Tetrahedron Letters,Vol.22,No.52,pp 5327-5330,1981 0040-4039/81/525327-04$02.00/0
Printed in Great Britain

RUTHENIUM CATALYZED TRANSFORMATION OF ALCOHOLS TO ESTERS AND LACTONES

Shun-Ichi Murahashi*, Kei-ichiro Ito, Takeshi Naota, and Yoshihiro Maeda
Department of Chemistry, Faculty of Engineering Science, Osaka University,
Machikaneyama, Toyonaka, Osaka, Japan 560.

Homogeneous catalytic oxidative condensation of alcohols and diols to their corresponding esters and lactones has been accomplished using $RuH_2(PPh_3)_4$.

Although catalytic transformation of alcohols to esters is of importance in view of industrial process and synthetic means, reported methods are limited to few non-selective heterogeneous reactions.[1] During the course of exploring catalytic reactions of alcohols with amines[2], we have found an efficient homogeneous catalyzed oxidative condensation of alcohols to esters and lactones.[3] Recent paper by Shvo which reports hydrogen transfer reaction of alcohols with $Ru_3(CO)_{12}$ prompts us to report our efficient method.[4]

The reaction of alcohols with dihydridotetrakis(triphenylphosphine)-ruthenium (1) takes place at 180° highly efficiently as depicted in eq(1).

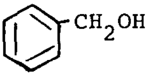
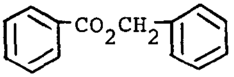
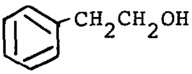
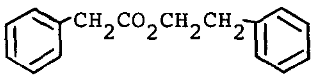
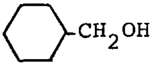
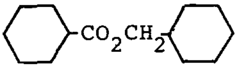
$$RCH_2OH \xrightarrow{RuH_2(PPh_3)_4 \quad (1)} RCO_2CH_2R \quad + \quad H_2 \qquad (1)$$

This process provides a convenient method for synthesis of esters and lactones because of its high efficiency, simplicity, and facile isolation of the desired products.

The catalytic activity of various metal complexes has been examined for the reaction of 1-hexanol. The products which are detected during the reactions are hexyl hexanoate (2), 1,1-dihexyloxyhexane (3), and dihexyl ether (4). The dihydride complex 1 gave the ester 2 (98%) with a trace amount of 3. The control experiments showed that 3 was not the precursor of 2. The chloride complexes, such as $PdCl_2$, $RuCl_3 \cdot 3H_2O$, $RuCl_2(PPh_3)_3$, $RhCl_3 \cdot 3H_2O$, and $RhCl(PPh_3)_3$ produced either 2 or 3 predominantly. Using solvents such as hexane, toluene, and mesitylene or without solvents satisfactory results were obtained.[5]

Table 1 summarizes the representative examples of the ester formation. In a typical case, a mixture of 1-hexanol (0.255 g, 2.5 mmol) and $RuH_2(PPh_3)_4$ (0.058 g, 0.05 mmol) was dissolved in dry toluene (0.5 mL) under argon. The solution was reacted in a sealed tube at 180°C for 24 hr. Removal of toluene, followed by distillation gave hexyl hexanoate (bp 110°/6mmHg) (0.176 g, 70%).

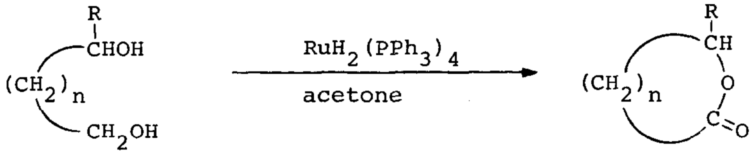
Table 1. The Ruthenium Catalyzed Reaction of Primary Alcohols[a]

Entry	Alcohol	Time(hr)	Conv.(%)	Ester	Yield[b](%)
1	C_4H_9OH	24	76	$C_3H_7CO_2C_4H_9$	98
2	$C_6H_{13}OH$	24	75	$C_5H_{11}CO_2C_6H_{13}$	98
3		24	88		97
4		16	53		92
5	$EtCH(Me)CH_2OH$	20	52	$EtCH(Me)CO_2CH_2CH(Me)Et$	78
6		24	89		93[c]

[a] A mixture of an alcohol (2.5 mmol) and $RuH_2(PPh_3)_4$ (0.05 mmol) in dry toluene (0.5 mL) was reacted at 180° under argon. [b] GLC yield based on the starting alcohol. [c] Diphenylacetylene (2.5 mmol) was added.

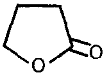
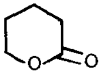
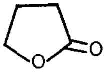
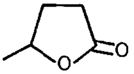
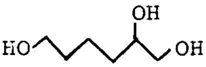
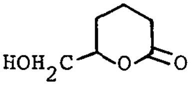
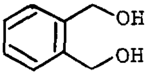
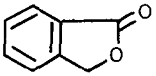
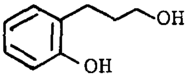
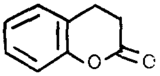
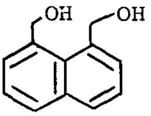
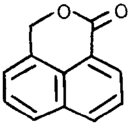
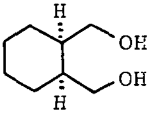
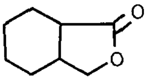
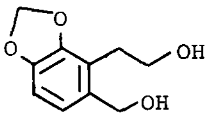
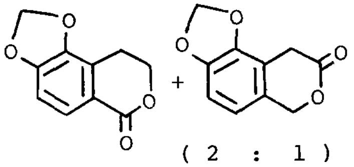
Since the dehydrogenation steps in the present reaction are reversible[6], the reaction is enhanced by accepting hydrogen with an appropriate hydrogen acceptor. Indeed, the conversion of alcohols increased 85 - 90%, however, the yields of esters decreased to 75 - 80%.

