Magnetically separable phase-transfer catalysts†

Masato Kawamura and Kazuhiko Sato*

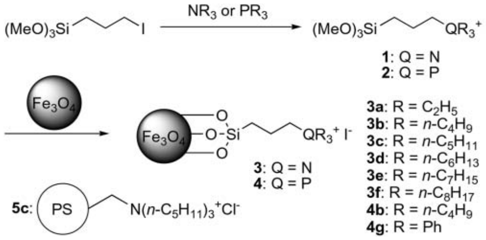
Received (in Cambridge, UK) 17th August 2006, Accepted 11th September 2006
First published as an Advance Article on the web 27th September 2006
DOI: 10.1039/b611906a

Magnetic nanoparticles-supported quaternary ammonium and phosphonium salts were prepared and evaluated as phase-transfer catalysts. Some of them exhibited good activities that were comparable to that of tetra-*n*-butylammonium iodide. The catalysts were readily separated using an external magnet and reusable without significant loss of their catalytic efficiency.

Recently, much attention has been focused on phase-transfer reactions since they have been recognized as environmentally benign alternatives to many homogeneous reactions.[1] A practical problem associated with phase-transfer catalysis technology is the difficulty of separating conventional phase-transfer catalysts (PTCs) such as quaternary ammonium salts. The immobilization of a PTC on a solid support has afforded a solution to overcome this problem.[2,3] So far, cross-linked polystyrene resin (PS resin) is the most common catalyst support and has been utilized for many phase-transfer reactions.[4] However, PS resin-supported PTCs have several drawbacks including swelling in organic solvents, which usually requires a long conditioning time prior to use, and their activities being highly dependent on the solvent used.[5] Moreover, the activities of PS resin-supported PTCs are often lower than those of their non-supported counterparts, and the deactivation often occurs in the reuse process.[6]

Magnetic nanoparticles (MNPs) have emerged as new catalyst supports.[7] A striking feature of the MNPs-supported catalysts is that they can be readily separated using an external magnet, which achieves simple separation of the catalysts without filtration. Additionally, the MNPs-supported catalysts showed not only high catalytic activity but also a high degree of chemical stability, and they do not swell in organic solvents. Although the use of MNPs has been promising, the application of MNPs to catalyst support is still limited as compared with that of PS resin.

Herein, we report the first example of magnetic nanoparticles-supported PTCs through the immobilization of a quaternary ammonium and phosphonium salt on magnetite and the preliminary evaluation of their catalytic activity in phase-transfer reactions.



Scheme 1 Preparation of magnetite nanoparticles-supported ammonium and phosphonium salts **3–4**.

Magnetite nanoparticles were chosen for use as magnetic supports since they could be readily prepared by the conventional coprecipitation method.[8] As described in Scheme 1, the silane coupling agents **1–2** were initially prepared by reaction of the corresponding amines or phosphines with (3-iodopropyl) trimethoxysilane. The immobilization of **1–2** was performed according to a previously described method,[9] and magnetite nanoparticles were treated by excess **1–2** to give magnetite-supported ammonium salts **3** and phosphonium salts **4**. The catalyst loadings of **3–4** were determined by iodide-ion analysis to range from 0.10 to 0.25 mmol g^{-1}. A SEM image of **3c** is shown in Fig. 1. It was confirmed that the catalyst was made up of nanometer-sized particles. The PS resin-supported counterpart **5c** was also synthesized from commercially available chloromethylated polystyrene (Argonaut PS-Cl, 1% cross-linked).[10]

To evaluate the catalytic activity of **3–4** as PTCs, the reaction of PhONa with n-BuBr was examined as a model reaction. As control experiments, tetra-n-butylammonium iodide (TBAI) and **5c** were employed for the same reaction.[11] The results are summarized in Table 1. As can be seen from entries 3–8, the catalytic activity was strongly affected by the alkyl group of ammonium moiety.[12] Although **3a** did not catalyze the reaction (entry 3), the catalytic activities of **3b–d** were comparable to that of TBAI (entries 4–6 *vs* 2). It seemed that lipophilicity of the ammonium moiety initially increased the catalytic activities. However, the reactions with **3e** and **3f** produced the ether in moderate yields, which were inferior to that using **3c**. We thus concluded that the long alkyl groups (n-C$_7$H$_{15}$- and n-C$_8$H$_{17}$-) were hydrophobic to the extent that the diffusion of the catalyst was restrained. Phosphonium salt **4b** was less effective than the corresponding ammonium salt **3b** (entry 4 *vs* 9), and the activity

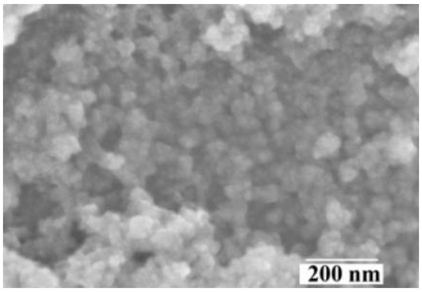
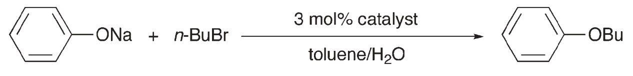


Fig. 1 SEM image of **3c**.

