The reactivity of calix[4]resorcinolarene anions towards *p*-nitrophenyl esters of tetracoordinated phosphorus acids

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The results of a kinetic study have shown that the reactivity of monomeric forms of amphiphilic tetra- ($[H_4L]^{4-}$) and octa- ($[L]^{8-}$) anions of calix[4]resorcinolarenes (H_8L) towards *p*-nitrophenyl esters of tetracoordinated phosphorus acids in aqueous dimethylformamide (50 vol.% of DMF) is determined by the nucleophilic centres of the anions, whereas an increase in the concentration of H_8L inhibits the process, which is due to the formation of aggregates.

Supramolecular systems are convenient biomimetic models of ionophores and enzymes. Calixarenes exhibit enzyme-like catalytic activities in hydrolysis of esters.[1,2] For example, water-soluble cationic calix[6]arenes present at concentrations lower than the critical micelle concentration exhibit high catalytic activity by a ‘host–guest’ mechanism in the alkaline hydrolysis of nitrophenyl dodecanoate[1] and dinitrophenyl phosphate anion.[2] Analogous calix[4]arenes[†] do not possess this sort of activity.[1,2] However, side by side with the catalytic activity of calixarenes in the hydrolysis of esters their reactivity in particular as nucleophiles in the transesterification of esters is also of considerable interest.

In the present work, we studied the kinetics of reactions of *p*-nitrophenyl ethyl chloromethylphosphonate **1** and *p*-nitrophenyl diphenyl phosphate **2** with amphiphilic anions derived from calix[4]resorcinolarenes (H_8L). These anions have nucleophilic centres in the hydrophilic rim and a hydrophobic cavity formed by the aromatic rings and hydrophobic substituents R.

Previously, it has been shown by conductimetry that in aqueous DMF (containing 50 or 80% of DMF), $[H_4L_b]^{4-}$ and $[H_4L_c]^{4-}$ tetraanions form aggregates.[4]

The purpose of the present work is to study the reactivity of the calix[4]resorcinolarene anions and their aggregates towards esters of tetracoordinated phosphorus acids and to elucidate the influence of the length of the alkyl group R in the anions on these processes.

The reactions of the anions derived from H_8L with the substrates **1** and **2** were carried out in water–DMF solutions (50% of DMF by volume) at 25±0.1 °C and pH 10.7. The reaction kinetics were monitored under pseudo-first-order conditions by spectrophotometry, based on the increase in the optical density due to the liberation of *p*-nitrophenolate ($\lambda = 400$ nm). The observed rate constants (k_{obs}) were calculated from a first-order equation using the least-squares method (correlation coefficient not less than 0.99). The yield of *p*-nitrophenolate was approximately 85%.

Deprotonation of H_8L to $[H_4L]^{4-}$ or to $[L]^{8-}$ was carried out by adding ~8 or 20 (or 30) equiv. of NaOH, respectively. This ratio of H_8L to NaOH, as well as the fact that $[H_4L]^{4-}$ or $[L]^{8-}$ do occur in solution, were confirmed from plots of the k_{obs} values for the reactions with **1** and **2** *vs.* concentration of NaOH; the plots were constructed at a constant concentration of H_8L_b, equal to 4×10^{-4} mol dm^{-3} (Figure 1).

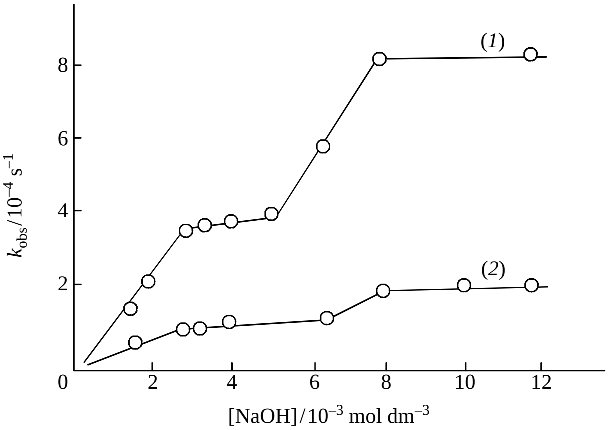
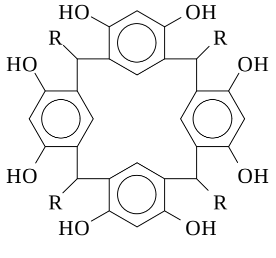


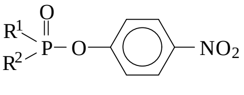
Figure 1 Dependence of the observed rate constants (k_{obs}) for the reactions of **1** (*1*) and **2** (*2*) with H_8L_b ($[H_8L] = 4\times10^{-4}$ mol dm^{-3}) on the concentration of NaOH.

It can be seen from Figure 1 that both curves have two plateaux. The first corresponds to the range of existence of $[H_4L]^{4-}$, which is in agreement with the data reported previously.[5] The second plateau is observed at a k_{obs} value which is approximately twice as large as that in the first plateau. These data make it possible to conclude that starting from a ~10-fold excess of NaOH with respect to H_8L, the tetraanions are further deprotonated up to the generation of $[L]^{8-}$. The possibility of the existence of $[L_a]^{8-}$ has been shown previously.[5]

