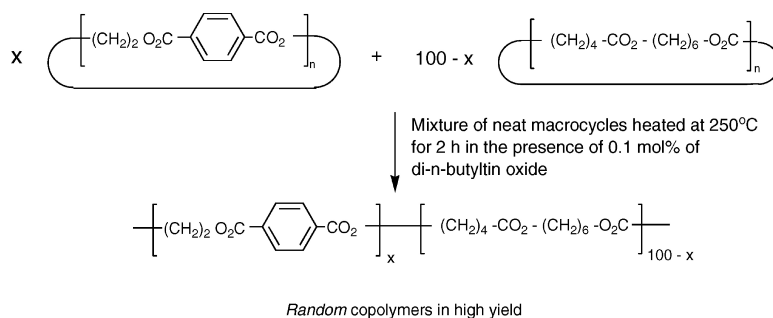


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# High Throughput Synthesis of Polyesters Using Entropically Driven Ring-Opening Polymerizations

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Copolyesters were synthesized in a high throughput (HT) manner and in high yield on ca. a 90 mg scale using entropically driven ring-opening polymerizations (ED-ROPs). This synthetic approach is a valuable addition to the HT polymer synthesis arsenal in that it allows condensation-type polymers with relatively large repeat units, such as those in poly(ethylene terephthalate) and poly(butylene terephthalate), to be obtained easily. The synthetic procedure involved taking mixtures of the appropriate macrocyclic oligoesters and heating them together under neat conditions at 250–300 °C for 2 h in the presence of 0.1 mol % of di-*n*-butyltin oxide or tetra-*n*-butylammonium tetrafluoroborate. In most cases Mw values were >25 000 and, as expected for ED-ROPs, the polydispersity indices were close to 2.0. Higher molecular weights could be obtained by using longer reaction times, but this might lead to product decomposition. The method worked well for esters formally derived from aliphatic or aromatic acids and alcohols, but less well for esters derived from phenols. Attempts were also made to synthesize copolymers by mixing together the two homopolymers and heating with a catalyst. These reactions were successful in a few instances, but generally, they were not. This is probably because the homopolymers did not mix well. An aluminum reaction block with 36 wells lined with Teflon cups, that fitted snugly in a cylindrical Büchi oven, was the most successful method for carrying out syntheses in an HT manner.

## Introduction

High throughput (HT) methods have been applied extensively to problems in peptide and protein chemistry<sup>1</sup> and in the search for new pharmaceuticals.<sup>2</sup> Such methods are now being applied increasingly in materials research,<sup>3</sup> including polymer research.<sup>4–7</sup> Projects using HT methods typically involve four stages: HT synthesis, HT characterization, HT screening for the property or properties of particular interest, and then the processing and analysis of the data so obtained. Often, given the information gained from the first cycle, a second more focused cycle is carried out.

So far the use of HT methods in polymer synthesis has focused heavily on vinyl polymerizations. For example, in a study of transfection, a library of 124 polyacrylates was prepared using free radical polymerizations.<sup>8</sup> HT methods have been used to optimize RAFT (reversible addition fragmentation chain transfer) free radical polymerizations of acrylates and methacrylates,<sup>9</sup> anionic polymerizations of styrenes,<sup>10</sup> macroinitiators for nitroxide-mediated polymerizations,<sup>11</sup> and chromium-based catalysts for ethylene oligomerization and polymerization.<sup>12</sup> *Enthalpically*-driven ring-opening polymerizations (ROPs) have also been studied using HT methods. Examples include the ROPs of lactides,

lactones,<sup>13</sup> and oxazolines<sup>14</sup> and the optimization of zinc-based and lanthanide-based catalysts for ROPs.<sup>15,16</sup>

While chain-growth polymerization methods, such as those above, can often be adapted relatively easily to an HT approach, step-growth methods are usually less easily adapted and accordingly fewer examples have been reported. One based on *addition* polymerization involved the synthesis of a library of 140 polymers by the Michael addition of *primary*- or *secondary*-amines to bis-acrylates.<sup>17</sup> Three based on *condensation* have been described. One involves the synthesis of a library of 112 polyarylates by the reaction of bis-phenols with diacids in the presence of diisopropylcarbodiimide, 4-dimethylaminopyridine, and *p*-toluenesulfonic acid,<sup>18</sup> and one, the use of lipases to synthesize rather limited polyester libraries,<sup>19</sup> while the other involves the synthesis of a library of 96 poly(arylene ethynylene)s by the condensation of various aromatic dibromides with aromatic diacetylenes in the presence of palladium-based catalysts.<sup>20</sup>

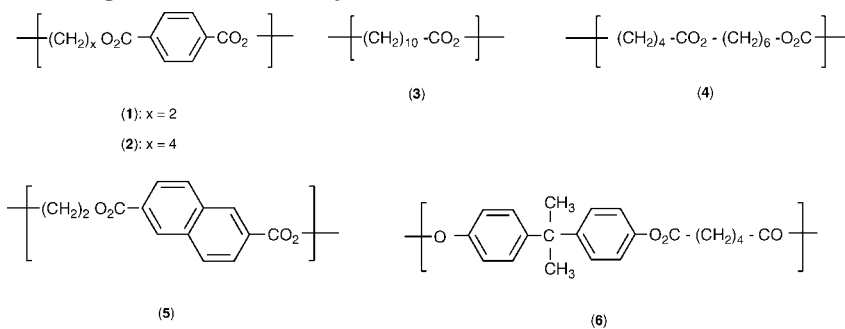
Adaption of the most important type of *condensation* polymerizations, such as those of polyesters like poly(ethylene terephthalate) (**1**) (PET) and poly(butylenes terephthalate) (**2**), to an HT approach can pose many problems (see Chart 1). For example a typical synthesis of PET (**1**) from dimethyl terephthalate and ethylene glycol requires a reaction time of several hours, a reaction temperature of 222 °C rising to 283 °C, the continuous removal of methanol and/or excess glycol under reduced pressure (0.3 mm of Hg), much of the time combined with thorough agitation of an

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Chart 1. Polymers Used as Starting Materials in This Project



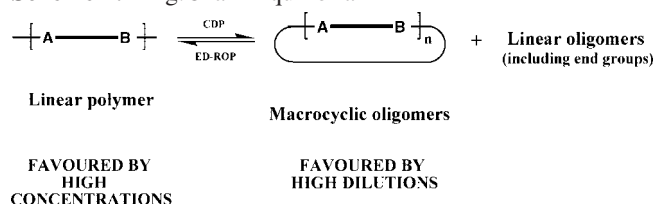
increasingly viscous reaction mixture.<sup>21</sup> Moreover, normally when two monomers are involved, it is vital to maintain very accurately the stoichiometric balance between them. To add to these problems the HT syntheses will often need to be carried out on just a small scale to give, say, 100 mg of product.

