Pergamon

Tetrahedron Letters, Vol. 38, No. 41, pp. 7215-7218, 1997

0040-4039/97 $17.00 + 0.00

PII: S0040-4039(97)01719-X

Bismuth Bromide as an Efficient and Versatile Catalyst for the Cyanation and Allylation of Carbonyl Compounds and Acetals with Organosilicon Reagents[1]

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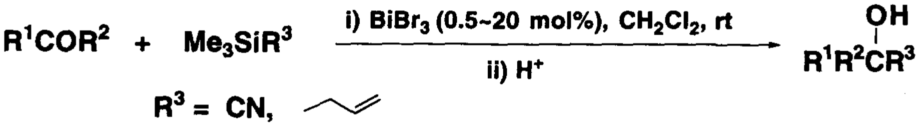
Abstract: Bismuth bromide was found to work efficiently as a versatile catalyst for the cyanation and allylation of carbonyl compounds and acetals with organosilicon reagents, affording the corresponding alcohols and ethers in high yields. © 1997 Elsevier Science Ltd.

Although commercial bismuth(III) salts are mostly nontoxic and easy to handle, their application to organic synthesis is poorly documented.[2] In recent years, however, an increasing number of reports have shown their promise as a catalyst.[3] In our continuing effort to develop bismuth salts as a catalyst for organic reactions,[4] we have explored the utility of bismuth bromide, which was almost unnoticed previously as a catalyst,[3a,4b] and found it to be efficient for the cyanation and allylation of carbonyl compounds and acetals with organosilicon reagents.

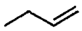
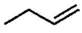
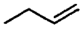
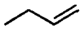
Although several catalysts have successfully been employed for the cyanation[5] and allylation[6] with organosilicon reagents, bismuth bromide has now proven itself to be a most useful and convenient catalyst due to its high efficiency and versatility. Its catalytic efficiency is comparable to and sometimes higher than that of trimethylsilyl trifluoromethanesulfonate (TMSOTf)[7] and trimethylsilyl iodide (TMSI). Noteworthy is that this catalyst can also be employed for the Sakurai-Hosomi reaction of aldehydes, which usually requires the use of a stoichiometric amount or excess of Lewis acid with strong oxophilicity such as $TiCl_4$ and $SnCl_4$.

Scheme 1



The general procedure is as follows: To a stirred suspension of bismuth bromide[8] (0.5~20 mol%), dried *in vacuo* prior to use, in dry dichloromethane (2 mL) were added successively a substrate (1.0 mmol) and an organosilicon reagent (1.2 equiv) with a syringe at room temperature under an argon atmosphere. The mixture was stirred for the time given in Tables 1 and 2, while the progress of the reaction was monitored intermittently by GLC. After completion of the reaction, the mixture was hydrolyzed by the addition of HCl aq–MeCN. Chromatographic purification (ethyl acetate/hexane=1/10 as an eluent) of the crude product on silica gel gave the corresponding alcohols and ethers in the yields as listed in the Tables.

Table 1. $BiBr_3$ catalyzed cyanation and allylation of carbonyl compounds with organosilicon reagents.

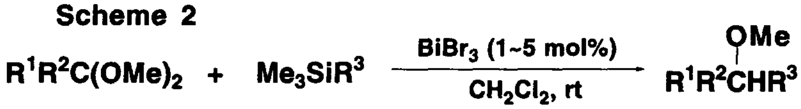
Run	R^1	R^2	R^3	Catalyst (mol %)	React. time (h)	Yield[a] (%)
1	Ph	H	CN	$BiBr_3$ (0.5)	1	91
2	Ph	H	CN	$BiCl_3$ (5.0)	1.5	92
3	Ph	H	CN	BiI_3 (5.0)	7	trace
4	Ph	H	CN	$SbCl_3$ (5.0)	2.5	90
5	4-$MeOC_6H_4$	H	CN	$BiBr_3$ (1.0)	0.5	89
6	2-Furyl	H	CN	$BiBr_3$ (1.0)	0.5	89[b]
7	*n*-C_7H_{15}	H	CN	$BiBr_3$ (1.0)	1	75
8	Ph	Me	CN	$BiBr_3$ (1.0)	6	91
9	-$(CH_2)_5$-		CN	$BiBr_3$ (1.0)	0.5	88
10	Ph	H		$BiBr_3$ (5.0)	1	87
11	Ph	H		$BiCl_3$ (5.0)	9	74
12	Ph	H		$SbCl_3$ (5.0)	6.5	trace
13	*n*-C_7H_{15}	H		$BiBr_3$ (20)	4	87

