One-Pot Synthesis of Tetrahydrofuran Derivatives from Allylic Alcohols and Vinyl Ethers by Means of Palladium(II) Acetate

Keigo FUGAMI,† Koichiro OSHIMA,* and Kiitiro UTIMOTO*
Department of Industrial Chemistry, Faculty of Engineering, Kyoto University, Sakyo-ku, Kyoto 606
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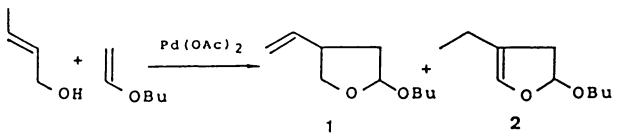
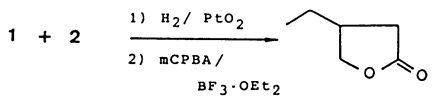
Reaction of allylic alcohol with vinyl ether in the presence of $Pd(OAc)_2$ afforded furan derivatives in good yield. $Pd(OAc)_2$ was essential for the reaction. $PdCl_2$ complex did not afford cyclized product but gave acetal exclusively. Three components were combined at once to produce 4-(3-butenyl)-2-butoxy-4-methyltetrahydrofuran upon treatment of a mixture of 2-methyl-2-propen-1-ol, butyl vinyl ether, and allyl bromide. The reaction could successfully be extended to the synthesis of nitrogen containing heterocycles by use of *N*-tosyl allylic amines in place of allylic alcohols.

We now report here the reaction between allylic alcohols and vinyl ethers promoted by $Pd(OAc)_2$. Treatment of (*E*)-2-buten-1-ol in butyl vinyl ether with $Pd(OAc)_2$ gave unexpected cyclic products **1** and **2** in 74% combined yield (Scheme 1). Hydrogenation



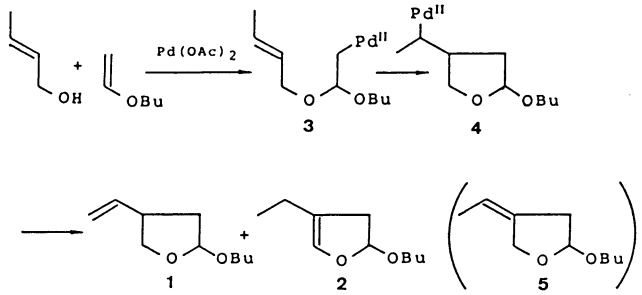
Scheme 1.

of the products **1** and **2** followed by oxidation[1] provided 3-ethyl-γ-butyrolactone which was identical with the authentic sample[2] (Scheme 2).



Scheme 2.

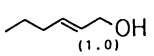
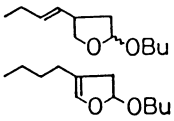
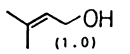
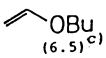
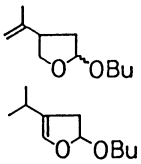
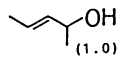
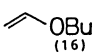
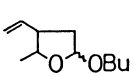
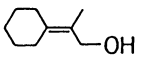
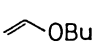
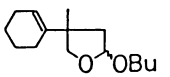
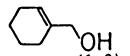
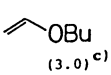
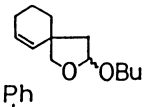
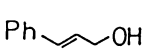
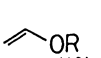
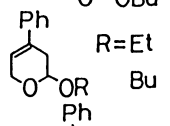
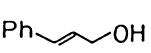
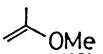
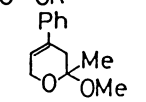
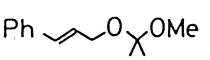
Other results are summarized in Table 1. Five-membered rings were formed in preference to six-membered rings with an exception of the reaction of cinnamyl alcohol which gave a dihydropyran derivative solely (Entries 6 and 7). As shown in Scheme 3, the formation of furan derivatives could be explained by assuming an intermediary palladium compound **3**,



Scheme 3.

† Recipient of the Fellowships of the Japan Society for the Promotion of Science for Japanese Junior Scientists.