Copolymers are of considerable interest because while many of their properties are often similar to those of the corresponding homopolymers, they can also be significantly different. Thus, there is an opportunity to tune or optimize the properties of particular interest, for example, the melting point, the solubility, or the crystallinity. When copolymers are prepared using two types of repeat unit, the latter can come in an infinite number of different sequences, the extremes being block copolymers and alternating copolymers. Random copolymers are another type of copolymer. They have the repeat units randomly distributed and as they are usually the final end point of equilibrating systems they can be prepared reproducibly.

This paper focuses on the HT syntheses of libraries of random copolyesters. It is mainly concerned with the synthesis stage. HT methods for characterization, some successful screens, and data analysis have been reviewed recently.<sup>4–7,22</sup> Our synthetic approach exploits entropically-driven ring-opening polymerizations (ED-ROPs)<sup>11,12</sup> and is a valuable addition to the HT polymer synthesis arsenal in that it allows condensation-type polymers with relatively large repeat units, such as those in polymers **1** and **2**, to be obtained easily. The general approach has the potential to be used also for the HT polymer synthesis of polycarbonates, polyamides, polyurethanes, a wide range of high performance aromatic polymers, and olefin-containing polyesters and amides because all of these types of polymers have been prepared successfully by ED-ROPs.<sup>23–25</sup>

ED-ROPs exploit the well-known ring:chain equilibria (RCE) that, in the presence of a catalyst that promotes rapid cleavage and reformation of the linkages between the repeat units, exist between an homologous family of macrocyclic oligomers (MCOs) and the corresponding condensation polymer: see Scheme 1.<sup>23–27</sup> A useful feature of RCEs is that the position of the equilibria are very sensitive to the concentration. Thus, at high concentration they lie heavily in favor of the polymer while at high dilution they lie heavily in favor of the MCOs. Typically under *neat* conditions at equilibrium there is ca. 98% polymer and ca. 2% MCOs. Accordingly, *if a mixture of MCOs, or one pure MCO, is taken either neat or at high concentration and the equilibria*

*established polymer synthesis occurs in high yield.* As it is an equilibration process, the polydispersity index (PDI) of the polymeric product is ca. 2.0 and the crude reaction product contains ca. 2% of MCOs. The MCOs are usually much more soluble than the corresponding polymer and can usually be removed simply by reprecipitation. A feature of ED-ROPs is that since the repeat units are added to the chain several at a time, for example, if a cyclic tetramer is added the polymer chain grows by four units of one type as a result of just one reaction, the initial polymer will be blocky. This is especially the case if the chain happens to grow by the sequential addition of more than one MCO from the same family. As the system progresses further to full equilibration, the initial blocky polymer will be transformed gradually into a random copolymer. The results presented below provide evidence for these two stages of polymer synthesis.

Scheme 1. Ring:Chain Equilibria<sup>a</sup>

<sup>a</sup> ED-ROP = entropically-driven ring-opening polymerization; CDP = cyclo-depolymerization.

ED-ROPs have several features which make them attractive for adaption to an HT approach.

- (i) They are easily carried out on a small scale.
- (ii) In general, little or no solvent is needed.
- (iii) No small molecules are eliminated, so it is not necessary to carry out reactions under a vacuum.
- (iv) Stirring is not usually essential.
- (iv) Precise stoichiometry is achieved automatically because within each MCO there is a perfect balance of repeat units.

An important requirement for successful ED-ROPs is to keep molecular mobility in the system throughout the polymerization, especially in the later stages of the reaction. This allows full equilibration to be achieved. Molecular mobility is maintained by carrying out the polymerization at temperatures  $>T_g$  and, in the case of semicrystalline polymers, temperatures  $>T_m$  of the final polymer.

It might appear that a simple alternative HT approach to copolyesters is simply to mix the two homopolyesters or a concentrated solution of the two polymers and react them

Chart 2. Macroyclic Oligomers Prepared and Used in This Project

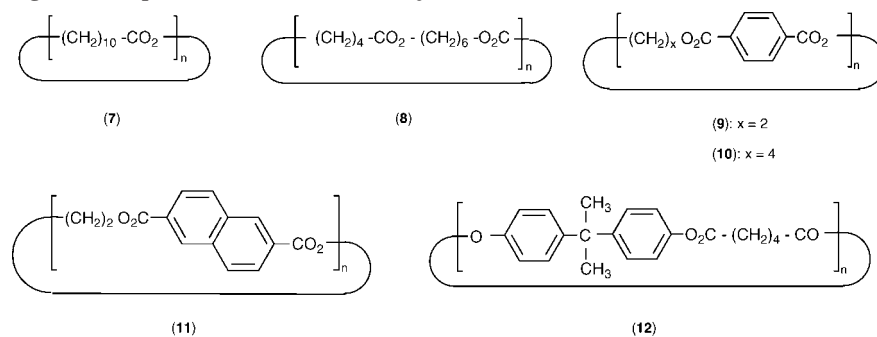


Table 1. Properties of Homopolyesters 1–6 and Derived Families of Macrocyclic Oligomers 7–12

entry	polymer	Mw <sup>a</sup> (× 10 <sup>-3</sup> )	PDI <sup>a</sup>	intrinsic viscosity (dL/g)	derived MCOs	yield (%)	composition of MCOs <sup>a</sup>					ref <sup>b</sup>
							C1	C2	C3	C4	>C5	
1	<b>3</b>	25.6	1.8		<b>7</b>	96	2	39	21	13	25	28
2	<b>4</b>	15.4	2.1		<b>8</b>	80	0	47	27	11	15	
3	<b>1</b>			0.64 <sup>c</sup>	<b>9</b>	72	0	0	79	5	16	29, 30
4	<b>2</b>			1.10 <sup>d</sup>	<b>10</b>	73	0	32	36	18	14	31
5	<b>5</b>			0.56 <sup>e</sup>	<b>11</b>	93	0	2	68	14	26	30
6	<b>6</b>	30.8	2.6		<b>12</b>	46 <sup>f</sup>	0	46	14	13	27	

