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Helix Formation in Synthetic Polymers by Hydrogen Bonding with Native Saccharides in Protic Media

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Abstract: Water-soluble poly(*m*-ethynylpyridine)s were designed to realize saccharide recognition in protic media. UV/Vis, ^{1}H NMR, and fluorescence measurements revealed that the polymer forms a helical higher order structure by solvophobic interactions between the ethynylpyridine units in the protic medium. The resulting pore in the helix behaves like a binding pocket in proteins, by taking advantage of inwardly directed hydrogen-bonding functional groups of the polymers. Molecular recognition of native saccharides by the polymers was investigated by circular dichroism (CD). The chirality of the saccharide was transferred to the helical sense of the polymers, accompanied by the appearance of induced CDs (ICDs) in the absorptive region of the polymers. In MeOH/water (10/1), mannose and allose showed intense ICDs, and the apparent association constant between the polymer and D-mannose was 14 M^{-1}.

Keywords: helical structures · hydrogen bonds · molecular recognition · Pi interactions · supramolecular chemistry

Introduction

Hydrogen bonds play an important role in structures and functions of biopolymers such as DNA, proteins, and polysaccharides. Examples[1] include complementary bonding between base pairs in DNA and RNA duplexes and molecular recognition of substrates by enzymes and antibodies. In the field of molecular-recognition chemistry, mimicking biological systems by hydrogen bonding with designed synthetic host molecules is subject to continuing interest.[2] These mimetics may provide not only information for understanding biological events but also an approach for the development of medical treatments. So far, hydrogen-bonding-driven molecular recognition of biomolecules has been investigated mainly in less polar media[3–5] and at air/water interfaces.[6] However, the results should be no different than those under abiotic conditions. In polar media, and moreover in protic ones, hydrogen bonding suffers from overwhelming competition of the bulk solvent molecules. Especially the recognition of saccharides by hydrogen bonding is strongly affected, because the multiple hydroxyl groups of saccharides are prone to interact with the surrounding solvent molecules. Even biotic receptors bind to saccharides with much difficulty: the binding constants between various native proteins and monosaccharides have been reported to be 10^7 M^{-1} at most.[3c,7] Thus, the development of artificial host molecules that recognize saccharides in protic media is an exciting and challenging subject.[8]

Recently, Davis et al. reported a notable exception in which a tricyclic polyamide host recognizes saccharides in water by CH–π and probably some hydrogen-bonding interactions.[9] The binding event for this highly preorganized host was mainly assessed by NMR titration. These "lock-and-key" interaction modes would be favorable for forming host–guest complexes without entropic loss caused by restructuring of the conformations.[10] At the same time, however, such a rigid frame in the host structure hardly changes its optical properties when recognizing substrates. This sometimes hides interactions, especially in the case of weak interactions.

During the course of our studies on molecular recognition of saccharides,[5] we have developed terpyridine[5a,b,c] and polypyridine structures[5d,e] with acetylene bridges, fashioned to fit guest polyols. The poly(*m*-ethynylpyridine)s alone adopt unfolded conformations in less polar media such as CH_2Cl_2 and $CHCl_3$ and can recognize saccharides by multiple hydrogen bonds between the pyridine N atoms and sac-

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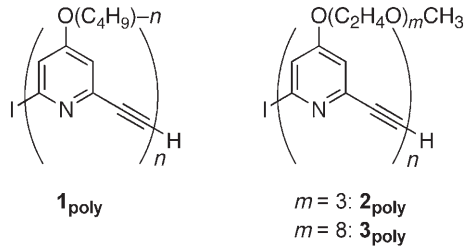
charide OH groups.[5d] The resulting complexes are biased helical structures, and this drastic conformational change in the polymers was easily detected by circular dichroism (CD). The pore inside the helix will be isolated from bulk solvent molecules and is expected to behave as a "binding pocket". Therefore, if the polymers prefer helical conformations to unfolded ones due to hydrophobic effects in aqueous media, it may be possible to import the polymers into such conditions for saccharide recognition. Herein we report the syntheses and saccharide-recognition abilities of amphiphilic water-soluble poly(*m*-ethynylpyridine)s in 100% protic media.

Results and Discussion

Molecular design of water-soluble *m*-ethynylpyridine polymers: To render poly(*m*-ethynylpyridine)s soluble in protic media, amphiphilic poly(ethylene glycol) chains were introduced in the pyridine rings of the polymers $\mathbf{2}_{poly}$ and $\mathbf{3}_{poly}$. In



$\mathbf{1}_{poly}$ $m = 3$: $\mathbf{2}_{poly}$ $m = 8$: $\mathbf{3}_{poly}$

polar aqueous media, the polymers are expected to spontaneously form a helical structure[11] by solvophobic interactions between one pyridine ring and another at an interval of one pitch (Figure 1). In the helix, pyridine rings line up in *cisoid* conformation, so that all of the pyridine nitrogen atoms are directed to the inside of the pore. The pore simultaneously provides a "low-entropy" location compared to the outside for protic solvent molecules that can form hydrogen bonds with one another. Thus, the included solvent molecules within the pore can be substituted by other hydrogen-bonding substrates of sufficient size to fill the pore volume.[12] With these speculations in mind, we expected that the recognition of native saccharides may be realizable with water-soluble poly(*m*-ethynylpyridine)s in aqueous media. Even if the recognition proceeds, detection of the event might be difficult because of disturbance from bulk solvent molecules. This problem could be overcome by means of CD spectroscopy for detecting the chirality of the resulting higher order structures:[13] in a mixture of a poly(*m*-ethynylpyridine) and a native saccharide, CD observed in the wavelength range longer than 200 nm is only attributable to complexation of the polymer with the saccharide, because the polymer is achiral by itself and the saccharide has no absorption in that wavelength region.

Preparation of *m*-ethynylpyridine polymers $\mathbf{2}_{poly}$ and $\mathbf{3}_{poly}$: Polymers $\mathbf{2}_{poly}$ and $\mathbf{3}_{poly}$ were designed to have amphiphilicity by introducing tri- and octaethylene glycol side chains, respectively, and obtained by copolymerization of two types of corresponding trimers ($\mathbf{2}_{poly}$ from **9a** and **11a**; $\mathbf{3}_{poly}$ from **9b** and **11b**; Scheme 1). Iridium-catalyzed direct boration[14] of commercially available 2,6-dibromopyridine (**4**) and subsequent oxidative cleavage of the C–B bond afforded 2,6-dibromopyridin-4-ol (**5**). Halogen exchange of **5** with an excess of CuI and KI[15] gave 2,6-diiodopyridin-4-ol (**6**), which was converted to tri- and octaethylene glycolic derivatives **7a** and **7b**[16] by Williamson and Mitsunobu reactions,[17] respectively. Diiodides **7** were ethynylated to **8** by Sonogashira reaction with (trimethylsilyl)acetylene followed by protiodesilylation. Diiodo trimers **9** were obtained by coupling between **8** and an excess of **7**. Further Sonogashira reaction of **9a** with *tert*-butyldimethylsilylacetylene afforded disilylated trimer **10a**, and deprotection of **10a** yielded diacetylene-terminated trimer **11a**. Copolymerization of **9a** and **11a** by Sonogashira reaction yielded polymer $\mathbf{2}_{poly}$. On the other hand, Sonogashira reaction of **9b** and *tert*-butyldimethylsilylacetylene was deliberately controlled to give a mixture of trimers **10b** and **12b**, which were separated by reverse-phase HPLC. Protiodesilylation of **10b** afforded diacetylene-terminated trimer **11b**. Finally, copolymerization of **9b** and **11b** furnished target polymer $\mathbf{3}_{poly}$. Monoacetylene-terminated trimer **13b** was also prepared as a short reference oligomer from spare **12b**.

