chromatographic analyses (GC) were made on a Shimadzu 4CPT instrument. GC quantitative analyses of reaction products were made with internal standards with calibration based upon authentic samples employing a 20% silicone DC 550 on Celite 545 column. Preparative-layer chromatography (PLC) was carried out by using 20 × 20 × 0.2 cm plates prepared with Merck aluminum oxide 60 PF-254. Preparative medium-pressure liquid chromatography (MPLC) was carried out by using a prepacked silica gel column (CPS-223L-1) supplied by Kusano Kagaku Co. Melting points were determined on a Yanaco MP melting point measurement apparatus and are uncorrected.

Tetrahydrofuran (THF) was distilled from $LiAlH_4$ under nitrogen. Benzene and toluene were distilled from CaH_2 under nitrogen. (*Z*)-2-Butene-1,4-diyl diacetate (**2**) was distilled under nitrogen after drying over $CaSO_4$. (*Z*)-2-Butene-1,4-diyl bis(methyl carbonate) (**1**) was prepared by the reaction of (*Z*)-2-butene-1,4-diol with methyl chloroformate in THF in the presence of pyridine. *N*- and *N,N'*-substituted ethylenediamines **3a–c** and *N*-benzylethanolamine (**3f**) were commercially available and were distilled under nitrogen after drying over anhydrous KOH. *N,N'*-Bis(*p*-tolylsulfonyl)diamines **3e**, **5a**, and **5b** were prepared by tosylation of the corresponded unsubstituted diamines according to the published method.[8] *N*-Methyl-*N'*-(*p*-tolylsulfonyl)ethylenediamine (**3d**) was prepared according to the published method.[8] $Pd_2(dba)_3{\cdot}CHCl_3$[9] and $Pd(PPh_3)_4$[10] were prepared by the reported procedures. $P(OPr^i)_3$ was a commercial reagent, which was distilled under nitrogen after drying over $CaSO_4$.

Palladium(0)-Catalyzed Reaction of (*Z*)-2-Butene-1,4-diyl Bis(methyl carbonate) (1) with *N,N'*-Bis(*p*-tolylsulfonyl)-ethylenediamine (3e). To a stirred THF (1.6 mL) solution containing $Pd_2(dba)_2{\cdot}CHCl_3$ (0.0046 g, 0.0050 mmol), $P(OPr^i)_3$ (0.010 ml, 0.040 mmol), and **3e** (0.0733 g, 0.200 mmol) was added under N_2 a THF (0.4 mL) solution of **1** (0.0408 g, 0.20 mmol) at room temperature. GC analysis of the mixture after 4 h showed disappearance of **1**. The reaction mixture was concentrated under vacuum to give a residue. Purification by PLC (hexane–ethyl acetate = 3:2 (v/v)) gave *N,N'*-bis(*p*-tolylsulfonyl)-2-vinylpiperazine (**4e**) (0.058 g, 69%), which was further purified by MPLC (chloroform–ethyl acetate = 1:1 (v/v)) to give a white solid: mp 181.5–182.7 °C; IR (KBr, cm^{-1}) 1630, 1455, 1345, 1155, 920, 815; ^1H NMR (200 MHz) 2.35–2.55 (m, 1 H), 2.40 (s, 3 H), 2.45 (s, 3 H), 2.57 (dd, *J* = 11.6, 3.6, 1 H), 3.15–3.30 (m, 1 H), 3.50–3.70 (m, 3 H), 4.45 (br s, 1 H), 5.19 (d, *J* = 9.2, 1 H), 5.26 (d, *J* = 16.0, 1 H), 5.73 (ddd, *J* = 17.2, 10.7, 6.4, 1 H), 7.24 (d, *J* = 9.0, 2 H), 7.33 (d, *J* = 7.9, 2 H), 7.56 (d, *J* = 8.3, 2 H), 7.60 (d, *J* = 8.3, 2 H); MS *m/e* (relative intensity) 420 (M^+, 0.7), 328 (13), 265 (100), 110 (24), 109 (18). Anal. Calcd for $C_{20}H_{24}N_2O_4S_2$: C, 57.12; H, 5.75; N, 6.66; S, 15.25. Found: C, 57.03; H, 5.80; N, 6.70; S, 15.09.

