

## Reduction of acid chlorides using zirconium borohydride triphenylphosphine complex as a new, efficient and stable reducing agent

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**Abstract:** Zirconium borohydride triphenylphosphine complex (ZrBTP) is easily prepared in high yield from commercially available starting materials. It is stable under mild aqueous acidic conditions (pH 4 - 6) and survives in H<sub>2</sub>O for several days without losing its reducing abilities. Its application for the efficient reduction of aliphatic and aromatic acid chlorides is presented.

**Keywords:** Zirconium borohydride triphenylphosphine; Acid chloride; Reduction; Alcohol.

### Introduction

A number of covalent transition metal borohydride complexes are known, which are volatile, unstable materials and which cannot be used as reducing agents [1] without modification in organic synthesis. For example zirconium borohydride is a highly volatile solid, which decomposes around room temperature, inflames in air, and which hydrolyses explosively [2]. There are only a few reports in the literature of the use of modified and stable forms of these compounds for reductive transformations which include (Ph<sub>3</sub>P)<sub>2</sub>CuBH<sub>4</sub> [3], [(PPh<sub>3</sub>)<sub>2</sub>CuBH<sub>3</sub>CN]<sub>2</sub> [4], (C<sub>5</sub>H<sub>5</sub>)<sub>2</sub>Zr(Cl)BH<sub>4</sub> [5], Zn(BH<sub>4</sub>)<sub>2</sub> [6], DABCO and (pyz)Zn(BH<sub>4</sub>)<sub>2</sub> [7,8], [Zr(BH<sub>4</sub>)<sub>2</sub>Cl<sub>2</sub>(DABCO)<sub>2</sub>] [9], (Ppyz)Zr(BH<sub>4</sub>)<sub>2</sub>Cl<sub>2</sub> [10], and Zr(BH<sub>4</sub>)<sub>2</sub>-crown ethers [11]. In this study we have prepared a new stable ligand-metal zirconium borohydride, [Zr(BH<sub>4</sub>)<sub>2</sub>(PPh<sub>3</sub>)<sub>2</sub>], (ZrBTP), in high yield as a white, stable, non-hygroscopic powder. The compound can be stored at room temperature for months without significant change in its reducing ability. This zirconium borohydride is much more stable than NaBH<sub>4</sub> in H<sub>2</sub>O, CH<sub>3</sub>OH and also in mild aqueous acidic conditions. Chemical formula of the compound has been established by quantitative chemical analysis and also by IR, <sup>1</sup>H, <sup>13</sup>C and <sup>31</sup>P NMR spectroscopy.

Direct conversion of acid chlorides into the corresponding alcohols is one of the key functional group interconversions in organic chemistry and some

hydride reductants have been introduced for this purpose [12]. NaBH<sub>4</sub> involves vigorous conditions for achieving this transformation [13]. However, this method is less effective for polyfunctional molecules and produces different reduction products. In order to eliminate these problems, several modified methods have been developed in and reported the literature, such as the use of Zn(BH<sub>4</sub>)<sub>2</sub>N,N,N',N'-tetramethylene diamine (TMEDA) [12], 1-benzyl-4-aza-1-azoniabicyclo [2,2,2]octane tetrahydroborate (BAAOTB) [14], tetrabutyl ammonium tetrahydroborate (TBATB) [15], N-methyl pyrrolidine zinc borohydride (NMP-Zn(BH<sub>4</sub>)<sub>2</sub>) [16] and Zr(BH<sub>4</sub>)<sub>2</sub>Cl<sub>2</sub>(DABCO)<sub>2</sub> (ZrBDC) [17]. Here we report a safe and efficient method for the preparation of alcohols from acid chlorides using ZrBTP in THF under reflux conditions (Scheme 1).

### Results and discussion

In order to find the optimum conditions for the reduction of acid chlorides with ZrBTP, we have chosen 2-chlorobenzoyl chloride as a model compound. Reduction of 2-chlorobenzoyl chloride was first investigated in different solvents such as THF, CH<sub>2</sub>Cl<sub>2</sub> and Et<sub>2</sub>O. We observed that THF was the best solvent for this purpose.

