

Silylcupration of 1,3-Dienes Followed by
an Electrophilic Trapping Reaction

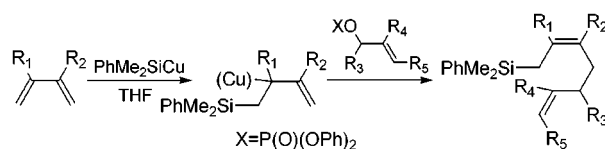
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ABSTRACT



Silylcupration reaction of 1,3-dienes with a cyanocuprate reagent, $\text{PhMe}_2\text{SiCuCNLi}$, followed by an electrophilic trapping has been reported for the first time. The use of allylic phosphates as electrophiles resulted in a highly regioselective reaction with overall 1,4-addition of the silyl and allyl moieties across the diene.

Silylcupration reaction of acetylenes and allenes has been studied by Fleming and co-workers.^{1,2} Scarce literature data, however, is available on silyl-metalations of alkenes. Silyl-manganation of acetylenes and 1,3-dienes³ and catalytic silicon–silicon bond addition to double bonds⁴ and 1,3-dienes⁵ involving silylpalladation have been reported. However, to the best of our knowledge, there are no publications in the literature on silylcupration of dienes. Recently, we reported on a silylcupration reaction of substituted and

unsubstituted styrene.⁶ These results encouraged us to study the silylcupration reaction of 1,3-dienes.

Most of the silylcupration reactions have been done with the silylcuprate reagent $(\text{PhMe}_2\text{Si})_2\text{CuLi}\cdot\text{LiCN}$ or more bulky silylcuprate reagents.^{2d} Recently, cyanocuprate reagent $\text{PhMe}_2\text{SiCuCNLi}$ ⁷ has been used by Pulido⁸ and us⁹ in allene silylcupration reactions. The advantage of the silylcopper reagent $\text{PhMe}_2\text{SiCuCNLi}$ over the disilyl cuprate reagent $(\text{PhMe}_2\text{Si})_2\text{CuLi}\cdot\text{LiCN}$ is that it makes use of all the silyl on copper. With the latter reagent only one of the two groups is transferred and the remaining silyl copper reagent may lead to side products upon reaction with the electrophile employed.

Here we wish to report for the first time on a silylcupration reaction of 1,3-dienes. The copper intermediate obtained can be efficiently trapped by different electrophiles, including allylic phosphates,¹⁰ which are readily accessible allylic substrates for metal-catalyzed reactions.^{6,9,11}

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Table 1. Silylcupration of 1,3-Dienes Followed by Trapping with “Reactive” Electrophiles

entry	diene	electrophile	t, °C	products	yield (%) ^a
1		H ₂ O	-40 °C	PhMe ₂ Si-CH ₂ -CH=C(CH ₃) ₂ (4a) : PhMe ₂ Si-CH=C(CH ₃) ₂ (5a) 85 : 15	76
2	6	H ₂ O	-78 °C	4a + 5a 85 : 15	62
3	6	H ₂ O	0 °C	4a + 5a 85 : 15	50
4	6		-40 °C	PhMe ₂ Si-CH ₂ -CH=C(CH ₃) ₂ (4b) : PhMe ₂ Si-CH=C(CH ₃) ₂ -COCH ₃ (5b ^b) 63 : 37	75
5		H ₂ O	-40 °C	PhMe ₂ Si-CH ₂ -CH=C(CH ₃) ₂ (4c) : PhMe ₂ Si-CH=C(CH ₃) ₂ (5c) 60 : 40	53
6		H ₂ O	-40 °C	PhMe ₂ Si-CH ₂ -CH=CH-CH=CH ₂ (4d) : PhMe ₂ Si-CH=CH-CH=CH ₂ (5d ^b) 70 : 30	41

^a Isolated yields. ^b >97% *Z*-isomer for **5b**, and *E*-isomer in the case of **5d**. Stereochemistry established by NOESY.

Silylcupration of 1,3-dienes with **1** proceeds smoothly at temperatures ranging from -78 to 0 °C.¹² The resulting copper intermediates **2** and **3** were allowed to react with various electrophiles to give products **4** and **5**. The ratio between products **4** and **5** depends very much on the electrophile employed. For example with more reactive electrophiles the regioisomer **4** predominates, and protonation of the isoprene adduct afforded **4a** and **5a** in a ratio of 85:15 (entry 1, Table 1). Acetyl chloride quenching of the isoprene adduct gave **4b** and **5b** in a ratio of 63:37. The use of dienes **7** and **8** in the silylcupration followed by quenching with water gave **4c** and **5c** in a ratio of 60:40 and **4d** and **5d** in a ratio of 70:30, respectively.