2-Vinylpiperazine derivatives **4a–d**, *N*-benzyl-2-vinylmorpholine (**4f**), and diazacycles **6a** and **6b** were similarly obtained as described above and were identified as follows. The regiochemistries of the products **4a**, **4d**, and **4f** produced from unsymmetrically substituted ethylenediamines were determined by ^1H NMR NOE measurements. The product purity was judged to be ≥95% for the products **4c**, **4f**, and **6b** and ≥90% for the products **4a** and **4b** by ^1H NMR spectral determinations. The product **4a** was isolated by preparative GC: IR (neat, cm^{-1}) 1640, 1490, 1060, 1020, 740, 680; ^1H NMR (400 MHz) 1.70 (s, 1 H), 1.84 (t, *J* = 10.5, 1 H), 2.06 (td, *J* = 10.9, 3.6, 1 H), 2.70–2.80 (m, 1 H), 2.81 (ddd, *J* = 10.8, 2.8, 1.8, 1 H), 2.90–3.00 (m, 2 H), 3.30–3.40 (m, 1 H), 3.51 (s, 2 H), 5.07 (dt, *J* = 10.5, 1.4, 1 H), 5.20 (dt, *J* = 17.3, 1.5, 1 H), 5.78 (ddd, *J* = 17.2, 10.7, 6.4, 1 H), 7.20–7.35 (m, 5 H); MS *m/e* (relative intensity) 202 (M^+, 7), 134 (83), 111 (37), 91 (100), 49 (35); HRMS (*m/e*) 202.1468, calcd for $C_{13}H_{18}N_2$ 202.1470. **4b** (column chromatography on alumina, pentane–ether = 1:1 (v/v)): IR (neat, cm^{-1}) 1635, 1435, 1085, 790; ^1H NMR (200 MHz) 1.95–2.10 (m, 1 H), 2.24 (s, 3 H), 2.28 (s, 3 H), 2.15–2.35 (m, 2 H), 2.55–2.90 (m, 4 H), 5.15 (dd, *J* = 10.2, 2.0, 1 H), 5.25 (dd, *J* = 17.0, 2.0, 1 H), 5.69 (ddd, *J* = 18.0, 10.0, 8.4, 1 H); MS *m/e* (relative intensity) 140 (M^+, 40), 96 (61), 91 (24), 84 (41), 83 (100), 82 (45), 43 (71); HRMS (*m/e*) 140.1314, calcd for $C_8H_{16}N_2$ 140.1314. **4c** (PLC, THF–triethylamine = 10:1 (v/v)): IR (neat, cm^{-1}) 1635, 1120, 1070, 1045, 915, 735, 700, 680; ^1H NMR (200 MHz) 2.05–2.25 (m, 3 H), 2.60–2.75 (m, 3 H), 2.93 (td, *J* = 9.1, 2.9, 1 H), 3.07 (d, *J* = 13.5, 1 H), 3.48 (s, 2 H), 4.05 (d, *J* = 13.5, 1 H), 5.18 (dd, *J* = 10.2, 1.8, 1 H), 5.27 (dd, *J* = 17.4, 1.8, 1 H), 5.84 (ddd, *J* = 17.4, 10.1, 8.2, 1 H), 7.15–7.35 (m, 10 H); MS *m/e* (relative intensity) 292 (M^+, 30), 201 (72), 161 (25), 160 (77), 91 (100); HRMS (*m/e*) 292.1937, calcd for $C_{20}H_{24}N_2$ 292.1940. **4d** (PLC, hexane–ethyl acetate = 1:1 (v/v)): IR (neat, cm^{-1}) 1630, 1445, 1345, 1155, 810, 795; ^1H NMR (400 MHz) 2.07 (td, *J* = 11.2, 3.4, 1 H), 2.20 (s, 3 H), 2.25 (dd, *J* = 11.4, 3.9, 1 H), 2.42 (s, 3 H), 2.60–2.70 (m, 2 H), 3.25 (ddd, *J* = 12.7, 11.0, 3.1, 1 H), 3.51 (dtd, *J* = 