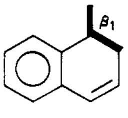
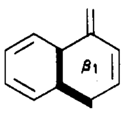
J. Org. Chem. 1981, 46, 2125–2130

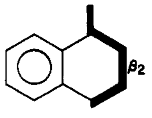
graph can be accomplished in seven different ways, two of which are exemplified below, giving nine β_1 contributions



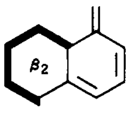
residual
SC = 2



residual
SC = 1



residual
SC = 2



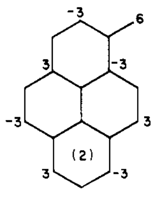
residual
SC = 1

to the resonance energy. Analogously, one counts nine β_2 terms, corresponding to the pentadienyl resonance interaction. The resonance energy is then determined to be as shown in eq 10. These procedures can be verified by

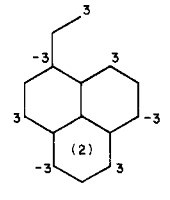
$$RE = \tfrac{2}{10}(4\gamma_1 + \gamma_2 + 9\beta_1 + 9\beta_2) \qquad (10)$$

drawing all structures. For moderately sized systems, the resonance energy can be determined by utilizing a single graph of the π radical.

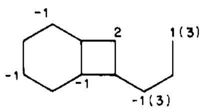
Corrected Structure Count (CSC). In isolated instances the sum of the absolute values of the coefficients of a nonbonding MO does not correspond to the actual number of valence bond structures (cf. entries for Py-1 in Table II and –Bi-1, –Bi-2, and –Py-1 in Table III). In agreement with earlier results,[13,24] the sum of the absolute values of the coefficients is defined as the CSC, and it is postulated that the CSC will be a more accurate predictor of stability than the SC for qualitative purposes. In the cases of systems incorporating cyclic 4*n* rings (cyclobutadiene, biphenylene, etc.), the background and theory supporting a calculated diminished resonance energy have been previously discussed in detail.[13]



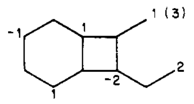
SC(Py-1) = 29
CSC = 27



SC(–Py-1) = 23
CSC = 21



SC(–Bi-1) = 11
CSC = 7



SC(–Bi-2) = 10
CSC = 8

Registry No. A, 1981-80-2; P, 3808-35-3; H, 15671-45-1; VP, 76613-39-3; Bz, 2154-56-5; Nph-2, 7419-61-6; Nph-1, 7419-60-5; BiphyMe, 4939-76-8; diPhyMe, 4471-17-4; triPhyMe, 2216-49-1; diPhyNph-2, 7094-19-1; diPhyNph-1, 7094-18-0; triBiphyMe, 76613-40-6; diPhyBiphyMe, 7261-23-6; diBiphyPhyMe, 20694-33-1; triBiphyMe, 6418-50-4; Anth-2, 19003-81-7; Anth-1, 19003-80-6; Phen-2, 19003-84-0; Phen-3, 19004-14-9; Phen-4, 19004-15-0; Phen-1, 19003-83-9; Phen-9, 19004-16-1; Py-2, 76613-41-7; Anth-9, 16407-06-0; Py-4, 76613-42-8; Chry-2, 76613-43-9; Py-1, 76613-44-0; Chry-3, 76613-45-1; Chry-5, 76613-46-2; Chry-4, 76613-47-3; Chry-1, 76613-48-4; Tr-2, 76613-49-5; Tr-1, 76613-50-8; Chry-6, 76613-51-9; -Nph-2, 55185-63-2; -Bi-1, 76613-52-0; -Nph-1, 20671-30-1; -Bi-2, 76613-53-1; -Anth-2, 76613-54-2; -Phen-2, 76613-55-3; -Phen-3, 76613-56-4; -Phen-4, 76613-57-5; -Anth-1, 76613-57-5; -Py-2, 76613-58-6; -Phen-1, 76613-59-7; -Phen-9, 20671-31-2; -Py-1, 76630-72-3.

Polymer-Supported Phase-Transfer Catalysts. Crown Ethers and Cryptands Bonded by a Long Alkyl Chain to a Polystyrene Matrix

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The synthesis of ω-aminononyl-substituted 18-crown-6 and [2.2.2]cryptand is described. These are easily bonded to chloromethylated polystyrene cross-linked with varying amounts of *p*-divinylbenzene. The polymer-bound polyethers can be successfully used as catalysts (0.01 molar equiv) in anion-promoted phase-transfer reactions. As is the case for the analogous soluble systems, the catalytic activity of the cryptands is higher than that of the crown ethers and quaternary onium salts. Due to their high chemical stability, polymer-bound polyethers are more advantageous than polymer-bound quaternary onium salts and can be recycled several times with no chemical degradation. However, loss of mechanical properties due to the grinding of the polymer matrix remains a problem. Methods allowing titration of polyether centers on the resin are also described.

