Protection and Polymerization of Functional Monomers. 11. Synthesis of Well-Defined Poly(4-vinylbenzoic acid) by Means of Anionic Living Polymerization of 2-(4-Vinylphenyl)-4,4-dimethyl-2-oxazoline

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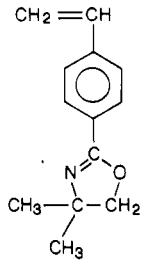
ABSTRACT: Anionic polymerization of 2-(4-vinylphenyl)-4,4-dimethyl-2-oxazoline (1) was investigated in THF at −78 °C with oligo(α-methylstyryl)dilithium, -disodium, or -dipotassium or cumylpotassium. The polymerization of 1 proceeded without chain transfer and termination reactions with each of the above initiators to afford a stable living polymer. Yields of polymers were quantitative in all cases. The resulting polymers had predictable molecular weights based on the monomer to initiator ratios and narrow molecular weight distributions ($\bar{M}_w/\bar{M}_n$ = 1.04–1.13). Mark–Houwink equation for poly(1), $[\eta] = 5.1_4 \times 10^{-4} M^{0.54_5}$ (in THF at 40 °C) was correlated. It is clear that the polymer is relatively contracted in THF compared to polystyrene. Poly(4-vinylbenzoic acid) with a well-defined structure was successfully obtained by acid hydrolysis and subsequent saponification to remove the oxazolinyl protecting group from the resulting poly(1). New types of block copolymers, poly(1-*block*-styrene-*block*-1), poly(1-*block*-α-methylstyrene-*block*-1), and poly(1-*block*-isoprene-*block*-1) were prepared by means of this living system.

Introduction

During the past several years we have synthesized a variety of linear functional polymers having a high uniformity of chain lengths as well as predictable molecular weights.[1] Our approach to the synthesis of such polymers involves the anionic living polymerization of monomers with suitably protected functional groups followed by the removal of the protecting groups to regenerate the original functional groups on the polymer chain. In this approach choice of the protecting group is especially of importance in this regard, because the protected functionality must be stable under the conditions of the anionic polymerization and the protecting group must be completely and selectively removed without chain degradation from the resulting polymer.

In the preceding paper[2], we found that the anionic polymerization of 2-(4-vinylphenyl)-4,4-dimethyl-2-oxazoline (1)proceeded well without chain-transfer and termination



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reactions to afford a stable living polymer at −78 °C. The resulting polymers, as expected, had predictable molecular weights and narrow molecular weight distributions. Acid hydrolysis and subsequent saponification of the polymer gave a pure poly(4-vinylbenzoic acid).

The resulting poly(4-vinylbenzoic acids) by this method may be attractive from a viewpoint of molecular design, since they have well-defined structures with regard to the chain lengths as mentioned above. Furthermore, they are useful as ion-exchange resins, polymer chelates, and supports when one considers their carboxy functionality in the polymers.

This paper describes a detailed study of the anionic polymerization of 1 followed by removal of the oxazoline group and of the synthesis of block copolymers containing the poly(4-vinylbenzoic acid) sequence.

Results and Discussion

Meyers and his co-workers have demonstrated the utility of the 1,3-oxazoline moiety as a protecting group for various carboxylic acids.[3,4] Since 2-substituted-1,3-oxazoline can mask both the carbonyl and hydroxy groups of a carboxy moiety at the same time, it is remarkably stable toward highly reactive nucleophiles such as organolithium compounds, often used as anionic initiators. This suggests that by masking the carboxy group of 4-vinylbenzoic acid as its oxazoline derivative, the anionic polymerization of the protected monomer 1 is expected to proceed without difficulty.

Although 1 was previously unknown, its preparation was readily accomplished simply by treating 4-vinylbenzoyl chloride with 2-amino-2-methyl-1-propanol followed by cyclization according to the method established by Meyers. Overall yields are usually in the range of 50–70% based on the starting 4-vinylbenzoic acid. It should be noted that 1 has a strong tendency to be polymerized. Significant amounts (20–40%) of monomer were always lost due to the thermal polymerization during fractional distillation. The oxazoline ring of 1 is stable to neutral and even strongly basic conditions like 5 N NaOH but is readily cleaved by 3 N HCl.

