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Use of Polyoxetane Resin-Supported Quaternary Onium Salts as a Polymeric Phase-Transfer Catalyst for Preparing Ethers from Hydroxy Compounds and Alkyl Halides

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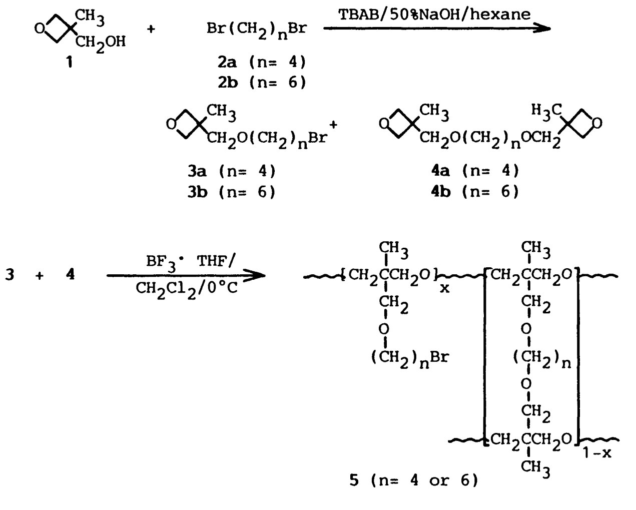
As a polymer support for preparing polymeric phase-transfer catalysts (PTC), soft, moderately polar polyoxetane resins were employed which were synthesized by a cationic ring-opening copolymerization of oxetanes $Br(CH_2)_nOCH_2$-X with bisoxetanes X-$CH_2O(CH_2)_nOCH_2$-X, where X=3-methyl-3-oxetanyl and n=4 or 6. In a few cases of those polymerizations, 3-(2-oxadecyl)-3-methyloxetane was used as a comonomer with a lipophilic pendant. The terminal bromine of the pendant groups of such polyoxetane resins was quaternized with tributylamine or tributylphosphine in DMF in order to examine the phase-transfer catalyzing ability of the resultant quaternary onium bromides in the etherification reaction between alkyl halides and alcohols or phenols. These reactions gave the desired products in fairly good yields within reaction periods of 1—3 h, indicating that the catalytic activities of those PTCs are comparable to that of tetrabutylammonium bromide. A fairly high catalytic activity of the polymeric PTC was observed at each of ten stages in a process using the polymeric PTC repeatedly for the etherification reaction of 3-hydroxymethyl-3-methyloxetane with 1,4-dibromobutane.

It has recently been increasingly recognized that synthetic polymers can be conveniently used in organic syntheses as reagents, catalysts, membranes, and substances with other various functionalities.[1,2] The polymeric phase-transfer catalyst (PTC) has attracted the attention of investigators who have hoped to readily obtain novel and important organic compounds by a simple work-up of a reaction mixture and to use the catalyst repeatedly after easily recovering it. Hereby, the use of various polymeric PTCs in organic syntheses has been reviewed.[1-6]

In the preparation of the polymeric PTCs, insoluble cross-linked polystyrenes have been widely used as polymeric supports for anchoring a catalytic group to the support. These polymeric supports have not always been used advantageously in organic syntheses using polar or ionic reagents and solvents, due to the low polarity of the polystyrene support. Furthermore, the movability of the catalytic group, which is anchored to hard (or unflexible) polymer matrices of the polystyrene support, would be more or less restricted, exerting an entropically unfavorable influence on the catalytic behavior. The catalytic activity of PTC was enhanced upon introducing a moderately long spacer between the catalytic group and the polymer matrix;[7] owing to the existence of such a long spacer, the catalytic group was kept apart from sterically crowded polymer matrices. In order to improve such undesirable qualities of the polymeric support as hardness (or unflexibility), low polarity, and low hydrophilicity, polyoxiranes have also been chosen as soft, polar, or hydrophilic segments in block and graft polymers.[8-12] Particularly, poly(oxyethylene) (POE) has often been successfully applied not only to the segments mentioned above, but also to catalysts and ionophors, which realize their functions via a cooperative action of the ether oxygen.[13-16]

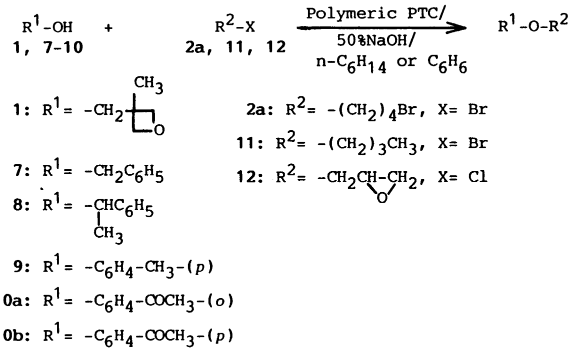
In our previous papers, we reported facile syntheses of oxetanes **3a** and **3b** carrying ω-bromo-2-oxapolymethylene side chains at the C-3 position of an oxetane ring, of bisoxetanes **4a** and **4b** being as a cross-linking agent, and of soft, moderately polar polyoxetane resins **5** by a cationic ring-opening copolymerization of those oxetanes.[17] We also briefly reported a fairly high catalytic activity of a polymeric PTC, which was prepared by quaternizing the pendant bromide of a polyoxetane resin with tributylamine (**6**), on the etherification reaction between the alcohol **1** and the dibromide **2a**.[18]

Thus, polyoxetane resins are thought to be very promising as a polymeric support. So far, there has been no investigation concerning the phase-transfer



Scheme 1.

catalysis using such polyoxetane resin-supported onium salts as a PTC, although polystyrene resin-supported PTCs have often been employed in various reactions of organic synthesis.[1-5] In this article, our investigation results are described in more detail concerning the application of polyoxetane resins to the polymeric support of PTCs for readily preparing several ethers from hydroxy compounds and alkyl halides.



Scheme 2.

