Communications to the Editor

An Unusual, Selective η^3–η^1 Allyl Isomerization in a Chiral Allylic Alkylation Catalyst

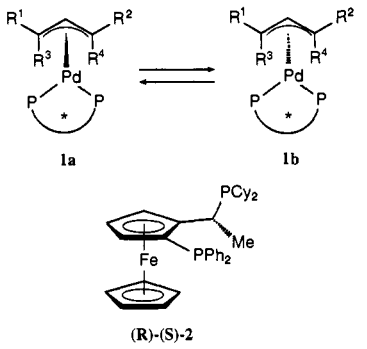
Claude Breutel, Paul S. Pregosin,* Renzo Salzmann, and Antonio Togni*

Laboratory of Inorganic Chemistry
Swiss Federal Institute of Technology
ETH-Zentrum, CH-8092 Zürich, Switzerland

Received December 14, 1993

Homogeneous catalytic allylic alkylation using palladium complexes is a well-understood reaction with potential synthetic applications.[1] When chiral ligands are employed, the organic products can display relatively high enantiomeric excesses.[2] The use of chelating phosphines as the source of the chirality leads to diastereomeric allylic intermediates such as **1** (see Scheme 1 below). The observed enantiomeric excess depends upon which

Scheme 1



terminal carbon (and/or which allyl face) is attacked by the incoming nucleophile.[3] There are several possible mechanisms for interconversion of these allylic diastereomeric complexes, the most common one involving η^3–η^1 allyl isomerization, followed by recoordination of the olefin via its other face.[4]

We report here the first example of interconversion of two diastereomeric η^3-allyl (C_3H_5) complexes, which contain the new ligand **2**,[5] via a *selective* η^3–η^1 allyl isomerization in which only one of the two possible terminal CH_2 allyl carbons is σ-bonded.

The complex $[Pd(\eta^3\text{-}C_3H_5)(\mathbf{2})](CF_3SO_3)$ (**3**) was readily prepared[6] and is an excellent catalyst for the standard allylic alkylation reaction of 1,3-diphenyl-1-acetoxypropene with dimethyl malonate.[7] The corresponding alkylation product is obtained in 93% ee.[5]

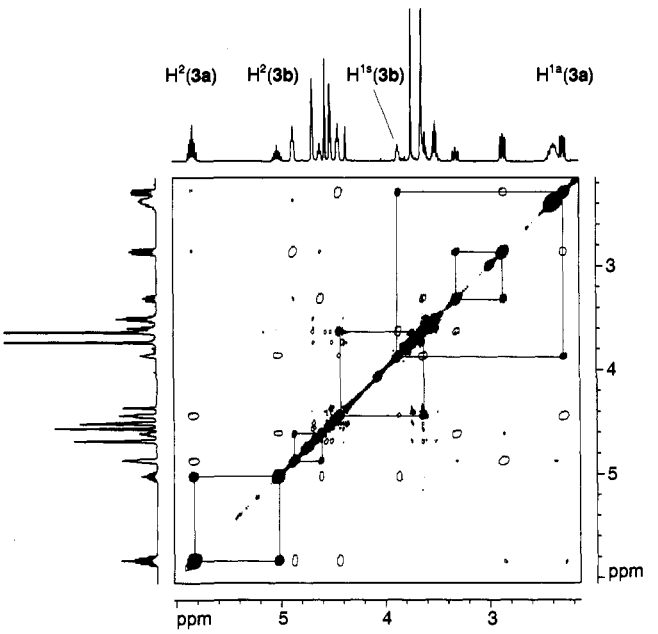


Figure 1. Section of the 2-D NOESY spectrum (500 MHz, $CDCl_3$) showing NOE (○) and exchange (●) cross-peaks. The five most important exchange cross-peaks are indicated with solid lines.

The ^{31}P NMR spectrum of **3** reveals two AX spin systems, in the approximate ratio 2:1. These signals arise due to the presence of **3a** and **3b**, the two diastereomers which differ with respect to the position of the central allyl hydrogen H^2 relative to the η^5-C_5H_5 ring. In **3a**, the C(2)-H^2 vector points "down", toward the η^5-C_5H_5 ligand, whereas in **3b** this vector points "up", away from the Cp ring.[8] The phase-sensitive 2-D ^1H NOESY spectrum for **3** (see Figure 1) shows a sufficient number of interligand NOEs to allow the two structures to be correctly assigned, with **3a** predominating.[8] Note that the H^1 protons (C(1)) are trans to the PCy_2 fragment and the H^3 protons (C(3)) are trans to the PPh_2 donor (see Scheme 2). In addition to the negative NOE cross-peaks which arise from cross-relaxation, one finds a series of positive cross-peaks, connecting **3a** and **3b**, thereby indicating that these two isomers are in equilibrium.[9] Close examination of the allyl proton-exchange cross-peaks indicates that the exchange is very selective, as shown at the bottom of Scheme 2. These observations can be accommodated only via a selective

(1) See, e.g.: Trost, B. M.; Verhoeven, T. R. In *Comprehensive Organometallic Chemistry*; Wilkinson, G. Stone, F. G. A., Abel, E. W., Eds.; Pergamon Press: Oxford, 1982; Vol. 8, pp 799–938.

