Communications to the Editor

Recognition of Alkyl Groups on a Polymer Chain by Cyclodextrins

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Since cyclodextrins (CDs) were discovered a century ago, a large number of inclusion complexes with low molecular weight compounds have been prepared and characterized.[1] It is only in recent years that cyclodextrins were found to form inclusion complexes not only with small molecules but also with polymers.[2] Previously, we reported that α-CD forms complexes with poly(ethylene glycol) (PEG),[3] *β*-CD with poly(propylene glycol) (PPG),[4] and *γ*-CD with poly(methyl vinyl ether) (PMVE)[5] and polyisobutylene.[6] These complexes were found to form channel type inclusion complexes: a main chain is included in the channel formed by CDs.[7]

Macromolecules are identified by other molecules through the recognition of their main chains and side chain groups. In biological systems, recognition of side chains plays an important role in constructing supramolecular structures, achieving functions, and maintaining their lives.[8] For example, antigens are identified by antibodies through recognition of their side chains.[9] DNAs recognize each other through the sequence of the side chains. Accordingly, we studied the interactions of guest moieties attached on a polymer chain with CDs. We found that CDs bind guest moieties on a polymer chain efficiently and selectively.

Polymers having guests on a main chain have been prepared by copolymerization of acrylamide with methacrylates or acrylates of *n*-butanol, isobutyl alcohol, *tert*-butyl alcohol, *n*-hexanol, isooctanol, and dodecanol. We chose acrylamide as a comonomer because the homopolymer is soluble in water so the solubilities of the copolymer can be controlled by the comonomer ratios. Methacrylates and acrylates were chosen other comonomers having guests in a monomeric unit because they can be readily polymerized with acrylamide by addition polymerization (such as radical polymerization and ionic polymerization). We have obtained both water-soluble polymers and water-insoluble polymers depending on the comonomer ratios.

When α-CD was added to the suspension of insoluble copolymers of acrylamide and *n*-butyl methacrylate (acrylamide unit:*n*-butyl methacrylate unit = 5:1), the insoluble polymer was solubilized into water to give a homogeneous solution. In contrast, when *β*-CD was added to the suspension of the same insoluble copolymer of *n*-butyl methacrylate, there was no change. These results indicate that α-CD includes an *n*-butyl moiety of the insoluble polymer to give a soluble complex, but *β*-CD did not include an *n*-butyl moiety of the polymer. On the contrary, when *β*-CD was added to the suspension of the insoluble copolymer of acrylamide and *tert*-butyl methacrylate (acrylamide unit:*tert*-butyl methacrylate unit = 5:1), the insoluble polymer was solubilized into water to give a clear homogeneous solution. In contrast, when α-CD was added to the suspension of the same insoluble copolymer of *tert*-butyl methacrylate, there was no change. These results indicate that *β*-CD includes a *tert*-butyl moiety of the insoluble polymer to give a soluble complex, although α-CD did not include a *tert*-butyl moiety of the polymer.

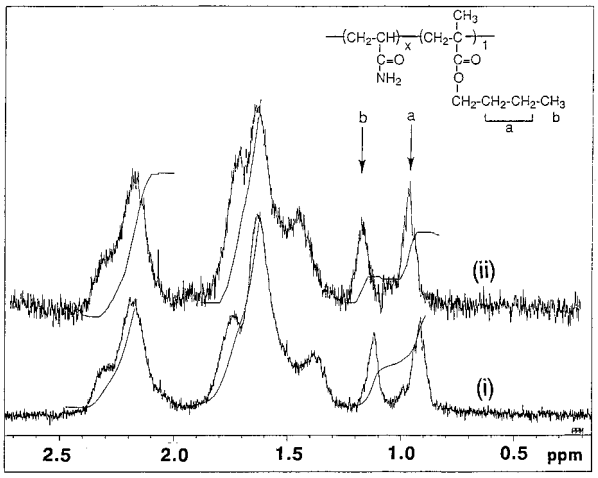

Figure 1. ^{1}H NMR spectra (270 MHz) of the soluble copolymer of acrylamide and *n*-butyl methacrylate (alkyl unit: 1 mM) in the absence (i) and presence (ii) of α-CD (50 mM) in D_2O.

