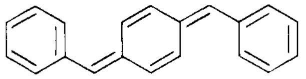
We have prepared I by the Wittig reaction on equivalent amounts of phenyllithium, 1,4-cyclohexanedione, and *p*-xylylenebis(triphenylphosphonium chloride) in *N*,*N*-dimethylformamide (DMF) for 5 days at a final temperature of 145 °C. The solid product (20% conversion) was filtered and washed with alcohol to give a lemon green, flaky solid, mp 265–267 °C. This product is slightly soluble in CS_2. It was purified by washing with methanol and extracting with CS_2 in a Soxhlet apparatus. The IR spectrum of this material showed peaks at 3050, 3080, 1600, 1515, 1450, 810, 745, and 685 cm^{-1} (KBr pellet). The ^{13}C NMR spectrum (CS_2) showed only four resonances: δ 126.561, 126.886, 127.591, 128.67 (Me_4Si); similarly, the ^1H NMR spectrum showed only two resonances: δ 6.99 (s, 1 H), 7.39 (m, 4 H). The UV spectrum (CS_2) showed λ_{max} 378.4 nm, log ϵ 3.896. Elemental analysis (calcd for $C_{14}H_{14}$ (II): C, 92.25; H, 7.72; found: C, 93.17; H, 6.71) suggests that dehydrogenation of the expected Wittig product II occurred to yield I (anal. calcd for $C_{14}H_{10}$ (I): C, 94.34; H, 5.66). We suggest that dehydrogenation of II to I was effected by triphenylphosphine oxide. This reaction should give triphenylphosphine and water; however, no triphenylphosphine could be isolated.

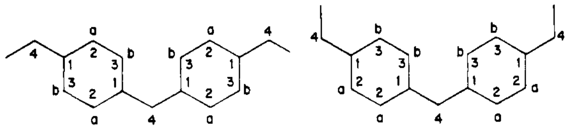
The elemental analysis totals 99.88% C and H; thus 0.12% of the product consists of other elements, probably carbonyl oxygen and triphenylphosphonium end groups. Assuming that the polymer contains either or both of these end groups, the 0.12% discrepancy in the C,H analysis suggests a $\overline{DP} > 70$. The end groups, especially triphenylphosphonium chloride, could also account for the difference between observed and calculated C,H analyses.

We believe I has a narrow melting point range (265–267 °C) because it has a narrow molecular weight distribution due to its precipitation from the reaction mixture as it reaches a molecular weight that renders it insoluble.

Compared to the ^1H NMR resonances of the model compound[12] shown below, the corresponding resonances of I suggest equivalence of the rings. Moreover, the all-trans form would exhibit greater splitting in the aromatic region than the all-cis form. The existence of four resonances in the ^{13}C NMR spectrum of I is also consistent with ring equivalence. In the formulas below letters refer to the different ring protons and numbers refer to the different carbons. Obviously ^{13}C NMR cannot distinguish between cis and trans isomerism.



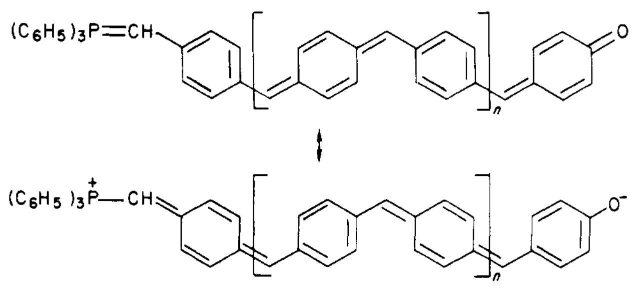
model compound



all trans all cis

The UV absorption λ_{max} of I at 378.4 nm is also consistent with a system of delocalized electrons when compared with λ_{max} of 295, 305, and 320 nm for the model compound.[12]

The equivalence of rings in I is consistent with the high $\overline{DP}$ suggested by elemental analysis. With long chains the effect of end groups in favoring one resonance form over the other is minimal especially with polar end groups:



The electrical conductivity of a crystal of I, measured with the four-probe apparatus described by Wnek,[13] was less than $10^{-7}\ \Omega^{-1}\ cm^{-1}$. Doping with I_2 vapor raised the conductivity to $6 \times 10^{-5}\ \Omega^{-1}\ cm^{-1}$.

