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Synthesis of symmetric triarylmethane derivatives catalyzed by AIL ionic liquid

Li Q. Kang¹ · Han Gao¹ · Yue Q. Cai²

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Abstract An efficient, eco-friendly ionic liquid was described for the synthesis of symmetric triarylmethane derivatives via Baeyer condensation of *N*,*N*-dimethylaniline with different active aromatic aldehyde compounds using amide ionic liquid as a catalyst. The syntheses were achieved for the first time using amide ionic liquid as a catalyst eliminating the need for a volatile organic solvent. The advantages of this ionic liquid are low cost and operational simplicity.

Graphical abstract



Keywords Triarylmethanes · Condensation · Amide ionic liquid

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Li Q. Kang klq@sit.edu.cn

- ¹ School of Chemical and Environmental Engineering, Shanghai Institute of Technology, 100 Haiquan Road, Shanghai 201418, People's Republic of China
- ² School of Chemistry and Molecular Engineering, East China University of Science and Technology, Shanghai 200237, China

Introduction

Triphenylmethane (TRAMs) is a very important class of organic compound with a wide range of applications. Triarylmethanes and their analogues, which are important leucobases [1], are an important class of synthetic dyes used to color silk, wool, jute, leather, cotton, and paper. Several catalysts have been reported for the synthesis of triarylmethane derivatives, which include such strong protic acids as *p*-toluenesulfonic acid [2, 3], sulfuric acid [4], or some Lewis acids such as $FeCl_3$ [5], $TiCl_4$ [6], or ZrOCl₂ [7], NbCl₅ [8], SbCl₃ [9], or polymer-supported sulfonic acid [10], perfluorinated sulfonic acid resin [11], I₂ [12], cerium(IV) ammonium nitrate [13], or montmorillonite [14]. These catalysts have their own advantages and drawbacks. The main drawbacks of these catalysts were that in addition to being nonrecoverable, corrosive and requiring tedious workup for the isolation of the products. Recently, Yb(OTf)₃ [15] and transition metal-catalyzed [16–18] routes have emerged as an alternative method to provide structurally diverse triarylmethanes. One kind of amine ionic liquid N-methyl-2-pyrrolidonium methyl sulfonate had already been used for esterification [19]. Motivated by these literature voids, we broadened the scope of amine ionic liquid and used them for condensation. During our work, we were surprised to find that the amide ionic liquid derived from N,N-dimethylformamide can be used as an excellent catalyst for the condensation of N,N-dimethylaniline with various aromatic aldehydes. It will be shown that shorter reaction time and high yield are possible using N,N-dimethylformamide hydrogen sulfate ionic liquid (AIL) as an alternative, environmentally benign catalyst (Scheme 1).

Scheme 1



4-CI-C₆H₄, 2,4-Cl₂-C₆H₃, α -naphthyl

Results and discussion

To find out a suitable catalyst, a model reaction was chosen by using benzaldehyde (2 mmol), N,N-dimethylaniline (5.0 mmol) in the presence of different ILs and the results are summarized in Table 1.

It is clear from Table 1 that the use of higher quantity of catalyst did not improve the yield, but the use of lower

Table 1 Effect of catalysts on model reaction

Entry	Catalyst	Mol%	Temp /°C	Yield /%
1	$\sim N \sim N \sim SO_3 H$ (A)	10	120	65
2	$N \sim N \sim B$ (B)	10	120	73
3	$\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $	10	120	75
4	$\begin{array}{c} O\\ H \stackrel{\bigoplus \\ V \\ H \\ H \end{array} \stackrel{CH_3}{\overset{\bigoplus \\ CH_3}{ H SO_4^{\ominus}}} HSO_4^{\ominus} \end{array} (D)$	10	120	85
5	$\begin{array}{c} O\\ H \stackrel{\bigoplus CH_3}{\longrightarrow} CH_3 \\ H \stackrel{\bigoplus CH_3}{\longrightarrow} HSO_4^{\ominus} (D) \end{array}$	15	120	85
6	$\begin{array}{c} O\\ H \stackrel{(1)}{\longrightarrow} CH_3\\ H \stackrel{(2)}{\longrightarrow} CH_3\\ H \stackrel{(2)}{\rightarrow} CH_3 \end{array} HSO_4^{\ominus} \qquad (D)$	5	120	76
7	$\begin{array}{c} O\\ H \stackrel{(I)}{\longrightarrow} CH_3\\ H \stackrel{(I)}{\longrightarrow} CH_3\\ H \stackrel{(I)}{\rightarrow} CH_3 \end{array} HSO_4^{\ominus} \qquad (D)$	10	140	75
8	$\begin{array}{c} O\\ H \stackrel{(I)}{\longrightarrow} CH_3\\ H \stackrel{(I)}{\longrightarrow} CH_3\\ H \stackrel{(I)}{\rightarrow} CH_3 \end{array} HSO_4^{\ominus} \qquad (D)$	10	100	78
9	$\begin{array}{c} O\\ H \stackrel{()}{\longrightarrow} CH_3\\ H \stackrel{()}{\longrightarrow} CH_3\\ H \stackrel{()}{\rightarrow} CH_3 \end{array} HSO_4^{\ominus} \qquad (D)$	10	80	67
10	$\stackrel{O}{\amalg} \stackrel{CH_3}{\overset{\oplus}{\longrightarrow}} \stackrel{CH_3}{\overset{H}{\longrightarrow}} \stackrel{HSO_4^{\ominus}}{\overset{O}{\longrightarrow}} (D)$	10	50	60

