

# The DABCO-catalysed Baylis–Hillman reactions in the chloroaluminate room temperature ionic liquids: rate promoting and recyclable media

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## Abstract

The 1,4-diazabicyclo[2,2,2]octane (DABCO)-catalysed Baylis–Hillman reactions have been shown to be faster in the chloroaluminate room temperature ionic liquids with their good recovery after the completion of reactions.

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**Keywords:** Baylis–Hillman reaction; DABCO; Ionic liquid; Rates

## 1. Introduction

The Baylis–Hillman reaction (Scheme 1), one of the most important carbon–carbon bond-forming processes is very sluggish in nature [1]. In the past, several attempts have been made to accelerate this reaction by using water, salt solutions, different combinations of standard amine catalyst, 1,4-diazabicyclo[2,2,2]octane (DABCO), high pressure, ultrasound method and microwave irradiation [2]. Considering the urgent need of replacing volatile organic solvents by environmental-benign reaction media in the wake of Green Chemistry, the room temperature ionic liquids are emerging as useful media for carrying out several organic reactions. The preference of room temperature ionic liquids over conventional organic solvents in organic synthesis and other areas is established and is described in several reports [3].

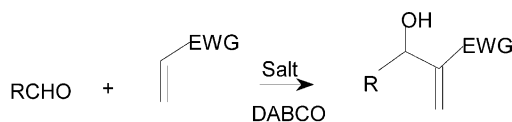
The chloroaluminates constituting a class of room temperature ionic liquids are versatile agents due to the fact that their nature can be easily altered from basic (1-ethyl-3-methyl-1H-imidazolium chloride (EMIC) or N-1-butylpyridinium chloride (BPC) in excess) to acidic ( $\text{AlCl}_3$  in excess) by manipulating its composition [4]. The ratio of  $\text{AlCl}_3$  over BPC or EMIC governs the nature of the chloroaluminates.

The chloroaluminates (Fig. 1) are the ambient temperature ionic liquids with composition as  $\text{AlCl}_3:\text{MCl}$ , where MCl is either N-1-butylpyridinium chloride (BPC)

or 1-ethyl-3-methyl-1H-imidazolium chloride (EMIC). The chloroaluminate ionic liquids have been used to improve the reaction conditions of Diels–Alder reactions [5,6], electrophilic aromatic substitutions [7] and many other reactions, including oligomerization [8] and electrochemical polymerisation [9]. Other significant reactions in the chloroaluminates include a variety of organometallic reactions [10].

DABCO is one of the most popular catalysts used for accelerating sluggish Baylis–Hillman reactions. A recent report has described acceleration of the DABCO-catalysed Baylis–Hillman reaction in an ionic liquid called 1-*n*-butyl-3-methylimidazolium hexafluorophosphate ([bmim][PF<sub>6</sub>]) [11]. It was later shown that the imidazolium salts are deprotonated under mild basic condition in order to offer reactive nucleophiles [12]. The low yields reported in the ionic liquids [11] result from the reaction between aldehyde and the reactive nucleophiles under mild basic conditions [12]. Kim et al. [13] have employed various 1-*n*-butyl-3-methylimidazolium [bmin]-based ionic liquids to accelerate Baylis–Hillman reactions. They achieved the maximum rate enhancement for the reaction of benzaldehyde and methyl acrylate with DABCO in [bmim][PF<sub>6</sub>]. A moderate acceleration in the reaction rates was observed if the above ionic liquid was used in combination with Lewis acid or H-bond additives. More importantly, the authors noted that the rate-enhancing effects of the ionic liquid and Lewis acid or H-bond donors were not additive. A two-fold rate increase was achieved in the mixtures of [bmim][PF<sub>6</sub>], Lanthanum triflate ( $\text{La}(\text{OTf})_3$ ) and 2,2',2''-nitrilotris[ethanol]. Kabalka et al. [14] have also employed [bmim]Br, [bmim]BF<sub>4</sub> and

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R = Ph / *o*-C<sub>6</sub>H<sub>4</sub>OMe / *p*-C<sub>6</sub>H<sub>4</sub>OMe

Scheme 1.

