



Organic iodine(V) compounds as terminal oxidants in iron(III) phthalocyanine catalyzed oxidation of alcohols

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ABSTRACT

The pseudocyclic iodine(V) oxidants, such as esters of iodoxybenzoic acid (IBX-esters) and 2-iodylphenol ethers, can serve as stable and efficient sources of oxygen in catalytic oxidations, and their reactivity is similar to the commonly used thermally unstable and potentially explosive iodosylbenzene. In a specific example, primary or secondary benzylic alcohols are selectively oxidized by isopropyl IBX-ester in the presence of μ -oxo-(tetra-*tert*-butylphthalocyaninato)iron(III) (0.1 mol equiv) in dichloromethane at room temperature in 0.5–2 h to afford the respective carbonyl compounds in 100% conversion and preparative yields 91–95% after column chromatography.

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Hypervalent iodine compounds are used extensively in organic synthesis as highly selective and environmentally friendly oxidizing reagents.¹ Among these reagents, iodosylbenzene, (PhIO)_n, is particularly important as an oxygen transfer agent that has found widespread application in catalytic oxygenation reactions after the discovery of its supreme efficacy as a source of oxygen atoms for oxidations catalyzed by cytochrome P-450 and by discrete transition metal complexes.^{2,3} Despite its usefulness as an oxidant, practical applications of iodosylbenzene are hampered by its low solubility in non-reactive media,³ as well as low thermal stability and explosive properties upon moderate heating.⁴

In this Letter, we report preliminary results on the use of stable and soluble pseudocyclic hypervalent iodine(V) reagents **1–3** (Fig. 1) as terminal oxidants in biomimetic oxidation of alcohols catalyzed by the Fe(III) phthalocyanine complex **4** or metal porphyrin complexes **5** and **6** (Fig. 2). Complex **4** was prepared using direct high-temperature reaction between 4-*tert*-butylphthalonitrile and iron(II) acetate as described previously,⁵ while Co(II) tetraphenylporphyrin **5** and Ru(II)-carbonyl tetraphenylporphyrin **6** were used from commercial sources.

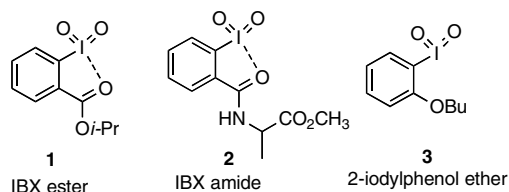


Figure 1. Hypervalent iodine(V) oxidants.

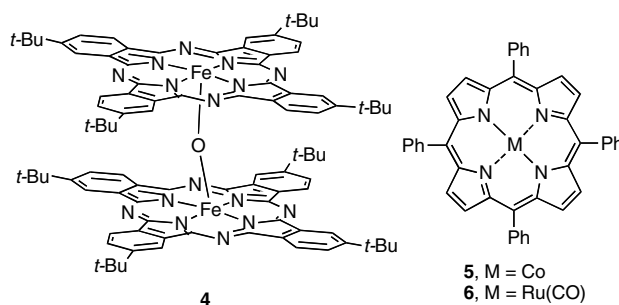


Figure 2. Iron(III) phthalocyanine **4** and metal porphyrin complexes **5** and **6**.

Isopropyl ester of 2-iodylbenzoic acid **1** was prepared by the hypochlorite oxidation of the readily available isopropyl ester of 2-iodobenzoic acid and was isolated in the form of a stable, white, microcrystalline solid.^{6a} Compound **1** is also commercially available from several chemical companies.^{6b} 2-Iodylbenzamide **2**^{7a} and 2-iodylphenol ether **3**^{7b} were prepared by oxidation of the respective iodides using dimethyldioxirane. Both reagents are isolated as stable and non-explosive microcrystalline products. The previously reported X-ray studies of compounds **1–3** revealed the presence of strong intramolecular I···O interactions, which partially replace the intermolecular I···O secondary bonds disrupting the polymeric structure typical of other ArIO₂.^{6,7} Due to this structural feature, compounds **1–3** have excellent solubility in non-polar organic solvents and can be used as efficient and convenient oxidizing reagents.^{6–8}

