Enantioselecitve Elimination of Pd–H from η^3-Allylpalladium–Tol BINAP Complexes. Evidence of Syn Elimination Pathway

Ryohei Ogawa, Yusuke Shigemori, Koichi Uehara, Jiro Sano, Takayuki Nakajima, and Isao Shimizu*
Department of Applied Chemistry, School of Science and Engineering, Waseda University, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555

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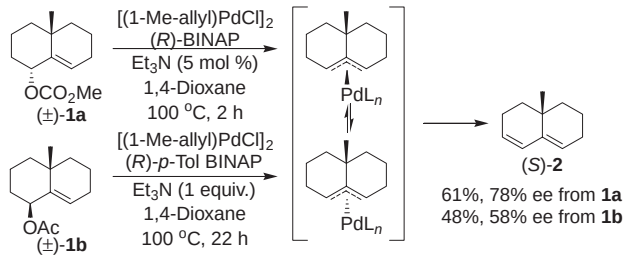
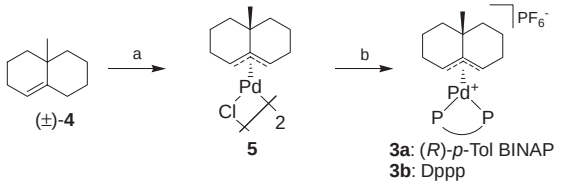
The palladium-catalyzed elimination of the bicyclic *cis*-acetate **1b** using Pd catalyst and (*R*)-*p*-Tol BINAP gave the (*S*)-diene **2** with 58% ee. Bicyclic η^3-allylpalladium complex **3a** with (*R*)-*p*-Tol BINAP, considered as an intermediate in the catalytic reaction from **1b**, was prepared. Enantioselectivity in decomposition of **3a** is dependent on the reaction conditions. The thermal decomposition of **3a** without base gave the (*S*)-**2** with 70% ee. However, the decomposition of **3a** in the presence of excess base gave (*R*)-**2** with 58% ee. Syn elimination from **3a** was found to proceed preferentially from the decomposition results of the deuterium-labeled complexes.

Asymmetric allylic alkylation catalyzed by palladium complexes bearing chiral ligands is a useful synthetic method. The direction of nucleophilic attack caused by the desymmerrization of allylic moiety by the coordination of chiral ligands is explained.[1] Although numerous studies of the palladium-catalyzed allylic alkylation have appeared, enantioselective elimination from allylic compounds to optically active 1,3-dienes has scarcely been explored.[2] Several years ago, we reported that the reaction of bicyclic *trans*-allylic carbonate **1a** in the presence of catalytic amounts of [(1-Me-allyl)PdCl]$_2$ and (*R*)-BINAP gave the bicyclic diene (*S*)-**2** with 86% ee (Scheme 1).[3] In our continuous studies, the catalytic reaction was carried out using **1b** under similar conditions as **1a** to give the same S isomer **2** in 58% ee. The same stereochemical outcome from the opposite configuration of starting allylic substrates suggests that equilibration of η^3-allylpalladium intermediate proceeded prior to the elimination as shown in Scheme 1. In order to elucidate the intermediate of the enantioselective elimination reactions, we have prepared {Pd(η^3-$C_{11}H_{17}$)[(*R*)-*p*-Tol BINAP]}PF_6 complex **3a**, and decomposition reaction of **3a** was investigated to gain insight into precise mechanisms of the elimination reactions.

At first the bicyclic η^3-allylpalladium complexes, which correspond to the *trans*-η^3-allylpalladium intermediate obtained directly from **1b**, were prepared. Treatment of the complex **5**[4] with the diphosphine ligands, (*R*)-*p*-Tol BINAP or Dppp, and

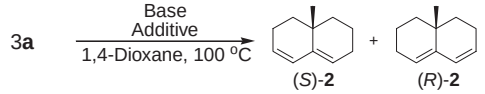


Scheme 1. Palladium-catalyzed enantioselective elimination of bicyclic allylic compounds **1a** and **1b**.[3]



Scheme 2. Synthesis of [Pd(η^3-$C_{11}H_{17}$)(diphosphine)]PF_6. Reagents and conditions: (a) $PdCl_2(PhCN)_2$, $CHCl_3$, reflux, 23% (b) diphosphine, $AgPF_6$, CH_2Cl_2, 73% (for **3a**), 80% (for **3b**).

