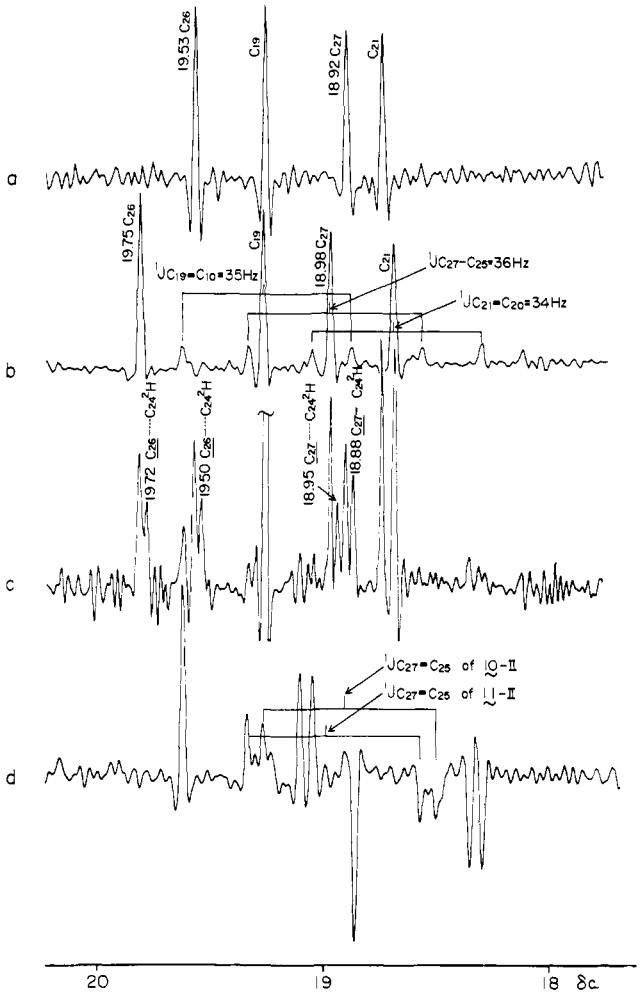
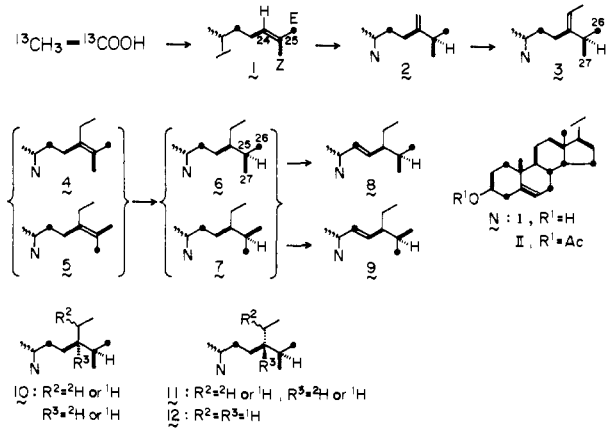


Figure 1. ^{1}H-complete-decoupled ^{13}C NMR spectra, region of C-26 and C-27 of (a) clionasteryl acetate (**12**-II), (b) sitosteryl acetate (**6**-II) from [1,2-^{13}C]acetate in tissue cultures of *P. peruviana*, (c) a mixture of [^{13}C,24,28-^{2}H]sitosteryl acetate (**10**-II) and [^{13}C,24,28-^{2}H]clionasteryl acetate (**11**-II) derived from **3**-II which was biosynthesized from [1,2-^{13}C]acetate in *P. peruviana*, and (d) the same sample determined using Freeman's "INADEQUATE" pulse sequence (ref 8). The following ^{13}C–^{13}C coupled signals are observed in d: C_{19} (δ_C 19.24, J_{CC} = 35), C_{21} (δ_C 18.77, J_{CC} = 34), and C_{27} (δ_C 18.92, J_{CC} = 36) coupled to C_{10} (δ_C 36.46), C_{20} (δ_C 36.15), and C_{25} (δ_C 28.84), respectively, for **11**-II; C_{19} (δ_C 19.24 J_{CC} = 35), C_{21} (δ_C 18.72, J_{CC} = 34), and C_{27} (δ_C 18.98, J_{CC} = 36) coupled to C_{10} (δ_C 36.46), C_{20} (δ_C 36.03), and C_{25} (δ_C 29.06), respectively, for **10**-II. The singly labeled C_{26} signals (δ_C 19.53 for **11**-II, δ_C 19.75 for **10**-II) were suppressed in d.

