

I_2O_5 : mild and efficient reagents for the oxidation of alcohols in water

Zhong-Quan Liu,* Yankai Zhao, Haiqing Luo, Lingzhi Chai and Qiuju Sheng

Institute of Organic Chemistry, Gannan Normal University, Ganzhou, Jiangxi 341000, PR China

Received 24 January 2007; revised 19 February 2007; accepted 26 February 2007

Available online 1 March 2007

Abstract—The mild and efficient nature of HIO_3 and I_2O_5 as environmentally benign, commercially available, atom efficient, and safe reagents for the oxidation of alcohols has been demonstrated. Additionally, these oxidants are highly chemoselective, and effect smooth room temperature oxidation of various electron-rich alcohols with catalytic amounts of KBr in water.

© 2007 Elsevier Ltd. All rights reserved.

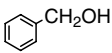

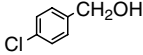
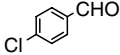
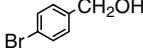
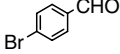
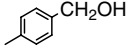
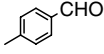
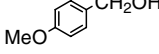
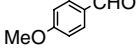
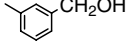
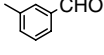
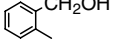
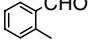
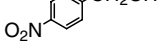
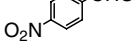

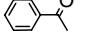
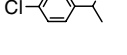
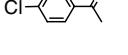
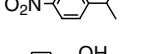
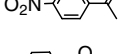
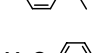
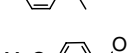
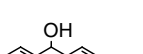
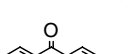

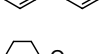

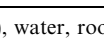
The oxidation of alcohols into the corresponding aldehydes or ketones is one of the most important functional group transformations in organic synthesis. Although numerous methods using a variety of reagents and conditions have been explored, the development of selective oxidation using safe, economic, and environmentally benign agents remains a critical challenge in organic synthesis.¹ Hypervalent iodine reagents have been extensively explored in organic chemistry as a result of their high efficiency, commercial availability, easy handling, and low toxicity.² For example, 1-hydroxy-1,2-benziodoxol-3(1*H*)-one-1-oxide (IBX) and Dess–Martin periodinane (DMP) have been successfully used for the oxidation of alcohols to the corresponding carbonyl compounds.³ However, most of these procedures were conducted in organic solvents such as DMSO, CH_2Cl_2 , and acetone. Herein, we wish to report an efficient selective catalytic oxidation of primary and secondary alcohols to the corresponding aldehydes and ketones in water by using iodic acid (IA, HIO_3) or its anhydride iodine pentoxide (IP, I_2O_5) as the stoichiometric oxidants. Although IA and IP are widely utilized in industry, these convenient inorganic hypervalent iodines have rarely been used in organic procedures.⁴ According to the investigation of Nicolaou et al.,⁵ alcohols are inert to IA and IP in DMSO which is believed to form complex. Our research was inspired by the results of the TEMPO– Br_2/I_2 system by Miller and Hoerrner⁶ and the PhIO–KBr system by Kita and co-workers.⁷ However, both suffered from overloading of the stoichiometric terminal

oxidants and catalysts (Miller's system: 2 equiv I_2 /10 mol % TEMPO/Toluene; Kita's system: 2.2 equiv PhIO/10 mol % KBr or 1.1 equiv PhIO/1.0 equiv KBr) in spite of their high efficiency. Recently, we found the aromatization of 1,3,5-trisubstituted pyrazolines could not be carried out smoothly by IA and IP unless a catalytic amount of bromide salts were added.⁸ The addition of bromide salts such as NaBr, KBr, and CuBr was found to activate IA and IP remarkably. Then, we began to question that a bromide salt-catalyzed alcohol oxidation with more atom-efficient stoichiometric IA and IP could be established. Fortunately, we successfully accomplished an efficient KBr-catalyzed alcohol oxidation at room temperature with a number of economic, commercially available, atom-efficient, environmental friendly, and safe iodine (V) agents in water (Table 1).

