyl-4-ylmethyl)glycerol (*= 3-([1,1′-Biphenyl]-4-ylmethoxy)propane-1,2-diol*). According to the *G. P.*, but extraction with AcOEt instead of Et_2O. ^{1}H-NMR ($CDCl_3$, 500 MHz): 7.55–7.57 (*m*, 4 arom. H); 7.42 (*t*, *J* = 7.77, 2 arom. H); 7.37 (*d*, *J* = 8.2, 2 arom. H); 7.33 ('*t*', *J* = 7.5, 1 arom. H); 4.57 (*s*, ArCH_2); 3.91 (*m*, 1 H); 3.68–3.72 (*m*, 1 H), 3.60–3.64 (*m*, 1 H); 3.52–3.59 (*m*, 2 H); 2.9 (br., 2 OH). ^{13}C-NMR ($CDCl_3$, 125.7 MHz): 140.9; 140.7; 136.7; 128.8; 128.3; 127.4; 127.2; 127.1; 73.3; 71.8; 70.7; 64.1. EI-MS: 258 (7, M^+), 183 (48, $C_{13}H_{11}O^+$); 167 (100, $C_{13}H_{11}^+$), 152 (33, $C_{12}H_8^+$).

Typical Procedure for the Determination of Pd Leaching on Preparation of 4-Phenylmandelic Acid. To supported catalyst (500 mg, 1.5 μmol of Pd-complex **2a** or **3** on either FRPSG or silica gel), an aq. stock soln. of the substrates (15 ml, containing 1.5 mmol of 4-bromomandelic acid, 1.65 mmol of phenylboronic acid, and 3.0 mmol of Na_2CO_3) was added under Ar. The mixture was shaken at 80° for 16 h. The mixture was cooled to r.t. and filtered. The FRPSG was washed with H_2O (4 × 5 ml). The combined filtrate was evaporated, and the Pd-content of the solid residue was determined by ICP-MS (*Solvias*, Basel, Switzerland).

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