Polymer-supported quaternary ammonium and phosphonium salts allow a radical simplification of the process of phase-transfer catalysis, provided that the reactivity of the immobilized catalyst is comparable with that of the analogous soluble catalysts.[1] When working under fluid-bed conditions, the polymer-bound catalyst can be filtered at the end of reaction and reused for another run. The product is directly isolated by separation from the immiscible aqueous phase and evaporation of the solvent.[1] This aspect becomes more important in the case of more sophisticated or more expensive catalysts, such as crown ethers or cryptands. Indeed the use of these systems is often discouraged by the difficulties of recovery at the end of reaction although, especially in the case of lipophilic cryptands, the much higher chemical stability and the

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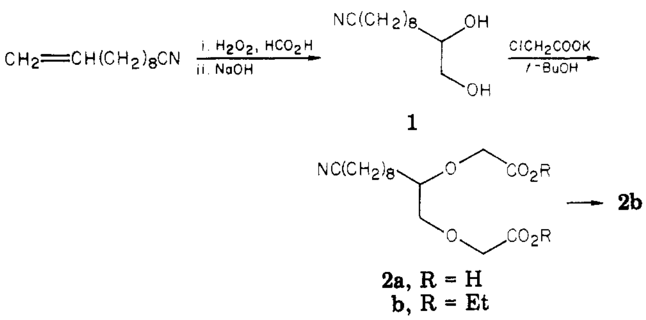
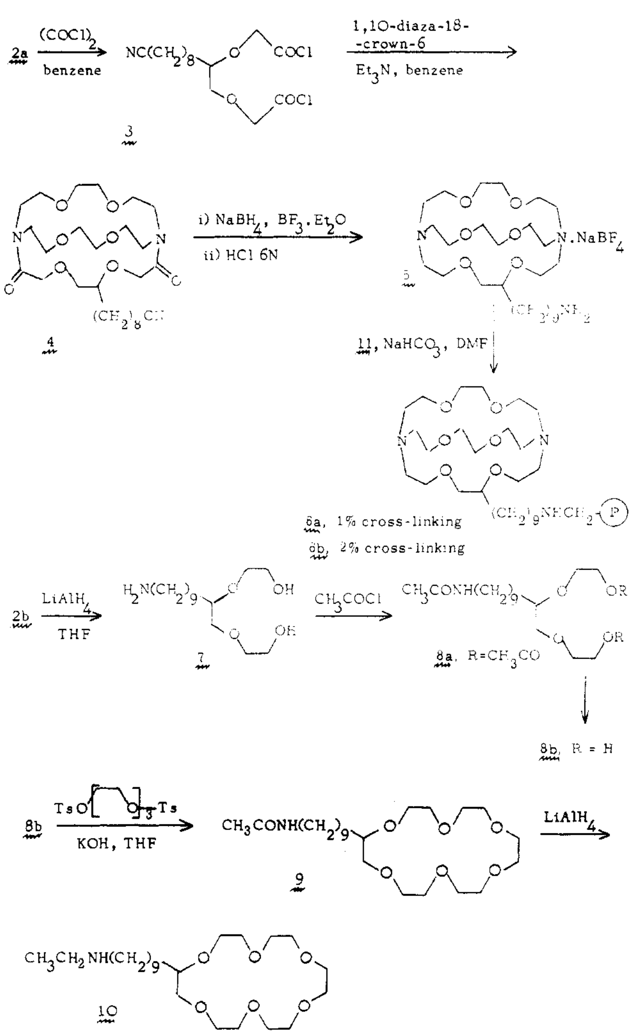
[1] Molinari, H.; Montanari, F.; Quici, S.; Tundo, P. *J. Am. Chem. Soc.* **1979**, *101*, 3920.

Scheme I





enhanced anionic activation compared to quaternary salts[2-4] would make these catalysts very attractive.

A few examples of crown ethers and cryptands bonded to polymer matrices have been reported by other authors,[5] but these studies have been generally centered[5a-c] on complexation and cation transport. We describe in this paper the immobilizations of 18-crown-6 and [2.2.2]cryptand on polystyrene matrices through linear alkyl chains, which afford systems capable of anion activation similar to that of analogous nonimmobilized crown ethers and cryptands.[6]

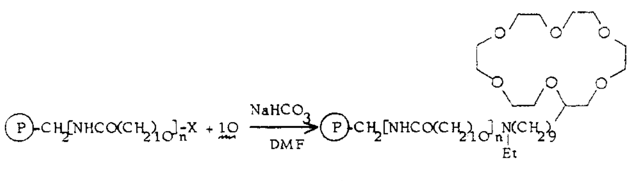
Results and Discussion

Synthesis. The systems studied were [2.2.2]cryptand and 18-crown-6 bonded to a cross-linked polystyrene matrix by a linear spacer chain of 11 atoms; 18-crown-6 has been also linked by longer alkyl chains of 23 and 35 atoms, respectively. The synthesis indicated in Scheme I offers the advantage of easy construction of crown ether and cryptand, starting from the same intermediates. The long alkyl chain ensures enough distance between the catalytic center and the polymeric matrix, for greater accessibility of reagents to the catalytic site, as already observed[1] for the immobilized quaternary salts.

Condensation of 10-cyano-1,2-decanediol 1 (from 10-undecenenitrile and performic acid) with chloroacetic acid afforded dicarboxylic acid **2a**. Reaction of the corresponding dichloride **3** with 1,10-diaza-18-crown-6 under high-dilution conditions and subsequent reduction of the bicyclic diamide **4** with diborane gave the ω-amino-substituted [2.2.2]cryptand, isolated as sodium fluoroborate complex **5**.

Reduction of diethyl ester **2b** to the amino diol **7** with lithium aluminium hydride–tetrahydrofuran, followed by N-acetylation to **8b**, cyclization to the crown ether **9** with triethylene glycol ditosylate, and finally reduction of the acetylamino group with lithium aluminium hydride, afforded the ω-(ethylamino)nonyl-substituted 18-crown-6 **10**.