Scheme I



the signal assignments of C-26 and C-27 of sitosteryl and clionasteryl acetates are shown in Table I.

Table I. ^{13}C NMR Spectral Data for C-26 and C-27 of Phytosterols from [1,2-^{13}C]Acetate in Tissue Cultures of Some Higher Plants[a] [10]

	3-II[7]	6-II	12-II	8-II	8A-II	2-II
C-26 δ_C	20.93, s	19.75, s	19.53[b]	21.01, s	21.02, s	21.79, s
C-27 δ_C	21.01,	18.98,	18.92[b]	18.92,	18.93,	21.93,
($^1J_{CC}$, Hz)	d (36)	d (36)		d (36)	d (36)	d (36)

[a] 3-II and 2-II; Isofucosteryl acetate and 24-methylenecholesteryl acetate from *Physalis peruviana*. 6-II: Sitosteryl acetate from *Physalis peruviana*, *Dioscorea tokoro*,[4] and *Isodon japonicus*.[5] 8-II: Stigmasteryl acetate from *Physalis peruviana*, *Bupleurum falcatum*, and *Dioscorea tokoro*. 12-II: Clionasteryl acetate. 8A-II: α-Spinasteryl acetate (Δ^7 isomer of 8-II) from *Bupleurum falcatum*. [b] These assignments were reversed in ref 4, 11, 12, and 13.

We examined the labeling patterns of C-26 and C-27 of several typical sterols, sitosterol (**6**-I), stigmasterol (**8**-I), α-spinasterol (**8A**-I), and 24-methylenecholesterol (**2**-I), biosynthesized from [1,2-^{13}C]acetate in cell cultures of some higher plants (see Table I[10]). In all cases, C-26 (*pro-R* methyl group at C-25) predominantly originated from C-2 of MVA and C-27 (*pro-S* methyl group) from C-6.

Acknowledgment. We thank Drs. K. Okabe, H. Ishii, K. Tori, and Y. Terui of these laboratories and Professor Y. Tomita, Niigata Pharmaceutical College, for their encouragement.

Registry No. 2-I, 474-63-5; **3**-I, 481-14-1; **6**-I, 83-46-5; **8**-I, 83-48-7; **8A**-I, 481-18-5; **12**-I, 83-47-6.

(10) Carbon-13 NMR spectra were recorded on a Varian XL-200 NMR spectrometer in a 10-mm spherical cell at 23 °C at 0.02–0.2 M in $CDCl_3$. Typical FT measurement conditions: spectral width, 9058 Hz; pulse width, 6 μs (45°); acquisition time, 1.766 s; number of transients, 70K. Accuracies of δ_C and J_{CC} are within 0.02 ppm and 1 Hz, respectively.

(11) Wright, J. L. C.; McInnes, A. G.; Shimizu, S.; Smith, D. G.; Walter, J. A.; Idler, D.; Kall, W. *Can. J. Chem.* **1978**, *56*, 1898–1903.
(12) Koizumi, N.; Fujimoto, Y.; Takeshita, T.; Ikekawa, N. *Chem. Pharm. Bull.* **1979**, *27*, 38–42.
(13) Wright, J. L. C. *Phytochemistry* **1981**, *20*, 2403–2405.

Novel Silicon-Promoted Cyclialkylation of Alkenylmetal Derivatives

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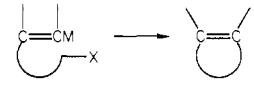
Cyclization of alkenylmetals via cyclialkylation (eq 1) is a



(1)

potentially useful but largely untested methodology.[2] We disclose herein two such reactions in which silicon plays subtle but critical roles. A particularly noteworthy feature of these reactions is that the cis arrangement of the two cyclizing groups, i.e., M and X, that might seem a requisite, either is unimportant or can readily be attained under the cyclization conditions.

In our recent study of the effects of hetero substituents on the Zr-catalyzed carbometalation of alkynes,[3] 1-(trimethylsilyl)-4-bromo-1-butyne (**1b**) was treated with Me_3Al (2 equiv) in the

(1) On leave from Ube Industries, Ltd., Ube, Japan.
(2) For cyclialkylation of aryllithiums, see: Parham, W. E.; Bradsher, C. K. *Acc. Chem. Res.* **1982**, *15*, 300.
(3) (a) For a review of this reaction, see: Negishi, E. *Pure Appl. Chem.* **1981**, *53*, 2333. (b) Rand, C. L.; Van Horn, D. E.; Moore, M. W.; Negishi, E. *J. Org. Chem.* **1981**, *46*, 4093.

