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Gadolinium triflate: an efficient and convenient catalyst for acetylation of alcohols and amines

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Abstract

Gadolinium triflate ($Gd(OTf)_3$) was found to be a simple and efficient catalyst for the acetylation of alcohols and amines. Acetylation reactions using acetic anhydride as the reagent proceed in excellent yields, in the presence of catalytic amounts (0.01–0.1 mol%) of $Gd(OTf)_3$, at ambient temperature. Aliphatic alcohols as well as phenols and amines undergo acetylations under mild conditions. The intermediate formation of the mixed anhydride, acetic trifluoromethanesulfonic anhydride was demonstrated by ^{13}C NMR spectroscopy experiments.

Keywords: Acetylation; Acetic anhydride; Lewis acid; Gadolinium triflate; Acetic trifluoromethanesulfonic anhydride

1. Introduction

Lewis acid catalyzed acetylation reactions are of enormous interest in organic synthesis [1]. Although a number of acid and base catalyzed acetylation reactions are known, many of them are limited in their applications either due to the instability of reactants or products under the reaction conditions or tedious workup procedures involved [2–5].

A variety of Lewis acid catalyzed acylations of alcohols and amines with acid anhydrides have been explored. Lewis acids such as $TaCl_5$ [6], Me_3SiOTf [7], $Cu(OTf)_2$ [8], $MgBr_2$ [9], $Sc(OTf)_3$ [10], $In(OTf)_3$ [11], $Bi(OTf)_3$ [12,13] have been used as catalysts for these transformations. Most of these metal triflates are either too expensive or are water-sensitive. Further, reagents such as Me_3SiOTf are strongly acidic and cannot be used for the acylation of acid-sensitive alcohols. Recently imidazolium-based room temperature ionic liquids (RTILs) have been used as solvents for the acetylation of alcohols in the presence of Lewis acids, $Cu(OTf)_2$, $Yb(OTf)_3$, $Sc(OTf)_3$, $HfCl_4(THF)_2$, and $InCl_3$ [14].

In 1994 Kobayashi and Hachiya [15] used the $Gd(OTf)_3$ as a water-tolerant Lewis acid in the aldol reactions of silyl enol ethers with aldehydes in aqueous media. As part of our interest in the Lewis acid catalyzed reactions, we have explored the applications of $Gd(OTf)_3$ as a mild and inexpensive reagent for the acetylation of alcohols and amines.

2. Results and discussion

$Gd(OTf)_3$ is relatively more water tolerant than other lanthanide-based metal triflates [15]. Thus strictly anhydrous conditions that have been used with other Lewis acid catalysts can be avoided in the case of this catalyst. In addition, it is a relatively inexpensive reagent. We have initially tested this reagent on the acetylation of alcohols using acetic anhydride as the reagent in acetonitrile as the solvent (Scheme 1). The reactions of a variety of primary, secondary and tertiary alcohols proceeded at relatively high rates at ambient temperatures. We have found that $Gd(OTf)_3$ acts as a catalyst for these reactions at as low concentration as 0.01 mol%. Whereas the acetylation of tertiary alcohols, such as trityl alcohol, are not possible using $Bi(OTf)_3$ [12], we have found that these reactions can be carried out conveniently using $Gd(OTf)_3$ as

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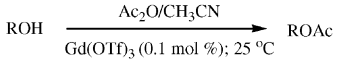
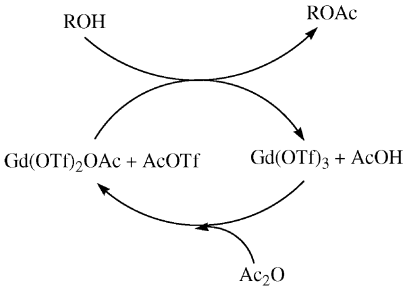


Scheme 1. $Gd(OTf)_3$ catalyzed acetylation of alcohols.

the catalyst. These $Gd(OTf)_3$ catalyzed acetylation reactions also proceed in excellent yields with phenols and allyl alcohols (Table 1). The relatively low yield for the acetylation of trityl alcohol (45%) is due to the hydrolysis of some of the trityl acetate in the aqueous workup. The reaction was nearly quantitative as observed by ^{1}H NMR spectroscopy.