Experimental

Materials. Oxetanes **3a** and **3b**, bisoxetanes **4a** and **4b**, and 3-(2-oxadecyl)-3-methyloxetane (**13**) were prepared by the phase-transfer catalytic reaction according to a method reported by us previously.[17] The hydroxy compounds **7**—**10**, the alkyl halides, **2a**, **2b**, **11**, and **12**, and tetrabutylammonium bromide (TBAB) were used without further purification of commercially available reagents. 1-Benzyloxy-4-bromobutane (**24**), 1-benzyloxybutane (**25**),[19] 1-(1-phenylethoxy)butane (**26**), benzyl 2,3-epoxypropyl ether (**27**),[20] 2,3-epoxypropyl 1-phenylethyl ether (**28**),[20] 1-(*p*-methylphenoxy)butane (**29**),[21] 1-(*o*- and *p*-acetylphenoxy)-4-bromobutanes (**30a** and **30b**), and 1,4-bis(*o*- and *p*-acetylphenoxy)butanes (**31a** and **31b**) were prepared by a phase-transfer catalytic reaction of the appropriate alcohol or phenol with the halide in the presence of TBAB, and were employed to draw calibration curves of the gas chromatography (GC) determination. IR and ¹H NMR spectra confirmed structures of these compounds.

24: bp 79—80 °C (14.7 Pa); IR(neat) 3075, 3040, 1600, 1580, 735, and 695 (monosubstituted benzene), and 1100 cm⁻¹ (aliphatic ether); ¹H NMR(CDCl₃) δ=1.6—2.2 [4H, m, $OCH_2(C\underline{H}_2)_2CH_2Br$], 3.42, 3.48 [each 2H, each bt, $C\underline{H}_2(CH_2)_2C\underline{H}_2Br$], 4.48 (2H, s, OCH_2Ar), and 7.33 (5H, m, ArH).

Found: C, 54.23; H, 6.19; Br, 32.83%. Calcd for $C_{11}H_{15}BrO$: C, 54.33; H, 6.23; Br, 32.86%.

26: bp 93—94 °C (0.31 kPa); IR(neat) 3075, 3040, 1600, 1500, 760, and 700 (monosubstituted benzene), and 1100 cm⁻¹ (aliphatic ether).

30a: bp 132.5 °C (26.7 Pa); IR(neat) 3075, 3040, 1595, 1575, 1480, and 750 (1,2-disubstituted benzene), 1670 (C=O), and 1240 cm⁻¹ (aromatic ether); ¹H NMR(CDCl₃) δ=1.7—2.3 [4H, m, $OCH_2(C\underline{H}_2)_2CH_2Br$], 2.58 (3H, s, $COCH_3$), 3.2—3.7 (2H, bt, CH_2Br), 3.8—4.3 (2H, bt, CH_2OAr), 6.7—7.9 (4H, m, ArH).

Found: C, 52.97; H, 5.54; Br, 29.62%. Calcd for $C_{12}H_{15}BrO_2$: C, 53.15; H, 5.59; Br, 29.47%.

30b: bp 147 °C (20.0 Pa); IR(neat) 3060, 3000, 1600, 1575, 1510, and 830 (1,4-disubstituted benzene), 1685 (C=O), and 1250 cm⁻¹ (aromatic ether); ¹H NMR(CDCl₃) δ=1.8—2.3 [4H, m, $OCH_2(C\underline{H}_2)_2CH_2Br$], 2.54 (3H, s, $COCH_3$), 3.3—3.7 (2H, bt, CH_2Br), 3.9—4.3 (2H, bt, CH_2Ar), and 6.7—8.1 (4H, quartet-like, ArH).

Found: C, 53.02; H, 5.51; Br, 29.24%. Calcd for $C_{12}H_{15}BrO_2$: C, 53.15; H, 5.59; Br, 29.47%.

31a: mp 151.5—152.5 °C (acetone); IR(KBr) 1595, 1570, 1500, 1465, and 779 (1,2-disubstituted benzene), 1665 (C=O), and 1235 cm⁻¹ (aryl ether); ¹H NMR(CDCl₃) δ=1.8—2.3 [4H, m, $(C\underline{H}_2)_2CH_2OAr$], 2.61 (6H, s, $COCH_3$), 3.9—4.4 (4H, m, CH_2OAr), and 6.8—7.9 (8H, m, ArH).

Found: C, 73.29; H, 6.77%. Calcd for $C_{20}H_{22}O_4$: C, 73.59; H, 6.81%.

31b: mp 146.0—147.5 °C (acetone); IR(KBr) 1595, 1579, 1500, and 1465 (1,4-disubstituted benzene), 1670 (C=O), and 1240 cm⁻¹ (aryl ether); ¹H NMR(CDCl₃) δ=1.8—2.3 [4H, m, $(C\underline{H}_2)_2CH_2OAr)$], 2.56 (6H, s, $COCH_3$), 3.9—4.3 (4H, m, CH_2OAr), and 6.8—8.2 (8H, quartet-like, ArH).

Found: C, 73.60; H, 6.76%. Calcd for $C_{20}H_{22}O_4$: C, 73.59; H, 6.81%.

The polyoxetane resins with the pendant bromide were made by the copolymerization of **3a** or **3b** with **4a** or **4b**, and, if necessary, **13** in dichloromethane (DCM) at 0 °C with boron trifluoride (BF_3)-tetrahydrofuran (THF) complex (0.5% to total mole of the oxetane ring) as an initiator, as described by us previously.[17] The seven polymeric PTCs were prepared by heating a polyoxetane-supported bromide with a threefold molar excess of tributylamine (**6**) or -phosphine (**14**) in DMF at 100 °C for 10 h. The polymeric catalyst was filtered, washed successively with methanol and ether, and dried at 80 °C under reduced pressure of 27 Pa for 6 h.