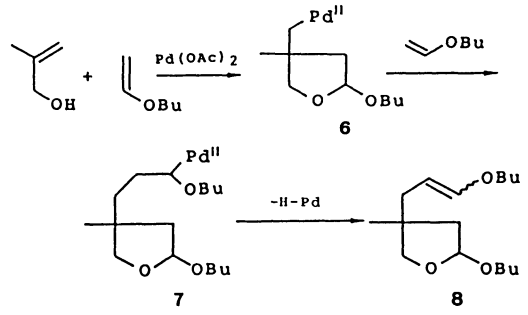
Table 1. Palladium(II)-Promoted Tetrahydrofuran Synthesis[a]

Entry	Allylic alcohol (mmol)	Vinyl ether (mmol)	Product	Yield[b] %
1				82 12
2				58 23
3				75
4				55
5				47
6				R=Et 88 Bu 63
7				54
				27

a) Reactions were performed at 25 °C using one mmol of $Pd(OAc)_2$. b) Isolated yield based on $Pd(OAc)_2$ employed. c) Toluene was used as solvent. In other cases, CH_2=CH-OR was used as solvent.

which undergoes intramolecular olefin insertion followed by β-elimination of palladium hydride from palladium complex **4** to afford vinyltetrahydrofuran **1** as a major product along with dihydrofuran derivative **2**. 4-Ethylidenetetrahydrofuran **5** could not be detected in the reaction mixture.

In the reaction of methallyl alcohol, two molar



Scheme 4.

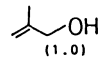
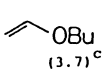
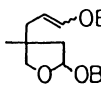
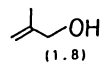
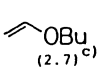
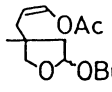
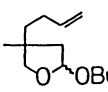
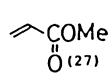
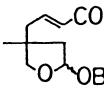
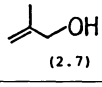
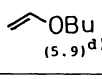
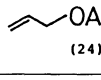
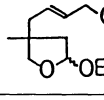
equivalents of butyl vinyl ether were consumed per one 2-methyl-2-propen-1-ol to afford 2-butoxy-4-(3-butoxy-2-propenyl)-4-methyltetrahydrofuran (**8**) (Entry 1 in Table 2).[3] In this case, β-elimination of palladium hydride could not occur from the intermediary palladium complex **6**, then the complex added to the second molecule of butyl vinyl ether to give **7** which was converted into the final product **8** by β-elimination (Scheme 4). It was anticipated that olefins such as vinyl acetate, allyl bromide, and methyl acrylate act as the third component in place of the second butyl vinyl ether. This was indeed the case and these olefins reacted with the complex **6** through the addition-elimination process to give the corresponding coupling products as shown in Table 2. In Entry 3, it was supposed that Pd(II) species would be regenerated in the course of the reaction, but the amount of $Pd(OAc)_2$ could not be reduced.[4] In the case of (*E*)-2-buten-1-ol, the third component such as allyl bromide did not participate in the reaction and the ordinary product **1** was obtained in good yield. Thus, the β-elimination of palladium hydride from the complex **4** took place much faster than the addition of Pd-C bond to the olefinic double bond of allyl bromide.

The reaction of simple allyl alcohol which cannot give vinyltetrahydrofuran derivative resulted in the formation of a complex mixture.

Palladium(II) acetate is essential for the construction of furan or pyran rings. The use of $PdCl_2(CH_3CN)_2$ gave acetal without any contamination by desired cyclized product.[5] It turned out, however, that an addition of an appropriate base to the reaction mixture is effective to give the furan or pyran derivatives. Treatment of a *t*-BuOH solution of 2-methyl-2-propen-1-ol, butyl vinyl ether, and allyl bromide with $PdCl_2(CH_3CN)_2$ in the presence of potassium acetate gave the cyclized product, 4-(3-butenyl)-2-butoxy-4-methyltetrahydrofuran as a single product. The reaction between lithium alkoxide, $PhCH{=}CHCH_2OLi$, and ethyl vinyl ether also enabled us to use $PdCl_2(CH_3CN)_2$ instead of $Pd(OAc)_2$ and provided the corresponding dihydropyran derivative in 99% yield.[6] The $Pd(OAc)_2$-promoted reactions sometimes gave a small amount of noncyclized acetal as a by-product. The extent of the acetal formation seemed to depend on the quality of $Pd(OAc)_2$ employed. In such cases, an addition of one molar equivalent of potassium acetate perfectly suppressed the acetal formation and gave the desired heterocycle exclusively, although the reaction rate was somewhat retarded.

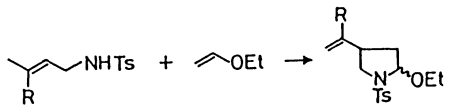
The amount of $Pd(OAc)_2$ could be reduced to 0.3 molar equivalent when $Cu(OAc)_2$ was added as a co-

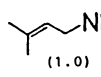
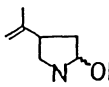
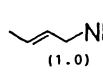
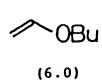
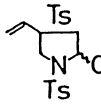
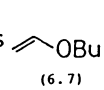
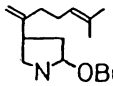
Table 2. Three Component Combination Reaction[a]

Entry	Allylic alcohol (mmol)	Vinyl ether (mmol)	Olefin (mmol)	Product	Yield[b] %
1	 (1.0)	 (3.7)[c]			31
2	 (1.8)	 (2.7)[c]	 (14)		90
3	 (1.4)	 (7.0)[c]	 (21)		81
4	 (2.6)	 (6.6)[c]	 (27)		95
5	 (2.7)	 (5.9)[d]	 (24)		98

a) Reactions were performed at 25 °C using one mmol of $Pd(OAc)_2$. b) Isolated yield based on $Pd(OAc)_2$ employed. c) Toluene was used as solvent. d) Allyl acetate was used as solvent.