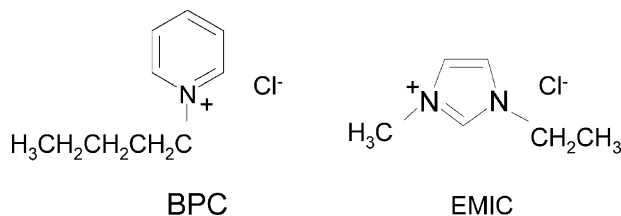


Fig. 1. The chloroaluminate ionic liquid.

[bmim]PF<sub>6</sub> ionic liquids for the transformation of acetates of Baylis–Hillman adducts into trisubstituted alkenes.

In this work, we wish to investigate the possibility whether the chloroaluminate ionic liquids can accelerate the DABCO-catalysed Baylis–Hillman reactions. We also attempt to check the performance of the chloroaluminates by recycling and reusing them in the reaction.

## 2. Experimental

### 2.1. Preparation of chloroaluminates

The chloroaluminates were prepared by the procedures described in the literature [15–18]. For a typical batch of BPC, pyridine (0.30 mol) and *n*-butyl chloride (0.28 mol) were refluxed in dark for about 72 h. After reflux, the mixture was cooled and solid was obtained after separating it from liquid by filtration. The solid was washed with ethyl acetate and recrystallized with 1:1 ethyl acetate/acetonitrile. After repeated filtration and washing with ethyl acetate the solid was transferred in a RB flask. The solid was dried over 70 °C for about 24 h under high vacuum. The solid was transferred to the dry box where it was stored in dark glass bottles. The chloroaluminate was prepared by mixing appropriate amount of AlCl<sub>3</sub> with BPC while stirring under nitrogen atmosphere [17]. The material obtained was a clear colourless liquid. A similar procedure was used to prepared EMIC-based chloroaluminate [16]. Due care was taken to handle the moisture-related problems of chloroaluminates [3d,16].

The composition of chloroaluminate was based on the scale of mole%.

### 2.2. Chemicals

All the aldehydes and acrylates employed in the investigation were of high quality and were distilled before use.

DABCO obtained commercially was purified prior to its use in reactions. All the solvents and AlCl<sub>3</sub> were of high quality and used as purchased.

### 2.3. Reactions

In a typical reaction, DABCO was added to the stirred mixtures of reactants dissolved in ionic liquid at 25 °C with the concentration parameters described in the tables. The reaction was quenched at the times reported with 3 ml of chilled water, neutralised with NaOH and the organics extracted with CH<sub>2</sub>Cl<sub>2</sub>. The crude mixture after usual work up was analysed with column chromatography using the published data [2,11]. The reactions were carried out in multiple vials to ensure that no further increase in yield took place after the times reported. The reported yields are isolated yields.

The products are known and their characteristics are reported in the literature [2,11]. The spectral data of the products were identical to those previously reported [2,11].

### 2.4. Rate determination

The progress of the reaction was monitored by GC. Five microliters sample withdrawn from the reaction mixture at desired time intervals was diluted with CH<sub>2</sub>Cl<sub>2</sub> was injected in GC. The conversion was determined by comparing the peak areas for the product and unreacted aldehyde. The relative rates were calculated with respect to the rate determined in CH<sub>3</sub>CN.

### 2.5. Recycle

Methyl acrylate was added to a magnetically stirred solution of benzaldehyde and DABCO in the chloroaluminates and stirred for 24 h and the reaction medium extracted with CH<sub>2</sub>Cl<sub>2</sub>. The ethereal extracts were reduced to 4 ml and applied to a TLC plate. Then methyl acrylate, benzaldehyde and DABCO were added to the recycled chloroaluminate for repeating the cycles.