We have also investigated the acetylation reactions of amines using the $Gd(OTf)_3$ as the catalyst. Using as low as 0.1 mol% of the catalyst we have obtained high yields of the *N*-acetyl amines. The $Gd(OTf)_3$ catalyzed acetylations of amines proceed in relatively shorter times as compared to the acetylation of alcohols (Table 2).

In order to understand the nature of the reactive intermediates involved in the $Gd(OTf)_3$ catalyzed acetylation reactions we have recorded the ^{13}C NMR spectrum of a solution of $Gd(OTf)_3$ and acetic anhydride (1:5). We have observed a minor absorption (about 5%) at δ^{13}C 178.0 which is probably due to the mixed anhydride, acetic trifluoromethanesulfonic (triflic) anhydride (AcOTf) [16,17]. The high reactivity of the latter mixed anhydride with alcohols results in the formation of the corresponding esters and regeneration of the $Gd(OTf)_3$ catalyst (Scheme 2).



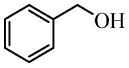
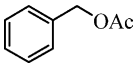
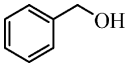
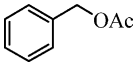
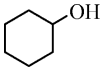
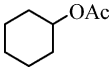
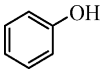
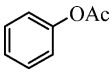
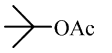
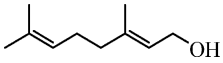
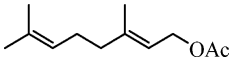
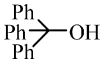
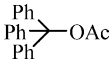
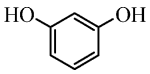
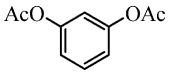
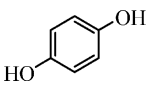
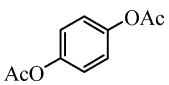
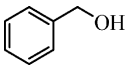
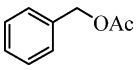
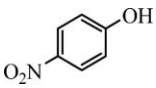
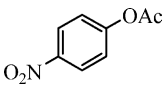
Scheme 2. Proposed mechanism for the $Gd(OTf)_3$ catalyzed acetylation of alcohols.

3. Experimental

3.1. General remarks

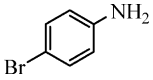
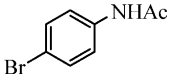
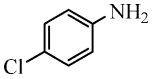
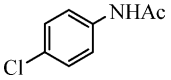
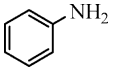
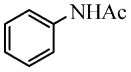
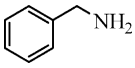
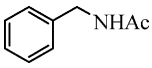
All reactions were carried out at ambient temperature in oven-dried glassware. Thin layer chromatography was car-

Table 1
$Gd(OTf)_3$ catalyzed acetylation of alcohols using acetic anhydride

Entry	Alcohol	Time	Product	Catalyst (mol%)	Yield (%)[a]
1		30 min		0.1	97
2		3 h		0.01	92
3		30 min		0.1	88
4		45 min		0.1	92
5		2 h		0.5	70[b]
6		1 h		0.1	95
7		14 h		1	45[c]
8		30 min		0.1	94
9		30 min		0.1	99
10		2 h		0.1	85[b]
11		1 h		0.1	97

[a] Isolated yields.
[b] Reactions were carried out in CH_2Cl_2 as solvent.
[c] Yield estimated by GC/MS.

Table 2
$Gd(OTf)_3$ catalyzed acetylation of amines using acetic anhydride

Entry	Amine	Time	Product	Catalyst (mol%)	Yield (%)[a]
1		5 min		0.1	95
2		5 min		0.1	98
3		15 min		0.1	88
4		1 h		0.1	92

[a] Isolated yields.

ried out using silica gel coated polyester backed sheets. Gadolinium triflate and all other reagents are purchased from Aldrich chemical company and were used as received. GC/MS spectra were recorded on Hewlett-Packard 5989 A spectrometer, equipped with a Hewlett-Packard 5890 gas chromatograph. ^{1}H NMR and ^{13}C NMR spectra for $CDCl_3$ solutions were recorded on an INOVA-Varian 400 MHz spectrometer at 400 and 100 MHz, respectively. The chemical shifts of the compounds were referenced with respect to internal tetramethylsilane.

