Bismuth Triflate-Catalyzed Fries Rearrangement of Aryl Acetates

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Abstract: Bismuth triflate was found to be an efficient catalyst in the Fries rearrangement of phenyl or 1-naphthyl acetates. Both reactions proceeded smoothly with a catalytic amount of bismuth triflate (10 mol%) to afford the corresponding hydroxyaryl ketone in moderate to good yields in most cases.

Key words: Fries rearrangement, bismuth(III), Lewis acid, phenol, hydroxyaryl ketone, green chemistry

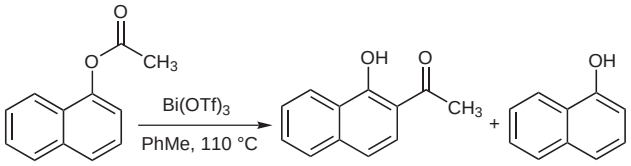
Hydroxyaryl ketones are versatile intermediates in the synthesis of biologically active naphthoquinones, chalcones, and flavanones. Although Friedel–Crafts reactions provide an efficient synthetic route for the preparation of hydroxyaryl ketones by direct 2-acylation reactions of phenols and 1-naphthols, the Fries rearrangement has been reported to be the most efficient process.[1] Both of these reactions are usually carried out using stoichiometric amount of $AlCl_3$ or strong acids. An excess of the acid is often required, due to the quenching of the acid by the reaction products. These corrosive reaction conditions have led to severe side reactions and to environmental problems. Lately, synthetic methodologies involving lanthanide triflates as catalysts for the Fries rearrangement have been described.[2] High catalytic activity, low toxicity, moisture and air tolerance make use of lanthanide triflates attractive catalysts. However, the high cost of these catalysts limits their use. Clearly, there is a need for the development of new cheap Lewis acids that can promote the above reaction in a catalytic amount.

Bismuth compounds have attracted recent attention due to their low toxicity, low cost, and good stability.[3] Bismuth(III) salts have been reported as catalysts for epoxide opening,[4] imine allylation,[5] Mukaiyama-aldol reaction,[6] formation and deprotection of acetals,[7] Friedel–Crafts reactions,[8] Diels–Alder reactions,[9] and intramolecular Sakurai cyclizations.[10] $Bi(OTf)_3$ is particularly attractive because it is commercially available or can be easily prepared from commercially available starting materials.[11]

Herein, we report an attractive method using bismuth(III) triflate tetrahydrate as a catalyst for the Fries rearrangement of aryl acetates. Hydroxyaryl ketones are obtained efficiently in the presence of 10 mol% of $Bi(OTf)_3$.

Initially, we screened various quantities of catalyst for the Fries rearrangement of 1-naphthyl acetate (**1a**) in toluene at reflux (Table 1). Among various catalyst loadings tested, 10 mol% of $Bi(OTf)_3$ was found to give the expected product **2a** with the best yield (Table 1, entry 2). Clearly, the optimal catalyst loading was 10 mol%, as the yield of deacetylated product, 1-naphthol (**3a**), was minimized in these conditions.[12]

Table 1 $Bi(OTf)_3$-Catalyzed Fries Rearrangement of 1-Naphthyl Acetate



1a **2a** **3a**

Entry	n Equiv $Bi(OTf)_3$	Time (h)	Yield of **2a** (%)[a]	Yield of **3a** (%)[a]
1	0.05	7	68	32
2	0.10	6	80	20
3	0.20	8	52	26

[a] Isolated yield.

We hence further studied the scope and limitations of this reaction with differently substituted naphthyl acetates. Several examples of $Bi(OTf)_3$-catalyzed Fries rearrangement of 4- or 5-substituted 1-naphthyl acetates **1** are summarized in Table 2. The corresponding hydroxynaphthyl ketones **2** are obtained in moderate to good yield with 10 mol% of $Bi(OTf)_3$ in toluene or nitroethane. Toluene can be replaced by nitroethane, which is an industrially compatible solvent.[13] Similar yields were indeed obtained with the rearrangement of 1-naphthyl acetate and 4- or 5-methoxy 1-naphthyl acetates (Table 2, entries 1–6). However, nitroethane gave a decreased yield vs toluene of the 4-chloro derivative (Table 2, entries 7, 8). Surprisingly, the reaction performed in nitroethane with the 4-acetoxy derivative only led to decomposition (Table 2, entry 10).

