JOC*Note*

Palladium(II)-Catalyzed Isomerization of Olefins with Tributyltin Hydride†

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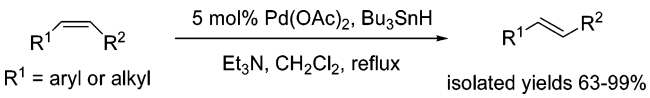
Received March 29, 2007



A new efficient method for the synthesis of geometrically pure (*E*)-alkenes from (*Z*)-alkenes is described. The reaction of aryl- or alkyl-substituted (*Z*)-alkenes with tributyltin hydride and triethylamine in the presence of a catalytic amount of palladium acetate afforded the corresponding (*E*)-alkenes in good yields.

Isomerization of a mixture of (*Z*)- and (*E*)-alkenes to geometrically pure (*E*)-isomer is one of the most important reactions in the preparation of carbon−carbon double bonds because, in some reactions, like Wittig reaction[1] and olefin metathesis,[2] a mixture of isomers is formed. Many isomerization reactions of alkenes have been developed during the past decade using radical,[3] photochemical,[4] or organometallic reagents,[5] but these reactions usually afford a mixture of olefin isomers showing double-bond migration. Recently, Yu et al. demonstrated a convenient means of preparing (*E*)-arylalkenes via the palladium(II)-catalyzed isomerization of (*Z*)-arylalkenes,[6] but this method was applied to specific alkenes, such as arylalkenes. Baag et al. developed an efficient isomerization of (*Z*)-alkene to give (*E*)-alkene using *N*-bromosuccinimide, dibenzoyl peroxide, and azobisisobutyronitrile.[7] The isomerization of (*Z*)-alkenes under these conditions afforded the corresponding (*E*)-alkenes in excellent yields, but undesirable brominated compounds were obtained from (*Z*)-alkenes possessing allylic hydrogens. Therefore, a general, mild, and facile method for the conversion of alkene mixtures or (*Z*)-alkenes to geometrically pure (*E*)-alkenes is still required. Herein, we describe a new efficient synthetic method for producing geometrically pure (*E*)-alkenes from (*Z*)-alkenes with allylic hydrogens and from conjugated (*Z*)-arylalkenes, using palladium acetate, tributyltin hydride, and triethylamine.

As a part of our ongoing research program aimed at developing polyhydroxylated alkaloids, we undertook the palladium(II)-catalyzed deprotection of the *N*-Cbz moiety in a mixture of (*Z*)- and (*E*)-cinnamyl compounds using $Pd(OAc)_2$, triethylsilane, and triethylamine under reflux in methylene chloride.[8] During this reaction, the deprotection of *N*-Cbz moiety and isomerization of the double bond in the cinnamyl moiety took place in a one-pot reaction. Presumably, this isomerization reaction proceeds via the palladium(II)-mediated addition and elimination of Et_3SiH.[9]

We considered that this reaction could be applied to the preparation of pure (*E*)-alkenes from (*Z*)-alkenes and from mixtures of (*Z*)- and (*E*)-alkenes. Thus, we examined the palladium-catalyzed isomerization of (*Z*)-alkene **1** using triethylsilane (Et_3SiH), triphenylgermanium hydride (PPh_3GeH),[10] or tributyltin hydride (Bu_3SnH) as hydrogen donors. Our results are summarized in Table 1.

As shown in entry 1, the reaction of (*Z*)-alkene **1** with triethylsilane afforded a mixture of **1** and **2** and a hydrogenated compound **3**. Also, treatment of **1** with triphenylgermanium hydride resulted in low conversion (14% yield) to the (*E*)-alkene **2** (entry 2). Fortunately, isomerization of **1** with tributyltin hydride in the presence of 5 mol % of palladium(II) acetate was significantly accelerated (as compared with Et_3SiH and PPh_3GeH) to give (*E*)-alkene **2** (entry3). However, the reaction of **1** with Bu_3SnH or Et_3SiH in the presence of 5 mol % $PdCl_2$ for 48 h provided the isomerization product **2** in 51% or 42% yields, as shown in entries 4 and 5.

On the basis of the above results, we planned to investigate the palladium-catalyzed isomerization of several types of alkenes containing various functional groups. Results are summarized in Table 2.

