and the mixture purified by chromatography on silica gel ($CHCl_3$/acetonitrile/ethanol 40/2/1). Characterization was carried out by mass spectrometry and UV/Vis and NMR spectroscopy.

To synthesize the rhodamine dye **2** sulforhodamine B acid chloride (0.40 mmol) was dissolved in CH_2Cl_2 (20 mL) and cooled in an ice bath. Pyridine (100 μL) and (3-aminopropyl)triethoxysilane (181 mg) were added, and the mixture was stirred for 24 h. The product was precipitated in *tert*-butyl methyl ether, intensively washed, and characterized by mass spectrometry and UV/Vis and NMR spectroscopy.

For the synthesis of the dye-loaded Si-MCM-41 water (24 g), NH_3 (3 g, 25 %), and 1-butanole (230 μL) were mixed. Portions (6–125 mg) of the dyes were dissolved in TEOS (2.4 g) in an ultrasonic bath. The two solutions were combined under stirring and CTAB (1.4 g) in water (6 g) was slowly added over 15 min. Subsequently, the synthesis gel was placed in a teflon autoclave and heated under continuous stirring in a microwave oven (MLS 1200, Milestone) for 5 min at 403 K (480 W) and then at 373 K (60 W) for 15 min. The isolated product was washed in water and ethanol several times. To remove the template Si-MCM-41 (250 mg) was stirred for 12 h in an aqueous 1 M HCl solution (100 mL) at 343 K and washed afterwards with water and ethanol.

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Immobilization of TADDOL with a High Degree of Loading on Porous Silica Gel and First Applications in Enantioselective Catalysis**

Alexander Heckel and Dieter Seebach*

The immobilization of organic compounds (and enzymes)[1] on (or in) highly porous SiO_2 instead of organic polymers (for example, by cross-linking copolymerization)[2–4] for solid-phase synthesis and catalysis has the following advantages:[5, 6] the material has a rigid structure and does not swell in solvents; hence it can be used both at high or low temperatures and at high pressures; depending on the porosity, the degree of loading with functional groups can be high; the surface of the silica can be rendered hydrophobic; the support is chemically inert—except to strong alkali and fluoride.

For comparison with TADDOL ligands grafted onto Merrifield resin or immobilized in polystyrene[3, 4] we have now grafted a TADDOL derivative onto two commercially available CPGs (*c*ontrolled-*p*ore *g*lass)[7] with different pore sizes, made the surface hydrophobic, and finally loaded the TADDOL moieties with titanates (Scheme 1, Table 1). The resulting material (**1a–c** and **2**) has been tested in the Lewis acid-mediated enantioselective addition of Et_2Zn to benzaldehyde and in the [3 + 2]cycloaddition of diphenylnitrone to *N*-crotonoyl-1,3-oxazolidin-2-one[12] (both reactions show a linear relationship between the enantiomeric purities of TADDOL and product; see Equation (1) and (2) in Scheme 2).[3, 13, 14]

As shown in Scheme 2 we have achieved virtually the same conversion, diastereo- (% *ds*) and enantioselectivities (% *es*) with the CPG-bound Ti-TADDOLates as in the homogeneous phase, under otherwise identical conditions. Much more important are the results obtained in the multiple use of the CPG-bound Ti-TADDOLates (Figures 1 and 2): 1) As with the polystyrene-bound catalyst[4] there is a slight decrease in enantioselectivity with multiple uses. 2) However, a high loading (up to 0.32 mmol TADDOL per g) does not have a negative effect on selectivity, here. This is a most welcome feature since the percentage of supporting material in the total mass of the heterogeneous catalyst can thus be kept low. 3) To our surprise, the material can be washed with HCl/H_2O/acetone, dried, and reloaded with titanate, for example, after 10 or even 20 catalytic runs, and the selectivities observed are as good as in the beginning. This means that the loss of catalytic activity was not a consequence of a loss of TADDOL moieties or surface hydrophobization, but rather of impurities that could be removed by washing with acid.[15, 16] 4) The rate

