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## Organometallic reactions in aqueous media: the allylations of carbonyl compounds mediated in Zn/CdSO<sub>4</sub> and Zn/SnCl<sub>2</sub> bimetal systems

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Abstract— $Zn/CdSO_4$  and  $Zn/SnCl_2$  bimetal systems were employed in the allylations of aldehydes or ketones in distilled water to afford the corresponding homoallylic alcohols in good yields. Also, the chemoselectivity was studied under the same condition. It was found that good chemoselectivity of allylations could be obtained for different carbonyl compounds under the mediation of our bimetal systems.

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A typical and popular organic reaction in aqueous media is the allylations of carbonyl compounds.<sup>1</sup> Up to now, many metals have been used in the allylation and different reaction conditions have been tested in order to broaden the scope of carbonyl compounds and enhance the reaction yield.<sup>2</sup> However, enhancing the reaction yield and extending the variety of carbonyl compounds is still a challenge to chemists. Recently, we found that  $Zn/CdSO_4$  and  $Zn/SnCl_2$  bimetal systems are quite efficient for the allylations of carbonyl compounds.

Intrigued by the allylations of carbonyl compounds in the bimetal systems,<sup>3</sup> we attempted to find more efficient bimetal systems to mediate the allylations of carbonyl compounds. The allylation of benzaldehyde was initially carried out in the presence of zinc in distilled water and the corresponding homoallylic alcohol was obtained in 20% yield (Table 1, entry 1). Once 0.1 mmol of cadmium sulfate was added to this reaction mixture, the allylation could proceed smoothly to afford the desired product in good yield and the reaction rate was enhanced significantly (Table 1, entry 3). Without metal zinc, the allylation of benzaldehyde was inert in the presence of cadmium sulfate in distilled water (Table 1, entry 2). The experimental results demonstrated that this new bimetal

Table 1.	Allylation	of	benzaldehyde	mediated	by	different	metal
systems							

Ph-CHO + $H_{2}$ Br $H_{2}$ $H_{2}$ PhCH(OH)CH <sub>2</sub> CH=CH <sub>2</sub>					
1	2	3			
Entry	Conditions <sup>a</sup>	Yield% <sup>f</sup> /time (h)			
1	Zn	20/24			
2	$CdSO_4$	0/24			
3	Zn/CdSO4 <sup>b</sup>	85/7.0			
4	Zn/CdSO4 <sup>c</sup>	87/7.0			
5	Mg/CdSO4 <sup>b</sup>	23/34			
6	Fe/CdSO <sub>4</sub> <sup>b</sup>	0/30 <sup>g</sup>			
7	Al/CdSO4 <sup>b</sup>	0/30			
8	Zn/SnCl2 <sup>d</sup>	28/24			
9	Zn/SnCl2 <sup>e</sup>	96/1.5			
10	Sn	93/13			
11	Cd	20/24			

<sup>a</sup> Metal(0) (2.0 mmol) unless stated.

<sup>b</sup>CdSO<sub>4</sub> (0.1 mmol).

<sup>c</sup>CdSO<sub>4</sub> (1.0 mmol).

<sup>d</sup> SnCl<sub>2</sub> (0.1 mmol).

<sup>e</sup>SnCl<sub>2</sub> (1.0 mmol).

<sup>f</sup> Determined by <sup>1</sup>H NMR.

<sup>g</sup> Polymerization occurred.

system  $(Zn/CdSO_4)$  was very efficient to mediate the allylation and there was a cooperating effect between Zn and CdSO<sub>4</sub> to the allylation. When the dosage of cadmium sulfate was increased from 0.1 to 1.0 mmol, there was little influence on the allylation of benzaldehyde

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(Table 1, entries 3 and 4). In addition to Zn, other metals were also employed as mediators in order to search for more efficient bimetal systems. The allylation of benzaldehyde gave the desired product with a low yield in the Mg/CdSO<sub>4</sub> system (Table 1, entry 5). In the Fe/CdSO<sub>4</sub> or Al/CdSO<sub>4</sub> system, no desired product was observed (Table 1, entries 6 and 7). Of all the examined bimetal systems, Zn/CdSO<sub>4</sub> turned out to be the most efficient system for the allylation. Considering the toxicity of cadmium salt, however, we have attempted to substitute CdSO<sub>4</sub> with other Lewis acids. After many trials, CdSO4 in the bimetal system was replaced with SnCl<sub>2</sub>. It was found that Zn/SnCl<sub>2</sub> bimetal system promoted the allylation more effectively than Zn/CdSO<sub>4</sub>. The difference compared with the Zn/CdSO<sub>4</sub> system was that the dosage of stannous chloride has an influence on the allylation of benzaldehyde. When 0.1 mmol of stannous chloride was added to this system, for example, the allylation generated the corresponding product in 28% yield after reaction for 24h (Table 1, entry 8). Once the dosage of stannous chloride was increased to 1.0 mmol, the allylation could proceed smoothly in 96% yield after reaction for 1.5h (Table 1, entry 9). In comparison with metal Sn or Cd, Zn/SnCl<sub>2</sub>, and Zn/ CdSO<sub>4</sub> systems for the allylation of benzaldehyde were obviously more effective (Table 1, entries 3, 9, 10, and 11). Subsequently, allylations of a variety of aldehydes and ketones were tested in the Zn/CdSO<sub>4</sub> and Zn/SnCl<sub>2</sub> systems. The results of the reactions are listed in Table 2.