## 3. Results and discussion

The reaction of benzaldehyde with methyl acrylate in the presence of DABCO was carried in the chloroaluminates (Table 1). The reaction in DABCO alone (without chloroaluminates) offered 65% product in 19 h.

The reaction in chloroaluminates containing 45% of AlCl<sub>3</sub> with BPC offered 67% product in 17 h, while the same composition with EMIC gave a product of 69% in 15 h (Table 1, entry 1) as compared to a yield of 35% in 24 h obtained in CH<sub>3</sub>CN. The product increases with increasing amounts of AlCl<sub>3</sub> in BPC to reach 76% in 11.5 h with 57% of AlCl<sub>3</sub>. A 20-fold rate enhancement was achieved in 60% AlCl<sub>3</sub>–BPC chloroaluminate. A high yield of 80% in 8 h is noted in 60%

Table 1  
DABCO-catalysed reaction of benzaldehyde with methyl acrylate in chloroaluminates ionic liquid<sup>a</sup>

Entry	% AlCl <sub>3</sub>	BPC			EMIC		
		Time (h)	Yield <sup>b</sup> (%)	Relative rate	Time (h)	Yield <sup>b</sup> (%)	Relative rate
1	45	17	67	3	15	69	3
2	47	15	71	5	13	72	6
3	49	14	73	6	12	75	7
4	51	13	74	10	11	76	12
5	53	12	75	12	10	78	13
6	55	12	76	14	9	79	18
7	57	11.5	76	16	9	79	21
8	60	11	75	20	8	80	23
9 <sup>c</sup>		24	35				
10 <sup>d</sup>		21	65	1			

<sup>a</sup> Reaction conditions: 1 mmol of benzaldehyde, 1.2 mmol of methyl acrylate, 1 mmol of DABCO, 1 ml solvent, no further increase in yield after the reported time.

<sup>b</sup> Isolated yields.

<sup>c</sup> In CH<sub>3</sub>CN.

<sup>d</sup> In 10% DABCO neat condition.

of AlCl<sub>3</sub> with EMIC with a 23-fold rate increase. No further improvements in yields are seen. The results listed in Table 1 shows that EMIC + AlCl<sub>3</sub> is more efficient chloroaluminate ionic liquid than the BPC + AlCl<sub>3</sub>, as it offers higher yields in comparatively shorter time. In order to examine the issue of how the product was influenced by time, the reactions were stopped at the desired intervals of time and analysed for their products. In 60% AlCl<sub>3</sub> with EMIC, we noted a sharp increase in the yield in the first 7h followed by 80% yield in 8.5 h. On the other hand, the reactions carried in BPC with 57% AlCl<sub>3</sub> showed comparatively slow increase

in the yields in the first 7 h to ultimately give 75% product in 11 h.

We next examined some very sluggish Baylis–Hillman reactions in the above-mentioned ionic liquids (Table 2). The reaction of benzaldehyde with acrylonitrile, which gave 82% yield in 9 h in DABCO alone, became faster by 9–10 times both in BPC and EMIC with 60% AlCl<sub>3</sub>. A mild increase in yield was observed. Similarly, the reactions of *p*-anisaldehyde and of isobutyraldehyde with ethyl acrylate became 9 and 12 times faster with improved yields in the presence of BPC and EMIC with 60% of AlCl<sub>3</sub> as compared

Table 2  
Yields and reaction times for Baylis–Hillman reactions in BPC and EMIC<sup>a</sup>

Entry	% AlCl <sub>3</sub>	BPC			Entry	EMIC		
		Yield (%)	Time (h)	Relative rate		Yield (%)	Time (h)	Relative rate
Benzaldehyde + acrylonitrile <sup>b</sup>								
1	45	87	8	2	4	87	7	3
2	55	90	7	5	5	92	7	6
3	60	93	5	9	6	95	6	10
<i>p</i> -Anisaldehyde + ethyl acrylate <sup>c</sup>								
7	45	65	36	3	10	67	35	4
8	55	70	31	6	11	74	30	7
9	60	75	27	9	12	79	27	12
Isobutyraldehyde + ethyl acrylate <sup>d</sup>								
13	45	21	44	3	16	23	41	3
14	55	26	40	6	17	28	39	8
15	60	26	35	8	18	30	34	10
<i>o</i> -Anisaldehyde + <i>tert</i> -butyl acrylate <sup>e</sup>								
19	45	27	17	4	22	29	15	5
20	55	33	12	7	23	35	10	9
21	60	39	8	10	24	39	7	11