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Highly Stable Unibilayer Vesicles Formed by Cationic Cholesterol-Containing Polymers

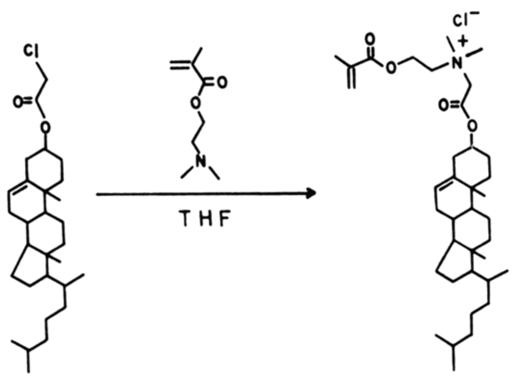
Recently, the effort to construct synthetic vesicle systems which can be employed as mimetic biological systems has become intense. This is founded on the obvious expectation that successful endeavor in vesicle science could lead to various practical applications.[1]

Formation of biomembrane-like bilayer vesicles from a totally synthetic didodecyldimethylammonium bromide was first reported by Kunitake et al.[2] However, synthetic dialkyl amphiphile vesicles are thermodynamically unstable and undergo fusion on standing. Thus, all possible applications based on their long-term stability such as drug carriers or models for biological membranes are limited. Recognizing the need for enhanced stability, Regen reported the first synthesis of polymerized surfactant vesicles.[3]

It is to be noted of these reported studies that synthetic bilayer vesicles are commonly prepared by sonication, while biomembrane vesicles undergo spontaneous formation of bilayer vesicles.[4-13] It is widely known that liposome membranes composed of dialkyl chain moieties become more stable when cholesterol is incorporated into the membranes.[14-16] It is commonly observed in natural plasma membranes that such membranes have high contents of incorporated cholesterol. We have focused our attention on this point and designed a polymeric amphiphile containing cholesterol, in the search for thermodynamically stable bilayer membranes.[17]

We have found a novel amphiphilic monomer which spontaneously forms stable polymeric unibilayer microvesicles in an aqueous system upon polymerizations and we now wish to report the preliminary results. These polymeric vesicles not only retain intrinsic bilayer characteristics but in addition always form spherical unibilayer microvesicles, as evidenced by electron micrographs and $[^{14}C]$ entrapments.

An amphiphilic cholesterol-based monomer, coded CHODAMA, was synthesized from cholesteryl chloroacetate by reacting it with 2-(dimethylamino)ethyl methacrylate as shown in the following synthetic scheme.



CHODAMA

The chemical structure of the ammonium salt of CHODAMA was confirmed by ^{1}H NMR.[18] CHODAMA is soluble in water and its aqueous solution is clear and viscous. The viscosity of a 0.5% aqueous CHODAMA solution was 370 cP as determined by a Brookfield viscometer (RVT type, spindle no. 1, 1 rpm). Also, a phase transition of CHODAMA was observed at 25 °C by differential scanning calorimetry.[19]

Many dialkyl amphiphilic surfactants, when dissolved in water without sonication, exhibit lamellar structures and/or vesicles. However, CHODAMA was observed as randomly clustered structures, as shown by electron micrographs (Figure 1a). Also the entrapment of $[^{14}C]$sucrose revealed the complete absence of any closed vesicles in their aqueous solutions.

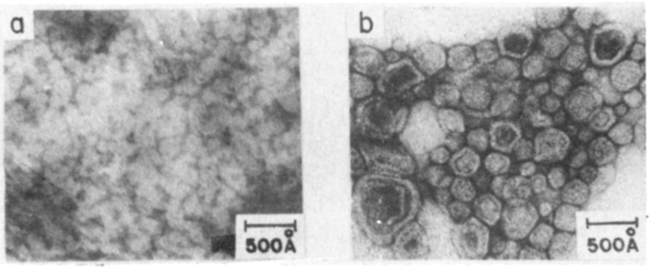


Figure 1. Electron micrographs of samples stained by 2% uranyl acetate solution: (a) 0.5% aqueous CHODAMA solution (× 65 000); (b) polymeric bilayer vesicles of CHODAMA initiated by $K_2S_2O_8$ (× 65 000).