As shown in Table 2, all the allylations proceeded smoothly to give the corresponding products in high yields and side reactions such as reductions and coupling reactions were not observed. Moreover, the reaction condition was so mild as not to affect chloro (Table 2, entry 5), methyl (Table 2, entry 6), and methoxyl (Table 2, entry 7) groups on the aromatic ring. Even hydroxyl group, which is unstable because of the rapid protonation with an allylation reagent, gave the corresponding allylation product under the reaction condition (Table 2,

Table 2. Allylation of various carbonyl compounds with allyl bromide

Ph-CHO+	$H_2O \xrightarrow{\text{Br}} \frac{\text{Zn/CdSO}_4(\text{or SnCl}_2)}{\text{H}_2O}$	PhCH(OH)CH <sub>2</sub> CH=CH <sub>2</sub>
1	2	3
Entry	Substrate	Yield%/time (h) <sup>a,b</sup>
1	C <sub>6</sub> H <sub>5</sub> CHO (1a)	85/7.0 (96/1.5)
2	Piperonal (1b)	63/17 (99/2.0)
3	CH <sub>3</sub> COCH(OH)CH <sub>3</sub> (1c)	81/5.5 (90/5.0)
4	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>5</sub> CHO (1d)	83/7.5 (96/3.0)
5	4-Cl–C <sub>6</sub> H <sub>4</sub> –CHO (1e)	67/8.0 (99/2.0)
6	4-CH <sub>3</sub> -C <sub>6</sub> H <sub>4</sub> -CHO (1f)	65/9.0 (99/2.0)
7	4-CH <sub>3</sub> O–C <sub>6</sub> H <sub>4</sub> –CHO ( <b>1g</b> )	64/9.0 (99/2.0)
8	1-Naphthaldehyde (1h)	35/18 (99/2.0)
9	1-Furaldehyde (1i)	80/18 (50/2.5)
10	$CH_3COC_2H_5$ (1j)	73/5.5 (99/2.5)
11	Cyclohexanone (1k)	80/20 (50/4.0)
12	CHO(CH <sub>2</sub> ) <sub>3</sub> CHO (11)	82/13 (70/3.0)
13	$4-NO_2-C_6H_4-CHO$ (1m)	c (60/2.0)

<sup>a</sup> Isolated yield.

<sup>b</sup> Data in parenthesis are the yields in Zn/SnCl<sub>2</sub>.

<sup>c</sup>Reduction reaction was observed.

entry 3). In particular, the Zn/SnCl<sub>2</sub> system mediated the allylations more effectively, and gave the corresponding homoallylic alcohols in excellent yields. In some cases, Zn/SnCl<sub>2</sub>-mediated allylations generated the corresponding adducts quantitatively (Table 2, entries 2, 5, 6, 7, 8, and 10). For the allylation of *p*-nitrobenzaldehyde, as far as we know, it is difficult to get the allylation product but the reduced nitro group products when mediated by indium or tin powder.<sup>2h,4</sup> In the Zn/ SnCl<sub>2</sub> system, however, the allylation of *p*-nitrobenzaldehyde gives the desired product in about 60% yield (Table 2, entry 13). This indicates that Zn/SnCl<sub>2</sub> could particularly improve the allylations. The allylations of butan-2-one, 3-hydroxy-butan-2-one, and heptanal were also mediated by Zn/SnCl<sub>2</sub> in distilled water and gave the corresponding alcohols in high yields (Table 2, entries 3, 4, and 10), while these allylations gave the corresponding adducts in the low yields of less than 50%when mediated by tin.<sup>2h</sup>

