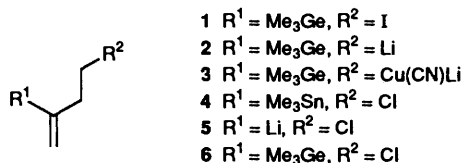# Platinum-catalysed Addition of Trimethylgermane to 1-Trimethylsilylalk-1-ynes: a Convenient Synthesis of Functionalised 2-Trimethylgermylalk-1-enes

Edward Piers * and René Lemieux
Department of Chemistry, University of British Columbia, 2036 Main Mall, Vancouver, British Columbia, Canada V6T 1Z1

Two experimentally simple steps [i, Me_3GeH, $H_2PtCl_6\cdot6H_2O$ (catalytic amount), CH_2Cl_2; ii, toluene-*p*-sulfonic acid monohydrate, CH_2Cl_2] serve to convert 1-trimethylsilylalk-1-ynes into synthetically useful 2-trimethylgermylalk-1-enes.
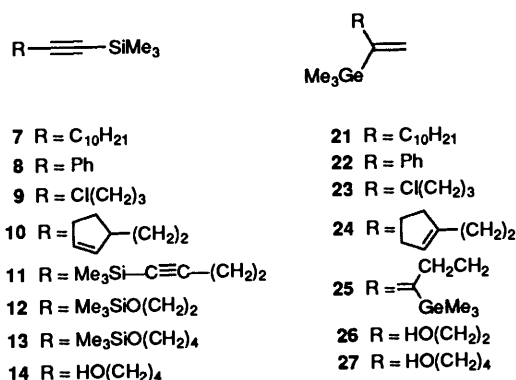
Previous reports[1-3] from this laboratory have disclosed that 4-iodo-2-trimethylgermylbut-1-ene 1 serves as an effective precursor of synthetically useful bifunctional reagents. For example, treatment of 1 with Bu^tLi (~ 2.2 equiv.) in dry tetrahydrofuran (THF) at low temperatures ($\sim -95\,°C$) provides the corresponding lithio reagent 2.[1,2] Upon reaction with 1 equiv. of copper(i) cyanide, 2 is readily converted into the corresponding lower order heterocuprate 3, which has been employed in the development of synthetically valuable annulation sequences.[1-3]

1 $R^1 = Me_3Ge$, $R^2 = I$
2 $R^1 = Me_3Ge$, $R^2 = Li$
3 $R^1 = Me_3Ge$, $R^2 = Cu(CN)Li$
4 $R^1 = Me_3Sn$, $R^2 = Cl$
5 $R^1 = Li$, $R^2 = Cl$
6 $R^1 = Me_3Ge$, $R^2 = Cl$

In our earlier work in this area,[1-3] 1 was prepared from 4-chloro-2-trimethylstannylbut-1-ene 4.[4,5] Thus, transmetallation (MeLi, THF, $-78\,°C$) of 4, followed by treatment of the resultant lithio reagent 5[5] with Me_3GeBr, produced 6. Reaction of 6 with NaI in refluxing acetone provided 1.[1] Although, in terms of efficiency, this preparation of 1 from 4 (72% overall yield) was quite satisfactory, it involved the use of two expensive reagents, namely $(Me_3Sn)_2$ (used in the preparation of 4[4,5]) and Me_3GeBr. Consequently, it seemed sensible to develop a more direct, less expensive protocol for the synthesis of 1 and of other functionalised, potentially useful 2-trimethylgermylalk-1-enes. We report herein that platinum-catalysed hydrogermylation of 1-trimethylsilylalk-1-ynes with Me_3GeH,† followed by protodesilylation of the resultant mixture of products, provides good yields of the corresponding 2-trimethylgermylalk-1-enes.

