Platinum-Catalyzed Intermolecular Hydroamination of Unactivated Olefins with Carboxamides

Xiang Wang and Ross A. Widenhoefer*

Duke University, P. M. Gross Chemical Laboratory, Durham, North Carolina 27708-0346
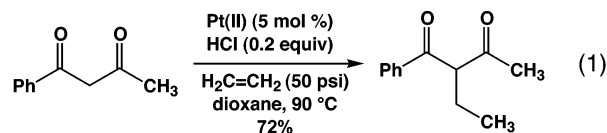
Summary: Reaction of benzamide with a catalytic 1:2 mixture of [PtCl₂(H₂C=CH₂)]₂ (2.5 mol %) and PPh₃ in dioxane at 120 °C for 24 h led to isolation of N-ethylbenzamide in 97% yield. A range of primary, acyclic aryl and alkyl carboxamides and secondary cyclic carboxamides and carbamates also underwent platinum-catalyzed addition to ethylene and propylene.

In contrast to the mild and effective procedures that have been developed for the intramolecular amination of unactivated olefins,[1] intermolecular amination of an unactivated olefin requires employment of a highly basic alkali metal[2] or a highly oxophilic lanthanide metallocene catalyst.[3] Given the extreme air and moisture sensitivity and poor functional group compatibility of these catalysts, there has been considerable interest in the identification of late-transition-metal catalysts for the intermolecular amination of unactivated olefins. However, despite prolonged effort in this area, late-transition-metal-catalyzed intermolecular olefin amination has, with one exception, been restricted to activated olefins such as vinyl arenes,[4,5] conjugated dienes,[6] strained olefins,[7] and electron-deficient Michael acceptors.[8] The lone exception is the RhCl₃-catalyzed addition of secondary amines to ethylene, which requires forcing conditions and is of extremely limited scope.[9]

Palladium(II) complexes activate simple olefins toward nucleophilic attack, and for this reason, Pd(II) complexes have been widely employed as catalysts for olefin amination.[1,5,10] Platinum(II) complexes also activate olefins toward nucleophilic attack, but in contrast to their Pd(II) counterparts, the resulting Pt(II) alkyl complexes are stable with respect to β-hydride elimina-

tion but reactive toward protonolysis.[11,12] We have recently exploited this reactivity through the employment of Pt(II) complexes as catalysts for the intramolecular alkylation of 2-alkenylindoles[13] and the intermolecular hydroalkylation of ethylene with β-diketones (eq 1).[14] This latter transformation, in particular, sug-

gested that simple Pt(II) complexes might also catalyze the intermolecular hydroamination of unactivated olefins. Here we report a mild and efficient platinum-catalyzed protocol for the hydroamination of ethylene and propylene with carboxamides.

When a dioxane solution of benzamide, ethylene (50 psi), and a catalytic amount of [PtCl₂(H₂C=CH₂)]₂ (**1**; 2.5 mol %) was heated at 90 °C for 24 h, 44% of the benzamide was consumed to form *N*-ethylbenzamide as the exclusive product with concomitant decomposition of **1** (Table 1, entry 1).[15,16] On the presumption that the active hydroamination catalyst might be stabilized by phosphine ligation, the conversion and efficiency of the reaction of ethylene with benzamide catalyzed by **1** was evaluated as a function of exogenous phosphine (Table 1). From this initial screen of phosphines, PPh₃ emerged as an effective and convenient cocatalyst for platinum-catalyzed hydroamination. For example, reaction of benzamide and ethylene catalyzed by a 2:1 mixture of PPh₃ and **1** (P:Pt = 1:1) at 120 °C for 24 h led to complete consumption of benzamide and isolation of *N*-ethylbenzamide in 97% yield (Table 1, entry 9). It is worth noting that increasing the PPh₃:Pt ratio above 1:1 led to a precipitous drop in reactivity. For example, heating a solution of benzamide, ethylene, and a catalytic 4:1 mixture of PPh₃ and **1** (P:Pt = 2) to 120 °C for

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* To whom correspondence should be addressed. E-mail: rwidenho@chem.duke.edu.

(1) Müller, T. E.; Beller, M. *Chem. Rev.* **1998**, *98*, 675.

(2) Howk, B. W.; Little, E. L.; Scott, S. L.; Whitman, G. M. *J. Am. Chem. Soc.* **1954**, *76*, 1899.

(3) Ryu, J.-S.; Li, G. Y.; Marks, T. J. *J. Am. Chem. Soc.* **2003**, *125*, 12584.

(4) Kawatsura, M.; Hartwig, J. F. *J. Am. Chem. Soc.* **2000**, *122*, 9546.