<sup>a</sup> Determined by SEC. C1 = cyclic monomer, C2 = cyclic dimer, etc. <sup>b</sup> Reference is to the CDP procedure. <sup>c</sup> Determined using an Ubbelohde viscometer. Solvent was TFA at 25 °C. Using literature constants, Mv = 14 500.<sup>37</sup> <sup>d</sup> Determined using an Ubbelohde viscometer. Solvent was in 60/40 w/w phenol/*sym*-tetra-chloroethane at 25 °C. Using literature constants, Mv = 36 700.<sup>37</sup> <sup>e</sup> Determined at a single concentration (0.1%) in concentrated sulfuric acid at 20 °C. Using literature constants, Mv = 30 100.<sup>37</sup> <sup>f</sup> Achieved using lithium phenoxide (3 mol %) as the catalyst.

together in the presence of a suitable catalyst. A problem here, however, as the present work demonstrates, is that the homopolymers do not always mix well, whether neat or in concentrated solution, and so, they may react together very slowly. Also if reaction is incomplete, there is the problem of separating the desired polymer from any unreacted homopolymers, a much more difficult task than separating MCOs from polymers.

## Results and Discussion

The present project involves synthesizing a range of MCOs, developing the use of pairs of these in ED-ROPs to successfully give copolyesters and, finally, characterizing the copolyesters. Each of these areas will be discussed in turn.

**Preparation of macrocyclic oligomers.** For the present HT syntheses to be useful the appropriate MCOs need to be readily available. Synthesis of MCOs can be achieved easily using RCE. Thus, if the RCE are established starting with a *dilute* solution of the condensation polymer, the corresponding family of MCOs is formed in high yield.<sup>23–25</sup> This process is called cyclo-depolymerization (CDP); see Scheme 1. In the present project this method was used to convert polymers **1–6**, see Chart 1, into MCOs **7–12**, see Chart 2. In several cases, CDPs described in the literature were repeated:<sup>28–31</sup> in other cases, analogous CDPs were carried out. Table 1 lists the molecular weight data for the polymers used for the CDPs and, for other experiments described below, summarizes the various CDP reactions and gives the proportions of the MCOs obtained in each homologous family. It should be noted that using a family of MCOs for ED-ROPs can be advantageous in that the mixture often has a lower melting point than one pure cyclic oligomer.<sup>23,24</sup> The alternative method of synthesis is a classical high dilution ring-closing reaction, but in this approach there are many end groups present and consequently potentially

significant amounts of linear species. Accordingly, the products of such syntheses generally require very careful purification to remove linear products. Contamination with the latter is serious since their presence will dramatically lower the molecular weights that can be obtained from subsequent ED-ROPs.

**Selection of Initial Polymerization Procedure.** Prior to carrying out the HT polymer syntheses, reaction conditions were selected that it was anticipated could be used successfully in most cases. Previous work has shown that di-*n*-butyltin oxide is an excellent catalyst for ED-ROPs and CDPs of esters, especially nonphenolic esters, so in the present work, this catalyst was chosen for reactions involving only nonphenolic esters.<sup>23,24,28</sup> Tetra-*n*-butylammonium tetrafluoroborate has proved to be a better catalyst for phenolic esters,<sup>32</sup> though nonphenolic esters do react, so this catalyst was used for copolymerisations involving phenolic esters.<sup>33</sup> Previous polyester syntheses using ED-ROPs suggest that treatment of the *neat* MCOs with 0.1 mol % of catalyst at 250 °C for 2 h would achieve equilibration successfully. Accordingly these conditions were *initially* adopted as standard, though it was recognized that sometimes temperatures as high as 300 °C would be needed. Only a small amount of catalyst was used, so that contamination of the final product is minimized.

A commercially available reaction block suitable for synthesizing polymers under the above reaction conditions was not available. Furthermore, most commercially available temperature-controlled ovens cannot operate both in the range 280–300 °C and under vacuum. Accordingly reactions were initially carried out on an 80–100 mg scale in small glass vials (10 mm diameter, 30 mm long), and the vials were mounted in 2 mm deep recesses in an aluminum block that was heated in a small cylindrical Büchi oven. The reactants were heated under a partial atmosphere of dry nitrogen. The



block was specially shaped to fit snugly into the oven. This approach allowed 10 reactions to be carried out at once. In later work, see below, this number was significantly increased. The reaction products were analyzed by size exclusion chromatography (SEC) and  $^1\text{H}$  NMR spectroscopy, in both cases taking advantage of automated sample loading techniques and, in the case of SEC, rapid throughput columns. Initially, the polymeric products were not precipitated as it was of interest to determine, by SEC, whether small amounts of MCOs were present, as expected for RCEs, and whether the theoretical polydispersities were obtained.

In selected cases, the copolymers were also analyzed by  $^{13}\text{C}$  NMR spectroscopy to determine whether the repeat units were random. Copolymers were deemed random if the obtained dyad sequence distributions match well with those calculated from monomer mole fractions using Bernoullian expressions, i.e. they conform to Bernoullian statistics.<sup>34</sup> In the present study if the measured and calculated values differed by more than  $\pm 3\%$ , the copolymers were deemed not to be random. Selected data from these studies are given in the Supporting Information.

In a few selected cases, see Tables 3–7, ED-ROPs were also carried out in differential scanning calorimetry (DSC) sample pans in a DSC instrument. This approach is particularly useful if the thermal properties of the polymeric products are of interest. Thus, ED-ROPs can be carried out by raising the temperature of the sample in the pan to an appropriate level. After a suitable reaction time the sample is thermally scanned to determine whether the starting MCOs have reacted and whether polymer is present. Once polymer is formed in high yield its thermal properties can be measured. This approach can be used in an HT manner if the DSC instrument is programmable and has automated sample loading.