Table I
Viscosity of Solutions of CHODAMA and Its Polymers

	polymn conditions			
sample	initn method	temp, °C	time, h	η_{rel}[a]
CHODAMA				4.36[b]
PV-1	$K_2S_2O_8$	90	24	1.03
PV-2	UV (254 nm)	25	1.5	2.30
PV-3	UN (254 nm)	25	3.0	1.83
PV-4	sonication[c]	30	12	1.26

[a] A Cannon-Fenske viscometer (size 100) was used. Solvent, water; concentration, 0.5 wt. % (8 mmol/L). [b] 370 cP (Brookfield viscometer RTV type, spindle no. 1, 1 rpm). [c] Branson bath-type sonicator B-52 (sonic power, 240 W).

CHODAMA was polymerized in water either by free radical initiators or by UV irradiation. In spite of its bulkiness, the monomer was polymerized readily in water, suggesting the alignment of monomer molecules in an aqueous phase. It was interesting to observe that as the polymerization took place, the viscosity of solution decreased rather than increased (Table I). This anomalous change in viscosity during polymerization was attributed to an accompanying phase change. We believe that, as evidenced in electron micrographs, the lyotropic liquid-crystalline CHODAMA changes to polymeric microvesicles; the formation of microvesicles could be considered as a phase separation at the molecular level, thus exhibiting decreased viscosity.

Cholesterol-containing polymeric bilayer vesicles were prepared by stirring 0.05 g (0.08 mM) of CHODAMA and 1 mg of water-soluble free radical initiator (potassium persulfate) in 10 mL of distilled water at 70 °C for 12 h. After polymerization, the solution, which showed slight turbidity, was chromatographed through a Sephadex G-50-80 column with distilled water as eluent to sieve the vesicles.

An electron micrograph of this sample recorded on an JEOL JEM-100CX microscope confirmed the presence of closed spherical vesicles having diameters ranging between 200 and 500 Å (Figure 1b). Further evidence for closed vesicles comes from the entrapment of $[^{14}C]$sucrose. A representative entrapment experiment is as follows: After polymeric vesicle formation by stirring 1 mL of 0.5% aqueous CHODAMA solution containing 1 μCi of $[^{14}C]$-sucrose and 0.1 mg of potassium persulfate ($K_2S_2O_8$), unentrapped sucrose was removed by gel filtration on Sephadex G-50-80. Fractions (1.25 mL) were eluted every 1.5 min. The activity determination of the recovered vesicle-containing solution indicated that approximately 0.2% of the sucrose was entrapped.[20] These results clearly demonstrate that polymerization induces the spontaneous formation of well-developed unibilayer vesicles by the cholesterol-containing amphiphilic monomer.

Polymeric CHODAMA vesicles were stable for at least several months. Copolymerization with acrylamide enhanced the stability of polymeric CHODAMA vesicles even more. We have also observed that vesicles of poly(CHODAMA) are highly stable thermally, showing no notable change even when heated to 90 °C.

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Detailed characterization and morphological studies of these and other related vesicles are now in progress. Our interests are also directed to vesicle formation by copolymers with dialkyl amphiphilic monomers, thereby enabling one to control the thermal stability of vesicles.

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(18) ^{1}H NMR ($CDCl_3$): δ 6.12 (m, 1 H, vinyl), 5.63 (m, 1 H, vinyl), 5.19 (m, 1 H, $CH_2CH{=}C$), 4.96 (s, 2 H, $OCOCH_2{}^+N$), 4.63 (t, 2 H, OCH_2), 4.46 (t, 2 H, $CH_2{}^+N$), 4.7–4.3 (br m, 1 H, OCH), 3.76 (s, 6 H, $(CH_3)_2{}^+N$), 1.95 (s, 3 H, CH_3C), 2.5–0.65 (br m, 43 H, cholesterol).
(19) Du Pont Model 910 differential scanning calorimeter: concentration, 2% in water; heating rate, 5 °C/min.
(20) Beckman Model LS-3133T scintillation spectrometer: cocktail solution, 10 mL.