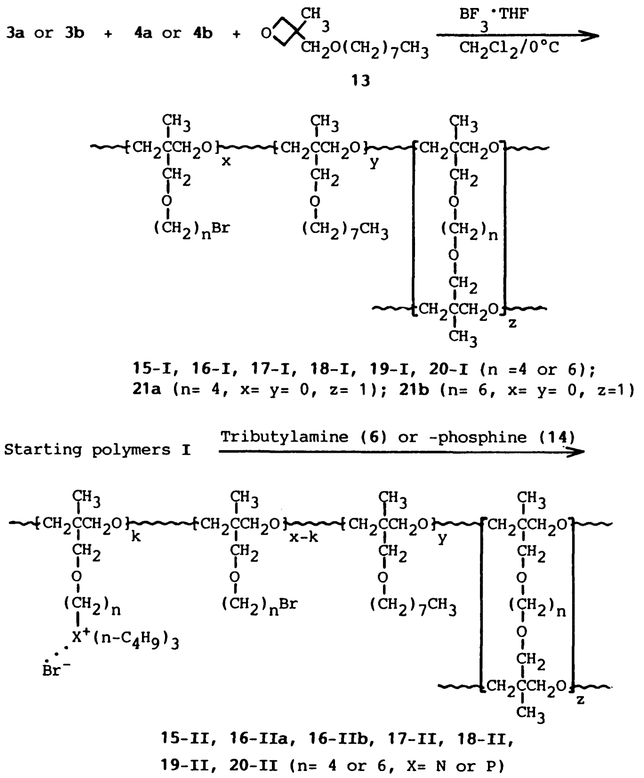
Phase-Transfer Catalytic Reaction between Hydroxy Compounds and Alkyl Halides. In a round-bottomed flask there were placed a polymeric PTC, a hydroxy compound, an alkyl halide, and an internal standard of GC analysis. A 50% aqueous sodium hydroxide (NaOH) solution and hexane as a solvent were added into the mixture of reactants with ice-cooling. This was heated under reflux with efficiently stirring by means of a magnetic or mechanical stirrer. At every desired time, the mixture was cooled below 5 °C and an aliquot of the organic layer was withdrawn into a microsyringe to determine the product yield by GC. In a reaction on a preparative scale using 10 g of **1**, water (300 cm³) was added into the resulting mixture below 5 °C after an appropriate reaction time. This was transferred to a separatory funnel to extract the product with ether. An aqueous layer was discarded as thoroughly as possible and the remainder was filtered to separate the polymeric catalyst. The polymer was washed successively with water, ether, and methanol. Here, methanol was successfully used to rinse the funnel. The organic layer of the filtrate was dried over Na_2SO_4 and distilled to give the products. In the examination of the repeated use of the polymeric PTC, the polymer collected by filtration was employed during the next stage of the process, using it repeatedly in the reaction between **1** and **2a** after or without drying the polymeric PTC.

Measurement. GC analysis of the products was performed in a Shimadzu GC 8A apparatus: glass column (3.2ϕ×1 m) packed with Silicone High Vacuum Grease

(30%)/Celite (80—100 mesh); carrier gas, He (66 cm^3 min^{-1}); temp, 140 or 210 °C. The IR spectra were recorded on a JASCO A-202 spectrometer, and on a ^{1}H NMR 60 (Hitachi R-24B) or 100 MHz instrument (JEOL FX-100S) using $CDCl_3$ as a solvent and TMS as an internal standard. A differential scanning calorimetry (DSC) measurement was carried out in a DSC/560 (Daini Seikohsha) at a heating rate of 20 °C min^{-1} for a sample in air.

Results and Discussion

Preparation of Polyoxetane Resin-Supported PTCs. The polyoxetane supports **15-I**, **16-I**, **17-I**, **18-I**, **19-I**, and **20-I** carrying a bromide at the pendant spacer end were prepared by cationic ring-opening copolymerization of **3** with **4**. All cross-linked polyoxetanes, thus obtained, were white elastic polymers insoluble in the ordinary organic solvents used, although the homopolymers from **3a** and **3b** were viscous materials with number-average molecular weight ($\overline{M}_n$) 3300—5500 and soluble in the ordinary solvents.[17] In a few cases of the above polymerization, **13** was used as a comonomer with a lipophilic pendant group. Those oxetane derivatives showed IR absorption bands due to a cyclic ether linkage at 980 and 835 cm^{-1}; however, these bands disappeared in the IR spectra of the polymers.[17] The pendant bromide of the supports was quaternized by heating with **6** or **14** in DMF at 100 °C to obtain the polymeric PTCs **15-II** to **20-II** carrying an onium bromide at the pendant spacer end. The polymeric PTCs, so obtained, are listed in Table 1. The mole fractions of the monomeric units (*x*, *y*, and *z*) in a starting polymer are assumed to be identical, respectively, with those in monomers charged in the copolymerization. The content of the onium bromide was calculated on the basis of nitrogen or phosphorus content determined by elemental analysis. IR spectra of the quaternized polymers indicated a considerably strong, broad band around 3400 cm^{-1}, even after drying the polymer at 60 °C for 8 h in vacuo, suggesting that the onium salt may adsorb molecules of water rigidly. For the present, to roughly estimate the mole fraction *k* of the monomeric unit with the pendant onium salt in a PTC, the *k* value was calculated on the basis of the nitrogen or phosphorus content and mole fractions *x*, *y*, and *z* in the dried PTC.



Scheme 3.

Table 1. Polymeric Catalysts Used for the Phase-Transfer Catalytic Reaction

PTC No.	Anal. (%) for N or P	k$^{c)}$	Onium bromide$^{a)}$	Starting polymer$^{b)}$			
					Mole fractions		
			mequiv g^{-1}	*n*	*x*	*y*	*z*
15-II	N, 2.48	0.63	1.77	4	0.90	0.00	0.10
16-IIa	N, 1.50	0.33	1.07	4	0.70	0.00	0.30
16-IIb	P, 5.32	0.64	1.72	4	0.70	0.00	0.30
17-II	N, 1.04	0.21	0.74	4	0.50	0.00	0.50
18-II	N, 2.08	0.48	1.48	4	0.74	0.17	0.09
19-II	N, 0.94	0.18	0.67	4	0.36	0.50	0.14
20-II	N, 1.70	0.42	1.21	6	0.79	0.00	0.21

a) Milliequivalent of the onium per g of a dry polymer. b) These polymers were used as polymer supports with a pendant bromide for preparing the polymeric PTCs. The letters *n*, *x*, *y*, and *z* are presented in Scheme 3. c) A mole fraction of the unit with an onium group, as shown in Scheme 3.