Anionic Polymerization of 1. A series of polymerizations of 1 was carried out with various anionic initiators in tetrahydrofuran (THF) at −78 °C under high-vacuum conditions. The initiators include alkali-metal salts (Li, Na, K) of α-,methylstyrene oligomers and 2-phenyl-2-propylpotassium (cumyl potassium).

Upon mixing of 1 with each of the initiator solutions, the polymerization appeared to proceed instantly as evidenced by the observation of a viscosity increase of the system. The reaction mixtures were deep red in color except for the case initiated with cumylpotassium which exhibited a pale orange red color. These characteristic colors, which remain unchanged at −78 °C after 24 h, indicate that the living polystyryl anion derived from 1 is in existence in each case. They immediately disappeared by adding a few drops of methanol. The mixtures were poured into a large amount of water for precipitation. Virtually quantitative conversions were obtained in all cases based on the form of poly(1). The polymers were reprecipitated an additional 3 times from their THF solutions into hexane.

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Table I
Anionic Polymerization of 1 with Various Initiators in THF at −78 °C for 5–10 Min[a]

1, mmol	initiator type	initiator mmol	α-methylstyrene, mmol	$\bar{M}_n$(calcd) × 10^{-4}	$\bar{M}_n$(obsd)[b] × 10^{-4}	$\bar{M}_w/\bar{M}_n$
4.69	K-Nap[c]	0.204	0.564	1.0	0.91	1.05
2.59	K-Nap	0.0987	0.480	1.2	1.1	1.06
6.46	Li-Nap[d]	0.190	0.567	1.4	1.3	1.13
7.13	Li-Nap	0.204	0.626	1.5	1.3	1.06
6.22	Na-Nap[e]	0.172	0.520	1.5	1.6	1.09
4.97	K-Nap	0.102	0.590	2.1	2.6	1.10
6.23	cumyl K[f]	0.0376	0.547	3.5	3.7	1.06
4.89	cumyl K	0.0224		4.4	5.0	1.04
5.44	cumyl K	0.0164		6.7	7.5	1.07
7.14	cumyl K	0.0213	0.256	7.3	8.7	1.06
8.68	cumyl K	0.0218	0.565	8.2	8.0	1.06

[a] Yields of polymers isolated were near quantitative in each case. [b] $\bar{M}_n$(obsd) was obtained by VPO in benzene solution. [c] Potassium naphthalenide. [d] Lithium naphthalenide. [e] Sodium naphthalenide. [f] Cumylpotassium.

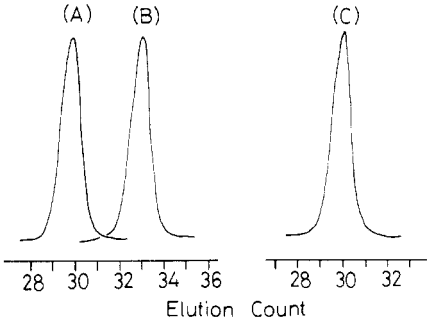

Figure 1. GPC curves for poly(1)s (A, B) and for standard polystyrene (C): peak A, $\bar{M}_n$(obsd) = 8.0 × 10^4, $\bar{M}_w/\bar{M}_n$ = 1.06; peak B, $\bar{M}_n$(obsd) = 1.3 × 10^4; peak C, $\bar{M}_n$(obsd) = 4.27 × 10^4, $\bar{M}_w/\bar{M}_n$ = 1.03.

The resulting polymer samples were measured by IR and ^{1}H NMR spectroscopies which showed that the absorptions and signals were found for the poly(1). Our ^{1}H NMR data showed no indication that cleavage of the oxazoline linkage was observed in the resulting polymers during the above workup. Accordingly, the characterizations of the polymers by vapor pressure osmometry (VPO) and gel permeation chromatography (GPC) were performed in the form of poly(1). The molecular weights and their distribution parameters, $\bar{M}_w/\bar{M}_n$, for this series of polymers are listed in Table I.

