

Palladium-Catalyzed Decarboxylation and Decarbonylation under Hydrothermal Conditions: Decarboxylative Deuteration

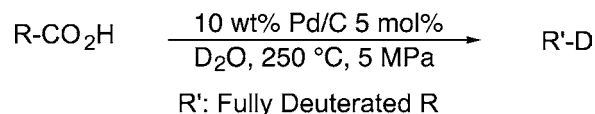
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ABSTRACT



Decarboxylation of free carboxylic acid was performed by Pd/C catalyst under hydrothermal water (250 °C/4 MPa). Under the hydrothermal conditions of deuterium oxide, decarboxylative deuteration was observed to give fully deuterated hydrocarbons from carboxylic acids or aldehydes.

The decarboxylation of free carboxylic acids is often difficult except for some activated acids such as aryl carboxylic acid. Even in this case, it was performed by palladium or nickel catalyst at high temperatures in the gas phase under a hydrogen atmosphere.^{1a,b} Conversion of the free carboxylic acids into proper derivatives such as acid anhydrides or esters makes the transition metal-catalyzed decarboxylation reaction easy,² and these have also been applied to various coupling reactions.³ Recently, we focused on organic reactions under hydrothermal conditions. When water in a closed pot is heated beyond the boiling point, it becomes hydrothermal and finally reaches the supercritical point (374 °C, 22 MPa),^{4,5} and these conditions were applied for various chemical processes. We reported that palladium catalyst under hydrothermal deuterium oxide was effective for H–D

exchange reaction of hydrocarbons.⁶ In this reaction, we assumed that the palladium deuteride, which seems to be also effective for the decarboxylation reaction,^{1c} works as a reagent. Here, we report that the combination of palladium catalyst and hydrothermal water was found to be effective for decarboxylation of free carboxylic acids and decarbonylation of aldehydes. These degradation reactions can also be applied for the preparation of deuterium-labeled compounds.

As shown in Scheme 1, 2-(4-hydroxyphenyl)-propanoic acid (**1**, 3.0 mmol) was treated with 10 wt % Pd on active carbon (100 mg, 0.1 mmol Pd) and water (20 g) in a 30 mL Teflon-lined autoclave at 250 °C.^{6,7} The internal pressure reached 4–5 MPa. The mixture was heated at the same temperature for 12 h. The obtained product was 4-hydroxy-

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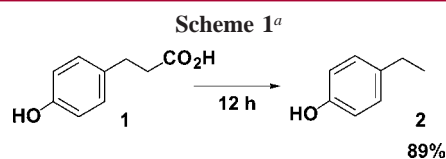
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^a Conditions: 10 wt % Pd/C (5 mol %), H₂O, 250 °C, 4–5 MPa.

phenylethane (**2**) in 89% yield. Without the catalyst, carboxylic acid **1** was recovered quantitatively, under the same hydrothermal conditions (250 °C/4–5 MPa).

Table 1. Degradation of Carboxylic Acids, Aldehydes, and Amides^a

Substrates	Reaction time	Product	Yield
	14 h		25% ^b
	14 h		22% ^b
	14 h		23% ^b
	14 h		77%
<i>n</i> -C ₁₃ H ₂₇ CO ₂ H	12 h	<i>n</i> -C ₁₃ H ₂₈	28% ^b
	14 h		74%
	14 h		70%
Ph ₃ CCO ₂ H	14 h	Ph ₃ CH	99%
	4 h		81%
	4 h		86%
	14 h		50%

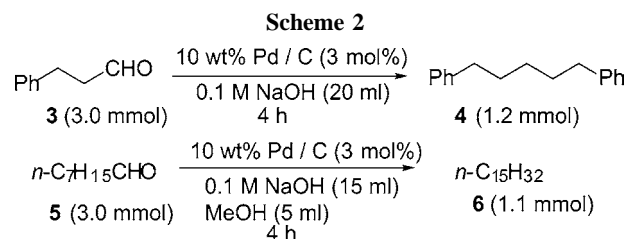
^a Conditions: substrate (3.0 mmol), 10 wt % Pd/C (3 mol %), H₂O (20 mL), 250 °C, 4–5 MPa. ^b Rest of the compounds were the starting carboxylic acids.