12.8, 3.2, 1.0, 1 H), 4.33 (br s, 1 H), 5.13 (dt, *J* = 11.7, 1.3, 1 H), 5.18 (dt, *J* = 17.3, 1.4, 1 H), 5.86 (ddd, *J* = 17.2, 10.5, 6.6, 1 H), 7.27 (d, *J* = 7.6, 2 H), 7.67 (d, *J* = 8.4, 2 H); ^{13}C NMR 21.5, 42.0, 46.2, 54.4, 56.2, 59.8, 117.4, 127.6, 129.5, 134.9, 136.8, 143.7; MS *m/e* (relative intensity) 280 (M^+, 1.5), 216 (8), 126 (100), 125 (100), 82 (54). Anal. Calcd for $C_{14}H_{20}N_2O_2S$: C, 59.97; H, 7.19; N, 9.99; S, 11.44. Found: C, 59.70; H, 7.15; N, 9.86; S, 11.36. **4f** (PLC, ethyl acetate): IR (neat, cm^{-1}) 1640, 1105, 1075, 1020, 735, 700; ^1H NMR (400 MHz) 1.94 (dd, *J* = 11.2, 10.3, 1 H), 2.18 (td, *J* = 11.4, 3.3, 1 H), 2.67 (dq, *J* = 11.5, 2.0, 1 H), 2.77 (dt, *J* = 11.3, 2.1, 1 H), 3.51 (s, 2 H), 3.71 (td, *J* = 11.4, 2.4, 1 H), 3.90 (ddd, *J* = 11.3, 3.3, 1.7, 1 H), 4.00–4.05 (m, 1 H), 5.15 (dt, *J* = 10.8, 1.5, 1 H), 5.29 (dtd, *J* = 17.4, 1.6, 0.4, 1 H), 5.79 (ddd, *J* = 17.3, 10.7, 5.6, 1 H), 7.25–7.35 (m, 5 H); MS *m/e* (relative intensity) 203 (M^+, 21), 202 (12), 146 (71), 103 (19), 91 (100); HRMS (*m/e*) 203.1297, calcd for $C_{13}H_{17}NO$ 203.1310. **6a** (PLC, hexane–ethyl acetate = 1:1 (v/v); MPLC, hexane–ethyl acetate = 3:2 (v/v)): mp 148.5–150.2 °C; IR (KBr, cm^{-1}) 1645, 1320, 1150, 820, 665; ^1H NMR (200 MHz) 1.90–2.05 (m, 2 H), 2.43 (s, 6 H) 3.29 (t, *J* = 5.7, 4 H), 3.90 (d, *J* = 5.6, 4 H), 5.72 (t, *J* = 4.2, 2 H), 7.33 (d, *J* = 8.3, 4 H), 7.68 (d, *J* = 8.2, 4 H); ^{13}C NMR 21.5, 30.5, 47.5, 47.8, 127.2, 128.8, 129.7, 135.1, 143.5; MS *m/e* (relative intensity) 434 (M^+, 2), 280 (17), 279 (100), 155 (10), 123 (14), 82 (15). Anal. Calcd for $C_{21}H_{26}N_2O_4S_2$: C, 58.04; H, 6.03; N, 6.45; S, 14.76. Found: C, 57.57; H, 5.97; N, 6.39; S, 14.64. **6b** (PLC, hexane–ethyl acetate = 1:1 (v/v); MPLC, chloroform–ethyl acetate = 1:1 (v/v)): mp 227.5–229.5 °C; IR (KBr, cm^{-1}) 1320, 1145, 805, 670; ^1H NMR (200 MHz) 1.55–1.85 (m, 4 H), 2.43 (s, 6 H), 2.93 (br s, 2 H), 3.08 (br s, 2 H), 3.47 (br s, 2 H), 3.91 (br s, 2 H), 5.77 (t, *J* = 4.0, 2 H), 7.32 (d, *J* = 8.8, 4 H), 7.68 (d, *J* = 8.3, 4 H); MS *m/e* (relative intensity) 354 (4), 207 (9), 197 (6), 44 (100). HRMS did not also produce the parent peak. Anal. Calcd for $C_{22}H_{28}N_2O_4S_2$: C, 58.90; H, 6.29; N, 6.24; S, 14.29. Found: C, 57.99; H, 6.24; N, 6.12; S, 14.04. The purity of the product **6b** judged by ^1H NMR spectral determination was ≥95%.