[a] Isolated yield. [b] Without acid hydrolysis, a mixture of cyanohydrin and *O*-trimethylsilyl derivative (16:84) was obtained.

Results of the cyanation and allylation of aldehydes and ketones are summarized in Table 1. In runs 1~4 and 10~12, the catalytic efficiency of bismuth and antimony(III) halides was compared for the cyanation and allylation of benzaldehyde under the same conditions. In the cyanation, $BiBr_3$ exhibited a powerful catalytic activity in an amount as low as 0.5 mol%, which was enough to complete the reaction within one hour (run 1). However, $BiCl_3$ (run 2), BiI_3 (run 3), and $SbCl_3$ (run 4) showed less or little catalytic activity. Without a catalyst, the reaction did not take place even after 7 h stirring under the same conditions. The allylation of benzaldehyde was also catalyzed by $BiBr_3$ efficiently (run 10). A marked contrast was observed between the bismuth and antimony salts in the allylation; $BiBr_3$ and $BiCl_3$ worked as a good catalyst (runs 10 and 11), while $SbCl_3$ showed little catalytic activity (run 12). Among the catalysts examined, $BiBr_3$ proved best for both the cyanation and allylation. Other carbonyl compounds were also cyanated or allylated smoothly with $BiBr_3$ as catalyst to give the corresponding alcohols in good to excellent yields,[9] except the allylation of ketones which led to only low to moderate yields. The allylation generally required a larger amount of catalyst (5–20 mol%) than the cyanation. Furfural was cyanated in high yield without any resinification or crotonization (run 6).[31,10] When the reaction mixture was hydrolyzed under aqueous acidic conditions, the yield diminished to 30~50 % probably due to resinification and/or crotonization. These results indicate that $BiBr_3$ can selectively activate the carbonyl function of furfural, keeping the furan ring intact, but Brϕnsted acid may cause undesirable side effects on the furan ring.[11] As compared with previously reported achiral Lewis acid catalysts used for the intermolecular allylation[12] with allyltrimethylsilane,[13] which include TMSOTf,[14] TMSI,[14] $TfOH_2^+B(OTf)_4^-$,[15] TMSB(OTf)$_4$,[14] Ph$_2$BOTf,[16] and Sc(OTf)$_3$,[17] BiBr3 is superior in activity to TMSOTf and TMSI, is much cheaper than Sc(OTf)$_3$, and easier to handle than TfOH$_2^+$B(OTf)$_4^-$, TMSB(OTf)$_4$, and Ph$_2$BOTf.

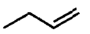
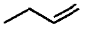
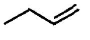
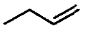
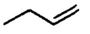
The cyanation and allylation of acetals were also carried out successfully as shown in Table 2. As was the case with the cyanation and allylation of benzaldehyde, a similar trend in catalysis was observed for BiBr3, BiCl3, and SbCl3 in the reaction of benzaldehyde dimethylacetal (runs 1~3 and 6~8). BiBr3 proved to be most efficient (runs 1 and 6) and BiCl3 was less satisfactory (runs 2 and 7), while SbCl3 showed low to little activity (runs 3 and 8). Other dimethylacetals were also cyanated or allylated in good yields within 4.5 h in the presence of 1-5 mol% of BiBr3 (runs 4, 5, 9, and 10). BiBr3 exhibited a catalytic efficiency similar to TMSOTf in the cyanation,[7] and to trityl perchlorate and Ph$_2$BOTf in the allylation.[16] Compared with TMSOTf[7,18] and TMSI[19] (10 mol%), a less amount of BiBr3 (5 mol%) was sufficient to complete the allylation.