Table 3. Palladium(II)-Mediated Pyrrolidine Synthesis[a]



Entry	*N*-Tosyl allylic amine (mmol)	Vinyl ether (mmol)	Product	Yield[b] %
1	 (1.0)	 (5.6)		77
2	 (1.0)	 (6.0)		94
3	 (1.0)	 (6.7)		86
4	 (1.0)	 (8.2)		82

a) Reactions were performed at 25 °C using one mmol of $Pd(OAc)_2$ in toluene. b) Isolated yield based on $Pd(OAc)_2$ employed.

oxidizer.[7] For instance, stirring of an acetonitrile solution of 2-hexen-1-ol (1.0 mmol) and butyl vinyl ether (3.4 mmol) at 25 °C for 20 h under the coexistence of $Pd(OAc)_2$ (0.3 mmol) and $Cu(OAc)_2$ (2.5 mmol) provided 4-(1-butenyl)-2-butoxytetrahydrofuran in 90% yield.

The reaction was successfully extended to the synthesis of pyrrolidine or piperidine derivatives from the corresponding *N*-tosyl allylic amine.[8] The typical results were summarized in Table 3. The presence of tosyl group on nitrogen atom was essential for the successful reaction. Desired heterocycles were not obtained from the reaction of free allylic amines.

Experimental

Distillations of the products were performed by use of Kugelrohr (Büchi), and boiling points are indicated by an air-bath temperature without correction. All melting points were obtained on a Yanaco MP-50929 melting point apparatus and are uncorrected, too. ^1H NMR spectra were taken on a Varian XL-200 spectrometer, $CDCl_3$ was used as solvent, chemical shifts being given in δ with tetramethylsilane as an internal standard. IR spectra were determined on a JASCO IR-810 spectrometer. The analyses were carried out by the staff at the Elemental Analyses Center of Kyoto University. Tetrahydrofuran (THF) was freshly distilled from sodium benzophenone ketyl.

Synthesis of *N*-Tosyl Allylic Amines. These compounds were prepared according to a reported procedure.[9,10] Preparation of *N*-geranyl-*p*-toluenesulfonamide is representative. Sodium (0.87 g, 38 mmol) was dissolved in ethanol (20 ml) and ethyl *N*-tosylcarbamate (11 g, 45 mmol) was added at room temperature under an argon atmosphere. After stirring for half an hour, geranyl bromide (5.0 g, 23 mmol) was added to the resulting clear solution. A white precipitate appeared after stirring for an additional hour. Resulting white suspension was stirred over night. White precipitate was filtered off, and the filtrate was poured into aqueous ammonium chloride solution and extracted twice with dichloromethane. Organic layer was dried over anhydrous sodium sulfate and the residue after evaporation of solvent under reduced pressure was submitted to a silica-gel column chromatography to afford 4.0 g (45% yield) of ethyl *N*-geranyl-*N*-tosylcarbamate. A THF solution (10 ml) of *N*-geranyl-*N*-tosylcarbamate (4.0 g, 10 mmol) was added to a 50% aqueous solution of sodium hydroxide (10 ml) and then 10 ml of methanol was added in order to make the reaction mixture homogeneous. After stirring for 12 h, the reaction mixture was poured into aqueous ammonium chloride solution and extracted with dichloromethane. Organic layer was concentrated and purification by silica-gel column chromatography of the residue gave 3.1 g (99% yield) of *N*-geranyl-*p*-toluenesulfonamide: bp 132 °C/2 Torr (1 Torr= 133.322 Pa); IR (neat) 3276, 2920, 2852, 1599, 1496, 1438, 1328, 1160, 1095, 1050, 814, 662 cm^{-1}; ^1H NMR δ=1.54 (br.s, 3H), 1.57 (br.s, 3H), 1.67 (br.s, 3H), 1.9—2.1 (m, 4H), 2.44 (s, 3H), 3.56 (dd, J=6.4, 6.3 Hz, 2H), 4.25 (t, J=6.3 Hz, 1H), 5.0—5.2 (m, 2H), 7.32 (d, J=8.2 Hz, 2H), 7.76 (d, J=8.2 Hz, 2H); Found: C, 66.40; H, 8.16; N, 4.39%. Calcd for $C_{17}H_{25}NO_2S$: C, 66.41; H, 8.20; N, 4.56%.