Reaction of functionalized [2.2.2]cryptate **5** and 18-crown-6 **10** with chloromethyl polystyrene **11** to give resins **6a,b** and **14a–c**, respectively, was carried out in dimethylformamide at 70 °C for 7 days, in the presence of sodium hydrogen carbonate. Chloromethylpolystyrene had a chlorine content in the range of 0.7–3.7 mequiv/g and was cross-linked with 1, 2, and 4.5% by weight of *p*-divinylbenzene. Resins **15** and **16**, containing 18-crown-6 bonded to the polystyrene matrix by spacer chains of 23 and 35 atoms, respectively, were obtained by condensation of **10** with polystyrenes **12** and **13** functionalized with suitable ω-bromo-substituted linear chains, as previously described.[1] Yields of resins **6** and **14–16** were in the range 30–90%, as determined by titrimetric analysis.



11 n = 0, X = Cl
12 n = 1, X = Br
13 n = 2, X = Br

14a n = 0, 1% cross-linking
14b n = 0, 2% "
14c n = 0, 4.5% "
15 n = 1, 2% "
16 n = 2, 2% "

Titration of Polymer-Bonded Macrocyclic Polyethers. The frequencies of macrocyclic polyethers immobilized on the resins were determined titrimetrically in three different ways: direct titration of a methylene chloride–water suspension of the resin with aqueous potassium picrate (method A); addition of a molar excess of

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(2) Landini, D.; Maia, A.; Montanari, F.; Tundo, P. *J. Am. Chem. Soc.* **1979**, *101*, 2526.

(3) Landini, D.; Maia, A.; Montanari, F. *J. Chem. Soc., Perkin Trans. 2* **1980**, 46.

(4) Montanari, F.; Tundo, P. *Tetrahedron Lett.* **1979**, 5055.

(5) (a) Skah, S. C.; Smid, J. *J. Am. Chem. Soc.* **1978**, *100*, 1426 and references therein. (b) Bormann, S.; Brossas, J.; Franta, E.; Gramain, P.; Kirch, M.; Lehn, J. M. *Tetrahedron* **1975**, *31*, 2791. (c) Blasius, E.; Maurer, P. G. *J. Chromatogr.* **1976**, *125*, 511. (d) Tomoi, M.; Abe, O.; Ikeda, M.; Kihara, K.; Kaiuchi, H. *Tetrahedron Lett.* **1978**, 3031. (e) Akabori, S.; Miyamoto, S.; Tanabe, H. *J. Polym. Sci., Polym. Lett. Ed.* **1978**, *16*, 533. (f) Tomoi, M.; Kihara, F.; Kakiuchi, H. *Tetrahedron Lett.* **1979**, 3485. (g) Bogatskii, A. V.; Lukyanenko, N. G.; Pastushok, V. N. *Dokl. Akad. Nauk. SSSR* **1979**, *247*, 1153.

(6) Preliminary communications: (a) Cinquini, M.; Colonna, S.; Molinari, H.; Montanari, F.; Tundo, P. *J. Chem. Soc., Chem. Commun.* **1976**, 394; (b) Molinari, H.; Montanari, F.; Tundo, P. *Ibid.* **1977**, 639.

Table I. Analytical Data of Polymer-Supported Crown Ethers and Cryptands

catalyst	% cross-linking	titer (mequiv of polyether/g) by weight increase	titer by titrimetric analysis A	B	C	frequency of functionalized monomeric units[a]	yield of binding, %
6a	1	0.35				1:20[b]	35
6b	2	0.26	0.29	0.24	0.30	1:28[c]	47
		0.26, 0.21[d]		0.27[d]	0.30[d]		
14a	1	0.71				1:9[b]	78
14b	2	0.95	0.80	1.05	1.10	1:4.3[e]	53
		0.97, 1.04[d]		1.11[d]	1.26[d]		
14c	4.5	1.0				1:4.5[f]	47
15	2	0.48				1:7	34
16	2	0.48				1:6	40
17a[g]	1	1.0	0.95-1.0			1:7	100
18	1	0.41		0.41	0.50		
19	1	0.97	0.65	0.94, 1.04[d]	1.15		
20[h]			100[i]				
21			65[i]	99.5[i]			

[a] Calculated on the weight increase. [b] From (chloromethyl)polystyrene with 1.29 mequiv of Cl/g and 1:7 frequency of functionalized groups. [c] From (chloromethyl)polystyrene: 0.7 mequiv of Cl/g; 1:13 frequency. [d] After 1 recycle in the Br–I exchange reaction on *n*-octyl bromide. [e] From (chloromethyl)polystyrene: 3.5 mequiv of Cl/g; 1:2.3 frequency. [f] From (chloromethyl)polystyrene: 3.7 mequiv of Cl/g; 1:2.1 frequency. [g] Values from ref 1. [h] As $NaBF_4$ complex. [i] Percent of the theoretical value.

potassium picrate to a methylene chloride–water suspension of the resin, followed by spectrophotometric analysis of noncomplexed picrate in the aqueous phase (method B); titration of iodide ion bonded to the resin, after complexation with excess solid potassium iodide (method C). The last method gave the least accurate results.

Method A gave correct results for cryptates **6**, as confirmed by titration of soluble cryptates[2] $[Na^+(2.2.2,C_{14})]BF_4^-$, but not for crown ethers **14–16**. Indeed, the results for soluble crown ethers, like 18-crown-6-$CH_2OC_{16}H_{33}$,[4] corresponded to 65% of the theoretical value, due to the partial complexation.[7] For these compounds, method B afforded more reliable results, since complexation may be brought to completion with a large excess (up to tenfold) of picrate. Experimental errors increase with the picrate/crown ether molar ratio, due to the minor variation of absorbance compared to the total absorbance.

Analytical data for resins **6** and **14–16** are reported in Table I, including frequencies of monomeric units functionalized by crown ethers and cryptands, % cross-linking by *p*-divinylbenzene, and length of spacer chains.