**HT Synthesis of Various Copolyesters.** The polyesters selected for the present study can be divided into four types. Those with ester links formally derived from an aliphatic acid and an alcohol; those from an aromatic acid and an alcohol; those from an aliphatic acid and a phenol; and those derived from an aromatic acid and a phenol. The six families of copolymers prepared in the work described below involve various combinations of these types. As there are significant differences to note between the different combinations, to simplify the discussion the results for each of them are discussed separately.

**(i) Copolymers of Polyundecanoate (3) and Poly(Hexamethylene Adipate) (4).** The first copolyesters selected for study were those prepared from cyclic oligoundecanoates (**7**) and cyclic oligo(hexamethylene adipate)s (**8**). These particular copolymers were chosen because both the MCOs and the polymers are readily soluble in tetrahydrofuran (THF), and so, the reactions can be monitored easily by SEC. The two homopolymers and a range of 7 different copolymers were prepared by heating cyclic oligomers **7** and/or **8** in the appropriate proportions under the standard reaction conditions with di-*n*-butyltin oxide as the catalyst: see Table 2, entries 1–9. The products were white solids. By SEC, the mass distributions in all cases were unimodal and, except in one case, they consisted of  $>97\%$  polymer, with  $<3\%$

MCOs. This suggests that equilibration had been achieved successfully. The Mw values were  $>20\,200$  with polydispersities in the range 1.8–2.0. Analysis of the  $^{13}\text{C}$  NMR spectra of the products described in entries 4–7 indicated, based on the relative intensities of the signals in the  $-\text{CH}_2\text{O}-$  region, that the products were random copolymers. Thus, it is possible to rapidly prepare many random copolymers of these two soft polymers by ED-ROP.

To check that a reaction time of 2 h was satisfactory, syntheses of the 25/75 and 75/25 copolymers were carried out similarly but with reaction times of 30 min and 6 h: see Table 2, entries 10–13. It is evident from the results that the Mws increase steadily with time. Thus, for the 25/75 copolymer the Mws for reaction times of 30 min, 2 h, and 6 h were 19 300, 23 400, and 32 300, respectively, while for the 75/25 copolymer they were 20 000, 21 000, and 28 400. The increase in Mw between 2 and 6 h was, however, not considered to be sufficiently large to justify exposing the products to the high reaction temperatures for so much longer. By  $^{13}\text{C}$  NMR spectroscopy all these products had random sequences.

An alternative route to the copolymers is to take an appropriate mixture of the homopolymers **3** and **4** plus catalyst and heat them together. This was investigated for the 25/75 and 75/25 copolymers using a reaction time of 2 h: see Table 2, entries 14 and 15. The copolymers obtained had very similar properties to those obtained from the MCOs and were random but, as will be reported below, this is not always the case with other copolymers. The present pair of homopolymers have very similar structures and this no doubt helps them to mix well so facilitating transesterifications between the different chains. In further experiments attempts were made to synthesize the 25/75 and 75/25 copolymers by reacting the homopolymers together for just 30 min: see Table 2, entries 16 and 17. By  $^{13}\text{C}$  NMR spectroscopy the copolymer repeat unit sequences of these products were *not* random, although, as discussed above, they were after 2 h. This indicates that the random distribution of repeat units is approached faster by copolymerization of the MCOs than by direct transesterification of the homopolymers.

**(ii) Copolymers of Poly(Hexamethylene Adipate) (4) and Poly(Ethylene Terephthalate) (1).** Attention was next turned to copolymers of poly(hexamethylene adipate) (**4**) and poly(ethylene terephthalate) (**1**) formed from MCOs **8** and **9**. The two homopolymers and a range of 7 different copolymers were prepared and analyzed as before: see Table 3. The products were pale brown in color. SEC analyses were possible in most cases; see entries 1–7. They indicated that the products were  $>97.5\%$  polymer, the remainder being MCOs. The mass distributions of these polymers were unimodal, with Mw values  $>23\,000$  and polydispersities in the range 1.8–2.0. In the other two cases, the pure poly(ethylene terephthalate) (**1**) and the 90/10 copolymer (see entries 9 and 8, respectively), the products were too insoluble in THF for analysis by SEC, so molecular weights were estimated by intrinsic viscosity measurements in trifluoroacetic acid (TFA) at 25 °C. The Mvs were 8600 and 7400, respectively. Analysis by  $^{13}\text{C}$  NMR spectroscopy of the copolymers in entries 3–7 showed, based on the intensities

**Table 2.** Synthesis of Polyundecanoate (**3**), Poly(Hexamethylene Adipate) (**4**), and Copolymers<sup>a</sup>

entry	feed composition of MCOs (mol %)		reaction time (h)	percentage of polymer in product <sup>b</sup>	repeat unit composition of polymeric product <sup>c</sup> (mol %)		molecular weight <sup>d</sup> (Mw × 10 <sup>-3</sup> )	PDI (Mw/Mn)	Tm <sup>e</sup> (°C)
	MCOs <b>7</b>	MCOs <b>8</b>			RU <b>3</b>	RU <b>4</b>			
1	0	100	2	95.7	0	100	28.3	1.9	59
2	10	90	2	97.2	8	92	22.2	2.0	58
3	25	75	2	98.2	24	76	23.4	2.0	54
4	35	65	2	96.6	36	64	22.5	1.8	55
5	50	50	2	98.7	51	49	20.2	2.0	59
6	65	35	2	90.0	65	35	20.4	1.8	65
7	75	25	2	98.0	75	25	21.0	1.9	71
8	90	10	2	98.5	91	9	22.5	1.9	79
9	100	0	2	97.8	100	0	27.7	1.9	87
10	25	75	0.5	98.3	25	75	19.3	1.9	
11	25	75	6	98.0	26	74	32.3	2.1	
12	75	25	0.5	98.0	75	25	20.0	2.1	
13	75	25	6	94.2	75	25	28.4	1.9	
14 <sup>f</sup>	25	75	2	98.2	24	76	15.8	1.9	
15 <sup>f</sup>	75	25	2	98.5	74	26	5.9	1.9	71
16 <sup>f</sup>	25	75	0.5	98.0	24	76	15.6	2.1	54
17 <sup>f</sup>	75	25	0.5	98.4	74	26	24.6	2.0	

<sup>a</sup> Unless indicated otherwise, polymerizations were carried out at 250 °C under a nitrogen atmosphere with 0.1 mol % of di-*n*-butyltin oxide as the catalyst. <sup>b</sup> By SEC analysis: the remainder is MCOs. <sup>c</sup> Measured by <sup>1</sup>H NMR spectroscopy. <sup>d</sup> By SEC analysis: relative to polystyrene standards. <sup>e</sup> By DSC under a nitrogen atmosphere at a heating rate of 10 °C/min. <sup>f</sup> Homopolymers mixed and heated under the same reaction conditions as in footnote a.