These results indicate that the nature of alkene substituents controls the reaction outcome. As was expected, the stabilization of the carbocation offered by the phenyl group facilitated the isomerization reaction (entries 1−4). The nonconjugated alkenes, *cis*-decene **7a** and the allyl ether **8a**, were isomerized to the corresponding *trans*-olefins **7b** and **8b** in high yield, but the rate of reaction was slower than for conjugated alkenes. Dimethyl maleate **9a**, which possesses an electron-withdrawing group ($COOCH_3$), was converted to dimethyl fumarate **9b**, although this required an extended reaction time (48 h) to achieve a conversion of 66%. Furthermore, the isomerization of allyl alcohol **10a** afforded two different products, (*E*)-allyl alcohol **10b** (65%) and a terminal olefin (22%), in which the hydroxyl group was eliminated. Also, allyl acetate **11a** underwent the isomerization to give (*E*)-allyl alcohol **11b** (63%) and eliminated olefins, an inseparable mixture of (*E*)-internal alkene (10%) and terminal olefin (5%).

† This paper is dedicated to Professor Michael E. Jung on the occasion of his 60th birthday.

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(1) For a review of Wittig reaction, see: Maryanoff, B. E.; Reitz, A. B. *Chem. Rev.* **1989**, *89*, 863.

(2) For a review of olefin metathesis, see: Grubbs, R. H. *Tetrahedron* **2004**, *60*, 7117.

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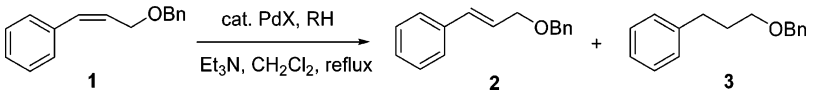
(9) (a) Chatgilialoglu, C. *Chem. Rev.* **1995**, *95*, 1229. (b) Mirza-Aghayan, M.; Boukherroub, R.; Bolourtchian, M.; Hoseini, M.; Tabar-Hydar, K. *J. Organomet. Chem.* **2003**, *678*, 1.

(10) For references on the isomerization of olefin using PPh_3GeH, see: (a) Nozaki, K.; Ichinose, Y.; Wakamatsu, K.; Oshima, K.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1990**, *63*, 2268. (b) Ichinose, Y.; Nozaki, K.; Wakamatsu, K.; Oshima, K.; Utimoto, K. *Tetrahedron Lett.* **1987**, *28*, 3709.

10.1021/jo0705263 CCC: $37.00
Published on Web 06/07/2007

TABLE 1. Reaction Conditions[a] and Product Ratios[b] for the Reaction between (*Z*)-Olefin 1 and Metal Hydride (MH) in the Presence of PdX

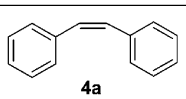
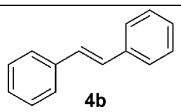
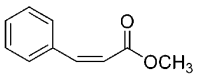
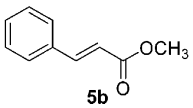
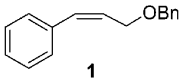
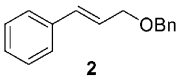
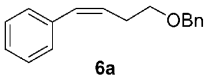
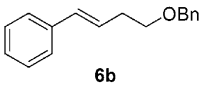
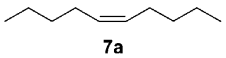
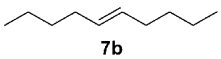
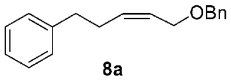
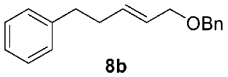
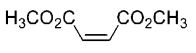
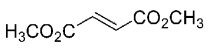
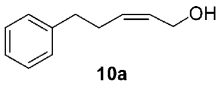
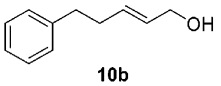
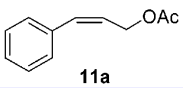
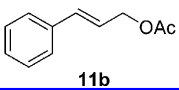


1 2 3

	reaction condition[a]			product ratio[b] (%)		
entry	PdX	MH	time (h)	**1**	**2**	**3**
1	$Pd(OAc)_2$	Et_3SiH	36	25	56	17
2	$Pd(OAc)_2$	PPh_3GeH	48	82	14	0
3	$Pd(OAc)_2$	Bu_3SnH	14	5	91	0
4	$PdCl_2$	Bu_3SnH	48	34	51	0
5	$PdCl_2$	Et_3SiH	48	23	42	28

[a] All reactions were carried out using PdX (5 mol %), RH (2.2 equiv), or Et_3N (0.16 equiv) in CH_2Cl_2 under reflux. [b] Product ratios were calculated from ^1H NMR spectra of isolated materials.