Reactivity of Polymer-Supported Catalysts. The catalytic activity of polymer-supported catalysts **6** and **14–16** under PTC conditions was evaluated in a few standard reactions: Br–I, Br–CN, and Br–SPh exchange in *n*-octyl bromide, reactions 1–3; reduction of 2-octanone to 2-octanol by boranate ion, reaction 4; alkylation of benzyl methyl ketone with *n*-butyl bromide, reaction 5.

$$n\text{-}C_8H_{17}Br + X^- \xrightarrow[H_2O]{\text{cat.}} n\text{-}C_8H_{17}X + Br^- \quad (1\text{-}3)$$

$$X = I \text{ (eq 1)};\ X = CN \text{ (eq 2)};\ X = PhS \text{ (eq 3)}$$

$$n\text{-}C_6H_{13}COCH_3 + BH_4^- \xrightarrow[H_2O]{\text{cat.}} n\text{-}C_6H_{13}CH(OH)CH_3 \quad (4)$$

$$PhCH_2COCH_3 + n\text{-}C_4H_9Br \xrightarrow[\text{50\% NaOH (aq)}]{\text{cat.}} PhCH(C_4H_9\text{-}n)COCH_3 + Br^- \quad (5)$$

Table II. Observed Pseudo-First-Order Kinetic Constants for Anion-Promoted Reactions under Phase-Transfer Conditions in the Presence of Polymer-Supported Crown Ethers and Cryptands[a]

catalyst	% cross-linking	$k_{obsd} \times 10^5$, s^{-1} for reaction 1[b]	2[b]	3[b]	4[c]	5[d]
6a	1	130	69	34	13	21
6b	2	43	39			3
14a	1	32				
14b	2	22 (32)[e]	10	17	7	8
14c	4.5	12				2
17b	2	24	2	11		
20[f]		377 (445)[e]				
21		22 (75)[e]				

[a] Catalyst, 0.01 mmol; stirring speed 1100–1300 rpm. [b] Reactions 1 and 2 at 90 °C, reaction 3 at 25 °C; 1-bromooctane, 2.0 mmol; KI or PhSNa, 2.4 mmol; KCN, 5.0 mmol; toluene, 0.80 mL; H_2O, 0.75 mL; conditioning time 3-15 h at 90 °C without KI or KCN in reaction 1 and 2, respectively, at 25 °C without 1-bromooctane in reaction 3. [c] At 25 °C; 2-octanone, 2.0 mmol; $NaBH_4$, 3.0 mmol; toluene, 0.75 mL; H_2O, 1.6 mL; conditioning time 3 h at 25 °C without 2 octanone. [d] At 25 °C; benzyl methyl ketone, 2.0 mmol; 1-bromobutane, 2.4 mmol; 50% aqueous NaOH, 2.0 mL; conditioning time 3 h at 25 °C without 1-bromobutane. [e] KI, 8 mmol. [f] As $NaBF_4$ complex.

Kinetics were measured in a thermostated reactor equipped with magnetic stirrer, using preconditioned resins, as previously described[1] (see also Experimental Section and Tables II and III). The stirring speed was maintained at about 1100–1300 rpm, in order to minimize the influence of diffusion.[8] Reaction rates were measured

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(7) Pedersen, C. G.; Frensdorff, H. K. *Angew. Chem., Int. Ed. Engl.* **1972**, *11*, 16.

(8) Reactions proceed at markedly lower rates in the absence of stirring. The observation[1,9] of appreciable reaction rates in the absence of stirring is related to a large contact surface between the two liquid phases within the resin. However, under standard reaction conditions, efficient stirring is necessary for a fast enough variation of the liquid microenvironment of the resin particles. In the presence of long spacer chains resins become much more hydrophobic, so a lack of aqueous phase inside the resin[10] leads to reaction rates of practically zero in the absence of stirring.

(9) Regen, S. L.; Besse, J. *J. Am. Chem. Soc.* **1979**, *101*, 4059.

Table III. Influence of Solvent and of Spacer Chain Length on the Observed Pseudo-First-Order Kinetic Constants (k_{obsd}) for Anion-Promoted Reactions under Phase-Transfer Conditions in the Presence of Polymer-Supported Catalysts[a]

catalyst	reaction 1 ($k_{\mathrm{obsd}} \times 10^5$, s^{-1}) *n*-heptane	toluene	chlorobenzene	reaction 3 ($k_{\mathrm{obsd}} \times 10^5$, s^{-1}) in toluene
14b	6	22	21	17
15	8	26	26	26
16	19	28	27	30
6b	11	43	45	
17b		24		11

[a] For reaction conditions see Table II, footnotes *a* and *b*.

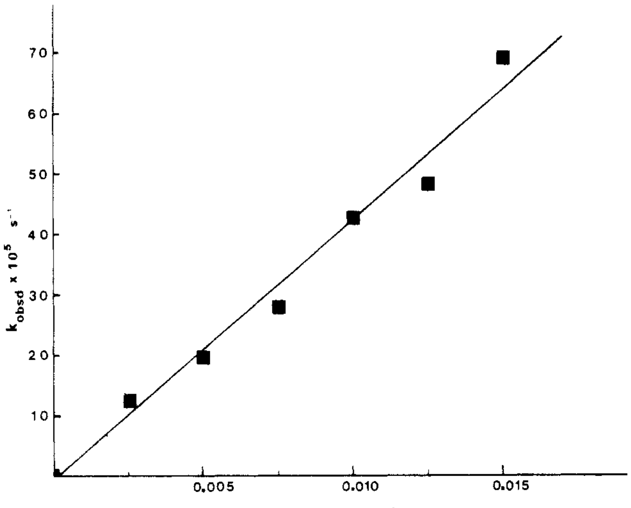


Figure 1. Dependence of the observed pseudo-first-order rate constants (k_{obsd}) on molar equivalents of heterogeneous [2.2.2]-cryptate, for Br–I exchange reaction in 1-bromooctane–toluene–water; °C; 2% cross-linked catalyst **6b**.