The dependences of k_{obs} on the concentrations of $[H_4L]^{4-}$ and $[L]^{8-}$ for the reactions with **1** and **2** are shown in Figures 2 and 3. These curves contain two sections: a linear section and a descending one, the latter being followed by a plateau. The concentrations at which k_{obs} sharply decrease correspond to the critical concentrations of aggregation (CCA), which are equal to ≈ 1–1.2×10^{-3} and 8×10^{-4} mol dm^{-3} for H_8L : NaOH ratios of 1 : 8 and 1 : 20 (or 30), respectively (Figures 2 and 3). It should be noted that not only the $[H_4L]^{4-}$ anions form aggregates (this has been reported previously[4]) but also octaanions of H_8L [Figure 2(*b*)]. Aggregation of the anions derived from calix[4]resorcinolarenes inhibits the processes under consideration; the occurrence of a plateau in the region the aggregates exist indicates that they bind substrates. For reactions with both **1** and **2**, the k_{obs} values corresponding to the plateau are ~4 times lower than those near the maximum (Figures 2 and 3). Apparently, this can be explained by a decrease in the charge on the anions derived from H_8L upon aggregation, by the lesser accessibility of the nucleophilic



R = CH_3 (H_8L_a), C_7H_{15} (H_8L_b), C_9H_{19} (H_8L_c)



1 $R^1 = ClCH_2$, $R^2 = C_2H_5O$
2 $R^1 = R^2 = PhO$

[†] Calix[4]resorcinolarenes have been obtained by a previously reported procedure.[3]

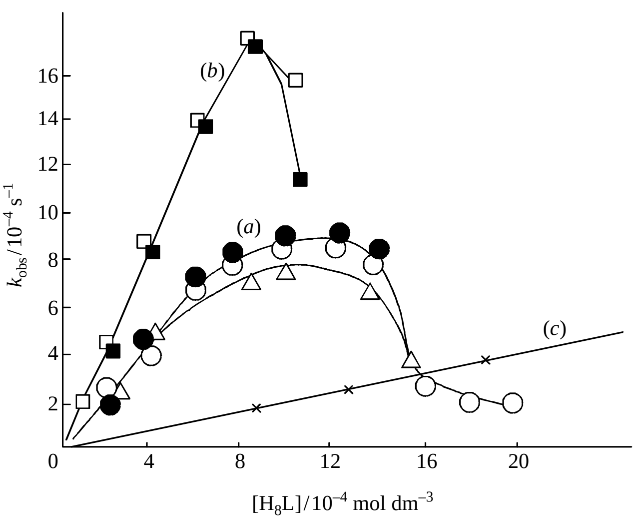


Figure 2 Dependence of k_{obs} for the reaction of **1** with $[H_4L_a]^{4-}$ (△), $[H_4L_b]^{4-}$ (○) and $[H_4L_c]^{4-}$ (●), (*a*); $[L_b]^{8-}$ [H_8L_b : NaOH = 1 : 20 (□), H_8L_b : NaOH = 1 : 30 (■)] (*b*) and 4-hexylresorcinol anions $[HL]^-$ (*c*) on their concentrations.

centres in the aggregates to substrates and by the change in the microenvironment of the reactants.

The reactivities of $[H_4L_b]^{4-}$ and $[H_4L_c]^{4-}$ anions with C_7H_{15} and C_9H_{19} alkyl groups in the reaction with substrate **1** in 50% DMF are virtually identical [Figure 2(*a*)]. In the case of $[L_b]^{8-}$, the reactivity towards substrate **1** does not change on passing from H_8L : NaOH = 1 : 20 to 1 : 30 [Figure 2(*b*)], which is confirmed by the presence of the second plateau in Figure 1. The concentration dependences of k_{obs} for reactions of the $[HL]^-$ anion derived from 4-hexylresorcinol (H_2L) with **1** and **2** are linear up to a concentration of 0.01 mol dm^{-3} [Figures 2(*c*) and 3(*b*)].

Comparison of the bimolecular rate constants (*k*) calculated for the reaction with **1** in the linear sections (Figure 2), which are 2.0 for $[L_b]^{8-}$, 1.0 for $[H_4L]^{4-}$ and 0.23 dm^3 mol^{-1} s^{-1} for $[HL]^-$, makes it possible to assume that the reactivity of monomeric anions derived from H_8L (at concentrations below the CCA) is governed by their nucleophilic centres alone. The bimolecular rate constants for $[H_4L]^{4-}$ and $[L]^{8-}$ are ~4 and 8 times greater than that for the $[HL]^-$ anion derived from 4-hexylresorcinol. The *k* values for the reactions of $[H_4L]^{4-}$ and $[HL]^-$ with **2** are 0.15 and 0.035 dm^3 mol^{-1} s^{-1}, respectively (Figure 3).

Thus, it was shown by the kinetic method that amphiphilic anions derived from calix[4]resorcinolarenes behave similarly to 4-hexylresorcinol anions, whereas the aggregates formed from them bind the substrates and thus inhibit the reaction with *p*-nitrophenyl esters of phosphorus acids. It is noteworthy that the hydrophobicity of R does not influence the reactivity of the monomeric anions derived from calix[4]resorcinolarenes, and influences the reactivity of aggregates only slightly.

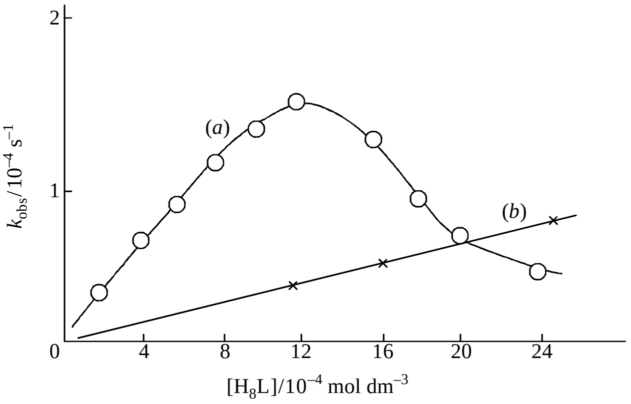


Figure 3 Dependence of k_{obs} for the reaction of **2** on the concentration of $[H_4L_b]^{4-}$ (*a*) and $[HL]^-$ (*b*).

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