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Sequential Cyclization-Silylation Reactions of 1,1-Disubstituted Alkenes Catalyzed by a Cationic Zirconocene Complex

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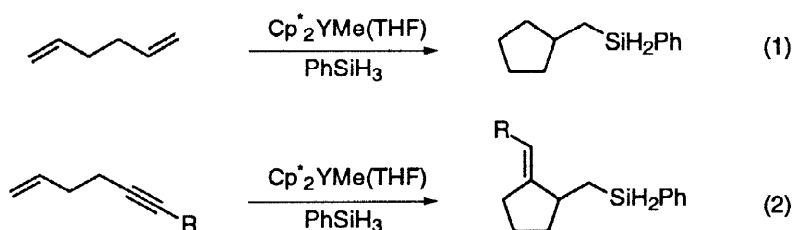
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Abstract: A catalytic method for the sequential cyclization-silylation of dienes containing one or two 1,1-disubstituted alkene moieties to form various cyclic and bicyclic organosilanes in good yield is presented.

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Keywords: *Zirconocene; cyclization; silylation; organosilane.*

Carbon-carbon bond-forming reactions are of fundamental importance to synthetic organic chemists. Of particular interest are catalytic, intramolecular bond-forming reactions that yield cyclic products. We have investigated the use of group 3 and lanthanide organometallic complexes as catalysts for the cyclization of dienes and enynes [1]. These d^0 , electrophilic organometallic species have proven to be very effective in the preparation of cyclized organosilanes from acyclic, monosubstituted diene starting materials, and exhibit remarkable regio- and diastereoselectivity because of the steric environments about the catalyst center (eqs 1,2) [2].

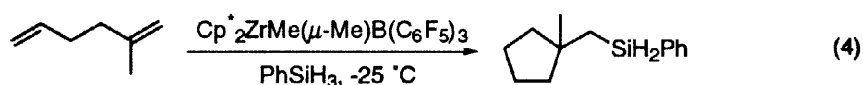
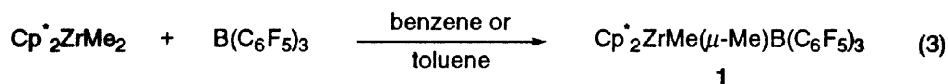


It seemed reasonable to expand our research efforts to include cationic group 4 organozirconium complexes, in particular to address the issue of reactivity with more hindered 1,1-disubstituted diene systems. Cationic zirconocenes are isoelectronic (d^0) with group 3 and lanthanide complexes and should display higher reactivities as a result of the

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charged, electron deficient metal center. Indeed, the higher reactivity of cationic zirconocenes allowed cyclization and subsequent silylation of dienes when one or both of the alkene moieties was 1,1-disubstituted. This is the first time such a process with this class of catalysts has been reported, and, until only recently, this represented the only catalyst system that effectively cyclized sterically hindered dienes of this type [3].

During the course of our investigation, we found that the permethylated zirconocene-derived catalyst **1** developed by Marks and coworkers [4] and used by Waymouth in cyclization-alumination reactions [5] was most useful. The active catalyst was easily prepared either prior to use or most conveniently via an *in situ* preparation in toluene (eq 3).


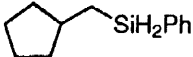
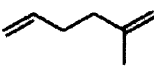
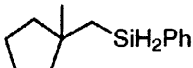
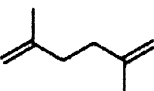
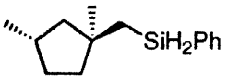
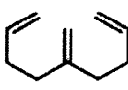
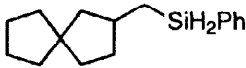
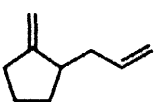
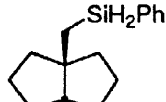
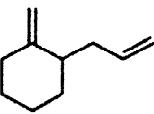
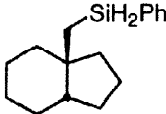
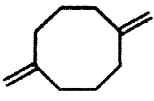
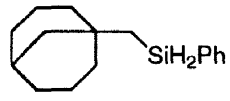
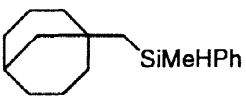
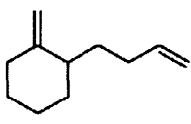
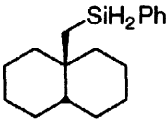


