[1] K. D. Shimizu, J. Rebek, Jr., *Proc. Nat. Acad. Sci. USA* **1995**, *92*, 12403–12407.

[2] For recent reviews of calixarene chemistry see: V. Böhmer, *Angew. Chem.* **1995**, *107*, 785–818; *Angew. Chem. Int. Ed. Engl.* **1995**, *34*, 713–745; P. Linnane, S. Shinkai, *Chem. Ind. (London)* **1994**, 811–814; C. D. Gutsche, *Aldrichimica Acta* **1995**, *28*, 3–9; S. Shinkai, *Tetrahedron* **1993**, *49*, 8933-8968.

[3] M. C. Etter, T. W. Panunto, *J. Am. Chem. Soc.* **1988**, *110*, 5896–5897; M. C. Etter, Z. Urbañczyk-Lipkowska, M. Zia-Ebrahimi, T. W. Panunto, *J. Am. Chem. Soc.* **1990**, *112*, 8415–8426.

[4] C. D. Gutsche, P. F. Pagoria, *J. Org. Chem.* **1985**, *50*, 5795–5802.

[5] P. Timmerman, W. Verboom, D. N. Reinhoudt, A. Arduini, S. Grandi, A. R. Sicuri, A. Pochini, R. Ungaro, *Synthesis* **1994**, 185–189; P. Timmerman, K. G. A. Nierop, E. A. Brinks, W. Verboom, C. J. M. van Veggel, W. P. van Hoorn, D. N. Reinhoudt, *Chem. Eur. J.* **1995**, *1*, 132–143.

[6] For other host guest compounds with calixarenes see: J. D. van Loon, R. G. Janssen, W. Verboom, D. N. Reinhoudt, *Tetrahedron Lett.* **1992**, *33*, 5125–5128; K. Koh, K. Araki, S. Shinkai, *ibid.* **1994**, *35*, 8255–8258.

[7] The ^{19}F NMR spectrum of fluorobenzene in $[D_{10}]$*p*-xylene showed a resonance at $\delta = -113.1$; upon encapsulation with **2-2** a new resonance appeared at $\delta = -118.5$. The resonance for **2-2** appeared at $\delta = -119.4$ and remained unchanged upon encapsulation of fluorobenzene.

[8] For examples of encapsulation in covalently linked hemispheres see: T. A. Robbins, C. B. Knobler, D. R. Bellow, D. J. Cram, *J. Am. Chem. Soc.* **1994**, *116*, 111–122; A. Ikeda, S. Shinkai, *J. Chem. Soc. Perkin Trans. I* **1993**, 2671–2673; L. Garel, J. P. Dutasta, A. Collet, *Angew. Chem.* **1993**, *105*, 1249–1251; *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 1169–1171. For encapsulation in noncovalent assemblies see: N. Branda, R. Wyler, J. Rebek, Jr., *Science* **1994**, *263*, 1267–1268; R. Meissner, J. de Mendoza, J. Rebek, Jr., *ibid.* **1995**, *270*, 1485–1488.

[9] A recent study of encapsulation using hydrogen-bonded assemblies also finds pyrazine a welcome guest: R. G. Chapman, J. C. Sherman, *J. Am. Chem. Soc.* **1995**, *117*, 9081–9082.

[10] N. Branda, Ph.D. Thesis, Massachusetts Institute of Technology, **1994**; G. J. Kleyweht, T. A. Jones, *Acta Crystallogr. Sect. D* **1994**, 50, 178.

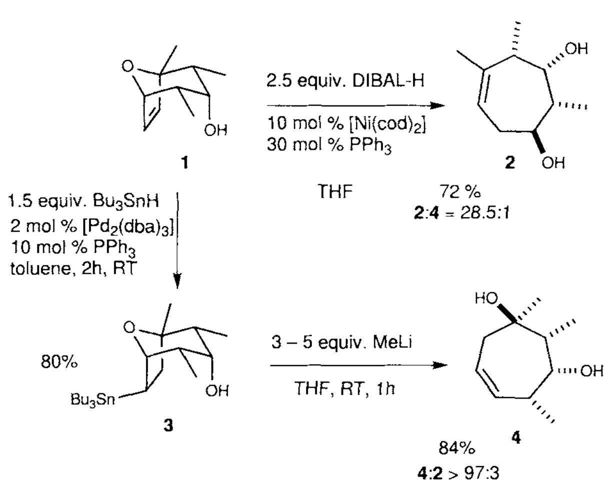
[11] C. N. Eid, Jr., D. J. Cram, *J. Chem. Educ.* **1993**, *70*, 1993.

