Evidence for Reversible Aminopalladation of Olefins

JAN-E. BÄCKVALL and
EVA E. BJÖRKMAN

Department of Organic Chemistry,
Royal Institute of Technology,
S-100 44 Stockholm, Sweden

Nucleophilic addition to alkenes coordinated to a transition metal has become an important type of reaction in organic chemistry.[1,2] Through these reactions one may obtain a variety of different functionalizations of carbon–carbon double bonds. In the oxyamination reaction[3] a double bond is converted to an amino-alcohol derivative *via* a palladium(II)-promoted nucleophilic addition of amine to the olefin followed by an oxidative cleavage[2,4] of the palladium-carbon bond (eqn. 1).

During our studies on the oxyamination reaction[3] we observed that the regiochemistry for the addition to non-symmetrical olefins depends on the reaction conditions, and in particular on the reaction time for amination before trapping the σ-complex by the oxidant.

Results and discussion. Oxyamination of allyl phenyl ether (*1*) in THF with diethylamine, following the general procedure,[3a, 3b] gives the aminoacetate *2* as the only regioisomer. The presence of *N,N*-dimethyl-α-phenethylamine (*4*) as ligand did not change the regiochemical result.[3c]

However, at very short reaction times for the amination step, a considerable amount of the other regioisomer *3* was formed when *4* was used as ligand. The results for the oxyamination of *1* at different amination times are given in Table 1. As

Table 1. Oxyamination of *1* in the presence of ligand *4*.

Reaction time of amination step (min)	Product distribution[a] *2:3*	Yield (%)[b] (*2+3*)
1	10:9.5	39
10	10:1.4	41
30	10:–	38

[a] Determined by ^{1}H NMR spectroscopy. [b] The relative yield in the different cases was determined by GLC using an internal standard (heptadecane) and calibrated by the isolated yields.

0302-4369/84 $2.50

Table 2. Oxyamination of 1-hexene.

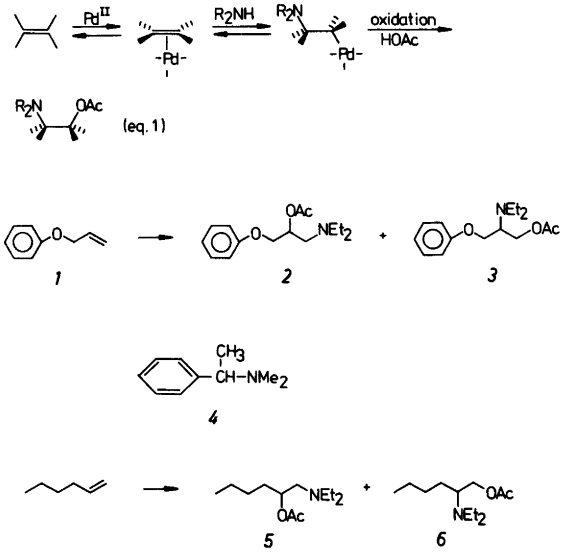
Reaction time of amination step (min)	Product distribution[a] *5:6*	Yield (%)[b] (*5+6*)
1	10:6	22
5	10:7	53
10	10:8	47
30	10:9	43

[a] Determined by GLC. [b] Determined by GLC using an internal standard.

can be seen, the total yield of aminoacetate does not change significantly with reaction time. However, the distribution *2:3* changes from approximately 1:1 after 1 min to give exclusively *2* after 30 min.

Further investigation showed that also for other olefins the distribution between regioisomers depends on the reaction time. Interestingly, 1-hexene seems to kinetically favour attack by amine on the terminal carbon (Table 2). On prolonged reaction time the product with amine attack at the non-terminal carbon increases.

We also investigated the amination of 1-hexene in the presence of ligand *4*, since the change in regiochemistry for oxyamination of *1* was less pronounced in the absence of that ligand. The results from the amination of 1-hexene in the presence of *4* (Table 3) show that the ratio *5:6*



Scheme 1.

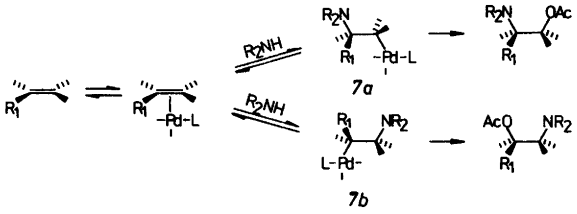
Table 3. Oxyamination of 1-hexene in the presence of ligand *4*.

Reaction time of amination step (min)	Product distribution [a] *5:6*	Yield (%)[b] *(5+6)*
1	10:5.4	32
30	10:9.4	29

[a] Determined by GLC. [b] Determined by GLC using tetradecane as internal standard.

after one minute reaction time is *ca.* 2:1, which is only slightly higher than the ratio obtained without the ligand. After 30 min the ratio *5:6* is approximately *1:1* in accordance with the results in the absence of ligand *4*.

The results can be explained by the equilibria shown in Scheme 1. The oxyamination of the olefin involves three descrete steps: (i) formation of a π-olefin complex, (ii) addition of an amine nucleophile to the coordinated olefin, and (iii) oxidative cleavage of the palladium-carbon σ-bond. The third step is probably the only irreversible step. The product distribution can be explained by a kinetically controlled attack to favour either *7a* or *7b*. On prolonged reaction time the σ-complexes *7a* and *7b* will equilibrate *via* an elimination-readdition of palladium and amine through the π-olefin complex.