Phase-Transfer Catalysis Using the Polymeric PTC. The phase-transfer catalyzing abilities of the polymeric PTCs were examined in an etherification reaction between the hydroxy compounds and the halides. Figure 1 and Table 2 show the results of a phase-

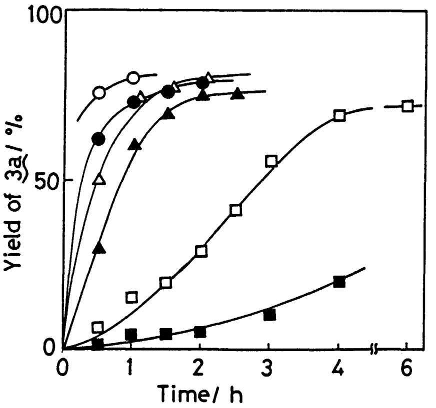


Fig. 1. Time-yield curves for the phase-transfer catalytic reaction of **1** with **2a** at 70 °C in the presence of **16-IIa**: **1**, 1.99 mmol; **2a**, 5.98 mmol; *n*-$C_{16}H_{34}$, 1.07 mmol; 50% NaOH, 2.8 g; hexane, 2.0 cm^3. Mol% of an ammonium group to **1**: (●) 2.7; (△) 1.1; (▲) 0.3; (□) 0.1; (○) 1.7 mol% of TBAB; (■) without PTC.

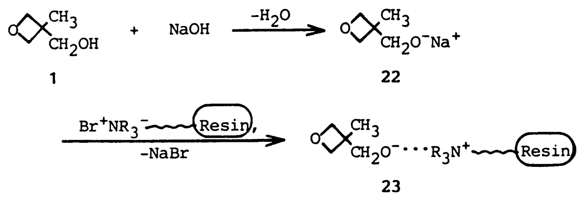
Table 2. Ether Synthesis from **1** and **2a** by Phase-Transfer Catalysis Using the Polymeric PTC[a]

PTC (Mol% to **1**)[b]	Product	Yields of **3a** and **4a** by GC/% Reaction time/h 0.5	1.0	1.5	2.0	3.0	4.0
15-II (3.0)	**3a**:	50.4	66.7	72.1	77.1		
	4a:	2.9	7.0	8.7	8.7		
16-IIb (4.3)	**3a**:	77.5	83.2	84.0	85.8	87.6	
	4a:	8.5	8.1	8.6	9.1	9.6	
15-II (2.7)[c]	**3a**:	57.2	69.0	73.7	80.9	86.2	
	4a:	3.1	4.5	5.2	5.7	6.5	
TBAB (5.0)	**3a**:	83.0	81.1				
	4a:	14.6	14.6				
16-IIa (2.7)[d]	**3a**:	35.4	19.7	6.6	1.9	0.0	
	4a:	19.4	35.7	46.8	51.3	52.0	
TBAB (5.0)[d]	**3a**:	5.8	0.2	0.0			
	4a:	56.8	62.0	63.1			
21a[e]	**3a**:	1.3	2.1	4.4	6.2	24.3	27.3
21b[e]	**3a**:	1.3	2.5	4.0	5.3	8.3	13.4
POE 400[e]	**3a**:	35.4	48.4	66.7	71.6	77.8	
None	**3a**:	1.2	2.9	4.1	4.8	11.1	20.9

a) **1**, 1.99 mmol; **2a**, 5.98 mmol; n-$C_{16}H_{34}$ (internal standard of GC determination), 1.07 mmol; 50% NaOH, 2.8 g; hexane, 2.0 cm^3; at reflux temperature. b) Mol% of the onium bromide to **1**. c) Benzene was used as a solvent. d) **1** and **2a** were charged at a molar ratio of 1 : 1. e) 0.5 mol of ether oxygen of **21a**, **21b**, or POE 400 was used per one mole of **1**.

transfer catalytic reaction of **1** with **2a** using each of the several polymeric PTCs in 50% NaOH and an organic solvent at 70 °C. As shown in Fig. 1, a rate of the formation of **3a** decreased with an decrease in the amount of **16-IIa** from 2.7 to 0.1 mol% to **1**. A fairly good yield of 67% for **3a** was reached, even in the presence of only 0.1 mol% of the ammonium salt of polymeric PTC, although a prolonged reaction time of 4 h was required. When 1.1 to 2.7 mol% of the pendant ammonium salt was used, the formation rates of **3a** are almost comparable to the reaction rate in the presence of 1.7 mol% of TBAB. However, **3a** was formed very slowly in the absence of the catalyst. Similarly, in the presence of each polymeric PTC other than **16-IIa**, a sufficient yield of **3a** or **4a** as a main product was achieved within a few hours (Table 2). The formation of the main product depended on a **2a**/**1** molar ratio of 3.0 or 1.0. The catalytic activity of the phosphonium bromide of **16-IIb** was somewhat higher than that of the corresponding ammonium bromide of **16-IIa** and seemed to be comparable to the catalytic activity of TBAB. It is generally known that quaternary phosphonium salts act as PTC more effectively than the ammonium analogues (vide infra).