The same conditions applied to various phenyl acetates did not afford the corresponding rearranged products as smoothly as in the naphthyl series. The Fries rearrangement did not occur with phenyl acetate and only led to traces of the expected product (Table 3, entry 1). The reaction was efficient using electron-rich *meta*-substituted phenyl acetates and the corresponding hydroxyphenyl ketones **5b** and **5c** were obtained with moderate yields (Table 3, entries 2 and 4). Using nitroethane instead of

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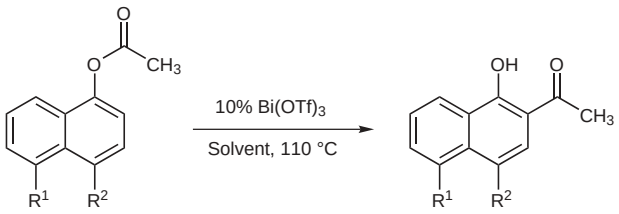
Table 2 $Bi(OTf)_3$-Catalyzed Fries Rearrangement of Substituted 1-Naphthyl Acetates



1 **2**

Entry	R^1	R^2	Solvent[a]	Compound	Yield of **2** (%)[b]
1	H	H	PhMe	**2a**	80
2	H	H	$EtNO_2$	**2a**	84
3	H	OCH_3	PhMe	**2b**	71
4	H	OCH_3	$EtNO_2$	**2b**	81
5	OCH_3	H	PhMe	**2c**	65
6	OCH_3	H	$EtNO_2$	**2c**	66
7	H	Cl	PhMe	**2d**	82
8	H	Cl	$EtNO_2$	**2d**	41
9	H	O_2CCH_3	PhMe	**2e**	64
10	H	O_2CCH_3	$EtNO_2$	**2e**	6[c]

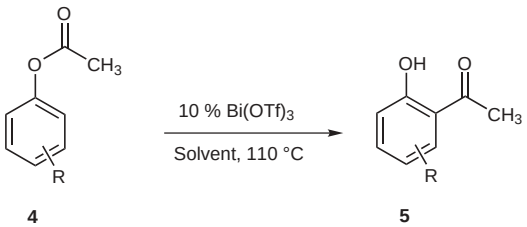
[a] Conditions: 4-/5-substituted naphthyl acetate (1.00 equiv), $Bi(OTf)_3 \cdot 4H_2O$ (0.10 equiv), solvent, 110 °C, 3–15 h.
[b] Isolated yield.
[c] GC yield.

toluene led to very poor yield or decomposition (Table 3, entries 3 and 5). *Para*-substituted phenyl acetates only led to rearranged products in low yields (Table 3, entries 6 and 7).

Following recent reports of direct 2-acylation reactions of phenols and 1-naphthols with $Sc(OTf)_3$ and $Hf(OTf)_4$,[14] we compared the direct Friedel–Crafts *ortho*-acylation of 1-naphthol with the Fries rearrangement of naphthyl acetate. As seen from Table 4, our conditions are efficient using acetyl chloride or acetic anhydride as acylating agent. The reaction is chemoselective in that only C-acylation is observed. Although the precise mechanism has not been elucidated, we suppose that the reaction occurs by formation of a Bi(III)–phenolate complex. However, O-acylation followed by Fries rearrangement cannot be ruled out as $Bi(OTf)_3$ is a known catalyst for the acylation of alcohols and phenols.[15] Further investigations on the mechanism of this transformation are in progress.

