

Remarkable Rate Acceleration of Pd(0)-Catalyzed Hydrogermylation of Alkynes and Dienes in Water

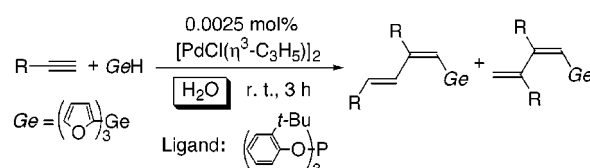
Hidenori Kinoshita, Tomoaki Nakamura, Hirotada Kakiya, Hiroshi Shinokubo, Seiji Matsubara, and Koichiro Oshima*

Department of Material Chemistry, Graduate School of Engineering, Kyoto University, Kyoto 606-8501, Japan

oshiba@fm1.kuic.kyoto-u.ac.jp

Received May 27, 2001

ABSTRACT



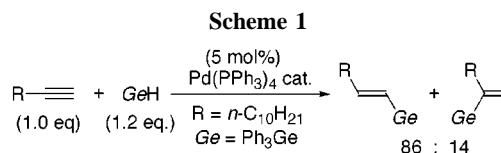
Without the use of hydrophilic cosolvents or phase transfer catalysts, Pd(0)-catalyzed hydrogermylation of alkynes in water provides dienylderived germanes efficiently with high stereo- and regioselectivity. The reaction in water proceeds much faster than the reaction under neat conditions. By using an aqueous system, hydrogermylation can be conducted at a low catalyst loading.

In recent years, organic reactions in aqueous media have received much attention for environmental and safety reasons.¹ In particular, water-soluble ligands have allowed the rapid development of transition-metal-catalyzed reactions.² However, the use of water-soluble ligands occasionally decreases the reaction rate and, therefore, requires increased catalyst loading or reaction time.

During our research on Pd(0)-catalyzed hydrogermylation of alkynes,³ we observed a remarkable rate acceleration in a heterogeneous aqueous system. This allows for a reduction

in the amount of catalyst employed. This acceleration phenomenon in water proved to be general, and thus hydrogermylation of 1,3-dienes also proceeds more efficiently in water than under neat conditions.

We reported that the Pd(0)-catalyzed reaction of 1-alkyne (1.0 equiv) with Ph_3GeH (1.2 equiv) provided a mixture of alkenylgermanes (Scheme 1).^{3f} The use of excess alkyne



changed the reaction pathway dramatically. The reaction of 1-octyne (3 equiv) with Ph_3GeH in the presence of $\text{Pd}(\text{PPh}_3)_4$ (5 mol %) furnished a mixture of dienylderived germane **1a** and alkenylgermane **3a** (Scheme 2).⁴ The use of tri(2-furyl)-

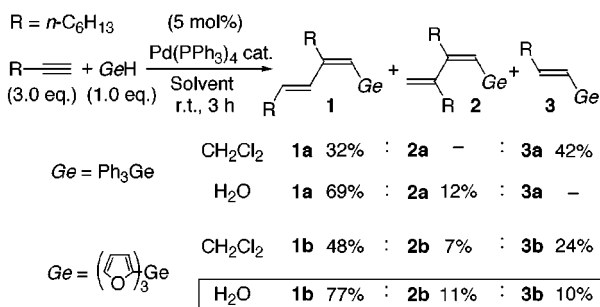
(4) Hydrosilylation of alkynes to provide 1-silyl-1,3-dienes has been reported: (a) Kawanami, Y.; Yamamoto, K. *Synlett* **1995**, 1232. (b) Lappert, M. F.; Nile, T. A.; Takahashi, S. *J. Organomet. Chem.* **1974**, 72, 425.

(1) (a) Li, C.-J.; Chan, T.-H. *Organic Reactions in Aqueous Media*; John Wiley: New York, 1997. (b) *Organic Synthesis in Water*; Grieco, P. A., Ed.; Blackie Academic & Professional: London, 1998. (c) Lubineau, A.; Augé, J. In *Modern Solvent in Organic Synthesis*; Knochel, P., Ed.; Springer-Verlag: Berlin, 1999; p 1.

(2) For transition-metal-catalyzed reactions in aqueous media, see: (a) Sinou, D. In *Modern Solvent in Organic Synthesis*; Knochel, P., Ed.; Springer-Verlag: Berlin, 1999; p 41. (b) Cornils, B.; Herrmann, W. A. *Aqueous-Phase Organometallic Chemistry*; Wiley-VCH: Weinheim, 1998.