General Procedure for the Reaction of Allylic Alcohol or *N*-Tosyl Allylic Amine with Vinyl Ether in the Presence of $Pd(OAc)_2$. Typical procedure is as follows. To a solution of (*E*)-2-buten-1-ol (72 mg, 1.0 mmol) in butyl vinyl ether (3 ml, 10 mmol), $Pd(OAc)_2$ (0.23 g, 1.0 mmol) was added and the resulting mixture was stirred at 25 °C for 2 h. The mixture was diluted with hexane (10 ml) and pyridine (0.1 g) was added. After stirring for an additional 10 min, the precipitated palladium residue was filtered off and filtrate was concentrated in vacuo. Purification of the residual oil by silica-gel column chromatography gave 2-butoxy-4-vinyltetrahydrofuran (**1**) (0.13 g, cis:trans=1:1) in 74% yield: bp 75 °C/25 Torr; IR (neat) 2954, 2932, 2869, 1643, 1459, 1347, 1098, 1070, 1032, 1011, 994, 916 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.1 Hz, 3H), 1.3—1.9 (m, 5H), 2.07 (dd, J=12.5, 7.8 Hz, 0.5H), 2.30 (ddd, J=13.4, 9.4, 5.4 Hz, 0.5H), 2.7—3.0 (m, 0.5H), 3.0—3.3 (m, 0.5H), 3.3—3.5 (m, 1H), 3.5—3.8 (m, 2H), 3.95 (t, J=8.0 Hz, 0.5H), 4.07 (t, J=8.1 Hz, 0.5H), 5.0—5.2 (m, 3H), 5.7—6.0 (m, 1H); Found: C, 70.80; H, 10.86%. Calcd for $C_{10}H_{18}O_2$: C, 70.55; H, 10.66%.

2-Butoxy-4-(1-butenyl)tetrahydrofuran (60:40 Mixture of Diastereomers): Bp 104 °C/21 Torr; IR (neat) 2956, 2930, 2870, 1641, 1459, 1443, 1345, 1097, 1069, 1030, 1005, 968, 918 cm^{-1}; ^1H NMR δ=0.8—1.0 (m, 6H), 1.2—2.5 (m, 8H), 2.6—2.9 (m, 0.6H), 2.9—3.2 (m, 0.4H), 3.3—3.8 (m, 4H), 5.0—5.2 (m, 1H), 5.2—5.7 (m, 2H); Found: C, 72.67; H, 11.42%. Calcd for $C_{12}H_{22}O_2$: C, 72.68; H, 11.18%.

2-Butoxy-4-isopropenyltetrahydrofuran (2:1 Mixture of Diastereomers): Bp 74 °C/20 Torr; IR (neat) 2956, 2932, 2870, 1648, 1458, 1378, 1345, 1181, 1103, 1047, 890 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.2 Hz, 3H), 1.2—2.1 (m, 8.67H, including two singlets at 1.69 ppm (1.0H) and 1.72 ppm (2.0H)), 2.2—2.4 (m, 0.33H), 2.7—3.0 (m, 0.33H), 3.0—3.3 (m, 0.67H), 3.3—3.5 (m, 1H), 3.6—3.8 (m, 2H), 3.93 (t, J=8.1 Hz, 0.33H), 4.05 (t, J=8.4 Hz, 0.67H), 4.74 (br.s, 1.33H), 4.76 (br.s, 0.67H), 5.1—5.2 (m, 1H); Found: C, 71.74; H, 11.02%. Calcd for $C_{11}H_{20}O_2$: C, 71.70; H, 10.94%.

2-Butoxy-4-isopropyl-2,3-dihydrofuran: Bp 94 °C/20 Torr; IR (neat) 2956, 2930, 2870, 1735, 1656, 1459, 1364, 1283, 1187, 1103, 1056, 939, 852 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.2 Hz, 3H), 1.03 (d, J=6.8 Hz, 3H), 1.05 (d, J=6.8 Hz, 3H), 1.2—1.8 (m, 4H), 2.2—2.5 (m, 2H, including d, at δ=2.36, J=16.3 Hz, 1H), 2.73 (dddd, J=16.3, 7.3, 2.5, 1.2 Hz, 1H), 3.47 (dt, J=9.6, 6.8 Hz, 1H), 3.76 (dt, J=9.6, 6.6 Hz, 1H), 5.48 (dd, J=7.3, 2.8 Hz, 1H), 6.04 (br.s, 1H); Found: C, 71.64; H, 11.11%. Calcd for $C_{11}H_{20}O_2$: C, 71.70; H, 10.94%.