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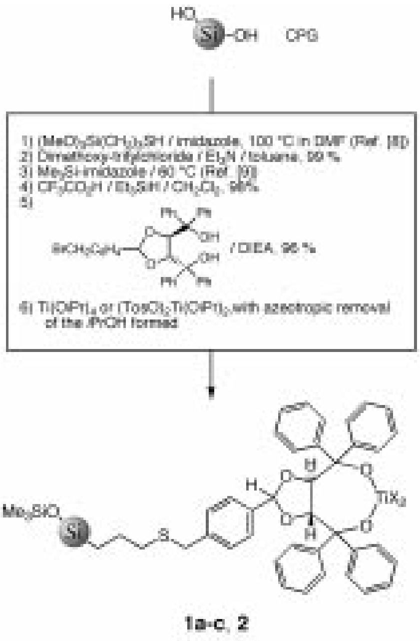
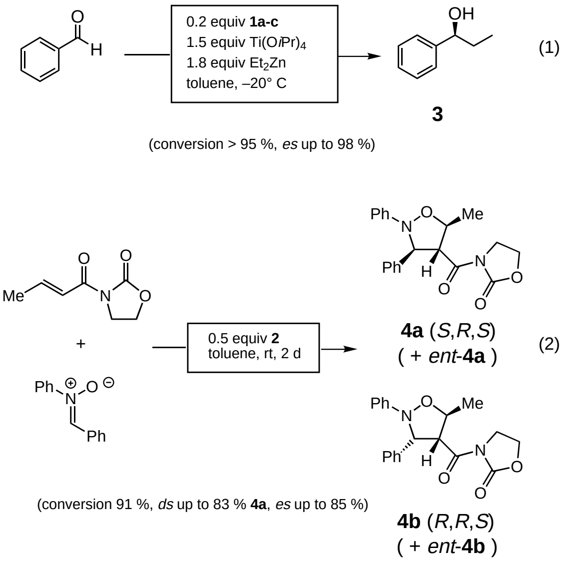


Scheme 1. Synthesis of the CPG-bound TADDOL derivatives **1a–c** and **2** (X = OTos, O*i*Pr). The reaction was monitored quantitatively by the determination of free SH groups[10] or by the cleavage and subsequent quantitative determination of the stable dimethoxytrityl cations formed.[11] For a semi-quantitative control of the hydrophobization a solution of Methyl Red in benzene was used.[5] The yields given refer to the synthesis of the 200 Å material, the TADDOL derivative used is described in ref. [3] DIEA = diisopropylethylamine (Hünig base; Tos = toluene-4-sulfonyl).

Table 1. Specification of the TADDOL derivatives **1** and **2** immobilized on CPG

	X	Loading [mmol g^{-1}]	Pore size [Å]
1a	O*i*Pr	0.32	200
1b	O*i*Pr	0.08	200
1c	O*i*Pr	0.12	500
2	OTos	0.32	200



Scheme 2. First applications of the CPG-bound TADDOL derivatives **1a–c** and **2**. The addition of Et$_2$Zn to PhCHO in solution and in the presence of 0.2 equiv TADDOL gives >99% conversion and 98% *es*. Under homogeneous conditions Jørgensen et al. found 86% conversion, 85% *ds*, and 92.5% *es* in the [3+2]cycloaddition with a comparable TADDOL derivative.[12]

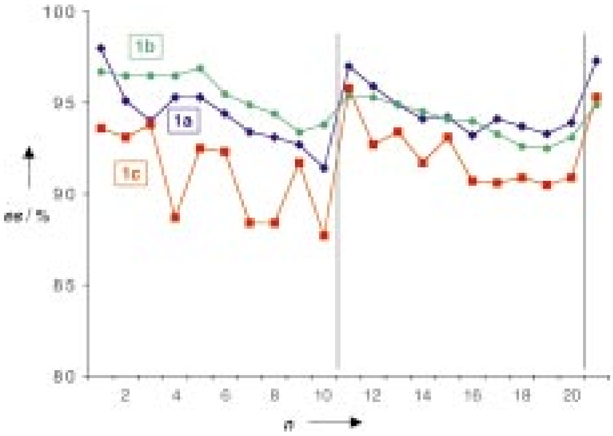


Figure 1. Enantioselectivities obtained in multiple uses of the heterogeneous TADDOL derivatives **1a–c** in the addition of Et$_2$Zn to benzaldehyde (the *es* value (%) is the percentage of (*S*)-**3** determined by gas chromatography). The contents of the reaction flask were mixed on a shaking machine. After the 10th and 20th catalytic cycle the catalyst was washed with HCl/H$_2$O/acetone, dried, and re-loaded with titanate. Otherwise the catalyst was only washed with toluene under protective gas between consecutive catalytic cycles. *n* = catalytic cycle.