The stereochemistry of products **5b** and **5d** was determined by NOESY experiments. Product **5b** was found to be the

Z-isomer, and **5d** the *E*-isomer. In both cases ¹H NMR indicated that the selectivity was greater than 97%.

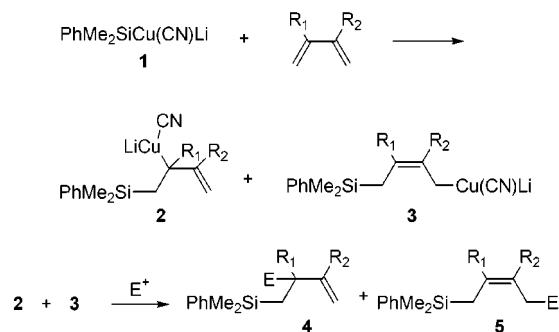
The electrophilic trapping reaction of allylic cuprates **2** and **3** with reactive electrophiles such as a proton (H₂O) or CH₃COCl is expected to proceed through direct electrophilic attack on the allyl moiety to form the product. As with other allylmetal species, reaction of **2** and **3** with these more reactive electrophiles can occur in two ways: it may proceed in an S_E2 and/or an S_E2' fashion leading to α- and/or γ-cleavage, respectively. Thus, the ratio **4**:**5** will depend on the electrophile employed. We believe that there is only slow equilibration between **2** and **3**. This is supported by the observation that when isoprene was reacted with silylcopper reagent **1** at different temperatures and quenched with water, the ratio between **4a** and **5a** was constant (Table 1, entries 1–3).

A direct 1,2-silylcupration of one of the double bonds of the diene in a concerted addition would give adduct **2** (Scheme 1). To explain formation of adduct **3** one would

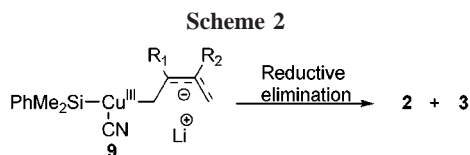
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(12) **Typical Procedure.** A total of 0.65 mmol of PhMe₂SiLi (~1 M solution in THF) was added to a stirred suspension of CuCN (1 equiv) in dry THF (0.65 mL) at 0 °C and stirred at this temperature for 30 min. Then the mixture was cooled to -40 °C, isoprene (1.2 equiv) was added dropwise, and the reaction mixture was stirred for 1 h at this temperature. The temperature was lowered to -78 °C, and allylic phosphate **11** (1.2 equiv) in 0.6 mL of THF was added slowly over 30 min. After the reaction mixture had been stirred for 1 h at -78 °C, 4 mL of saturated aqueous NH₄Cl was added, and the aqueous phase was extracted with pentane (5 × 3 mL). Column chromatography on silica with pentane as eluent afforded compound **5f** as a colorless oil in 71% yield. *R*_f = 0.43 (hexane). ¹H NMR (CDCl₃ 400 MHz): δ 7.54 (m, 2H), 7.38 (m, 3H), 5.20 (t, *J* = 8.5 Hz, 1H), 4.71 (s, 1H), 4.69 (s, 1H), 2.10 (m, 2H), 2.00 (m, 2H), 1.75 (s, 3H), 1.72 (m, 3H), 1.68 (d, *J* = 8.5 Hz, 2H), 0.31 (s, 6H). ¹³C NMR (CDCl₃ 75.4 MHz): δ 146.4, 139.3, 133.8, 133.6, 129.0, 127.8, 120.0, 109.6, 36.0, 30.2, 23.5, 22.7, 17.6, -3.0.

Scheme 1

have to assume isomerization of **2** to **3**. Recently, we proposed⁶ that silylcupration of styrene proceeds via a mechanism involving nucleophilic attack by the silylcopper reagent **1** at the terminal carbon of the double bond in analogy with a conjugate addition. A similar mechanism has been proposed for the carbocupration of acetylenes.¹³ It is likely that the analogous mechanism operates for silylcupration of 1,3-dienes, which would involve copper(III)-intermediate **9**.¹⁴ Intermediate **9**, formed by addition of reagent **1** to the terminal carbon of the diene, would undergo reductive elimination to give a mixture between the two copper intermediates **2** and **3** (Scheme 2).



Reaction of cuprate adducts **2** and **3** with less reactive electrophiles such as allylic phosphates, allylic phosphinates, and MeI gave only the regioisomer of type **5** where the electrophile has attacked the terminal carbon (Table 2). Thus, when allylic phosphates **10**, **11**, **12**, and **13** were used to trap the silylcupration adduct from isoprene (**6**), products **5e**, **5f**, **5g**, and **5h**, respectively, were obtained in high regioselectivity (>98%, entries 1–4). Also phosphinate **14** and MeI gave the same regioselectivity with the isoprene silylcupration adduct to give **5i** and **5j**, respectively (entries 5 and 6). Some other dienes, **7** and **8**, were used in the silylcupration-cleavage reaction employing the “less reactive” electrophiles. Also with these dienes only one regioisomer was formed (entries 7–10, Table 2).