It can be seen that in all samples the predictable number-average molecular weights are in close accord with the observed values by VPO. The GPC charts of all these samples in Table I indicated that each polymer possessed a narrow distribution of molecular weight. The values of $\bar{M}_w/\bar{M}_n$ are calculated to be around 1.1 by Tung's method using a standard polystyrene calibration.[5] Representative GPC profiles are illustrated in Figure 1. A chromatogram of a standard polystyrene sample was also shown as a comparison. These results confirm that the polymerization of 1 proceeds in the absence of chain-transfer and termination reactions. Furthermore, the narrowness of molecular weight distribution indicates that the initiation reaction is rapid enough compared to the propagating step.

No polymer was produced with either Grignard reagents such as benzyl- and ethylmagnesium bromides or lithium aluminum hydride at −78 °C. The starting monomer was recovered in a near quantitative yield in each case. Their reactivities might be considered to be too low to initiate the polymerization of 1.

The polymer of 1 is a white solid in the molecular weight range prepared here. The solubility of poly(1) resembles that of polystyrene, as previously reported.[2] The poly(1) can be cast from its THF solution to give a transparent, colorless, and brittle film.

Table II
Values of Intrinsic Viscosity and $\bar{M}_n$ Measured by VPO for Poly(1)

$[\eta]_{THF}^{40°C}$, dL/g	$\bar{M}_n$(VPO) × 10^{-4}	$\bar{M}_w/\bar{M}_n$
0.0806	1.1	1.06
0.132	2.5	1.14
0.142	3.3	1.06
0.208	5.0	1.11
0.232	7.5	1.06
0.243	8.0	1.06

Mark–Houwink Equation of Poly(1). The intrinsic viscosities of poly(1) measured in THF at 40 °C were correlated by the Mark–Houwink equation, $[\eta] = KM^a$.[6,7] In this case M is $\bar{M}_n$ for number-average molecular weight measured by VPO ranging from 1.1–8.0 × 10^4. For this correlation the polymers of 1 prepared here are good candidate because they all have narrow molecular weight distributions. The $[\eta]$ and $\bar{M}_n$ data of Table II yield the following relation.

$$[\eta]_{THF}^{40°C} = 5.1_4 \times 10^{-4} M^{0.54_5}$$

As a comparison the relation for polystyrene was also determined under the same conditions by using commercially available standard samples of $\bar{M}_n$ in the range of 0.99–10.7 × 10^4 with $\bar{M}_w/\bar{M}_n$ ratios of 1.01–1.04.

$$[\eta]_{THF}^{40°C} = 1.1_7 \times 10^{-4} M^{0.71_9}$$

The value of a for polystyrene in THF is 0.72, showing that THF is a good solvent for polystyrene. In constrast, the value of a for poly(1), 0.55, suggests that the polymer chain is relatively contracted in THF compared to that of polystyrene which is reasonably extended. Since a molecular weight range for meaningful K and a determinations is somewhat narrow, both values listed here should be considered preliminary.

The data of intrinsic viscosity and GPC measurements in THF at 40 °C can be used to calculate molecular weight by the universal calibration technique.[8] The agreement of molecular weights determined in this way compared with number-average molecular weight measured by VPO is reasonably good as can be seen in Table III. This signifies that the universal calibration technique is also good means to determine the molecular weight of the polymer of 1.