**Table 3.** Synthesis of Poly(Ethylene Terephthalate) (**1**), Poly(Hexamethylene Adipate) (**4**), and Copolymers<sup>a</sup>

entry	feed composition of MCOs (mol %)		percentage of polymer in product <sup>b</sup>	repeat unit composition of polymeric product <sup>c</sup> (mol %)		molecular weight <sup>d</sup> (Mw × 10 <sup>-3</sup> )	PDI <sup>d</sup> (Mw/Mn)
	MCOs <b>9</b>	MCOs <b>8</b>		RU <b>1</b>	RU <b>3</b>		
1	0	100	95.7	0	100	28.3	1.9
2	10	90	97.5	10	90	25.4	2.0
3	25	75	97.8	24	76	26.2	2.0
4	35	65	97.5	38	62	28.0	1.8
5 <sup>e</sup>	50	50	97.9	51	49	23.0	2.0
6	65	35	98.1	65	35	26.8	2.0
7	75	25	98.3	76	24	23.3	2.0
8	90	10		89	11	7.4 <sup>f</sup>	
9	100	0		100	0	8.6 <sup>f</sup>	

<sup>a</sup> Unless indicated otherwise, polymerizations were carried out at 250 °C under a nitrogen atmosphere for 2 h with 0.1 mol % of di-*n*-butyltin oxide as the catalyst. <sup>b</sup> By SEC analysis: the rest is MCOs. <sup>c</sup> Measured by <sup>1</sup>H NMR spectroscopy. <sup>d</sup> Mw and PDI by SEC analysis, relative to polystyrene standards. <sup>e</sup> A similar reaction was carried out in a DSC capsule at 250 °C under a nitrogen atmosphere. This used 0.1 mol % of di-*n*-butyltin oxide catalyst and a reaction time of 1.5 h. The product consisted of 98.5% polymer, had the two types of repeat unit in the ratio 50:50, a Mw of 25 000, and a polydispersity of 2.1. <sup>f</sup> Viscosity average molecular weights (Mv × 10<sup>-3</sup>) estimated by viscosity measurements of the products in TFA at 25 °C.<sup>37</sup>

of signals in the —CH<sub>2</sub>O— region, that the products were random copolymers. Thus, ED-ROP can also be used successfully to prepare random copolymers of poly(hexamethylene adipate) (**4**) and poly(ethylene terephthalate) (**1**).

**(iii) Copolymers of Poly(Ethylene Terephthalate) (**1**) and Poly(Butylene Terephthalate) (**2**).** Copolymers of poly(ethylene terephthalate) (**1**) and poly(butylene terephthalate) (**2**) have been prepared before by Brunelle et al. but all except one of the syntheses involved ROP of cyclic *co-oligomers* rather than the physically mixed cyclic homooligomers **9** and **10**.<sup>35</sup> In the present work, a range of copolymers was prepared from MCOs **9** and **10**, but a reaction temperature of 300 °C was used in order to exceed the Tm of poly(ethylene terephthalate) (**1**): see Table 4. The products were cream colored solids. The insolubility of the products in THF precluded SEC analyses so intrinsic viscosities were determined for solutions in TFA at 25 °C. All were in the range 0.37–0.84, indicating significant molecular weights. The <sup>1</sup>H NMR spectra confirmed that the products had essentially the same composition as the feed. The Tm values, determined by DCS, fell from those of the

homopolymers to a minimum at the 50/50 copolymer. Even without precipitation of the polymers the values agree well with those reported recently in the literature for random copolymers.<sup>36</sup> <sup>13</sup>C NMR spectroscopy, based on signal intensities in the carbonyl region, showed that the 25/75 and 75/25 copolymers were random. Thus, ED-ROPs can also be used successfully to prepare random copolymers of poly(ethylene terephthalate) (**1**) and poly(butylene terephthalate) (**2**).

Copolymers were also prepared by treating mixtures of the homopolymers under the same reaction conditions: see Table 4, entries 10 and 11. By <sup>13</sup>C NMR spectroscopy the copolymers were *not* random. The same result was obtained when the homopolymers were reacted with the catalyst in the presence of *o*-dichlorobenzene (50% w/v) at 180 °C for 8 h. These results indicate that again the random distribution of repeat units is approached more rapidly by copolymerization of the MCOs rather than by direct transesterification of the homopolymers.

Interesting results were also obtained when the copolymers described in Table 4, entries 3 and 7, were analyzed by

**Table 4.** Synthesis of Poly(Ethylene Terephthalate) (**1**), Poly(Butylene Terephthalate) (**2**), and Copolymers<sup>a</sup>

entry	feed composition of MCOs (mol %)		repeat unit composition of polymeric product <sup>b</sup> (mol %)		intrinsic viscosity <sup>c</sup> (dL/g)	Tm <sup>d</sup> (°C)
	MCOs <b>9</b>	MCOs <b>10</b>	RU <b>1</b>	RU <b>2</b>		
1	0	100	0	100	0.71	228
2	10	90	11	89	0.84	208
3	25	75	24	76	0.68	196
4	35	65	33	67	0.65	189
5 <sup>e</sup>	50	50	50	50	0.63	181
6	65	35	65	35	0.58	188
7	75	25	73	27	0.48	207
8	90	10	88	12	0.37	233
9	100	0	100	0	0.49	253
10 <sup>f</sup>	25	75			0.64	
11 <sup>f</sup>	75	25			0.67	

<sup>a</sup> Unless indicated otherwise, polymerizations were carried out for 2 h at 300 °C under a nitrogen atmosphere with 0.1 mol % of di-*n*-butyltin oxide as the catalyst. <sup>b</sup> Determined by <sup>1</sup>H NMR spectroscopy. <sup>c</sup> Estimated using an Ubbelohde viscometer at 25 °C with trifluoroacetic acid as solvent. <sup>d</sup> By DSC under a nitrogen atmosphere of the total product: heating rate = 10 °C/min. <sup>e</sup> A similar reaction was carried out in a DSC capsule at 300 °C under a nitrogen atmosphere. This used 0.1 mol % of di-*n*-butyltin oxide catalyst and a reaction time of 1.5 h. The product had a viscosity of 0.70 and a Tm of 182 °C. <sup>f</sup> Homopolymers mixed and heated under the same reaction conditions as in footnote *a*.