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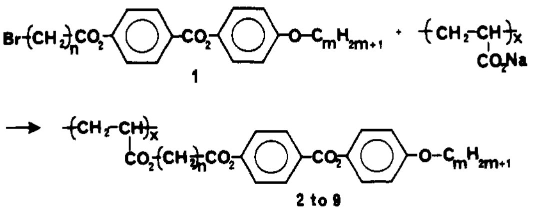
Synthesis of Liquid Crystalline Side-Chain Polyacrylates via Phase-Transfer Catalysis

Thermotropic liquid crystalline polymers, which have been the subject of intensive scientific and technological research,[1–6] are classified in two categories: "main-chain" and "side-chain" polymers. In the first, the liquid crystalline character is a property of the chain backbone; i.e., the mesogenic groups are linked to form the macromolecular chain. In the side-chain liquid crystalline polymers, with which this work deals, low molar mass mesogenic groups are linked to the polymeric chain as side chain directly or via flexible spacers.

Scheme I



Liquid crystalline side-chain polymers can be prepared by two general processes.[6] The most conventional method is to introduce into a mesogenic molecule a reactive group capable of undergoing addition polymerization. Generally, the polymerizable group is a methacrylate[7,8] or an acrylate[8], which form a flexible vinyl backbone after radical polymerization. The second possibility starts with "reactive polymers" which can be modified to mesogenic side-chain polymers by using suitable reactive mesogenic monomers. An example is the addition of vinyl-substituted mesogenic monomers to poly(hydrogenmethylsiloxane) to form mesogenic polysiloxane.[9,10] This synthetic method has some advantages, one being that known polymers are used as starting materials for liquid crystalline polymer synthesis. This could permit unambiguous studies on the effect of the chemical structure of the mesogenic moiety on the liquid crystalline properties of the polymers. However, analogous reactions involving polymers other than polysiloxanes, have not been extensively investigated.[11,12]

We describe here a new synthesis of mesomorphic polyacrylates resulting from the reaction of sodium polyacrylates on mesogenic ω-bromoalkyl esters (1) under phase-transfer conditions.

Results and Discussion. The synthesis of mesomorphic polyacrylates (Scheme I) is achieved by displacement of bromide ion from ω-bromoalkyl esters 1 with sodium polyacrylates under phase-transfer conditions. Formally, this substitution reaction is similar to the well-known displacement of bromide ion by acetate anion[13] (or methacrylate–acrylate anions[14]) under phase-transfer conditions.

The required ω-bromoalkyl esters 1 are prepared by direct esterification of (alkyloxy)phenyl 4-hydroxybenzoates[15] with ω-bromoalkanoic acids using the convenient procedure of Hassner and Alexanian.[16]

The sodium polyacrylate solutions are obtained by neutralization with sodium hydroxide of poly(acrylic acid) samples of commercial sources, with two different average molecular weights ($\overline{MW}$ = 2000; $\overline{MW}$ = 5000) (see experimental part).

The ω-bromoalkyl esters 1 are heated under reflux in water–chloroform solvent with sodium polyacrylates and tetrabutylammonium bromide as phase-transfer reagent. Mesomorphic polyacrylates are isolated from chloroform solutions by precipitation with diethyl ether and methanol as nonsolvents (see experimental part).

The melting and transition points for the prepared ω-bromoalkyl esters (1) and the mesomorphic polyacrylates (2–9) are listed in Tables I–III. Identification of the mesophases has been done by examination of the textures exhibited by thin samples sandwiched between two glass slides.

From the data given in Tables II and III, it can be seen that the mesomorphism of the polyacrylates is strongly influenced by the structure of the mesogenic side chain. Polymers with mesogenic groups bearing a short terminal chain (m = 1; polymers **2**, **3**, **6**, and **7**) exhibit only a nematic phase whatever the molecular weight of the poly-

0024-9297/84/2217-2937$01.50/0