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Cobalt phthalocyanine catalyzed aerobic oxidation of secondary alcohols: an efficient and simple synthesis of ketones

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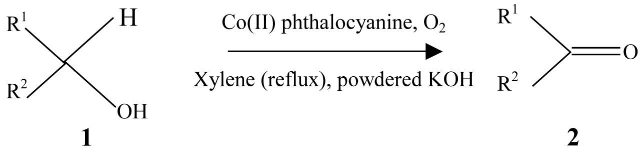
Abstract—A variety of activated and non-activated secondary alcohols have been efficiently oxidized to their corresponding ketones in excellent yields with molecular oxygen using cobalt phthalocyanine as catalyst in the presence of powdered potassium hydroxide. © 2002 Elsevier Science Ltd. All rights reserved.

The oxidation of secondary alcohols to carbonyl compounds is an important synthetic transformation[1] and many stoichiometric oxidants notably chromium(VI) and manganese reagents, producing copious amounts of heavy metal wastes, have been used to accomplish this reaction.[2] Molecular oxygen is an attractive oxidant and the development of synthetic methodologies using molecular oxygen as the sole oxidant is a rewarding goal both from economic and environmental points of view.[3] In this context aerobic oxidation of secondary alcohols to ketones by using metal catalysts such as hydrated $RuCl_3$,[4] $RuO_2{\cdot}H_2O$,[5] a combination of cobalt and ruthenium,[6] tetrapropylammonium perruthenate,[7] Ru^{3+}-exchanged hydroxyapatite,[8] a ruthenium complex along with Co–salen,[9] Ru–Al–Mg hydrotalcites,[10] Pd(II) hydrotalcite[11] and cobalt complexes with 2-methylpropanal as the sacrificial aldehyde[12] have been reported in the literature.

However, these procedures suffer from one or more drawbacks such as the use of expensive metal catalysts like ruthenium and palladium, oxidation of only activated alcohols such as benzylic and allylic alcohols, the need for a sacrificial aldehyde, and severe reaction conditions, for example, high pressure.

Metal phthalocyanines (MPc), which are easily accessible, stable and a cost effective alternative of the biomimetic oxidation catalysts, are known to catalyze a variety of organic reactions.[13] Being insoluble in common organic solvents they can be easily separated from the reaction mixture for reuse and thus can behave as heterogeneous catalysts without the inherent limitations of leaching commonly associated with for example, heterogenised homogeneous catalysts. In continuation of our studies on oxidation with molecular oxygen as primary oxidant,[14] herein we report a simple and convenient method for the oxidation of both activated and non-activated secondary alcohols to their corresponding ketones in near quantitative yields by using molecular oxygen as the sole oxidant and cobalt phthalocyanine as the catalyst (Scheme 1).

The oxidation of various activated and non-activated secondary alcohols was carried out with molecular oxygen using a catalytic amount of cobalt phthalocyanine in the presence of an equimolar amount of powdered potassium hydroxide.[15] All the alcohols studied were smoothly converted to the corresponding ketones in excellent yields. These results are presented in Table 1. Among the various alcohols studied those containing a carbonyl at the α-position were found to be the most reactive and required shorter reaction times for their oxidation (Table 1, entries 10–13). Furthermore aromatic alcohols were found to be more reactive than aliphatic alcohols (Table 1, entries 1 and 2).



Scheme 1.

Keywords: cobalt phthalocyanine; secondary alcohols; oxidation; molecular oxygen; ketones.

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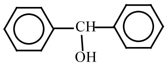
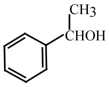
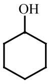
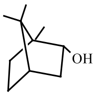
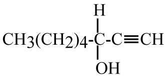
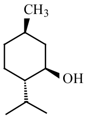
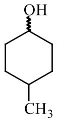
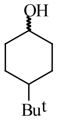
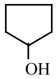
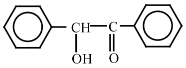
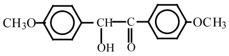
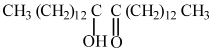
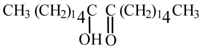
Table 1. Aerobic oxidation of secondary alcohols to ketones using cobalt phthalocyanine as catalyst[a]

