Magnetic nanoparticle-supported crown ethers†

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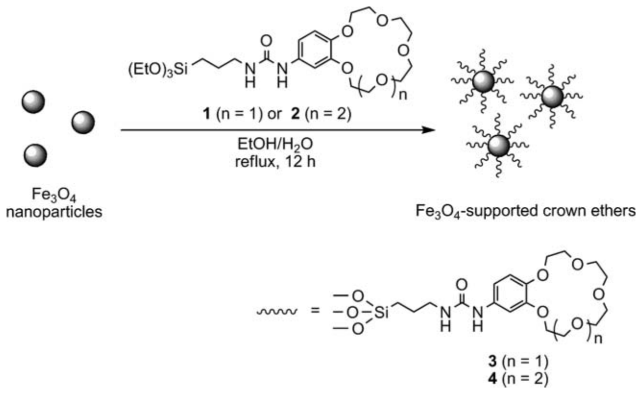
Magnetic nanoparticle (MNP)-supported crown ethers were successfully prepared and evaluated as catalysts for solid–liquid phase-transfer reactions; the catalytic activities of the MNP-supported crown ethers were not inferior to those of non-supported crown ethers; after the reactions, the catalysts could be readily separated using an external magnet and reused without significant loss of catalytic efficiency.

Since Pedersen's discovery of crown ethers in 1967,[1] a large number of crown ethers and related compounds have been extensively developed because of their remarkable cation-binding properties that is termed "host–guest complexation".[2] In the field of organic synthesis, crown ethers have been utilized as versatile phase-transfer catalysts.[3–5] It is well known that "host–guest complexation" is the origin of the concept of solid–liquid (S–L) phase transfer catalysis (PTC).[5a] By binding a metal cation, crown ethers allows an ionic solid reagent to be dissolved in a non-polar organic solvent, in which a weakly solvated counter anion ("naked anion") shows high reactivity.

However, there have been two major problems with using crown ethers as phase-transfer catalysts. One is that they are generally highly toxic; hence, careful handling is required.[3] Another is the fact that they are both difficult to reuse and very expensive. Immobilization of crown ethers on a polymer support, such as cross-linked polystyrene (PS) resin, improves their recyclability and ease of handling.[6] The advantage of polymer-supported catalysts is that they can be recovered by filtration. However, phase-transfer reactions often require vigorous stirring, which leads to mechanical destruction of the supports; consequently, catalyst recovery becomes troublesome and difficult.[7] In addition, the catalytic performance of polymer-supported catalysts is generally inferior to that of non-supported catalysts.[8]

In this communication, we propose a new solution for recycling crown ethers: magnetic nanoparticle (MNP)-supported crown ethers.[9,10] The MNP-supported crown ethers are easily separable using magnetism; therefore, filtration is not required for catalyst recovery. Moreover, MNPs are expected to be more tolerant of vigorous stirring than PS-resin because MNPs are extremely small spheres of metal compounds. We have developed MNP-supported crown ethers through immobilization of crown ethers on the surfaces of MNPs, and evaluated their catalytic performance and recyclability.



Scheme 1 Preparation of MNP-supported crown ethers **3–4**.

As MNPs for catalyst supports, magnetite (Fe_3O_4) nanoparticles (average diameter = 12 nm) were used and prepared by a common co-precipitation method.[11] Immobilization of crown ethers on the surface of magnetite nanoparticles was carried out according to a silanization protocol.[12] As described in Scheme 1, magnetite nanoparticles were treated by organosilane **1**[13] and **2** to give the MNP-supported crown ethers **3** and **4**, where the crown ethers were covalently bonded to the surface of magnetite nanoparticles.[14] The loading of the crown ethers on magnetite nanoparticles was determined by elemental microbial analysis of nitrogen, and the values ranged from 0.23 to 0.27 mmol g^{-1}.