Effect of the Polyether Network: Regarding the reaction using a polymeric PTC at a **2a**/**1** mole ratio of 3.0, **4a** was formed in lower yields than that with TBAB, suggesting that it is somewhat difficult to form **4a** from substrate **3a**, which has a bulkier substituent than **2a**, and the nucleophile **1** at the S_N2 reaction stage crowded with polymer matrices. In our previous investigation of the preparation of oxetane derivatives under the phase-transfer catalytic conditions using TBAB in 50% NaOH and an organic solvent, it was found that hexane and ether were suitable solvents for such synthesis, while the catalysis of TBAB in benzene gave **3a** in a lower yield by about 13% than in hexane.[17] However, the yield of **3a** with **15-II**, in spite of using benzene as a solvent, was comparable to the yield of **3a** formed by the reaction in a hexane solvent, indicating that an aliphatic ether structure of the polyoxetane backbone of polymeric PTC plays an important role upon the above catalysis as the so-called "solid phase cosolvent" for the production of **3a** in higher yield.[22] The polyoxetane resin with a pendant onium salt spread in the form of oily or gelatinous particles over the interface between organic and aqueous layers; this aspect was clearly observed when the reaction mixture was permitted to stand in a reactor. On the other hand, the ether network of such polyoxetanes as **21a** and **21b** was hardly swellable in water and somewhat swellable in such organic solvents as ether, chloroform, and benzene, although the level of swellability of the polyether network itself in such solvents was not quite so remarkable as that of the polymeric PTC. The remarkable swelling of the polyoxetane support in the phase-transfer catalysis is attributable to the hydrophilicity of the pendant onium salt as well as to an expanding ability of the soft or elastic cross-linked network containing the ether linkage abundantly. Such a formation of the oily or gelatinous particles due to the swelling of the polymeric PTC has been not observed in the case of using the hard or rigid network of the cross-linked polystyrene support with the pendant onium salt. The ether network of **21a** and **21b** could hardly conduct the phase-transfer catalytic reaction of **1** with **2a**, since the relationships between the reaction time and the product yield are almost similar to that for the reaction in the absence of a PTC (Table 2). POE with a molecular weight of 400 showed a fairly high catalytic activity in the above-mentioned reaction, owing to a cooperative action of ether oxygens of POE. The ether network itself of the polyoxetane support can probably not efficiently solvate the sodium alkoxide **22** (which is generated from **1** and concentrated NaOH) via cooperative action analogous to that of POE, although an ether network of **21a** seems to have the slight ability to transfer the



Scheme 4.

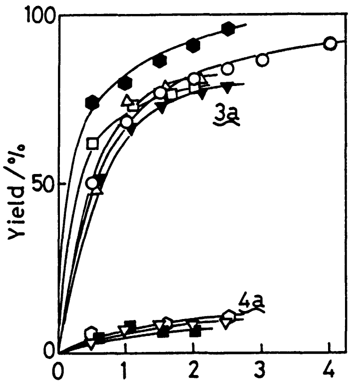


Fig. 2. Influence of the cross-linking agent and of the spacer length on yields of **3a** (▼, △, □, ○, ⬢) and **4a** (▽, ■, ⬡) in the phase-transfer catalytic reaction at a **1**/**2a** mole ratio of 1 : 3. PTC, mole fraction of **4a** or **4b** in a polymeric support, and mol% of an ammonium group to **1**: (▼, ▽) **15-II**, 0.10, 3.0; (△) **16-IIa**, 0.30, 1.1; (□, ■) **16-IIa**, 0.30, 2.7; (○) **17-II**, 0.50, 1.1; (⬢, ⬡) **20-II**, 0.21, 3.0.

ionic species **22** from an aqueous layer to an organic one.

Effects of the Cross-Linking Level and the Spacer: In Fig. 2, in comparisons of the PTCs used in a similar amount of the ammonium group between **16-IIa** and **17-II** (each 1.1 mol% to **1**), and **15-II** and **16-IIa** (each about 3 mol% to **1**), their apparent catalytic activities are taken to be comparable to each other, in spite of the order **15-II**>**16-IIa**>**17-II** for the *k* value and the inverted order for the *z* value. These results are interesting since, in general, the catalytic activity of a polymeric catalyst is considered to be lowered by decreasing the loading of a catalytic group and by increasing the mole fraction of the cross-linking agent in a polymeric support. Furthermore, the formation rate of **3a** is also hardly influenced by varying the amount of the ammonium group from 1.1 to 3.0% molar respect to **1**, as shown in the use of **16-IIa**, suggesting that an optimum amount of the catalytic group lies in a range 1 to 3 mol% to **1** (also see Figs. 1 and 4). When the pendant ammonium group of a PTC acts as a countercation accompanying an alkoxide anion of **22** into an organic layer, access of the accompanied alkoxide anion to each other, due to a local assembly of the ammonium group in the PTC, is undesired because of an electrostatic and/or a steric repulsion between the counteranions. Such a locally increased concentration of the ammonium group is realized by increasing the *k* value and/or the amount of the PTC used. A limited amount of the assembling ammonium group acts effectively as the countercation accompanying the alkoxide anion, particularly when using PTCs with high loading (or high *k* values).

It is concluded, therefore, that the *k* and *z* values have little influence on the catalytic activity of the PTC based on a polyoxetane support. Thus, the yield of **3a** reached a range of 76—80% within 2 h in every case of using the polymeric PTCs with cross-linking levels of 10, 30, and 50 mol%. Even the polymeric PTC with a 50 mol% cross-linking level swelled sufficiently under applied phase-transfer catalytic conditions. These results suggest that polyether networks with cross-linking levels of up to 50 mol% are soft (or elastic) and swellable enough for their use as a polymeric support of the PTC, being a contrast to the widely employed polystyrene supports containing only a few mol% of divinylbenzene as a cross-linking agent; use of PTCs with higher divinylbenzene contents frequently leads to remarkably lower product yields or requires hard reaction conditions to obtain a fairly good product yield.

The somewhat improved yields of **3a** were obtained by lengthening the spacer by an ethylene unit in both the side chain and cross-linking agent of a polymeric PTC, as shown in each comparison between **15-II** and **20-II**, and between **16-IIa** and **20-II** (each about 3 mol% to **1**). **20-II** gave a slightly higher yield of **3a** than **15-II** and **16-IIa** within the same reaction time, although **20-II** has a lower *k* and higher *z* values than **15-II**, and a higher *k* and lower *z* values than **16-IIa**. However, the loading and cross-linking levels of these PTCs are taken to be unimportant here (as mentioned above). Presumably, a longer spacer of the cross-linking agent causes the network to expand more sufficiently, and a longer spacer of the side chain causes the catalytic group to be located more apart from the crowded polymer matrices. It has also been reported that lengthening an alkyl chain between polymer matrices and a terminal onium group of the side chain significantly improves the yield of *O*-alkylated product in a phase-transfer catalytic reaction of 2-naphthol with benzyl bromide.[1,7)]