Supplementary Material Available: ^1H NMR spectra showing the purity of the products **4a–c**, **4f**, and **6b** (5 pages). Ordering information is given on any current masthead page.

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A Facile Synthesis of 2-Acetonylcycloalkanones by Using 2-(Halomethyl)-3,5-dioxahex-1-ene

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Many biologically active natural products are characterized by a cyclopentenone moiety as a main structural feature, hence an interest exists in developing new synthetic routes to substituted cyclopentenones.[1] One important method for obtaining cyclopentenones depends on

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Scheme I

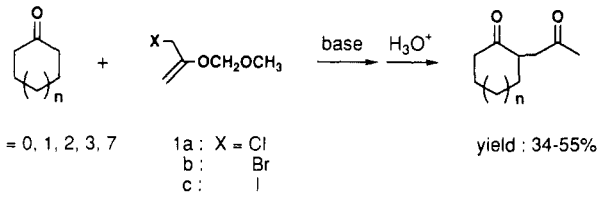


Table I. Acetonylation of Cyclohexanone with 2-(Halomethyl)-3,5-dioxahex-1-ene (1)

reagent 1, X	reaction conditions: base	solvent	temp,[a] °C	time, h	yield, %
Cl	LDA	THF	25	24	no reaction
Cl	NaH	ether	reflux	24	no reaction
Cl	NaH	THF	reflux	24	8
Cl	NaH	DMF	80	24	27
Cl	NaH	DMF	120	2	51
Cl	NaH	xylene	120	1	53
Br	LDA	THF	25	10	40
Br	NaH	xylene	120	1	52
I	LDA	THF	25	6	53
I	NaH	xylene	120	1	53

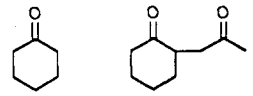
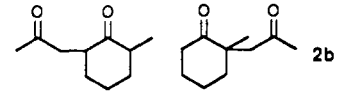
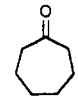
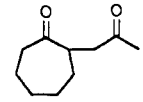
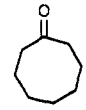
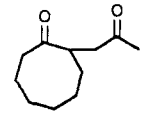
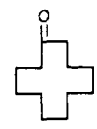
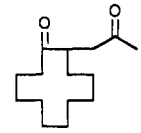
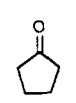
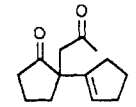
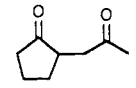
[a] Reaction temperature of cyclohexanone anion with 2-(halomethyl)-3,5-dioxahex-1-ene.

effective synthesis of γ-diketones.[2-4] The methods for preparation of 2-acetonylcycloalkanones from imines and 2-methoxyallyl bromide developed by Jacobson[5] and from cycloalkanones and isopropenyl acetate in the presence of ceric ammonium nitrate reported by Baciocchi[6] recently attracted our attention. In our previous study, 2-(chloromethyl)-3,5-dioxahex-1-ene (**1a**) was found to be a convenient acetonylating reagent for various active proton-containing compounds.[7,8] During the investigation on the reactivity of **1a** to extend its utility in organic synthesis, we have found that **1a** could undergo a new type of 1,3-migration of the methoxymethyl group in the presence of aluminum chloride to give 2-oxo-5-oxahexyl derivatives.[9] Here, we report another useful reaction in which cycloalkanones were acetonylated easily by using **1a** to afford 2-acetonylcycloalkanones. The reactivities of 2-(halomethyl)-3,5-dioxahex-1-ene, 2-(bromomethyl)-3,5-dioxahex-1-ene (**1b**), and 2-(iodomethyl)-3,5-dioxahex-1-ene (**1c**) were examined for the acetonylation of cyclohexanone.

The acetonylation reaction was carried out by treating cycloalkanones with sodium hydride in xylene and then by reacting with 1.1 equiv of 2-(chloromethyl)-3,5-dioxahex-1-ene (**1a**) at 120 °C for 1 h, followed by hydrolysis in 1% aqueous sulfuric acid (Scheme I). The 2-acetonylcycloalkanones were usually obtained in moderate yields (34–55%).

The effect of reaction conditions such as the kind of base, solvent, and reaction temperature on the yield is shown in Table I. The results of acetonylation for cycloalkanones using **1a** are summarized in Table II. Table I shows that the use of sodium hydride as a base and reaction in xylene or DMF at 120 °C gives rise to good results of allylation. If the reaction was carried out in ether

Table II. Acetonylation[a] of Cycloalkanones with 2-(Chloromethyl)-3,5-dioxahex-1-ene

substrate	product	yield,[b] %
	2a	53
	 2b (18:82)[c]	55
	 2c	45
	 2d	51
	 2e	34
	 2f	60
	 2g	40[d]

[a] Sodium hydride was used as a base and reacted at 120 °C for 1 h in xylene, unless otherwise stated. [b] Kugelrohr distillation. [c] Isomer ratio determined by ^{1}H NMR spectroscopy. [d] LDA as a base and 2-(iodomethyl)-3,5-dioxahex-1-ene as an acetonylation reagent were used, and the allylation reaction proceeded at room temperature.

