J|A|C|S
COMMUNICATIONS

Development of a Highly Efficient Catalytic Method for Synthesis of Vinyl Ethers

Yoshio Okimoto, Satoshi Sakaguchi, and Yasutaka Ishii*

Department of Applied Chemistry, Faculty of Engineering, Kansai University, Suita, Osaka 564-8680, Japan

Received October 26, 2001

The achievement of environmentally benign, highly efficient catalytic processes results in contributions to organic synthesis for the supply of raw materials needed in our life. Vinyl ethers are important raw materials as practical chemicals for the production of glutaraldehyde[1] as well as vinyl polymer materials[2] containing oxygen which are expected to degrade easily in nature. Practically, vinyl ethers are prepared by the reaction of acetylene with alcohols that was developed by Reppe et al. in 1956.[3] The reaction must be carried out under severe conditions at higher pressure (20−50 atm) and temperature (180−200 °C) in the presence of KOH as a catalyst. Several other methods are reported that prepare vinyl and alkenyl ethers: for example, mercury-catalyzed transvinylation of alcohols with vinyl ethers,[4] elimination of the alcohol moiety or HBr from acetals or α-bromo ethers, respectively,[5,6] isomerization of allyl ethers,[7] and carbometalation of alkynic ethers.[8] However, employment of these methods is limited to small-scale synthesis, and some methods call for the use of very toxic metals. Despite numerous attempts to overcome these drawbacks, no versatile methods have appeared for the synthesis of vinyl ethers so far. Therefore, successful production of vinyl ethers in practical scale will make it possible to provide new environmentally benign, biodegradable polymer materials. This paper discloses the first versatile catalytic method to allow the production of highly desired vinyl ethers from vinyl acetate and alcohols.

We have recently reported that iridium complexes such as $[IrCl(cod)]_2$ (**1**) catalyze unique coupling of imines with alkynes,[9a] hydrogenation of enones with alcohols,[9b] rearrangement of allyl homoallyl ethers,[9c] and aziridination of imines with diazoacetate.[9d] This iridium complex, **1**, was found to catalyze efficiently a new type of reaction between vinyl acetate (**2**) and alcohols or phenols leading to the corresponding vinyl ethers (Scheme 1).

The reaction of *n*-octyl alcohol (**3**) with **2** by **1** was carried out under various reaction conditions to confirm the optimum conditions (Table 1).

When a mixture of **1**, **2**, **3**, and Na_2CO_3 (the molar ratio is 0.01:2.0:1.0:0.6) in toluene was stirred at about 100 °C for 2 h, *n*-octyl vinyl ether (**4**) was obtained in almost quantitative yield [as determined by gas chromatographic analysis] (run 1). Evaporation of the solvent and the starting materials followed by a short column chromatography on silica gel (*n*-hexane) gave **4** in 98% isolated yield. It is worth noting that the present reaction produced vinyl ether **4** exclusively, because the vinyl ethers formed would tend to react further with an additional alcohol to form acetals rather than vinyl ethers in the Pd-catalyzed reaction.[10] Almost no reaction took place in the absence of Na_2CO_3 (run 4). Both AcONa and $NaHCO_3$ were also efficient as bases for the present reaction, but K_2CO_3, Cs_2CO_3, and pyridine were inert (runs 5−9). The reaction smoothly occurred even at 90 °C (run 10). The reaction with vinyl benzoate gave almost the same result as that with **2** (run 12).

Scheme 1

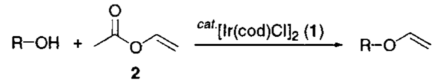


Table 1. Reaction of **3** with **2** to **4** Catalyzed by **1**[a]

run	additive	(mmol)	conv./%	yield/%[b]
1	Na_2CO_3	(0.6)	100	quantitative
2[c]	Na_2CO_3	(0.3)	100	82
3[c]	Na_2CO_3	(0.01)	86	67
4[c]	none		3	1
5	NaOAc	(0.6)	100	82
6	$NaHCO_3$	(1.2)	99	93
7	K_2CO_3	(0.6)	39	3
8	Cs_2CO_3	(0.6)	30	6
9	pyridine	(1.2)	2	1
10[d]	Na_2CO_3	(0.6)	98	96
11[e]	Na_2CO_3	(0.6)	85	84
12[f]	Na_2CO_3	(0.6)	98	97

[a] **3** (1 mmol) was allowed to react with **2** (2 mmol) in the presence of **1** (0.01 mmol) in toluene (1 mL) at 100 °C for 2 h under Ar. [b] GC yield. [c] **2** (5 mmol) was used. [d] 90 °C, 3 h. [e] 1,4-Dioxane (1 mL) was used as a solvent. [f] Vinyl benzoate (1 mmol) was used instead of **2**.