Heterogeneous Palladium-Catalyzed Regioselective Hydrostannation of Alkenes**

Mark Lautens,* Sophie Kumanovic, and Christophe Meyer

Hydrometalation of carbon–carbon multiple bonds is a powerful method for the generation of useful organometallic compounds.[1] We have previously described the nickel-catalyzed hydroalumination and ring opening of oxabicyclic systems such as **1** leading to the cycloalkenol **2** (Scheme 1).[2] Recently we reported the palladium-catalyzed hydrostannation of **1**,[3] leading to the organostannane **3** in which the tin occupies a distal position. Transmetalation of the latter with methyllithium afforded the regioisomeric ring-opened product **4**.

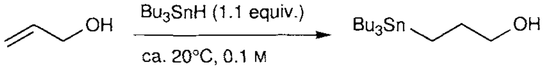
We were interested in extending the scope of the hydrostannation reaction to a wider variety of alkenes. It is well-known that palladium complexes catalyze the hydrostannation of alkynes to yield vinylstannanes.[4] However, the corresponding reaction of unactivated alkenes has not been reported to our knowledge. This reaction should, in principle, lead to tetraalkylstannanes. Although simple tetraalkylstannanes fail to undergo efficient tin–lithium exchange, an appropriately located heteroatom shifts the equilibrium due to coordination to the newly formed organolithium compound, thus allowing the exchange to proceed.[5] Interestingly, 3-tributylstannyl-1-propanol has been shown by Seebach and Meyer to be transmetalated to 3-lithioalkoxypropyllithium,[6a] and the dramatic influence of the alkoxy moiety in a related process has been nicely illustrated by Carpenter and Newman-Evans.[6b] More recently, Knochel et al. have applied this tin–lithium exchange reaction to the synthesis of chiral, γ-functionalized secondary alcohols.[6c]



Scheme 1. Hydrometalation–ring opening sequences of oxabicyclic compound **1**. RT = room temperature, DIBAL-H = diisobutylaluminum hydride.

Hydrostannation of double bonds has mostly been achieved under radical conditions by heating the compounds in neat tin hydrides, sometimes in the presence of a radical initiator.[7] Activated alkenes including styrene react rapidly, but this reaction lacks generality. Since addition of stannyl radicals onto a carbon–carbon double bond is reversible,[7b] a high concentration of tin hydride is required to achieve an efficient quench of the initially formed β-stannyl radical. Alternatively, ultrasound-promoted radical hydro- and hydroxystannations of activated double bonds have also been described.[7e]

When we attempted to perform the hydrostannation of allyl alcohol [Eq. (a)] with the homogeneous Pd catalyst that worked efficiently for the conversion of **1** to **3**, the corresponding 3-tributylstannyl-1-propanol was produced in no more than 5% yield (Table 1, entry 1). Similarly, other allylic alcohols failed to give high yields of hydrostannated products in the presence of the commonly used soluble catalyst $[Pd(PPh_3)_4]$.



(a)

However, we have found that this reaction can be performed in high yield under heterogeneous catalysis. Pd/C was the first

Table 1. Hydrostannation of allyl alcohol according to Equation (a).

Entry	Catalyst	Solvent	Time [a]	Yield [%] [b]
1	$[Pd_2(dba)_3]$ 2.5 mol% PPh_3 10 mol%	THF	ca. 12 h	4
2	·	EtOH abs.	ca. 12 h	23 [c]
3	Pd/C 10 mol%	AcOEt	ca. 12 h	35
4	$[Pd(OH)_2]/C$ [d, e]	EtOH abs.	2 h	50
5	$[Pd(OH)_2]/C$ [d]	THF	1 h	82

[a] Total time elapsed before workup. [b] Yield of isolated product. [c] No reaction occurs if the solvent is degassed, or if galvinoxyl is added. Galvinoxyl = 2,6-di-*tert*-butyl-α-(3,5-di-*tert*-butyl-4-oxo-2,5-cyclohexadien-1-ylidene)-*p*-tolyloxy (free radical). [d] 10 mol% Pd from Pearlman's catalyst (dry weight basis). [e] Addition of galvinoxyl has no effect on this reaction.