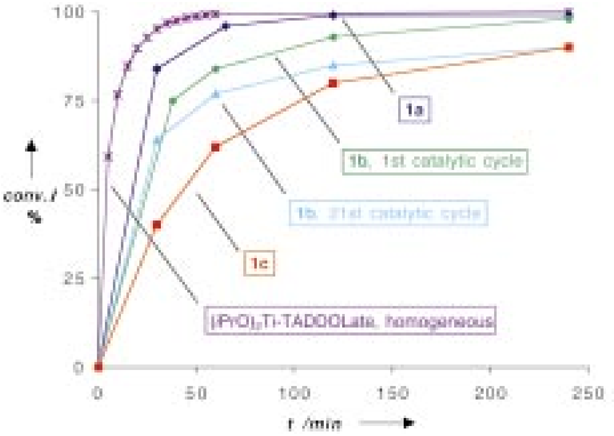


Figure 2. Reaction rates of the addition of Et$_2$Zn to benzaldehyde with the heterogeneous TADDOL derivatives **1a–c** and comparison with the reaction rate in homogenous solution. The 21st cycle with **1b** was done after the second washing (compare with Figure 1).

of addition of Et$_2$Zn to benzaldehyde is only slightly lower with the highly loaded CPG **1a** than a reaction with homogeneous Ti-TADDOLate. Furthermore, the rate in the 21st run using the lower-loaded material **1b**—after the second washing procedure—was almost the same as in the first run (Figure 2). 5) Good reproducibility in the [3+2]cycloaddition is also possible when the catalyst is re-used (Equation 2 in Scheme 2). However, the heterogeneous catalyst has to be washed after every use in this case, as described above. Only a small loss of activity is observed after four runs.

Chiral Lewis acids usually have a high molecular weight and often a large quantity (5 to over 100 mol%) has to be employed.[17] Therefore, immobilization and re-use is very important. This fact, the possible high degree of loading on porous silica gel, its constant volume, and the stability in washing procedures are motivation for further investigations in this field. These include the testing of different types of reactions (especially under conditions where the use of polystyrene derivatives is problematic), immobilizing different ligands, and immobilizing dendritically modified ligands in the sol–gel process.

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Phosphane-Free Palladium-Catalyzed Coupling Reactions: The Decisive Role of Pd Nanoparticles[**]

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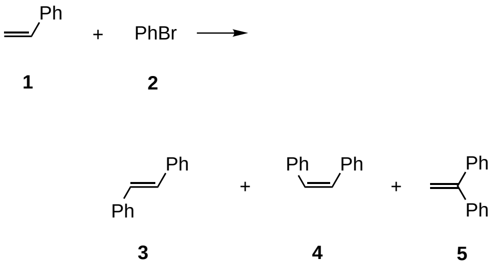
The number of examples of Pd-catalyzed C–C bond forming reactions continues to rise, for example, in the area of Heck, Suzuki, and Stille coupling reactions.[1] One of the most common catalysts is $[Pd(PPh_3)_4]$, but precatalysts such as PdX_2 in the presence of excess PPh_3, which reduces Pd^{II} to Pd^0, are also used. In addition to new types of catalysts or precatalysts such as Pd–carbene complexes[2] or phosphapalladacycles,[3] simple Pd salts such as $PdCl_2$ or $Pd(OAc)_2$ in the *absence* of stabilizing phosphane ligands are increasingly being used in Heck and Suzuki reactions.[1] Preparatively significant examples are the Jeffery system[4] in which $Pd(OAc)_2$ in the presence of an excess of a phase-transfer catalyst such as $n\mathrm{Bu}_4\mathrm{N}^+\mathrm{Cl}^-$ is used, or $Pd(OAc)_2$ in an aqueous medium.[5] In both cases aryl iodides are usually employed as the arylating agent. In the case of the industrially more interesting aryl bromides, $Pd(OAc)_2$ (or $PdCl_2$) with or without *N*,*N*-dimethylglycine (DMG) as an additive is currently one of the cheapest and most active catalysts.[6] How can such simple phosphane-free catalyst systems be understood, given that it is generally assumed that phosphanes exert a stabilizing and activating effect?[1] We report here a mechanistic study[7] supported by transmission electron microscopy (TEM) which points to the involvement of intermediary Pd nanoparticles as colloids in such systems.

First the Heck reaction of styrene (**1**; 12 mmol) with bromobenzene (**2**; 10 mmol) at 130 °C in *N*-methylpyrrolidinone (NMP; 10 mL) was studied. Our previously reported catalyst system with $[PdCl_2(C_6H_5CN)_2]$ (1.5 mol%)/DMG as the precatalyst and sodium acetate (20 mmol) as the base was used.[6] As expected, essentially complete conversion with formation of the Heck products **3**–**5** in a ratio of 96:1:3 was observed over 6 h [Eq. (1)].



(1)

The course of the reaction was monitored by periodically taking samples and analyzing them by gas chromatography. Parallel to these analyses, the samples were studied by TEM.

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