3.2. General acylation procedure

Acetylation of benzyl alcohol (Table 1, entry 1): to a stirred solution of benzyl alcohol (6.0 g, 55.5 mmol) in CH_3CN (30 mL) was added Ac_2O (8.5 g, 83 mmol) and gadolinium triflate (34.5 mg, 0.06 mmol, 0.1 mol%), and the progress of the reaction was monitored by TLC. After completion of the reaction (30 min) CH_3CN was removed on a rotary evaporator, 10% aq. Na_2CO_3 solution (30 mL) was added to the contents, and extracted with diethyl ether (3×30 mL). The combined organic layers were washed with aq. Na_2CO_3 solution, brine (20 mL), and dried (Na_2SO_4). The solvents were removed on a rotary evaporator to give benzyl acetate (8.1 g, 97%). Characeterization of the product is achieved by ^{1}H NMR and ^{13}C NMR, and GC/MS.

4. Conclusions

In conclusion, $Gd(OTf)_3$ is an efficient catalyst for the acetylation of aliphatic and aromatic alcohols, and amines. A variety of primary, secondary, and tertiary alcohols and amines have been acetylated in relatively short reaction times using catalytic quantities of the catalyst. The intermediate formation of the mixed anhydride, anhydride, AcOTf, is indicated by ^{13}C NMR spectroscopy. $Gd(OTf)_3$ is also a water-tolerant reagent eliminating the use of strictly anhydrous solvents for these reactions.

Acknowledgement

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References

[1] T.W. Green, P.G.M. Wuts, Protective Groups in Organic Synthesis, 3rd ed., Wiley, New York, 1999.
[2] R.I. Zhdanov, S.M. Zhendarova, Synthesis (1975) 222.
[3] G. Stork, T. Takahashai, I. Kawamoto, T. Suzuki, J. Am. Chem. Soc. 100 (1978) 8272.
[4] G. Hoefle, V. Steglich, H. Vorbrueggen, Angew. Chem. Int. Ed. Engl. 17 (1978) 569.
[5] E.F.V. Scriven, Chem. Soc. Rev. 12 (1983) 129.
[6] S. Chandrasekhar, T. Ramachander, M. Takhi, Tetrahedron Lett. 39 (1998) 3263.
[7] P.A. Procopiou, S.P.D. Baugh, S.S. Flack, G.G.A. Ingliss, J. Org. Chem. 63 (1998) 2342.
[8] P. Saravanan, V.K. Singh, Tetrahedron Lett. 40 (1999) 2611.
[9] E. Vedejs, O. Daugulis, J. Org. Chem. 61 (1996) 5702.
[10] K. Ishihara, M. Kubota, H. Kurihara, H. Yamamoto, J. Am. Chem. Soc. 117 (1995) 4413.
[11] K.C. Kamlesh, G.F. Christopher, L. Ian, W. David, Synlett 11 (1999) 1743.
[12] M.D. Carrigan, R.S. Mohan, Synthesis 14 (2001) 2091.
[13] A. Orita, C. Tanahashi, A. Kakuda, J. Otera, Angew. Chem. Int. Ed. Engl. 39 (2000) 2877.
[14] S. Lee, J. Park, J. Mol. Catal. A 49 (2003) 194.
[15] S. Kobayashi, I. Hachiya, J. Org. Chem. 59 (1994) 3590.
[16] K.L. Chandra, P. Saravanan, V.K. Singh, Synlett 4 (2000) 359.
[17] K.L. Chandra, P. Saravanan, V.K. Singh, Tetrahedron 58 (2002) 1369.