Oxidation Catalysis with Nickel

DOI: 10.1002/anie.200702160

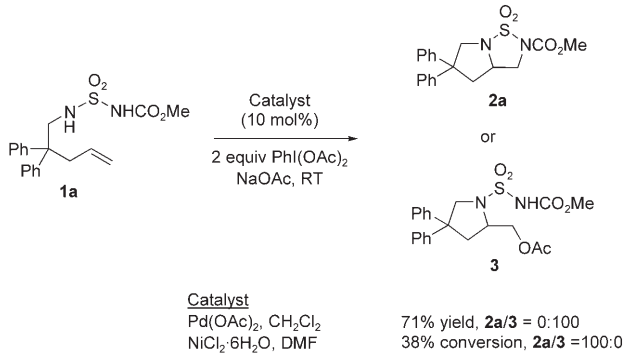
Exploring the Nickel-Catalyzed Oxidation of Alkenes: A Diamination by Sulfamide Transfer**

Kilian Muñiz, Jan Streuff, Claas H. Hövelmann, and Ana Núñez*

Nickel catalysts play an important role in catalytic processes under homogeneous conditions.[1] Their development is largely related to the fundamental work on organonickel structure chemistry by Wilke.[2] These advances led to the establishment of seminal reactions such as sp^2 and sp^3 C–C cross-coupling reactions,[3,4] enantioselective hydrovinylation,[5] cyclization and isomerization reactions,[6,7] as well as important industrial processes such as the Shell higher olefin process (SHOP).[8]

Herein, we describe the (to our knowledge) first application of nickel catalysts to a homogeneous oxidation of alkenes, namely direct diamination.[9] We consider the development of vicinal diamination of alkenes to be an important research target,[10] since it closes a methodological gap in the synthesis of this class of compounds.[11] For the development of useful synthetic transformations, the appropriate choice of protecting groups in the nitrogen source plays a dominant role.

To this end, we considered sulfamide groups particularly attractive,[12,13] since they allow for both a convenient liberation of the free diamine and a differentiation between the two nitrogen atoms. Palladium-catalyzed reactions with the sulfamide precursor **1a**[14] did not lead to the formation of the desired diamination product **2a**, but gave exclusively the aminoacetoxylation product **3** (Scheme 1).[15] The ratio of **2a** to **3** could be completely inverted in favor of diamination when the palladium(II) catalysts were replaced by nickel(II) salts. A first reaction in the presence of 10 mol% nickel(II) chloride hexahydrate provided diamine **2a** in an encouraging 38% yield. This new process required careful optimization of the reaction conditions. Investigation of different solvents and bases revealed that DMF and two equivalents of sodium acetate represent the optimum combination (Table 1). A comparison of various nickel salts showed that $NiCl_2$ and $[Ni(acac)_2]$ give the best results. These catalysts do not deactivate over time and are still active after 54 h reaction time. Finally, complete conversion was achieved with anhydrous precursor $NiCl_2$ or $[Ni(acac)_2]$ and two equivalents of oxidant under inert conditions at 40 °C.



Scheme 1. Catalyst-dependent oxidation of sulfamide **1a**.

Table 1: Optimization of the nickel-catalyzed transformation of **1a** into **2a**.[a]

Catalyst source	*T* [°C]	*t* [h]	Yield [%][b]
no Ni^{II} salt	40	18	0[c]
$NiSO_4$	40	18	<10
$NiCl_2 \cdot 6H_2O$	25	18	38
$NiCl_2 \cdot 6H_2O$	25	54	71
$NiCl_2$	40	18	100 (92[e])
$[(dppe)NiCl_2]$[f]	40	18	72
$[(bipy)NiCl_2]$[f]	40	18	80
$[Ni(acac)_2]$[d, f]	40	18	23
$[Ni(acac)_2]$	40	18	100 (92[e])

[a] General conditions: 10 mol% catalyst, 2 equiv $PhI(OAc)_2$, 2 equiv NaOAc, DMF. [b] Conversion according to ^1H NMR spectroscopy. [c] Reisolated starting material. [d] 1.1 equiv $PhI(OAc)_2$. [e] Yield of isolated product. [f] dppe = 1,2-bis(diphenylphosphanyl)ethane, bipy = bipyridine, acac = acetylacetonate.