The molecular weights of amphiphilic polymers $\mathbf{2}_{poly}$ and $\mathbf{3}_{poly}$ were estimated by gel permeation chromatography (GPC) as $M_n = 2.6 \times 10^4$, $M_w = 2.7 \times 10^4$ g mol^{-1} for $\mathbf{2}_{poly}$ and $M_n = 2.8 \times 10^4$, $M_w = 3.4 \times 10^4$ g mol^{-1} for $\mathbf{3}_{poly}$ (see Supporting Information). Copolymerization of **9b** and **11b** yielded a polymer longer than that obtained by simple self-polymeri-

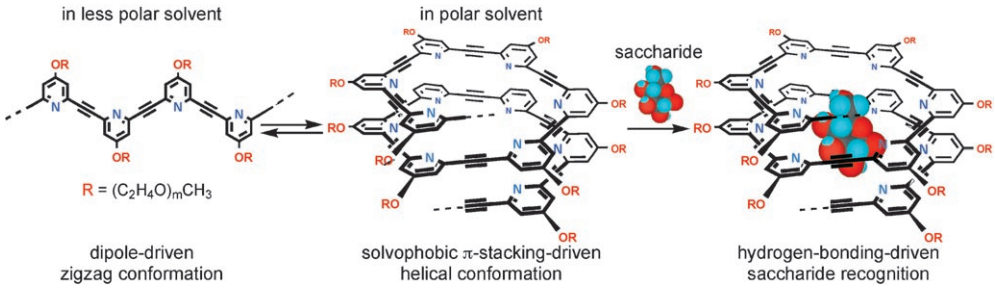
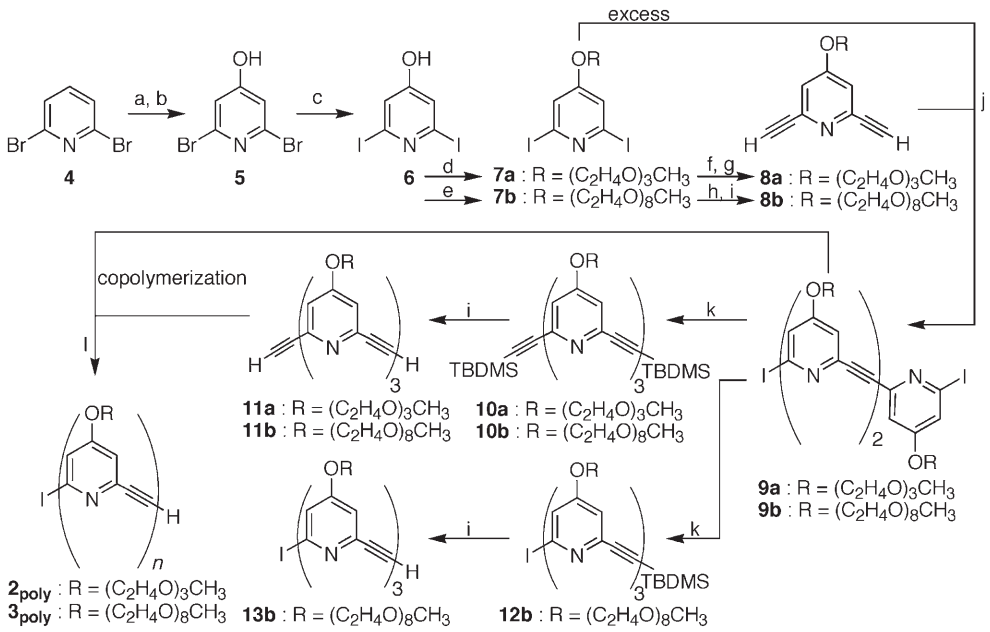


Figure 1. Conformation change of amphiphilic *m*-ethynylpyridine polymer driven by solvent effect, and saccharide recognition within the resulting pore.



Scheme 1. Preparation of amphiphilic poly(*m*-ethynylpyridine)s $\mathbf{2}_{poly}$ and $\mathbf{3}_{poly}$. a) Pinacolborane, [{IrCl(cod)}$_2$], DPPE; b) Oxone, H_2O, THF; c) KI, CuI, DMF; d) $TsO(C_2H_4O)_3CH_3$, K_2CO_3, acetone; e) $HO(C_2H_4O)_8CH_3$, DIAD (diisopropyl azodicarboxylate), PPh_3, toluene, *i*Pr_2NEt; f) 2-methyl-3-butyn-2-ol, [$PdCl_2(PPh_3)_2$], CuI, Et_2NH; g) NaH, toluene; h) (trimethylsilyl)acetylene, [$PdCl_2(PPh_3)_2$], CuI, Et_2NH, THF; i) TBAF, H_2O, THF; j) [$Pd_2(dba)_3$]·$CHCl_3$, PPh_3, CuI, *i*Pr_2NH, THF; k) (*tert*-butyldimethylsilyl)acetylene, [$PdCl_2(PPh_3)_2$], CuI, *i*Pr_2NH, THF; l) [$Pd(PPh_3)_4$], CuI, *i*Pr_2NH, THF.

zation of trimer **13b** bearing both iodo and ethynyl groups ($M_n = 1.0\times10^4$, $M_w = 1.8\times10^4$ g mol^{-1}). As expected, $\mathbf{2}_{poly}$ and $\mathbf{3}_{poly}$ are soluble in various less polar and polar solvents such as CH_2Cl_2, $CHCl_3$, AcOEt, CH_3CN, and MeOH. With regard to aqueous solvent systems, $\mathbf{2}_{poly}$ is soluble in MeOH/water (10/1), and $\mathbf{3}_{poly}$ is freely soluble even in pure water.

Structure of amphiphilic polymer $\mathbf{3}_{poly}$ in solution: UV/Vis, ^{1}H NMR, and fluorescence analyses were performed on $\mathbf{3}_{poly}$ to clarify its higher order structure. The shape of the UV/Vis absorbance spectrum of $\mathbf{3}_{poly}$ depended on the solvent (Figure 2). In CH_2Cl_2 (3.0×10^{-5} M monomer-unit concentration), two absorption maxima (λ_{max}) were observed at 275 and 317 nm. In MeOH, hypochromism occurred for the latter λ_{max} accompanied by a small red shift, which became more significant in water. The possible reasons for this red shift are 1) hydrogen bonding between the solvents and the nitrogen atoms of the chromophoric pyridine rings of the polymer and/or 2) intra- and/or intermolecular π-stacking interactions between the pyridine rings of the polymer.[11f,18]

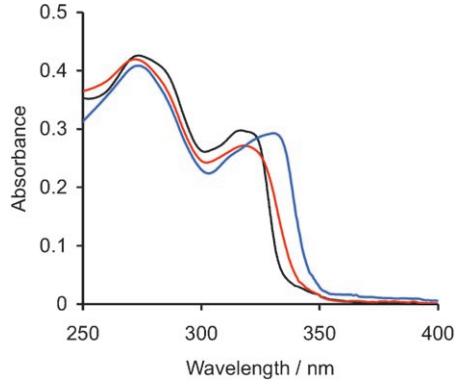


Figure 2. UV/Vis spectra of $\mathbf{3}_{poly}$ in CH_2Cl_2 (black), MeOH (red), and water (blue). Conditions: $\mathbf{3}_{poly}$ (3.0×10^{-5} M, monomer-unit concentration), 25 °C, light path length = 10 mm.