(5) Timokhin, V. I.; Anastasi, N. R.; Stahl, S. S. *J. Am. Chem. Soc.* **2003**, *125*, 12996.

(6) Baker, R.; Onions, A.; Popplestone, R. J.; Smith, T. N. *J. Chem. Soc., Perkin Trans. 2* **1975**, 1133.

(7) Casalnuovo, A. L.; Calabrese, J. C.; Milstein, D. *J. Am. Chem. Soc.* **1988**, *110*, 6738.

(8) Seligson, A. L.; Trogler, W. C. *Organometallics* **1993**, *12*, 744.

(9) Coulson, D. R. *Tetrahedron Lett.* **1971**, 429.

(10) (a) Hegedus, L. S. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 1113. (b) Lober, O.; Kawatsura, M.; Hartwig, J. F. *J. Am. Chem. Soc.* **2001**, *123*, 4366.

(11) (a) Palumbo, R.; De Renzi, A.; Panunzi, A.; Paiaro, G. *J. Am. Chem. Soc.* **1969**, *91*, 3874. (b) Panunzi, A.; De Renzi, A.; Palumbo, R.; Paiaro, G. *J. Am. Chem. Soc.* **1969**, *91*, 3879. (c) Panunzi, A.; De Renzi, A.; Paiaro, G. *J. Am. Chem. Soc.* **1970**, *92*, 3488.
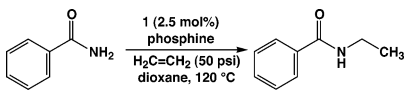
(12) Fanizzi, F. P.; Intini, F. P.; Maresca, L.; Natile, G. *J. Chem. Soc., Dalton Trans.* **1992**, 309.

(13) Liu, C.; Han, X.; Wang, X.; Widenhoefer, R. A. *J. Am. Chem. Soc.*, in press.

(14) Wang, X.; Widenhoefer, R. A. *Chem. Commun.* **2004**, 660.

(15) Continued heating of the reaction mixture led to no further consumption of benzamide. Reaction of secondary amines with ethylene catalyzed by **1** led to neither conversion nor catalyst decomposition, presumably due to formation of a stable platinum amine complex.
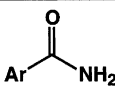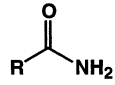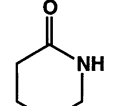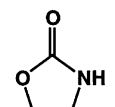
(16) A similar transformation has been achieved by stoichiometric aminomercuration/reduction: (a) Barluenga, J.; Jimenez, C.; Najera, C.; Yus, M. *J. Chem. Soc., Perkin Trans. 1* **1983**, 591. (b) Barluenga, J.; Ferrera, L.; Najera, C.; Yus, M. *Synthesis* **1984**, 831.

Table 1. Effect of Added Phosphine on the Platinum-Catalyzed Hydroamination of Ethylene with Benzamide

entry	phosphine	P:Pt	time (h)	conversion (%)[a]	isolated yield (%)[b]
1[c]	none		24	44	
2	P(o-tolyl)$_3$	1	24	0	
3	P(OMe)$_3$	1	24	95	
4	P(OPh)$_3$	1	24	90	77
5	P(t-Bu)$_3$	1	24	0	
6	PPh$_2$Et	1	24	98	95
7	P(C$_6$F$_5$)$_3$	1	24	75	60
8	P(n-Bu)$_3$	1	17	33	
9	PPh$_3$	1	24	>98	97
10	PPh$_3$	2	24	0	

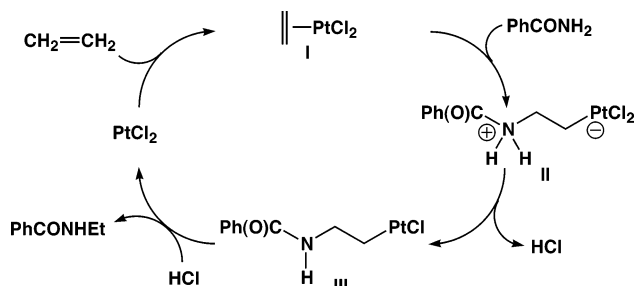[a] Determined by GC analysis. [b] Isolated material of ≥95% purity. [c] The reaction temperature was 90 °C.

