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Chelation-Assisted Hydroesterification of Alkenes Catalyzed by Rhodium Complex

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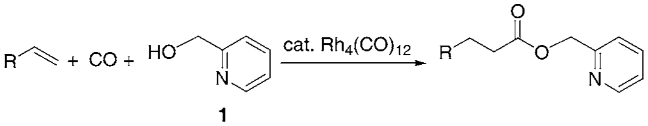
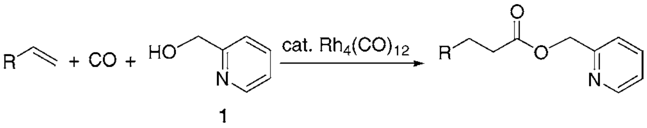
ABSTRACT



The hydroesterification of alkenes with 2-pyridylmethanol (1) catalyzed by $Rh_4(CO)_{12}$ is described. The reaction is accelerated by the presence of a pyridine ring in the alcohol 1. The reaction is applicable to various alkenes, both terminal and internal alkenes.

We successfully developed a series of catalytic reactions involving the cleavage of unreactive bonds, such as C−H,[1] C−C,[2] C−O,[3] and C−F,[4] by utilizing the chelation-assistance strategy.[5,6] We have already reported on a series of a chelation-assisted carbonylation reaction at C−H bonds on the basis of the methodology that heteroatom-directing groups promote the cleavage of C−H bonds.[7] In all cases, the substrates require the presence of an sp^2 nitrogen as the directing group at the appropriate position. The results indicate that the coordination of the sp^2 nitrogen to the metal center is a key step for the reaction to proceed. Next, we turned our attention to the cleavage an O−H bond in alcohols in order to utilize the O−H bond in the hydroesterification of alkenes. The hydroesterification of alkenes is an important process for both industrial and laboratory scales.[8] Although a variety of late transition metal complexes are known to be active, Co and Pd complexes are most frequently used as a catalyst. However, Co-catalyzed reactions require harsh reaction conditions (usually >140 °C and >100 atm of CO). Though Pd-catalysis can make the reaction temperature low (70−140 °C), the reaction needs 40−120 atm of CO yet. Moreover, 1,1- and 1,2-disubstituted alkenes give hydroesterified products in relatively lower yield. This result is in contrast to that of monosubstituted alkenes, which give the products in high yield. We wish to report that the Rh-catalyzed hydroesterification of terminal and internal alkenes is accelerated by the presence of an sp^2 nitrogen in an alcohol.

Scheme 1



The reaction of 1-hexene (6 mmol) and 2-pyridin-2-ylmethanol (**1**) (2 mmol) in the presence of $Rh_4(CO)_{12}$ (0.04 mmol) in toluene (1 mL) at 100 °C under 3 atm of CO for

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[1] Kakiuchi, F.; Kan, S.; Igi, K.; Chatani, N.; Murai, S. *J. Am. Chem. Soc*. **2003**, *125*, 1698.

[2] Chatani, N.; Ie, Y.; Kakiuchi, F.; Murai, S. *J. Am. Chem. Soc*. **1999**, *121*, 8645.

[3] Chatani, N.; Tatamidani, H.; Ie, Y.; Kakiuchi, F.; Murai, S. *J. Am. Chem. Soc*. **2001**, *123*, 4849.

[4] Ishii, Y.; Chatani, N.; Yorimitsu, S.; Murai, S. *Chem. Lett*. **1998**, 157.

[5] For a review on substrate-directed reactions, see: Hoveyda, A. H.; Evans, D. A.; Fu, G. C. *Chem. Rev.* **1993**, *93*, 1307.

[6] For recent papers on chelation-assisted reactions, see: Jun, C.-H.; Moon, C. W.; Hong, J.-B.; Lim, S.-G.; Chung, K.-Y.; Kim, Y.-H. *Chem. Eur. J*. **2002**, 485. Bendorf, H. D.; Colella, C. M.; Dixon, E. C.; Marchetti, M.; Matukonis, A. N.; Musselman, J. D.; Tiley, T. A. *Tetrahedron Lett*. **2002**, *43*, 7031. Itami, K.; Mitsudo, K.; Yoshida, J. *Angew. Chem., Int. Ed*. **2002**, *41*, 3481. Ko, S.; Han, H.; Chang, S. *Org. Lett*. **2003**, *5*, 2687.