at low temperature, no allylation occurred even in 24 h. This result may show that the reactivity of 2-alkoxyallyl chloride (**1a**) is lower than that of allyl chloride as achieved by Vanderwerf.[10]

In order to compare the reactivities of 2-(halomethyl)-3,5-dioxahex-1-enes **1a**, **1b**, and **1c**, cyclohexanone was used as the substrate to be acetonylated. Under the same reaction conditions as those in Table I, the yields were 52% (for **1b**) and 53% (for **1c**), the same as that for **1a** (53%), showing no difference among the reactivities of **1** under the drastic reaction conditions. However, when the reaction was carried out under mild conditions, for example at −78 °C using lithium diisopropylamide as a base, **1b** and **1c** gave the end product in the yields of 40% and 53%, respectively, while **1a** gave no end product.

In the case of acetonylation of cyclopentanone with **1a** and use of sodium hydride as a base, the sole product obtained is 2-acetonyl-2-cyclopentenylcyclopentanone (**2f**) by acetonylation of the aldol condensation compound, rather than expected 2-acetonylcyclpentanone. However, 2-acetonylcyclopentanone was obtained in yield of 40% by the reaction of cyclopentanone with **1c** at −78 °C using lithium diisopropylamide as a base.

In this acetonylation procedure, the yield of isolated end product was moderate to fair. (The reaction conditions were not optimized.) This may be depend on the unde-

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sirable formation of diallyl compound in the first step and of aldol condensation compound (cyclopentenone derivatives) in the acidic hydrolysis step, as well as the difficulty in separation of the end product from the raw cycloalkanone.

Thus, upon the use of 1.0, 1.1, and 1.5 equimolar amounts of **1a** on cyclohexanone (NaH: 1.1 equimolar amount), yields of the end product were 51, 48, and 53%, respectively, together with diacetonylated products in the yields of 10, 12, and 16%, respectively (calculated from the weight of the end monoacetonylated product and GLC of the hydrolysis reaction mixture).

For evaluation of the amounts of aldol condensation product, the reaction using cyclooctanone was examined as an example. At the end of allylation step, GLC showed the presence of monoallylated compound as the main product and of diallylated compound and the raw cyclooctanone as large as 15 and 8% of peak area of the main product, respectively, together with a few of unidentified very small peaks. After acidic hydrolysis of the allylation reaction mixture, peaks due to mono- and diallylated compounds disappeared and three major peaks appeared instead, except for that of cyclooctanone. Area ratio was 20:100:12. From GLC–mass spectroscopy, the peak (with area ratio 20) at the shortest retention time corresponded to the aldol condensation product, the cyclopentenone derivative, and the peak (with area ratio 12) at the longest retention time with diacetonyl compound.

In an another run, the isolated monoacetonyl compound was treated under the same reaction conditions as the hydrolysis conditions. A peak corresponded to the cyclopentenone derivative appeared after few minutes. And the area of this peak exceeded that of monoacetonylated compound in about 2 h, showing that the hydrolysis conditions affect the yield of acetonyl compound largely.

Differing from cycloalkanones, acyclic 2-octanone did not afford the corresponding acetonyl compound.

Experimental Section

^{1}H NMR spectra were recorded on a JEOL-PS-100 instrument in $CDCl_3$ with Me_4Si as an internal standard. Mass spectra were measured on a Hitachi RMU-6E spectrometer. GLC–mass spectra were recorded on a JEOL-LMS-DX 303 with EI ionization mode. All the reagents were of reagent grade and were used without further purification. 2-(Halomethyl)-3,5-dioxahex-1-ene (**1**) was prepared according to ref 7. Distillation was performed by Kugelrohr.