Effect of the Lipophilic Pendant Group: Furthermore, in designing a polymer which is effective for a phase-transfer catalysis, it is important to find an optimum with respect to the relative content of the hydrophilic and lipophilic groups in a polymer. At the $\mathrm{S_N2}$ reaction stage of the phase-transfer catalysis, it is required to create lipophilic domains dissolving the organic substrate to be allowed to react with the nucleophile which is transferred in the form of **23** from the aqueous phase to the organic phase. On the other hand, hydrophilic domains are required to stabilize ionic species of **23** transferred into the polymer matrices. The interesting behavior of water was also reported with respect to the mechanism of phase-transfer catalysis.[23,24)] Thus, the polymeric PTCs **18-II** and **19-II** were employed to examine an effect of the lipophilic octyl group on the catalytic activity (Fig. 3). Use of the polymeric PTC **18-II** with 17 mol% of the monomeric unit **13** did not indicate the appreciable improvement of the catalytic activity, as compared with that of **16-IIa** with no octyl group, assuming use

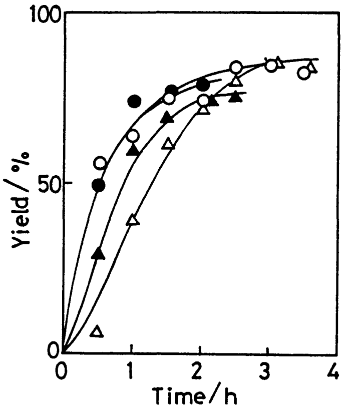
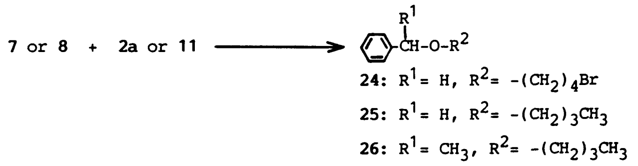


Fig. 3. Influence of a lipophilic unit **13** on a yield of **3a** in the phase-transfer catalytic reaction at a **1**/**2a** molar ratio of 1 : 3. PTC, mole fraction of **13**, and mol% of an ammonium group to **1**: (●) **16-IIa**, 0, 1.1; (▲) **16-IIa**, 0, 0.3; (○) **18-II**, 0.17, 0.7; (△) **19-II**, 0.50, 0.3.

of the similar amount of the ammonium group to each other for these PTCs (0.7 and 1.1 mol% to **1**, respectively). However, as shown obviously in a comparison between phase-transfer catalytic reactions using quaternary ammonium salts of **16-IIa** and **19-II** in 0.3% molar respect to **1**, a lower rate was observed in the formation of **3a** in the presence of **19-II**, which is considered to have an almost comparable content of lipophilic domains relative to **16-IIa** since the lipophilic character of a PTC support is realized not only by the pendant octyl group but also by hydrocarbon chains in the spacers of the monomeric units **3a** and **3b**, some bromine atoms of which are converted into the terminal quaternary onium bromide to act as a catalytic group, and of the cross-linking agent units **4a** and **4b**. When a PTC support has considerably high content of the monomeric unit **13**, the polymeric PTC must consequently contain the catalytic group in its low content. Such a catalytic group is apt to be surrounded with lipophilic hydrocarbon chains which are abundantly present in the pendants and cross-linkages of the PTC support. Probably, the octyl pendant of polymeric PTCs with considerably high contents of the monomeric **13** behaved as a somewhat sterically hindering group and/or as a lipophilic group, which is undesirable for the hydrophilic alcohol **1** (or its alkoxide ion **23**). The high contents of monomeric units having such long alkyl groups are not required virtually for preparing polymeric PTCs of the reaction using hydrophilic reactants. At this time, however, it is difficult to describe whether the existence of a lower content of the monomeric unit **13** in a polymeric PTC is required to design a polymeric PTC having an optimum relative content of the hydrophilic and lipophilic domains. This problem should be clarified by further investigations of the design of various functional polymers.



Scheme 5.

Preparation of the Other Ether Compounds by the Phase-Transfer Catalysis Using a Polymeric PTC: The onium salts attached to the polyoxetane resins were effective for the phase-transfer catalysis between aralkyl alcohols **7** or **8**, and alkyl bromide **2a** or **11** (Figs. 4—6). The catalytic activities of **16-IIa** and **16-IIb** were comparable to that of TBAB in producing **25** under the same reaction conditions (Fig. 4). When 1-phenylethanol (**8**) was used in place of **7**, the considerably prolonged reaction time was required to obtain a

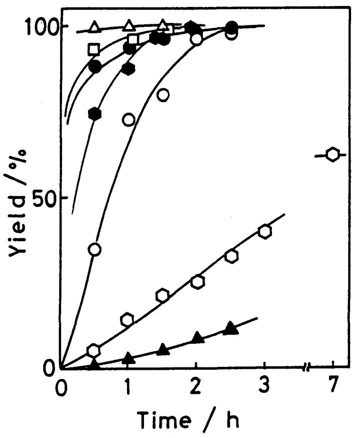


Fig. 4. Time-yield curves in the phase-transfer catalytic reaction at a **7**/**11** molar ratio of 1 : 3 in hexane-50% NaOH. PTC and mol% of ammonium group to **1**: (●) **16-IIa**, 2.9; (●) **16-IIa**, 1.3; (○) **16-IIa**, 0.8; (○) **16-IIa**, 0.1; (□) **16-IIb**, 4.3; (△) TBAB, 4.3; (▲) without PTC.

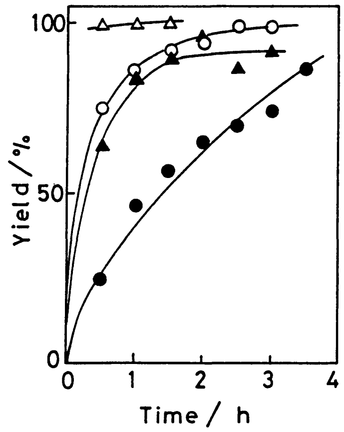


Fig. 5. Time-yield curves for **25** (△, ○) and **26** (▲, ●) in the phase-transfer catalytic reaction at a **7** or **8**/**11** molar ratio of 1 : 3 in hexane-50% NaOH. PTC and mol% of an ammonium group to **1**: (○, ●) **15-II**, 5.4; (△, ▲) TBAB, 5.0.