Although almost equally efficient, we favored the use of IP in these reactions over its diploid dosage oxidant IA. Initial investigation of stoichiometric oxidation of alcohols using IP catalyzed by KBr was carried out utilizing of 1-phenylethanol as substrate at room temperature in water. Theoretically, the mole ratio of I_2O_5 /alcohol may be about 1/5 as iodine was produced in the oxidation. As a matter of fact, the quantitative oxidation of 1-phenylethanol cannot be achieved unless more than 20 mol % of I_2O_5 or 40 mol % of HIO_3 is present regardless of the dosage of KBr. In addition, the appropriate quantity of the catalyst was then investigated in the oxidation of 1-phenylethanol using 25 mol % of I_2O_5 catalyzed by KBr with quantity varying from 1 mol % to 15 mol %. It is seen from Figure 1 that 5 mol % of KBr was found to be superior to others.

* Corresponding author. E-mail: liu_z_q@sina.com

Table 1. Atom-efficient oxidation of alcohols using HIO₃ and I₂O₅ in water^a

Entry	Substrate	Product	Method	Time (h)	Conv. (%) ^b	Select ^b (%)	Yield ^c (%)
1			A	24	87.8	71.9	62
2			A	4.5	74.8	100	70
3			A	4	94.3	100	92
4			A	12	90	89.5	80
5			B	12	90.5	100	86
6			A	12	75	100	72
7			A	12	100	100	98
8			A	24	100	100	98
9			A	3.5	100	100	98
10			A	8	100	100	99
11			A	12	100	100	98
12			A	5	100	100	96
13			B	12	100	100	96
14			A	2.5	100	100	96
15			A	24	22.3	100	20

^a Reaction conditions: alcohol (10 mmol), water, room temperature. Method A: I₂O₅ (2.5 mmol), KBr (0.5 mmol); Method B: I₂O₅ (5 mmol), KBr (0.5 mmol).

^b Conversions and selectivities are determined by GC–MS.

^c Yield of isolated chromatographically pure compound.

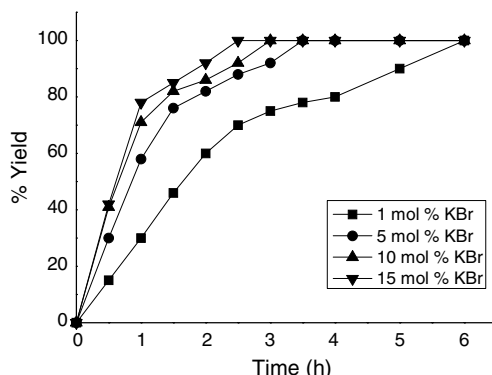


Figure 1. Oxidation of 1-phenylethanol using I₂O₅ catalyzed by KBr with varying quantity.

Under the following conditions: 10 mmol of alcohol, 25 mol % of I₂O₅, 5 mol % of KBr, H₂O, room temperature, almost all electron-rich alcohols were converted into their corresponding aldehydes, and ketones in high isolated yields (Table 1).⁹ It is seen from Table 1 that substituted benzyl alcohols gave good yields of the corresponding benzaldehydes derivatives (entries 1–8). The 25% of benzoic acid and 9% of 4-methylbenzoic acid were, respectively, obtained during the oxidation of the corresponding phenylmethanol (entry 1) and *p*-tolylmethanol (entry 4). Aromatic secondary alcohols gave almost quantitative yields of the corresponding ketones and no over oxidation by-products were found (entries 9–14). Cyclohexanone was obtained in 20% yield and 100% selectivity in the oxidation of cyclohexanol (entry 15). Due to the presence of double bond, the α,β -unsat-

urated aldehydes and ketones were not obtained from the corresponding alcohols. The alcohols with bromination of their aryl groups were produced in low yields from the corresponding primary alkyl substituted alcohols. A complex mixture was formed in the oxidation of some simple alcohols such as ethanol and *n*-butanol. The oxidation of aliphatic alcohols cannot be achieved in the catalytic process, however, the transition metal-free, cost-low, atom-efficient and the organic solvent-free features make this procedure very attractive.

In summary, this work demonstrates that I₂O₅/KBr is a very efficient, environmentally benign, commercially available, safe, atom-efficient, and low-cost system for the oxidation of alcohols. Additionally, these alternative reagents to IBX and DMP are chemoselective, and effect smooth room temperature oxidation of various electron-rich alcohols with catalytic amounts of KBr in water. These mild conditions may be helpful for a variety of other substrates that cannot tolerate strong oxidants. Extension of this process to expanded functional groups and further studies on the chemical selectivity are underway in this laboratory.