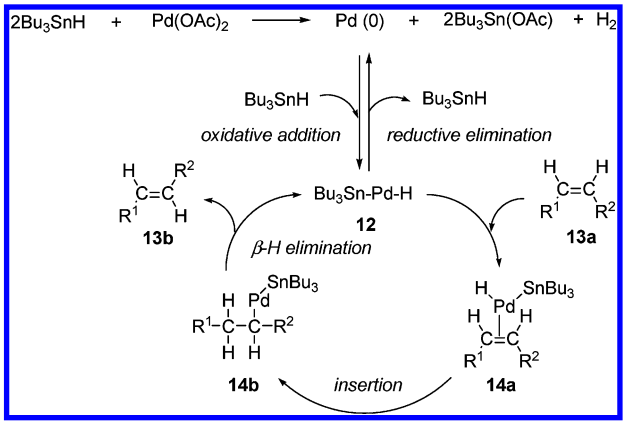
TABLE 2. Palladium(II)-Catalyzed Isomerization of Various (*Z*)-Alkenes with Bu_3SnH[a]

entry	substrate	product	time (h)	yield[b] (%)
1	 **4a**	 **4b**	3	99
2	 **5a**	 **5b**	8	98
3	 **1**	 **2**	16	95
4	 **6a**	 **6b**	18	99
5	 **7a**	 **7b**	36	75 (13)[c]
6	 **8a**	 **8b**	36	74 (21)[c]
7	 **9a**	 **9b**	48	66 (13)[c]
8	 **10a**	 **10b**	18	65
9	 **11a**	 **11b**	18	63

[a] All reactions were carried out using $Pd(OAc)_2$ (5 mol %), Bu_3SnH (2.2 equiv), and Et_3N (0.16 equiv) in CH_2Cl_2 under reflux. [b] Isolated yields of pure materials. [c] Recovery yields of starting materials.

A proposed reaction pathway for the formation of (*E*)-olefins is shown in Scheme 1. At the initial stage of the reaction, metallic Pd (0) would be generated by the reduction of palladium(II) acetate by tributyltin hydride. We assume that the Pd (0) thus formed serves as an active catalyst for the isomerization reaction. During the second stage, the oxidative addition of Bu_3SnH to Pd (0) affords the palladium−tin complex **12**, which undergoes insertion to generate **14b**. The β-H elimination of **14b** gives the thermodynamically stable (*E*)-olefin **13b** and $Bu_3Sn-Pd-H$ **12**, which regenerates Pd (0). Palladium hydride **12** also serves as a catalytic species through insertion into (*Z*)-alkene **13a**.

SCHEME 1. Proposed Mechanism of Palladium-Catalyzed Isomerization of (*Z*)-Alkenes in the Presence of Tributyltin Hydride



Summarizing, it was found that isomerization of (*Z*)-olefin compounds proceeded smoothly in the presence of palladium(II) acetate and tributyltin hydride to give (*E*)-olefin compounds in good yields. The described isomerization reaction provides a powerful method of preparing pure (*E*)-olefin compounds.

Experimental Section

General Methods. Commercially available reagents were used without additional purification, unless otherwise stated. All anhydrous solvents were distilled over CaH_2 or P_2O_5 or Na/benzophenone prior to reaction. All reactions were performed under an inert atmosphere of nitrogen or argon. Nuclear magnetic resonance spectra (^{1}H and ^{13}C NMR) were recorded on 300 and 500 MHz spectrometers for $CDCl_3$ solutions, and chemical shifts are reported as parts per million (ppm) relative to, respectively, residual $CHCl_3$ δ_H (7.26 ppm) and $CDCl_3$ δ_C (77.0 ppm) as internal standards. Resonance patterns are reported with the notations s (singlet), d (doublet), t (triplet), q (quartet), and m (multiplet). In addition, the notation br is used to indicate a broad signal. Coupling constants (*J*) are reported in hertz (Hz).

General Procedure for the Isomerization of (*Z*)-Alkenes to (*E*)-Alkenes. To a stirred solution of (*Z*)-alkene (1 mmol) in anhydrous CH_2Cl_2 (3.3 mL) was added Bu_3SnH (2.2 mmol), $Pd(OAc)_2$ (0.05 mmol), and triethylamine (0.16 mmol) at room temperature under N_2, and the reaction mixture was heated at reflux for the reaction time. The mixture was cooled in an ice bath and then was filtered through a Celite pad and was carefully concentrated in vacuo. The residue was purified by silica gel column chromatography or distillation to afford corresponding (*E*)-alkene.

