

An Efficient Catalytic Aerobic Oxidation of Alcohols in Water Using Hypervalent Iodine(V)

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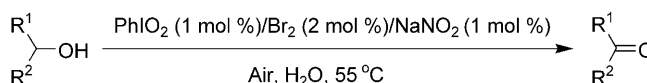
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Abstract: A transition metal-free aerobic oxidation of alcohols to the corresponding aldehydes or ketones can be effectively catalysed by iodoxybenzene (PhIO₂)/Br₂/NaNO₂ in water.

Keywords: alcohols; aldehydes; hypervalent iodine; ketones; oxidation; water as solvent

ing 1 mol % of iodoxybenzene as the active oxidant (Scheme 1 and Table 1). To the best of our knowledge, this is the first example of a hypervalent iodine(V)-catalyzed transition metal-free aerobic oxidation of alcohols in water.



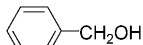
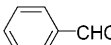
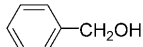
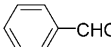
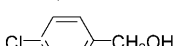
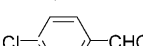
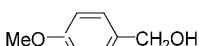
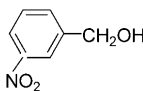
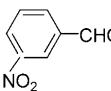
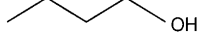
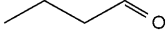
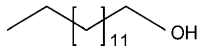
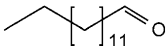
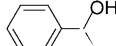
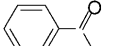
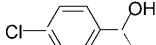
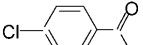
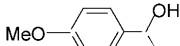
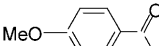
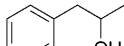
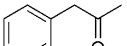
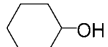
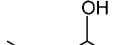
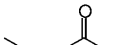
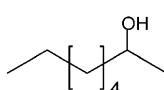
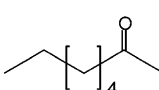
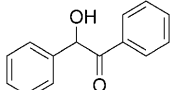
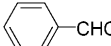
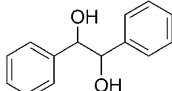
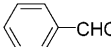
Scheme 1.

The development of a selective alcohol oxidation that uses environmentally benign and low-cost oxidants is a critical challenge for synthetic organic chemists. Recently, the use of molecular oxygen as the terminal oxidant has received great attention, and many catalytic systems have been developed for aerobic alcohol oxidation using palladium,^[1] copper,^[2] or ruthenium catalysts.^[3] Of particular interest are catalytic systems involving nitroxyl radicals (e.g., 2,2,6,6-tetramethyl-piperidyl-1-oxyl, TEMPO).^[4,5] However, many of these systems suffer from expensive transition metal catalysts, relatively high catalyst loadings and use of organic solvents.^[6,7] We wish to report herein an efficient selective catalytic aerobic oxidation of primary and secondary alcohols to the corresponding aldehydes and ketones in water by using iodoxybenzene (PhIO₂) as the active oxidant. Hypervalent iodine reagents, such as *o*-iodoxybenzoic acid (IBX) and the Dess–Martin periodinane (DMP), have been successfully used for oxidation of alcohols to the corresponding carbonyl compounds,^[8] while only limited reports dealt with use of iodoxybenzene as the oxidant.^[9] In addition, most of these procedures used stoichiometric hypervalent iodine, and were conducted in organic solvents, apart from the stoichiometric alcohol oxidation using IBX in an ionic liquid and water^[8h] and in water/acetone mixture in the presence of β -cyclodextrin,^[8i] as well as the oxidation of sulfides to sulfoxides in water by using 55 mol % of iodoxybenzene.^[9c] Taking advantage of the high solubility of iodoxybenzene in water,^[10] we successfully accomplished an efficient catalytic aerobic alcohol oxidation in water by us-

It is seen from Table 1 that benzyl alcohols gave excellent yields of the corresponding benzaldehydes and no over oxidation by-products were found (entries 1–5). Primary aliphatic alcohols also produced the corresponding aldehydes as the unique product, but the yields were low due to the lower conversion (entries 6 and 7). Aromatic and aliphatic secondary alcohols gave excellent yields of the corresponding ketones (entries 8–15). Benzoin and *meso*-hydrobenzoin gave the C–C bond cleavage product benzaldehyde (entries 16 and 17). The efficiency and selectivity are similar to the previously reported catalytic procedures,^[1–7] but the transition metal-free, low catalyst loading and the organic solvent-free features make this procedure very attractive.