In order to make clear the interactions of CDs with guest moieties on a polymer chain, the interactions have been studied using soluble copolymers of acrylamide and methacrylates (acryl amide unit:butyl methacrylate unit = 8:1) by ^{1}H NMR spectroscopy (270 MHz). Figure 1 shows the ^{1}H NMR spectra of the soluble copolymer of acrylamide and *n*-butyl methacrylate in the absence (i) and presence (ii) of α-CD. Although on addition of α-CD peaks of the main chain remain unchanged, peaks of the side chains (methyl and methylenes) shifted to a higher field. In contrast, there are no changes in the peaks of main chains and side chains on addition of *β*-CD under the same conditions. Figure 2A shows the effects of concentrations of α-CD on the shifts of the peaks of a side chain (methyl and methylene). Plots show saturation, indicating a stoichiometric complex formation. Figure 2B shows the Benesi−Hildebrand plots, which gave a linear relation between the reciprocal of the concentration of CD and that of the shift. From the slope and the intersection, association constants (K_a) have been determined. *β*-CD did not cause any changes in the spectrum of the *n*-butyl polymer at any concentration. On the contrary, *β*-CD caused shifts of peaks of methyl protons of *tert*-butyl groups of the soluble copolymer with acrylamide. α-CD did not cause any changes in the spectrum of the *tert*-butyl polymer.

Table 1 shows association constants of the complexes between CDs and polymer side chains. Only α-CD forms complexes with the *n*-butyl polymer. In contrast, the *tert*-butyl polymer forms complexes with *β*- and *γ*-CD, although it did not form complexes with α-CD. The *β*-CD complex with a *tert*-butyl group is more stable

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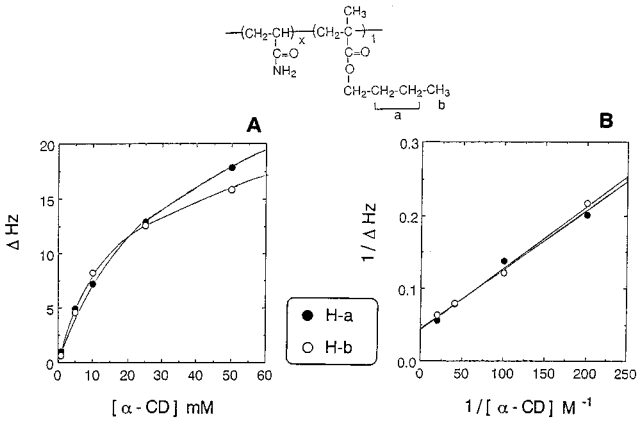

Figure 2. (A) Effects of concentrations of α-CD on the shifts of the peaks of a side chain (methyl and methylene). (B) Benesi−Hildebrand plots for (A).

Table 1. Association Constants (K_a) of the Complex between Alkyl Units on Polymers and CDs (M^{-1})[a]

	n-butyl	*tert*-butyl	isobutyl	*n*-hexyl	isooctyl	dodecyl
α-CD	55	*b*	36	290	303	990
β-CD	*b*	340	*b*	110	294	660
γ-CD	*b*	57	*b*	*b*	51	245

[a] Based on a side chain repeat unit, provided no interactions between complex sites. Error, within ±10%. [b] No peak shifts.

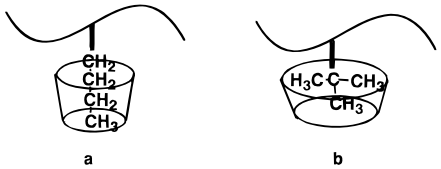

Figure 3. Proposed structures of the complexes between CDs and guests attached on a polymer chain: (a) α-CD and *n*-butyl polymer; (b) *β*-CD and *tert*-butyl polymer.

than the *γ*-CD complex, indicating that the *tert*-butyl group fits well in the *β*-CD cavity. The association constants of the complexes increased with the increasing carbon number of the side chain (*n*-butyl < *n*-hexyl < lauryl).

It is interesting that CDs form complexes with *n*-butanol and *tert*-butyl alcohol to give crystalline complexes and that α-CD forms complexes with both *n*-butanol (20 M^{-1}) and *tert*-butyl alcohol (6 M^{-1}). CDs are able to recognize guests on a polymer chain more specifically than low molecular weight guests. This may be due to the fact that CDs are able to include a guest only from one direction.

Figure 3 shows proposed structures of the complexes between CDs and guests attached on a polymer chain. Now we are studying interactions between cyclodextrins and polymers having various guests attached on a main chain to get more information about macromolecular recognition by artificial systems.

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