

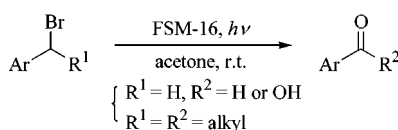
# Photooxidation of Arylmethyl Bromides with Mesoporous Silica FSM-16

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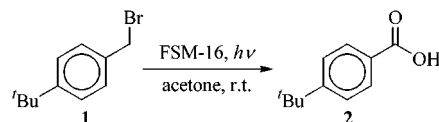
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**ABSTRACT**

A mesoporous silica FSM-16 was found to be a recyclable oxidizing promoter of arylmethyl bromides for the preparation the corresponding carboxylic acids, aldehydes, or ketones under photoirradiation conditions.

The syntheses of aryl aldehydes and aryl carboxylic acids are essential and important processes in organic synthesis. Although various methods for the syntheses of aryl aldehydes from arylmethyl halides, which involve 2-nitropropane sodium salt,<sup>1</sup> selenium compounds,<sup>2</sup> or DMSO,<sup>3,4</sup> have been developed, there have been no one-pot oxidations of arylmethyl halides to the corresponding aryl carboxylic acids reported, so far. In general, this transformation has been carried out via the corresponding alcohols or aldehydes in at least two steps through oxidative reactions, which need more than a stoichiometric amount of heavy metals of high environmental impact.<sup>5</sup> In the course of investigations on the utilities of mesoporous silicas in organic synthesis,<sup>6</sup> we found that  $\alpha$ -hydroxycarboxylic acids, phenyl acetic acid derivatives,<sup>7</sup> and N-protected  $\alpha$ -amino acids<sup>8</sup> afforded the corresponding carbonyl compounds through an oxidative decarboxylation reaction in the presence of a silica, FSM-16,<sup>9</sup> under photoirradiation. Since the substituents at the

$\alpha$ -position to the carboxyl group are thought to play an important role in this reaction, we examined the reactivity of a variety of  $\alpha$ -substituted carboxylic acids to elucidate the mechanism and develop its utilities. In the course of our study,  $\alpha$ -halocarboxylic acids were also found to afford the corresponding carbonyl products in high yield.<sup>10</sup> Furthermore, 4-*tert*-butylbenzyl bromide (**1**), which has no carboxyl group, was found to give the 4-*tert*-butylbenzoic acid (**2**) with FSM-16 under photoirradiation in acetone (Scheme 1). Now we

**Scheme 1**

report the utility of FSM-16 as a promoter for the one-pot oxidation of the arylmethyl bromides to the corresponding carboxylic acids.

In our previous paper on oxidative photodecarboxylation,<sup>7</sup> the results for the oxidative reaction with FSM-16 proved

(9) Inagaki, S.; Koiwai, A.; Suzuki, N.; Fukushima, Y.; Kuroda, K. *Bull. Chem. Soc. Jpn.* **1996**, *69*, 1449. Inagaki, S.; Fukushima, Y.; Kuroda, K. *J. Chem. Soc., Chem. Commun.* **1993**, 680. The unit cell dimension of FSM-16 was 4.63 nm. The pore diameter was 2.9 nm, and the specific surface area was 882 m<sup>2</sup>/g.

(10) Itoh, A.; Kodama, T.; Inagaki, S.; Masaki, Y. Unpublished results.

<sup>†</sup> Gifu Pharmaceutical University<sup>‡</sup> Toyota Central R & D labs., Inc.(1) Clanderman, B. H. *J. Org. Chem.* **1966**, *31*, 2618.(2) Syper, L.; MLochowski, J. *Synthesis* **1984**, 747.(3) Epstein, W. W.; Sweat, F. W. *Chem. Rev.* **1967**, *67*, 247.(4) Mancuso, A. J.; Swern, D. *Synthesis* **1981**, 165.(5) *Comprehensive Organic Transformations: A Guide to Functional Group Preparations*; Larock, R. C., Ed.; Wiley-VCH: New York, 1989.(6) Itoh, A.; Kodama, T.; Maeda, S.; Masaki, Y. *Tetrahedron Lett.* **1998**, *39*, 9461. Itoh, A.; Kodama, T.; Masaki, Y. *Synlett* **1999**, 357.(7) Itoh, A.; Kodama, T.; Inagaki, S.; Masaki, Y. *Org. Lett.* **2000**, *2*, 331.(8) Itoh, A.; Kodama, T.; Inagaki, S.; Masaki, Y. *Chem. Lett.* **2000**, 542.