Typical Procedure: Synthesis of 2-Acetonylcyclohexanone (2a). Cyclohexanone 4.9 g (0.05 mol) was added to a mixture of sodium hydride, 2.2 g (0.055 mol, 60% in oil, washed with xylene), and xylene, 80 mL, and stirred at 40 °C for 3 h. 2-(Chloromethyl)-3,5-dioxahex-1-ene (**1a**), 7.5 g (0.055 mol), was added dropwise, and the mixture was stirred at 120 °C for 1 h. Then the unreacted sodium hydride was quenched with methanol, and the solution was washed with water. After extraction of the organic material with dichloromethane and then removal of the solvents, 5 mL of 1% aqueous sulfuric acid and 5 mL of dioxane were added to the residue, and the mixture was heated at 60 °C for 1 h. The product was extracted with ether, and the organic phase was dried over anhydrous magnesium sulfate. After removal of solid material by filtration and evaporation of the solvent, the crude product was fractionated by Kugelrohr distillation under reduced pressure to give **2a** as a colorless oil: 4.1 g, yield 53%; bp 50 °C (0.05 Torr); ^{1}H NMR ($CDCl_3$) δ 1.18–2.54 (m, 7 H), 2.25 (s, 3 H), 2.28–2.52 (m, 2 H), 2.82–3.14 (m, 2 H); MS m/z (relative intensity) 154 (M^+, 34), 111 (37), 97 (48), 55 (41), and 43 (100); IR (neat) 2940, 2860, 1720, and 1450 cm^{-1}. Anal. Calcd for $C_9H_{14}O_2$: C, 70.10; H, 9.15. Found: C, 69.78; H, 9.20.

On distilling the reaction mixture, 0.7 g of forerun and 1.5 g of residue were separated from the main fraction (4.1 g). GLC of the forerun showed its composition to be a mixture of a small amount of the raw cyclohexanone (GLC peak area ratio 12), a large amount of the end product (area ratio 100), and unidentified product (area ratio 5). GLC-detectable compounds in the residue were a substantial amount of the diacetonylated product and a small amount of an unidentified heavier product.

Acetonyl-2-methylcyclohexanone (2b). With the general procedure described above, **2b** (as a mixture of 2-acetonyl-2-methylcyclohexanone and 6-acetonyl-2-methylcyclohexanone, 82:18) was isolated as a colorless liquid in yield of 55%: bp 45 °C (0.03 Torr); ^{1}H NMR ($CDCl_3$) δ 0.96–1.04 (d, 0.54 H), 1.17 (s, 2.46 H), 1.48–2.68 (m, 8 H), 2.13 (s, 3 H), 2.84–3.10 (m, 2 H); MS m/z (relative intensity) 168 (M^+), 111 (43), 55 (30), and 43 (100); IR (neat) 2940, 2860, 1720, and 1450 cm^{-1}. Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.32; H, 9.66.

2-Acetonylcycloheptanone (2c). With the general procedure described above, **2c** was obtained as a colorless oil in yield of 45%: bp 43 °C (0.03 Torr); ^{1}H NMR ($CDCl_3$) δ 1.02–2.72 (m, 11 H), 2.07 (s, 3 H), 2.84–3.08 (m, 2 H); MS m/z (relative intensity) 168 (M^+), 111 (34), 55 (44), and 43 (100); IR (neat) 2950, 2870, 1715, and 1460 cm^{-1}. Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.08; H, 9.60.

2-Acetonylcyclooctanone (2d). With the general procedure described above, **2d** was isolated in yield of 51% as a colorless liquid: bp 65 °C (0.08 Torr); ^{1}H NMR ($CDCl_3$) δ 1.28–2.96 (m, 13 H), 2.13 (s, 3 H), 3.03–3.32 (m, 2 H); MS m/z (relative intensity) 182 (M^+), 125 (22), 55 (31), and 43 (100); IR (neat) 2940, 2860, 1720, and 1460 cm^{-1}. Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.20; H, 9.97.

GLC and GLC–Mass Spectral Study Using 2d. At the stage of allylation, GLC (SE 30, 3% on Celite 545, 1 m, started at 60 °C, temperature increment 20 °C/min) showed the presence of two main peaks which corresponded to monoallylated cyclooctanone (retention time 4.9 min, area ratio 87) and diallylated compound (retention time 7.6 min, area ratio 13) besides a few small peaks. After typical acidic hydrolysis, three main peaks were observed at retention times of 2.5 min (area ratio 15), 3.7 min (76), and 5.5 min (9). These were identified from the GLC–mass spectra to be the cyclopentenone derivative by condensation of monoacetonylcyclooctanone, monoacetonylcyclooctanone, and diacetonylcyclooctanone, respectively.