Removal of the Oxazoline Protecting Group. When conversion of the oxazoline to the carboxylic acid is required, the most common method is usually by treatment of the oxazoline in aqueous HCl solution. It was found that, in most instances, the oxazoline can be readily hydrolyzed to the corresponding carboxylic acid in excellent to quantitative conversions.[9] In cases where acidic hy-

Table III
Molecular Weights Calculated, Measured by VPO, and Determined by the Universal Calibration Method for Poly(1)

$\bar{M}_n$(calcd) × 10^{-4}	$\bar{M}_n$(obsd)[a] × 10^{-4}	($\bar{M}_w/\bar{M}_n$)	$\bar{M}_n$(UC)[b] × 10^{-4}	($\bar{M}_w/\bar{M}_n$)
1.1	1.1	(1.06)	1.2	(1.02)
1.7	2.5	(1.14)	2.6	(1.15)
3.5	3.3	(1.06)	3.7	(1.05)
4.4	5.0	(1.11)	5.2	(1.12)
6.7	7.5	(1.07)	7.8	(1.10)
8.2	8.0	(1.06)	8.1	(1.10)

[a] $\bar{M}_n$(obsd) was obtained by VPO. [b] $\bar{M}_w$(UC) was determined by the universal calibration method.

drolysis is not desirable, the oxazoline can be removed by transformation of its oxazolinium salts followed by alkaline hydrolysis.[10]

Under the similar conditions reported previously, attempts to hydrolyze the poly(1) prepared here, however, resulted in only partially hydrolyzed products. The complete hydrolysis of poly(1) to poly(4-vinylbenzoic acid) could be successfully achieved by treatment of poly(1) with 3 N HCl–aqueous THF at 80–90 °C for 10 h followed by an alkaline hydrolysis with 20% NaOH–aqueous methanol at 80–90 °C for 6 h. After neutralization poly(4-vinylbenzoic acids) were obtained in 70–80% yields.

The IR and ^{1}H NMR spectra of the resulting polymer revealed the complete removal of the oxazoline group and the expected structure of pure poly(4-vinylbenzoic acid) within the analytical limit of both spectra. More reliable evidence for the complete deprotection of the oxazoline group was obtained by elemental analysis which showed no nitrogen content at all. The elemental analysis also indicated that the poly(4-vinylbenzoic acid) contained 7/10 mol of water per each monomer unit of the polymer. The water molecules that were probably physically sorbed on the polymer were difficult to remove even by heating 50–60 °C) for 72 h in vacuo. The polymer associated with water molecules was a white solid, soluble in THF, methanol, ethanol, *N,N*-dimethylformamide, and dimethyl sulfoxide.

Attempts to analyze poly(4-vinylbenzoic acid) by GPC were not successful. No chromatogram for the polymer was observed. This is probably due to the physical adsorption effect of the carboxylic acid function to the GPC column of polystyrene–divinylbenzene copolymer during the size-exclusion process. Therefore, we converted the poly(4-vinylbenzoic acid) to poly(methyl 4-vinylbenzoate) via methylation by diazomethane and measured again the methylated polymer by GPC. The ^{1}H NMR spectra of the polymer confirmed that the methylation proceeded nearly quantitatively.

The GPC of the esterified sample showed a single peak with a narrow molecular weight distribution eluting in a reasonable molecular weight region. Figure 2 shows the chromatograms for a polyme before and after hydrolysis followed by esterification. The shapes of the two chromatograms are almost identical. This result indicates that

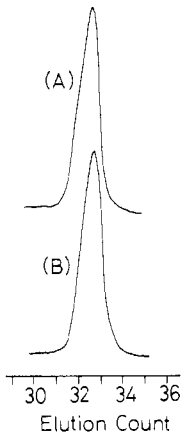

Figure 2. GPC curves for poly(1) (A) and for poly(methyl 4-vinylbenzoate) (B) obtained by hydrolysis of poly(1) followed by methylation: peak A, $\bar{M}_n$(obsd) = 1.3 × 10^4, $\bar{M}_w/\bar{M}_n$ = 1.06; peak B, $\bar{M}_n$(obsd) = 1.2 × 10^4, $\bar{M}_w/\bar{M}_n$ = 1.06.

the deprotection step does not cause any detectable chain branching and/or main-chain degradation. Accordingly, the poly(4-vinylbenzoic acid) obtained by the anioic living polymerization of 1, followed by the removal of the oxazoline group, should be a linear polymer with a well-defined structure, a known molecular weight, and a narrow molecular weight distribution.