(3) (a) Corriu, R. J. P.; Moreau, J. J. E. *J. Organomet. Chem.* **1972**, 40, 73. (b) Dimens, V.; Barabanov, D. I.; Liepins, E.; Ignatovich, L. M.; Lukevics, E. *J. Organomet. Chem.* **1992**, 435, 257. (c) Wada, F.; Abe, S.; Yonemura, N.; Kikukawa, K.; Matsuda, T. *Bull. Chem. Soc. Jpn.* **1991**, 64, 1701. (d) Piers, E.; Lemieux, R. *J. Chem. Soc., Perkin Trans. 1* **1995**, 3. (e) Widenhofer, R. A.; Vadehra, A.; Cheruvu, P. K. *Organometallics* **1999**, 18, 4614. (f) Ichinose, Y.; Oda, H.; Oshima, K.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1987**, 60, 3468. For a review of hydrogermylation, see: Wolfsberger, W. *J. Prakt. Chem.* **1992**, 334, 453.

Scheme 2



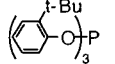
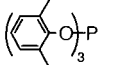
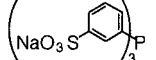
germane,⁵ instead of Ph_3GeH , exhibited better selectivity and afforded dienyldermanes **1b** and **2b** predominantly. The substituent on germanium is important. Triethylgermane provided none of the desired adducts under the same reaction conditions. The reaction solvent also plays a critical role. Interestingly, water was the best solvent we examined, although the reaction system is completely heterogeneous. We then focused our attention on the reaction in aqueous media.

In water, various ligands were examined, using $[\text{PdCl}(\eta^3\text{-C}_3\text{H}_5)_2]$ as the palladium source (Table 1). After several

Table 1. Pd(0)-Catalyzed Hydrogermylation of 1-Octyne with Tri(2-furyl)germane in Water^a

$R\text{-C}\equiv\text{C} + \text{GeH} \xrightarrow[\text{H}_2\text{O, Ligand}]{[\text{PdCl}(\eta^3\text{-C}_3\text{H}_5)_2]}$

$R = n\text{-C}_6\text{H}_{13}$ $\text{Ge} = \left(\begin{array}{c} \diagup \\ \text{O} \\ \diagdown \end{array}\right)_3\text{Ge}$

entry	ligand	yield (%)			
		1b	2b	3b	
1		6	91	8	-
2 ^b	6	87	9	-	
3 ^c	6	66	6	22	
4 ^d	6	58	3	23	
5 ^e	6	67	5	15	
6 ^f	6	87	10	-	
7		7	89	-	10
8		8	9	11	4

^a Reactions were performed with 1-octyne (3.0 mmol) and tri(2-furyl)germane (1.0 mmol) using $[\text{PdCl}(\eta^3\text{-C}_3\text{H}_5)_2]$ (2.5 mol %) and a ligand (10 mol %) in water (18 mL) at 25 °C unless otherwise noted. ^b The reaction was conducted under neat conditions. ^c In the presence of Triton X-100 (5 mol %). ^d In the presence of sodium dodecyl sulfate (5 mol %). ^e In the presence of methyltriocylammonium chloride (5 mol %). ^f The reaction was carried out with 0.0025 mol % of $[\text{PdCl}(\eta^3\text{-C}_3\text{H}_5)_2]$ and the ligand **6** (0.01 mol %).

experiments, we found phosphites furnished dienyldermanes predominantly. Tris(2-*tert*-butylphenyl) phosphite (**6**) ex-

hibited the best selectivity among the ligands examined. Tris(2,6-dimethylphenyl) phosphite (**7**) yielded **1b** without formation of the regioisomer **2b**. Interestingly, these phosphites are superior to the water-soluble ligand **8**.