It is interesting to note that good chemoselectivity of the allylations can be observed in these two bimetal systems.<sup>5</sup> The experimental results are summarized in Table 3. It was found that allylation favored the aromatic aldehyde (1a) in the presence of an equivalent mole of aromatic ketone (1n) (Table 3, entry 1). When benzaldehyde (1a) mixed with o-methoxybenzaldehyde (10), benzaldehyde (1a) was easier to be allylated (Table 3, entry 2). When the methoxyl group was moved from ortho position to para position, p-methoxy-benzaldehyde (1g) favored the allylation more than benzaldehyde (Table 3, entry 3). These results could be ascribed to the steric hindrance. When aliphatic aldehyde (1d or 1p) was mixed with an equivalent mole of aromatic aldehyde (1a), the allylation squint toward aliphatic aldehyde (1d or 1p) (Table 3, entries 4 and 5) under this condition. Similarly, for an equivalent mole mixture of 1g and 1d, the allylation favored the aliphatic aldehyde 1d (Table 3, entry 6). However, it was found that allylation favored an aromatic aldehyde, 4-chloro-benzaldehyde (1e), in the presence of an equivalent mole of heptaldehyde (1d) possibly due to the electron-withdrawing effect of chlorine atom (entry 7). Such a reactivity difference between aldehyde and ketone or between aromatic aldehyde and aliphatic aldehyde suggests a useful method for chemoselectivity in aqueous allylations that has a potential application in synthetic strategies to construct complex molecules. In order to study this chemoselectivity further, some intramolecular competitive reactions were carried out under reaction conditions A and B, (Table 3). The compounds (1q, r) bearing both aldehyde and ketone groups gave the absolute predominant aldehyde allylation products (3q,r) (entries 12 and 13). The compound (1s) bearing both aromatic and aliphatic aldehyde groups gave predominantly the aliphatic aldehyde allylation product (3s) (entry 14). In a previous report, aliphatic aldehyde (1d) and aromatic aldehyde (1a) could be allylated equally in acidic aqueous media mediated by different metals such as zinc, indium, tin, or organometallic agents, respectively (entries 8, 9, 10 and 11).<sup>2d</sup>

In conclusion, two novel bimetal systems were applied to the allylations of carbonyl compounds, affording the

Table 3. Product distribution of allylation of different carbonyl compounds

	Substrate	Condition <sup>a</sup>	Yield% <sup>b</sup>
1	$(1a) \qquad O \\ O \\ C \\$	A B	<b>3a:3n</b> >99:1 <b>3a:3n</b> >99:1
2	(1a) O U H C H + O C H O C H O C H O C H O C H O C H O C H O C H O C H O C H O C H O O O C H O O C H O O O C H O O O C H O O O O O O O O O O O O O	A B	<b>3a:3o</b> >99:1 <b>3a:3o</b> >99:1
3	(1a) (1g) (1g) (1g) (1g) (1g) (1g) (1g) (1g	A B	<b>3a:3g</b> = 49:51 <b>3a:3g</b> = 41:59
4	$(1a) O H + CH_3(CH_2)_5CHO$	A B	<b>3a:3d</b> = 32:68 <b>3a:3d</b> = 41:59
5	$(1a) O = CH + CH_3(CH_2)_2CHO$	A B	<b>3a:3p</b> = 38:62 <b>3a:3p</b> = 42:58
6	$H_{3}CO$ (1g) (1d)	A B	<b>3g:3d</b> = 38:62 <b>3g:3d</b> = 39:61
7	O CI CI (1e) (1d)	A B	<b>3e:3d</b> = 64:36 <b>3e:3d</b> = 84:16
8	$(1a) O CH_3(CH_2)_5CHO$	Zn (0.1 N HCl)	<b>3a:3d</b> = 50:50
9	O CH + CH <sub>3</sub> (CH <sub>2)5</sub> CHO (1a) (1d)	In (0.1 N HCl)	<b>3a:3d</b> = 50:50
10	$ \begin{array}{c} O \\ - CH \\ + CH_3(CH_2)_5CHO \\ (1a) \\ \end{array} $ (1d)	Sn (0.1 N HCl)	<b>3a:3d</b> = 50:50
11	O CH + CH <sub>3</sub> (CH <sub>2)5</sub> CHO (1a) (1d)	Allylmagnesium bromide, Et <sub>2</sub> O	<b>3a:3d</b> = 50:50
12	$H_3C - C - C + CH_2 - C - H$ (1q)	A B	$3q:4q = 99:1^{\circ}$ $3q:4q = 99:1^{\circ}$
13	$H_3C-C$	A B	$3r:4r = 80:20^{\circ}$ $3r:4r = 99:1^{\circ}$
14	CHO O H (1s)	A B	<b>3s:4s</b> = 87:13° <b>3s:4s</b> = 81:19°

<sup>a</sup> Condition A: 1.0 mmol of carbonyl compound, 2.0 mmol of allyl bromide, 2.0 mmol of Zn, and 0.1 mmol of 3CdSO<sub>4</sub>·8H<sub>2</sub>O (based on CdSO<sub>4</sub>). Condition B: 1.0 mmol of carbonyl compound, 2.0 mmol of allyl bromide, 2.0 mmol of Zn, and 1.0 mmol of SnCl<sub>2</sub>·2H<sub>2</sub>O (based on SnCl<sub>2</sub>). <sup>b</sup> Indentified by GC–MS.

<sup>c</sup> Compounds **3q**,**r** were the products when **1q** and **1r** were allylated at the aldehyde groups, and **4q**,**r** were the products when **1q**,**r** were allylated at the ketone groups. Compounds **3s**, **4s** were the products when **1s** was allylated at the aliphatic and aromatic aldehyde groups, respectively.

corresponding homoallylic alcohols in good yield. In particular, the allylations of aliphatic ketones and aldehydes were improved significantly under the reaction conditions. More importantly, good chemoselectivity can be obtained in these two bimetal systems.

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