by GLC analysis. For all catalysts used, the reactions followed pseudo-first-order eq 6 up to at least 80% conversion.

$$\text{rate} = k_{\mathrm{obsd}}[\text{substrate}] \qquad (6)$$

No appreciable reaction occurred in the absence of catalyst, and the observed rates depended on the amount of catalyst used. For reaction 1 in the presence of catalyst **6b** it was shown that the observed rate constant (k_{obsd}, s^{-1}) was linearly dependent on the molar equivalents of cryptate bonded to the resin, as found[1] for polymer-bonded quaternary salts (Figure 1).

Under the same reaction conditions, catalytic activity of polymer-bonded [2.2.2]cryptand **6** appears to be higher, as expected,[2,3] than that of the corresponding crown ethers **14–16** and ammonium quaternary salts (Tables II and III). As already found for the latter, reactivity decreases as cross-linking increases in parallel to the minor swelling capability of the resin.

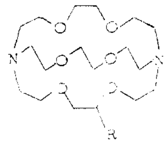
Reactivity of cryptates **6** and crown ethers **14** was compared, for reaction 1, with those of the corresponding free systems, cryptate **20** and crown ether **21**. While reaction rates of cryptates increase almost 3-fold from **6a** to **20**, as already observed for immobilized and soluble quaternary onium salts, reactivities of crown ethers remain practically constant.

This may result from different complexation constants for free and immobilized ligands. Accordingly, when the amount of potassium iodide was changed from 2.4 to 8.0 mmol, reaction rates were 1.5- and 3.5-fold higher for catalysts **14b** and **21**, respectively, whereas catalytic activity of cryptate **20** was almost constant.

$(\mathrm{P})\text{-}CH_2[NHCO(CH_2)_{10}]_n\text{-}\overset{+}{P}Bu_3\,Br^-$

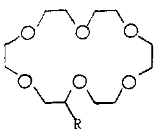
17a n = 0, 1% cross-linking

17b n = 1, 2% "



18, R = $CH_2\text{-}O\text{-}CH_2\text{-}(\mathrm{P})$

20, R = $C_{14}H_{29}$-*n*



19, R = $CH_2\text{-}O\text{-}CH_2\text{-}(\mathrm{P})$

21, R = $CH_2OC_{16}H_{33}$-*n*

The increase in length of the spacer chain from 11 to 23 and 35 atoms is accompanied by a reactivity increase, but no greater than 30% (Table III). This behavior is similar to that observed for quaternary salts,[1] in which the highest reactivity increase is observed by moving from resins in which the catalyst is directly bonded to the polymer matrix to those with a 13-atom spacer chain.

Although this aspect has not been extensively studied, the reported data (Table III) indicate that the effect of varying solvent polarity depends on the length of the spacer chain. Relatively more polar solvents, like chlorobenzene, tend to level the influence of the chain length, although a maximum reactivity is observed in this solvent, due to a better swelling of the resin. In low-polarity solvents, like *n*-heptane, the reactivity is noticeably lower than in chlorobenzene in the case of the 11-atom chain, but it increases more as the spacer chain is lengthened, as a consequence of the higher solvation assured by the latter. This behavior is again similar to that found[1] in the case of polymer-bonded quaternary salts.

Concluding Remarks. The original purpose of this work was the preparation of highly stable and efficient phase-transfer catalysts which, notwithstanding a relatively complex synthesis, could be recycled an indefinite number of times.

This goal has been partially achieved, since the combination of low cross-linking and a spacer chain of at least 10 atoms[1] minimizes the influence of diffusive factors and affords a reactivity close to that of the corresponding soluble PTC catalysts. Unfortunately, the mechanical properties of the resin decrease by decreasing the amount of cross-linking, so that the continuous stirring progressively crumbles the resin, with consequent difficulties of separation and recovery. A satisfactory compromise between the two opposing factors of a low diffusion control and high mechanical properties is clearly one of the main objectives of this kind of research.

Apart from this use as phase-transfer catalysts, resins **6** and **14–16** can be profitably used to resolve problems such as selective complexation and recovery from aqueous solutions of appropriate cations, for example, lanthanides and cesium.[4,10] These complexations do not involve fast stirring and therefore the problem of crumbling with loss of mechanical properties is avoided.

A final comment deals with the possibility, pointed out by Regen,[11] that side reactions due to the presence of the aminated spacer chains lead to a certain percentage of quaternary ammonium groups in our crown ether and

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[10] Montanari, F.; Tundo, P., unpublished results.

[11] Regen, S. L. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 421.

cryptand polymer-supported catalysts. If this were significant, titration with potassium picrate would give values higher than those expected on the basis of the weight increase after binding of the catalytic group to the polymer. As shown in Table I this is not the case. A small increase (5–10%) was observed after recycling, which could mean[11] that partial quaternarization occurs during catalysis. However, the same phenomenon has been observed in the case of crown ethers bonded to the resin through an ethereal bridge,[4,10] so that this is most probably due to the loss of mechanical properties and the consequent better swelling and/or increase in surface area[5f] of the resin. The activity of resins **6** and **14–16** remains unaltered after further recycles. As pointed out above, the reactivity of polymer cryptates is higher than that of the corresponding crown ethers and quaternary salts, in agreement with the observed behavior[2,3,12] of the nonimmobilized systems. Therefore, quaternarization of resins **6** and **14–16** does not occur, or in any case in amounts relevant to the catalytic and complexing activity of macrocyclic polyethers.