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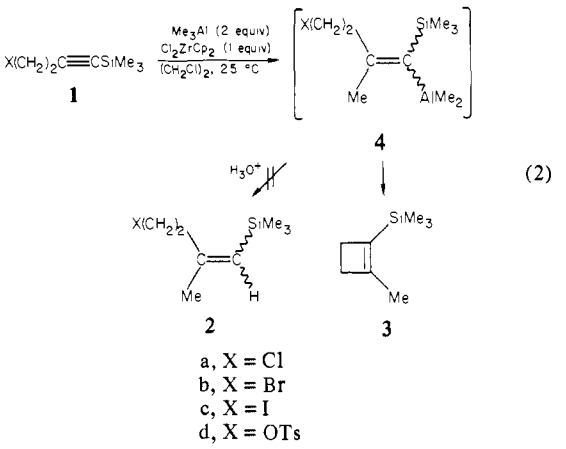
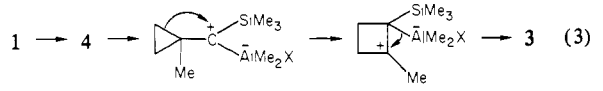
presence of 1 equiv of Cl_2ZrCp_2 (Cp = η^5-C_5H_5) at 25 °C. The reaction did not give the expected carbometalation-protonolysis product **2b**. Instead, it produced within 6 h a cyclic product **3**[4] in 92% yield (eq 2). At no time was there any indication for the



(2)

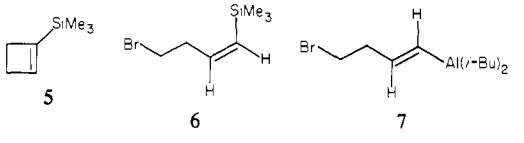
formation of **2b** upon protonolysis of the reaction mixture. The corresponding chloride **1a** and iodide **1c** also produce **3** in 80–100% yields within 24 h, their reactivity being roughly comparable with that of **1b**. The corresponding tosylate reacts more sluggishly, giving **3** in ca. 30% yield after 24 h.

Formation of cyclobutenes via cyclialkylation of alkenylmetals appears to be unprecedented. In addition, the reaction displays a few unexpected features. First, alkylation of alkenylalanes with primary alkyl halides does not occur under comparable conditions.[5] Second, although the Zr-catalyzed carboalumination of alkynylsilanes appears to give *E* and *Z* mixtures,[6] at least 50% of the presumed intermediates **4** must be "wrong" isomers for a σ-type cyclization, On the other hand, the reaction may involve interaction between the π orbital and the C–Br bond, but direct formation of a four-membered ring by a π-type cyclization, i.e., 4-endo-trig, would be an unfavorable process,[7] These considerations and the following observations led us to propose the scheme shown in eq 3 as a likely path.

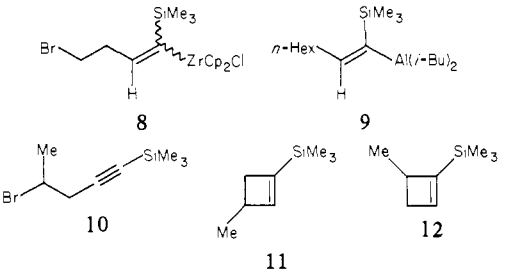


(3)

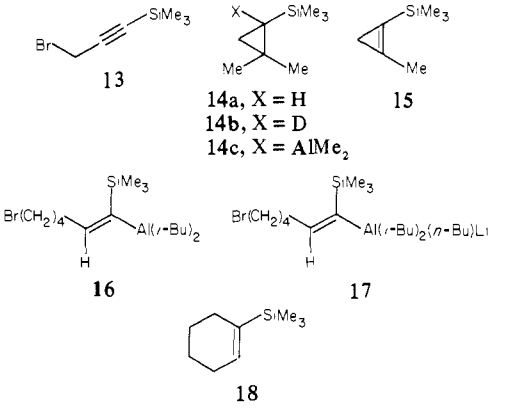
The reaction of **1b** with *i*-Bu_2AlH (DIBAH) in pentane or benzene at 25 °C gives within 1–2 h 1-(trimethylsilyl)cyclobutene[4] (**5**) in 80–100% yield, indicating that neither Cl_2ZrCp_2 nor the β-Me group is essential to the cyclization reaction, The same reaction run in Et_2O does not produce **5** but only the usual hydroalumination product **6**,[4] indicating that donor solvents may prevent the reaction. Both Al and Si appear to be necessary, since neither **6** nor **7** undergoes cyclization under similar conditions.