**Table 5.** Synthesis of Poly(Butylene Terephthalate) (**2**), Poly(Ethylene Naphthalene-2,6-dicarboxylate) (**5**), and Copolymers<sup>a</sup>

entry	feed composition of MCOs (mol %)		repeat unit composition of polymeric product <sup>b</sup> (mol %)		intrinsic viscosity <sup>c</sup> (dL/g)
	MCOs <b>10</b>	MCOs <b>11</b>	RU <b>2</b>	RU <b>5</b>	
1 <sup>d</sup>	0	100	0	100	0.73 <sup>e</sup>
2	25	75	24	76	0.67 <sup>f</sup>
3	75	25	73	27	0.49
4	100	0	100	0	0.48
5	25 <sup>g</sup>	75 <sup>g</sup>			0.62
6	75 <sup>g</sup>	25 <sup>g</sup>			0.65

<sup>a</sup> Unless indicated otherwise, polymerizations were carried out for 2 h at 300 °C under a nitrogen atmosphere with 0.1 mol % of di-*n*-butyltin oxide as the catalyst. <sup>b</sup> Determined by <sup>1</sup>H NMR spectroscopy. <sup>c</sup> Estimated using an Ubbelohde viscometer at 25 °C with TFA as solvent.<sup>37</sup> <sup>d</sup> Reaction carried out on pellet in a DSC pan under nitrogen at 300 °C with a reaction time of 2 h. <sup>e</sup> By DSC under a nitrogen atmosphere with the temperature increasing at 10°/min: Tm 120 °C. <sup>f</sup> By DSC under a nitrogen atmosphere with the temperature increasing at 10°/min: Tm 84 °C. <sup>g</sup> Homopolymers mixed and heated under the same reaction conditions as in footnote *a*.

MALDI ToF MS. With the equipment available to us, it was not expected that the polymers themselves could be analyzed, but it was expected that it would be possible to detect the small amounts (approximately 2% of MCOs in total over all ring sizes and all repeat unit combinations) of the MCOs present in the polymerization products. The spectra for the products of the 75/25 and 25/75 copolymerizations are shown for the 800–1900 amu region in Figure 1. The samples were prepared using dithranol as the matrix and sodium bromide as a cationizing agent. Accordingly, the main peaks observed in the mass spectrum are due to [M + Na]<sup>+</sup>. It is apparent from the figure that there are clusters of peaks separated from each other by 28 amu. The clusters correspond to mixed MCOs, i.e. cyclics containing different combinations of the two types of repeat unit, from the cyclic tetramers up to the cyclic nonamers. The peaks corresponding to the cyclic pentamers are typical. Taken together, all the pentamer combinations probably represent less than 0.15% of the sample. If the composition of the macrocycles are represented by “E” for ethylene terephthalate units and “B” for butylene terephthalate units, then the possible pentamers are E5; E4/B; E3/B2; E2/B3; E/B4; and B5, i.e., a series of six peaks.

The corresponding [M + Na]<sup>+</sup> peaks are expected to appear at 983; 1011; 1039; 1067; 1091; and 1123 amu, respectively. It is readily apparent from Figure 1a that in the E-rich product at least the first four members of the series are present, and from Figure 1b, that in the B-rich product the last four members of the series are present. These can only arise by CDP of the copolyesters that occur during the establishment of the RCE and are clear evidence for the occurrence of such CDPs.

#### (iv) Copolymers of Poly(Butylene Terephthalate) (**2**) and Poly(Ethylene Naphthalene-2,6-dicarboxylate) (**5**).

The two homopolymers and two copolymers were prepared by reacting the appropriate MCOs **10** and **11** together in the usual way, but because the Tm of polymer **5** is 261 °C,<sup>30</sup> a reaction temperature of 300 °C was used: see Table 5. Commercial samples of the two homopolymers were also mixed together and reacted under the same conditions. In all cases, the products were pale brown gums. The analyses confirmed that the MCOs reacted together to give copolymer compositions that are essentially the same as the oligomers feed composition ratios. A single Tg is observed for the 25/75 copolymer and a single Tm is observed for the 75/25 copolymer indicating that these products are copolymers. The homopolymers **2** and **5** do not react together well to give a random copolymer as evidenced by the fact that in both cases two Tms are observed that are characteristic of poly(butylene terephthalate) (**4**) (see ref 37; 221 °C) and poly(ethylene naphthalene-2,6-dicarboxylate) (**5**) (see ref 30; 261 °C). This suggests that the homopolymers are not miscible and that they remain phase separated for much, possibly all, of the reaction period. The same result was obtained when the homopolymers were reacted with the catalyst in the presence of *o*-dichlorobenzene (50% w/v) at 180 °C for 8 h. The <sup>13</sup>C NMR spectra of the copolymers prepared from the MCOs indicated, on the basis of signal intensities in the carbonyl region, the products were random copolymers.