2-Butoxy-5-methyl-4-vinyltetrahydrofuran (1:1 Mixture of Diastereomers): Bp 92 °C/21 Torr; IR (neat) 2958, 2930, 2868, 1643, 1459, 1445, 1379, 1095, 996, 936, 915, 658 cm^{-1}. ^1H NMR δ=0.92 (t, J=7.1 Hz, 3H), 1.23 (d, J=6.1 Hz, 1.5H), 1.29 (d, J=6.1 Hz, 1.5H), 1.2—2.8 (m, 7H), 3.3—3.5 (m, 1H, including ddd at δ=3.36, J=13.8, 9.5, 6.5 Hz), 3.6—3.9 (m, 2H, including ddd at δ=3.70, J=16.3, 6.8, 2.1 Hz, and dq at δ=3.82, J=6.1, 3.0 Hz), 5.0—5.3 (m, 3H), 5.67 (ddd, J=17.1, 10.1, 8.1 Hz, 0.5H), 5.74 (ddd, J=17.9, 9.0, 7.6 Hz, 0.5H); Found: C, 71.44; H, 11.23%. Calcd for $C_{11}H_{20}O_2$: C, 71.70; H, 10.94%.

2-Butoxy-4-(1-cyclohexenyl)-4-methyltetrahydrofuran (1:1 Mixture of Diastereomers): Bp 130 °C/1 Torr; IR (neat) 3020, 2958, 2928, 2862, 1456, 1437, 1358, 1325, 1122, 1097, 1028, 931, 669, 638 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.3 Hz, 3H), 0.97 (s, 1.5H), 0.98 (s, 1.5H), 1.2—2.3 (m, 14H), 3.3—3.8 (m, 4H), 5.2—5.3 (m, 1H), 5.7—5.8 (m, 1H); Found: C, 75.70; H, 11.17%. Calcd for $C_{15}H_{26}O_2$: C, 75.58; H, 10.99%.

9-Butoxy-8-oxaspiro[5.4]dec-1-ene (Mixture of Diastereomers): bp 120 °C/1 Torr; IR (neat) 3018, 2956, 2928, 2864, 1440, 1347, 1180, 1094, 1031, 931, 731, 656 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.2 Hz, 3H), 1.3—2.2 (m, 12H), 3.3—3.5 (m, 1H), 3.6—3.8 (m, 3H), 5.1—5.2 (m, 1H), 5.5—5.8 (m 2H); Found: C, 74.31; H, 10.82%. Calcd for $C_{13}H_{22}O_2$: C, 74.24; H, 10.54%.

2-Ethoxy-4-phenyl-3,6-dihydro-2*H*-pyran: Bp 105 °C/1 Torr; IR (neat) 2960, 2915, 2855, 1733, 1592, 1486, 1442, 1419, 1339, 1179, 1092, 1043, 1028, 993, 741, 689 cm^{-1}; ^1H NMR δ=1.21 (t, J=7.1 Hz, 3H), 2.71 (dm, J=16.5 Hz, 1H), 2.94 (dm, J=16.5 Hz, 1H), 3.51 (dq, J=9.8, 7.1 Hz, 1H), 3.78 (dq, J=9.8, 7.1 Hz, 1H), 4.69 (d, J=2.2 Hz, 1H), 4.71 (d, J=2.2 Hz, 1H), 5.24 (dd, J=5.0, 0.7 Hz, 1H), 6.4—6.5 (m, 1H), 7.1—7.5 (m, 5H); Found: C, 76.36; H, 7.95%. Calcd for $C_{13}H_{16}O_2$: C, 76.44; H, 7.90%.

2-Butoxy-4-phenyl-3,6-dihydro-2*H*-pyran: Bp 130 °C/2 Torr; IR (neat) 2948, 2922, 2860, 1660, 1594, 1488, 1445, 1420, 1340, 1175, 1095, 1032, 920, 743, 689 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.1 Hz, 3H), 1.2—1.7 (m, 4H), 2.70 (br.d, J=16.4 Hz, 1H), 2.91 (dm, J=16.4 Hz, 1H), 3.43 (dt, J=9.6, 6.7 Hz, 1H), 3.72 (dt, J=9.6, 6.8 Hz, 1H), 4.82 (br.s, 2H), 5.19 (d, J=4.9 Hz, 1H), 6.29 (br.s, 1H), 7.1—7.4 (m, 5H); Found: C, 77.54; H, 8.82%. Calcd for $C_{15}H_{20}O_2$: C, 77.55; H, 8.68%.