Synthesis of Block Copolymer Containing Poly(4-vinylbenzoic acid) Sequences. The synthesis of precisely tailored block copolymers has stimulated a great deal of interest from both a chemical and an industrial point of view.[11] Such copolymer synthesis is only possible through sequential living polymerization of different monomers. Since the living character of the polymerization of 1 was demonstrated in the preceding section, we applied this polymerization to the synthesis of well-defined block copolymers.

An ABA type triblock copolymer was prepared by the sequential polymerization of styrene as monomer B and 1 as monomer A with oligo(α-methylstyryl)dipotassium in THF at −78 °C. The polymer was obtained in virtually quantitative yield. The results are summarized in Table IV. It can be seen that the resulting polymer possesses a number-average molecular weight in close accord with the predictable value. The composition of each block determined by ^{1}H NMR spectrum was found to be nearly equal to that calculated from both monomers fed in the polymerization. GPC analysis showed that the peak of the starting polystyrene block shifted toward the higher molecular weight side after the addition of 1. Furthermore, the resulting polymer possessed a narrow distribution of molecular weight as shown in Figure 3. These analyses clearly indicate that the polymer consists primarily of an ABA-type triblock copolymer.

Similarly, ABA block copolymer could be prepared where A block was poly(1) and B block was poly(α-methylstyrene) or polyisoprene. The results are also listed in Table IV. The analyses by VPO, GPC, and ^{1}H NMR

Table IV
Block Copolymerization of 1 with Styrene, α-Methylstyrene, or Isoprene at −78 °C in THF with Oligo(α-methylstyryl)dipotassium

type of block copolymer	A monomer	B monomer	block copolymer[a] (homopolymer)[b] $\bar{M}_n$(calcd) × 10^{-4}	$\bar{M}_n$(obsd) × 10^{-4}
A–B–A	1	styrene	2.5 (1.1)	2.7 (1.1)
A–B–A	1	α-methylstyrene	4.1 (1.8)	4.9 (1.6)
A–B–A	1	isoprene	2.9 (1.6)	3.5 (2.2)

[a] Yields of polymers were 95–99%. Values of $\bar{M}_w/\bar{M}_n$ were 1.05–1.15. [b] Homopolymers were obtained at the first polymerization.

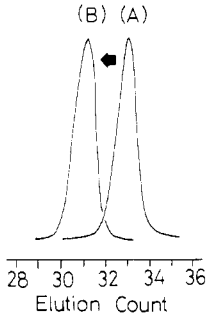

Figure 3. GPC curves for polystyrene (A) at the first polymerization and for poly(1-*block*-styrene-*block*-1): peak A, $\bar{M}_n$(obsd) = 1.1×10^4, $\bar{M}_w/\bar{M}_n = 1.09$; peak B, $\bar{M}_n$(obsd) = 2.7×10^4, $\bar{M}_w/\bar{M}_n = 1.12$.

were satisfactory in both cases. The conversion of poly(1) to the poly(4-vinylbenzoic acid) sequence in the block copolymers could successfully be achieved without detectable side reactions in a similar manner described in the hydrolysis of homopolymer of 1.

An attempt was made to synthesize triblock copolymer of BAB type by addition of α-methylstyrene to the polymeric dianion of 1, prepared from 1 and oligo(α-methylstyryl)dipotassium at −78 °C in THF. However, α-methylstyrene did not undergo polymerization with this polymeric anion. The resulting polymer was found not to include the poly(α-methylstyrene) unit by ^{1}H NMR analysis. The GPC peak of the polymer was virtually identical with that of the starting poly(1). Thus, the formation of the BAB triblock copolymer was unsuccessful by the sequential polymerization where 1 was polymerized first followed by the addition of α-methylstyrene as a second monomer. The result may possibly be explained by the low reactivity of 4-oxazolinyl substituted styryl anion presumably due to electron-withdrawing effect of the C=N bond of oxazoline group.