To evaluate the influence of hydrogen bonding on the UV spectra, solvent effects were also studied for reference trimer **13b**, which is too short for intramolecular π stacking. If the red shift observed for $\mathbf{3}_{poly}$ were due to merely the hydrogen-bonding interactions with solvents and independent of π-stacking interactions, the UV/Vis spectrum of **13b** should reveal similar solvent effects to those for $\mathbf{3}_{poly}$. When the UV/Vis spectrum of **13b** was measured in various solvents, the red shift was very small even in water (see Supporting Information). Therefore, hydrogen bonding has only little influence on the red shift observed in Figure 2, which is mainly due to π-stacking interactions between the pyridine rings in $\mathbf{3}_{poly}$.

However, there are still two possible π-stacking modes for $\mathbf{3}_{poly}$: intra- and intermolecular. To rule out a contribution from the intermolecular interaction, the dependence of the UV/Vis absorbance of $\mathbf{3}_{poly}$ on concentration was studied in various solvents. In CH_2Cl_2, MeOH, and water, the absorbances at 275 and 323 nm obeyed Beer's law at concentrations below 1.0×10^{-3} M (monomer-unit concentration). This rules out the possibility that intermolecular interaction of $\mathbf{3}_{poly}$ caused the red shift in Figure 2. Therefore, the observed red shift should be attributed to the intramolecular π-stacking interaction in $\mathbf{3}_{poly}$. This conclusion was further supported

on the basis of the following ^{1}H NMR and fluorescence analyses.

^{1}H NMR analyses were carried out for polymer $\mathbf{3}_{poly}$ and short reference trimers **9b** and **11b**. For the trimers **9b** and **11b** in CD_3OD, the signals of the protons on the central pyridine rings were observed at $\delta = 7.40$ and 7.41 ppm, respectively (Figure 3a, b). In the spectrum of polymer $\mathbf{3}_{poly}$, the

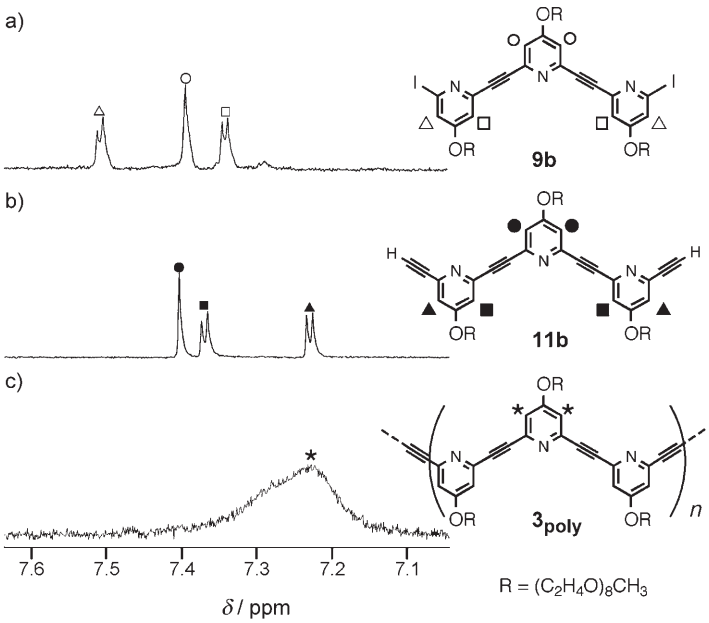


Figure 3. ^{1}H NMR (300 MHz) spectra in CD_3OD for trimers **9b** (a) and **11b** (b) and polymer $\mathbf{3}_{poly}$ (c) at 23 °C.

signal for the aromatic protons appeared as a broad peak around 7.23 ppm (Figure 3c). This upfield shift can be rationalized by an anisotropic effect in the π-stacked pyridine rings of $\mathbf{3}_{poly}$. Similar observations have been reported for other kinds of intramolecularly π-stacked oligomers and polymers.[11c,19] Moreover, the broadening of the aromatic signal for $\mathbf{3}_{poly}$ would reflect the slowness of its molecular motion in the ordered structure.[4a,11g] On the other hand, the spectra of **9b**, **11b**, and $\mathbf{3}_{poly}$ in $CDCl_3$ showed almost the same chemical shift for the protons on the pyridine rings, at $\delta =$ 7.16 ppm for **9b**, $\delta = 7.17$ ppm for **11b**, and $\delta = 7.18$ ppm for $\mathbf{3}_{poly}$. This finding means that $\mathbf{3}_{poly}$ in $CDCl_3$ does not form higher order structures, in agreement with the previous result for $\mathbf{1}_{poly}$ in less polar solvents.[5d] Thus, ^{1}H NMR analyses gave further evidence for the π-stacked higher order structure of $\mathbf{3}_{poly}$ in polar solvents.

The fluorescence emission spectra of $\mathbf{3}_{poly}$ gave additional information on the intramolecular π interactions from the viewpoint of its excited state. When $\mathbf{3}_{poly}$ (3.0×10^{-5} M, monomer-unit concentration) was excited at 300 nm in various solvents, the fluorescence emission spectrum exhibited two bands at $F_{max} \approx 330$ and 520 nm, and the latter was broad and structureless (Figure 4). A similar broad emission was also observed for $\mathbf{1}_{poly}$ around 525 nm, and in that case intramolecular excimer-like π interaction was assumed to cause

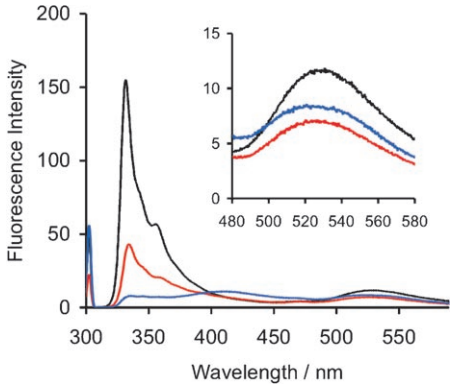


Figure 4. Fluorescence emission spectra of $\mathbf{3}_{poly}$ in CH_2Cl_2 (black), MeOH (red), and water (blue). Conditions: $\lambda_{ex} = 300$ nm, $\mathbf{3}_{poly}$ (3.0×10^{-5} M, monomer-unit concentration), 25 °C, light path length = 10 mm. The inset expands the region of the excimer-like emission.

this emission.[5d,11d] Based on this similarity, the broad emission of $\mathbf{3}_{poly}$ could be due to intramolecular π interaction between one excited segment and another, usually the ground state in $\mathbf{3}_{poly}$. Indeed, the trimer **13b** did not exhibit such an excimer-like emission because it is too short to interact intramolecularly (see Supporting Information). Furthermore, the monomer emission significantly decreased in polar solvents, especially in water. This suppression would result from the enforced solvophobic intramolecular π-stacking interactions between two ground-state segments in $\mathbf{3}_{poly}$.[11f]

These three spectroscopic investigations indicated the contribution of intramolecular π-stacking interactions in $\mathbf{3}_{poly}$ in polar solvents, and these interactions probably arise from the helical structure of $\mathbf{3}_{poly}$ shown in Figure 1. In the helical structure, the pyridine rings located near the inside pore overlap with each other, and the amphiphilic side chains extend from the helix to the outside, where they interact with polar solvents. Thus, one might expect that the inside pore would effectively incorporate saccharides in polar solvents to form chiral helical complexes biased by the chirality of the saccharides.