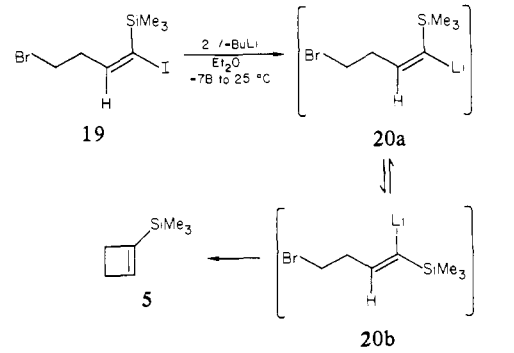
Hydrozirconation[8] of **1b** with $Cl(H)ZrCp_2$ in benzene for 12 h at 25 °C gives **5** only in 10% yield. Examination of the reaction mixture by ^1H NMR clearly indicates the formation of **8** as an *E* and *Z* mixture in 80–90% yield. As expected, its treatment with $AlCl_3$ (1.1 equiv) in CH_2Cl_2 at O °C produces **5** in 84% yield, indicating that hydrometalation or carbometalation products can be intermediates for the cyclic products. It is also worth noting that there is no detectable reaction between **9** and homoallyl bromide. Finally, the intermediacy of cyclopropylcarbinyl derivatives is supported by the reaction of **10** with DIBAH in pentane at 25 °C, which produces **11**[4] in 80% yield, the yield of **12**, if any, being <3%. Direct cyclization would have yielded **12** instead of **11**,



To explore the scope of the reaction with respect to ring size, 1-(trimethylsilyl)-3-bromo-1-propyne (**13**) was treated with Me_3Al (2 equiv) and Cl_2ZrCp_2 (1 equiv) at 25 °C. On protonolysis, **14a**[4] was obtained in 64% yield rather than the expected product **15**. Even when only 1 equiv of Me_3Al was used, **14a** (50% yield) was essentially the only cyclization product, the balance of the material being the unreacted **13**. Evidently, **15** was formed but reacted further to give **14c** at a faster rate. The formation of **14c** was indicated by its conversion into **14b** (≥95% D) upon deuterolysis. Our attempts to apply the methodology to the preparation of five- and six-membered rings have not been successful. Thus, for example, neither **16** nor its alanate **17** cyclizes to give 1-(trimethylsilyl)cyclohexene (**18**).



In search for an alternate and more general method, **1b** was treated with DIBAH in Et_2O and quenched with I_2 to produce **19**. Attempts to isomerize **19** to its *Z* isomer under the influence of 5 mol % of *t*-BuLi[9] failed, but the reaction did produce a small amount of **5** (eq 4). Instead of catalyzing the desired isomeri-



(4)

(4) All isolated products were adequately characterized by IR, ^1H NMR, and high-resolution mass spectrometry. Some of them were further characterized by ^{13}C NMR.

(5) Alkenylalanates are known to react, albeit somewhat sluggishly, with primary alkyl halides [(a) Baba, S.; Van Horn, D. E.; Negishi, E. *Tetrahedron Lett.* **1976**, 1927. (b) Eisch, J. J.; Damasevitz, G. A. *J. Org. Chem.* **1976**, *41*, 2214. (c) Uchide, K.; Utimoto, K.; Nozaki, H. *J. Org. Chem.* **1976**, *41*, 2215].

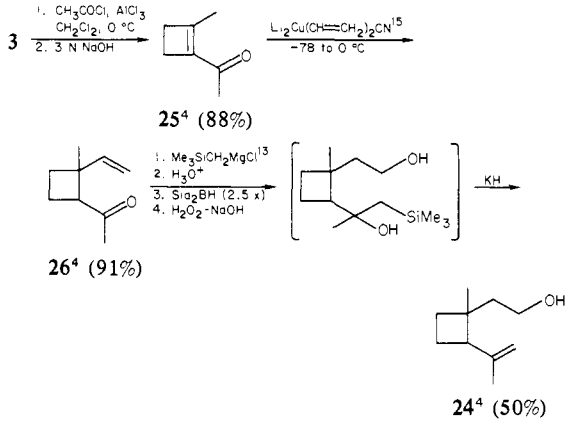
(6) Snider, B. B.; Karras, M. *J. Organomet. Chem.* **1979**, *179*, C37.