A similar phenomenon has been recently observed in the block copolymerization of *N*,*N*-diisopropyl-4-vinylbenzamide and α-methylstyrene. It was found that a 4-(*N*,*N*-diisopropylamido) substituted styryl anion, which was stabilized by an electron-withdrawing character of amido carbonyl group, did not initiate the polymerization of α-methylstyrene.[12] Königsberg and Jagur-Grodzinski also have reported that the poly(4-bromostyryl) anion has no ability to polymerize styrene due to the same effect as above.[13]

Monomers more reactive toward anionic polymerization than α-methylstyrene, such as vinylpyridine, methyl methacrylate, and ethylene oxide, would be expected to be polymerized by such a polymeric anion, although this has not been tested yet. Utilization of such a polymeric anion from 1 as a further initiator of polymerization would thus be limited. Further studies will be required to determine the limitations of this operating concept and will be published in the near future.

Experimental Section

Materials. 4-Vinylbenzoic acid was kindly supplied from Hokko Chemical Industry Co., Ltd. It was used without further purification. Styrene, α-methylstyrene, and isoprene were distilled over calcium hydride. THF was refluxed over sodium wire for 5 h and distilled from sodium naphthalenide solution. Naphthalene was purified by sublimation. Cumylpotassium was prepared by the reaction of cumyl methyl ether with potassium–sodium alloy in THF at room temperature for 10 h.[14] The reaction mixture was filtered and the bright red filtrate was colorimetrically titrated by using standardized 1-octanol to a colorless end point in a sealed reactor via break-seals. The oligo(α-methylstyryl)-dilithium, -disodium, and -dipotassium were freshly prepared just prior to polymerization from the corresponding metal naphthalenides and a 2–4 M quantity of α-methylstyrene at 30 °C and then at -78 °C for 10 min. The concentration of metal naphthalenide was determined by titration with standardized 1-octanol in a sealed reactor through break-seals under vacuum.

4-Vinylbenzoyl Chloride. To a mixture of 4-vinylbenzoic acid (18.0 g, 122 mmol) and 4-*tert*-butylpyrocatecol (10 mg), a portion of thionyl chloride (36 mL) was added dropwise under cooling. The reaction mixture was kept below 10 °C for 4 h and the gradually warmed to 40 °C for 1 h. After removal of unreacted thionyl chloride, distillation gave 18.2 g (110 mmol, 90%) of 4-vinylbenzoyl chloride as a colorless liquid at 90–91 °C (1 mmHg) (lit.[15] 69.5–70.0 °C (0.1 mmHg)): 60-MHz ^{1}H NMR (CCl_4) δ 8.08, 7.47 (4 H, 2d, J = 10 Hz, C_6H_4), 6.78 (1 H, 2d, CH=CH_2), 5.88, 5.44 (2 H, 2d, J = 17, 10 Hz, CH_2=CH).

2-(4-Vinylphenyl)-4,4-dimethyl-2-oxazoline (1). 1 was prepared according to the method previously well established by Meyers.[4] 4-Vinylbenzoyl chloride (7.6 g, 46 mmol) was dissolved in dichloromethane (25 mL) and added dropwise to a stirred solution of 2-amino-2-methyl-1-propanol (8.5 g, 96 mmol) in dichloromethane (20 mL) at 0 °C. The mixture was stirred at 25 °C for 2 h. The white precipitate was filtered and the filtrate was washed with water and dried over $MgSO_4$. After evaporation of dichloromethane, distillation gave a very viscous oil which was solidified by cooling. Almost pure *N*-(2,2-dimethyl-3-hydroxypropyl)-4-vinylbenzamide (10.0 g, 46 mmol, 100%) was used without further purification.