National Institute of Advanced Industrial Science and Technology (AIST), Central 5 Higashi 1-1-1, Tsukuba, Ibaraki, Japan.
E-mail: k.sato@aist.go.jp; Fax: +81-29-861-4852; Tel: +81-29-861-4852

† Electronic supplementary information (ESI) available: Experimental procedures for the synthesis of compounds **1–4** and phase-transfer reactions. See DOI: 10.1039/b611906a

Table 1 *O*-Alkylation reaction of PhONa with *n*-BuBr under phase-transfer conditions



Entry[a]	Catalyst	%Yield[b]
1	None	28
2	TBAI	86
3	**3a**	36
4	**3b**	86
5	**3c**	93
6	**3d**	84
7	**3e**	69
8	**3f**	70
9	**4b**	80
10	**4g**	79
11	**5c**	50

[a] All reactions were performed at 100 °C for 12 h in toluene/H_2O (1/1) with 0.75 mmol of $PhONa\cdot3H_2O$ and *n*-BuBr (1.5 equiv.). [b] Determined by GC analysis using *n*-tetradecane as an internal standard.

Table 2 Recycling of **3c** for the alkylation reaction of PhONa with *n*-BuBr

Entry[a]	Recycle	%Yield[b]
1	1st	94
2	2nd	90
3	3rd	90
4	4th	89

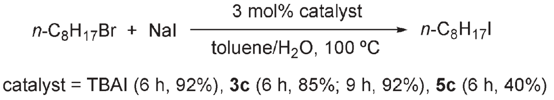
[a] All reactions were performed at 100 °C for 12 h in toluene/H_2O (1/1) with 0.75 mmol of $PhONa\cdot3H_2O$ and *n*-BuBr (1.5 equiv.). [b] Determined by GC analysis using *n*-tetradecane as an internal standard.

of **4g** was identical to that of **4b**. It should be noted that the immobilization on magnetite-nanoparticles did not decrease the catalytic activity whereas the reaction with PS resin-supported catalyst **5c** was much less effective under the same conditions (entry 11).

Easy and rapid separation of the catalyst by magnetism is the most advantageous feature of these catalysts. After the reaction, the catalysts were concentrated on the sidewall of the reaction vessel using an external magnet, the aqueous and the organic phases were separated by decantation, and the residual catalyst in the reaction vessel was washed and dried and then subjected to the next run directly. We examined the recycling of **3c** for the reaction of PhONa with *n*-BuBr. As shown in Table 2, **3c** was reusable without any significant loss of activity for the 4th recycling.

The halogen exchange reaction of 1-bromooctane was also examined as another model reaction (Scheme 2). This reaction proceeded negligibly without PTC (12 h, 6%), whereas the reaction with 3 mol% TBAI gave 1-iodooctane in good yield (6 h, 92%). The activity of **3c** was comparable to that of TBAI, although the yield was slightly reduced under the same reaction conditions (6 h, 85%; 9 h, 92%). On the other hand, **5c** showed low activity, and the yield of 1-iodooctane was drastically decreased (40%, 6 h).

In summary, we have developed magnetically separable PTCs through the immobilization of ammonium and phosphonium salts on magnetic nanoparticles. The catalysts are readily reusable without loss of catalytic activity. To the best of our knowledge, this is the first example of magnetically separable PTCs. We believe that these results expand the scope of phase-transfer catalysis technology. Further investigation of magnetically collectable PTCs is currently in progress.


$$n\text{-}C_8H_{17}Br + NaI \xrightarrow[\text{toluene/}H_2O,\ 100\ ^\circ C]{3\text{ mol\% catalyst}} n\text{-}C_8H_{17}I$$

catalyst = TBAI (6 h, 92%), **3c** (6 h, 85%; 9 h, 92%), **5c** (6 h, 40%)

Scheme 2 Halogen exchange reaction of 1-bromooctane under phase-transfer conditions.

This work was supported by a Grant-in-Aid for Scientific Research on Priority Areas “Advanced Molecular Transformations of Carbon Resources” from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

Notes and references

1 For recent reviews, see: (*a*) M. Makosza, *Pure Appl. Chem.*, 2000, **72**, 1399; (*b*) M. J. O'Donnell, *Aldrichimica Acta*, 2001, **24**, 3; (*c*) B. Lygo and B. I. Andrews, *Acc. Chem. Res.*, 2004, **37**, 518.