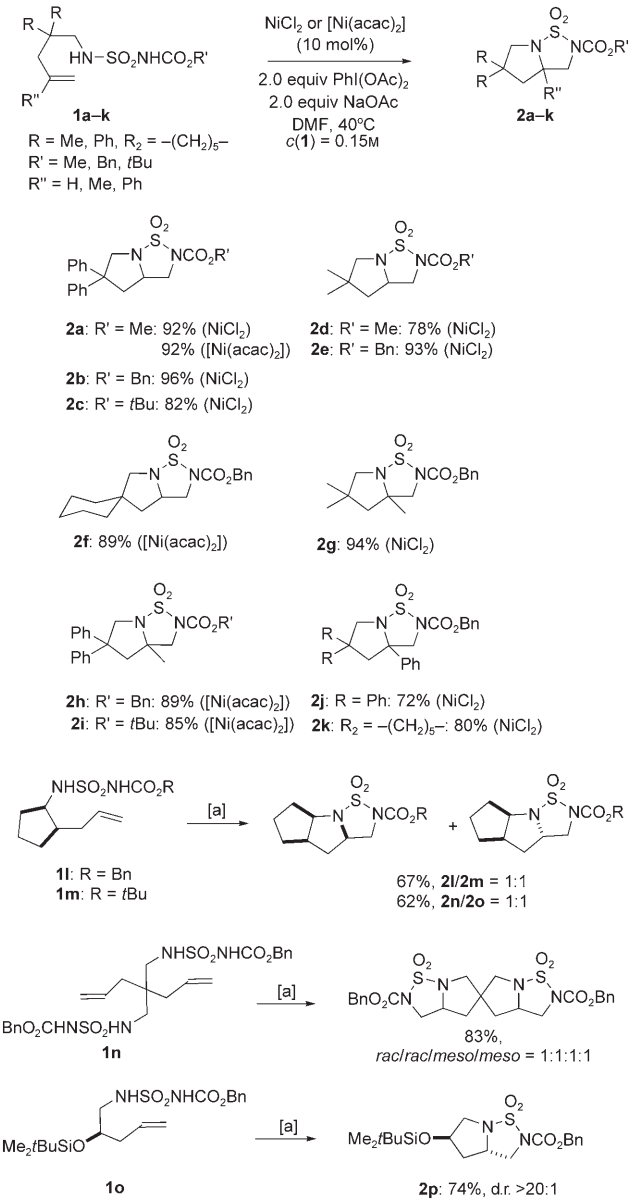
The oxidation is even catalyzed by unligated nickel(II) salts, but addition of common chelating ligands such as bipyridine gives stable catalysts as well. Control experiments monitored by ^{31}P NMR spectroscopy revealed that $[(dppe)NiCl_2]$ readily loses the diphosphine ligand under oxidative conditions to generate a free nickel salt and phosphine oxide. As a consequence, $NiCl_2$ or $[Ni(acac)_2]$ were employed as catalysts for subsequent investigation of the intramolecular diamination of sulfamides (Scheme 2).

All reactions proceeded with complete selectivity, and no products other than the cyclic sulfamides were observed. A range of substrates with different substituents was tolerated, which includes the styrene derivatives **1j** and **k**. Chiral compounds **1l**, **m** were transformed into the two corresponding diastereoisomeric products. The novel cyclization precursor **1n** underwent clean oxidation to yield an equimolar

[*] Prof. Dr. K. Muñiz, Dipl.-Chem. J. Streuff, Dipl.-Chem. C. H. Hövelmann, Dr. A. Núñez
Université Louis Pasteur
Institut de Chimie, UMR 7177
4, rue Blaise Pascal, 67070 Strasbourg (France)
E-mail: muniz@chimie.u-strasbg.fr
Homepage: http://www-chimie.u-strasbg.fr/~lchsm/

[**] This work was generously supported by the Fonds der Chemischen Industrie and the Agence Nationale de la Recherche. The authors thank Prof. J. González and E. Campos (Oviedo) for a sample of compound **6b**.