2-Methoxy-2-methyl-4-phenyl-3,6-dihydro-2*H*-pyran: Bp 80 °C/2 Torr; IR (neat) 2984, 2938, 2906, 2850, 2824, 1665, 1599, 1492, 1449, 1422, 1381, 1324, 1309, 1203, 1157, 1131, 1061, 1025, 933, 838, 775, 749, 694 cm^{-1}; ^1H NMR δ=1.52 (s, 3H), 2.7—2.9 (m, 2H), 3.26 (s, 3H), 4.65 (ddd, J=13.9, 4.2, 2.3 Hz, 1H), 4.73 (ddd, J=13.9, 4.1, 2.1 Hz, 1H), 6.3—6.4 (m, 1H), 7.1—7.5 (m, 5H); Found: C, 76.53; H, 8.08%. Calcd for $C_{13}H_{16}O_2$: C, 76.44; H, 7.90%.

2-Butoxy-4-(3-butoxy-2-propenyl)-4-methyltetrahydrofuran (*E*:*Z*=1:1): Bp 96 °C/2 Torr; IR (neat) 2956, 2930, 2868, 1664, 1653, 1458, 1376, 1187, 1104, 1030, 928, 737 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.2 Hz, 6H), 1.06 (s, 3H), 1.2—1.8 (m, 9H, including dd, at δ=1.68 J=13.3, 3.4 Hz, 1H), 1.89 (dd, J=13.3, 5.7 Hz, 1H), 2.0—2.2 (m, 1H), 2.2—2.3 (m, 1H), 3.3—3.6 (m, 2H), 3.6—3.8 (m, 4H), 4.9—5.1 (m, 1H), 5.16 (dd, J=5.7, 3.4 Hz, 1H), 5.82 (ddt, J=16.9, 10.3, 5.7 Hz, 1H); Found: C, 71.08; H, 11.45%. Calcd for $C_{16}H_{30}O_3$: C, 71.07; H, 11.18%.

(*Z*)-4-(3-Acetoxy-2-propenyl)-2-butoxy-4-methyltetrahydrofuran (65:35 Mixture of Diastereomers): Bp 130 °C/1 Torr; IR (neat) 2956, 2932, 2870, 1757, 1672, 1459, 1444, 1370, 1215, 1153, 1098, 1032, 934 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.1 Hz, 3H), 1.05 (s, 1.95H), 1.06 (s, 1.05H), 1.3—2.0 (m, 6H), 2.12 (s, 1.95H), 2.15 (s, 1.05H), 2.15 (br.s, 0.65H), 2.19 (br.s, 0.65H), 2.31 (br.s, 0.35H), 2.35 (br.s, 0.35H), 3.3—3.8 (m, 4H), 5.1—5.2 (m, 1H), 5.40 (dt, J=12.4, 8.1 Hz, 1H), 7.11 (dm, J=12.4 Hz, 1H); Found: C, 65.34; H, 9.58%. Calcd for $C_{14}H_{24}O_4$: C, 65.60; H, 9.44%.

4-(3-Butenyl)-2-butoxy-4-methyltetrahydrofuran: Bp 110 °C/2 Torr; IR (neat) 2956, 2930, 2866, 1642, 1459, 1379, 1098, 1032, 911 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.3 Hz, 3H), 1.06 (s, 3H), 1.2—2.2 (m, 10H, including dd, at δ=1.69, J=13.4, 3.3 Hz, 1H, and ddd, at δ=1.88, J=13.4, 5.7, 0.7 Hz, 1H), 3.3—3.8 (m, 4H), 4.9—5.1 (m, 2H), 5.15 (dd, J=5.7, 3.3 Hz, 1H), 5.82 (ddt, J=17.1, 10.2, 6.5 Hz, 1H); Found: C, 73.38; H, 11.52%. Calcd for $C_{13}H_{24}O_2$: C, 73.54; H, 11.39%.

Methyl 4-(4-Butoxy-3-methyltetrahydrofuran-3-yl)-2-butenoate: Bp 105 °C/2 Torr; IR (neat) 2956, 2868, 1727, 1656, 1437, 1341, 1272, 1195, 1096, 1033, 926 cm^{-1}; ^1H NMR δ=0.91 (t, J=7.1 Hz, 3H), 1.08 (s, 3H), 1.2—1.7 (m, 4H), 1.78 (dd, J=13.4, 2.9 Hz, 1H), 1.87 (dd, J=13.4, 5.4 Hz, 1H), 2.3—2.4 (m, 2H), 3.37 (dt, J=9.5, 6.4 Hz, 1H), 3.52 (d, J=8.2 Hz, 1H), 3.6—3.8 (m, 5H, including s at δ=3.74, 3H), 5.15 (dd, J=5.4, 2.9 Hz, 1H), 5.88 (dt, J=15.5, 1.4 Hz, 1H), 6.93 (dt, J=15.5, 7.8 Hz, 1H); Found: C, 65.82; H, 9.69%. Calcd for $C_{14}H_{24}O_4$: C, 65.60; H, 9.44%.