To evaluate the catalytic activities of the MNP-supported crown ethers, a halogen exchange reaction of 1-bromooctane with KI was examined under S–L PTC conditions. The results are summarized in Table 1. It should be noted that the MNP-supported crown ethers showed almost identical catalytic activity to the non-supported controls (entries 2 *vs.* 4 and 3 *vs.* 5). Their catalytic performance depended strongly on the ring size of the crown

Table 1 Halogen exchange reaction of *n*-$C_8H_{17}Br$ with KI under S–L PTC conditions

$$n\text{-}C_8H_{17}Br + KI \xrightarrow[\text{toluene, 100 °C}]{\text{3 mol\% catalyst}} n\text{-}C_8H_{17}I$$

Entry[a]	Catalyst	Yield[b] (%)
1	None	2
2	Benzo-15-crown-5	34
3	Benzo-18-crown-6	88
4	**3**	48
5	**4**	81

[a] The reactions were performed in toluene (1 ml) at 100 °C for 8 h. [b] Catalyst : *n*-$C_8H_{17}Br$: KI = 3 : 100 : 500. [c] Determined by GC analysis using *n*-tetradecane as an internal standard.

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† Electronic supplementary information (ESI) available: SEM and TEM images, particle size distribution histograms, experimental procedures for the synthesis of compounds **2–4** and phase-transfer reactions. See DOI: 10.1039/b705640k

Table 2 Substitution reaction of BnBr with AcOK under S–L PTC conditions

$$\mathrm{BnBr} \quad + \quad \mathrm{AcOK} \xrightarrow[\text{toluene, 80 °C}]{\text{3 mol\% catalyst}} \mathrm{AcOBn}$$

Entry[a,b]	Catalyst	Time/h	Yield[c] (%)
1	None	8	Trace
2	Benzo-15-crown-5	6	3
3	Benzo-18-crown-6	6	71
4	**3**	6	78
5	**4**	6 (8)	95 (96)

[a] The reactions were performed in toluene (1 ml) at 80 °C. [b] Catalyst : BnBr : AcOK = 3 : 100 : 300. [c] Determined by GC analysis using *n*-tetradecane as an internal standard.

Table 3 Recycling of **4** for the substitution reaction of BnBr with AcOK[a]

Recycle	1st	2nd	3rd	4th	5th	6th	7th	8th
Yield[b] (%)	>99	99	99	99	>99	99	>99	>99

[a] All reactions were performed in toluene (1 ml) at 80 °C for 8 h using 0.75 mmol of BnBr, and 2.25 mmol of AcOK. [b] Determined by GC analysis using *n*-tetradecane as an internal standard.

ethers, and the reaction with **4** gave better results than that with **3** (entry 4 *vs.* 5). Clearly, this result can be attributed to the fact that 18-membered crown ethers are generally more suitable for extracting K^+ than 15-membered crowns.[1,2a,15] Furthermore, the MNP-supported crown ethers did not require any pretreatment, while PS-resin supported catalysts generally require a long preconditioning time.[16]

We also examined a substitution reaction of benzyl bromide with potassium acetate under S–L PTC conditions (Table 2). It is well known that the acetate anion in organic solvents exhibits high nucleophilicity in the presence of crown ethers.[5b] Remarkably, the MNP-supported catalyst **4** was much more efficient than the benzo crown ethers (entries 2 and 3 *vs.* 5), and gave the best result. Furthermore, **3** showed good catalytic activity, slightly superior to that of benzo-18-crown-6 (entry 3 *vs.* 4), while benzo-15-crown-5 did not promote the reaction at all (entry 2).[17] When the reaction was conducted under liquid–liquid (L–L) PTC conditions (in toluene/H_2O) with 3 mol% of benzo-18-crown-6, the yield was drastically decreased to 40% (55% conversion), and ester hydrolysis occurred partially.[18]

Recycling of the MNP-supported crown ethers was indeed simple and easy. After the reaction, the toluene phase could be separated without filtration since the MNP-supported crown ether was rapidly concentrated as soon as an external magnet was set close to the sidewall of the reaction vessel. The residual catalyst was washed and dried, then immediately reused for the next run. We examined recycling of **4** for the reaction of BnBr with AcOK under identical reaction conditions (80 °C, 8 h). As shown in Table 3, the catalyst could be recycled for at least 8 times without loss of catalytic activity.

In summary, magnetically separable crown ethers were successfully prepared through the immobilization of crown ethers on magnetite nanoparticles. The MNP-supported crown ethers were efficient for S–L phase-transfer reactions, easily recoverable using magnetism, and reusable without loss of catalytic activity. To the best of our knowledge, this is the first successful example of magnetically separable and reusable crown ethers.

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18. Benzyl alcohol, a hydrolysis product, was detected by GC analysis (9% yield).