JOC*Note*

Converting *exo*-Selective Diels−Alder Reaction to *endo*-Selective in Chloroloaluminate Ionic Liquids

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Abstract: The *endo*:*exo* ratio of 0.35:1 for the reaction of cyclopentadiene with methyl methacrylate observed in organic solvents can be converted to 3:1 in chloroaluminate ionic liquids with their effective reuse in Diels−Alder reactions.

The effect of solvents and their salt solutions on the rates and stereoselectivities of Diels−Alder reactions has been a subject of intense study[1] since the pioneering work of Breslow,[2] who discovered the special effect of water in enhancing the *endo*:*exo* ratios and rates of Diels−Alder reactions. Considering an urgent need of replacing conventional organic solvents due to environmental problems caused by them, room temperature ionic liquids have lately emerged as potential substitutes with their use in a variety of reactions.[3]

The chloroaluminates (Figure 1) are ambient temperature ionic liquids with composition $AlCl_3$:MCl, where MCl is either *N*-1-butylpyridinium chloride (BPC) or 1-ethyl-3-methyl-1*H*-imidazolium chloride (EMIC). Chloroaluminates are versatile agents because their nature can easily be altered from basic (EMIC or BPC in excess) to acidic ($AlCl_3$ in excess) by manipulating their composition.[4] The rationale to employ chloroaluminates in this connection is based on the fact that Lewis acid catalysis is known to influence the kinetics of Diels−Alder reactions.[5]

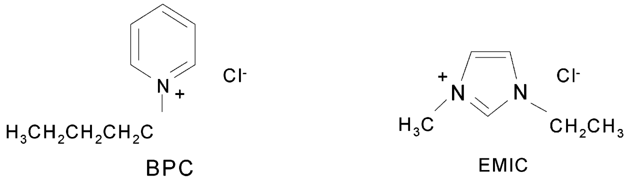

FIGURE 1.

The Diels−Alder reaction of cyclopentadiene **1** with methyl acrylate **2a** offers a higher amount of *endo*-stereoisomer **3a** (for example, *endo* = 84% in ethanol), whereas that with methyl methacrylate **2b** results in a higher amount of *exo*-stereoisomer **4b** (for example *exo* = 65% in ethanol). Slightly higher amounts of *endo*-products **5a** (for example, *endo* = 62% in ethanol) are noted for the reaction of **1** with methyl *trans*-crotonate **2c**.[6]

In this Note, we show that the reaction of **1** with **2b**, which gives more *exo*-product in conventional organic solvents, offers more *endo*-product in the chloroaluminate ionic liquid. In the past, ionic liquids have been used to further increase the *endo*-product of the known *endo*-selective Diels−Alder reactions.[7] Enhanced *endo*-product has been reported for the reaction of **1** with **2a** in chloroaluminates.[7d] The reversal of an *exo*-selective reaction to an *endo*-selective reaction in the Diels−Alder reaction of furan with **2a** was reported in an ionic liquid.[8] The usual *endo*:*exo* ratio of 1:2 in a conventional organic solvent was successfully converted into 2.3:1.

We carried out the reaction of **1** with **2b** in both BPC- and EMIC-containing chloroaluminates with varying $AlCl_3$ compositions (Table 1). No change in *exo*-product (entry 1, *exo* = 74%) was observed in the BPC-chloroaluminate with 45% $AlCl_3$ as compared to that in 2,2,4-trimethylpentane, a nonpolar solvent (entry 9, *exo* = 76%). This reaction, when conducted in the BPC-containing chloroaluminate ionic liquid with 60% $AlCl_3$ gave 25% *exo*-product (entry 8, Table 1). The *endo*-product was, therefore, enhanced by about three times from 26% (in 45% $AlCl_3$) to 75% (in 60% $AlCl_3$) in the BPC-chloroalu-

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10.1021/jo035038j CCC: $27.50

SCHEME 1

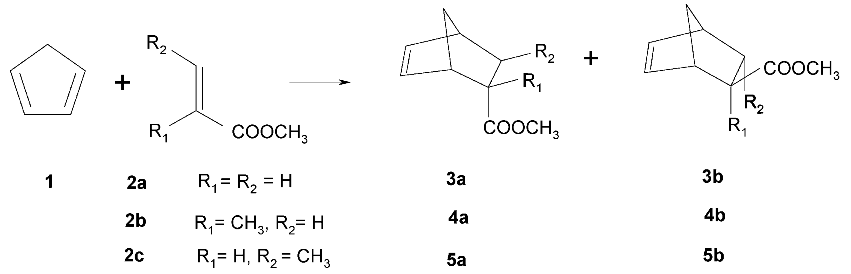

TABLE 1. Reaction of 1 with 2b in Chloroaluminate Ionic Liquid[a]

		BPC		EMIC	
entry	mol % $AlCl_3$	*exo*, %	yield,[a] %	*exo*, %	yield, %
1	45	74	18	73	20
2	47	75	18	74	20
3	49	72	18	74	20
4	51	68	22	70	26
5	53	65	25	63	30
6	55	60	30	53	35
7	57	49	35	40	41
8	60	25	47[b]	18	58[c]
9	*d*	76	15		
10	*e*	40	34		

[a] Isolated yields. [b] 90 min. [c] 75 min. [d] 2,2,4-Trimethylpentane. [e] $AlCl_3$; no further changes in *endo*- or *exo*-products and yields after the times reported.