to be affected by the solubility of oxygen to the solvents.<sup>11</sup> Table 1 shows the results of the photooxidation of 4-*tert*-

**Table 1.** Solvents for Photooxidation of 4-*tert*-Butylbenzyl Bromide **1** with FSM-16

entry	solvent	recovery of <b>1</b> (%)	yield of <b>2</b> (%)
1	<i>n</i> -hexane	80	11
2	Et <sub>2</sub> O	75	5
3	AcOEt	0	75 <sup>a</sup>
4	toluene	88	trace
5	acetone	0	86
6	acetone	54	21 <sup>b</sup>
7	acetone	88	0 <sup>c</sup>
8	MeCN	71	22
9	MeOH	28	65 <sup>d</sup>
10	DMF	20	0
11	CH <sub>2</sub> Cl <sub>2</sub>	0	86

<sup>a</sup> 4-*tert*-Butylbenzal bromide was obtained in 14% yield. <sup>b</sup> The reaction was carried out without FSM-16. <sup>c</sup> The reaction was carried out in the dark. <sup>d</sup> Methyl 4-*tert*-butylbenzoate was obtained as the product.

butylbenzyl bromide (**1**, 50 mg) in the presence of FSM-16 (100 mg) in several solvents using 400-W high-pressure mercury lamps at room temperature.<sup>12</sup> The solvents, except methylene chloride, in Table 1 are arranged in the order of solubility of oxygen;<sup>11</sup> however, the yield of **2** proved to have no correlation to the order. Acetone and methylene chloride were found to be good solvents for the reaction to afford **2** in high yields (entries 5 and 11). Both photoirradiation and FSM-16 proved essential for this reaction to proceed smoothly (entries 6 and 7).

Interestingly, 65% of methyl 4-*tert*-butylbenzoate was obtained as the main product instead of **2** when methanol was used (entry 9).

The results of the photooxidation in acetone, which is environmentally more benign, with typical mesoporous silicas, MCM-41,<sup>13</sup> HMS,<sup>14</sup> and 10% Ti-HMS,<sup>15</sup> are shown in Table 2. FSM-16 was found to be better as a promoter than the others.

Table 3 shows the results for the photooxidation of several arylmethyl bromides. 4-*tert*-Butylbenzyl chloride (**3**) was

(11) Che, Y.; Tokuda, K.; Ohsaka, T. *Bull. Chem. Soc. Jpn.* **1998**, *71*, 651.

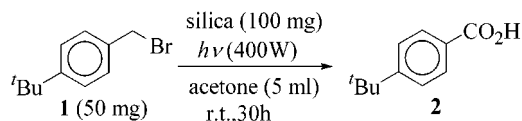
(12) **Typical procedure:** In a Pyrex tube, a suspension of 4-*tert*-butylbenzyl bromide (**1**, 50 mg) and FSM-16 (100 mg) in dry acetone (5 mL) was irradiated externally at room temperature with a 400-W high-pressure mercury lamp for 30 h. FSM-16 was then filtered off and washed with ethyl acetate, and the filtrate was concentrated under reduced pressure. Pure 4-*tert*-butylbenzoic acid (**2**) (34 mg, 86%) was obtained after purification by preparative TLC.

(13) Kresge, C. T.; Leonowicz, M. E.; Roth, W. J.; Vartuli, J. C.; Beck, J. S. *Nature* **1992**, *359*, 710.

(14) Tanev, P. T.; Pinnavaia, T. J. *Science* **1995**, *267*, 865.

(15) Zhang, W.; Froba, M.; Wang, J.; Tanev, P. T.; Wong, J.; Pinnavaia, T. J. *J. Am. Chem. Soc.* **1996**, *118*, 9164. Tanev, P. T.; Chibwe, M.; Pinnavaia, T. J. *Nature* **1994**, *368*, 321.