We observed remarkable rate acceleration in the aqueous reaction as shown in Figure 1. Surprisingly, quantitative

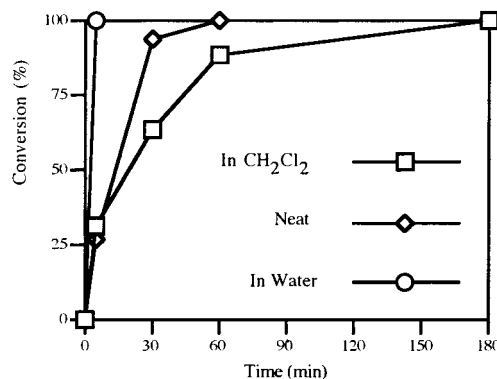


Figure 1. Conversion of tri(2-furyl)germane. 1-Octyne (3.0 mmol) and tri(2-furyl)germane (1.0 mmol) were employed with $[\text{PdCl}(\eta^3\text{-C}_3\text{H}_5)_2]$ (2.5 mol %) and the phosphite **6** (10 mol %) at 25 °C.

conversion of tri(2-furyl)germane was achieved within 5 min in aqueous media,⁶ whereas the reaction in CH_2Cl_2 required 3 h for completion. It is notable that the aqueous reaction proceeds much faster than the reaction under neat conditions. Interestingly, an addition of surfactants such as Triton X-100, sodium dodecyl sulfate, or methyltriocylammonium chloride, although they homogenized the reaction system, retarded the reaction and decreased the selectivity of dienyldermanes (Table 1, entries 3–5).⁷

It is remarkable that the palladium catalyst can be reduced to 0.0025 mol % (Table 1, entry 6). A turnover frequency of ca. 6500 h^{-1} is obtained in this case. The catalyst can work efficiently at such a low catalyst loading only in water. In contrast, no observable reaction occurred under neat conditions with 0.0025 mol % of the catalyst. This is one of the significant benefits of using water as the reaction solvent.

The reaction of various alkynes proceeds efficiently in water (Table 2).⁸ Hydrogermylation of 1-trimethylsilylacetylene provided **1c** and **3c** in 60% and 40% yield, respectively. Although the selectivity for the dienyldermane was disap-

(5) (a) Nakamura, T.; Yorimitsu, H.; Shinokubo, H.; Oshima, K. *Synlett* **1999**, 1415. (b) Tanaka, S.; Nakamura, T.; Yorimitsu, H.; Shinokubo, H.; Oshima, K. *Org. Lett.* **2000**, 2, 1911.

(6) This reaction can be conducted in a separatory funnel. See Supporting Information.

(7) Kobayashi, S.; Lam, W. W.-L.; Manabe, K. *Tetrahedron Lett.* **2000**, 41, 6115 and references therein.

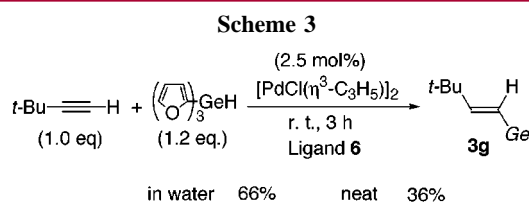
(8) **General Procedure.** $[\text{PdCl}(\eta^3\text{-C}_3\text{H}_5)_2]$ (9.1 mg, 0.025 mmol), **6** (47.9 mg, 0.1 mmol), and 1-octyne (0.33 g, 3.0 mmol) were placed in a flask. Water (18 mL) was introduced, and the mixture was stirred vigorously (1500 rpm) for 20 min. Tri(2-furyl)germane (0.27 g, 1.0 mmol) was added via a syringe. After stirring for 3 h, the mixture was extracted with hexane (20 mL \times 3). The organic layers were dried over Na_2SO_4 and concentrated. Purification of the residual oil afforded a mixture of **1b** and **2b** (94/6 isomeric mixture, 0.49 g, 0.99 mmol) in 99% combined yield.

Table 2. Hydrogermylation of Various Alkynes in Water^a

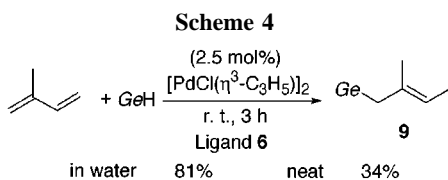
entry	R ¹	R ²	yield (%)	
			1	3
1	Me ₃ Si	H	1c 60	3c 40
2	Me	Me	1d 70	3d 27
3	CH ₂ =C(Me)	H	1e 87	
4	HOCH ₂	H	1f 68 (8) ^b	
5	<i>t</i> -Bu	H	1g 25	3g 71

^a Alkyne (3.0 mmol) and tri(2-furyl)germane (1.0 mmol) were used in water (18 mL) with [PdCl(η³-C₃H₅)₂] (2.5 mol %) and **6** (10 mol %) at 25 °C. ^b The yield of regioisomer **2** is shown in parentheses.