Acknowledgment

The authors thank the Gannan Normal University for financial support.

References and notes

- Hudlicky, M. *Oxidations in Organic Chemistry*; American Chemical Society: Washington, DC, 1990.
- For reviews, see: (a) Stang, P. J.; Zhdankin, V. V. *Chem. Rev.* **1996**, *96*, 1123; (b) Zhdankin, V. V.; Stang, P. J. *Chem. Rev.* **2002**, *102*, 2523; (c) Varvoglis, A. *Hypervalent Iodine in Organic Synthesis*; Academic Press: San Diego, 1997; (d) Wirth, T.; Hirt, U. H. *Synthesis* **1999**, 1271; (e) Stang, P. J. *J. Org. Chem.* **2003**, *68*, 2997; (f) Tohma, H.; Kita, Y. *Adv. Synth. Catal.* **2004**, *346*, 111; (g) Wirth, T. *Angew. Chem.* **2005**, *117*, 3722; *Angew. Chem., Int. Ed.* **2005**, *44*, 3656.
- (a) Dess, D. B.; Martin, J. C. *J. Org. Chem.* **1983**, *48*, 4155; (b) Dess, D. B.; Martin, J. C. *J. Am. Chem. Soc.* **1991**, *113*, 7277; (c) Wirth, T. *Angew. Chem.* **2001**, *113*, 2893; *Angew. Chem., Int. Ed.* **2001**, *40*, 2812; (d) More, J. D.; Finney, N. S. *Org. Lett.* **2002**, *4*, 3001; (e) Liu, Z.; Chen, Z. C.; Zheng, Q. G. *Org. Lett.* **2003**, *5*, 3321; (f) Surendra, K.; Krishnaveni, N. S.; Reddy, M. A.; Nageswar, Y. V. D.; Rao, K. R. *J. Org. Chem.* **2003**, *68*, 2058; (g) Weik, S.; Nicholson, G.; Jung, G.; Rademann, J. *Angew. Chem.* **2001**, *113*, 1489; *Angew. Chem., Int. Ed.* **2001**, *40*, 1436.
- For selected examples, see: (a) Hiroto, U.; Keiji, N.; Katsumi, O.; Patent No. JP 06040710; *Chem. Abstr.* **1994**, *120* 326849; (b) Chandrasekhar, S.; Gopalaiiah, K. *Tetrahedron Lett.* **2002**, *43*, 4023; (c) Hashemi, M. M.; Rahimi, A.; Jaber, Z. K.; Ahmadibeni, Y. *Acta Chim. Slov.* **2005**, *52*, 86.
- Nicolaou, K. C.; Montagnon, T.; Baran, P. S. *Angew. Chem.* **2002**, *114*, 1444; *Angew. Chem., Int. Ed.* **2002**, *41*, 1386.
- Miller, R. A.; Hoerrner, R. S. *Org. Lett.* **2003**, *5*, 285.
- (a) Tohma, H.; Takizawa, S.; Maegawa, T.; Kita, Y. *Angew. Chem.* **2000**, *112*, 1362; *Angew. Chem., Int. Ed.* **2000**, *39*, 1306; (b) Tohma, H.; Maegawa, T.; Takizawa, S.; Kita, Y. *Adv. Synth. Catal.* **2002**, *344*, 328.
- Chai, L. Z.; Zhao, Y. K.; Sheng, Q. J.; Liu, Z. Q. *Tetrahedron Lett.* **2006**, *47*, 9283.
- Typical procedure*: An alcohol (10 mmol) was mixed with iodine pentoxide (2.5 mmol) and KBr (0.5 mmol) in water (30 mL). The mixture was stirred at room temperature until the reaction was completed as monitored by TLC. Extraction of the reaction mixture with ether, washed by Na₂SO₃, dried with anhydrous MgSO₄, removal of the solvent under reduced pressure, and column chromatographic separation gave the pure product which was identified by ¹H NMR. The conversion and selectivity were determined by GC–MS.