^aReaction conditions: benzaldehyde (2 mmol), *N*,*N*-dimethylaniline (5.0 mmol), and in neat conditions for 4 h ^bIsolated yield

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amount of catalyst decreased the yield. Neither higher temperature (140 °C) nor lower temperature (50 °C) improved the yield of reaction (Table 1, entries 7 and 10). From Table 1 it is evident that AIL was the most efficient catalyst. The optimized condition for this reaction was chosen as use of 10 mol% catalyst (AIL) at 120 °C for 4 h (Table 1, entry 4) which provided 85% yield. In order to state high reaction rates with the catalyst AIL and judge which part of the ionic liquid is responsible for the activity, twelve parallel reactions were chosen by using benzaldehyde (2 mmol), N,N-dimethylaniline (5.0 mmol) in the presence of 10 mol% DMF, H₂SO₄, and N,N-dimethylformamide hydrogen sulfate ionic liquid at 120 °C in different reaction time, the results are shown in Fig. 1. The reaction was slow catalyzed by DMF or H₂SO₄. After 4 h the isolated yield of triphenylmethane was only 10 and 50%, respectively. The reaction was efficiently catalyzed by N,N-dimethylformamide hydrogen sulfate ionic liquid.



Fig. 1 Yield as a function of reaction time

It shows the high reaction rate catalyzed by AIL is the interaction of anionic and cationic of ionic liquid.

Various aromatic aldehydes (containing both electronwithdrawing and electron-donating groups) were converted to their corresponding TRAMs 3 in good to excellent yields with AIL. The aromatic aldehyde with electron-withdrawing groups showed higher reactivity than the electrondonating group. The aromatic substrate with electronwithdrawing groups such as chloro (Table 2, entry 2), bromo (Table 2, entry 3) and 2,4-dichloro (Table 2, entry 8) reacted quickly, whereas those with electron-donating groups such as methyl (Table 2, entry 4), methoxy (Table 2, entry 5), and N,N-dimethylamino (Table 2, entry 6) reacted slowly because of the decrease in electrophilicity of the aldehydic carbonyl carbon. To further demonstrate the scope of the reaction catalyzed by AIL, indole was reacted with aldehydes (Scheme 2). Three kinds of triarylmethanes were synthesized under the optimal conditions (Table 2, entries 10–12). Continuing these efforts, we designed a simple plan to get asymmetrically substituted triarylmethanes employing N,N-dimethylaniline, indole, and benzaldehyde under the optimized condition (Scheme 3). It was observed that as expected a mixture of triarylmethanes containing asymmetrically substituted triarylmethane (9%). 4,4'-(phenylmethylene)bis(N,N-dimethylaniline) (26%), and 3,3'-(phenylmethylene)bis(1H-indole) (45%) was formed. Elevated temperature or lower temperature inclined toward the formation of mixture and hence the sole asymmetrically substituted triarylmethane could not be obtained. Further



extension of the reaction time to 1 day led to a very complex mixture with only traces of the asymmetrically substituted triarylmethane.

We propose the following mechanism for the formation of TRAMs (Scheme 4). The role of the AIL is to protonate the aldehydic carbonyl carbon and thereby increase the electrophilicity of this functional group followed by nucleophilic attack by *N*,*N*-dialkylaniline.

We investigated the thermostability of AIL via thermogravimetric analysis (TGA) measurement. Thermodynamic stability of AIL is in N₂ performed at a scan rate of 100 cm³/min. TGA curve measured for the catalyst of AIL revealed a two-step weight loss process with a thermal decomposition temperature (*T*) in 0–400 °C range (Fig. 2). As shown in Fig. 2, a sharp mass loss below 100 °C suggests loss of sorbed water. A mass loss begins at 250 °C which is attributed to the dehydration of AIL. Therefore, AIL retained a high thermostability before 250 °C. This provides the basis for our later catalytic experiments.