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catalyst we examined (entry 3), but [Pd(OH)$_2$]/C (Pearlman's catalyst, entries 4 and 5) was more efficient at promoting the hydrostannation of a variety of alkenes, provided that Bu_3SnH was added slowly over one or more hours. Transition metals are known to catalyze the decomposition of tributyltin hydride to hexabutyldistannane and molecular hydrogen,[7a] and this was the main side reaction we had to overcome. The major side product of the reaction is Bu_6Sn_2, which is easily removed by column chromatography.

The catalytic influence of palladium hydroxide is demonstrated by the fact that in its absence, 3-tributylstannyl-1-propanol is produced in only 23% yield, because of an inefficient radical pathway (entry 2). The latter pathway can be completely inhibited by degassing the solvent or by adding radical scavengers such as galvinoxyl. THF was the optimum solvent for this heterogeneously catalyzed hydrostannation (entry 5), although ethanol gave good yields as well.

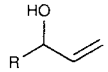
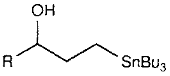
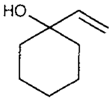
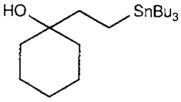
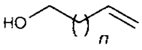
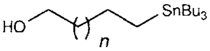
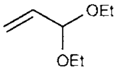
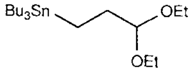
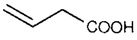
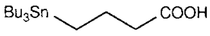
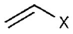
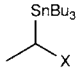
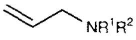
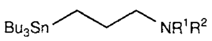
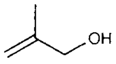
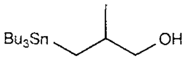
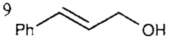
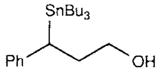
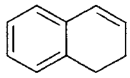
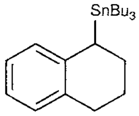
The reaction has been successfully applied to a wide variety of alkenes (Table 2). The allylic alcohols can be either secondary or tertiary (entries 1 and 2). The presence of a coordinating group located at the allylic position is not required for the reaction to proceed, since 3-buten-1-ol, 10-undecen-1-ol (entry 3), acrolein diethyl acetal (entry 4), and vinylacetic acid (entry 5) are regioselectively hydrostannated in good yields. In the case of acrylonitrile (entry 6), both heterogeneously and previously reported homogeneously catalyzed hydrostannations afford the α adduct,[8] confirming that the reaction follows a polar pathway. *N*-Vinylphthalimide (entry 6) is hydrostannated in acceptable yield, and the resulting compound is of significant interest, since α-phthalimidostannanes can function as α-aminostannane equivalents in Stille-type coupling reactions.[9]

Allyl amine derivatives (entry 7) are also hydrostannated in excellent yields under the same conditions, which provides an efficient route to γ-aminostannanes.

1,1-Disubstituted alkenes react efficiently (entry 8), but unactivated 1,2-dialkyl-substituted alkenes give low yields of hydrostannated products under these conditions. However, aryl substituted alkenes react smoothly, leading to benzylstannanes (entries 9 and 10). Interestingly, in the case of 1,2-dihydronaphthalene, we have found that radical-initiated addition of Bu_3SnH proceeds with the opposite regiochemistry in 88% yield.

In conclusion, we have shown that a wide variety of alkenes can be efficiently hydrostannated under heterogeneous conditions, providing easy access to organostannanes that are not easily prepared by other routes. This reaction can also be complementary to the radical-based hydrostannation reactions in terms of the regioselectivity of the addition. Further developments on this reaction, especially in the design of diastereo- and enantioselective hydrostannations, are currently underway.

Table 2. Heterogeneously catalyzed hydrostannation of substituted alkenes.