2 For reviews, see: (*a*) S. L. Regen, *Angew. Chem., Int. Ed. Engl.*, 1979, **18**, 421; (*b*) T. J. Dickerson, N. N. Reed and K. D. Janda, *Chem. Rev.*, 2002, **102**, 3325; (*c*) D. E. Bergbreiter, *Chem. Rev.*, 2002, **102**, 3345; (*d*) M. Benaglia, A. Puglisi and F. Cozzi, *Chem. Rev.*, 2003, **103**, 2401.

3 For recent examples of phase-transfer reactions with solid supported PTCs, see: (*a*) R. Annunziata, M. Benaglia, M. Cinquini, F. Cozzi and G. Tocco, *Org. Lett.*, 2000, **2**, 1737; (*b*) B. Thierry, J.-C. Plaquevent and D. Cahard, *Tetrahedron: Asymmetry*, 2000, **11**, 3277; (*c*) M. Benaglia, M. Cinquini, F. Cozzi and G. Tocco, *Tetrahedron Lett.*, 2002, **43**, 3391; (*d*) B. Tamami and H. Mahdavi, *Tetrahedron Lett.*, 2002, **43**, 6225; (*e*) L. Li, J. Shi, J. Yan, H. Chen and X. Zhao, *J. Mol. Catal. A: Chem.*, 2004, **209**, 227.

4 For recent examples of PS-resin supported PTCs, see: (*a*) M. Xu, Z. Ou, Z. Shi, M. Xu, H. Li, S. Yu and B. He, *React. Funct. Polym.*, 2001, **48**, 85; (*b*) H.-S. Wu and C.-S. Lee, *J. Catal.*, 2001, **199**, 217; (*c*) Z.-T. Wang, L.-W. Xu, C.-G. Xia and H.-Q. Wang, *Helv. Chim. Acta*, 2004, **87**, 1958.

5 (*a*) A. Guyot, *Pure Appl. Chem.*, 1988, **60**, 365; (*b*) F. Švec, *Pure Appl. Chem.*, 1988, **60**, 377; (*c*) A. R. Vaino and K. D. Janda, *J. Comb. Chem.*, 2000, **2**, 579.

6 It was reported that significant decomposition of a PS resin-supported ammonium salt occurred through a dequaternarization process: H. J.-M. Fou, R. Gallo, P. Hassanaly and J. Metzger, *J. Org. Chem.*, 1977, **42**, 4275 and ref. 2*a*.

7 (*a*) T.-J. Yoon, W. Lee, Y.-S. Oh and J.-K. Lee, *New J. Chem.*, 2003, **27**, 227; (*b*) A.-H. Lu, W. Schmidt, N. Matoussevitch, H. Bönnemann, B. Spliethoff, B. Tesche, E. Bill, W. Kiefer and F. Schüth, *Angew. Chem., Int. Ed.*, 2004, **43**, 4303; (*c*) H. M. R. Gardimalla, D. Mandal, P. D. Stevens, M. Yen and Y. Gao, *Chem. Commun.*, 2005, 4432; (*d*) A. Hu, G. T. Yee and W. Lin, *J. Am. Chem. Soc.*, 2005, **127**, 12486; (*e*) Y. Zheng, P. D. Stevens and Y. Gao, *J. Org. Chem.*, 2006, **71**, 537; (*f*) D. Lee, J. Lee, H. Lee, S. Jin, T. Hyeon and B. M. Kim, *Adv. Synth. Catal.*, 2006, **348**, 41; (*g*) R. Abu-Rezig, H. Alper, D. Wang and M. L. Post, *J. Am. Chem. Soc.*, 2006, **128**, 5279.

8 S. Giri, B. G. Trewyn, M. P. Stellmaker and V. S.-Y. Lin, *Angew. Chem., Int. Ed.*, 2005, **44**, 5038.

9 M. Ma, Y. Zhang, W. Yu, H.-Y. Shen, H.-Q. Zhang and N. Gu, *Colloids Surf., A*, 2003, **212**, 219.

10 H. Molinari, F. Montanari, S. Quici and P. Tundo, *J. Am. Chem. Soc.*, 1979, **101**, 3920.

11 Control experiments are essential for the evaluation of solid-supported PTCs since the reaction rates are highly affected by various factors: M. Tomoi and W. T. Ford, *J. Am. Chem. Soc.*, 1981, **103**, 3821 and 3828 and ref. 5.

12 A similar structural dependency of catalytic activity was reported: M. Cinouni, S. Colonna, H. Molinari, F. Montanari and P. Tundo, *J. Chem. Soc., Chem. Commun.*, 1976, 394.