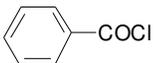
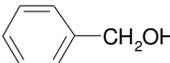
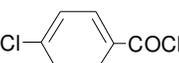
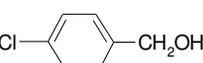
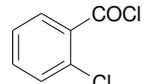
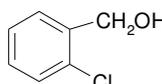
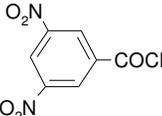
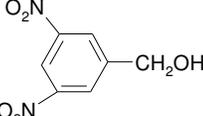
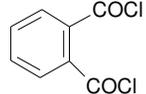
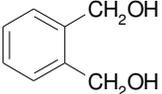
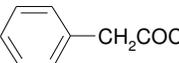
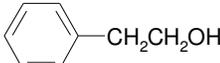
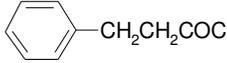
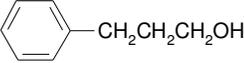
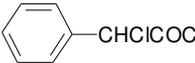
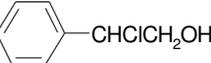
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A number of alkyl and aryl benzoyl chlorides were successfully reduced to the corresponding alcohols in excellent yields using this reduction system. The results are summarized in Table 1. The data indicate that reduction of different aromatic and aliphatic acid chlorides to the corresponding alcohols occurs in excellent yields using ZrBTP in THF. Chemoselective reduction in the presence of different substituents at the aromatic ring has been performed smoothly under similar reaction conditions (Table 1). Chloro and nitro groups were not affected during the progress of the

reaction. The effect of the nature of the substituents at the aromatic ring in the acid chlorides becomes clear from Table 1. Interestingly, ortho-phthaloyl chloride gave an excellent yield of ortho-phthalyl alcohol.

In order to show the advantages and drawbacks of our method, we have compared in Table 2 some of our results with those reported in the literature. As indicated in Table 2 our method in comparison with other reducing agents gives excellent yields of the corresponding alcohols using a lower molar ratio of ZrBTP to substrate.

**Table 1.** Reduction of different acid chlorides to the corresponding alcohols with ZrBTP

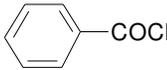
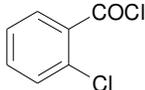
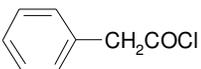
Acid chlorides <sup>a</sup>	Product <sup>b</sup>	Time (h)	Yield % <sup>c</sup>
		1	95
		0.7	98
		0.7	97
		0.8	97
		2.5	94
		1.2	95
		1.7	95
		1	96

<sup>a</sup>All reactions were carried out under reflux conditions with ZrBTP/acid chloride (1:1).

<sup>b</sup>All products were characterized by comparing their spectroscopic and physical data with those of authentic samples.

<sup>c</sup>Yields refer to isolated Products.

**Table 2.** Comparison of ZrBTP with other reagents in the reduction of acid chlorides to the corresponding alcohols

Substrate	ZrBTP		TBATB <sup>a</sup>		Zn(BH <sub>4</sub> ) <sub>2</sub> /TMDE <sup>b</sup>		BAAOTB <sup>c</sup>	
	Molar Equivalent Ratio	Time/h Yield %	Molar Equivalent Ratio	Time/h Yield %	Molar Equivalent Ratio	Time/h Yield %	Molar Equivalent Ratio	Time/h Yield %
	1	1 (95)	4	2 (90)	1.4	4.5 (95)	–	–
	1	0.8 (97)	4	0.5 (95)	–	–	3	0.25 (95)
	1	1.2 (95)	4	1.5 (85)	1.4	0.5 (95)	3	2 (85)

<sup>a</sup>Tetrabutylammonium tetrahydroborate (TBATB) [17].

<sup>b</sup>Zn (BH<sub>4</sub>)<sub>2</sub>/N,N,N',N'-tetramethylene diamine(TMEDA) [15].

<sup>c</sup>1-Benzyl-4-aza-1-azoniabicyclo[2,2,2]octanetetrahydroborat (BAAOTB) [14].

In conclusion, although there are several methods available for the reduction of acid chlorides to the corresponding alcohols we believe that the present method offers considerable advantages in terms of simpleness, functional selectivity, readily available reagents, mild reaction conditions, easy reaction workup, efficiency, excellent yields and lack of requirement of an inert atmosphere.