In summary, we have found that $Bi(OTf)_3$ is an efficient catalyst for the Fries rearrangement of naphthyl acetates. The reaction appeared to be more general for naphthyl acetates as compared to phenyl acetates. An optimization of the catalyst amount showed that the reaction works best with a catalyst loading of 10 mol%.[16] $Bi(OTf)_3$ has also

Table 3 $Bi(OTf)_3$-Catalyzed Fries Rearrangement of Substituted Phenyl Acetates

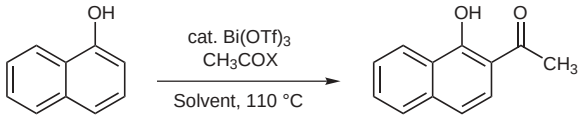


4 **5**

Entry	R	Solvent[a]	Compound	Yield of **5** (%)[b]
1	H	PhMe	**5a**	10[c]
2	*m*-CH_3	PhMe	**5b**	61
3	*m*-CH_3	$EtNO_2$	**5b**	12
4	*m*-OCH_3	PhMe	**5c**	72
5	*m*-OCH_3	$EtNO_2$	**5c**	50
6	*p*-OCH_3	$EtNO_2$	**5d**	13[c]
7	*p*-O_2CCH_3	PhMe	**5e**	12

[a] Conditions: substituted phenyl acetate (1.00 equiv), $Bi(OTf)_3 \cdot 4H_2O$ (0.10 equiv), solvent, 110 °C, 6–33 h.
[b] Isolated yield.
[c] GC yield.

Table 4 $Bi(OTf)_3$-Catalyzed *ortho*-Acylation of 1-Naphthol



3a **2a**

Entry	Conditions	Solvent	Time (h)	Yield (%)[a]
1	0.10 equiv $Bi(OTf)_3$, 1.10 equiv CH_3COCl	PhMe/ $MeNO_2$	5	69
2	0.10 equiv $Bi(OTf)_3$, 1.50 equiv $(CH_3CO)_2O$	PhMe	25	57
3	0.20 equiv $Bi(OTf)_3$, 1.50 equiv $(CH_3CO)_2O$	PhMe	14	74

[a] Isolated yield.

proven to be effective for the direct *ortho*-acylation of 1-naphthol with acetyl chloride or acetic anhydride. Both methods offer several advantages including mild reaction conditions, low quantity of the catalyst (10%), and no formation of decomposition products. Because of its various benefits, the $Bi(OTf)_3$ protocol should find utility in the synthesis of biologically active compounds. Development of other $Bi(OTf)_3$-catalyzed Fries rearrangements and related mechanistic studies will be reported in due course.

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References

(1) (a) Martin, R. *Org. Prep. Proced. Int.* **1992**, *24*, 369. (b) Crouse, D. J.; Hurlbut, S. L.; Wheeler, D. M. S. *J. Org. Chem.* **1981**, *46*, 374.

(2) (a) Kobayashi, S.; Moriwaki, M.; Hachiya, I. *Bull. Chem. Soc. Jpn.* **1997**, *70*, 267. (b) Kobayashi, S.; Moriwaki, M.; Hachiya, I. *Tetrahedron Lett.* **1996**, *37*, 2053. (c) Kobayashi, S.; Moriwaki, M.; Hachiya, I. *J. Chem. Soc., Chem. Commun.* **1995**, 1527. (d) Mouhtady, O.; Gaspard-Iloughmane, H.; Roques, N.; Le Roux, C. *Tetrahedron Lett.* **2003**, *44*, 6379; and erratum: *Tetrahedron Lett.* **2003**, *44*, 8037.

(3) (a) *Organobismuth Chemistry*; Suzuki, H.; Matano, Y., Eds.; Elsevier: Amsterdam, **2001**. (b) Gaspard-Iloughmane, H.; Le Roux, C. *Eur. J. Org. Chem.* **2004**, 2517. (c) Leonard, N. M.; Wieland, L. C.; Mohan, R. S. *Tetrahedron* **2002**, *58*, 8373.

(4) (a) Ollevier, T.; Lavie-Compin, G. *Tetrahedron Lett.* **2004**, *45*, 49. (b) Ollevier, T.; Lavie-Compin, G. *Tetrahedron Lett.* **2002**, *43*, 7891.

(5) Ollevier, T.; Ba, T. *Tetrahedron Lett.* **2003**, *44*, 9003.

(6) (a) Le Roux, C.; Ciliberti, L.; Laurent-Robert, H.; Laporterie, A.; Dubac, J. *Synlett* **1998**, 1249. (b) Le Roux, C.; Gaspard-Iloughmane, H.; Dubac, J.; Jaud, J.; Vignaux, P. *J. Org. Chem.* **1993**, *58*, 1835. (c) Wada, M.; Takeichi, M.; Matsumoto, T. *Bull. Chem. Soc. Jpn.* **1991**, *64*, 990. (d) Ohki, H.; Wada, M.; Akiba, K. *Tetrahedron Lett.* **1988**, *29*, 4719.