We have investigated catalytic oxidation of alcohols to carbonyl compounds using oxidants **1–3** and complexes **4–6**. The use of iodosylbenzene in the catalytic oxidation of alcohols in the presence

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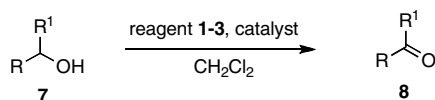
of various transition metal complexes has previously been documented in the literature.⁹

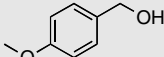
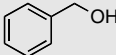
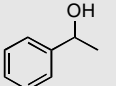
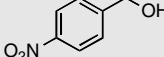
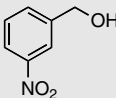
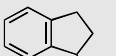
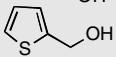
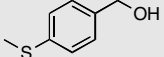
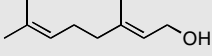
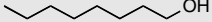

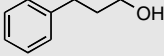
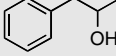
In a typical procedure, the oxidation of alcohols was carried out at room temperature in dry dichloromethane with 0.7 mol equiv (1.4 equiv of active oxygen) of the iodine(V) reagent and 0.1 equiv of the appropriate catalyst (Table 1).¹⁰ After indicated time, the catalyst was removed by flash chromatography and the obtained

solution was analyzed by GC–MS to determine the conversion of alcohol **7** to the respective carbonyl compound **8**. According to the GC–MS and NMR data, carbonyl compounds **8** and the appropriate iodides resulting from the reduction of reagents **1–3** were the only products formed under these reaction conditions. Dichloromethane was found to be the best solvent; the conversion was found to be much lower when the oxidation was performed in

Table 1

Catalytic oxidation of alcohols **7** to carbonyl compounds **8** using hypervalent iodine reagents^a



| Entry | Reagent | Catalyst | Substrate 7 | Conversion (preparative yield) (%) | Time (h) |
|-------|-------------------|-----------------------|---|------------------------------------|----------|
| 1a | 1 | 4 | | 100 (95) | 1 |
| 1b | 1 | 5 | | 15 | 22 |
| 1c | 1 | 6 |  | 100 | 1.5 |
| 1d | 2 | 4 | | 31 | 2.5 |
| 1e | 3 | 4 | | 11 | 2 |
| 1f | PhIO ^b | 4 | | 68 | 3 |
| 1g | 1 | None | | 0 | 24 |
| 2a | 1 | 4 |  | 100 | 1.5 |
| 2b | 1 | 5 | | 0 | 48 |
| 2c | 1 | 6 | | 94 | 3 |
| 2d | 3 | 4 | | 53 | 3 |
| 2e | 1 | None |  | 55 | 168 |
| 3a | 1 | 4 | | 100 (91) | 2 |
| 3b | 1 | 6 | | 100 | 2.5 |
| 3c | 3 | 4 | | 54 | 3 |
| 4a | 1 | 4 |  | 100 | 0.5 |
| 4b | 1 | 5 | | 3 | 24 |
| 4c | 1 | 6 | | 100 | 1 |
| 4d | 3 | 4 | | 100 | 0.5 |
| 4e | PhIO ^b | 4 |  | 96 | 1.5 |
| 5 | 1 | 4 | | 100 | 3 |
| 6a | 1 | 4 |  | 31 | 5 |
| 6b | 1 | 4 ^c | | 70 ^c | 4 |
| 6c | 1 | 6 | | 100 | 2.5 |
| 6d | 3 | 4 |  | 31 | 5.6 |
| 7 | 1 | 4 | | 24 | 3 |
| 8 | 1 | 4 |  | 20 ^d | 3 |
| 9a | 1 | 4 |  | 100 | 1 |
| 9b | 3 | 4 | | 100 | 2.5 |
| 9c | PhIO ^b | 4 | | 100 | 1 |
| 10a | 1 | 4 |  | 22 | 7 |
| 10b | 1 | 4 ^c | | 25 ^c | 3 |
| 11 | 1 | 4 |  | 11 | 8 |
| 12 | 1 | 4 |  | 10 | 4.5 |
| 13 | 1 | 4 |  | 6 | 3.5 |

^a All oxidations were carried out at room temperature in dry dichloromethane with 0.7 equiv of reagents **1**, **2**, or **3** and 0.1 equiv of catalyst. Catalyst was removed by flash chromatography and obtained solution was analyzed by GC–MS.