Table 2. Reaction of **3** with **2** to **4** Catalyzed by Several Transition Metal Complexes[a]

run	catalyst	conv./%	yield/%[b]
1	**1**	100	quantitative
2	$[Ir(cod)_2]^+BF_4{}^-$	72	70
3	$[Ir(cod)(CH_3CN)]^+BF_4{}^-$	98	90
4	$IrCl(CO)(PPh_3)_2$	no reaction	
5	$[RhCl(cod)]_2$	28	3[c]
6	$RuCl_2(cod)$	4	4
7	$PtCl_2(cod)$	9	1
8	$Pd(OAc)_2/PPh_3$	no reaction	

[a] Reaction was run as shown in Table 1 *a*. [b] GC yield. [c] *n*-Octyl acetate (25%) was produced.

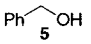
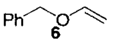
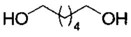
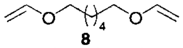
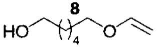
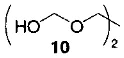
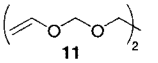
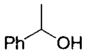
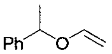
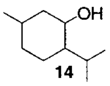
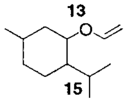
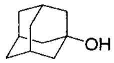
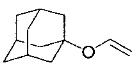
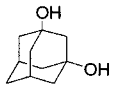
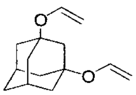
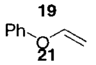
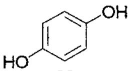
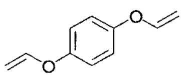
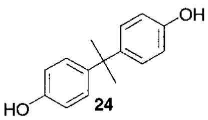
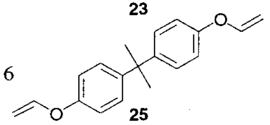
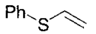
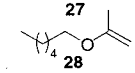
Table 2 summarizes the reaction of **3** with **2** under the influence of several transition metal complexes. Interestingly, the iridium complexes except for the Vaska complex have high catalytic activity for the present reaction, while other transition metal complexes such as Rh, Ru, and Pt complexes were inert (runs 4−7). In the case of the reaction with the Rh complex, *n*-octyl acetate was obtained in low yield (run 5). The reaction by the use of a $Pd(OAc)_2/PPh_3$ system did not take place (run 8).

On the basis of these results, the synthesis of various vinyl and divinyl ethers was examined (Table 3).

The reaction of **2** with hydroquinone (**22**) in the presence of AcONa led to divinyloxyhydroquinone (**23**) in 85% yield (run 9). The compounds **4** and **23** are not now available from commercial suppliers, although usage of these vinyl ethers is expected to be very interesting in polymer chemistry as components of homo- and copolymers. Similarly, aliphatic α,ω-diol like 1,6-hexanediol (**7**)

10.1021/ja0173932 CCC: $22.00 © 2002 American Chemical Society

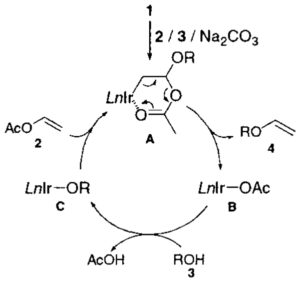
Table 3. Reaction of Various Alcohols with **2** Catalyzed by **1**[a]

Run	Substrate	Time / h	Product	Yield /%
1	 **5**	2	 **6**	94
2[b,c]	 **7**	6	 **8**  **9**	87 2
3[b,c]	 **10**	6	 **11**	63
4	 **12**	2	 **13**	95
5	 **14**	4	 **15**	86
6[d]	 **16**	5	 **17**	91
7[e]	 **18**	6	 **19**	75
8	Ph-OH **20**	2	 **21**	98 (79.7)[f] (99)[g]
9[c]	 **22**	6	 **23**	85
10[b,c]	 **24**	6	 **25**	90
11[h]	Ph-SH **26**	24	 **27**	92
12[i]	**3**	2	 **28**	78

[a] Substrate (1.0 mmol) was allowed to react with **2** (2 mmol) in the presence of **1** (0.01 mmol) and Na_2CO_3 (0.6 mmol) in toluene (1 mL) at 100 °C under Ar. [b] **2** (4 mmol). [c] NaOAc (1.2 mmol) was used instead of Na_2CO_3. [d] **2** (3 mmol). [e] **1** (0.02 mmol), **2** (5 mmol), and Na_2CO_3 (1.2 mmol). [f] **1** (1.04 μmol) was used. At 110 °C for 5 h. [g] **20** (100 mmol) was allowed to react with **2** (200 mmol) in the presence of **1** (1 mmol) and Na_2CO_3 (60 mmol) in toluene (100 mL) at 100 °C under Ar. [h] NaOAc (0.03 mmol) was used instead of Na_2CO_3. [i] Isopropenyl acetate (2 mmol) was used instead of **2**.