This catalyst was effective in the cyclization of various diene substrates (eq 4, Table 1). Optimal conditions included: 2-5 mol% catalyst loading, dilute reaction conditions (0.05-0.20 M substrate), 2-3 equivalents of silane, syringe addition of the substrate and silane over several hours, and low temperatures (-25 °C to 0 °C in most cases). Best results were obtained for starting materials that contained at least one 1,1-disubstituted alkene. Less hindered alkenes, such as 1,5-hexadiene, gave low yields of cyclized organosilane. This is likely the result of extensive polymerization of the starting material and/or cyclized organozirconium intermediate. For reactions of monosubstituted dienes under extremely dilute conditions with very slow addition of the diene, yields failed to exceed 40%. Also, substrates that formed six-membered rings did not give good yields of the desired product. This is presumably the result of a slower cyclization (6-exo versus 5-exo). The slower cyclization event leads to polymerization and/or trapping of the uncyclized organozirconium intermediate. Of the many silane trapping agents used, phenylsilane was found to be most useful. Hindered silanes such as phenylmethylsilane or diphenylsilane slowed down the trapping of the cyclized organozirconium intermediate and led to increased polymerization. All silanes were observed to oligomerize via a dehydrogenative coupling process [6] as evidenced by the presence of silane dimers and hydrogenated starting materials.

One interesting result was the cyclization of 1,5-bis(exomethylene)cyclooctane (Table 1). This transannular cyclization was very rapid at low temperatures and provided good yields of the bicyclic silane. The higher yield obtained with phenylmethylsilane is presumably the result of reduced silane polymerization and a concomitant reduction in hydrogenated starting material. Other bicyclic products were produced in good yields but required longer reaction times and displayed more side reactions.

A typical procedure for a cyclization-silylation reaction is as follows: A 1.8 mL toluene solution containing 50 mg (0.52 mmol) of 2-methyl-1,5-hexadiene and 150 mg (1.39 mmol) of phenylsilane was added over 4 h via syringe to a solution of 14 mg (0.015

Table 1. Results for Cyclization-Silylation Reactions of Dienes Mediated by $\text{Cp}^*_2\text{ZrMe}(\mu\text{-Me})\text{B}(\text{C}_6\text{F}_5)_3$

substrate	product	temp, °C	time, h	% isolated yield
		-10	2.5	36
		0	4.0	82
		rt	1.5	79
"	"	-25	3.5	92
		-25	3.0	56
		0	7.0	77
		0	16	73
		-25	1.0	67
"	"	-40	2.0	64
"		-30	0.5	87 ^a
		rt	22	<30

^a PhMeSiH₂ was used as the silylating agent.

mmol, 3 mol%) of catalyst **1** in 1.8 mL of toluene at 0 °C. The resulting solution was allowed to warm to room temperature before being filtered through a small plug of silica to remove the catalyst. The filtrate was concentrated and the product was isolated by flash chromatography using hexanes as an eluent to provide 87 mg (82%) of 1-methyl-1-[(phenylsilyl)methyl]cyclopentane.

Although we have obtained good yields for several unsaturated hydrocarbon systems, limitations remain. The use of a highly electrophilic catalyst does not allow introduction of heteroatoms. Various protected alcohols, amines and alkyl halides were not tolerated under the reaction conditions utilized. Indeed, even simple phenyl substituents were problematic.

In conclusion, we have developed a catalytic method for the cyclization-silylation of dienes using a highly reactive cationic zirconium complex. This catalytic system effectively cyclizes unsaturated hydrocarbons in good yields at low temperatures with short reaction times.

Acknowledgements

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References and Notes

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