

Catalytic hydrogen-transfer reactions of benzylic and allylic alcohols with palladium compounds in the presence of vinyl acetate or under an ethylene atmosphere

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An efficient and simple process for conversion of benzylic and allylic alcohols into their corresponding carbonyl compounds has been developed using a catalytic amount of a palladium compound (Pd(OAc)₂ or Pd/C) and an alkene (vinyl acetate or ethylene).

The transformation of alcohols into aldehydes and ketones is one of the most fundamental reactions in organic synthesis.¹ For this purpose, some stoichiometric oxidizing agents such as chromium and manganese salts have previously been used. However, these metal salts are usually toxic and hazardous and they often cause environmental problems. Therefore catalytic processes using oxygen or aqueous H₂O₂ as oxidizing agents with the aid of less toxic metal complexes are desirable from an environmental viewpoint. Recently, Markó *et al.* reported an efficient catalytic system consisting of CuCl–phenanthroline–K₂CO₃–DBADH₂ (1,2-bis(*tert*-butoxycarbonyl)hydrazine)^{2a} and TPAP (tetrapropylammonium perruthenate) and MS 4 Å^{2b} using oxygen or air as an oxidant. Noyori and co-workers developed organic solvent- and halide-free oxidation of alcohols with aqueous H₂O₂ using Na₂WO₄ and a phase-transfer catalyst (PTC) system.^{2c} With regard to a Pd(II) catalyzed process, Uemura *et al.* reported Pd(OAc)₂-catalyzed oxidation of alcohols using molecular oxygen in the presence of MS 3 Å.^{2d} A similar type of palladium-catalyzed oxidation of alcohols was reported by Peterson and Larock.^{2e} Hydrogen-transfer reactions using transition metal catalysts have also been examined intensively.³ During our study of C-glycoside synthesis using D-glucal,⁴ we found that the hydrogen-transfer reaction of D-glucal using a catalytic amount of a palladium compound such as Pd(OAc)₂ or Pd/C in the presence of vinyl acetate or under an ethylene atmosphere, led to the catalytic and efficient synthesis of 1,5-anhydrohex-1-en-3-uloses.⁵ This successful discovery prompted us to examine the general utility of this hydrogen-transfer reaction for other alcohols, since this extremely simple reaction could become a valuable method for the transformation of alcohols into their corresponding carbonyl compounds. Here we would like to report the hydrogen-transfer reaction of some benzylic and allylic alcohols with a catalytic amount of Pd(OAc)₂ or Pd/C in the presence of vinyl acetate or under an ethylene atmosphere.⁶

A variety of benzylic and allylic alcohols were converted into the corresponding carbonyl compounds under the following conditions; 20–50 weight% of 10% Pd/C, 3 equiv. of vinyl acetate or an ethylene atmosphere in acetonitrile at 50–80 °C. The results obtained are summarized in Table 1. In many cases, the combination of Pd/C and ethylene exhibited the most efficient conversion, although this proved to be slightly dependent on the nature of the substrates. Secondary benzylic alcohols such as benzhydrol, *sec*-phenethyl alcohol, and 2-hydroxy-2-phenylacetophenone (benzoin) were converted into their corresponding ketones in high yields (78–90% yield) under the above conditions. It should be mentioned that in the *absence* of ethylene, the secondary benzylic alcohols such as **1**, **3** and **5** were dehydrogenated to the corresponding ketones **2**, **4** and **6** in lower yields, due to by-products such as dehydroxylation prod-

ucts being obtained. For example, in the case of alcohol **1**, diphenylmethane was obtained in 16–24% yield, whereas under an ethylene atmosphere the formation of diphenylmethane was not observed at all. Primary allylic alcohols such as cinnamyl alcohol, geraniol and nerol were less reactive, although isomerization was not observed under the reaction conditions. The corresponding α,β -unsaturated aldehydes were obtained in 64, 36 and 21% yields, respectively. Steroidal allylic alcohol was also oxidized. The reaction of **11** with Pd/C under an ethylene atmosphere gave 19-nortestosterone (**12**) in 84% yield and ketone **13** in 5% yield. In this catalytic system the allylic alcohol was oxidized whilst the non-allylic hydroxy group was not. This is in contrast with the products obtained *via* equimolar reactions. For example, Czernecki and co-workers reported that both of the hydroxy groups in **11** were oxidized by treatment with a stoichiometric amount of Pd(OAc)₂.⁷ The reaction of **11** with 9 equiv. of activated MnO₂ (in CHCl₃, 50 °C, 23 h) gave **12** in 68% yield.

The reactions of cyclohex-2-en-1-ol (**14**) and cyclohex-2-en-1-one (**16**) with Pd(OAc)₂ are shown in Tables 2 and 3. The reaction of **14** with 5 mol% of Pd(OAc)₂ in the absence of ethylene in a sealing tube gave 24% phenol (**15**), 40% cyclohexanone (**17**) and 36% cyclohexanol (**18**). On the other hand, when the reaction was performed under an ethylene atmosphere, the yield of phenol was increased to 68% (cyclohexanone **17**, 28%; cyclohexanol **18**, 4%). The formation of cyclohex-2-en-1-one (**16**) was not observed either case when the reactions were completed.⁸ We then examined the reaction of cyclohex-2-en-1-one (**16**) with Pd(OAc)₂. The reaction of **16** was less reactive than that of **14** and required a longer reaction time (Table 3).