Reversible oxymetalations are well known. In particular oxymercuration–deoxymercuration has been well studied,[5] and the related aminomercuration also seems to be a reversible reaction.[6] A reversible hydroxypalladation step was suggested in the Wacker oxidation of ethene[7] and reversible chloro- and oxypalladations occur in palladium-catalyzed vinylic exchange reactions.[8] By addition of strongly coordinating ligands to aminopalladation adducts elimination of amine and palladium occurs to yield olefin.[9]

Hoffmann and co-workers[10] have recently proposed a model in which the olefin is non-symmetrically bound to the metal in (π-olefin)metal complexes. According to this model the preferred site for the addition of the nucleophile would be at the carbon with the longest distance to the metal. For a terminal olefin like 1-hexene coordinated to palladium a Markownikoff addition is predicted, which is also observed for hydroxypalladation of 1-hexene.[11] However, as indicated in Tables 2 and 3 the kinetic adduct from diethylamine attack is the anti-Markownikoff one. This could be a steric effect by the rather bulky amine. Finally it must be pointed out that conclusions based on the regiochemistry of nucleophilic addition to (π-olefin)metal complexes should be treated with care if there is a possibility of an equilibrium between the σ- and the π-complex as is the case in the present study.

Experimental. General procedure for oxyamination of olefins. A solution of 0.3 ml of olefin in 2.5 ml of anhydrous THF was added to $(PhCN)_2PdCl_2$ (192 mg, 0.5 mmol) under nitrogen atmosphere at 0 °C. After the mixture was stirred for 10 min, the temperature was decreased to −50 °C, and 2 mmol of amine in THF (1 ml) was added during 1 min. The temperature was kept at −50 °C for 1, 5, 10 or 30 min, and then $Pb(OAc)_4$ containing 20 % (by weight) of acetic acid (390 mg of the mixture, ≈0.7 mmol) was added. The solution was kept at −50 °C for an additional 1 min and then allowed to slowly warm to room temperature. After 1 h the mixture was cooled (0 °C) and stirred for another 30 min. Then 6 ml of 2 M NaOH, 6 ml of ether and 0.5 g of $NaBH_4$ were added, and the mixture was stirred for 20 min. The palladium black and other precipitates that formed, were filtered off and washed with ether (2×3 ml) and GLC analyses were made. The organic layer was separated and extracted with 2 M HCl (3×2 ml). The aqueous phase was washed with ether (3×2 ml) and made alkaline with K_2CO_3 and finally with NaOH. The resulting solution was extracted with ether (3×3 ml) and the organic layer was washed with brine (1 ml) and dried (K_2CO_3).

General procedure for oxyamination of olefins, with the use of N,N-*dimethyl-α-phenylethylamine (4).* A solution of 0.3 ml of olefin in 2.5 ml of anhydrous THF was added to $(PhCN)_2PdCl_2$ (192 mg, 0.5 mmol) under nitrogen atmosphere at 0 °C. After the mixture was stirred for 10 min the temperature was decreased to −30 °C, and 75 μl of *4* (0.5 mmol) in THF (1 ml) was added during 1 min. The temperature was kept at −30 °C for 30 min, and then decreased to −50 °C, and 150 μl (1.5 mmol) of diethylamine was added. After 1, 10 or 30 min, the mixture was oxidized with $Pb(OAc)_4$ and worked-up as described above. The aminoacetate obtained from *1* was separated from *4* by bulb-to-bulb distillation.

Acknowledgements. We are grateful to the Swedish Natural Science Research Council and the Swedish Board for Technical Development for financial support.

1. a. Bäckvall, J. E. In Braterman, P. S., Ed., *Reaction of Coordinated Ligands* Plenum Press. *In press;* b. Birch, A., Jenkin, I. D. In Alper, H., Ed. *Transition Metal Oranometallics in Organic Synthesis* Academic Press, New York, 1976, Vol. 1.
2. Bäckvall, J. E. *Acc. Chem. Res. 16* (1983) 335; b. Åkermark, B., Bäckvall, J. E. and Zetterberg, K. *Acta Chem. Scand. B 36* (1982) 557.
3. a. Bäckvall, J. E. and Björkman, E. E. *J. Org. Chem. 45* (1980) 2893; b. Bäckvall, J. E. and Byström, S. E. *J. Org. Chem. 47* (1982) 1126; c. Bäckvall, J. E., Björkman, E. E., Byström, S. E. and Solladie-Cavallo, A. *Tetrahedron Lett. 23* (1982) 943.
4. Flood, T. C. *Top in Stereochem. 12* (1981) 37.
5. a. Kitching, W. *Organometal. Chem. Rev. 3* (1968) 61; b. Chatt, *J. Chem. Rev. 62* (1962) 611; c. Winstein, S., Traylor, T. G. and Carner, C. S. *J. Am. Chem. Soc. 77* (1965) 3741.
6. Bäckvall, J. E. and Åkermark, B. *J. Organometal. Chem. 78* (1974) 177.
7. Bäckvall, J. E., Åkermark, B. and Ljunggren, S. O. *J. Am. Chem. Soc. 101* (1979) 2411.
8. a. Henry, P. M. *Acc. Chem. Res. 6* (1973) 16; b. Henry, P. M. "Palladium-Catalyzed Oxidation of Hydrocarbons" D. Reidel Publishing Company, Dordrecht, 1980.
9. Zetterberg, K. *Dissertation,* Stockholm 1977.
10. Eisenstein, O. and Hoffman, R. *J. Am. Chem. Soc. 103* (1981) 4308.
11. Maitlis, P. M. *The Organic Chemistry of Palladium* Vol. 2, Academic Press, New York and London, 1971.

Received November 16, 1983.