Saccharide recognition with amphiphilic polymer $\mathbf{3}_{poly}$: Previously, we reported that the butoxy-substituted polymer $\mathbf{1}_{poly}$ forms biased helical complexes with octyl glycosides that show ICDs in the absorptive region of $\mathbf{1}_{poly}$.[5d] Polymer $\mathbf{3}_{poly}$ (1.0×10^{-3} M, monomer-unit concentration) and each of naturally occurring monosaccharides (0.30 M) in Figure 5 were mixed in MeOH/water (10/1), and the mixtures were subjected to CD measurements. The saccharides were used as an α/β and furanose/pyranose equilibrium mixture after the solution had been left for 48 h.[20] As shown in Figure 6, the mixed solutions showed significant ICDs in the absorptive region of $\mathbf{3}_{poly}$. These ICDs indeed demonstrate that $\mathbf{3}_{poly}$ associates with native saccharides even in a 100% protic medium. With the enantiomeric pairs of mannose (**D-Man** and **L-Man**) and fructose (**D-Fru** and **L-Fru**), we observed pairs of spectra as mirror images (Figure 6A). Thus, the ICDs must result from the chirality of the saccharides. The

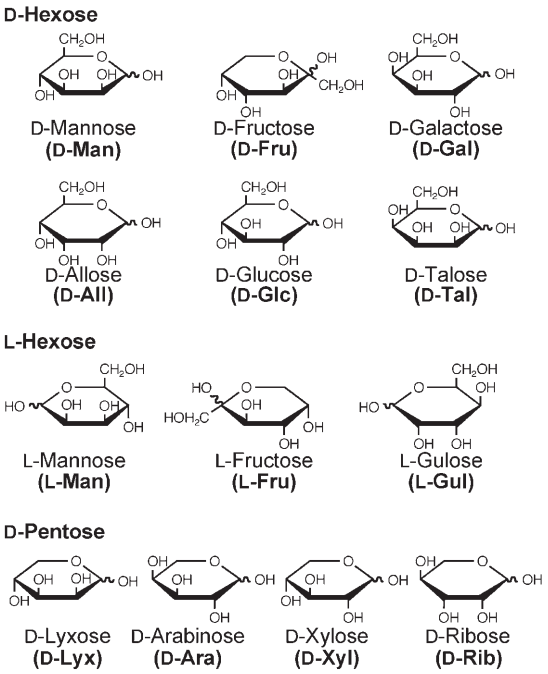


Figure 5. Native hexoses and pentoses as guest saccharides (pyranose forms).

CD spectra of the mixtures of $\mathbf{3}_{poly}$ and other saccharides are shown in Figure 6B. Of the hexoses, D-allose (**D-All**) exhibited the strongest positive ICD, while D-glucose (**D-Glc**), the most common monosaccharide, showed only a weak negative ICD with the longest wavelength. Unfortunately, D-galactose (**D-Gal**) was scarcely soluble in the mixed solvent and showed no meaningful ICD. Pentoses also revealed ICDs by interacting with $\mathbf{3}_{poly}$ under the same conditions, and the observed ellipticities were relatively strong for D-ribose (**D-Rib**) and D-lyxose (**D-Lyx**), weak for D-xylose (**D-Xyl**), and negligible for D-arabinose (**D-Ara**).

The shapes of these ICDs are similar to those for $\mathbf{1}_{poly}$ with saccharide derivatives in less polar media. This resemblance would suggest that the complexes between poly(*m*-ethynylpyridine)s and saccharides in both protic and aprotic media have similar biased helical structures. Therefore, it would be reasonable to assume that saccharide recognition by $\mathbf{3}_{poly}$ in MeOH/water is also driven by hydrogen bonding, as in the case of $\mathbf{1}_{poly}$. To support this assumption, solvent effects were examined for the ICDs of the complex between $\mathbf{3}_{poly}$ and **D-Man** in MeOH/water mixtures of various ratios (Figure 7). With increasing fraction of water, the ICD around 337 nm gradually decreased and almost disappeared in MeOH/water (2/1). This shows that complex formation between $\mathbf{3}_{poly}$ and native saccharides was disturbed by the bulk water and implies that hydrogen bonding is one of the driving forces for the complexation. When the ratio of MeOH to water was increased, the ICD again began to decrease above MeOH/water = 10/1 (see Supporting Information). Thus, the two interactions may operate in a conflicting manner for the recognition process in protic media: solvophobic interactions causing helix formation in $\mathbf{3}_{poly}$ (advantageous in water, disadvantageous in MeOH) and hydrogen bonding of $\mathbf{3}_{poly}$ to saccharides with biasing of the sense of the helicity (disadvantageous in water, advantageous in MeOH). The net attractive interaction would be a maximum

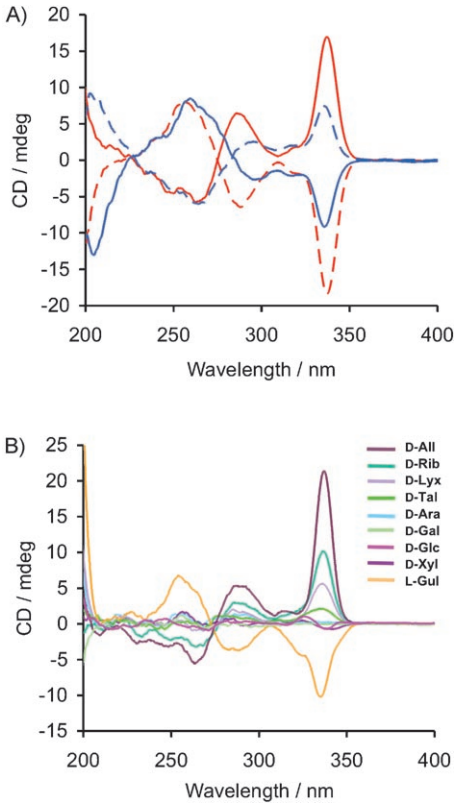


Figure 6. A) ICDs of the complexes between $\mathbf{3}_{poly}$ and the enantiomeric pairs of mannose and fructose: **D-Man** (red solid line), **L-Man** (red broken line), **D-Fru** (blue solid line), and **L-Fru** (blue broken line). Conditions: $\mathbf{3}_{poly}$ (1.0×10^{-3} M, monomer-unit concentration), saccharides (0.30 M), MeOH/water (10/1), 25 °C, light path length = 1 mm. B) ICDs of the complexes between $\mathbf{3}_{poly}$ and various monosaccharides. Conditions: $\mathbf{3}_{poly}$ (1.0×10^{-3} M, monomer-unit concentration), saccharide [0.30 M except for **D-All** (0.22 M) and **D-Gal** (virtually insoluble)], MeOH/water (10/1), 25 °C, light path length = 1 mm.