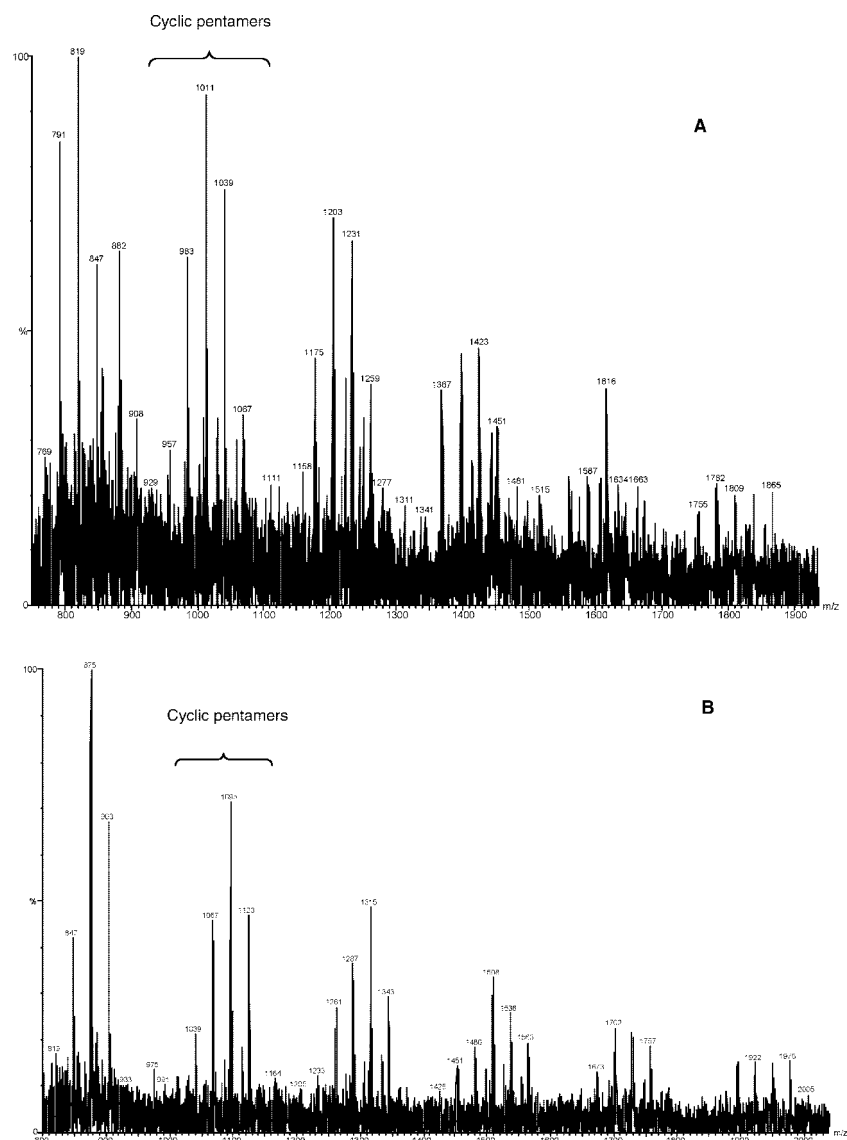
#### (v) Copolymers of Poly(Hexamethylene Adipate) (**4**) and Poly(BisphenolA Adipate) (**6**).

The two homopolymers and two copolymers were prepared by reacting the appropriate MCOs **8** and **12** together with 0.1 mol % of tetra-*n*-butylammonium tetraphenylborate as the catalyst and a reaction temperature of 300 °C: see Table 6. Samples of the

**Table 6.** Synthesis of Poly(Hexamethylene Adipate) (**4**), Poly(BisphenolA Adipate) (**6**), and Copolymers<sup>a</sup>

entry	feed composition of MCOs (mol %)		percentage of polymer in product <sup>b</sup>	repeat unit composition of polymeric product <sup>c</sup> (mol %)		molecular weight <sup>d</sup> (Mw × 10 <sup>-3</sup> )	PDI (Mw/Mn)
	MCOs <b>8</b>	MCOs <b>12</b>		RU <b>4</b>	RU <b>6</b>		
1 <sup>e</sup>	0	100	99.0	0	100	7.0	2.0
2	25	75	99.0	27	73	11.9	2.0
3	75	25	98.5	75	25	10.9	2.0
4 <sup>f</sup>	100	0	95.7	100	0	28.3	1.9
5 <sup>g</sup>	25	75	50.6	37	63	4.4	2.9
6 <sup>g</sup>	75	25	68.0	85	15	15.5	1.8

<sup>a</sup> Unless indicated otherwise, polymerizations were carried out at 300 °C under a nitrogen atmosphere for 2 h with 0.1 mol % of tetra-*n*-butylammonium tetrafluoroborate as the catalyst. <sup>b</sup> By SEC analysis: the rest is MCOs. <sup>c</sup> Measured by <sup>1</sup>H NMR spectroscopy. <sup>d</sup> By SEC analysis: relative to polystyrene standards. <sup>e</sup> Reaction carried out in a DSC pan with 1 mol % of the catalyst and a reaction time of 30 min. <sup>f</sup> Reaction was carried out at 250 °C with 0.1 mol % of di-*n*-butyltin oxide as the catalyst. <sup>g</sup> Homopolymers mixed and heated under the same reaction conditions as in footnote *a*.



**Figure 1.** MALDI TOF MS of (A) the 75/25 and (B) 25/75 copolymers of poly(ethylene terephthalate) (**1**) and poly(butylene terephthalate) (**2**) in the 800–1900 amu region, showing peaks due to small amounts of MCOs present in the copolymers. The peaks are due to  $[M + Na]^+$ .

two homopolymers were also mixed together and reacted under the same conditions. In all cases, the products were pale brown gums. The analyses indicate that the MCOs reacted together to give copolymers with compositions close to the feed composition ratios. By SEC, the products had unimodal molecular weight distributions with polydispersities

of 1.9 or 2.0, but the molecular weights were generally modest. The homopolymers do not react together well, and surprisingly, a substantial percentage of the final reaction mixture was MCOs. The composition of these copolymers, after removal of the oligomers by precipitation, was far from the expected values: see Table 6 entries 5 and 6. By <sup>13</sup>C



