An efficient protocol for the acylation of *t*-butanol in the presence of samarium diiodide

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Samarium diiodide (SmI_2) promotes the rapid acylation of *t*-butanol with a variety of acid chlorides under neutral conditions to afford cleanly the corresponding *t*-butyl esters in excellent yields.

Keywords: acylation, samarium diiodide, *t*-butanol, *t*-butyl esters, acid chlorides

Numerous naturally occurring as well as synthetically and biologically interesting compounds like nucleosides, carbohydrates, carbocycles, steroids *etc*. have hydroxyl functions as part of their structures. Several reactions, such as oxidations, halogenations or dehydrations of these compounds need protection of the hydroxyl groups to increase yields and reduce undesired side reactions. A wide variety of methods for the protection of alcohols are well documented and their protection as esters is among the most used methods in organic synthesis because of the ease of formation as well as mild conditions for deprotection.[1] However, these procedures often suffer from serious limitations, especially if acid or base labile moieties are an inherent part of the substrates and in most of the cases the reported methods work well on primary or secondary alcohols only and fail to protect tertiary alcohols.

The use of samarium diiodide as a strong and versatile one-electron-transfer reducing agent in organic synthesis has been explored widely since it was introduced by Kagan's group.[2] Also, samarium diiodide has been investigated extensively[3] as a catalyst in organic synthesis. We have very recently described the acylation of alcohols with acid chlorides using samarium metal as a promoter.[4] However, *t*-butanol does not react under the same reaction conditions. Moreover, carboxylic *t*-butyl esters have been greatly utilised in β-keto- and β-hydroxy ester synthesis owing both to their resistance to self-condensation by strong base and to their easy hydrolysis by acid.[5] We wish now to report an efficient method for the synthesis of carboxylic *t*-butyl esters using samarium diiodide as a promoter (Scheme 1). To the best of our knowledge, this is the first report of samarium diiodide-promoted acylation of *t*-butanol.

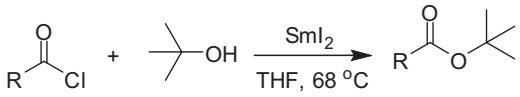
The reaction conditions were standardised after conducting the acylation of *t*-butanol with benzoyl chloride under different reaction conditions using varying amounts of samarium diiodide (Table 1). Thus, under optimum conditions, *t*-butanol (1 equivalent) was acylated at 68°C almost quantitatively with benzoyl chloride (1 equivalent) in the presence of 0.75 equivalent SmI_2 (Table 1, entry 5).

The results of the reactions of a diverse range of acid chlorides are summarised in Table 2. In all cases, acid chlorides react smoothly with *t*-butanol without any side products observed.(Table 2, entries 1–7). Many functional groups, such as carbon–carbon double bonds and chloro and alkoxyl groups in the substrates, were not affected under the reaction conditions and yields appear not to be affected by the substituents on the aromatic ring. Furthermore, any expected steric hindrance was not significant since *o*-chlorobenzoyl chloride could be readily converted into the corresponding *t*-butyl *o*-chlorobenzoate in 91% yield (Table 2, entry 2).

A comparison of the present protocol with selected previously known protocols is presented in Table 3 to demonstrate that the present protocol is indeed superior to several of the other protocols. *t*-Butanol is completely acylated by benzoyl chloride or phenylacetyl chloride in less than 6 min in almost quantitative yields using the present protocol. However, the other protocols listed take not only too long a reaction time for completion but also give poor yields even in the presence of strong base. Al_2O_3 and $ZrOCl_2$ did not catalyse the benzoylation of *t*-butanol.

Although the mechanism of the reaction has not been clarified, it seems that coordination of the C=O bond of the acyl chloride to the samarium ion activates the carbonyl group and enhances the leaving ability of the chloride. It is noteworthy that the dehydration of *t*-butanol, the hydrolysis of acyl chlorides and the decomposition of *t*-butyl esters do not occur using the present protocol.

In conclusion, we have presented a novel and efficient protocol for the acylation of *t*-butanol to carboxylic *t*-butyl esters in excellent yields. Some of the major advantages of this protocol are high yields, neutral conditions, short reaction times and avoidance of side reactions such as hydrolysis of acid chlorides and decomposition of *t*-butanol and *t*-butyl esters.



R= alkyl, aryl

Scheme 1

Table 1 Benzoylation of *t*-butanol (1 mmol) based on SmI_2 and benzoyl chloride (1 mmol) under different reaction conditions.

Entry	Equiv of SmI2	Temp/°C	Time/min	Yield/%
1	None	rt	90	0
2	None	68	90	0
3	0.15	68	90	10
4	0.5	68	10	61
5	0.75	68	6	96
6	0.75	rt	90	30
7	0.75	40	90	65

Table 2 SmI_2 promoted acylation of *t*-butanol with acid chlorides

Entry	R	Time/min	Yield/%[a]
1	Ph	6	96
2	*o*-ClC_6H_4	9	91
3	*p*-ClC_6H_4	5	92
4	*p*-MeC_6H_4	6	90
5	*p*-$MeOC_6H_4$	8	93
6	PhCH=CH	4	98
7	$PhCH_2$	3	95

[a]Isolated yield.