^b 1.5 equiv of PhIO was used.

^c Oxidations were carried out under reflux conditions.

^d No products of oxidation on sulfur were observed.

toluene or acetonitrile. The results of the oxidations are summarized in Table 1.

Using benzylic alcohols as model substrates, we have found that IBX-ester **1** is the most efficient stoichiometric oxidant in the catalytic oxidation reactions. Indeed, the oxidation of 4-methoxybenzyl alcohol using oxidant **1** at room temperature in the presence of Fe(III) phthalocyanine complex **4** (10 mol %) affords the respective aldehyde in a 100% conversion (95% isolated yield after chromatography) after 1 h of stirring at room temperature (Table 1, entry 1a). The conversion is much lower when reagents **2** and **3** are employed for the oxidation of benzylic alcohols under similar conditions using the same catalyst **4** (entries 1d, 1e, 2d, 3c, 4d, and 6d). Iron(III) phthalocyanine complex **4** and ruthenium(II)-carbonyl tetraphenylporphyrin **6** are the most efficient catalysts in these oxidations. The oxidations in the presence of Ru(II) complex **6** (entries 1c, 2c, 3b, 4c, and 6c) proceed only slightly slower compared to the Fe(III) complex **4** (entries 1a, 2a, 3a, 4a, 5, and 6a,b), while the Co(II) tetraphenylporphyrin **5** did not show any significant catalytic effect (entries 1b, 2b, and 4b). The availability and low cost of iron(III) complex **4** as compared those of to the ruthenium porphyrin **6** clearly make it a potentially useful reagent for biomimetic catalytic transformations.

The oxidation of alcohols with reagent **1** in the absence of catalyst proceeds extremely slow and shows measurable conversion to the aldehyde only after 4–7 days of stirring at room temperature (entries 1g and 2e).¹¹ The sulfur-containing benzylic alcohols (entries 7 and 8) show significantly lower reactivity in the catalytic oxidations, and the oxidation of organic sulfur to sulfoxide or sulfone is not observed under these conditions. The allylic alcohol demonstrates about the same reactivity in the catalytic oxidations (entries 9a,b), while the aliphatic substrates are much less reactive (entries 10–13).

IBX ester **1** and iodosylbenzene show similar reactivity in the oxidation of same substrates in the presence of Fe(III) phthalocyanine complex **4** as catalyst (compare entries 1a and 1f, 4a and 4e, 9a and 9c). Both iodosylbenzene and reagent **1** are commercially available or can be conveniently prepared from common precursors. However, in contrast to the insoluble, thermally unstable and potentially explosive iodosylbenzene,^{3,4} reagent **1** is soluble in organic solvents, can be stored for extended periods at room temperature, and is not explosive. The results of our comparative studies (Table 1) confirm that IBX ester **1** can be effectively used as a stoichiometric oxidant in biomimetic oxidations catalyzed by metal porphyrin or phthalocyanine complexes.

Acknowledgments

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- Typical procedure*: To a vigorously stirred solution of reagents **1–3** (0.08 mmol) and catalysts **4–6** (0.011 mmol) in dry dichloromethane (3 ml), the appropriate alcohol (0.11 mmol) was added. The resulting solution was stirred at room temperature for the indicated time (Table 1). A portion of the crude reaction mixture (0.1 ml) was passed through 1 cm of silica gel suspended in a pasteur pipet and washed with the mixture of hexane and ethyl acetate 3:2 (1 ml). The obtained solution was analyzed by GC-MS.
- It was previously reported that reagents **1** and **3** do not oxidize alcohols in dichloromethane at room temperature in the absence of acids or Lewis acids.^{6,7b} IBX-amide **2** can effectively oxidize alcohols without catalysts,^{7a} and in fact the addition of Fe(III) phthalocyanine complex **4** does not lead to any improvement of oxidative reactivity of reagent **2** (entry 1d of Table 1).