(2) For a arecent review, see: (a) Hayashi, T. In *Catalytic Asymmetric Synthesis*; Ojima, I., Ed.; VCH Publishers: New York, 1993; pp 325–365 and references cited therein. For recent reports, see, e.g.: (b) von Matt, P.; Pfaltz, A. *Angew. Chem., Int. Ed. Engl.* **1993**, *32*, 566–568. (c) Trost, B. M.; Van Vranken, D. L.; Bingel, C. *J. Am. Chem. Soc.* **1992**, *114*, 9327–9343. (d) Togni, A. *Tetrahedron: Asymmetry* **1991**, *2*, 683–690.

(3) Consiglio, G.; Waymouth, R. M. *Chem. Rev.* **1989**, *89*, 257–276.

(4) The interconversion of diastereometric π-allyl complexes such as **1** can occur via an η^3–η^1–η^3 mechanism provided that $R^1 = R^3$ or $R^2 = R^4$ (see ref. 3).

(5) Togni, A.; Breutel, C.; Schnyder, A.; Spindler, F.; Landert, H.; Tijani, A. *J. Am. Chem. Soc.* preceding paper in this issue.

(6) Complex **3** was prepared as follows: 300 mg (0.5 mmol) of ligand (*R*)-(*S*)-**2** and 92 mg (0.25 mmol) of $[Pd_2(\eta^3\text{-}C_3H_5)_2Cl_2]$ were dissolved in 10 mL of CH_2Cl_2, and 126 mg (0.5 mmol) of silver triflate, dissolved in 1.5 mL of methanol, was added. The mixture was stirred for 1 h in the dark, filtered on a plug of Celite, and then evaporated to dryness, leaving a red, gummy residue. This was triturated successively with diethyl ether and hexane, affording an orange solid which was recrystallized from a concentrated CH_2Cl_2 solution, layered with hexane. Yield: 464 mg (90%); $[\alpha]^{22}_D = -217$ (*c* = 0.2, CH_2Cl_2); mp 120 °C dec. Anal. Calcd for $C_{40}H_{49}F_3FeP_2PdO_3S$: C, 53,92; H, 5.54. Found: C, 53,75; H, 5.74. For NMR data, see ref 8.

(7) The allylic alkylation reactions were carried out under the conditions reported by Pfaltz (ref 2b).

(8) Selected NMR parameters for **3a**: ^1H NMR (500 MHz, $CDCl_3$) δ 2.29 (H^{1a}), 2.86 (H^{3a}), 4.37 (H^{1s}), 4.87 (H^{3s}), 5.84 (H^2); ^{13}C NMR (125.721 MHz, CDCl3) δ 66.9 (C(3)), 76.3 (C(1)), 121.9 (C(2)); ^{31}P NMR (202.404 MHz, $CDCl_3$) δ 13.5 (PPh_2, $^2J(P,P) = 51$), 58.5 (PCy_2). Selected NMR parameters for **3b**: ^1H NMR (500 MHz, $CDCl_3$) δ 3.31 (H^{3a}), 3.63 (H^{1a}), 3.85 (H^{1s}), 4.61 (H^{3s}), 5.04 (H^2); ^{13}C NMR (125.721 MHz, $CDCl_3$) δ 65.6 (C(3)), 78.2 (C(1)), 120.7 (C(2)); ^{31}P NMR (202.404 MHz, $CDCl_3$) δ 13.6 (PPH_2, $^2J(P,P) = 50$), 58.2 (PCy_2). The NOESY spectrum was measured twice with mixing times of 0.8 and 1.0 s. The η^5-C_5H_5 ligand shows a strong NOE to one set of ortho protons of one of the PPh_2 phenyl groups, and these ortho protons show selective NOEs to either the allyl proton H^2 when it is "down" (**3a**, see Scheme 2) or the anti allyl protons H^{1a} when it is "up" (**3b**).

(9) Hull, W. E. In *Two-Dimensional NMR Spectroscopy. Applications for Chemists and Biochemists; Methods in Stereochemical Analysis*; Croasmun, W. R., Carlson, R. M. K., Eds; VCH: New York 1987; Vol. 9, pp 67–231