Table 1. Thermal decomposition of complex **3a**[5]



Entry	Base /equiv.	Additive /equiv.	Time /h	Yield/%[a]	ee/%[b]
1			4	79	18 (*S*)
2		LiCl (10)	0.4	85	70 (*S*)
3	Et_3N (1)		6	76	8 (*R*)
4	Et_3N (10)		1	92	58 (*R*)
5	Et_3N (10)	LiCl (10)	18	58	8 (*S*)

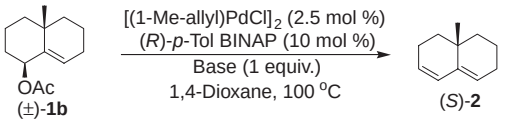
[a]Isolated yield. [b]Enantiomeric excess was determined by GLC using a chiral column.

$AgPF_6$ in CH_2Cl_2 at room temperature to give **3a** (73% yield) or **3b** (80% yield), respectively, after recrystallization from a mixture of hexane–CH_2Cl_2 (Scheme 2). The NMR spectrum of **3a** shows unsymmetrical feature of the allylic moiety in the complex **3a**, although that of the complex **3b** with achiral phosphine has C_S symmetrical structure.[6]

The decomposition of **3a** was carried out under various conditions. As shown in Table 1, the enantioselection and enantioselectivity were dependent on the reaction conditions. The thermal decomposition of **3a** at 100 °C in 1,4-dioxane without a base and an additive gave the (*S*)-diene **2** in 79% yield with low enantioselectivity (18% ee). When LiCl was added, the elimination proceeded with high enantioselectivity to give (*S*)-**2** (70% ee, 85% yield). Interestingly when one equivalent of Et_3N was added, the opposite enantiomer (*R*)-**2** was obtained but low enantioselectivity (8% ee). Furthermore, when excess Et_3N (10 equiv.) was used, the decomposition proceeded smoothly to give (*R*)-**2** with considerable enantioselectivity (58% ee, 92% yield). Although **3a** was one of plausible intermediates from **1b**, the stereochemical results of the decomposition of **3a** using Et_3N were not in accordance with the enantioselection for (*S*)-**2** in the catalytic reaction starting with **1b**.

Takacs and co-workers reported the palladium-catalyzed elimination of allylic compounds proceeded via specific base-

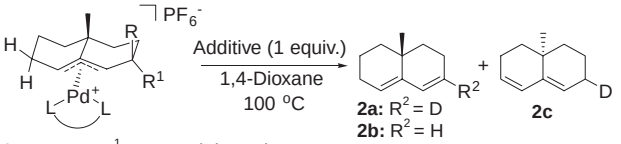
Table 2. Catalytic elimination reaction of (±)-**1b**[5]



Entry	Base	Time/h	Yield/%[a]	% ee[b]
1		6	27	89
2	K_2CO_3	4	77	31
3	Et_3N	22	48	58
4[c]	Et_3N	4	91	78

[a]Isolated yield. [b]Enantiomeric excess was determined by GLC using a chiral column. [c]An equivalent of LiCl was added.