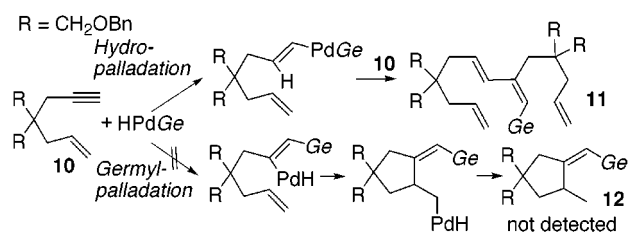
pointing, the combined yield of **1c** and **3c** was quantitative. The reaction of internal alkynes such as 2-butyne also proceeded efficiently to furnish dienyldermane **1d** in good yield. 2-Methyl-1-buten-3-yne provided tetraenyldermane **1e** in good yield. In contrast to water-insoluble substrates, water-soluble propargyl alcohol exhibited little acceleration in water, and the reaction did not go to completion in 3 h.⁹ The reaction of *tert*-butylacetylene provided alkenyldermane **3g** predominantly, presumably as a result of its steric bulkiness (entry 5). However, the mono-insertion reaction also can be accelerated in aqueous media (Scheme 3).



We have discovered another example of the acceleration effect in the hydrogermylation of 1,3-dienes in water. The aqueous reaction of isoprene with tri(2-furyl)germane in the presence of the palladium catalyst provided allyldermane **9** in good yield with high regio- and stereoselectivity (Scheme 4). The yield was much better than that obtained under neat conditions.

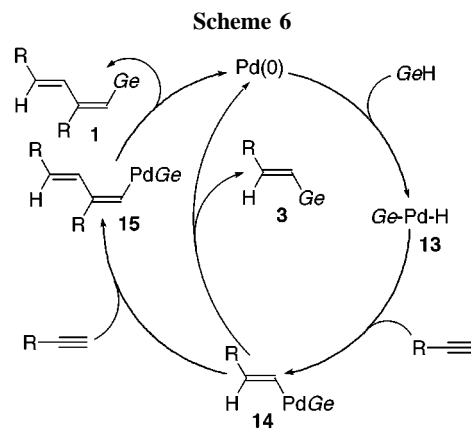


To elucidate the reaction mechanism, we carried out the following experiment. Scheme 5 envisages the expected

Scheme 5

products resulted from gernylpalladation or hydropalladation. Hydropalladation would yield dienyldermane **11** via the double insertion of alkynes. On the other hand, gernylpalladation followed by cyclization would provide cyclopentane **12**. In fact, the reaction of enyne **10** yielded dienyldermane **11** and none of the cyclized product **12**.¹⁰

On the basis of this result, we propose the following reaction mechanism (Scheme 6): (1) oxidative addition of



tri(2-furyl)germane providing **13**, (2) hydropalladation onto an alkyne, (3) carbopalladation toward the second alkyne, and (4) reductive elimination from dienyldermane **15** to produce a dienyldermane **1** and regenerate the Pd(0) catalyst. It is not clear why water can accelerate this catalytic cycle at this stage.

In conclusion, the palladium-catalyzed hydrogermylation of alkynes and 1,3-dienes is accelerated in aqueous media. Notably, the heterogeneous reaction system is superior to neat conditions. It is typically thought that water is a poor choice for hydrophobic substrates and homogenization is necessary. Water, however, does accelerate this reaction remarkably despite the heterogeneous conditions.¹¹ Our results indicate that the heterogeneous aqueous system can

(9) The reaction of propargyl alcohol in CH₂Cl₂ provided **1f** in 81% yield along with the regioisomer **2f** in 11% yield.

(10) Gernylpalladation of 1,6-enynes has been reported to induce cyclization; see: Chatani, N.; Morimoto, T.; Muto, T.; Murai, S. *J. Organomet. Chem.* **1994**, 473, 335.

(11) For recent examples of palladium-catalyzed reactions in a heterogeneous aqueous system, see: Uozumi, Y.; Shibatomi, K. *J. Am. Chem. Soc.* **2001**, 123, 2919 and references therein.

be excellent media for reactions employing substrates insoluble in water, without the use of phase transfer catalysts or water-soluble ligands.

Acknowledgment. We thank Prof. Tamejiro Hiyama and Dr. Hiroto Yoshida (Kyoto University) for helpful discussions. This work was supported by Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports,

Science, and Technology. H.K. and T.N. acknowledge the JSPS Research Fellowship for Young Scientists.

Supporting Information Available: General procedures and spectral data for compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

OL0161817