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Table 3 Comparison of protocols for the acylation of *t*-butanol

Entry	Reagent/catalyst	Acylating agent	Time/min	Temp/°C	Yield/%	References
1	SmI_2	PhCOCl	6	68	96	a
2	SmI_2	$PhCH_2COCl$	3	68	95	a
3	Zn	PhCOCl	90	25	67	6
4	Al_2O_3	PhCOCl	No reaction			7
5	ZnO	PhCOCl	120	40	45	8
6	$ZrOCl_2$	PhCOCl	No report			9
7	Pyridine	$PhCH_2COCl$	900	Reflux	45	10
8	*t*-BuOLi	$PhCH_2COCl$	900	RT	47	11

[a]Present work.

Experimental

IR spectra were recorded with a Perkin-Elmer 580 spectrometer. ^{1}H NMR spectra were recorded on a Bruker AM-300 spectrometer in $CDCl_3$ with TMS as an internal standard. Tetrahydrofuran was freshly distilled from sodium/benzophenone ketyl prior to its use.

General experimental procedure: To a mixture of *t*-butanol (1.0 mmol) and samarium diiodide (0.75 mmol, freshly prepared) in THF (10 ml) was added the acid chloride (1.0 mmol) with stirring at 68°C under a nitrogen atmosphere. The progress of the reaction was monitored by TLC. After completion of the reaction (Table 2), the resulting mixture was quenched with saturated sodium bicarbonate solution (20 ml) and extracted with dichloromethane (2 × 10 ml). The combined extracts were dried with anhydrous magnium sulfate, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel eluting with petroleum ether/ethyl acetate (100:1) to afford the products. All of the products are known and were identified by their IR and ^{1}H NMR spectra (for AA'XX' systems $J^* = J_{23} + J_{25}$).

1. t-butyl benzoate: Oil (lit.[12]); ν_{max} (KBr)/cm^{-1} 2977, 2927, 1718, 1594, 1488, 1458, 1368, 1293, 1092; δ_H ($CDCl_3$/TMS): 8.0 (d, J = 9.6 Hz, 2H), 7.52–7.38 (m, 3H), 1.58 (s, 9H).

2. t-butyl 2-chlorobenzoate: Oil (lit.[13]); ν_{max} (KBr)/cm^{-1} 3063, 2973, 2930, 1725, 1594, 1488, 1369, 1254, 1113; δ_H ($CDCl_3$/TMS): 7.84 (d, J = 7.5 Hz, 1H), 7.39–7.30(m, 3H), 1.51 (s, 9H).

3. t-butyl 4-chlorobenzoate: Oil (lit.[14]); ν_{max} (KBr)/cm^{-1} 3061, 2978, 2932, 1713, 1603, 1478, 1451, 1368, 1293, 1115; δ_H ($CDCl_3$/TMS): 7.84 (d, J^* = 9.0 Hz, 2H), 7.29 (d, J^* = 9.0 Hz, 2H), 1.46 (s, 9H).

4. t-butyl 4-methylbenzoate: Oil (lit.[14]); ν_{max} (KBr)/cm^{-1} 2977, 2927, 1712, 1612, 1457, 1368, 1292, 1109; δ_H ($CDCl_3$/TMS): 7.88 (d, J^* = 8.4 Hz, 2H), 7.20(d, J^* = 8.4 Hz,2H), 2.39 (s, 3H), 1.56 (s, 9H).

5. t-butyl 4-methoxybenzoate: Oil (lit.[14]); ν_{max} (KBr)/cm^{-1} 2976, 2934, 1708, 1606, 1458, 1368, 1292, 1102; δ_H ($CDCl_3$/TMS): 7.93 (d, J^* = 9.6 Hz, 2H), 6.87(d, J^* = 9.6 Hz, 2H), 3.82 (s, 3H), 1.54 (s, 9H).

6. t-butyl cinnamate: Oil (lit.[14]); ν_{max} (KBr)/cm^{-1} 3061, 3028, 2978, 2931, 1708, 1637, 1578, 1496, 1392, 1283, 1207, 1150; δ_H ($CDCl_3$/TMS): 7.59 (d, J = 16.2 Hz, 1H), 7.50–7.33 (m, 5H), 6.37 (d, J = 16.2 Hz, 1H), 1.54 (s, 9H).

7. t-butyl phenylacetate: Oil (lit.[15]); ν_{max} (KBr)/cm^{-1} 3064, 3031, 2978, 2927, 1734, 1604, 1496, 1455, 1368, 1298, 1142; δ_H ($CDCl_3$/TMS): 7.12–7.20 (m, 5H), 3.41 (s, 2H), 1.33 (s, 9H).

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