A plausible mechanism for this catalytic oxidation is depicted in Scheme 2 that comprises three redox cycles, similar to that proposed previously for the TEMPO-mediated oxidation.^[7c] In the scheme iodoxybenzene is the active oxidant that oxidizes the alcohol to the corresponding carbonyl compound. The acid-catalyzed oxidation of alcohols by the stoichiometric iodoxybenzene in organic solvents has been reported previously.^[9a] The running of the cycle I continuously provides iodoxybenzene by oxidizing the intermediate dihydroxyiodobenzene,^[11] the reduced form of iodoxybenzene, with Br₂, which in turn, is reduced to HBr. Although NaNO₂ cannot directly react with HBr, it can disproportionate in acidic aqueous solution to produce NO₃[–] and NO [Eq. (1)].^[12] Oxidation of NO by atmospheric oxygen produces NO₂ which reoxidizes HBr to Br₂ as illustrated in the cycle II,^[12] and the NO₂ is reduced back to NO (cy-

Table 1. Catalytic aerobic alcohol oxidation in water.^[a]

Entry	Substrate	Product	Time [h]	Conv. ^[b] [%]	Yield ^[c] [%]
1			1	100	94
2			1	100	94
3			1	100	97
4			1	100	94
5			1.5	100	98
6			2	48.0	42
7			2	73.6	67
8			1.5	100	98
9			1.5	100	97
10			1.5	100	95
11			1	100	93
12			1.5	100	94
13			1.5	100	95
14			2	100	92
15			2	100	93
16			8	100	91
17			7	100	96

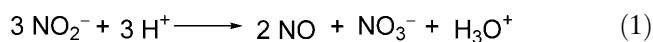
^[a] Reaction conditions, see Experimental Section. All products were identified by comparing their MS and ¹H NMR data with those in the literature.

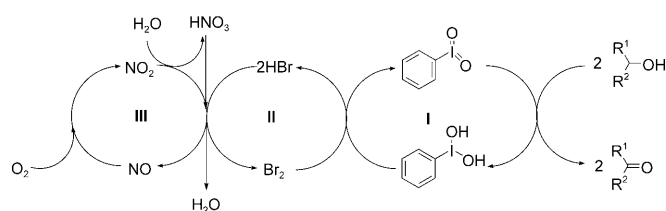
^[b] Conversion determined by GC-MS.

^[c] Isolated yield of pure products.

cle III).^[12] The coupling of these three redox cycles are so efficient that only 1 mol % of iodoxybenzene, 2 mol % of Br₂ and 1 mol % of NaNO₂ are sufficient to complete the overall catalytic process. In addition, HNO₃ produced from Eq. (1) and from dissolving NO₂ in water

can also oxidize HBr to Br₂ [Eq. (2)] as reported recently.^[7d]





Scheme 2. Our proposed mechanism.



In conclusion, this work demonstrates that $\text{PhIO}_2/\text{Br}_2/\text{NaNO}_2$ is a very efficient catalytic system for selective aerobic oxidation of alcohols in water. Extension of this procedure to other substrates is underway in this laboratory.

Experimental Section

^1H NMR spectra were recorded on a Varian Mercury Plus-300 spectrometer in CDCl_3 with TMS as internal standard. Mass spectra were determined on a Hewlett Packard 5988A spectrometer by direct inlet at 70 eV. GC/MS were determined using a Finnigan Trace 2000 GC/MS system. All products were identified by NMR, MS and/or comparison with authentic samples. Iodoxybenzene was prepared according to the literature procedure.^[10] Alcohols and other reagents were all purchased from commercial sources.

In a typical experiment an alcohol (10 mmol) was mixed with iodoxybenzene (0.1 mmol), Br_2 (0.2 mmol) and NaNO_2 (0.1 mmol) in water (40 mL). The mixture was heated to 55°C to facilitate dissolution of iodoxybenzene and kept at this temperature under vigorous stirring and a balloon pressure of air until the reaction was completed as monitored by TLC. Extraction of the reaction mixture with ether followed by removal of the solvent under reduced pressure and column chromatographic separation gave the pure product which was identified by MS and ^1H NMR. The conversion and selectivity were determined by GC-MS.

Acknowledgements

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