Experimental Section

10-Cyano-1,2-decanediol (1). A solution of 16.5 g (0.1 mol) of 10-undecenenitrile[13] in 20 mL of 99% formic acid was added dropwise at 20 °C to a stirred mixture of 110 mL of 99% formic acid and 10 mL of 36% hydrogen peroxide. The reaction mixture was stirred for 12 h at room temperature. Excess acid was evaporated under vacuum, giving the bisformate of 1 which was directly saponified with a slight excess of 50% aqueous sodium hydroxide (45 min at 35–40 °C). The mixture was extracted with methylene chloride, the organic phase dried and evaporated, and the residue distilled under vacuum to give 16.4 g (80%) of **1**, as a colorless oil: $n^{20}{}_{D}$ 1.4573; bp 176 °C (0.3 torr); IR (CCl_4) 3400 (OH), 2250 (C≡N) cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.82–3.00 (m, 5 H), 2.35 (t, 2 H), 1.36 (br s, 14 H). Anal. Calcd for $C_{11}H_{21}NO_2$: C, 66.3; H, 10.6; N, 7.0. Found: C, 66.4; H, 10.2; N, 7.0.

Ethyl 3-Oxa-5-[1-oxa-2-(ethoxycarbonyl)ethyl]-13-cyanotridecanoate (2b). A solution of 11.8 g (0.13 mol) of monochloroacetic acid in 50 mL of *tert*-butyl alcohol was added slowly to a refluxing mixture of 10.2 g (0.05 mol) of 1 and 30.0 g (0.25 mol) of potassium *tert*-butoxide in 300 mL of *tert*-butyl alcohol. Reflux and stirring were continued for 3 h. After acidification with hydrochloric acid the solvent was evaporated under vacuum. Extraction of the residue with benzene afforded acid **2a** (noncrystallizable oil). Crude **2a** was dissolved in 100 mL of absolute ethanol and 100 mL of benzene, 0.3 g of *p*-toluenesulfonic acid was added, and the mixture was heated to reflux for 4 h, with continuous circulation of condensed vapors through anhydrous sodium sulfate. Solvent was evaporated, the ethereal solution of the residue washed with sodium hydrogen carbonate, and the product distilled under vacuum to give 8.0 g (43%) of a colorless oil: bp 198 °C (0.2 torr); $n^{20}{}_{D}$ 1.4535; IR (neat) 2260 (C≡N), 1750 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.4–3.9 (m, 8 H), 3.58 (s, 3 H), 2.35 (t, 2 H), 1.38 (br s, 14 H), 1.25 (t, 6 H). Anal. Calcd for $C_{19}H_{33}O_6N$: C, 61.4; H, 8.9; N, 3.8. Found: C, 61.1; H, 9.0; N, 3.5.

4,7,13,16,21,24-Hexaoxa-2,9-dioxo-5-(8-cyano-*n*-octyl)-1,10-diazabicyclo[8.8.8]hexacosane (4). Aqueous potassium hydroxide (50%) was added dropwise to a stirred methanol solution of diethyl ester **2b**, keeping the temperature below 45 °C. The mixture was left at room temperature for 24 h, acidified, and extracted with methylene chloride to afford quantitative yields of acid **2a**: oil; $n^{20}{}_{D}$ 1.4725; ^1H NMR ($CDCl_3$) δ 10.65 (br s, 2 H), 4.19 (s, 2 H), 4.10 (s, 2 H), 3.17 (s, 3 H), 2.38 (t, 2 H), 1.35 (br s, 14 H). A mixture of 3.15 g (0.01 mol) of **2a**, 2.1 g (0.016 mol) of oxalyl chloride, and 2 drops of pyridine in 11 mL of anhydrous benzene was stirred for 15 h at room temperature. Excess oxalyl chloride was evaporated under vacuum, and anhydrous benzene was then added twice more and removed to give the oily dichloride **3**, IR (liquid film) 2260 (C≡N), 1800 (C=O) cm^{-1}. A solution of **3** in 500 mL of anhydrous benzene and a solution of 2.62 g (0.01 mol) of 1,10-diaza-18-crown-6[14] and 2.38 g (0.024 mol) of triethylamine in 500 mL of anhydrous benzene were simultaneously dropped into 500 mL of the same solvent over an 8-h period, with vigorous stirring, under high-dilution conditions.[14] Triethylamine hydrochloride was filtered, the solvent was removed, and the crude reaction mixture was chromatographed on a short column of alumina (chloroform) to give 3.58 g (68%) of **4**, as a colorless oil: $n^{20}{}_{D}$ 1.5065; IR (neat) 2250 (C≡N), 1650 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.6–3.4 (m, 31 H), 2.35 (t, 2 H), 1.33 (br s, 14 H). Anal. Calcd for $C_{27}H_{47}O_8N_3$: C, 59.9; H, 8.8; N, 7.8. Found: C, 60.1; H, 8.5; N, 7.5.