Supporting information for this article is available on the WWW under http://www.angewandte.org or from the author.

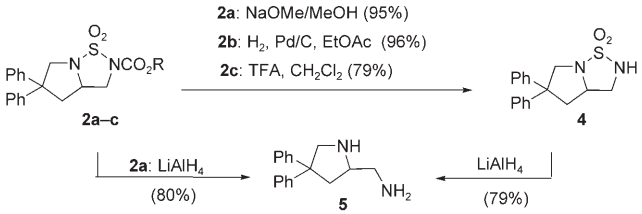


Scheme 2. Nickel-catalyzed diaminations. Given yields are based on isolated material. All reactions proceed with 100% selectivity in favor of diamination. Bn = benzyl. [a] Reactions with $[Ni(acac)_2]$.

mixture of all four possible stereoisomeric tetraamination products. A diastereoselective reaction succeeded with the chiral substrate **1o**, which cleanly yielded the prolinyl amine derivative **2p**.

All reactions proceeded at room temperature as well, albeit at a slower rate (50–80% conversion after 16 h). The exception is precursor **1b**, which gives quantitative product formation after 18 h at room temperature. The reaction scale can be varied; an increase to 4.5 g (10 mmol) of **1b** in the presence of 10 mol% Ni catalyst gives quantitative formation of **2b**.

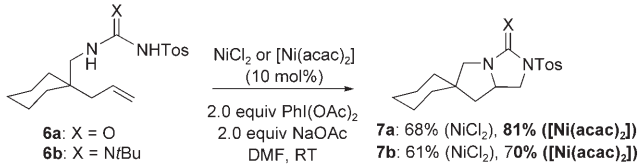
The sulfamide products can be conveniently transformed into the free diamines (Scheme 3).[16] The removal of the carbamate groups in **2a–c** can be accomplished through basic



Scheme 3. Deprotection to the free diamine **5**. TFA = trifluoroacetic acid.

cleavage with methoxide for **2a**, hydrogenolysis in case of **2b**, or protonolysis for **2c**, yielding free sulfamide **4**. Direct treatment with lithium aluminium hydride furnishes free aminomethyl pyrrolidine **5**, which is also directly accessible from **2a**. These sequences illustrate that sulfamides can be used advantageously in diamination reactions.

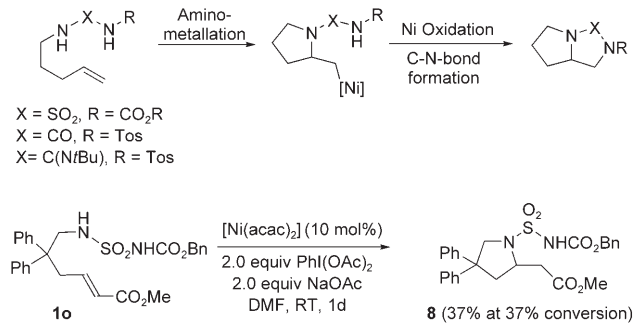
Urea groups[14] are cyclized equally well under the conditions of nickel-catalyzed diamination. For example, diamination of the cyclohexyl derivative **6a** to **7a** proceeds with complete selectivity (Scheme 4), and the related guani-



Scheme 4. Nickel-catalyzed diamination of urea and guanidine derivatives. Values in bold refer to the better catalyst. Tos = toluene-4-sulfonyl.

dine derivative **6b** is oxidized cleanly to the corresponding cyclic derivative **7b**. These examples further exemplify the range of functional groups that are tolerated by the new nickel-catalyzed intramolecular diamination.