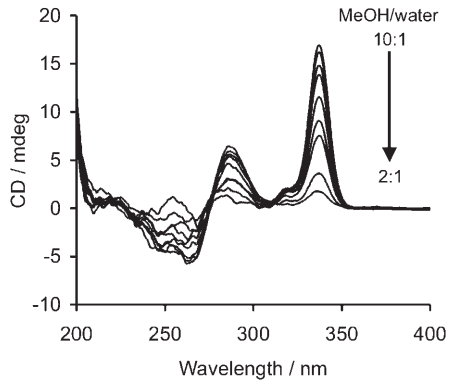


Figure 7. ICDs of the complexes between $\mathbf{3}_{poly}$ and **D-Man** in aqueous MeOH of various ratios. Conditions: $\mathbf{3}_{poly}$ (1.0×10^{-3} M, monomer-unit concentration), **D-Man** (0.30 M), MeOH/water (10/1 to 2/1), 25 °C, light path length = 1 mm.

for the formation of chiral complexes at a MeOH/water ratio of about 10/1.

To examine the influence of the amphiphilic side chains on saccharide recognition, triethylene glycol-derived polymer $\mathbf{2}_{poly}$ was subjected to CD measurement under the same conditions as $\mathbf{3}_{poly}$. Mixtures of $\mathbf{2}_{poly}$ (1.0×10^{-3} M, monomer-unit concentration) and **D-Man** or **D-Fru** (0.30 M) in MeOH/water (10/1) gave ICDs similar to those with $\mathbf{3}_{poly}$ (see Supporting Information). Thus, the contribution of the longer amphiphilic side chains in $\mathbf{3}_{poly}$ is limited to solubility in water, and is irrelevant not only to saccharide recognition but also to formation of the higher order structure of the polymer.

To obtain quantitative information on the associations, the apparent association constants K_a between $\mathbf{3}_{poly}$ and various hexoses were evaluated by CD titration experiments (see Supporting Information). When a hexose (**D-Man**, **D-Fru**, or **D-All**) was added incrementally to a solution of $\mathbf{3}_{poly}$ (1.0×10^{-3} M, monomer-unit concentration) in MeOH/water (10/1), the ICD band around 337 nm increased gradually and showed isodichroic points at 274 and 310 nm (see Supporting Information). From these titrations, the apparent association constants were evaluated by using a least-squares curve-fitting method based on the assumptions of a 1/1 binding model and a molecular weight of $\mathbf{3}_{poly}$ of $M_n=2.8\times10^4$ g mol^{-1} (from GPC analysis, see above). The free-energy changes ΔG were calculated from the K_a values by using

Table 1. Apparent association constants and thermodynamic parameters for $\mathbf{3}_{poly}$ and saccharides.[a]

Guest	K_{a298} [M^{-1}]	ΔG_{298} [kJ mol^{-1}]	ΔH [kJ mol^{-1}]	$T\Delta S$ [kJ mol^{-1}]	$\Delta H/T\Delta S$
D-Man	14	−6.5	−24	−17	1.4
D-Fru	5.5	−4.2	−24	−20	1.2
D-All	4.4	−3.7	−25	−21	1.2

[a] All apparent association constants were evaluated by using nonlinear least-square analyses fitting to the 1/1 binding model. Thermodynamic parameters were estimated by a van't Hoff plot using the K_a values at 283, 288, 293, and 298 K (see Supporting Information).

$\Delta G=-RT\ln K_a$ (Table 1). Although the values of K_a and the binding energies $-\Delta G$ were small, association was found to be clearly preferred even in 100% protic medium. To determine the thermodynamic parameters for the association, a van't Hoff plot was performed at several temperatures (Table 1). The ratios $\Delta H/T\Delta S$ lie in the range of 1.2–1.4 and are much larger than those in cyclodextrin/monosaccharide complexes mainly formed by hydrophobic interactions in water ($\Delta H/T\Delta S=-0.01$).[21] Thus, saccharide recognition by $\mathbf{3}_{poly}$ is largely attributed to enthalpic affinities, that is, hydrogen bonds will make a substantial contribution to the interaction even in aqueous media.

Conclusion

Amphiphilic poly(*m*-ethynylpyridine)s spontaneously form helical conformations in protic media. In the resulting helical pore, native saccharides interact with the polymer, and this association could be clearly and easily detected by CD spectroscopy. In MeOH/water (10/1), the complexes with native saccharides showed substantial ICDs in the absorptive region of the polymer. In these complexes, the chirality of the saccharides was transferred to the helical sense of the polymer. Several experiments revealed that this recognition event might, at least partially, be driven by hydrogen-bonding interactions even in 100% protic media. By further modification of the polymer backbone or side chains, saccharide recognition may be performable in 100% water, which would extend the molecular recognition of saccharides to the next stage.

Experimental Section

General: ^{1}H and ^{13}C NMR analyses were performed in $CDCl_3$, CD_3OD, and [D$_6$]DMSO at 23 °C and 300 and 75 MHz, respectively. UV/Vis, fluorescence and CD spectra were measured at 25 °C in CH_2Cl_2 and MeOH of commercial spectroscopic grade or in Milli-Q water by using a quartz cell of 1 or 10 mm path length. IR spectra were recorded with NaCl plates or as KBr pellets. High-resolution MS analyses were carried out on an ESI-TOF instrument.

2,6-Dibromopyridin-4-ol (5):[5b] This compound was prepared by Ir-catalyzed direct boration[14] of 2,6-dibromopyridine (**4**) and subsequent oxidation. A mixture of **4** (12 g, 51 mmol), pinacolborane (32 g, 250 mmol), [{IrCl(cod)}$_2$] (cod = 1,5-cyclooctadiene; 0.68 g, 1.0 mmol), and 1,2-bis(diphenylphosphino)ethane (0.81 g, 2.0 mmol) was stirred under Ar for 4 h at 130 °C. The resulting mixture was allowed to cool to room temperature and evaporated in vacuo. The concentrated residue was diluted with THF (190 mL). To the THF solution was added aqueous Oxone (34 g, 56 mmol in 170 mL) slowly over 5 min. After stirring for 7 min at room temperature, the mixture was quenched with aqueous $NaHSO_3$ and extracted with diethyl ether. The separated ethereal layer was washed with water and brine, dried over $MgSO_4$, evaporated, and purified by silica-gel column chromatography (eluent: AcOEt/hexane 1/5) to afford **5** (12 g, 92%) as a colorless solid. This product was identical to that previously synthesized by us.[5b]

2,6-Diiodopyridin-4-ol (6): This compound was prepared by a modification of the published procedure by Suzuki, Inouye et al.[15] A mixture of **5** (6.1 g, 24 mmol), CuI (106 g, 0.56 mol), and KI (214 g, 1.30 mol) in DMF (400 mL) was stirred for 24 h at 120 °C. The resulting brown mixture was concentrated in vacuo, diluted with AcOEt, and filtered. The precipitate was further extracted with AcOEt in a Soxhlet extractor for 24 h. The combined AcOEt extract was evaporated, and the residue was purified by silica-gel column chromatography (eluent: AcOEt/hexane 1/4) to afford **6** (6.1 g, 87%) as a yellow solid. M.p. 234–237 °C; IR (KBr): $\tilde{\nu}=1579$, 1532 cm^{-1}; ^{1}H NMR (300 MHz, [D$_6$]DMSO): $\delta=7.22$ (s, 2H), 11.43 ppm (s, 1H); ^{13}C NMR (75 MHz, [D$_6$]DMSO): $\delta=117.4$, 121.7, 164.5 ppm; ESI-HRMS: *m/z*: calcd for $C_5H_4I_2NO$ $[M+H]^+$: 347.8383; found: 347.8337.