reacted with **2** under these conditions to afford 1,6-divinyloxyhexane (**8**) in good yield (87%) along with 6-vinyloxyhexyl alcohol (**9**) (2%) (run 2). Triethylenglycol (**10**) gave the corresponding divinyl ether, **11**, in good yield (run 3). The present catalytic system was found to be applicable to the synthesis of vinyl ethers from **2** and secondary and tertiary alcohols (runs 4−11). Thus, 1-adamantyl vinyl ether (**17**) was obtained from adamantanol (**16**) and **2** in 91% yield (run 6). Similarly, the reaction of phenol (**20**) with **2** produced the desired vinyl ether (**21**) in excellent yield (98%) (run 8). The reaction was found to take place with high turnover number (766). Additionally, a large-scale experiment was run. The reaction of 100 mmol (9.4 g) of **20** with 2 equiv of **2** under the same reaction conditions gave **21** in almost the same yield. It is noteworthy that thiophenol (**26**) reacted with **2** to form thiophenyl vinyl ether (**27**) in 92% yield (run 11), although sulfur compounds frequently inhibit transition metal-catalyzed reactions. In addition, the reaction of **3** with isopropenyl acetate under these conditions afforded isopropenyl *n*-octyl ether in 78% yield (run 12).

Scheme 2. Possible Reaction Path



To obtain mechanistic information, phenol-*d* (**20**-*d*) was allowed to react with **2** under these conditions.[11] It was found that no deuterium was introduced into the resulting phenyl vinyl ether. This may suggest the following reaction path through an intermediate **A** resulted from the reaction of **1** with vinyl acetate **2** and alcohol **3** under the influence of Na_2CO_3 (Scheme 2). The release of an alkyl vinyl ether **4** from the intermediate **A** gives rise to an iridium acetoxy complex **B**, which then reacts with alcohol **3**, leading to an iridium alkoxy complex **C**, and the coordination of the vinyl acetate **2** to the complex **C** followed by insertion regenerates the **A**.

In conclusion, a versatile synthetic method for a wide variety of vinyl ethers, which are very difficult to prepare thus far, through the addition−elimination sequence of alcohol and acetic acid using iridium complex as a catalyst has been developed.

Supporting Information Available: Experimental procedures and spectral data for compounds **11**, **19**, and **25** (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

References

(1) (a) Longley, R. A., Jr.; Emerson, W. S. *J. Am. Chem. Soc.* **1950**, *72*, 3079−3801. (b) Cope, A. C.; Dryden, H. L. Jr.; Howell, C. F. *Organic Syntheses*; Wiley & Sons: New York, 1963; Collect. Vol. IV, pp 816−819.

(2) (a) *Comprehensive Polymer Science*; Allen, G., Ed.; Pergamon Press: New York, 1989; Vol. 3. (b) *Encyclopeida of Polymer Science and Engineering*, 2nd ed.; Mark, H. F., Bikales, N., Overberger, C. G., Menges, G., Eds.; John Wiley: New York, 1989; Vol. 16. (c) Kojima, K.; Sawamoto, M.; Higashimura, T. *Macromolecules* **1989**, *22*, 1552−1557.

(3) Reppe, W. *Ann.* **1956**, *601*, 84−111.

(4) (a) Watannabe, W. H.; Conlon, L. E. *J. Am. Chem. Soc.* **1957**, *79*, 2828−2833. (b) Lüssi, H. *Helv. Chim. Acta* **1966**, *49*, 1681−1684.

(5) (a) Nerdel, F.; Buddrus, J.; Brodowski, W.; Hentschel, P.; Klamar D.; Weyerstahl, P. *Justus Liebigs Ann. Chem.* **1967**, *710*, 36−58. (b) Rhoads, S. J.; Chattopadhyay, J. K.; Waali, E. E. *J. Org. Chem.* **1970**, *35*, 3352−3358.

(6) (a) Yamawaki, J.; Kawate, T.; Ando, T.; Hanafusa, T. *Bull. Chem. Soc. Jpn.* **1983**, *56*, 1885−1886. (b) Mizuno, K.; Kimura, Y.; Otsuji, Y. *Synthesis* **1979**, 688.

(7) Larock, R. C. In *Comprehensive Organic Transformations*, 2nd ed.; Wiley-VCH: New York, 1999; pp 222 and 225−226.

(8) Alexakis, A.; Cahiez, G.; Normant J. F.; Villieras, J. *Bull. Soc. Chim. Fr.* **1977**, 693−698.

(9) (a) Sakaguchi, S.; Kubo T.; Ishii, Y. *Angew. Chem., Int. Ed.* **2001**, *40*, 2534−2536. (b) Sakaguchi, S.; Yamaga T.; Ishii, Y. *J. Org. Chem.* **2001**, *66*, 4710−4712. (c) Higashino, T.; Sakaguchi S.; Ishii, Y. *Org. Lett.* **2000**, *2*, 4193−4195. (d) Kubo, T.; Sakaguchi, S.; Ishii, Y. *Chem. Commun.* **2000**, 625−626.

(10) Tusji, J. *Palladium Reagents and Catalysts*; John Wiley & Son: New York, 1995; pp 33−34.

(11) AcOD was formed in this reaction. The formation of AcOD was confirmed by the conversion of AcOD to 1-acetoxy-2-deuterio-1-ethoxyoctane by the reaction with octyl vinyl ether without any catalyst.

JA0173932