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Oxidation of benzoins to benzils using bismuth(III) nitrate–copper(II) acetate

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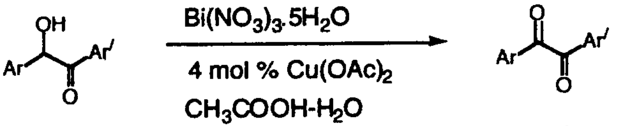
Abstract

Benzoins are oxidized to benzils in excellent yields by 0.4 equivalents of $Bi(NO_3)_3 \cdot 5H_2O$ and 4 mol% of $Cu(OAc)_2$. $Bi(NO_3)_3 \cdot 5H_2O$ is a stable, inexpensive, commercially available solid. The relatively low cost and low toxicity of bismuth(III) nitrate makes this procedure a particularly attractive method for oxidation of benzoins.

Keywords: bismuth; bismuth compounds; oxidation; copper; copper compounds.

The oxidation of benzoins to benzils has been accomplished by several reagents such as nitric acid,[1] Fehling's solution,[1] thallium nitrate,[2] ammonium nitrate–copper acetate,[3] and ammonium chlorochromate–alumina.[4] Many of these reagents such as ammonium chlorochromate are highly toxic and produce waste that persist in the environment. Due to environmental concerns, there is increasing need and interest in developing processes that minimize production of toxic waste. Recently, the oxidation of benzoins to benzils on alumina-supported copper(II) sulfate under microwave irradiation has been reported.[5] Bismuth compounds are attractive candidates for use in green chemistry because bismuth is the least toxic of the heavy metals.[6] The biochemistry,[7] toxicology,[8] and environmental effects[9] of bismuth compounds have been well documented. The oxidation of benzoins to benzils has been carried out using bismuth(III) oxide in acetic acid.[10] While this method represents an important early example of green chemistry, it requires the use of a slight excess of Bi_2O_3. We wish to report that bismuth(III) nitrate pentahydrate (0.4 equivalents) in the presence of 4 mol% of copper(II) acetate smoothly oxidizes benzoins to the corresponding benzils in good to excellent yields (Eq. 1).



1a-f **2a-f** (1)

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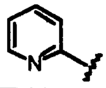
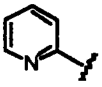
Table 1
Oxidation of benzoins[a] to benzils[b] using $Bi(NO_3)_3 \cdot 5H_2O$-$Cu(OAc)_2$

Entry	Ar	Ar′	Yield (%)[c]	Lit Ref
1a	Ph	Ph	99	3
1b	*p*-$MeOC_6H_4$	*p*-$MeOC_6H_4$	99	3
1c	*p*-MeC_6H_4	*p*-MeC_6H_4	95	2
1d	Ph	*p*-$MeOC_6H_4$	95	14
1e			58[d]	3
1f			10[e]	10

[a] Benzoins were purchased commercially except entry 1d which was synthesized according to a literature procedure.[13] [b] Products were identified by melting point, ^1H and ^{13}C NMR spectroscopy. [c] Refers to yield of pure isolated product. [d] Yields did not improve with increased amounts of solvent. [e] A small amount of pure pyridil was isolated when the oxidation was carried out in THF-acetic acid (6:1) as the solvent.

Bismuth(III) nitrate pentahydrate is a stable, inexpensive, commercially available solid. The oxidation is carried out in 80% acetic acid–20% water (v/v) as the solvent. The work-up is simple and products are obtained in good to excellent yields. No toxic solid waste products are produced. The use of 0.4 equivalents of bismuth(III) nitrate was found to be optimal. The use of more equivalents of the oxidant did not accelerate the reaction or increase the yields. The use of less than 0.4 equivalents of bismuth(III) nitrate resulted in an incomplete reaction. The reaction works well with variety of symmetrical and unsymmetrical benzoins as shown in Table 1.

In contrast to the oxidation of benzoins by bismuth(III) oxide, oxidation of furoin (entry **1e**) with $Bi(NO_3) \cdot 5H_2O$ gave only a modest yield of furil **2e**. When furil itself was subjected to the reaction conditions, it was recovered unchanged in almost quantitative yield. This suggested that furoin was undergoing competitive cleavage under the reaction conditions to give water soluble products. A similar observation has been reported in the oxidation of benzoin by ceric ammonium nitrate.[11] In this case, benzoin is cleaved to give benzaldehyde and benzoic acid. We attribute the lower yield in oxidation of furoin to competitive cleavage forming water soluble products: furfural and furoic acid. Oxidation of pyridoin (entry **1f**) did not yield any isolable product. When commercial pyridil was subjected to the same oxidation conditions, no product could be isolated even though TLC analysis showed disappearance of starting material. The cleavage products pyridine-2-carboxaldehyde and pyridine-2-carboxylic acid are water soluble and would be expected to remain in the aqueous layer.

The oxidation does not proceed in the absence of copper(II) acetate at any significant rate and works well only with α-hydroxyketones. Oxidation of mandelic acid and methyl mandelate was attempted using the same reaction conditions.[12] Even though starting material was seen to disappear by TLC, the expected keto acid or the keto ester product were not formed. Only benzoic acid could be isolated in low (<20%) yield.

A representative procedure is given here: A mixture of *p*-anisoin (2.00 g, 7.34 mmol), $Bi(NO_3)_3 \cdot 5H_2O$ (1.41 g, 2.90 mmol), and $Cu(OAc)_2$ (0.0530 g, 0.29 mmol) in a solution of 80% acetic acid in water (v/v) was refluxed for 3 h and cooled to rt. Water (10 mL) and dichloromethane (20 mL) were added and the mixture was transferred to a separatory funnel. The organic layer was separated, washed with 10% aq. Na_2CO_3 (2×15 mL), saturated aqueous NaCl (10 mL), dried (Na_2SO_4) and concentrated on a rotary evaporator to yield 1.90 g (99%) of pure *p*-anisil. Products were identified by comparison of melting point with literature values as well as by ^1H and ^{13}C NMR spectroscopy.

In summary, $Bi(NO_3)_3 \cdot 5H_2O$-$Cu(OAc)_2$ in acetic acid is an excellent reagent for oxidation of benzoins to benzils. It has the advantages of being commercially available, inexpensive and relatively non-toxic.

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12. The work-up was slightly modified. After addition of CH_2Cl_2 and filtration, the organic layer was extracted with 10% aqueous sodium carbonate until basic and then the aqueous layer was made acidic. The solid formed upon cooling was collected by suction filtration. In another modification of the procedure, the Na_2CO_3 extraction was omitted and the CH_2Cl_2 layer was dried and removed at reduced pressure and the solid obtained was recrystallized with hot water. Neither procedure gave a good mass recovery.
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