Table 3. Decomposition of complexes **3aa**, **3ab**, and **3ac**



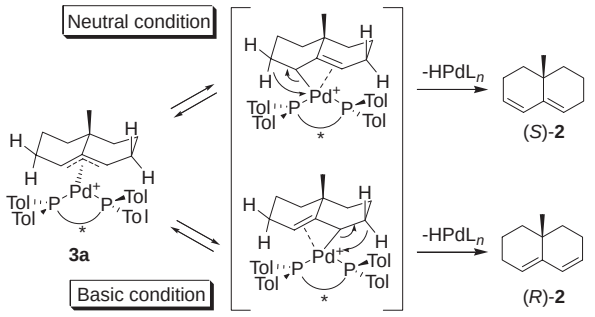
3aa: R = H, R^1 = D, L = (*R*)-*p*-Tol BINAP
3ab: R = D, R^1 = H, L = (*R*)-*p*-Tol BINAP
3ac: R = D, R^1 = H, L = (*S*)-*p*-Tol BINAP

Entry	Substrate	Additive	Time/h	Yield/%[a]	**2a**/**2b**/**2c**[b]
1	**3aa**	Et_3N	1	68	10:48:42
2	**3ab**	Et_3N	1	60	48:10:42
3	**3ac**	LiCl	0.5	99	61:8:31

[a]Isolated yield. [b]The ratio of **2a**:**2b**:**2c** was caluculated by ^{1}H NMR spectra and GLC using a chiral column.

promoted anti elimination of Pd–H from the η^3-allylpalladium intermediate.[7] However, stereochemical studies using characterized η^3-allylpalladium complexes relevant to the catalytic reaction have not been reported. We carried out the elimination of **1b** using 1:4 [(1-Me-allyl)PdCl]$_2$:(*R*)-*p*-Tol BINAP catalyst, and (*S*)-**2** was obtained mainly in all cases (Table 2). The reaction was very slow without a base, however, high enantioselectivity was obtained (Entry 1; 89% ee). When the reaction was carried out adding K_2CO_3, the reaction proceeded smoothly, however, the enantioselectivity decreased (31% ee, 77% yield). When Et_3N was used instead of K_2CO_3, the yield of **2** decreased, but the enantioselectivity increased (58% ee, 48% yield). Furthermore when LiCl was added, the reaction proceeded smoothly to give (*S*)-**2** with high enantioselectivity (78% ee, 91% yield).[8] It is noteworthy that the (*S*) isomer formed as a major product in each catalytic reaction of **1b**, evenwhen Et_3N was used, whereas (*R*)-**2** was obtained in the decomposition of **3a** (Entry 4 in Table 1).

In order to elicit direct evidence for the involvement whether syn or anti elimination of Pd–H occurs from the η^3-allylpalladium intermediates, we prepared the deuterium-labeled η^3-allylpalladium complexes with (*R*)- or (*S*)-*p*-Tol BINAP, **3aa**, **3ab**, and **3ac**, from the 2α or 2β duterio-1-octalin, (*R*)-2α-*d*-**4a** and (*R*)-2β-*d*-**4b**. Decomposition of **3aa** was carried out under similar conditions as shown in Table 3.[9] The ratio of **2a**:**2b** was 10:48, which indicates that the syn H(D) to palladium atom was picked up preferentially. The elimination was also examined with **3ab**, and the same syn:anti elimination ratio was observed.[10] These results indicated that the isotope effects were



Scheme 3. The relationship between the direction and reaction conitions in the elimination of Pd–H from **3a** to (*S*)- or (*R*)-**2**.

considered to be very small, which is in accordance with small kinetic isotopic effects in β-hydride elimination.[11] Furthermore, when the reaction of **3ac** was carried out with LiCl, syn elimination proceeded predominantly. In the reaction under conditions in Table 3, syn elimination is preferential from the η^3-allylpalladium complexes, although the catalytic reaction is known to proceed with anti elimination.

In conclusion, the palladium-catalyzed elimination reaction of **1b** was carried out smoothly with Et_3N and LiCl to give (*S*)-**2** with high enantiomeric excess. Enantioselection in decomposition of η^3-allylpalladium complexes **3a** with Et_3N was opposed to that without the base. The decomposition of **3a** took place in syn elimination pathway with or without a base (Scheme 3).

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References and Notes

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9 The ratios of **2a**:**2b**:**2c** were calculated by ^{1}H NMR spectra and GLC using a chiral column.
10 The large deuterium effect in anti elimination is described in Ref. 6a.
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