The high regioselectivity obtained with less reactive electrophiles (Table 2) can be explained by a copper(III)-intermediate, which is formed after oxidative addition of the electrophile, e.g., allylic phosphate, to **2** and **3** (Scheme 3). The two copper(III)-intermediates **15** and **16** produced would be in equilibrium with one another. Since the copper atom in the formal oxidation state +3 is very electrophilic, it tends to form π -allyl complexes of type **17** with the available allyl fragments in the molecule. Thus, the equilibration proceeds through a 16e complex **17**. This process would result in a thermodynamically more stable copper(III)-intermediate **16**, which on reductive elimination would give the 1,4-addition product **5e**.

Not only can the diene allyl fragment equilibrate via a π -allyl complex, but also the allyl fragment of the allylic

Table 2. Silylcupration of 1,3-Dienes Followed by Trapping with “Less Reactive” Electrophiles^a

entry	diene	phosphate	product ^b	yield ^c (%)
1	6	10	5e	72
2	6	11	5f	71
3	6	12	5g	68
4	6	13 R=C ₃ H ₇	5h E+Z ^d	71
5	6	14	5i	52
6	6	MeI	5j E+Z ^d	69
7	7	10	5k E+Z ^d	57
8	8	10	5l E+Z ^d	53
9	8	12	5m	70
10	8	MeI	5n	67

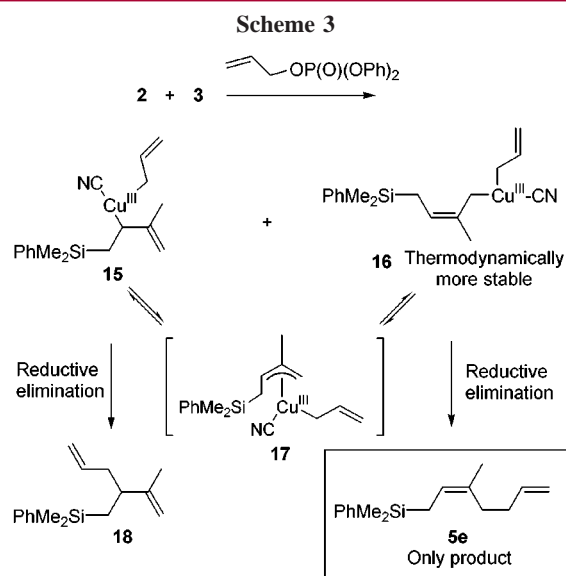
^a Reactions were carried out according to the experimental procedure given.¹² ^b Isomers **5e**, **5f**, **5g**, **5i** were of >97% Z-stereochemistry; **5m** and **5n** were E-isomers. The stereochemistry was established by NOESY. ^c Isolated yields. ^d The E and Z isomers could not be separated (ratio approximately 1:1 in all cases).

phosphate can do so. This can be seen from the different regiochemistry of the allylic substitution (Table 2, entries 3 and 4). In entry 3 (Table 2) only the γ -substitution product

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5g is formed, whereas in entry 4 only the α -substitution product **5h** is obtained. According to the generally accepted mechanism for copper-catalyzed allylic substitution,^{13,15} the allylic cuprate (**2** or **3**) would attack the γ -position of the allylic substrate to give a new σ -allyl on copper. The latter allyl can then undergo equilibration on copper so that only the terminal allyl is formed in both cases (**5g** and **5h**).

However, only 1,3-dienes with nonsubstituted terminal double bonds turned out to be reactive in the silylcupration

reaction. All attempts to silylcuprate 1,3-hexadiene, 1,3-cyclohexadiene or 4-methyl-1,3-pentadiene failed and did not give any reaction product. We think that this is due to the electron-releasing effect of the alkyl groups that hinder the nucleophilic attack of the silylcuprate reagent on the terminal carbon atom of the 1,3-diene.

Some allylic phosphates are unstable and difficult to prepare.¹⁶ We have demonstrated that allylic phosphinates¹⁷ from an allylic alcohol that failed to give the corresponding phosphate can be used as a more stable allyl-donor alternative to allylic phosphates (entry 5, Table 2).

In conclusion, the silylcupration of 1,3-dienes followed by electrophilic trapping is reported for the first time. With the use of allylic electrophiles the highly regioselective overall 1,4-carbosilylation of the conjugated diene constitutes a novel approach toward silylated 1,5-diene systems. The reaction provides an extension to the widely studied silylcupration reaction of other unsaturated compounds.

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