4-(4-Butoxy-3-methyltetrahydrofuran-3-yl)-2-butenyl Acetate: Bp 130 °C/2 Torr; IR (neat) 2956, 2930, 2868, 1742, 1458, 1444, 1380, 1363, 1231, 1196, 1029, 971, 926 cm^{-1}; ^1H NMR δ=0.92 (t, J=7.1 Hz, 3H), 1.05 (s, 3H), 1.2—1.7 (m, 4H), 1.73 (dd, J=13.5, 3.2 Hz, 1H), 1.87 (dd, J=13.5, 5.4 Hz, 1H), 2.07 (s, 3H), 2.22 (br.s, 1H), 2.25 (br.s, 1H), 3.36 (dt, J=9.5, 6.6 Hz, 1H), 3.48 (d, J=8.4 Hz, 1H), 3.6—3.8 (m, 2H, including d at δ=3.68, J=8.4 Hz, 1H), 4.53 (d, J=5.7 Hz, 1H), 5.14 (dd, J=5.4, 3.2 Hz, 1H), 5.5—5.8 (m, 2H); Found: C, 66.55; H, 9.86%. Calcd for $C_{15}H_{26}O_4$: C, 66.64; H, 9.69%.

(*E*)-3,3-Dimethyl-7-phenyl-2,4-dioxahept-6-ene. This compound was obtained by the following procedure. $PdCl_2(CH_3CN)_2$ (26 mg, 0.1 mmol) was added to a benzene solution (2 ml) of cinnamyl alcohol (134 mg, 1.0 mmol) and 2-propenyl methyl ether (0.7 g, 10 mmol) at room temperature under an argon atmosphere. The reaction mixture was stirred for 1 h and diluted with hexane and several drops of pyridine was added. Precipitated palladium species was filtered off and solvent was evaporated. Residual oil was purified by preparative thin-layer chromatography on silica gel to afford (*E*)-3,3-dimethyl-7-phenyl-2,4-dioxahept-6-ene (190 mg) in 95% yield: bp 83 °C/2 Torr; IR (neat) 2988, 2936, 1494, 1459, 1450, 1380, 1368, 1258, 1212, 1184, 1151, 1101, 1072, 1034, 965, 862, 824, 734, 690 cm^{-1}; ^1H NMR δ=1.41 (s, 6H), 3.25 (s, 3H), 4.13 (dd, J=5.8, 1.4 Hz, 2H), 6.30 (dt, J=15.9, 5.8 Hz, 1H), 6.63 (br.d, J=15.9 Hz, 1H), 7.2—7.5 (m, 5H); Found: C, 75.49; H, 8.79%. Calcd for $C_{13}H_{18}O_2$: C, 75.69; H, 8.80%.

The Reaction in the Presence of KOAc. Noncyclized acetal was major by-product in the reaction of allylic alcohol with vinyl ether mediated by $Pd(OAc)_2$. Though the by-product was hardly separable from the desired product, the formation of noncyclized acetal could be completely suppressed by an addition of base such as KOAc to the reaction mixture. Potassium acetate (98 mg, 1.0 mmol) was added to a benzene (2 ml) solution of cinnamyl alcohol (134 mg, 1.0 mmol) and 2-propenyl methyl ether (1.4 g, 19 mmol) and then $Pd(OAc)_2$ (450 mg, 2.0 mmol) was added to this suspension at room temperature under an argon atmosphere. The reaction mixture gradually turned black and was stirred for 15 h. The mixture was diluted with hexane and several drops of pyridine was added. Precipitated solid was filtered off and solvent was removed under reduced pressure. The residual oil was submitted to silica-gel column chromatography to afford 2-methyl-2-methoxy-4-phenyl-3,6-dihydro-2*H*-pyran (108 mg) in 53% yield along with 27% yield of cinnamaldehyde. (*E*)-3,3-Dimethyl-6-phenyl-2,4-dioxahex-5-ene, which was obtained in 27% yield in the experiment without KOAc, was not observed in this case. The rate of reaction was remarkably retarded and yield was usually slightly lower than that without base.