The oxidative condensation reaction can be applied to the lactone synthesis from diols. Such a reaction is particularly interesting in comparison with enzyme catalyzed oxidation reactions.[7] 1,4- and 1,5-Diols can be converted into γ- and δ-lactones in excellent yields, when the lactonization is carried out in the presence of 3 molar equivalents of acetone. Although ketones are generally less effective hydrogen acceptors than alkynes and α,β-unsaturated ketones[8], acetone is remarkably effective in the reaction. In the absence of acetone, the conversion of diols are limited to 40 - 50%.



Typical examples of the lactonization are summarized in Table 2. Most importantly, primary alcohols are oxidized chemoselectively, giving lactones (Entries 4 and 5). Quite recently Nozaki et al reported selective oxidation of alcohols to aldehydes using half mole of $RuCl_2(PPh_3)_3$.[9] Neither 1,3- nor 1,6-diols can be converted into the corresponding lactones (Entry 5). Allylic alcohols undergo the lactonization along with hydrogenation of carbon-carbon double bonds (Entry 3). Phenols undergo the lactonization slowly (Entry 7).

Table 2. The Ruthenium Catalyzed Lactonization of Diols[a]

Entry	Diol	Time (hr)	Acetone[b]	Conv. (%)	Lactone	Yield[c] (%) (Isolated)
1		3	1	90		100
2		2	3	86		95
3		3	3	100		88
4		3	3	96		96
5		3	3	100		(71)
6		12	0	100		(82)
7		10	3	89		90
8		6	3	100		(95)
9		15	0	100		(83)
10		3	3		 (2 : 1)	(60)

---

[a] A mixture of a diol (2.5 mmol), acetone and $RuH_2(PPh_3)_4$ (0.05 mmol) in dry toluene (0.5 mL) was reacted at 180° under argon. [b] The molar ratio of acetone/diol. [c] GLC yield based on the starting alcohol.

The course of the reaction can be readily accounted for by the mechanism in the following Scheme, where (Ru) stands for a coordinatively unsaturated low valent ruthenium complex and (RuH_2) for dihydride complex. Oxidative addition of ruthenium to the OH bond of a primary alcohol followed by β-elimination gives an aldehyde and (RuH_2). Hemiacetal formation followed by the similar dehydrogenation gives an ester.[1,10] Other mechanisms which involve the oxidative addition of ruthenium into RCHO, giving acylhydridoruthenium complex[11] or disproportionation of an aldehyde to an alcohol and an acid[12] seem unlikely in the present reaction.

Scheme

$$\mathrm{RCH_2OH} \xrightleftharpoons{\mathrm{(Ru)}} \mathrm{RCHO} + (\mathrm{RuH_2})$$

$$\mathrm{RCHO} + \mathrm{RCH_2OH} \rightleftharpoons \mathrm{RCH(OH)OCH_2R}$$

$$\mathrm{RCH(OH)OCH_2R} \xrightleftharpoons{\mathrm{(Ru)}} \mathrm{RC(O)OCH_2R} + (\mathrm{RuH_2})$$

References and Notes

1. K, Takeshita, S. Nakamura, and K. Kawamoto, Bull. Chem. Soc. Jpn., 51, 2622 (1978), and references therein.
2. S.-I. Murahashi, T. Shimamura, and I. Moritani, Chem. Comm., 931 (1974).
3. S.-I. Murahashi, K. Ito, and Y. Maeda, The 43rd Annual Meeting of the Chemical Society of Japan (Tokyo, April, 1981) 3D 45.
4. Y. Blum, D. Reshef, and Y. Shvo, Tetrahedron Lett., 1541 (1981).
5. Polar solvents such as THF and diglyme retarded the reaction.
6. Y. Sasson and J. Blum, Chem. Comm., 309 (1974).
7. I. J. Jakovac, G. Ng, K. P. Lok, and J. B. Jones, Chem. Comm., 515 (1980).
8. S. L. Regen and G. M. Whitesides, J. Org. Chem., 37, 1832 (1972); Y. Sasson and G. L. Rempel, Can. J. Chem., 52, 3825 (1974).
9. H. Tomioka, K. Takai, K. Oshima, and H. Nozaki, Tetrahedron Lett., 1605 (1981).
10. The typical control experiments are as follows: The reaction of 1-hexanol (1 mmol) with hexanal (1 mmol) in toluene at 180° for 4hr gave ester **2** in 81% (conv. of 1-hexanol, 41%), while the reaction of hexanal (2 mmol) gave **2** in 6% (conv. of 1-hexanol, 52%) under the similar condition.
11. H. Horino, T. Ito, and A. Yamamoto, Chem. Lett., 17 (1978).
12. J. Cook, J. E. Hamlin, A. Nutton, and P. M. Maitlis, Chem. Comm., 144 (1980).

(Received in Japan 14 September 1981)