<sup>a</sup> Reaction conditions: each reactant 1 mmol, 1 mmol of DABCO, 1 ml solvent, no further increase in yield after the reported time.

<sup>b</sup> In DABCO alone, yield = 82%, 9 h.

<sup>c</sup> In DABCO alone, yield = 62%, 44 h.

<sup>d</sup> In DABCO alone yield = 17%, 48 h.

<sup>e</sup> In DABCO alone, yield = 23%, 21 h.

to in DABCO alone. The reaction of isobutyraldehyde with ethyl acrylate is a sluggish process giving 17% product in 48 h when carried in DABCO. This reaction became faster with increasing  $\text{AlCl}_3$  to give up to 26 (35 h) and 30% (34 h) (Table 2, entries 13–18) in 60% of  $\text{AlCl}_3$  with BPC and EMIC, respectively. The rates were enhanced by 8–10 times in the BPC and EMIC-chloroaluminates. For the reaction of *o*-anisaldehyde with *tert*-butyl acrylate we also achieved a 16% increase in the yield and about 10-fold rate enhancement in both the BPC and EMIC containing 60%  $\text{AlCl}_3$  as compared to the results obtained in DABCO (Table 2, entries 19–24).

From the above reactions, it is clear that the enhancement in the reaction rates depends upon the  $\text{AlCl}_3$ -content of the ionic liquid.

The Baylis–Hillman reaction was reported to be faster by 1.6 times in  $\text{LiClO}_4$ -diethyl ether presumably due to the Lewis acid effect [2i]. In the current situation, we have consistently achieved an increase in rates of several reactions with the increase in the concentration of  $\text{AlCl}_3$ . Baylis–Hillman reactions are favoured in basic environment. The rate enhancement of Baylis–Hillman reactions due to Lewis acid effect in our case is a puzzling observation and is consistent with the experimental findings of Kim et al. [13]. With the available data, it is not possible to draw any conclusion on the role of ionic liquids and Lewis acid on the progress of Baylis–Hillman reactions (Table 3).

Recently, the formation of chlorinated product during the Baylis–Hillman reactions has been reported in the presence of  $\text{TiCl}_4$  and  $\text{ZrCl}_4$  in about 40–48 h, while in  $\text{BCl}_3$  in about 80 h [19]. Though the authors claim to have carried out the reactions in  $\text{AlCl}_3$ , no quantitative data were given to support the formation of chlorinated product in the presence of  $\text{AlCl}_3$ . In our work, we have not noted any amount of chlorinated products throughout in spite of repeated efforts.

Finally, it was possible to recover the chloroaluminates from the mixture by diluting it with diethyl ether. The recovered ionic liquid was used six times for the reaction of benzaldehyde with methyl acrylate. The yields recorded in all the six times ranged from 70 to 78% in the ionic liquids containing 60%  $\text{AlCl}_3$ . Each reaction was carried in the presence of DABCO.

Table 3

Yield for the reaction of benzaldehyde with methyl acrylate as a result of reuse of chloroaluminates (conditions defined in Table 1)<sup>a</sup>

Cycle	Yield (%) in BPC	Yield (%) in EMIC
1	74	78
2	71	77
3	73	78
4	72	75
5	71	76
6	70	76

<sup>a</sup> Each reaction carried in the presence of DABCO.

In summary, we have been able to demonstrate that the chloroaluminate ionic liquids can be employed to accelerate sluggish Baylis–Hillman reactions with recovery after their reuse.

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