In Table 1, other examples of reductive degradation reactions are demonstrated. Not only carboxylic acids but also aldehydes and amide were also degraded. Schleyer explained that the reductive decarboxylation by Pd/SiO₂ under H₂ proceeded via alkylidene palladium losing CO₂ gas on the metal surface.^{1a} Hydrogen reduced the intermediate. Under our reaction conditions (10 wt % Pd/C (3 mol %), H₂O, 250 °C, 4–5 MPa), 4-phenyl-3-buten-2-one was converted into 4-phenylbutan-2-one in 64% yield.⁸ This result

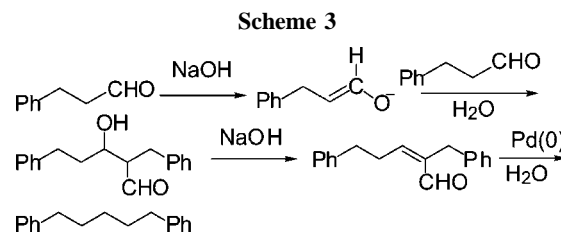
(8) Oxidation of alcohol by hydrogen transfer in water under microwave irradiation: Takahashi, M.; Oshima, K.; Matsubara, S. *Tetrahedron Lett.* **2003**, *44*, 9201.

means that a hydride species was formed from Pd/C and hydrothermal water. From this point, we can assume that our decarboxylation reaction proceeds in the same way as Schleyer's. The decarbonylation of aldehyde may proceed in a different way. A direct insertion into a C–H bond affords an acyl palladium carrying hydride on Pd, which will give the reductive degradation product.^{1c} Regardless, we cannot determine the mechanism at this moment.

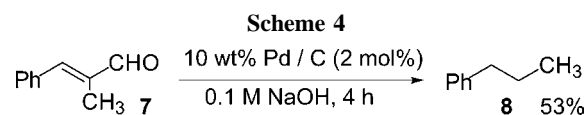
Treatment of hydrocinnamaldehyde (**3**) with Pd/C catalyst under the hydrothermal conditions of 0.1 M NaOH aq (250 °C, 4–5 MPa) gave the coupling product 1,5-diphenylpentane (**4**) in 90% yield. Octanal (**5**) was also converted into



n-pentadecane (Scheme 2). The reaction pathway is shown in Scheme 3. Aldol, which was formed by the aldol reaction

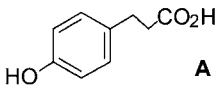
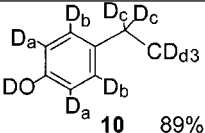
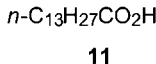

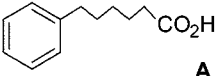
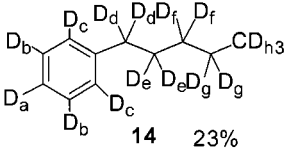
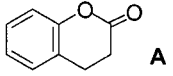
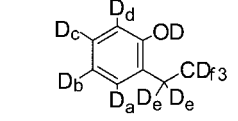
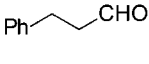
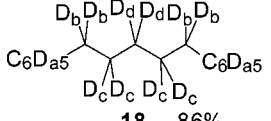


under basic conditions, was converted into enal as the sole product.⁸ The enal was transformed into **4** via reduction and decarbonylation. As shown in Scheme 4, treatment of enal **7** itself with Pd/C under basic hydrothermal conditions afforded saturated decarbonylated product **8** as shown in Scheme 4.



These degradation reactions under hydrothermal conditions can be performed in deuterium oxide instead of water as shown in Table 2.^{6,9–11} 4-Hydroxyphenylpropionic acid was converted into the fully deuterated 4-hydroxyphenylethane. Under hydrothermal conditions, H–D exchange on alkane proceeds as we reported and occurs smoothly at the α -position of carbonyl group, as its protons are acidic.^{6,9}

Table 2. Decarboxylative Deuteration

Substrate	Condition	Product	D%
	A		D _a : 98%D D _b : 98%D D _c : 97%D D _d : 97%D
$n\text{-C}_{13}\text{H}_{27}\text{CO}_2\text{H}$	A	$n\text{-C}_{13}\text{D}_{28}$	91%D
	A		28%
	A		D _a : >99%D D _b : >99%D D _c : 44%D D _d : 97%D D _e : 99%D D _{f,g} : 98%D D _h : 99%D
	A		D _a : 85%D D _b : 98%D D _c : 98%D D _d : 98%D D _e : 98%D D _f : 98%D
	B		D _a : 93%D D _b : 95%D D _c : 95%D D _d : 95%D

^a Conditions A: substrate (3.0 mmol), 10 wt % Pd/C (5 mol %), D₂O (20 mL), 250 °C, 4–5 MPa, 12 h. ^b Conditions B: substrate (3.0 mmol), 10 wt % Pd/C (5 mol %), 0.1 M NaOH/D₂O (20 mL), 250 °C, 4–5 MPa, 6 h.

Decarboxylation follows the exchange, so the deuteration ratio on the methyl group in compound **10** is quite high. The degradation reaction based on aldol condensation was also possible with deuteration (**16**).

Although the hydrothermal reaction was performed at 230–250 °C/4–5 MPa, the surrounding water prevents the decomposition of organic compounds. It is different from simple heating. Unfortunately, the inside of the reaction mixture has not been studied well, but we have begun the mechanistic studies.

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Supporting Information Available: Experimental details and spectral data of the compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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