Triethylene glycol-derived 2,6-diiodopyridine 7a: Triethylene glycol monomethyl ether monotosylate[16] (0.55 g, 1.7 mmol) was added to a suspension of **6** (0.60 g, 1.7 mmol) and potassium carbonate (1.2 g, 8.7 mmol) in acetone (5 mL), and then the mixture was refluxed for 24 h. The mixture was filtered and evaporated, and the resulting residue was purified by silica-gel column chromatography (eluent: AcOEt/hexane 2/1) to afford **7a** (0.82 g, 96%) as a yellow oil. IR (neat): $\tilde{\nu}=2878$, 1566, 1525, 1371, 1280, 1199, 1152 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta=3.38$ (s, 3H),

3.53–3.56 (m, 2H), 3.63–3.71 (m, 6H), 3.81–3.85 (m, 2H), 4.12–4.18 (m, 2H), 7.26 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.2, 68.3, 68.5, 69.2, 70.7, 71.1, 72.0, 121.4, 140.9, 164.7 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{12}H_{17}I_2NNaO_4$ $[M+Na]^+$: 515.9145; found: 515.9221.

Octaethylene glycol-derived 2,6-diiodopyridine 7b: Diisopropyl azodicarboxylate (3.0 g, 15 mmol) was added to a mixture of *i*Pr_2NEt (15 mL), **6** (5.2 g, 15 mmol), and PPh_3 (3.9 g, 15 mmol) in toluene (270 mL), and then the mixture was stirred for 1 h at room temperature. Octaethylene glycol monomethyl ether[16] (4.8 g, 12 mmol) was added, and the resulting mixture stirred for an additional 12 h at room temperature and concentrated. The residue was purified by silica-gel column chromatography (eluent: AcOEt) to afford **7b** (7.2 g, 81%) as a yellow oil. IR (neat): $\tilde{\nu}$ = 2873, 1574, 1536, 1287, 1108 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.38 (s, 3H), 3.54 (t, *J* = 4.2 Hz, 2H), 3.63–3.69 (m, 26H), 3.82 (t, *J* = 4.8 Hz, 2H), 4.14 (t, *J* = 4.8 Hz, 2H), 7.26 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.1, 68.3, 69.2, 70.6, 70.7, 71.0, 72.0, 115.7, 141.0, 164.6 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{22}H_{37}I_2NNaO_9$ $[M+Na]^+$: 736.0456; found: 736.0448.

Triethylene glycol-derived 2,6-bis(3-hydroxy-3-methyl-1-butynyl)pyridine: Compounds **7a** (2.5 g, 5.1 mmol) and 2-methyl-3-butyn-2-ol (1.7 g, 21 mmol) were added successively to a suspension of $[PdCl_2(PPh_3)_2]$ (144 mg, 0.21 mmol) and CuI (20 mg, 0.10 mmol) in Et_2NH (100 mL). The mixture was stirred for 5 h at room temperature and evaporated, the residue diluted with AcOEt, and insoluble salts filtered off. The filtrate was concentrated and subjected to silica-gel column chromatography (eluent: AcOEt) to afford triethylene glycol-derived 2,6-bis(3-hydroxy-3-methyl-1-butynyl)pyridine (2.1 g, 100%) as a yellow oil. IR (neat): $\tilde{\nu}$ = 3371, 2981, 2931, 2881, 2229, 1584, 1554 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.61 (s, 12H), 3.15 (s, 2H), 3.38 (s, 3H), 3.53–3.56 (m, 2H), 3.63–3.72 (m, 6H), 3.84 (t, *J* = 4.7 Hz, 2H), 4.16 (t, *J* = 4.7 Hz, 2H), 6.87 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 31.3, 59.2, 65.1, 68.0, 69.4, 70.7, 70.8, 71.1, 72.1, 80.7, 94.8, 113.2, 144.0, 165.1 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{22}H_{31}NNaO_6$ $[M+Na]^+$: 428.2049; found: 428.1995.

Triethylene glycol-derived 2,6-diethynylpyridine 8a: Triethylene glycol-derived 2,6-bis(3-hydroxy-3-methyl-1-butynyl)pyridine (2.3 g, 5.8 mmol) was added to a suspension of NaH (23 mg, 0.58 mmol; commercial 60% dispersion was washed thoroughly with hexane prior to use) in toluene (60 mL). The mixture was stirred at 80 °C for 30 min and evaporated. The evaporation residue was purified by silica-gel column chromatography (eluent: AcOEt/hexane 1/1) to afford **8a** (1.3 g, 88%) as a yellow oil. IR (neat): $\tilde{\nu}$ = 3234, 2882, 2112, 1582, 1556 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.12 (s, 2H), 3.38 (s, 3H), 3.53–3.56 (m, 2H), 3.63–3.71 (m, 6H), 3.86 (t, *J* = 4.7 Hz, 2H), 4.18 (t, *J* = 4.7 Hz, 2H), 7.01 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.2, 68.0, 69.3, 70.76, 70.81, 71.1, 72.1, 82.3, 100.7, 114.2, 143.7, 165.1 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{16}H_{19}NNaO_4$ $[M+Na]^+$: 312.1212; found: 312.1208.

Octaethylene glycol-derived 2,6-bis(trimethylsilylethynyl)pyridine: Compounds **7b** (2.9 g, 4.6 mmol) and (trimethylsilyl)acetylene (2.3 g, 23 mmol) were added successively to a mixture of $[PdCl_2(PPh_3)_2]$ (130 mg, 0.19 mmol) and CuI (18 mg, 0.093 mmol) in Et_2NH (80 mL). The mixture was stirred for 3.5 h at room temperature and evaporated. The evaporation residue was diluted with AcOEt and filtered to remove insoluble salts. The filtrate was concentrated and purified by silica-gel column chromatography (eluent: AcOEt) to afford octaethylene glycol-derived 2,6-bis(trimethylsilylethynyl)pyridine (2.5 g, 84%) as a yellow oil. IR (neat): $\tilde{\nu}$ = 2874, 2110, 1581, 1555, 1333, 1108 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.24 (18H), 3.38 (s, 3H), 3.55 (t, *J* = 2.7 Hz, 2H), 3.59–3.72 (m, 26H), 3.84 (t, *J* = 5.1 Hz, 2H), 4.17 (t, *J* = 5.1 Hz, 2H), 6.95 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = −0.1, 59.2, 68.0, 69.3, 70.6, 70.7, 71.1, 72.1, 95.1, 103.1, 113.8, 144.2, 164.9 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{32}H_{55}NNaO_9Si_2$ $[M+Na]^+$: 676.3313; found: 676.3368.

Octaethylene glycol-derived 2,6-diethynylpyridine 8b: *n*Bu_4NF (1.0 M in THF, 8.5 mL, 8.5 mmol) and a few drops of H_2O were added to a solution of octaethylene glycol-derived 2,6-bis(trimethylsilylethynyl)pyridine (2.5 g, 3.9 mmol) in THF (35 mL). The mixture was stirred for 3 h at room temperature, concentrated, and purified by silica-gel column chromatography (eluent: AcOEt) to afford **8b** (1.7 g, 87%) as a yellow oil. IR (neat): $\tilde{\nu}$ = 3230, 2874, 2111, 1581, 1555, 1334, 1108 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.14 (s, 2H), 3.38 (s, 3H), 3.54 (t, *J* = 5.1 Hz, 2H), 3.60–3.73 (m, 26H), 3.86 (t, *J* = 4.8 Hz, 2H), 4.17 (t, *J* = 4.8 Hz, 2H), 7.01 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.1, 68.0, 69.3, 70.58, 70.65, 71.0, 72.0, 82.2, 114.2, 143.6, 165.0 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{26}H_{39}NNaO_9$ $[M+Na]^+$: 532.2523; found: 532.2481.