(7) (a) Leonard, N. M.; Oswald, M. C.; Freiberg, D. A.; Nattier, B. A.; Smith, R. C.; Mohan, R. S. *J. Org. Chem.* **2002**, *67*, 5202. (b) Carrigan, M. D.; Sarapa, D.; Smith, R. C.; Wieland, L. C.; Mohan, R. S. *J. Org. Chem.* **2002**, *67*, 1027.

(8) (a) For a review on bismuth chloride and bismuth triflate in acylation reactions: Le Roux, C.; Dubac, J. *Synlett* **2002**, 181. (b) Desmurs, J. R.; Labrouillère, M.; Le Roux, C.; Gaspard, H.; Laporterie, A.; Dubac, J. *Tetrahedron Lett.* **1997**, *38*, 8871. (c) Répichet, S.; Le Roux, C.; Dubac, J.; Desmurs, J. R. *Eur. J. Org. Chem.* **1998**, 2743. (d) Laporte, C.; Marquie, J.; Laporterie, A.; Desmurs, J. R.; Dubac, J. *C. R. Acad. Sci. II C* **1999**, *2*, 455.

(9) (a) Garrigues, B.; Oussaid, A. *J. Organomet. Chem.* **1999**, *585*, 253. (b) Laurent-Robert, H.; Garrigues, B.; Dubac, J. *Synlett* **2000**, 1160.

(10) (a) Leroy, B.; Markó, I. E. *Org. Lett.* **2002**, *4*, 47. (b) Leroy, B.; Markó, I. E. *Tetrahedron Lett.* **2001**, *42*, 8685.

(11) (a) Répichet, S.; Zwick, A.; Vendier, L.; Le Roux, C.; Dubac, J. *Tetrahedron Lett.* **2002**, *43*, 993. (b) Labrouillère, M.; Le Roux, C.; Gaspard, H.; Laporterie, A.; Dubac, J.; Desmurs, J. R. *Tetrahedron Lett.* **1999**, *40*, 285. (c) Peyronneau, M.; Arrondo, C.; Vendier, L.; Roques, N.; Le Roux, C. *J. Mol. Catal. A: Chem.* **2004**, *211*, 89. (d) $Bi(OTf)_3$ has been prepared from Bi_2O_3 according to ref. 11a.

(12) Interestingly, a metal triflate screening for the catalytic Fries rearrangement was independently studied by C. Le Roux.[2d] He showed that $Bi(OTf)_3$ was slightly less efficient than $Sc(OTf)_3$ but could get a synergistic effect using $Bi(OTf)_3$ + $MeSO_3H$.

(13) Nitroethane is a good alternative to potentially explosive nitromethane in the presence of a Lewis acid.

(14) Kobayashi, S.; Moriwaki, M.; Hachiya, I. *Synlett* **1995**, 1153.

(15) (a) Orita, A.; Tanahashi, C.; Kakuda, A.; Otera, J. *J. Org. Chem.* **2001**, *66*, 8926. (b) Orita, A.; Tanahashi, C.; Kakuda, A.; Otera, J. *Angew. Chem. Int. Ed.* **2000**, *39*, 2877.

(16) A representative procedure for the $Bi(OTf)_3$-catalyzed Fries rearrangement is at follows: To a solution of acetate **1** or **4** (1.00 mmol) in the solvent (2 mL) was added $Bi(OTf)_3 \cdot 4H_2O$ (0.10 mmol). The mixture was magnetically stirred and heated at 110 °C for 3–33 h. The reaction mixture was quenched by the addition of H_2O, extracted with Et_2O, dried over anhyd Na_2SO_4, filtered, and concentrated under vacuum (rotary evaporator). The residue was purified by column chromatography on silica gel using hexanes–EtOAc (99:1–90:10) as eluent. All the compounds were characterized by IR and ^1H NMR spectroscopy, and accord exactly with those that have been previously reported in the literature.