## Experimental

ZrBTP used in this study was easily prepared in high yield from commercially available starting materials. Acid chlorides were purchased from Merck. All the products are known compounds and were identified by comparison of their spectra and physical data with those of the authentic samples. Infrared spectra were recorded on a Bruker VECTOR 22 spectrophotometer. <sup>1</sup>H, <sup>13</sup>C and <sup>31</sup>P NMR spectra were measured with a Bruker DRX 500 AVANCE and a GNM-EX90A spectrometer using CDCl<sub>3</sub> as solvent and tetramethylsilane as an internal standard. Elemental analysis was performed with a CHN-600 Elemental Analyzer, system 785-500, 1988 LECO Corporation. Reaction monitoring and purity determination of the products were accomplished by TLC.

### Preparation of [Zr (BH<sub>4</sub>)<sub>2</sub>(PPh<sub>3</sub>)<sub>2</sub>], (ZrBTP)

A slurry was produced by the addition of a solution of LiBH<sub>4</sub> (6.32 g, 0.29 mol) in 150 mL of diethyl ether to

anhydrous ZrCl<sub>4</sub> (16.08 g, 0.069 mol) under inert atmosphere. The resulting mixture was stirred for 12h [18a]. Then an ethereal solution of triphenylphosphine (36.2 g, 0.138 mol) in 250 mL of diethyl ether was added dropwise to the slurry and stirring was continued for 12 h to produce a cream colored solid. The resulting solid was filtered, washed with Et<sub>2</sub>O (125 mL), and dried under vacuum to afford a white powder. For further purification, the resulting powder was washed with (250 mL) of dry MeOH and (50 mL) of dry Et<sub>2</sub>O, respectively, and was left under vacuum overnight. ZrBTP was isolated in high yield as a white, stable, non-hygroscopic powder. It can be stored at room temperature for months without significant change in its reducing ability.

The chemical formula of the reagent was established from its IR spectrum as well as from <sup>1</sup>H NMR and <sup>31</sup>P NMR studies [18b,c].

Quantitative measurement of Zr was performed by the UV/VIS spectrophotometric method [19a]. Determination of the BH<sub>4</sub><sup>-</sup> content was conducted by iodometric titration method [19b] and quantitative measurement of the chloride content proceeded by potentiometric titration [19c].

IR (KBr, PPh<sub>3</sub> species),  $\nu$  (cm<sup>-1</sup>): 3055m, 1585w, 1481s, 1434s, 1388w, 744s, 735s, 700s and for BH<sub>4</sub><sup>-</sup> species,  $\nu$  (cm<sup>-1</sup>): 2381s, 2370s, 2340s, 2249w, 1104s, 1058s. <sup>1</sup>H NMR (CDCl<sub>3</sub>, 250 MHz):  $\delta$ = 0.82-1.86 (broad, 8H, BH<sub>4</sub><sup>-</sup>), 7.14-7.66 (m, 30H, Ph). <sup>13</sup>C NMR (CDCl<sub>3</sub>, 63 MHz),  $\delta$ = 129.1, 129.3, 130.0, 131.7,

131.7, 133.5, 133.7.  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ ,  $\text{CH}_2\text{Cl}_2$ ; 101 MHz),  $\delta$ = 21.4-21.9. Anal. Calcd for: Zr, 14.13; B, 3.35; P, 9.60; C, 66.93; H, 5.94. Found: Zr, 13.65; B, 3.44; P, 9.78; C, 68.98; H, 6.07.

#### General Procedure for the Reduction of Acid Chlorides with ZrBTP

To a solution of the acid chloride (1.0 mmol) in dry THF (5 mL), the reagent (0.646 g, 1 mmol) was added and the mixture was stirred under reflux conditions for the specified time (Table 1). The progress of the reaction was followed by TLC (eluent: *n*-hexane/EtOAc: 4/1). After completion of the reaction, 5 % HCl (10 mL) was added and the mixture was extracted with diethyl ether (2 × 20 mL). The combined organic layers were dried over anhydrous  $\text{MgSO}_4$  and the solvent was evaporated. The crude product was purified by column chromatography on silica gel, and eluted with 2-5 % solution of ethyl acetate in *n*-hexane to afford the pure alcohols in 94-98% yield. The products were identified by comparison of their spectra and physical data with those of authentic samples.

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