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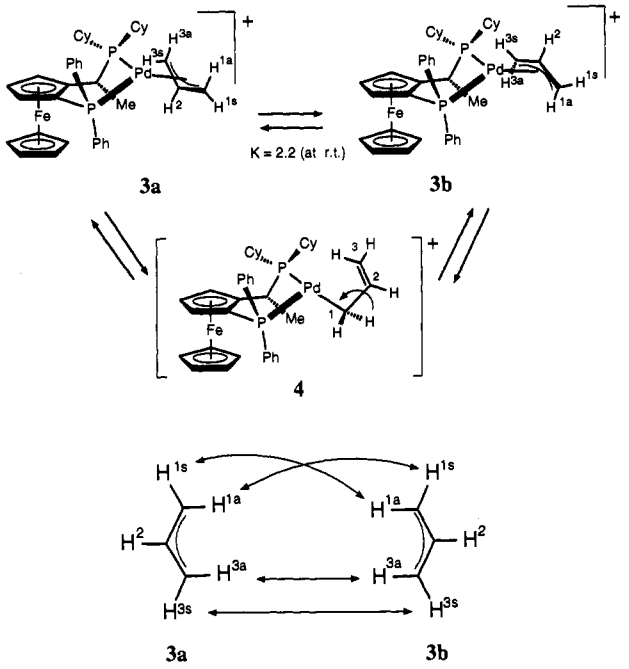
Scheme 2



η^3–η^1 isomerization in which *only C(1) becomes the* σ*-carbon.* An η^3–η^1 isomerization involving C(3) as the σ-carbon would result in a syn/anti equilibrium between H^{3a} (anti) of isomer **3a** and H^{3s} (syn) of isomer **3b**, and this is not observed. Moreover, a simple rotation of the allyl ligand around the Pd–allyl axis can also be excluded since this would not explain the syn/anti exchange found at C(1). Consequently, we conclude that the diastereomers exchange by an η^3–η^1 movement, followed by rotation around the sp^3–sp^2 bond (C(1)–C(2)) and finally coordination of the olefin. To the best of our knowledge, this is the first example of such a selective η^3–η^1 isomerization in a chiral π-allyl complex.

To support the NOESY result, we carried out a series of selective inversion experiments at 323 K.[10] One allyl proton of a single diastereomer was inverted with a 180° pulse, and its recovery, as well as the recovery of its exchanging partner, was followed as a function of time, e.g., H^{3a} in **3a** irradiated, with H^{3a} in both the major and the minor isomers monitored (see Figure 2). The experiment was then repeated with H^{3a} in **3b** inverted. This was done for several pairs of protons so that, apart from confirming the selective exchange, one can now put values on the forward and backward rates.[10]

The driving force for the selective formation of a C(1) σ-bond is not yet clear; however, it is tempting to believe that the steric differences between the PCy_2 and PPh_2 groups would favor an

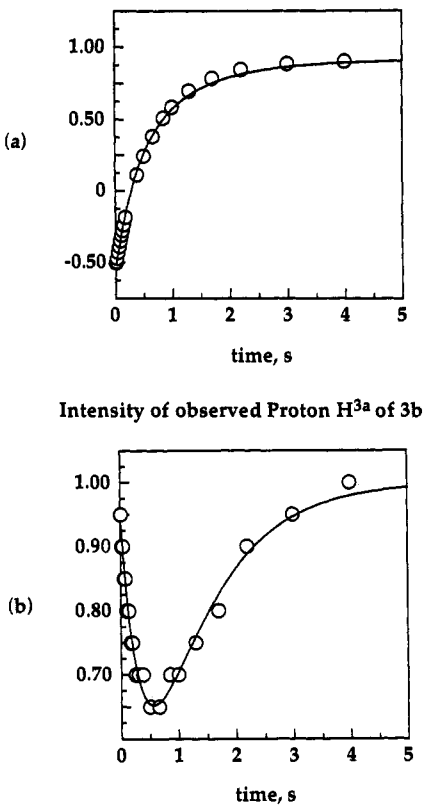


Figure 2. Results from the selective inversion of one allyl proton, H^{3a}. (a) Recovery of H^{3a} in **3a**, after a 180° pulse on H^{3a}. (b) Recovery of H^{3a} in the minor isomer (**3b**) after a 180° pulse on H^{3a} in the major isomer. The minimum in b is a consequence of the exchange (500 MHz, $CDCl_3$, 323 K).

η^1 isomer with Pd–C(1) σ-bond as opposed to an η^1 isomer with a Pd–C(3) σ-bond. Based on electronic effects, one might have expected the σ-bond to form to C(3), since the PCy_2 donor should have a stronger trans influence, thus weakening the bond trans to it.[11] Indeed, ^{13}C considerations support a stronger trans influence for the cyclohexylphosphine donor.[8]

In order to understand the origin of the observed site selectivity of the η^3–η^1–η^3 equilibrium in complexes of type **3**, it would be interesting to study related molecules with different substituents on the phosphorus atoms, i.e., with phosphine donors displaying different electronic properties. Furthermore, does the selective allyl isomerization correlate with the site of nucleophilic attack during the catalytic allylic alkylation? Experiments addressing these aspects are in preparation and will be reported in due course.

(10) This can be done using a long, selective 180° pulse. For the forward reaction $k_1 = 0.080\ s^{-1}$, and for the back reaction, $k_{-1} = 0.032\ s^{-1}$. We estimate these values to be good to ±5%.

(11) Generally speaking, trialkylphosphines show stronger trans influence than triarylphosphines. See, e.g.: Appleton, T. G.; Clark, H. C.; Manzer, L. E. *Coord. Chem. Rev.* **1973**, *10*, 335–422.