Entry	Alkene	Product [a]		Yield [%] [b]
1			R = Ph	96
			R = 2-furyl	92
2				94 [c]
3			$n = 1$	91 [d]
			$n = 8$	80
4				85
5				78
6			X = CN	84
			X = *N*-phthaloyl	60
7			$R^1 = H$, $R^2 = CO_2tBu$	89
			$R^1 = H$, $R^2 = Bn$	81
			$R^1 = R^2 = Bn$	80
			$R^1 = H$, $R^2 = COPh$	88
8				90
9				94
10				90

[a] Conditions: 1.5 equiv Bu_3SnH, 10 mol% Pd from Pearlman's catalyst, THF (0.1 M), room temperature, 1 h. [b] Yields of isolated products. [c] Reaction performed in absolute ethanol. [d] An 84:1 ratio of the linear and branched isomers was observed.

Experimental Procedure

General procedure for the heterogeneous, palladium-catalyzed hydrostannations of alkenes: Tributyltin hydride (1.5 mmol) was added over 1 hour by syringe pump to a well-stirred mixture of the alkene (1 mmol) and [Pd(OH)$_2$]/C (Pearlman's catalyst, 53 mg, 0.1 mmol of Pd) in THF (10 mL). The reaction mixture was stirred for an additional hour and then filtered through a pad of celite. Flash chromatography on silica gel (hexanes:ethyl acetate mixtures as eluent) gave the product.

1-Phenyl-3-(tributylstannyl)propan-1-ol (entry 1): Purified by flash chromatography (hexanes:ethyl acetate 100:0 to 10:1), colorless oil (yield 96%). ^1H NMR (400 MHz, $CDCl_3$) $\delta = 7.36-7.24$ (m, 5H), 4.53 (m, 1H), 1.96–1.83 (m, 3H), 1.52–1.20 (m, 12H), 0.89–0.59 (m, 17H); ^{13}C NMR (100 MHz, $CDCl_3$) $\delta = 144.5$, 128.3, 127.4, 125.9, 77.7, 36.2, 29.2, 27.4, 13.7, 8.80, 4.20.

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[1] J. A. Labinger, K. Smith, A. Pelter, J. J. Eisch, T. Hiyama, T. Kusumoto in *Comprehensive Organic Synthesis, Vol. 8* (Eds.: B. M. Trost, I. Fleming), Pergamon Press, Oxford, **1991**, p. 667–792.

[2] M. Lautens, P. Chiu, S. Ma, T. Rovis, *J. Am. Chem. Soc.* **1995**, *117*, 532.

[3] M. Lautens, W. Klute, *Angew. Chem.* **1996**, *108*, 472; *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 442.

[4] a) T. N. Mitchell, *J. Organomet. Chem.* **1986**, *304*, 1; b) Y. Ichinose, H. Oda, K. Oshima, K. Utimoto, *Bull. Chem. Soc. Jpn.* **1987**, *60*, 3468; c) K. Kikukawa, H. Umekawa, F. Wada, T. Matsuda, *Chem. Lett.* **1988**, 881; d) H. X. Zhang, F. Guibé, G. Balavoine, *J. Org. Chem.* **1990**, *55*, 1857; e) S. Casson, P. Kocienski, *Synthesis* **1993**, 1133.

[5] M. Pereyre, J. P. Quintard, A. Rahm, *Tin in Organic Synthesis*, Butterworths, London, **1986**.

[6] a) N. Meyer, D. Seebach, *Chem. Ber.* **1980**, *113*, 1290; b) R. H. Newman-Evans, B. K. Carpenter, *Tetrahedron Lett.* **1985**, *26*, 1141; c) W. Brieden, R. Ostwald, P. Knochel, *Angew. Chem.* **1993**, *105*, 629; *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 582.

[7] a) W. P. Neumann, *The Organic Chemistry of Tin*, Wiley, New York, **1970**, and references therein; b) H. G. Kuivila, R. Sommer, *J. Am. Chem. Soc.* **1967**, *89*, 5616; c) D. D. Davis, R. L. Chambers, H. T. Johnson, *J. Organomet. Chem.* **1970**, *25*, C13; d) W. P. Neumann, *Synthesis* **1987**, 665; e) E. Nakamura, Y. Imanishi, D. Machii, *J. Org. Chem.* **1994**, *59*, 8178.

[8] P. Four, F. Guibé, *Tetrahedron Lett.* **1982**, 1825.

[9] J. Ye, R. K. Bhatt, J. R. Falck, *J. Am. Chem. Soc.* **1994**, *116*, 1.