The 1-trimethylsilylalk-1-ynes 7–14‡ were employed as substrates in this study. Compounds 7–9 were readily prepared (yields $>90\%$) by sequential treatment of the requisite alk-1-yne with BuLi (~ 1.2 equiv., THF, $-78\,°C$) and Me_3SiCl (~ 1.5 equiv., $-78\,°C$ to room temperature). A similar protocol using 2.2 and 2.5 equiv. of the reagents BuLi and Me_3SiCl, respectively, served to convert hexa-1,5-diyne, but-3-yn-1-ol, and hex-5-yn-1-ol into the corresponding substrates 11 (71%), 12 (96%) and 13 (96%). Substrate 10 was prepared in 78% yield by reaction (THF–hexamethylphosphoramide, $0\,°C$) of 3-(2-iodoethyl)cyclopentene with 1-lithio-2-trimethylsilylethyne.

Our initial experiments were carried out on 6-trimethylsilyl-

R—≡—SiMe₃

7 $R = C_{10}H_{21}$
8 $R = Ph$
9 $R = Cl(CH_2)_3$
10 $R = $ [cyclopentenyl]—$(CH_2)_2$
11 $R = Me_3Si$—$C≡C$—$(CH_2)_2$
12 $R = Me_3SiO(CH_2)_2$
13 $R = Me_3SiO(CH_2)_4$
14 $R = HO(CH_2)_4$

21 $R = C_{10}H_{21}$
22 $R = Ph$
23 $R = Cl(CH_2)_3$
24 $R = $ [cyclopentenyl]—$(CH_2)_2$
25 $R = $ CH₂CH₂ / GeMe₃
26 $R = HO(CH_2)_2$
27 $R = HO(CH_2)_4$

hex-5-yn-1-ol 14, which was obtained by treatment of 13 with water in THF. Reaction (room temperature) of 14 with Me_3-GeH (1.5 equiv.)§ in dry CH_2Cl_2 (argon atmosphere) in the presence of $H_2PtCl_6\cdot6H_2O$ (0.02 equiv.) gave, in 83% yield, a mixture of four products (Scheme 1). Although chromato-
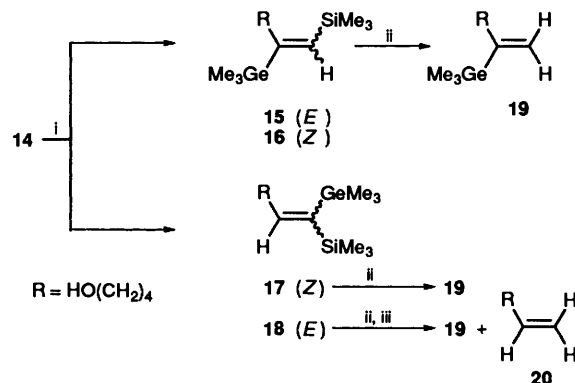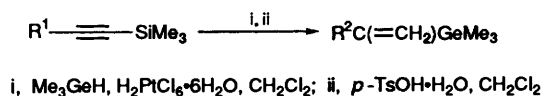

Scheme 1 Reagents and conditions: i, Me_3GeH, $H_2PtCl_6\cdot6H_2O$, CH_2Cl_2; ii, *p*-TsOH·H_2O, CH_2Cl_2, room temp.; iii, 30–35 °C

graphic separation of these materials proved to be difficult, essentially pure samples of each substance could be obtained by subjection of the mixture to a combination of silica gel and reverse phase (C_{18} column) HPLC. The two major products, comprising approximately 70 and 25% of the mixture, were shown by ^1H NMR spectroscopy (coupling patterns and

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† Hydrogermylations of alk-1-ynes with Pr_3GeH in the presence of $H_2PtCl_6\cdot6H_2O$ or other platinum catalysts provide mixtures of products in which the 2-tripropylgermylalk-1-enes are minor components (generally $<20\%$).[6]

‡ All compounds reported herein exhibited spectra consistent with structural assignments and new compounds gave satisfactory elemental analyses.