2-Acetonylcyclododecanone (2e). With the general procedure described above, **2e** was isolated in yield of 34% as a white wax: bp 110 °C (0.08 Torr); mp 56–57 °C; ^{1}H NMR ($CDCl_3$) δ 1.02–2.52 (m, 21 H), 2.14 (s, 3 H), 2.72–3.32 (m, 2 H); MS m/z (relative intensity) 238 (M^+, 39), 195 (32), 55 (37), and 43 (100); IR (neat) 2950, 2870, 1720, 1478, and 1400 cm^{-1}. Anal. Calcd for $C_{15}H_{26}O_2$: C, 75.58; H, 10.99. Found: C, 75.60; H, 11.03.

2-Acetonyl-2-cyclopentenylcyclopentanone (2f). With the general procedure described above, **2f** was isolated in yield of 60% as a colorless liquid: bp 55 °C (0.04 Torr); ^{1}H NMR ($CDCl_3$) δ 1.64–2.77 (m, 12 H), 2.12 (s, 3 H), 2.88 (s, 2 H), 5.44–5.54 (m, 1 H); MS m/z (relative intensity) 206 (M^+), 148 (30), 107 (41), and 43 (100); IR (neat) 2960, 2860, 1720, 1630, and 1400 cm^{-1}. Anal. Calcd for $C_{13}H_{18}O_2$: C, 75.69; H, 8.80. Found: C, 75.43; H, 8.66.

2-Acetonylcyclopentanone[5] (2g). To a solution of 0.02 mol of lithium diisopropylamide (generated in situ from diisopropylamine and butyllithium) in 50 mL of anhydrous THF was added 1.26 g (0.015 mol) of cyclopentanone. The solution was stirred at −78 °C for 0.5 h, and then 2-(iodomethyl)-3,5-dioxahex-1-ene, 4.56 g (0.02 mol), was added, followed by stirring for an additional 0.5 h at −78 °C. The solution was gradually warmed to room temperature and stirred for 6 h; 50 mL of water was added to the residue. After extraction of the organic product with ether and then removal of the solvent, 5 mL of 1% aqueous sulfuric acid and 5 mL of dioxane were added to the residue, and the mixture was heated at 60 °C for 1 h. The product was extracted with ether, and the organic phase was dried over anhydrous magnesium sulfate. After removal of solid material by filtration and evaporation of the solvent, **2g** was isolated by Kugelrohr distillation under reduced pressure as a colorless oil: 0.84 g, yield 40%; bp 50 °C (0.15 Torr); ^{1}H NMR ($CDCl_3$) δ 1.22–2.56 (m, 7 H), 2.17 (s, 3 H), 2.60–3.12 (m, 2 H); MS m/z (relative intensity) 140 (M^+), 97 (71), 83 (64), 43 (100); IR (neat) 2950, 2880, 1740, 1720, and 1410 cm^{-1}.

2-(Bromomethyl)-3,5-dioxahex-1-ene (1b). **1b** was prepared according to ref 7 in yield of 75% as a colorless liquid: bp 78 °C (25 Torr); ^{1}H NMR ($CDCl_3$) δ 3.47 (s, 3 H), 3.88 (s, 2 H), 4.42 (s,

2 H), 5.01 (s, 2 H); MS m/z (relative intensity) 182 ($M^+ + 2$), 180 (M^+), 101 (30), and 45 (100); IR (neat) 2950, 1640, 1430, 1160, 1100, and 1020 cm^{-1}. Anal. Calcd for $C_5H_9BrO_2$: C, 33.17; H, 5.01; Br, 44.14. Found: C, 33.17; H, 5.08; Br, 43.91.

Palladium-Catalyzed Addition of Trimethylgermyl Cyanide to Terminal Acetylenes

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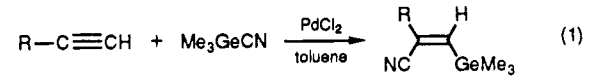
Trimethylsilyl cyanide, Me_3SiCN, has gained considerable recognition as a versatile reagent to introduce cyano groups into organic molecules,[1] and the reaction of Me_3SiCN with a wide variety of substrates such as aldehydes,[2] ketones,[3] acetals,[4] epoxides,[5] and acetylenes[6,7] has been extensively studied. Tributyltin cyanide, Bu_3SnCN, has been found to react with acid halides[8] and aryl halides[9] to give acid cyanides and aryl cyanides, respectively. In contrast, synthetic application of trimethylgermyl cyanide, Me_3GeCN (**1**), has not been developed so far. We now wish to report the Pd-catalyzed addition to **1** to terminal acetylenes with a high regio- and stereoselectivity to give β-cyano alkenylgermanes in high yields (eq 1).