2-Ethoxy-4-isopropenyl-1-tosylpyrrolidine: Bp 135 °C/2 Torr; IR (neat) 2972, 2930, 1649, 1598, 1442, 1343, 1165 1110, 1085, 1064, 986, 897, 814, 707, 670 cm^{-1}; ^1H NMR δ=1.20 (t, J=7.1 Hz, 3H), 1.37 (dd, J=12.6, 5.2 Hz, 1H), 1.56 (s, 3H), 1.91 (dd, J=12.6, 5.8 Hz, 1H), 2.43 (s, 3H), 2.93 (dd, J=10.3,

9.0 Hz, 1H), 3.0—3.3 (m, 1H), 3.4—3.7 (m, 2H), 3.7—4.0 (m, 1H), 4.63 (br.s, 1H), 4.71 (br.s, 1H), 5.2—5.3 (m, 1H), 7.32 (d, J=8.1 Hz, 2H), 7.74 (d, J=8.1 Hz, 2H); Found: C, 62.07; H, 7.61; N, 4.39%. Calcd for $C_{16}H_{23}NO_3S$: C, 62.11; H, 7.49; N, 4.53%.

2-Butoxy-1-tosyl-4-vinylpyrrolidine (75:25 Mixture of Diastereomers): Bp 133 °C/2 Torr; IR (neat) 2956, 2930, 2868, 1644, 1598, 1458, 1347, 1164, 1082, 998, 921, 814, 708, 673 cm^{-1}; ^1H NMR δ=0.91 (t, J=7.2 Hz, 0.75H), 0.92 (t, J=7.2 Hz, 2.25H), 1.22 (dd, J=12.4, 5.0 Hz, 0.75H), 1.2—1.8 (m, 4.25H), 1.94 (dd, J=12.4, 5.9 Hz, 0.75H), 1.9—2.0 (m, 0.25H), 2.44 (s, 3H), 2.87 (dd, J=9.7, 9.6 Hz, 0.75H), 2.9—3.1 (m, 1H), 3.2—3.7 (m, 2.25H), 3.76 (dt, J=9.6, 6.6 Hz, 1H), 4.9—5.2 (m, 2H), 5.18 (d, J=5.0 Hz, 0.75H), 5.29 (dd, J=6.1, 2.7 Hz, 0.25H), 5.50 (ddd, J=17.1, 10.1, 7.4 Hz, 0.75H), 5.78 (ddd, J=17.5, 9.8, 8.1 Hz, 0.25H), 7.32 (d, J=8.4 Hz, 2H), 7.74 (d, J=8.4 Hz, 2H); Found: C, 63.33; H, 7.91; N, 4.30%. Calcd for $C_{17}H_{25}NO_3S$: C, 63.13; H, 7.79; N, 4.33%.

2-Butoxy-4-(5-methyl-1-methylene-4-hexenyl)-1-tosylpyrrolidine (70:30 Mixture of Diastereomers): Bp 174 °C/2 Torr; IR (neat) 2954, 2926, 2868, 1643, 1598, 1495, 1449, 1347, 1164, 1108, 1083, 1024, 990, 892, 815, 708, 670, 596 cm^{-1}; ^1H NMR δ=0.91 (t, J=7.1 Hz, 0.9H), 0.92 (t, J=7.1 Hz, 2.1H), 1.2—2.4 (m, 15.7H), 2.43 (s, 3H), 2.63 (t, J=7.1 Hz, 0.3H), 2.8—3.0 (m, 1H), 3.0—3.3 (m, 1H), 3.4—3.9 (m, 3H), 4.64 (br.s, 0.7H), 4.73 (br.s, 1H), 4.76 (br.s, 0.3H), 5.03 (br.t, J=6.8 Hz, 1H), 5.19 (d, J=4.8 Hz, 1H), 7.31 (d, J=8.4 Hz, 2H), 7.74 (d, J=8.4 Hz, 2H); Found: C, 68.25; H, 8.89; N, 3.36%. Calcd for $C_{23}H_{35}NO_3S$: C, 68.11; H, 8.70; N, 3.45%.

2-Ethoxy-4-phenyl-1-tosyl-1,2,3,6-tetrahydropyridine: Bp 180 °C/2 Torr; IR (neat) 2974, 2926, 1735, 1598, 1493, 1448, 1345, 1164, 1097, 1071, 1045, 1025, 1011, 912, 814, 759, 716, 666, 590 cm^{-1}; ^1H NMR δ=1.17 (t, J=7.0 Hz, 3H), 2.41 (s, 3H), 2.5—2.6 (m, 2H), 3.54 (dq, J=9.6, 7.0 Hz, 1H), 3.78 (dq, J=9.6, 7.0 Hz, 1H), 4.1—4.4 (m, 2H), 5.33 (dd, J=4.7, 1.5 Hz, 1H), 6.3-6.4 (m, 1H), 7.1—7.5 (m, 7H), 7.44 (d, J=8.3 Hz, 2H); Found: C, 67.44; H, 6.48; N, 3.85%. Calcd for $C_{20}H_{23}NO_3S$: C, 67.20; H, 6.49; N, 3.92%.

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