4,7,13,16,21,24-Hexaoxa-5-(9-amino-*n*-nonyl)-1,10-diazabicyclo[8.8.8]hexacosane–$NaBF_4$ Complex (5). A diborane solution (excess) in tetrahydrofuran (THF) was prepared from 34 mL of boron trifluoride–ethyl ether complex and 7.6 g of sodium borohydrate and kept at 0 °C. A solution of 5.46 g (0.01 mol) of **4** in 50 mL of anhydrous THF was added over a 2-h period, and the mixture was maintained at room temperature for 30 min and then refluxed for 2 h. Excess diborane was destroyed with a few milliliters of water and the solvent evaporated. The borane complex of **5** obtained was heated to reflux for 3 h with 60 mL of 6 N HCl. The solvent was removed under vacuum and the residue dissolved in 30 mL of water. The solution was extracted with methylene chloride and neutralized with sodium hydroxide. Extraction with methylene chloride afforded the product: 5.0 g (80%); mp 39–42 °C from methylene chloride–ethyl ether; ^1H NMR ($CDCl_3$) δ 3.95–3.30 (m, 23 H), 2.65 (br t, 16 H), 1.32 (br s, 16 H). Anal. Calcd for $C_{27}H_{55}O_6N_3{\cdot}NaBF_4$: C, 51.7; H, 8.8; N, 6.7. Found: C, 51.4; H, 8.7; N, 6.5.

3-Oxa-5-(1-oxa-3-hydroxypropyl)-14-aminotetradecanol (7). Ester **2b** (7.4 g, 0.02 mol) was reduced with 3.3 g (0.08 mol) of lithium aluminium hydride in 150 mL of THF solution and heated to reflux for 3 h. After the mixture cooled, a mixture of 6 mL of water and 30 mL of THF, 6 mL of 15% aqueous sodium hydroxide, and a mixture of 15 mL of water and 30 mL of THF was added consecutively. The powdered inorganic material was filtered and washed several times with hot THF. The combined solutions were evaporated and the residue was distilled to give 2.7 g (46%) of **7**: bp 198–200 °C (0.3 torr); mp 48–51 °C; ^1H NMR ($CDCl_3$) δ 3.90–3.45 (m, 13 H), 3.88–2.55 (s and t, 4 H), 1.33 (br s, 16 H). Anal. Calcd for $C_{15}H_{33}O_4N$: C, 61.9; H, 11.3; N, 4.8. Found: C, 62.1; H, 11.5; N, 4.6.

3-Oxa-5-(1-oxa-3-hydroxypropyl)-14-acetamidotetradecanol (8b). Triacetyl derivative **8a** was obtained by dropwise addition of a solution of 16.6 g (0.2 mol) of acetyl chloride in 50 mL of anhydrous benzene to a stirred solution of 4.6 g (0.05 mol) of **7** and 26 g (0.25 mol) of triethylamine in 300 mL of anhydrous benzene at 45 °C. Filtration of triethylamine hydrochloride and evaporation of the solvent afforded 14.2 g (68%) of **8a**: colorless oil; $n^{20}{}_{D}$ 1.4650; ^1H NMR ($CDCl_3$) δ 4.4–3.1 (m, 13 H), 2.08 (s, 6 H), 1.97 (s, 3 H), 1.30 (br s, 16 H). Compound **8a** was directly converted into **8b** by dissolving it in a mixture of 135 mL of methanol and 135 mL of a aqueous 50% potassium hydroxide solution, maintaining a temperature of 40–45 °C. The solution was left for 5 h at room temperature and, after evaporation of methanol, the organic residue was extracted with methylene chloride, affording 15.5 g (93%) of **8b**: colorless oil; $n^{20}{}_{D}$ 1.4761; IR (neat) 1560 and 1650 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 6.85 (br s, 1 H), 4.3–2.9 (m, 15 H), 1.95 (s, 3 H), 1.30 (br s, 16 H). Anal. Calcd for $C_{17}H_{35}O_5N$: C, 61.3; H, 10.5; N, 4.2. Found: C, 60.9; H, 10.2; N, 4.0.

2-(9-Acetamido-*n*-nonyl)-1,4,7,10,13,16-hexaoxacyclooctadecane (9). To a refluxing mixture of 6.7 g (0.02 mol) of **8b** and 2.9 g of potassium hydroxide in 20 mL of THF and 2 mL of water was added with stirring 9.2 g (0.02 mol) of triethylene glycol ditosylate. Reflux and stirring were continued for 3 h. The solvent was evaporated and replaced by methylene chloride. Insoluble salts were filtered and the solution was washed with 2 N aqueous hydrochloric acid and then with water. Chromatography on alumina (chloroform) afforded 3.1 g (35%) of **9**: colorless oil; $n^{20}{}_{D}$ 1.4829; IR (neat) 1550 and 1660 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$)

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δ 3.9–2.85 (m, 25 H), 1.95 (s, 3 H), 1.25 (br s, 16 H). Anal. Calcd for $C_{23}H_{45}O_7N$: C, 61.7; H, 10.1; N, 3.1. Found: C, 61.3, H, 9.9; N, 3.0.

2-[9-(Ethylamino)-*n*-nonyl]-1,4,7,10,13,16-hexaoxacyclooctadecane (10). Reduction of 4.5 g (0.01 mol) of **9** with 2.0 g (0.06 mol) of lithium aluminium hydride was performed under the conditions described for **7**. The crude product was purified by extraction from a methylene chloride solution with 2 N aqueous hydrochloric acid and subsequent reprecipitation with tetraethylammonium hydroxide. Final extraction with methylene chloride afforded 3.4 g (78%) of **10**: colorless oil; n^{20}_{D} 1.4750; ^{1}H NMR ($CDCl_3$) δ 3.93–3.3 (m, 21 H), 2.83 (s, 1 H), 2.70 (q, 2 H), 2.62 (t, 2 H), 1.20 (br s, 13 H), 1.13 (t, 3 H). Anal. Calcd for $C_{23}H_{47}O_6N$: C, 63.7; H, 10.9; N, 3.2. Found: C, 63.8; H, 11.0; N, 3.3.