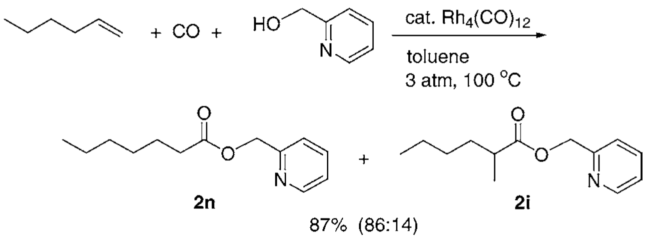
[7] For our recent paper on a chelation-assisted carbonylation at C−H bonds, see: Asaumi, T.; Chatani, N.; Matsuo, T.; Kakiuchi, F.; Murai, S. *J. Org. Chem*. **2003**, *68*, 7538.

[8] For a review on hydroesterification, see: Colquhoun, H. M.; Thompson, D. J.; Twigg, M. V. *Carbonylation. Direct Synthesis of Carbonyl Compounds*; Plenum Press: New York, 1991. Ali, B. E.; Alper, H. In *Transition Metals for Organic Synthesis*; Beller, M., Bolm, C., Eds.; Wiley-VCH: Weinheim, 1998; pp 49−67. Kiss, G. *Chem. Rev.* **2001**, *101*, 3435.

10.1021/ol035582e CCC: $25.00

20 h gave a 86:14 mixture of heptanoic acid pyridin-2-ylmethyl ester (**2n**) and 2-methylhexanoic acid pyridin-2-ylmethyl ester (**2i**) in total 87% isolated yield, along with a trace amount of 2-ethylpentanoic acid pyridin-2-ylmethyl ester (Scheme 2). Control experiments using benzyl alcohol, methanol, and pyridin-4-yl-methanol in place of **1** indicate that the presence of the nitrogen at the 2-position in the alcohol apparently accelerates the reaction.[9] Higher CO pressures (5 or 10 atm) have no effect on product yields (88% and 83% GC yields, respectively). $Ru_3(CO)_{12}$ was, unexpectedly, not active under identical conditions,[10] although it was found to be active for carbonylation at C−H bonds in *N*-heterocyclic compounds.[7]

Scheme 2



To explore the scope and synthetic utility of this reaction, a variety of alkenes were subjected to Rh-catalyzed hydroesterificaition (Table 1). The reaction of internal hexenes gave a linear ester as the main product, along with branched isomers. Higher temperatures slightly improved the linear selectivity, indicating that a rapid isomerization occurred at higher temperatures. The use of vinylcyclohexane and *tert*-butylethylene gave the corresponding linear esters selectively. The results of α-methylstyrene show that a higher CO pressure is required for the reaction to proceed effectively when the reaction is carried out at higher temperatures. This is probably because higher CO pressures keep the catalyst active at higher temperatures. Cyclic olefins also functioned as an olefin partner. Some carbonyl functionalities, such as ketones and esters, were tolerated under the reaction conditions. The hydroesterification of ethylene (5 atm) proceeded smoothly even at lower reaction temperatures (Scheme 3).

Scheme 3

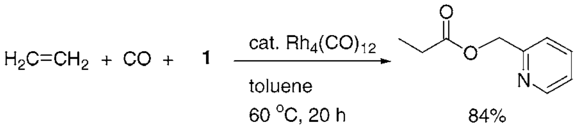
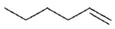
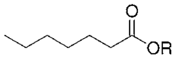
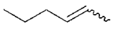
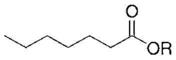
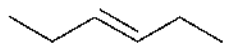
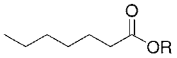
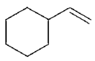
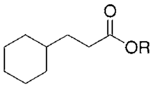
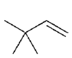
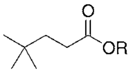
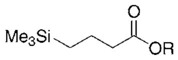
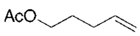
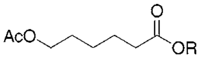
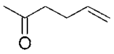
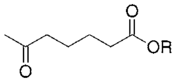
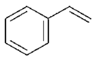
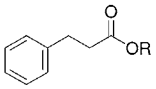
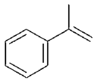
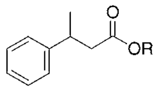
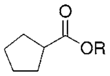
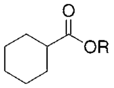