Table 1 Preparation of 2-trimethylgermylalk-1-enes

$$R^1 \text{—} \equiv \text{—SiMe}_3 \xrightarrow{\text{i, ii}} R^2C(=CH_2)GeMe_3$$

i, Me$_3$GeH, H$_2$PtCl$_6$·6H$_2$O, CH$_2$Cl$_2$; ii, p-TsOH·H$_2$O, CH$_2$Cl$_2$

			Reaction times (h)			
Entry[a]	Substrate	Equiv. of H$_2$PtCl$_6$·6H$_2$O[b]	Step 1[c]	Step 2[d]	Product	Yield (%)[e]
1	7	0.016	3.5	1.5	21	72
2	8	0.026	4.0	7.0	22	68
3	9	0.014	3.5	2.5	23	74
4	10	0.016	21	3.0	24	69
5	11	0.038	4.5	5.0	25	71
6	12	0.013	1.0	1.5	26	74
7	13	0.019	1.0	1.5	27	74

[a] In each of the experiments summarised in entries 1–4, 6 and 7, Me$_3$GeH (1.5 equiv.) and p-TsOH·H$_2$O (1.2 equiv.) were employed. These quantities were doubled for the conversions related to entry 5. [b] The fact that the amount of catalyst employed varied from experiment to experiment is not important. Typically, use of ~2 mol% of catalyst is adequate. Since the conversion of 11 into 25 (entry 5) involves hydrogermylation of two alkyne functions, ~4 mol% of catalyst was employed. [c] Reactions carried out at room temperature. [d] Reactions carried out at 30–35 °C. [e] Yield of purified, distilled product.

nuclear Overhauser enhancement difference experiments) to possess the structures shown in formulae 15 and 17, respectively. In similar fashion, the two minor products (each ca. 2–3% of the mixture) were revealed to be 16 and 18. Thus, in this catalysed hydrogermylation, the 2-trimethylgermyl isomers 15 and 16 were formed in preference to the positional isomers 17 and 18. Nevertheless, from a synthetic viewpoint, the regioselectivity of this process was less than impressive. Fortunately, this 'deficiency' turned out to be of little consequence.

Treatment (CH$_2$Cl$_2$, room temperature) of each of the compounds 15 and 16 with toluene-p-sulfonic acid monohydrate (p-TsOH·H$_2$O) gave, in very high yields, the 2-trimethylgermyl-alk-1-ene 19. Importantly, a similar reaction involving the use of 17 as substrate provided (85% yield) the same product 19. Thus, interestingly, the protodesilylation of 17 is accompanied by migration of the trimethylgermyl group from C-1 to C-2.* Subjection of compound 18 to identical conditions produced a mixture of 19 (minor) and the two geometrically isomeric 1-trimethylsilylalk-1-enes, resulting from protodegermylation of 18 (¹H NMR spectroscopic analysis). When the same reaction mixture was warmed to 30–35 °C, the 1-trimethylsilylalk-1-enes were transformed into the alkene 20, while compound 19 was recovered unchanged.

The set of experiments summarised above showed that the platinum-catalysed hydrogermylation of 1-trimethylsilylalk-1-ynes, followed by p-TsOH·H$_2$O promoted protodesilylation of the resultant product mixtures, should produce the corresponding 2-trimethylgermylalk-1-ynes in good yields. This expectation turned out to be correct and a number of examples involving this protocol are summarised in Table 1.

The hydrogermylations (Table 1, step 1), using ca. 1.5–4 mol% of the platinum catalyst, were generally complete within 5 h at room temperature. In the case of substrate 10, however, this process was accompanied by slow isomerisation of the cyclopentene double bond. Therefore, the reaction mixture was stirred until the bond migration was essentially complete (~21 h, ¹H NMR spectroscopic analysis). Protodesilylation of the resultant product mixture gave the 2-trimethylgermylalk-1-ene 24 in 69% yield (Table 1, entry 4).