(1)

The results obtained for some terminal acetylenes are shown in Table I. The reaction of phenylacetylene (**2a**) with **1** in the presence of $PdCl_2$ at reflux for 2 h afforded 2-phenyl-3-(trimethylgermyl)-2-propenenitrile (**3a**) in 99% isolated yield with a Z/E ratio of 97:3 (entry 1). A decrease in the reaction temperature resulted in a decrease in the yield of **3a** (entries 1–4). When the reaction was carried out at 40 °C, no reaction occurred (entry 4). Palladium complexes such as $Pd(PPh_3)_4$ and $PdCl_2$/DIBAH (i-Bu_2AlH) were not effective for the reaction of phenylacetylene with **1**. When Ni(0), generated in situ from the treatment of $NiCl_2$ with DIBAH, was used as a catalyst, the reaction exhibited inverse stereoselectivity (entry 5). The stereochemistry of **3a** was confirmed by the coupling constant between CN and vinyl proton in the ^{13}C NMR spectrum ($^3J_{CN-H}$ = 17 Hz for **3a*Z*** and $^3J_{CN-H}$ = 12 Hz for **3a*E***).[10] The yields were excellent for aromatic acetylenes (entries 1–11). Aliphatic acetylenes also reacted with **1** in the presence of $PdCl_2$ and gave β-cyano alkenylgermanes in high yields (entries 12–15). The reaction was compatible with functional groups such as methoxy, fluoro, chloro, acetoxy, and cyano. The reaction of the internal acetylenes 4-octyne and diphenylacetylene with **1** did not give addition products.

We have previously reported the Pd-catalyzed addition of Me_3SiCN to acetylenes giving β-cyano alkenylsilanes.[6b] The present study reveals that **1** is more reactive than Me_3SiCN. Thus, the present reaction was completed within 2 h, whereas the reaction of Me_3SiCN required at least 15 h to complete under the same reaction conditions as those for the reaction of **2a** with Me_3SiCN. In addition, the reaction of acetylenes with **1** gave a better stereoselectivity than that with Me_3SiCN.

In summary, the present reaction provides a new synthetic method for the preparation of alkenylgermanes[11,12] with a high degree of regio- and stereoselectivity.

Experimental Section

General Method. ^1H NMR and ^{13}C NMR spectra were recorded on a Bruker WM 360 spectrometer and are reported in ppm from tetramethylsilane or chloroform as an internal standard on the δ scale. Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, quint = quintet, m = multiplet), coupling constant, integration, and interpretation. Infrared spectra were obtained on a Hitachi 260-10 spectrometer. Peaks are reported in units of cm^{-1}. Mass spectra were obtained on a JMS-DX 300 with ionization voltages of 70 eV. Elemental analyses were performed on a Perkin-Elmer 240C by the ISIR Material Analysis Center at Osaka University. Melting points (mp) were determined on a Yanagimoto micro melting point apparatus and uncorrected. Bulb-to-bulb distillations were done on a GTO-250R Sibata glass tube oven; boiling points (bp) refer to air bath temperature and are uncorrected.

Materials. Phenylacetylene (**2a**), 1-octyne (**2h**), 5-hexynenitrile (**2j**), 4-octyne and diphenylacetylene are commercially available. Preparation of (4-fluorophenyl)- (**2b**), (4-chlorophenyl)- (**2c**), (3-methoxyphenyl)- (**2d**), (2-methoxyphenyl)- (**2e**), (2-naphthyl)- (**2f**), and (1-naphthyl)acetylene (**2g**) has already been reported in a previous paper.[6b] Trimethylgermyl cyanide (**1**) was prepared by the literature procedure.[13]

2-Phenyl-3-(trimethylgermyl)-(*Z*)-prop-2-enenitrile (3a*Z*). In a 20-mL round-bottomed flask were placed phenylacetylene (1 mmol, 0.11 mL), Me_3GeCN (2 mmol, 0.27 mL), and toluene (2 mL). To the solution was added $PdCl_2$ (0.1 mmol, 18 mg), and the mixture was heated at reflux under nitrogen. After 2 h, the solvent was removed in vacuo, and distillation of the residue by Kugelrohr distillation gave pure 2-phenyl-3-(trimethylgermyl)-2-propenenitrile (**3a**) (245 mg, 99%): bp 95–100 °C (0.35 Torr); ^1H NMR ($CDCl_3$) δ 0.49 (s, 9 H, $GeCH_3$), 7.31 (s, 1 H, CH=), 7.59

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