Triethylene glycol-derived diiodo trimer 9a: Compounds **7a** (0.82 g, 1.7 mmol) and **8a** (0.12 g, 0.42 mmol) were added successively to a mixture of $[Pd_2(dba)_3]\cdot CHCl_3$ (dba = *trans*,*trans*-dibenzylideneacetone; 8.6 mg, 8.3 μmol), PPh_3 (8.7 mg, 33 μmol), and CuI (0.2 mg, 1.1 μmol) in *i*Pr_2NH (25 mL)/THF (5 mL). The mixture was stirred for 3 h at room temperature, diluted with AcOEt, and filtered to remove insoluble salts. The filtrate was evaporated and the residue purified by silica-gel column chromatography to afford recovered **7a** (0.52 g, 80% recovery, eluent: AcOEt/hexane 2/1) and **9a** (0.33 g, 79% based on **8a**, eluent: AcOEt) as a yellow oil. IR (neat): $\tilde{\nu}$ = 2879, 1577, 1532, 1105 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.38 (d, *J* = 1.2 Hz, 9H), 3.54–3.58 (m, 6H), 3.64–3.75 (m, 18H), 3.86–3.90 (m, 6H), 4.18–4.25 (m, 6H), 7.17 (d, *J* = 2.1 Hz, 2H), 7.18 (s, 2H), 7.31 ppm (d, *J* = 2.1 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.0, 60.3, 68.1, 69.0, 70.45, 70.49, 79.8, 71.8, 86.7, 87.9, 114.56, 114.61, 117.6, 121.4, 143.2, 143.4, 164.5, 164.9 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{40}H_{51}I_2N_3NaO_{12}$ $[M+Na]^+$: 1042.2146; found: 1042.2078.

Octaethylene glycol-derived diiodo trimer 9b: Compounds **7b** (2.0 g, 2.7 mmol) and **8b** (0.35 g, 0.69 mmol) were added successively to a mixture of $[Pd_2(dba)_3]\cdot CHCl_3$ (28 mg, 0.027 mmol), PPh_3 (29 mg, 0.11 mmol), and CuI (5.2 mg, 0.027 mmol) in *i*Pr_2NH (20 mL)/THF (20 mL). The mixture was stirred for 12 h at room temperature, diluted with AcOEt, and filtered to remove insoluble salts. The filtrate was evaporated, and the residue purified by silica-gel column chromatography (eluent: AcOEt to acetone) to afford recovered **7b** (0.76 g, 48% recovery) and **9b** (0.86 g, 75% based on **8b**) as a yellow oil. IR (neat): $\tilde{\nu}$ = 2873, 1573, 1531, 1107 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.38 (s, 9H), 3.53–3.56 (m, 6H), 3.61–3.72 (m, 78H), 3.83–3.91 (m, 6H), 4.14–4.22 (m, 6H), 7.13 (d, *J* = 2.3 Hz, 2H), 7.16 (s, 2H), 7.30 ppm (d, *J* = 2.3 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.2, 68.3, 69.3, 70.6, 70.7, 71.1, 72.1, 86.8, 88.2, 114.7, 114.8, 117.7, 121.6, 143.5, 143.8, 164.7 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{70}H_{111}I_2N_3NaO_{27}$ $[M+Na]^+$: 1702.4992; found: 1702.5271.

Triethylene glycol-derived bis(silylethynyl) trimer 10a: Compounds **9a** (0.41 g, 0.40 mmol) and (*tert*-butyldimethylsilyl)acetylene (0.28 g, 2.0 mmol) were added successively to a mixture of $[PdCl_2(PPh_3)_2]$ (11 mg, 16 μmol) and CuI (1.5 mg, 8.0 μmol) in *i*Pr_2NH (20 mL)/THF (10 mL). The mixture was stirred for 12 h at room temperature and concentrated, and the concentrated residue was diluted with AcOEt and filtered to remove insoluble salts. The filtrate was evaporated and the residue purified by silica-gel column chromatography (eluent: AcOEt) to afford **10a** (0.29 g, 70%) as a yellow oil. IR (neat): $\tilde{\nu}$ = 2929, 2884, 2246, 2163, 1581, 1550, 1128 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.20 (s, 12H), 1.00 (s, 18H), 3.38 (d, *J* = 2.1 Hz, 9H), 3.54–3.58 (m, 6H), 3.64–3.75 (m, 18H), 3.86–3.90 (m, 6H), 4.19 (t, *J* = 4.5 Hz, 6H), 7.01 (d, *J* = 2.1 Hz, 2H), 7.13 (d, *J* = 2.1 Hz, 2H), 7.16 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = −4.5, 26.4, 59.2, 60.5, 68.0, 68.1, 69.3, 70.8, 71.1, 72.0, 87.2, 87.6, 93.7, 103.9, 113.9, 114.6, 114.7, 143.7, 143.9, 144.6, 164.9, 165.0 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{56}H_{81}IN_3NaO_{12}Si_2$ $[M+Na]^+$: 1066.5257; found: 1066.5141.

Triethylene glycol-derived diethynyl trimer 11a: *n*Bu_4NF (1.0 M in THF, 0.47 mL, 0.47 mmol) and a few drops of H_2O were added to a solution of **10a** (0.22 g, 0.21 mmol) in THF (6 mL). The mixture was stirred for 5 h at room temperature, concentrated, and the residue purified by silica-gel column chromatography (eluent: acetone) to afford **11a** (0.12 g, 71%) as a yellow oil. IR (neat): $\tilde{\nu}$ = 3232, 2879, 2110, 1582, 1552, 1126 cm^{-1}; ^{1}H NMR (300 MH, $CDCl_3$): δ = 3.16 (s, 2H), 3.38 (s, 9H), 3.54–3.58 (m, 6H), 3.64–3.75 (m, 18H), 3.87–3.90 (m, 6H), 4.20 (t, *J* = 4.5 Hz, 6H), 7.04 (d, *J* = 2.6 Hz, 2H), 7.16 (d, *J* = 2.6 Hz, 2H), 7.17 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.2, 68.1, 68.2, 69.3, 70.71, 70.74, 71.1, 72.0, 82.2, 87.3, 87.4, 114.2, 114.6, 114.7, 143.7, 143.8, 165.0, 165.1 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{44}H_{53}IN_3NaO_{12}$ $[M+Na]^+$: 838.3527; found: 838.3534.

Triethylene glycol-derived polymer 2_{poly}: Compounds **9a** (0.14 g, 0.13 mmol) and **11a** (0.11 g, 0.13 mmol) were added to a mixture of $[Pd(PPh_3)_4]$ (6.2 mg, 5.3 μmol) and CuI (1.0 mg, 5.3 μmol) in *i*Pr_2NH

(30 mL)/THF (30 mL). The mixture was stirred for four days at room temperature and concentrated, and the concentrated residue diluted with AcOEt and filtered to remove insoluble salts. The filtrate was evaporated and treated with a Sephadex LH-20 column (eluent: $CHCl_3$) to remove tarry impurities. The eluent was evaporated, and the residue was purified by preparative GPC (eluent: $CHCl_3$) to afford $\mathbf{2}_{poly}$ (0.10 g, 40% by weight) as dark brown oil. IR (neat): $\tilde{\nu}$ = 2877, 2225, 1583, 1109 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 3.38 (s, 3*n* H), 3.55–3.58 (m, 2*n* H), 3.64–3.73 (m, 6*n* H), 3.89 (s, 2*n* H), 4.21 (s, 2*n* H), 7.05–7.19 ppm (m, 2*n* H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.2, 68.3, 69.3, 70.8, 71.2, 72.1, 87.5, 114.8, 143.9, 165.2 ppm.