(7) Baldwin, J. E. *J. Chem. Soc., Chem. Commun.* **1976**, 734, 736, 778.

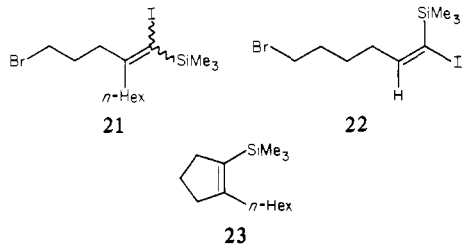
(8) For a review, see: Schwartz, J. *J. Organomet. Chem. Libr.* **1976**, *1*, 461.

(9) Zweifel, G.; Murray, R. E.; On, H. P. *J. Org. Chem.* **1981**, *46*, 1292.

Scheme I

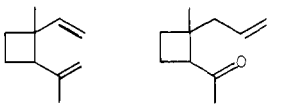


zation, the alkenyllithium **20** must have cyclized. We have indeed found that the treatment of **19** with 2 equiv of *t*-BuLi in Et_2O (−78 to 25 °C) cleanly produces **5** in 81% yield. This reaction, presumably a σ-process, has indeed turned out to be more general with respect to ring size than that described above. Thus, **21**[10] and **22**[4] were converted into **23**[4] (84%) and **18**[4] (64%), respectively,



upon treatment with *t*-BuLi (2 equiv). We then found that **23** could also be obtained cleanly in ca. 80% GLC yield by treating **21** with 1 equiv of *n*-BuLi. Although the applicability of this simplified procedure is yet to be fully explored, the above results indicate that intramolecular displacemenet of a bromide anion is much faster than intermolecular displacement of an iodide anion from *n*-BuI. It should be emphasized that (*E*)-1-iodo-6-bromo-1-hexene does not produce cyclohexene upon treatment with 2 equiv of *t*-BuLi. Nor does it produce any other monomeric product either in Et_2O or in Et_2O–THF. We conclude that polymerization must be the course of the reaction. Clearly, Si plays a critical role in promoting this cyclization as well. The precise nature of the promotion by Si is not clear. However, an increasing number of 1,1-dimetalloalkenes[11] have been shown to exhibit configurational instability presumably through interaction of the C=C bond with low-lying empty metal orbitals.

To demonstrate the synthetic utility of the above-described cyclization reactions, we synthesized grandisol[12] (**24**) from **3**, as shown in Scheme I. Although the formation of a ca. 2:1 mixture of the *Z* and *E* isomers of **26**[4] leaves room for improvement, no other significant byproduct is formed in this four-step conversion of **1** to **24** in overall 37% yield. The use of Me_3SiCH_2MgCl[13] in place of a Wittig-type reagent avoids the intermediacy of **27**, which was used as a key intermediate in one of the reported syntheses but is known to readily undergo the Cope rearrangement.[12b] The reaction of **25** with allyltrimethylsilane in the presence of $TiCl_4$[14] (−30 °C) also gives a ca. 2:1 *Z* and *E* mixture of **28**[4] in essentially quantitative yield.



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Registry No. 1a, 58435-00-0; **1b**, 69361-41-7; **1c**, 41423-29-4; **1d**, 86994-11-8; **3**, 86994-12-9; **5**, 83094-06-8; **6**, 86994-13-0; (*E*)-**8**, 86994-10-7; (*Z*)-**8**, 87038-35-5; **10**, 86994-14-1; **11**, 86994-15-2; **12**, 86994-16-3; **13**, 38002-45-8; **14a**, 86994-17-4; **14b**, 86994-18-5; **18**, 17874-17-8; **19**, 86994-20-9; **21**, 86994-22-1; **22**, 86994-23-2; **23**, 86994-24-3; **24**, 26532-22-9; **25**, 67223-99-8; (*Z*)-**26**, 30346-11-3; (*E*)-**26**, 30346-12-4; (*Z*)-**28**, 86994-21-0; (*E*)-**28**, 86994-25-4; (*E*)-1-iodo-6-bromo-1-hexene, 86994-19-6.

Supplementary Material Available: Listing of experimental data (2 pages). Ordering information is given on any current masthead page.