Mechanistic investigation of the exact course of the reaction is currently underway. We expect that the reaction proceeds through a stepwise process of aminometalation and C–N coupling comparable to the palladium-catalyzed variant (Scheme 5). These two steps have literature precedence. Nickel-catalyzed hydroamination is known for polarized alkenes[17] and butadienes,[18] and has been theoretically



Scheme 5. Mechanistic sequence and isolated hydroamination product **8**.

predicted for neutral akenes.[19] The isolation of **8** yields evidence for an initial involvement of aminometalation. This hydroamination product is formed when the C–Ni bond of the intermediate is selectively protonated, in agreement with the described intermolecular processes; no diamine is obtained.[20] Related internal alkenes with phenyl or methyl substituents show low reactivity and varying degrees of hydroamination, but no diamination. Hence, the overall reaction is dependent on the nature of the alkene, as only carbon atoms from terminal alkenes tend to favor the second amination.

This final step of the suggested mechanism consists of oxidative C_{alkyl}–N bond formation, presumably via a Ni^{III} intermediate from oxidation with $PhI(OAc)_2$. Such a process was investigated in detail by Hillhouse and co-workers, who elegantly demonstrated that the C_{alkyl}–Ni bond in intramolecular aziridine formation can be cleaved under retention or inversion of the overall configuration.[21] Recently, C_{aryl}–N bond formation from a Ni^{III} complex was also reported.[22,23] An intermediary involvement of an aminoacetoxylation product can be excluded, since **3** is not converted to diamine **2a** using the nickel-catalysis protocol.

The results presented herein illustrate the first selective C–N bond-forming reactions employing nickel oxidation catalysis. The selectively deuterated alkene **1a** forms a diastereomerically pure diamination product;[16] this result excludes the involvement of a radical mechanism and suggests the presence of a clean substitution process in the final step,[24] in complete agreement with the observations of Hillhouse and co-workers.

The electronic properties of the involved nitrogen atoms are of great importance for this second step. While in the case of palladium the carbamate-substituted nitrogen atom is unable to compete with acetate, nickel catalysts tolerate a broader range of nitrogen groups and thereby enable the first and selective diamination of sulfamides.[25] This broad applicability with respect to sulfamides as well as urea and guanidine derivatives should allow additional nickel-catalyzed amination reactions. Such approaches are under investigation.

We have extended the scope of nickel-catalyzed reactions to homogeneous alkene oxidation, which consists of a new, completely selective intramolecular diamination. This protocol is attractive in view of catalyst cost, reaction scope, and simplicity of subsequent product diversification.