Octaethylene glycol-derived bis(silylethynyl) trimer 10b and octaethylene glycol-derived iodo silylethynyl trimer 12b: Compound **9b** (0.74 g, 0.44 mmol) and (*tert*-butyldimethylsilyl)acetylene (93 mg, 0.66 mmol) were added to a mixture of $[PdCl_2(PPh_3)_2]$ (12 mg, 18 μmol) and CuI (1.7 mg, 8.8 μmol) in *i*Pr_2NH (20 mL)/THF (15 mL). The mixture was stirred for 15 h at room temperature and concentrated. The concentrated residue was diluted with AcOEt and filtered to remove insoluble salts. The filtrate was evaporated and treated by silica-gel column chromatography (eluent: AcOEt to acetone) to remove impurities. The eluent was evaporated, and the residue purified by preparative reverse-phase HPLC to afford **9b** (98 mg, 13% recovery), **10b** (0.15 g, 20%), and **12b** (0.27 g, 34%).

10b: yellow oil; IR (neat): $\tilde{\nu}$ = 2878, 2163, 1582, 1550, 1133 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 0.20 (s, 12H), 1.0 (s, 18H), 3.37 (s, 9H), 3.53–3.57 (m, 6H), 3.61–3.72 (m, 78H), 3.86–3.90 (m, 6H), 4.19 (t, J = 4.5 Hz, 6H), 7.01 (d, J = 2.4 Hz, 2H), 7.12 (d, J = 2.4 Hz, 2H), 7.16 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = −4.6, 16.9, 26.3, 59.1, 68.0, 69.2, 70.57, 70.63, 71.0, 72.0, 87.2, 87.6, 93.7, 103.8, 113.9, 114.6, 143.7, 143.9, 144.5, 164.8, 165.0 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{86}H_{141}N_3NaO_{27}Si_2$ $[M+Na]^+$: 1726.9189; found: 1726.9137.

12b: yellow oil; IR (neat): $\tilde{\nu}$ = 2873, 2160, 1582, 1550, 1109 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 0.20 (s, 6H), 1.00 (s, 9H), 3.37 (s, 9H), 3.52–3.58 (m, 6H), 3.61–3.72 (m, 78H), 3.84–3.92 (m, 6H), 4.16–4.22 (m, 6H), 7.01 (d, J = 2.4 Hz, 2H), 7.11 (d, J = 2.7 Hz, 2H), 7.17 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = −4.7, 14.3, 16.7, 21.1, 26.2, 59.0, 60.3, 67.9, 68.1, 68.3, 69.1, 70.4, 70.5, 70.6, 70.9, 71.9, 86.3, 87.0, 87.5, 88.0, 88.3, 93.5, 103.7, 113.9, 114.5, 117.5, 142.3, 143.1, 143.4, 143.5, 143.8, 144.4, 164.5, 164.7, 164.9, 165.8, 170.8 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{78}H_{126}N_3NaIO_{27}Si$ $[M+Na]^+$: 1714.7291; found: 1714.7343.

Octaethylene glycol-derived diethynyl trimer 11b: *n*Bu_4NF (1.0 M in THF, 0.23 mL, 0.23 mmol) and a few drops of H_2O were added to a solution of **10b** (0.163 g, 0.096 mmol) in THF (5 mL). The mixture was stirred for 5 h at room temperature, concentrated, and purified by silica-gel column chromatography (eluent: acetone) to afford **11b** (0.12 g, 83%) as a dark yellow oil. IR (neat): $\tilde{\nu}$ = 3526, 2874, 2115, 1582, 1551, 1108 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 3.17 (s, 2H), 3.53 (s, 9H), 3.52–3.58 (m, 6H) 3.60–3.73 (m, 78H), 3.84–3.91 (m, 6H), 4.16–4.22 (m, 6H), 7.05 (d, J = 2.1 Hz, 2H), 7.15 (d, J = 2.1 Hz, 2H), 7.17 ppm (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.1, 68.1, 69.2, 70.55, 70.62, 70.7, 71.0, 72.0, 82.2, 87.4, 114.1, 114.6, 143.7, 143.78, 143.81, 165.0 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{74}H_{113}N_3NaO_{27}$ $[M+Na]^+$: 1498.7460; found: 1498.7086.

Octaethylene glycol-derived ethynyl iodo trimer 13b: *n*Bu_4NF (1.0 M in THF, 83 μL, 0.083 mmol) and a few drops of H_2O were added to a solution of **12b** (0.12 g, 0.069 mmol) in THF (3 mL). The mixture was stirred for 4 h at room temperature, concentrated, and purified by silica-gel column chromatography (eluent: acetone) to afford **13b** (0.085 g, 78%) as a dark yellow oil. IR (neat): $\tilde{\nu}$ = 3235, 2873, 2114, 1581, 1551, 1109 cm^{-1}, ^1H NMR (300 MHz, $CDCl_3$): δ = 3.16 (s, 1H), 3.37 (s, 9H), 3.53–3.57 (m, 6H), 3.62–3.72 (m, 78H), 3.84–3.90 (m, 6H), 4.15–4.21 (m, 6H), 7.04–7.06 (m, 2H), 7.12–7.15 (m, 2H), 7.16 (s, 1H), 7.30 ppm (d, J = 2.4 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.2, 68.1, 68.4, 69.2, 70.7, 71.1, 72.0, 86.6, 87.2, 88.2, 114.2, 114.7, 142.5, 143.7, 143.8, 164.7, 165.1 ppm; ESI-HRMS: *m*/*z*: calcd for $C_{72}H_{112}IN_3NaO_{27}$ $[M+Na]^+$: 1600.6426; found: 1600.6464.

Octaethylene glycol-derived polymer $\mathbf{3}_{poly}$: Compounds **9b** (0.18 g, 0.076 mmol) and **11b** (0.11 g, 0.076 mmol) were added to a mixture of $[Pd(PPh_3)_4]$ (3.5 mg, 3.1 μmol) and CuI (0.6 mg, 3.1 μmol) in *i*Pr_2NH (20 mL)/THF (40 mL). The mixture was stirred for three days at room temperature and concentrated. The concentrated residue was diluted with AcOEt and filtered to remove insoluble salts. The filtrate was evaporated and treated with a Sephadex LH-20 column (eluent: $CHCl_3$) to remove tarry impurities. The eluent was evaporated, and the residue purified by preparative GPC (eluent: $CHCl_3$) to afford $\mathbf{3}_{poly}$ (0.10 g, 43% by weight) as a dark brown oil. IR (neat): $\tilde{\nu}$ = 2873, 2351, 1582, 1550, 1108 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 3.37 (s, 3*n* H), 3.52–3.57 (m, 2*n* H), 3.62–3.72 (m, 26*n* H), 3.89 (s, 2*n* H), 4.20 (s, 2*n* H), 7.15–7.35 ppm (m, 2*n* H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 59.2, 68.3, 69.3, 70.7, 71.1, 72.1, 87.5, 100.7, 114.8, 143.9, 165.1 ppm.

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