To cyclize the amide, thionyl chloride (16.5 g, 139 mmol) was added dropwise with stirring to the above benzamide (9.2 g, 42 mmol) at 0 °C. The mixture was stirred for 1 h at 0 °C. The resulting yellow solution was then poured into ether (100 mL). The yellow solid which crystallized on standing was collected and then neutralized with 20% NaOH and extracted with ether 3 times. The ether layer was dried over $MgSO_4$. Evaporation of the ether gave a pale yellow oil which was purified by distillation at 83–84 °C (1 mmHg) to give 6.0 g (30 mmol, 71%) of 1 as a colorless liquid. Further fractional distillation gave 1 with purity of more than 99.9%. It should be noted that a significant amount (20–40%) of 1 was always lost, probably due to the thermal polymerization during distillation: 60-MHz ^{1}H NMR (CCl_4) δ 8.00–7.33 (4 H, m, C_6H_4), 6.77 (1 H, 2d, CH=CH_2), 5.80, 5.30 (2 H, 2d, J = 17, 11 Hz, CH_2=CH), 4.03 (2 H, s, CH_2), 1.31 (6 H, s, CH_3); ^{13}C NMR δ 28.503 (CH_3), 67.590 (*C*N), 79.083 (CH_2), 115.459 (β-CH_2), 126.018 (Ar C2), 127.273 (Ar C4), 128.410 (Ar C3), 136.140 (α-CH), 140.166 (Ar C1), 161.752 (C=N).

In order to remove impurities in monomer 1, phenylmagnesium chloride (1.0 mL, 0.5 M THF solution) was added to 1 (5.0 g, 25 mmol) at 0 °C under nitrogen atmosphere. The mixture was stirred for 5 min and degassed. THF and 1 were then distilled on a vacuum line into ampules fitted with break-seals. Purified 1 in THF thus obtained was stored at −30 °C until used.

Polymerization Procedures. All the polymerizations were carried out at −78 °C with shaking under high-vacuum conditions ($\approx 10^{-6}$ mmHg) in an all-glass apparatus equipped with break-seals. The polymerizations were carried out for 30 min and were terminated with methanol. The polymers were precipitated by adding a large excess of water. They were redissolved in THF, precipitated into hexane 3 additional times, and freeze-dried.

Block copolymerization and the treatment of the resulting polymers were also performed in a similar manner as above.

Removal of the Oxazoline Protecting Group. The deprotection was carried out according to the method described in a previous paper.[2]

Methylation of Poly(4-vinylbenzoic acid). To a suspension of poly(4-vinylbenzoic acid) (0.103 g, 0.70 mmol based on monomer unit) and benzene (20 mL) was added 15.0 mL of diazomethane (0.2 M in ether)[16] at once at room temperature. The reaction mixture was stirring overnight at room temperature. After addition of acetic acid to decompose unreacted diazomethane, the mixture was poured into hexane, and the polymer precipitated was collected by filtration. The polymer was redissolved in THF, precipitated into hexane, and freeze-dried. The ^{1}H NMR spectrum of the resulting polymer indicates complete methylation of poly(4-vinylbenzoic acid).

Measurements. IR spectra were run with a Jasco IR-G spectrophotometer. ^{1}H NMR spectra (60 MHz) were recorded

with a JEOL JNM-PMX 60 instrument. ^{13}C NMR spectra (100 MHz) spectra were recorded with JEOL GX-400 instrument in $CDCl_3$. Gel permeation chromatograms were obtained with Toyo Soda HLC-802 instrument with UV or refractive index detection. THF was the carrier solvent at a flow rate of 1.4 mL min^{-1} and a temperature of 40 °C. Vapor pressure osmometry (VPO) measurements were made with a Corona 117 instrument with highly sensitive thermocouples and equipment of very precise temperature control. With this instrument, molecular weight up to 20×10^4 could be measured within analytical error of 10%. Intrinsic viscosities were obtained for all polymers in THF at 40 °C by using Ubbelohde-type viscometers.