TABLE 2. Reaction of 1 with 2c in Chloroaluminate Ionic Liquid[a]

		BPC		EMIC	
entry	mol % $AlCl_3$	endo, %	yield,[a] %	endo, %	yield, %
1	45	48	16	49	17
2	47	50	16	48	18
3	49	50	17	50	17
4	51	53	20	57	29
5	53	57	27	63	40
6	55	62	37	70	50
7	57	74	47	80	58
8	60	86	57[b]	92	68[c]
9	*d*	52	10		
10	*e*	53	16		

[a] Isolated yields. [b] 90 min. [c] 75 min. [d] 2,2,4-Trimethylpentane. [e] $AlCl_3$; no further changes in *endo*- or *exo*-products and yields after the times reported.

minates.The reaction in the 60% $AlCl_3$/EMIC-chloroaluminate yielded 18% *exo*-product (entry 8, Table 1). As the *exo*-product is reduced by about four times in the 60% $AlCl_3$/EMIC-chloroaluminate, the *endo*-product is enhanced by the same order of magnitude (Table 1). This shows that the EMIC-chloroaluminate ionic liquid is a more efficient ionic liquid than the one containing BPC. The use of higher concentrations of $AlCl_3$ offered lower *exo*-product.

In short, we obtained *endo*:*exo* ratio of 3:1 for the reaction of **1** with **2b** in 60% $AlCl_3$/BPC-chloroaluminate as compared to that (*endo*:*exo* = 0.35:1) noted in 45% $AlCl_3$/BPC-chloroaluminate. Higher degree of reversal in the *endo*:*exo* ratios (4.55:1) is, however, seen in the 60% $AlCl_3$/EMIC-chloroaluminate.

This reversal in the stereselectivity seems to be controlled by the Lewis acid effect caused by the presence of $AlCl_3$ as the increasing concentration of $AlCl_3$ in the chloroaluminates leads to a decrease in *exo*-product and therefore an enhanced *endo*-product. The effect of Lewis acid catalysis on Diels–Alder reaction is further supported by the observation that the basic conditions in 45%, 47%, and 49% of $AlCl_3$ do not influence the stereoselectivity of the reaction.

TABLE 3. Yields Obtained as a Result of Reuse of 60% $AlCl_3$/BPC- and EMIC-Chloroaluminates for Reactions of 1 with 2b and 2c[a]

	1 + 2b		**1 + 2c**	
cycle	BPC	EMIC	BPC	EMIC
fresh reaction	47	58	57	68
1	45	56	54	66
2	44	56	52	66
3	42	54	52	64
4	40	52	50	61
5	40	50	48	63
6	38	50	46	62

[a] Reaction conditions specified in the text.

The reactions conducted in $AlCl_3$ alone enhanced the *endo*-product to 60% as compared to 24% obtained in 2,2,4-trimethylpentane (Table 1).

The reaction of **1** with **2c**, which is *endo*-selective in organic solvents, was also carried out in the ionic liquid to give *endo*-product up to 86% and 92% in 60% $AlCl_3$ with BPC- and EMIC-chloroaluminates, respectively (entry 8, Table 2). Higher *endo*:*exo* ratios of 6:1 and 11.5:1 were obtained in the BPC- and EMIC-chloroaluminates (with 60% $AlCl_3$), respectively. The same reaction in $AlCl_3$ alone gave 53% *endo*-product.

The reactions of **1** with **2b** and **2c** in organic solvents were sluggish and gave about 10% yield in 10 and 23 h, respectively. The same reactions when conducted in chloroaluminates gave 47–68% yield (Tables 1 and 2, entry 8) in just 1–2 h.

Finally, it was possible to recover the chloroaluminates from the mixture by diluting it with diethyl ether. The reactions of **1** with **2b** and with **2c** when conducted in the recovered ionic liquid gave 50–65% yields (Table 3).

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Supporting Information Available: The synthesis of chloroaluminates and experimental method to carry out the reactions. This material is available free of charge via the Internet at http://pubs.acs.org.

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