The reaction of **16** gave phenol (**15**) and cyclohexanone (**17**) in almost equal yields (**15**, 53%; **17**, 47%) in the absence of ethylene, whereas under an ethylene atmosphere, the reactions catalyzed by Pd(OAc)₂ produced phenol in >99% yield (cyclohexanone **17**, <1%). A similar phenomenon was also observed in the reaction when using Pd/C–ethylene. The palladium precipitate which was formed in the reaction using Pd(OAc)₂ was found to be reusable. The composition of this palladium precipitate proved to be the same as palladium black, after analysis by powder X-ray diffraction.

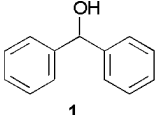
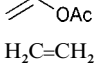
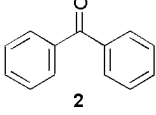
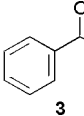
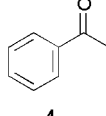
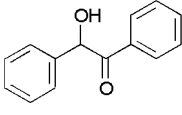
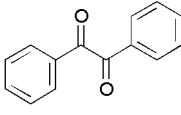
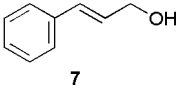
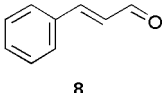
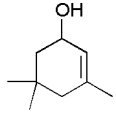
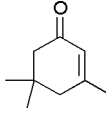
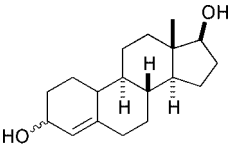
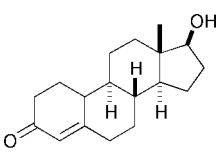
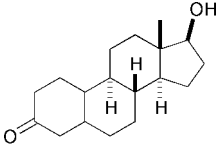
In summary, we have developed an efficient and catalytic system which transforms benzylic and allylic alcohols into their corresponding carbonyl compounds.† This extremely simple process is not only economically viable but it is also environmentally friendly. It is often the case that relatively long reaction times are necessary for completion of the reaction, therefore, the search for more reactive systems is now in progress in our laboratory.

Experimental

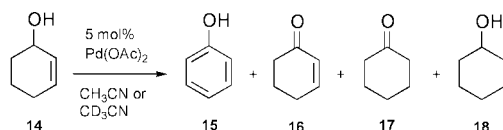
General

All melting points are uncorrected. ¹H and ¹³C NMR spectra were recorded on a Bruker Avance 400S spectrometer (400 and

Table 1 Conversion of benzylic and allylic alcohols into carbonyl compounds^a

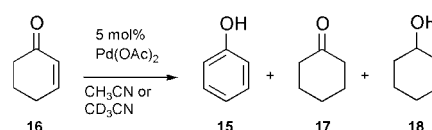
Entry	Substrate	Palladium compound ^b	Olefinic compound	T/ ^o C (t/days)	Product	Yield (%) ^c
1		Pd/C ^b	 H ₂ C=CH ₂	80 (2.5) 50 (4)		83 86
2		Pd/C ^b	H ₂ C=CH ₂	50 (2)		78
3		Pd/C	H ₂ C=CH ₂	50 (3.5)		86
4		Pd/C	H ₂ C=CH ₂	50 (4)		64 ^d
5		Pd/C	H ₂ C=CH ₂	50 (4)		75
6		Pd/C	H ₂ C=CH ₂	50 (4.5)		84
						5

^a All reactions were carried out in acetonitrile using 50 weight% of 10% Pd/C unless otherwise stated. ^b 20 weight% of 10% Pd/C was used. ^c Isolated yield unless otherwise stated. ^d Determined by ¹H NMR (400 MHz) with *s*-trioxane as an internal standard.

**Table 2** Reaction of cyclohex-2-en-1-ol (**14**) with a catalytic amount of Pd(OAc)₂^a

Substrate	Olefin	Conditions		Yield (%) ^b			
		T/ ^o C	t/h	15	16	17	18
14	None	50	7	24	0	40	36
14	Ethylene	50	30	68	0	28	4

^a Reactions were carried out using 5 mol% of Pd(OAc)₂. ^b Determined by GLC and ¹H NMR analysis.

**Table 3** Reaction of cyclohex-2-en-1-one (**16**) with a catalytic amount of Pd(OAc)₂^a

Substrate	Olefin	Conditions		Yield (%) ^b		
		T/ ^o C	t/h	15	17	18
16	None	50	66	53	47	0
16	Ethylene	50	66	>99	<1	0

^a Reactions were carried out using 5 mol% of Pd(OAc)₂. ^b Determined by GLC and ¹H NMR analysis.

100.6 MHz, respectively) using TMS as an internal standard unless otherwise stated. Gas-liquid phase chromatography (GLC) analyses were performed on a Hitachi G-5000 instrument. Preparative column chromatography was carried out on a

Fuji-Davison BW-820 or Wacogel 300 instrument. Thin layer chromatography (TLC): foil plates, silica gel 60 F₂₅₄ (Merck; layer thickness 0.2 mm). Acetonitrile was distilled from P₄O₁₀. Pd/C was purchased from Wako.

General procedure

A dry Schlenk tube containing a Teflon-coated stirring bar and an ethylene atmosphere was charged with alcohols (2.4–25 mmol) and acetonitrile (1–6 mL). To this mixture was added 5 or 10% Pd/C (20–50 weight% per alcohol) and the mixture was stirred vigorously at 50–80 °C for 2–4 days under an ethylene atmosphere using a balloon. The reactions without ethylene were carried out in sealing tubes. The conditions are indicated in Table 1. After the confirmation of the completion of the reactions by TLC and/or GLC, the palladium precipitate was filtered off. After removal of the solvent, the products were purified by distillation or silica-gel column chromatography. All spectral data of the products were identical with those of the commercially available authentic samples.

Acknowledgements

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Notes and references

† Simple primary and secondary alcohols such as *n*-octyl alcohol, cyclohexanol and (–)-menthol were inert under these reaction conditions.

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