Table 2. Hydroamination of Ethylene with Carboxamides and Carbamates Catalyzed by a Mixture of [PtCl$_2$(H$_2$C=CH$_2$)]$_2$ (1; 2.5 mol %) and PPh$_3$ (5 mol %) in Dioxane at 120 °C

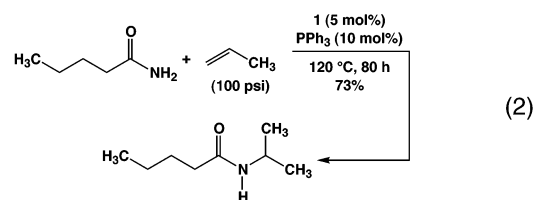| entry	nucleophile	time (h)	yield (%)[a]
	Ar–C(O)–NH$_2$		
1	Ar = 4-C$_6$H$_4$OMe	36	87
2	Ar = 4-C$_6$H$_4$Br	14	85
3	Ar = 4-C$_6$H$_4$NO$_2$	80	70
4	Ar = 4-C$_6$H$_4$Me	12	95
5	Ar = 2-C$_6$H$_4$Me	72	75
6	Ar = 2-naphthyl	36	91
7	Ar = 1-naphthyl	72	91
	R–C(O)–NH$_2$		
8	R = n-Bu	20	85
9	R = Cy	40	84
10	R = t-Bu	60	82
11	(δ-valerolactam)	36	98
12	(2-oxazolidone)	36	90

[a] Isolated product of ≥95% purity.

24 h led to no detectable formation of *N*-ethylbenzamide (Table 1, entry 10). These observations point to platinum mono(phosphine) complexes as the relevant intermediates in catalytic ethylene hydroamination.

A number of aryl carboxamides, including *p*-methoxy-, *p*-bromo-, and *p*-nitrobenzamide, *p*- and *o*-toluamide, and 1- and 2-naphthylcarboxamide, reacted with ethylene in the presence of a catalytic 2:1 mixture of PPh$_3$ and **1** to form the corresponding *N*-ethyl aryl carboxamides in good yield (Table 2, entries 1–7). Although detailed kinetics studies have not yet been performed, the rate of hydroamination appeared to decrease with increasing steric bulk near the amide nitrogen atom (Table 2, entries 4–7). The dependence of the rate of ethylene hydroamination on the electron density of the amide was more complex, and for substituted benza-

Scheme 1

mides the rate decreased in the order *p*-Me ≈ *p*-Br > *p*-H > *p*-OMe > *p*-NO$_2$ (Table 1, entry 9; Table 2, entries 1–4). In addition to arylamides, primary alkylamides, γ-valerolactam, and 2-oxazolidone also reacted with ethylene in the presence of a catalytic 2:1 mixture of PPh$_3$ and **1** to form the corresponding N-ethylated derivatives in good yield (Table 2, entries 8–12).

Unactivated α-olefins represent a particularly challenging substrate for catalytic amination,[1] and for this reason, it is significant that propylene also underwent platinum-catalyzed hydroamination. For example, reaction of valeramide with propylene (100 psi) and a catalytic 2:1 mixture of PPh$_3$ and **1** at 120 °C for 80 h formed *N*-isopropylvaleramide in 73% isolated yield as a single isomer (eq 2).

Mechanisms for transition-metal-catalyzed olefin amination initiated by either N–H bond activation or nucleophilic attack on a complexed olefin have been established.[1] However, because N–H bond activation has been observed only in the case of electron-rich late-transition-metal complexes[6] or highly electrophilic lanthanide metallocene complexes,[3] it appears unlikely that a mechanism involving N–H bond activation is operative for platinum-catalyzed hydroamination. Rather, we propose a mechanism initiated by outer-sphere attack of the amide on the platinum-complexed olefin of **I** to form zwitterion **II**, followed by loss of HCl to form the platinum β-amidoalkyl complex **III** (Scheme 1). Protonolysis of the Pt–C bond of **III** with HCl would release the *N*-ethyl carboxamide and form a platinum dichloride species that could react with ethylene to regenerate **I**.[17]

In summary, we have developed a mild and efficient platinum-catalyzed protocol for the hydroamination of ethylene and propylene with carboxamides. Current efforts are being directed toward expanding the scope and elucidating the mechanism of this transformation.

(17) Each of these intermediates is presumably ligated by a single PPh$_3$ group. It also appears possible that intramolecular proton transfer from nitrogen to the α-carbon atom of **II** could generate PtCl$_2$ without the intermediacy of **III**.

Note Added in Proof: The platinum-catalyzed hydroalkylation of ethylene with aniline derivatives in molten *n*-Bu$_4$PBr has recently been reported: Brunet, J.-J.; Cadena, M.; Chu, N. C.; Diallo, O.; Jacob, K.; Mothes, E. *Organometallics* **2004**, *23*, 1264.

Note Added after ASAP. In the version of this paper posted on the web March 18, 2004, reference 13 was incorrectly cited, due to a production error. All of the references are correct as they currently appear.

Supporting Information Available: Text giving experimental procedures and spectroscopic data for products. This material is available free of charge via the Internet at http://pubs.acs.org.

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