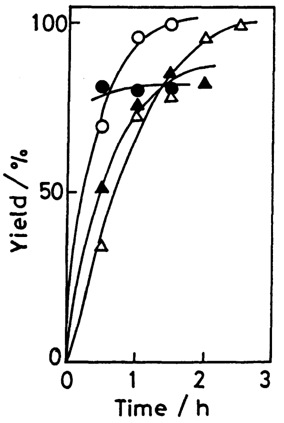


Fig. 6. Time-yield curves for **24** (●, ▲) and **25** (○, △) in the phase-transfer catalytic reaction at a **7**/**2a** or **11** molar ratio of 1:3 in hexane-50% NaOH. PTC and mol% of an ammonium group to **1**: (▲, △) **16-IIa**, 0.8; (●, ○) **20-II**, 3.3.

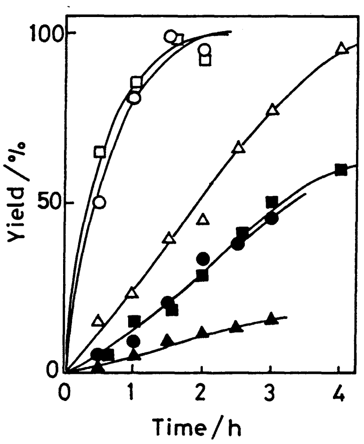
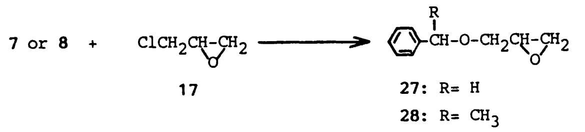


Fig. 7. Time-yield curves for **27** (○, △, □) and **28** (●, ▲, ■) at a **7** or **8**/**17** molar ratio of 1:3 in hexane-50% NaOH. PTC, mol% of an ammonium group to **1**, and reaction temperature: (○, ●) **16-IIa**, 3.5, reflux; (△, ▲) **16-IIb**, 3.4, 25 °C; (□, ■) **16-IIb**, 3.3, reflux.

satisfactory yield of **26** in every case using the polymeric PTC or TBAB, probably due to the steric hindrance of methyl group toward the nucleophilic reaction of **8** (Fig. 5). The glycidyl ethers **27** and **28** were also produced by the phase-transfer catalytic reaction of **7** or **8** with epichlorohydrin (**17**) in ether at 25 °C or reflux temperature in the presence of the polymeric PTC (Fig. 7). The phase-transfer catalysis of **7** with **17** at reflux temperature gave **27** in satisfactory yield, while **28** was given in much lower yield by a reaction of **8** with **17** under the influence of a steric hindrance of the benzylic methyl group. Mouzin et al. have prepared various glycidyl ethers by the phase-transfer catalytic reaction of alcohols with **17** in the presence of tetrabutylammonium hydrogensulfate without a solvent, and have recommended a reaction temperature of up to 25 °C for the reaction conditions.[20)] In our results, the yields of **28** by a 2 h-reaction in the presence of **16-IIb** were lower by 40—60% than those of **27** under the same reaction conditions, while at the most 20% for the difference of yield between **27** and **28** was reported by Mouzin and his coworkers. The lower yield of **28** obtained by using the polymeric PTC seems to be ascribable to the formation of a sterically hindered reaction stage involving a benzylic methyl group of **8** and the bulky polymer matrices.



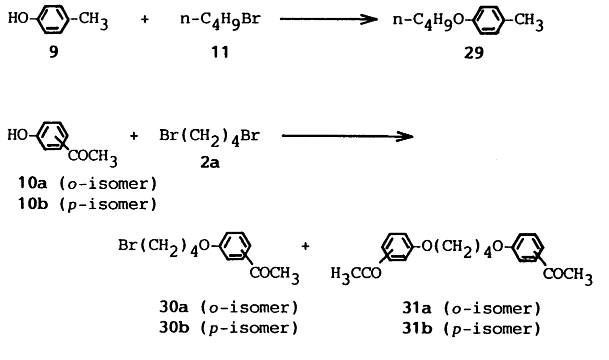
Scheme 6.

An *O*-alkylation of phenols was also examined by reactions of phenols with alkyl bromides using the polymeric PTC under the phase-transfer catalytic conditions (Table 3). The catalytic activity of the polymeric PTC was fairly high, as compared to that of TBAB with respect to the formation of those *O*-alkylated products. The reaction of **10a** with **2a** in the presence of **15-II** gave the monosubstituted product **30a** almost exclusively, although in the other

Table 3. Etherifications of Phenols with Bromides under Phase-Transfer Catalytic Conditions[a)]

Phenol	Bromide	PTC (mol%)[b)]	Time/h	Product No.	Yield/%	Molar ratio, **30**:**31**
9	**11**	**16a-II** (1.9)	5	**29**	91.6	—
9	**11**	**15-II** (3.9)	2.5	**29**	98.9	—
9	**11**	TBAB (5.0)	2	**29**	90.1	—
10a	**2a**	**15-II** (5.0)	4	**30a**	94.1	ca.100:0
				31a	0.6	
10a	**2a**	TBAB (5.0)	2	**30a**	73.7	94:6
				31a	8.7	
10b	**2a**	**15-II** (5.0)	6.5	**30b**	80.7	94:6
				31b	10.3	
10b	**2a**	TBAB (5.0)	4.5	**30b**	81.2	95:5
				31b	8.2	

a) Phenol, 36.7 mmol; bromide, 0.11 mol; benzene, 20 cm^3; 50% NaOH, 48 g; under reflux.
b) Mole percent of phase-transfer catalyst (PTC) to the phenol.



Scheme 7.

reactions in the presence of the polymeric PTC or TBAB the mono-, **30a** or **30b**, and the disubstituted products, **31a** or **31b**, were formed in a ratio of about 95 : 5, regardless of using either an ortho- or para-isomer. It is also thought that the acetyl substituent at the ortho position appreciably influenced the formation of **31a** via the further reaction of **30a** with **10a** in the sterically crowded matrices of the polymeric PTC.