Polymer-Supported Cryptands (6a,b) and Crown Ethers (14a–c, 15, 16). Chloromethylated polystyrenes **11**, 1, 2, and 4.5% cross-linked with *p*-divinylbenzene, were commercially available. Resins **12** and **13** were prepared as previously described.[1] Functionalized cryptand **5** and crown ether **10** were linked to resins **11**–**13** by heating the amount of the resin corresponding to 1 mol equiv of covalent halogen with 1.2 mol equiv of **5** or **10** in the presence of dimethylformamide (DMF) (4 mL for 1 g of resin) and 2.0 mol equiv of sodium hydrogen carbonate for 7 days at 65 °C. Initially the mixture was carefully deaerated under vacuum. At the end of reaction the resins were successively washed with water, ethyl alcohol, ethyl ether, methylene chloride, ethyl ether, methylene chloride, and ethyl ether and then dried at 60 °C for 3 h.

Titration of Polyethers on the Resins. Method A. A 0.01 N solution of picric acid in 0.1 N aqueous sodium hydroxide was added dropwise to a stirred suspension of a weighed amount (0.3–0.5 g) of resin in 10 mL of water and 10 mL of methylene chloride. Picrate anion was absorbed by the methylene chloride swelled resin, decoloring the aqueous phase. The end point (persistent yellow color of the aqueous phase) was sharp with cryptands but was broad with crown ethers due to the lower binding constant of the latter (Table I); indeed, when titration was tested on the corresponding soluble ligands **20** and **21**, it gave 99.5 and 65% of the expected values, respectively.

Method B. A molar excess of a 1.0×10^{-3} M solution of potassium picrate in a 0.1 N aqueous solution of sodium hydroxide (10 mL, 1.5–3.0 mol equiv with respect to the polymer-bound polyether) was stirred at room temperature for 15 h with a weighed amount (1–5 mg) of resin suspended in 10 mL of water and 10 mL of methylene chloride. A given portion (4.0 mL) of the aqueous phase was diluted with 50 mL of 0.1 N sodium hydroxide and spectrophotometrically analyzed at 360 nm. The amount of polyether was established by the equation polyether (mequiv/g of resin) $= 0.01 \times [(A_o - A)/A_o] \times 1/g$, where A_o and A are the observed absorbances without and with the resin, respectively, and g is the weighed amount of resin in grams. Method B was satisfactory for both polymer-supported cryptands and crown ethers, and results agreed with those expected on the basis of the weight increases upon functionalization of the resins (Table I).

Method C. A weighed amount of resin (0.2–0.5 g) was stirred at room temperature for 15 h with a chloroform suspension of excess solid potassium iodide. Swelling of resin occurred and potassium iodide was complexed by the polyether. After this time carbon tetrachloride was added to ensure better separation of the two solid phases and the supernatant resin was collected and washed with methylene chloride and ethyl ether. After being dried at 60 °C for 3 h, a weighed amount of resin was suspended in aqueous methanol and iodide ion was titrated[15] with silver nitrate. This method gave less accurate values compared with methods A and B (Table I).

Kinetic Measurements. Kinetics were run in a 4-mL flask, maintained at the appropriate temperature within ±0.1 °C, with magnetic stirring, following already described procedures.[1] Resins were first conditioned for 3–15 h at the reaction temperature in the presence of all reagents except one; the last reagent was added at zero time. The stirring speed, 1300 ± 50 rpm, was controlled by using a strobe light. The amounts of reagents for each kind of reaction studied are indicated in Tables II and III. The reactions were followed by GLC analysis (5% SE-30 on Chromosorb) and results were corrected by calibration with standard mixtures. The pseudo-first-order rate constants (k_{obsd}) were obtained by plotting ln [substrate] vs. time and determining the slope of the straight lines by the least-squares method.

Registry No. 1, 76665-94-6; **1** bisformate, 76684-18-9; **2a**, 61013-92-1; **2b**, 76665-95-7; **3**, 61013-91-0; **4**, 76665-96-8; **5**, 76684-20-3; **7**, 61013-93-2; **8a**, 76665-97-9; **8b**, 76665-98-0; **9**, 76665-99-1; **10**, 61013-89-6; **20**–$NaBF_4$ complex, 56725-51-0; **21**, 74339-04-1; 10-undecenenitrile, 53179-04-7; 1,10-diaza-18-crown-6, 23978-55-4; triethylene glycol ditosylate, 19249-03-7; chloroacetic acid, 79-11-8.

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Analysis of Carbon-13 Nuclear Magnetic Resonance Shifts in Terms of Substituent Parameters: Statistical Comparison of Dual and Single Substituent Parameter Treatments

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A systematic comparison is made, by using six different scales of substituent parameters, of the α-, β-, and γ-carbon-13 chemical shifts for the olefinic moiety in four series of styrene derivatives. There is no systematic significant superiority, in general, of a dual substituent parameter (DSP) treatment with respect to the simpler single substituent parameter (MSP) treatment. In the case of the γ-carbons, with the former type of analysis, the inductive effect is found to be more sensitive than the resonance effect to configurational differences.

Many studies deal with linear free energy relationships (LFER),[1] applied to NMR chemical shifts, especially to ^{13}C values, with a view either to gain some insight into the determining factors of the chemical shift, or, and perhaps more profitably, to use the chemical shift as a semiempirical measure of substituent effects. We single out, from this vast corpus, those investigations which have focussed upon the olefinic carbons (C_α and C_β) in the styrene series **1**.[2-9] Correlations have been reported for

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