Entry	Substrate	Reaction time (h)	Yield(%)[b]
1		0.75	94
2		3.00	95
3		5.50	75
4		7.00	92
5	 $CH_3(CH_2)_4\text{-}\overset{H}{\underset{OH}{C}}\text{-}C{\equiv}CH$	7.00	70
6		8.00	70
7		12.00	75
8		14.00	75
9		15.00	70
10		0.17	96
11		0.08	97
12	 $CH_3(CH_2)_{12}\underset{OH}{C}\;\underset{O}{\underset{\|}{C}}(CH_2)_{12}CH_3$	3.50	85
13	 $CH_3(CH_2)_{14}\underset{OH}{C}\;\underset{O}{\underset{\|}{C}}(CH_2)_{14}CH_3$	4.00	80

[a] Reaction conditions: Secondary alcohol (1 mmol), powdered potassium hydroxide (1 mmol), cobalt phthalocyanine (5 mol%) in xylene (5 ml) at reflux temperature under an oxygen atmosphere.

[b] Isolated yields.

The presence of powdered potassium hydroxide was found to be vital in these reactions Since the oxidation of benzhydrol to benzophenone with molecular oxygen using 5 mol% of cobalt phthalocyanine as catalyst in the absence of powdered potassium hydroxide was not complete even after 24 h, whilst it was complete within 45 min in the presence of an equimolar amount of potassium hydroxide. Other bases such as potassium carbonate and tertiary amines were found to be less effective than powdered potassium hydroxide.

To evaluate the effect of solvents, the aerobic oxidation of benzhydrol was carried out under similar reaction conditions but using different solvents: xylene, acetonitrile, methanol, toluene and 1,2-dichloroethane. Xylene was found to be the most suitable. The oxidation of secondary alcohols to the corresponding ketones was found to be very slow at room temperature and could be carried out more efficiently in refluxing xylene. The catalytic effect of the cobalt phthalocyanine was also investigated using benzhydrol as the substrate. In the absence of catalyst, the reaction was found to be very slow and was not complete even after 8 h whilst with 0.5 mol% cobalt phthalocyanine as catalyst, the reaction was complete within 1.5 h. An increase in catalyst from 0.5 to 10 mol% has only a marginal effect in decreasing the reaction time, indicating the effectiveness of catalyst even at low concentration. Non-activated alcohols such as borneol and cyclohexanol could not be oxidized in the absence of catalyst under the same reaction conditions. The use of cobalt phthalocyaninetetrasulphonamide[16] and cobalt phthalocyaninetetracarboxylic acid[17] as catalyst in place of cobalt phthalocyanine gave comparable results. The mechanism of this reaction is not clear at this stage and further studies in this direction are being carried out.

In summary, we have developed a simple and eco-friendly catalytic aerobic oxidation procedure for the oxidation of both activated and non-activated alcohols to the corresponding ketones. The simplicity of the system, the non-hazardous nature of the catalyst and the versatility of the method towards a range of activated and non-activated alcohols make cobalt phthalocyanine catalyzed oxidation an attractive, environmentally friendly synthetic tool for the oxidation of secondary alcohols to ketones by molecular oxygen.

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15. *Typical experimental procedure*: To a stirred solution of benzhydrol (184 mg, 1 mmol) in xylene (5 ml) was added powdered potassium hydroxide (56 mg, 1 mmol), cobalt phthalocyanine (28 mg, 5 mol%) and the reaction mixture was refluxed for 45 min under an oxygen atmosphere. The reaction progress was monitored by TLC (SiO_2). At the end of reaction cobalt phthalocyanine and powdered potassium hydroxide were removed by filtration. The filtrate obtained was evaporated under vacuum and the residue thus obtained was purified by column chromatography on silica gel using ethyl acetate/hexane (1:4) as eluent. Evaporation of the solvent yielded benzophenone

(171 mg, 94%). Other alcohols were oxidized using this procedure and their reaction times and yields are given in Table 1. The products were identified by comparing their physical and spectral data with those of authentic compounds reported in literature.

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