Repeated Use of the Polymeric PTC: The catalytic activity of polymeric PTC **15-II** was examined in a process using the PTC repeatedly in the reaction between **1** and **2a** at the mole ratio of 3.0 in 50% NaOH and hexane. The considerably high phase-transfer catalyzing ability of **15-II** was obviously shown at each of ten stages in the process (Table 4). The reaction rate was enhanced by increasing the concentrations of the reactants (or by decreasing a volume of hexane). When a dried PTC was used, a somewhat longer reaction period was required to obtain a satisfactory yield (75—85%) of **3a**, as compared with that in the use of a wet PTC. This indicates the requirement of a certain period for swelling the dried matrices with the organic and aqueous mediums used in the present catalysis.

Table 4. Examination of Repeated Use of a Polymeric PTC in Ether Formation from **1** and **2a**[a)]

Stage No.	Hexane	Product	Yields of 3a and 4a/%					
			Reaction time/h					
	cm^3		0.5	1.0	1.5	2.0	2.5	3.0
1	20	**3a**:	50.4	66.7	72.1	77.1	78.4	
		4a:	2.9	7.0	8.7	8.7	8.9	
2	20	**3a**:	57.7	69.1	74.4	77.2	81.3	
		4a:	4.7	7.0	8.8	9.8	10.5	
3	50	**3a**:	20.8	39.4	62.7	65.7	75.3	74.7
		4a:	0.5	2.3	5.2	6.8	7.5	6.9
4[b)]	20	**3a**:	66.0	76.9	77.0	81.3		
		4a:	5.8	6.9	7.5	8.0		
5	5	**3a**:	76.2	78.2	88.9			
		4a:	6.9	7.6	8.8			
6	5	**3a**:	74.1	81.1	86.9			
		4a:	8.2	8.4	8.7			
7	5	**3a**:	79.5	86.6	87.1			
		4a:	7.3	8.4	6.6			
8	5	**3a**:	74.0	79.0	81.5	82.1		
		4a:	5.8	6.5	7.3	8.6		
9[c)]	20	**3a**:	55.3	72.9	82.0	91.0	94.2	
		4a:	3.1	7.3	8.4	9.4	9.2	
10[b)]	20	**3a**:	61.3	79.3	88.6	89.2		
		4a:	3.6	7.3	8.5	9.4		

a) **1**, 19.9 mmol; **2a**, 58.7 mmol; polymeric PTC used on the reaction at the 1st stage, 0.33 g by dry weight of **15-II** (3.0 mol% to **1**); n-$C_{16}H_{34}$, 1.35 mmol; 50% NaOH, 26 g; at reflux temperature. b) A wet polymeric PTC was used. c) 0.27 g of dried **15-II** was recovered after the reaction at the 8th stage and, subsequently, was reused at this stage.

The unchanged pendant bromide of the polymeric PTC may be converted into the corresponding ether linkage by a phase-transfer catalytic reaction with the hydroxy compound used as the reactant, although the structural change of the pendant group was not confirmed in the present study. This problem is taken to be unimportant since the high catalytic activity was maintained during the experiment of the repeated use of polymeric PTC. The polymeric PTC was easily separated from a reaction mixture by filtration and reused at the next stage of the phase-transfer reaction after or without drying the PTC. A loss of 18% by weight of the dry catalytic PTC initially used was observed before reusing the PTC at the 9th stage, corresponding to an about 97% recovery of PTC per each stage.

The present polymeric PTCs were also proved to be useful for the ether synthesis on a preparative scale. The reaction of 10 g of **1** with three equivalents of **2a** in hexane in the presence of **17-II** in only 0.1% molar respect to **1** gave pure **3a** in a 74% isolated yield. **27** was isolated in a 85% yield by a reaction of 10 g of **7** with **17** in ether in the presence of **16-IIb** in 0.4 mol% of phosphonium salt to **7**.

Influence of the Reaction Temperature: The reaction temperature should be kept in a range of 70 to

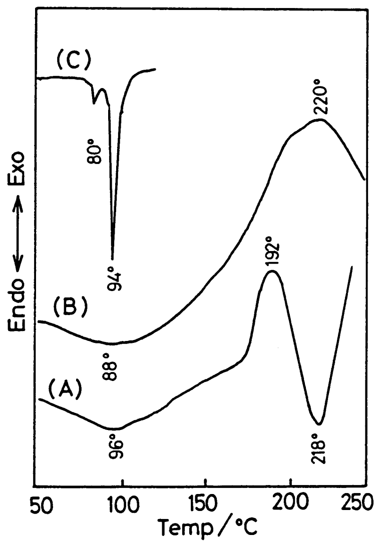


Fig. 8. DSC curves for polymeric PTCs **16-IIa** (A) and **16-IIb** (B), and TBAB (C).

80 °C in using the present polymeric PTCs. At lower temperatures the ether product was formed slowly, presumably requiring a prolonged reaction time to obtain a satisfactory yield. When those PTCs were used at temperatures above 100 °C, their catalytic activities decreased with the reaction time and, consequently, the reuse of the polymer as PTC became virtually impossible. Figure 8 shows the results of DSC measurements for the polymeric PTCs **16-IIa** and **16-IIb**, and TBAB. Probably due to a thermal decomposition, the quaternary ammonium-containing **16-IIa** begins to behave exothermally around 100 °C after indicating an endothermal peak at about 96 °C, which corresponds to a melting point of 94 °C for TBAB. The quaternary phosphonium-containing **16-IIb**, which has an exothermal peak at 220 °C, is taken to be somewhat more thermally stable than **16-IIa** with an exothermal peak at 192 °C. These results are compatible with those obtained for quaternary onium salts with low molecular weights.[25)]

In this paper we have demonstrated one of the applications of polyoxetane resins to a polymeric support for preparing functionalized polyethers. It is thus concluded that quaternary onium salts based on a soft, moderately polar polyoxetane support are useful polymeric PTCs for the facile synthesis of ethers.

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