Tungsten Carbene Complexes in Olefin Metathesis: A Cationic and Chiral Active Species

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We have briefly reported[1] the synthesis of the tungsten carbene complexes $W(CHR)(OCH_2R)_2X_2$ (R = *t*-Bu; X = Cl, Br) (**1**) and the conversion to extremely active catalysts for olefin metathesis on addition of 1 mol equiv of AlX_3. Although we formulated the predominant complex in solution under these conditions as the adduct **2a** (Scheme I, A = Al), we could not exclude the possibility that cationic species **2b**, in rapid equilibration with **2a**, was more directly involved in (i.e., within) the catalytic cycle, and we present evidence here that clarifies this important point.

Progressive addition of Ga_2Br_6 to **1** (X = Br) in halobenzene solution was followed by NMR (^1H and ^{13}C) at −35 °C and by conductivity measurements. Two regimes of behavior are observed:

(a) As *n* (the Ga/W ratio) increases from 0 to 1, all resonances[2] (^1H and ^{13}C) are displaced in a *linear* fashion. The formation of a strong 1:1 adduct ($K_1 > 100$ mol^{-1} at −35 °C) is indicated with a structure analogous to that previously proposed involving $AlBr_3$.[1]. Further the conductivity increase is small and at n = 1 a maximum of ca. 15% dissociation into **2b** is possible ($K_2 \sim 0.1$ at 20 °C). Hence the *major* species present under these conditions is indeed **2a** (Scheme I).

(10) The procedure for preparing **21** is due to Dr. J. A. Miller of our laboratory. Its details will shortly be published elsewhere.

(11) See, for example: Yoshida, T.; Negishi, E. *J. Am. Chem. Soc.* **1981**, *103*, 1276.

(12) (a) Tumlinson, J. H.; Hardee, D. D.; Gueldner, R. C.; Thompson, A. C.; Hedin, P. A.; Minyard, J. P. *Science (Washington, D.C.)* **1969**, *166*, 1010. (b) Billups, W. E.; Cross, J. H.; Smith, C. V. *J. Am. Chem. Soc.* **1973**, *95*, 3438. (c) Stork, G.; Cohen, J. F. *Ibid.* **1974**, *96*, 5270.

(13) Chan, T. H.; Chang, E. *J. Org. Chem.* **1974**, *39*, 3264.

(14) Hosomi, A.; Sakurai, H. *J. Am. Chem. Soc.* **1977**, *99*, 1673.

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(1) Kress, J.; Wesolek, M.; Osborn, J. A. *J. Chem. Soc., Chem. Commun.* **1982**, 514. Note that a square-pyramidal geometry (C_s symmetry) is also consistent with these results but this does not alter the conclusions reached below.

(2) ^1H NMR (C_6D_5Br, −35 °C) for n = 0: δ 11.22 (s, 1 H, C*H*CMe$_3$, J_{W-H} = 11 Hz), 4.44 (s, 4 H, OC*H*$_2$CMe$_3$), 1.18 (s, 9 H, CHC*Me*$_3$), 0.91 (s, 18 H, OCH$_2$C*Me*$_3$). The 4.44 and 0.91 peaks are each resolved into two singlets at room temperature. For n = 1: δ 12.12 (s, 1 H, J_{W-H} = 12 Hz, C*H*CMe$_3$), 4.52, 4.49 (s, 2 H, OC*H*$_2$CMe$_3$), 1.12 (s, 9 H, CHC*Me*$_3$), 0.95, 0.90 (s, 9H, OCH$_2$C*Me*$_3$). ^{13}C NMR (ppm, C_6D_5Br, −35 °C) for n = 0: 297.2 (d, J_{C-H} = 135, J_{C-W} = 159 Hz, *C*HCMe$_3$), 92.2, 90.9 (t, OCH$_2$CMe$_3$), 45.3 (s, CHCMe$_3$), 34.2, 34.0 (s, OCH$_2$CMe$_3$), 31.9 (q, CHC*Me*$_3$), 26.4 (q, OCH$_2$C*Me*$_3$). For n = 1: 315.2 (d, J_{C-H} = 133, J_{C-W} = 158 Hz, *C*HCMe$_3$), 91.5, 91.3 (t, OCH$_2$CMe$_3$), 48.2 (s, CHCMe$_3$), 35.1, 35.0 (s, OCH$_2$CMe$_3$), 31.8 (q, CHC*Me*$_3$), 26.8, 26.4 (q, OCH$_2$C*Me*$_3$).

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