The new method is compatible with the presence of a primary alkyl chloride function (entry 3). Each of the trimethylsilyl ether moieties present in substrates 12 and 13 (entries 6 and 7) was largely retained during the hydrogermylation step, but, as

expected, was cleaved during the protodesilylation process. Interestingly, the method was also successful in the case of a substrate possessing two 1-trimethylsilylalk-1-yne functions. Thus, 1,6-bis(trimethylsilyl)hexa-1,5-diyne 11 was converted efficiently into the structurally interesting product 2,5-bis(trimethylgermyl)hexa-1,5-diene 25 (entry 5).

Analysis of some of the crude products by ¹H NMR spectroscopy indicated that the regioselectivity of the hydrogermylation process varied with substrate structure. For example, although the regiochemical outcome of each of the reactions involving substrates 7, 12 and 13 was quite similar to that related to the starting material 14 (vide supra), compounds 8 and 9 produced mixtures in which the ratio of C-2 to C-1 trimethylgermyl products was about 14:1. As it turned out, of course, the composition of the hydrogermylation product mixtures was not of crucial importance, since, in each case, the next operation provided the desired 2-trimethylgermylalk-1-ene in good yield.

Experimental

3-Trimethylgermylbut-3-en-1-ol 26.—To a stirred solution of 4-trimethylsiloxy-1-trimethylsilylbut-1-yne 12 (13 g, 60.6 mmol) in dry CH$_2$Cl$_2$ (60 cm³) at room temperature under an atmosphere of argon was added H$_2$PtCl$_6$·6H$_2$O (0.47 g, 0.91 mmol). After the mixture had been stirred for 5 min, the light orange coloured solution was cooled to 0 °C and Me$_3$GeH (10.8 g, 90.9 mmol) was added via a cannula. The mixture was stirred at 0 °C for 5 min, after which it was warmed to room temperature, and then stirred for an additional 1 h. The solution was concentrated under reduced pressure (rotary evaporator) and the residual dark oil was passed through a column (6 × 35 cm) of silica gel (100 g, elution with 800 cm³ of Et$_2$O). The eluate was concentrated and the remaining dark oil was dissolved in CH$_2$Cl$_2$ (650 cm³). Solid p-TsOH·H$_2$O (13.8 g, 72.7 mmol) was added and the resulting stirred suspension was heated to 30–35 °C for 1 h. After the mixture had been cooled, it was washed with saturated aqueous NaHCO$_3$ (3 × 100 cm³). The combined aqueous washings were extracted with Et$_2$O (2 × 100 cm³) and EtOAc (100 cm³). The combined organic solutions were washed with brine (2 × 100 cm³), dried (MgSO$_4$), and concentrated. Flash chromatography (200 g of silica gel, 6 × 35 cm column, 4:1 light petroleum–EtOAC) of the residue, followed by distillation (92 °C/15 Torr) of the acquired liquid, afforded the title compound 26 as a colourless oil (8.01 g, 70%), which exhibited δ_H(400 MHz; CDCl$_3$; J/Hz) 5.61 (1 H, d, J 2.0), 5.32 (1 H, d, J 2.0), 3.65 (2 H, br q, J 6.0), 2.46 (2 H, t, J 6.0), 1.41 (1 H, br signal, exchanges with D$_2$O) and 0.21 (9 H, s).

* A possible mechanistic pathway for this process will be presented elsewhere.

References
1 E. Piers and P. C. Marais, *J. Chem. Soc., Chem. Commun.*, 1989, 1223.
2 E. Piers and P. C. Marais, *J. Org. Chem.*, 1990, **55**, 3454.
3 E. Piers and J. Renaud, *J. Org. Chem.*, 1993, **58**, 11.
4 E. Piers and J. M. Chong, *Can. J. Chem.*, 1988, **66**, 1425.
5 E. Piers and V. Karunaratne, *Tetrahedron*, 1989, **45**, 1089.
6 H. Oda, Y. Morizawa, K. Oshima and H. Nozaki, *Tetrahedron Lett.*, 1984, **25**, 3221.
7 D. A. Coates and J. M. Tedder, *J. Chem. Soc., Perkin Trans. 2*, 1978, 725.