Entry	Product ^a	R	t/h	Yield ^b /%	M.p./°C	
					Found	Reported
1	3a	C ₆ H ₅	4	85	95.1–95.4	93–94 [8]
2	3b	$2-Cl-C_6H_4$	3.5	83	143.7–144.6	143–144 [8]
3	3c	3-Br-C ₆ H ₄	3.5	87	111.1–111.5	111–112 [20]
4	3d	$4-CH_3-C_6H_4$	3.0	79	102.1-102.8	102–103 [21]
5	3e	$4-CH_3O-C_6H_4$	4.5	79	100.2-100.7	100–102 [7]
6	3f	$4-(CH_3)_2N-C_6H_4$	4.5	78	147.3-147.6	167–168 [20]
7	3g	4-Cl-C ₆ H ₄	4.5	81	97.8–98.2	98-100 [8]
8	3h	2,4-Cl ₂ -C ₆ H ₃	3.5	76	103.8-104.2	104–105 [22]
9	3i	α-Naphthyl	5	75	170.1-170.5	170.3 [23]
10	6j	C ₆ H ₅	3.5	82	148.8-148.9	149–150 [24]
11	6k	$4-HO-C_6H_4$	4.0	79	124.4-125.1	125–126 [25]
12	61	α-Furyl	4.0	78	220.3-220.4	_

Table 2 Formation of TRAMs using AIL ionic liquid as catalyst

^a Reaction conditions: aldehyde (2.0 mmol), N,N-dimethylaniline (5.0 mmol) or indole (5.0 mmol), AIL (0.2 mmol), 120 °C

^b Isolated yield

Scheme 3



O HC-N

Θo s^{₅0} ``0 но́

,CH₃

`CH₃

H₃C

H₃C

 $\stackrel{\mathsf{O} \oplus \mathsf{CH}_3}{\underset{\mathsf{H} \mathsf{C} - \mathsf{N}_1 \\ \mathsf{H} \mathsf{C} \mathsf{H}_3}{\overset{\mathsf{O}}{\mathsf{H}}} \mathsf{H} \mathsf{SO}_4^{\overset{\textcircled{O}}{\mathsf{O}}}$

_⊕ HÇ−R

H₃C^{-N}\CH₃

`QH

HÇ-R

H₃C^{-N}_CH₃

H₂O

Scheme 4



ТΜ



H₃C, CH₃ N 0 но-<u></u> , –о[⊝] HĊ-R O ∳ HC−N ,CH₃ ↓ Сн₃ H₃C `CH₃





Fig. 2 Weight at a function of T for TGA of AIL

Conclusion

Over just a few years, there has been remarkable progress for the synthesis of triarylmethanes. Here we have demonstrated a facile AIL-catalyzed synthesis of symmetric triarylmethane derivatives from readily available *N*,*N*-dimethylaniline or indole with different active aromatic aldehyde compounds. Hopefully the work described here will stimulate further work for the synthesis of unsymmetrical triarylmethanes.

Experimental

Melting points were measured on a WRS-IB digital melting point instrument. ¹H NMR was recorded on AVANG 500 MHz spectrometer with TMS as an internal standard. The ionic liquid AIL is synthesized and purified according to reference [26].

General procedure for the synthesis of 3a–3i and 6j–6l

To a mixture of aromatic aldehyde (2.0 mmol) and *N*,*N*-dimethylaniline or indole (5.0 mmol), ionic liquid AIL (0.2 mmol) was added, and the mixture was heated on an oil bath at 120 °C with good stirring. After the completion of the reaction, monitored by thin-layer chromatography (TLC), the mixture was diluted with 5 cm³ ethyl acetate and 1 cm³ water. The organic layer was separated, dried over magnesium sulfate, and concentrated under reduced pressure. The residue was recrystallized with ethanol and afforded the corresponding TRAMs **3a–3h** and **6j–6l** in good isolated yields. Or the residue was purified by silica gel column chromatography (200–400 mesh silica gel, 1:8 petroleum ether/ethyl acetate) to afford **3i**. The aqueous



Fig. 3 Yield as a function of run no.

layer containing the AIL was subjected to rotary evaporation at 60 °C under reduced pressure to afford the recovered AIL. Also, the catalyst could be reused easily six times without apparent loss of activity in terms of yield (85-83%; Fig. 3).

All compounds were known and their physical data were compared with those of authentic samples and found to be identical.

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