Registry No. 1, 102920-03-6; 1 (homopolymer), 102920-04-7; (1)($C_6H_5CH{=}CH_2$) (block copolymer), 112220-23-2; (1)($C_6H_5C(CH_3){=}CH_2$) (block copolymer), 112220-24-3; (1)($H_2C{=}CHC(CH_3){=}CH_2$) (block copolymer), 112220-25-4; $C_6H_5C(CH_3){=}CH_2$, 98-83-9; 4-$H_2C{=}CHC_6H_4COCl$, 1565-41-9; 4-$H_2C{=}CHC_6H_4CO_2H$, 1075-49-6; $HOCH_2C(NH_2)(CH_3)_2$, 124-68-5; 4-$HOCH_2C(CH_3)_2CH_2NHC_6H_4CH{=}CH_2$, 112220-26-5; potassium naphthalenide, 4216-48-2; lithium naphthalenide, 7308-67-0; sodium naphthalenide, 3481-12-7; cumyl potassium, 3003-91-6.

References and Notes

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Cholesterol-Containing Polymeric Vesicles: Syntheses, Characterization, and Separation as a Solid Powder

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ABSTRACT: A cholesteryl amphiphilic methacrylate monomer, [[(cholesteryloxy)carbonyl]methyl][2-(methacryloyloxy)ethyl]dimethylammonium chloride (CHODAMA), was synthesized from cholesteryl chloroacetate by reacting it with 2-(dimethylamino)ethyl methacrylate, and a double alkyl chain amphiphilic methacrylate monomer, [[[[α,α'-(dihexadecyloxy)glyceryl]oxy]carbonyl]methyl][2-(methacryloyloxy)ethyl]-dimethylammonium chloride (HELDAMA), was synthesized from α,α'-(dihexadecyloxy)glycerol. The size of copolymeric vesicles prepared from CHODAMA and HELDAMA could be increased by increasing the mer content of HELDAMA in the copolymers. Poly(HELDAMA) vesicles were ruptured in 35% ethanol or by addition of surfactant Triton X-100 (0.5% aqueous solution). However, poly(CHODAMA) vesicles were found to be stable under those conditions. As the salt concentration in the vesicle-forming polymerization mixture was raised, larger vesicles resulted. The vesicles formed by homopolymers of CHODAMA were excessively stable and did not precipitate even in saturated KCl solution. When the poly(CHODAMA) vesicles prepared by polymerization in the 0.4% uranyl acetate solution were dialyzed and aged for 1 day at room temperature, the addition of acetic acid converted those vesicles to right-handed helical tubular structures which were supposed to be the result of successive fusion of vesicles. The leakage rate of entrapped [^{14}C]sucrose by poly(CHODAMA) vesicles was considerably lower than that exhibited by poly(HELDAMA) vesicles. Poly(HELDAMA) vesicles were ruptured thermally at 40 °C, whereas copolymeric vesicles containing 25% CHODAMA were stable up to 80 °C. Solid powder of poly(CHODAMA) vesicles entrapping [^{14}C]sucrose which was obtained by freeze-drying of the vesicle solution was redispersable into water and those redispersed vesicles were found to retain 90% of the [^{14}C]sucrose originally entrapped. The level of [^{14}C]sucrose-entrapping in the vesicles dropped to 43% after 4 months of standing at room temperature.

Recently, the effort to construct synthetic vesicle systems which can be employed as mimic biomembrane systems has become intense. This is based on the obvious expectation that a successful endeavor in vesicle science may lead to various applications of practical value.[1]

Formation of bilayer vesicles by a totally synthetic surfactant, didodecyldimethylammonium bromide, was first reported by T. Kunitake et al.[2] Vesicles could be formed by synthetic amphiphiles composed of one, two, or three alkyl chains (hydrocarbons or fluorocarbons) and polar head groups such as quaternary ammonium, carboxylate, sulfate, sulfonate, hydroxide, or phosphate ions.[3] The vesicles formed by synthetic dialkyl surfactant are thermodynamically unstable, undergoing successive fusion on standing. Thus, all the possible applications, especially those for which long-term stability is required such as drug carriers or models for biological membranes, become very limited. The need for increased stability and controllable permeabilities has led to the syntheses of polymeric surfactant vesicles. Regen and his co-workers reported the first syntheses of polymerized surfactant vesicles.[4] Ringsdorf's group also reported polymeric bilayer vesicles

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