(*E*)-3-Benzyloxy-1-phenylprop-1-ene (2). R_f = 0.27 (hexane/EtOAc 30:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.26 (d, 2H, J = 6.3 Hz), 4.64 (s, 2H), 6.39 (dt, 1H, J = 15.9, 6.3 Hz), 6.70 (d, 1H, J = 15.9 Hz), 7.30−7.48 (m, 10H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 71.58, 72.97, 126.91, 127.33, 128.48, 128.51, 128.63, 129.39, 133.29, 137.54, 139.12. ^{1}H NMR and ^{13}C NMR spectra were consistent with literature values reported in *Arch. Pharm. Res.* **2001**, *24*, 371.

(*E*)-Stilbene (4b). R_f = 0.32 (hexane/EtOAc 50:1); mp 112∼113 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.29−7.60 (m, 12H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 126.78, 127.87, 128.94, 128.99, 137.62. ^{1}H NMR and ^{13}C NMR spectra were identical to an authentic sample.

(*E*)-4-Bromo-1-phenylbut-1-ene (5b). R_f = 0.24 (hexane/EtOAc 20:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.84 (s, 3H), 6.48 (d, 1H, J = 15.9 Hz), 7.39−7.45 (m, 3H), 7.53−7.58 (m, 2H), 7.74 (d, 1H, J = 15.9 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 51.85, 118.08, 128.30, 129.11, 130.50, 134.65, 145.06, 167.58. ^{1}H NMR and ^{13}C NMR spectra were identical to an authentic sample.

(*E*)-4-Benzyloxy-1-phenylbut-1-ene (6b). R_f = 0.27 (hexane/EtOAc 30:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.59 (dt, 2H, J = 6.9, 6.6 Hz), 3.65 (t, 2H, J = 6.6 Hz), 4.60 (s, 2H), 6.30 (dt, 1H, J = 15.9, 6.9 Hz), 6.52 (d, 1H, J = 15.9 Hz), 7.22−7.43 (m, 10H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 33.78, 70.10, 73.24, 126.29, 127.28, 127.29, 127.83, 127.94, 128.03, 128.64, 128.72, 131.88, 137.87, 138.73.

(*E*)-5-Decene (7b). bp 170∼173 °C (13 Torr, 61 °C); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.88−0.98 (m, 6H), 1.28−1.44 (m, 8H), 1.97−2.12 (m, 4H), 5.40−5.46 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.16, 22.42, 32.08, 32.50, 130.54. ^{1}H NMR and ^{13}C NMR spectra were identical to an authentic sample.

(*E*)-1-Benzyloxy-5-phenylpent-2-ene (8b). R_f = 0.25 (hexane/EtOAc 3:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.44 (dt, 2H, J = 7.5, 6.3 Hz), 2.78 (t, 2H, J = 7.5 Hz), 4.03 (d, 2H, J = 6.0 Hz), 4.52 (s, 2H), 5.69−5.81 (m, 2H), 7.23−7.44 (m, 10H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 34.32, 35.76, 71.05, 72.11, 126.10, 127.26, 127.78, 128.03, 128.58, 128.60, 128.66, 128.68, 134.00, 138.72, 142.01.

(*E*)-Dimethyl fumarate (9b). R_f = 0.34 (hexane/EtOAc 6:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.82 (s, 6H), 6.87 (s, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 52.42, 133.56, 165.50. ^{1}H NMR and ^{13}C NMR spectra were identical to an authentic sample.

(*E*)-5-Phenylpent-2-en-1-ol (10b). R_f = 0.27 (hexane/EtOAc 3:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.34−1.38 (br, 1H), 2.42 (dt, 2H, J = 7.5, 6.0 Hz), 2.75 (t, 2H, J = 7.5 Hz), 4.13 (d, 2H, J = 6.6 Hz), 5.66−5.84 (m, 2H), 7.20−7.37 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 34.18, 35.78, 63.91, 126.12, 128.56, 128.66, 129.87, 132.47, 141.93.

(*E*)-3-Phenylprop-2-enyl acetate (11b). R_f = 0.26 (hexane/EtOAc 20:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.15 (s, 3H), 4.78 (dd, 2H, J = 6.3, 1.2 Hz), 6.34 (dt, 1H, J = 15.9, 6.3 Hz), 6.70 (d, 1H, J = 15.9 Hz), 7.30−7.47 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.22, 65.29, 123.45, 126.85, 128.31, 128.84, 134.45, 136.48, 171.03.

Acknowledgment. This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2006-311-E00613) and by the Brain Korea 21 program.

Supporting Information Available: Experimental procedures and characterization data for all compounds are provided. This material is available free of charge via the Internet at http://pubs.acs.org.

JO0705263