Scheme 2



$$R^1R^2C(OMe)_2 + Me_3SiR^3 \xrightarrow[CH_2Cl_2,\ rt]{BiBr_3\ (1\sim5\ mol\%)} R^1R^2\overset{OMe}{C}HR^3$$

Table 2. BiBr$_3$ catalyzed cyanation and allylation of dimethylacetals with organosilicon reagents.

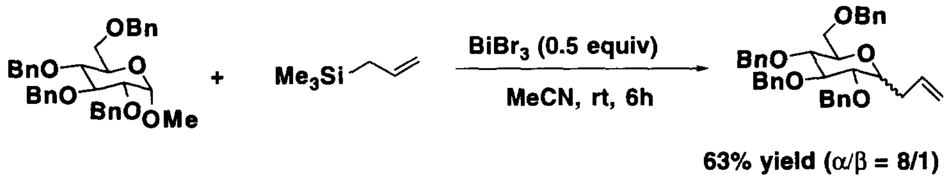
Run	R^1	R^2	R^3	Catalyst (mol %)	React. time (h)	Yield^a (%)
1	Ph	H	CN	BiBr$_3$ (1.0)	1	89
2	Ph	H	CN	BiCl$_3$ (5.0)	0.5	92
3	Ph	H	CN	SbCl$_3$ (5.0)	24	15
4	n-C$_7$H$_{15}$	H	CN	BiBr$_3$ (1.0)	2	77
5	-(CH$_2$)$_5$-		CN	BiBr$_3$ (1.0)	0.5	88
6	Ph	H		BiBr$_3$ (5.0)	1.5	68
7	Ph	H		BiCl$_3$ (5.0)	3	74
8	Ph	H		SbCl$_3$ (5.0)	24	trace
9	n-C$_7$H$_{15}$	H		BiBr$_3$ (5.0)	4.5	74
10	-(CH$_2$)$_5$-			BiBr$_3$ (5.0)	1	65

^{a} Isolated yield.

This reaction was further extended to the *C*-allylation of a glycopyranoside as shown in Scheme 3. Methyl 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside[20] was allowed to react with allyltrimethylsilane in the presence of 50 mol% of BiBr3 in acetonitrile at room temperature to afford a good yield of *C*-allylated glucopyranoside in high stereoselectivity (α/β=8/1).[21] Partial deprotection of the benzyl groups was the concurrent reaction, which considerably diminished catalytic efficiency as well as yield of the product. Further optimization of the reaction conditions would lead to more satisfactory results.

In conclusion, BiBr3 is disclosed to be an efficient and versatile catalyst for the cyanation and allylation of carbonyl compounds and acetals. It would find further application in other Lewis acid-promoted reactions.

Scheme 3



Acknowledgement: The present work was supported by a Grant-in-Aid for Scientific Research (No. 09750948) from the Ministry of Education, Science, Sports and Culture, Japan. We thank Professor Emeritus Toshio Sugita of Kyoto University for his helpful comments and encouragement.

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1 Part of this work was presented at the 6th International Kyoto Conference on New Aspects of Organic Chemistry (IKCOC-6), Kyoto, in November 1994 and the 1995 International Chemical Congress of Pacific Basin Societies (PACIFICHEM '95), Honolulu, Hawaii, in December 1995.

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(*Received in Japan* 15 *July* 1997; *revised* 14 *August* 1997; *accepted* 18 *August* 1997)