**Table 2.** Mesoporous Silicas for Photooxidation of 4-*tert*-Butylbenzyl Bromide **1**



entry	silica	recovery of <b>1</b> (%)	yield of <b>2</b> (%)
1	FSM-16	0	86
2	MCM-41	0	66 <sup>a</sup>
3	HMS	27	58
4	10% Ti-HMS	80	6 <sup>b</sup>

<sup>a</sup> 4-*tert*-Butylbenzal bromide was obtained in 13% yield. <sup>b</sup> 4-*tert*-Butylbenzaldehyde was obtained in 8% yield.

much less reactive than the corresponding bromide **1** (entries 1 and 2). When substrates that possess an electron-withdrawing group such as a nitro or cyano group were used, the yields were somewhat lower than the yields for the other reactions (entries 4 and 5). The corresponding ketone **12** was

**Table 3.** Photooxidation of Arylmethyl Bromides with FSM-16<sup>12</sup>

entry	halomethylarenes	products (%)
1		86
2		17 <sup>a</sup>
3		82 <sup>b</sup>
4		56 11 R = H R = OH
5		58 <sup>c</sup>
6		73 <sup>d</sup>
7		50
8		32 38 R = H R = OH
9	C <sub>16</sub> H <sub>33</sub> Br <b>17</b>	- <sup>e</sup>

<sup>a</sup> A total of 57% of starting material was recovered. <sup>b</sup> Benzal bromide was obtained in 7% yield. <sup>c</sup> A total of 26% of starting material was recovered. <sup>d</sup> Benzoic acid was obtained in 11% yield. <sup>e</sup> A total of 91% of starting material was recovered.

obtained from the secondary bromide **11** (entry 6). An allylic bromide, cinnamyl bromide (**13**), was also oxidized to afford **5**. Unfortunately, *n*-hexadecyl bromide (**17**), an aliphatic halide, remained intact under the reaction conditions.

Furthermore, the promoter FSM-16 was found to be a recyclable photocatalyst. Thus, the recovered FSM-16, which was dried at rt for 2 h under reduced pressure after the photoreaction of **1**, showed no loss of activity for the reaction after being used three times (Table 4).

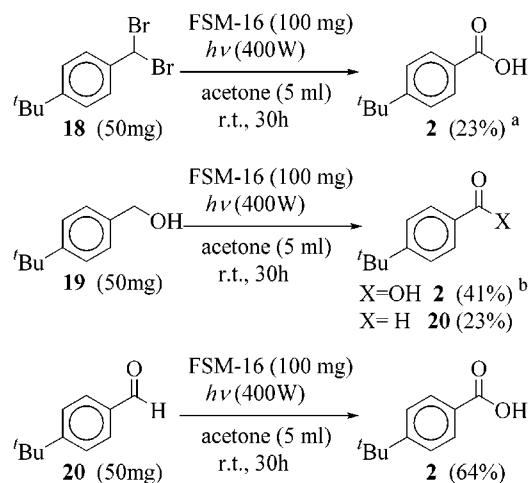
**Table 4.** Recycle of FSM-16

<b>1</b> $\xrightarrow[\text{acetone, r.t., 30h}]{\text{FSM-16, } h\nu}$ <b>2</b>	
cycle of FSM-16	1st 2nd 3rd
yield (%) of <b>2</b>	86 86 89

To clarify the reaction mechanism, possible reaction intermediates were examined. Bromide **1** was found to generate 4-*tert*-butylbenzal bromide (**18**) after 12 h of reaction in a 22% yield, which decreased with the reaction time: 5% after 24 h and trace amounts after 30 h. Contrary to expectation, **18** proved to afford only 23% of the product under the same conditions (Scheme 2). Furthermore, an alcohol, 4-*tert*-butylbenzyl alcohol (**19**), and an aldehyde, 4-*tert*-butylbenzaldehyde (**20**), are thought to be formed through substitution of the halogen atom with oxygen at the benzylic position. Both **19** and **20**, however, showed much lower reactivity than **1** (Scheme 2). These results suggest that other paths would be involved in the mechanism of the reaction. A more detailed study is necessary for elucidation of the mechanism, since benzyl radical species, formed under

(16) Norman, I.; Porter, G. *Proc. R. Soc.* **1955**, A230, 399.

**Scheme 2**



<sup>a</sup> A total of 72% of starting material was recovered. <sup>b</sup> A total of 15% of starting material was recovered.

irradiation of UV,<sup>16</sup> are thought to participate in the course of this reaction.

In conclusion, this new method for the transformation of arylmethyl bromides to benzoic acid derivatives is thought to be more environmentally friendly than previous methods, due to both the one-pot procedure and the use of a recyclable solid catalyst instead of heavy metals. Furthermore, the method is operationally simple from the viewpoint of the convenience of the workup in which FSM-16 can be easily removed only by filtration of the reaction mixture.

**Supporting Information Available:** Experimental details. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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