Table 1. Hydroesterification of Alkenes Catalyzed by $Rh_4(CO)_{12}$[a]

alkene	ester	temp	isolated yield
		100 °C	87% (86:14)[b]
 (cis/ trans mixture)		100 °C 120 °C 140 °C 140 °C[d]	37% (50:40:10)[c] 64% (61:32:7) 27% (52:39:9) 77% (68:25:7)
		140 °C[d]	86% (67:24:9)
		100 °C	93% (97:3)
		100 °C	95% (>99:1)
		100 °C	42% (83:17)
		100 °C	78% (81:18:1)
		100 °C	69% (70:29:1)
		100 °C	95% (75:25)
		120 °C 140 °C[d]	65% (>99:1) 98% (>99:1)
		120 °C	83%
		120 °C	82%

[a] Reaction conditions: alkene (6 mmol), 2-pyridylmethanol (2 mmol), $Rh_4(CO)_{12}$ (0.04 mmol), in toluene (1 mL) under 3 atm of CO for 20 h. [b] The ratio of linear (1-isomer) and branched isomer (2-isomer). [c] The ratio of 1-, 2-, and 3-isomers. [d] Under CO (10 atm) for 40 h.

Two mechanisms have been proposed to date for the hydroesterification of alkenes: a hydride mechanism and an alkoxy mechanism.[11] Although the mechanism of the present hydroesterification of alkenes remains controversial, the hydride mechanism is believed to be a true catalytic cycle. A recent ab initio molecular orbital study also supports the hydride mechanism.[12] The coordination of sp^2 nitrogen in **1** to a rhodium center followed by oxidative addition of an O−H bond gives hydride-rhodium complex **3**.[13] The successive insertion of an alkene and CO in **4** gives acyl-

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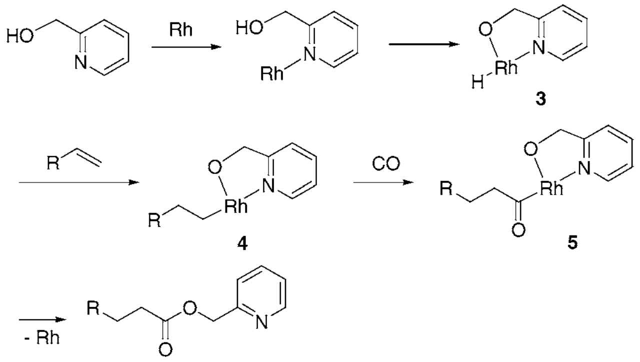
(9) The reaction of 1-hexene (6 mmol) with benzyl alcohol (2 mmol) in the presence of $Rh_4(CO)_{12}$ (0.04 mmol) gave a trace amount of heptanoic acid benzyl ester. When pyridine (2 mmol) was added, the benzyl ester was formed in 13% yield (n:i = 92:8). The use of 4-pyridylmethanol gave the corresponding ester in 13% yield (n:i = 95:5).

(10) When the reaction was carried out at 130 °C using $Ru_3(CO)_{12}$ as the catalyst in place of $Rh_4(CO)_{12}$, **2** was obtained in 35% yield (n:i = 82:18).

(11) del Rio, I.; Claver, C.; van Leeuwen, P. W. N. M. *Eur. J. Inorg. Chem.* **2001**, 2719.

(12) Kawana, M.; Nakamura, S.; Watanabe, E.; Urata, H. *J. Organomet. Chem.* **1997**, *542*, 185.

Scheme 4. Proposed Mechanism



rhodium complex **5**. A carbon−oxygen bond-forming reductive elimination would release the ester, regenerating the catalyst.

In summary, the chelation-assisted hydroesterification of alkenes, which is accelerated by the presence of a pyridine ring in an alcohol is demonstrated.[14] We are currently examining the catalytic use of pyridinemethanol in the hydroesterification of alkenes with methanol or ethanol. Other combinations of directing groups and catalysts are also under investigation.

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Supporting Information Available: Experimental procedure and characterization data of all new products. This material is available free of charge via the Internet at http://pubs.acs.org.

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(13) For a recent paper on the oxidative addition of alcohols with transition metals, see: Blum, O.; Milstein, D. *J. Am. Chem. Soc*. **2002**, *124*, 11456 and references therein.

(14) Chang recently reported on the chelation-assisted hydroesterification of alkenes with 2-pyridylmethyl formate using $Ru_3(CO)_{12}$ as the catalyst. No CO is required. Ko, S.; Na, Y.; Chang, S. *J. Am. Chem. Soc*. **2002**, *124*, 750.