Received: May 16, 2007
Published online: August 10, 2007

Keywords: diamines · homogeneous catalysis · nickel · oxidation · sulfamides

[1] *Modern Organonickel Chemistry* (Ed: Y. Tamao), Wiley-VCH, Weinheim, **2006**.
[2] G. Wilke, *Angew. Chem.* **1988**, *100*, 189; *Angew. Chem. Int. Ed. Engl.* **1988**, *27*, 185.
[3] Recent review: E.-i. Negishi, *Bull. Chem. Soc. Jpn.* **2007**, *80*, 233.
[4] a) M. R. Netherton, G. C. Fu, *Adv. Synth. Catal.* **2004**, *346*, 1525; b) A. C. Frisch, M. Beller, *Angew. Chem.* **2005**, *117*, 680; *Angew. Chem. Int. Ed.* **2005**, *44*, 674.
[5] T. V. RajanBabu, *Chem. Rev.* **2003**, *103*, 2845.
[6] J. Montgomery, *Angew. Chem.* **2004**, *116*, 3980; *Angew. Chem. Int. Ed.* **2004**, *43*, 3890.
[7] a) C. Böing, G. Franciò, W. Leitner, *Chem. Commun.* **2005**, 1456; b) C. Böing, G. Franciò, W. Leitner, *Adv. Synth. Catal.* **2005**, *347*, 1537.
[8] W. Kaim, *Angew. Chem.* **1990**, *102*, 251; *Angew. Chem. Int. Ed. Engl.* **1990**, *29*, 235.
[9] Generally, Ni-catalyzed homogeneous oxidation reactions appear to have been less investigated. For a recent study on an oxygen transfer reaction, see: J. M. Grill, J. W. Ogle, S. A. Miller, *J. Org. Chem.* **2006**, *71*, 9291.
[10] K. Muñiz, *New J. Chem.* **2005**, *29*, 1371.
[11] D. Lucet, T. Le Gall, C. Mioskowski, *Angew. Chem.* **1998**, *110*, 2724; *Angew. Chem. Int. Ed.* **1998**, *37*, 2580.
[12] For a diamination with *N*-alkyl sulfamides in the presence of excess copper acetate: T. P. Zabawa, D. Kasi, S. R. Chemler, *J. Am. Chem. Soc.* **2005**, *127*, 11250.
[13] Nicolaou et al. described Burgess reagents for stoichiometric transformation of amino alcohols into the corresponding cyclic sulfamides: a) K. C. Nicolaou, D. A. Langbottom, S. A. Snyder, A. Z. Nalbandian, X. H. Huang, *Angew. Chem.* **2002**, *114*, 4022; *Angew. Chem. Int. Ed.* **2002**, *41*, 3866; b) K. C. Nicolaou, S. A. Snyder, D. A. Langbottom, A. Z. Nalbandian, X. H. Huang, *Chem. Eur. J.* **2004**, *10*, 5581.
[14] J. Streuff, C. H. Hövelmann, M. Nieger, K. Muñiz, *J. Am. Chem. Soc.* **2005**, *127*, 14586.
[15] E. J. Alexanian, C. Lee, E. J. Sorensen, *J. Am. Chem. Soc.* **2005**, *127*, 7690.
[16] Additional information is included in the Supporting Information.
[17] a) L. Fadini, A. Togni, *Chem. Commun.* **2003**, 30; b) W. Zhuang, R. G. Hazell, K. A. Jørgensen, *Chem. Commun.* **2001**, 1240.
[18] a) J. Pawlas, Y. Nakao, M. Kawatsura, J. F. Hartwig, *J. Am. Chem. Soc.* **2002**, *124*, 3669; b) J. F. Hartwig, *Pure Appl. Chem.* **2004**, *76*, 507.
[19] H. M. Senn, P. Blöchl, A. Togni, *J. Am. Chem. Soc.* **2000**, *122*, 4098.
[20] This reaction is nickel-catalyzed and requires the presence of acetate. Reactions without nickel(II) and/or base do not lead to formation of **8**.
[21] a) B. L. Lin, C. R. Clough, G. L. Hillhouse, *J. Am. Chem. Soc.* **2002**, *124*, 2890; b) R. Waterman, G. L. Hillhouse, *J. Am. Chem. Soc.* **2003**, *125*, 13350; c) K. Koo, G. L. Hillhouse, *Organometallics* **1995**, *14*, 4421; d) K. Koo, G. L. Hillhouse, *Organometallics* **1996**, *15*, 2669.
[22] G. Bai, D. W. Stephan, *Angew. Chem.* **2007**, *119*, 1888; *Angew. Chem. Int. Ed.* **2007**, *46*, 1856.
[23] For Ni^0/Ni^{II}-catalyzed C_{aryl}–N bond-forming reactions, see: a) S. Ogoshi, H. Ikeda, H. Kurosawa, *Angew. Chem.* **2007**, *119*, 5018; *Angew. Chem. Int. Ed.* **2007**, *46*, 4930; b) J. P. Wolfe, S. L. Buchwald, *J. Am. Chem. Soc.* **1997**, *119*, 6054; c) C. Desmarets, R. Schneider, Y. Fort, *Tetrahedron* **2001**, *57*, 7657.
[24] At present, we are unable to distinguish between a *syn*/*anti* and an *anti*/*syn* process for the two-step diamination. For a discussion on *syn*- and *anti*-aminometalation in related palladium catalysis, see: A. Minatti, K. Muñiz, *Chem. Soc. Rev.* **2007**, *36*, 1142.
[25] Electron-withdrawing substituents at the second sulfamide nitrogen atom are essential for all reactions. Oxidative decomposition rather than diamination is observed for less acidic amides such as benzyl-substituted sulfamides.[12]