**Table 7.** Synthesis of Poly(Ethylene Terephthalate) (**1**), Poly(BisphenolA Adipate) (**6**), and Copolymers<sup>a</sup>

entry	feed composition of MCOs (mol %)		percentage of polymer in product <sup>b</sup>	repeat unit composition of polymeric product <sup>c</sup> (mol %)		molecular weight <sup>d</sup> (Mw × 10 <sup>-3</sup> )	PDI <sup>d</sup> (Mw/Mn)
	MCOs <b>9</b>	MCOs <b>12</b>		RU <b>1</b>	RU <b>6</b>		
1 <sup>e</sup>	0	100	99.0	0	100	7.0	2.0
2	25	75	97.9	28	72	7.4	2.0
3 <sup>f</sup>	75	25	98.5	75	25	9.9	2.0
4 <sup>g</sup>	100	0	97.9	100	0	18.3	1.9
5 <sup>h</sup>	25	75	96.5	27	73	6.1	1.9
6 <sup>h</sup>	75	25	99.0	75	25	20.8	2.0

<sup>a</sup> Unless indicated otherwise, polymerizations were carried out at 300 °C under a nitrogen atmosphere for 2 h with 0.1 mol % of tetra-*n*-butylammonium tetrafluoroborate as the catalyst. <sup>b</sup> By SEC analysis: the rest is MCOs. <sup>c</sup> Measured by <sup>1</sup>H NMR spectroscopy. <sup>d</sup> By SEC analysis: relative to polystyrene standards. <sup>e</sup> Reaction also carried out in a DSC pan under a nitrogen atmosphere with 1 mol % of the catalyst and a reaction time of 30 min. Similar analyses indicated that the product was 98.5% polymer with a Mw of 21 200 and a PDI of 1.9. <sup>f</sup> As in footnote e, but the product was 98.0% polymer with a Mw of 15 400 and a PDI of 2.0. The proportions of the two types of repeat units were 75:25. <sup>g</sup> Reaction was carried out with di-*n*-butyltin oxide as the catalyst. <sup>h</sup> Homopolymers mixed and heated under the same reaction conditions as in footnote a.

**Table 8.** Comparison of the Molecular Weights Obtained before and after Precipitation of Homo- and Copolymers Synthesized Using a Teflon Block<sup>a</sup>

entry	feed composition of MCOs (mol %)	percentage of polymer in product <sup>b</sup>		molecular weight (Mw × 10 <sup>-3</sup> ) and PDI <sup>c</sup>		Percentage yield after pptn
		before pptn	after pptn	before pptn	after pptn	
1	MCOs7;100	97.2	98.2	24.4/2.1	25.0/2.1	92
2	MCOs8;100	96.8	99.1	25.0/2.2	25.0/1.7	85
3	MCOs 7 and 8; 50:50	98.0	99.0	26.3/2.1	28.1/1.7	72
4	MCOs 8 and 9; 50:50	98.8	99.0	27.6/2.7	36.9/2.4	70
5	MCOs 9 and 10; 50:50 <sup>d</sup>			0.69 <sup>e</sup>	0.75 <sup>e</sup>	79

<sup>a</sup> Unless indicated otherwise, polymerizations were carried out at 250 °C under a nitrogen atmosphere for 2 h with 0.1 mol % of di-*n*-butyltin oxide as the catalyst. <sup>b</sup> By SEC analysis: the rest is MCOs. <sup>c</sup> By SEC analysis: relative to polystyrene standards. <sup>d</sup> Reaction carried out at 300 °C. <sup>e</sup> Estimated using an Ubbelohde viscometer at 25 °C with TFA as solvent.

NMR spectroscopy the copolymers prepared from the MCOs were neither blocked nor random. Thus, these ED-ROPs were not a satisfactory way to prepare copolymers of poly(hexamethylene adipate) (**4**) and poly(bisphenolA adipate) (**6**).

**(vi) Copolymers of Poly(Ethylene Terephthalate) (**1**) and Poly(BisphenolA Adipate) (**6**).** The two homopolymers and two copolymers were prepared by treating the appropriate MCOs with 0.1 mol % tetra-*n*-butylammonium tetrafluoroborate at 300 °C for 2 h. The same compositions of the homopolymers were also mixed together and reacted under the same conditions. The products from all the reactions were brown gums. They were analyzed in the usual way. Table 7 summarizes the results. Even though high yields of polymers were obtained, the molecular weights were low. <sup>13</sup>C NMR spectroscopy indicated that none of the products were random. It appears that in general the *phenolic* esters do not react as well as other types of esters either alone or in copolymerizations. Probably the catalysts are not the most appropriate to use for this type of ester linkage, and it may be that under the reaction conditions the phenyl esters have a tendency to undergo Fries rearrangements.<sup>38</sup>

#### Improved Procedures: Precipitation of the Products.

Thus far, all the syntheses had been carried out in glass vials. The use of such vials meant that the samples were easily collected and stored but in some cases it was found that some polymeric products adhered very strongly to the glass and were not easily removed from the vials. It was, therefore, considered of interest to try some ROPs in wells bored into a Teflon block in order to take advantage of Teflon's "nonstick" properties. Teflon melts at 335–345 °C<sup>37</sup> and so was expected to be stable under the usual polymerization conditions. Teflon blocks each containing 36 wells (3 rows of 12), each well 7 mm in diameter and 8 mm deep, were

fabricated in house. Several polymers were prepared in the blocks on an 80–100 mg scale by treating MCOs with 0.1 mol % di-*n*-butyltin oxide for 2 h at 250 °C. The experiments are summarized in Table 8. After polymerization the products were allowed to cool to room temperature. As anticipated the products could be removed easily from the Teflon wells. This may appear to be a small point but it is significant if large numbers of polymers are being prepared. As in the previous syntheses, the products were analyzed by SEC or intrinsic viscosities were measured. In all cases where SEC was possible at the end of the reaction period, a high proportion of polymer was obtained (>96.8%) and the molecular weights were comparable with those obtained using the glass vials.

Another important aspect of ED-ROP as a method of polymer synthesis is precipitation of the product. ED-ROPs are RCE reactions and, as already noted above, establishing such equilibria, even when *neat* reactants are used, means small amounts of MCOs will always be present at the end of the reaction. Since most MCOs are more soluble than the corresponding polymer, in general, they are easily removed by precipitation. This may also remove any side products and most, if not all, of the catalyst residues. This method of purification can also have a significant effect on the molecular weights since the smaller, more soluble, molecules tend to be eliminated. Using a multichannel pipet, precipitation was carried out easily in an HT manner by dissolving each product in the well in a minimum amount of chloroform, if necessary containing ca. 1% v/v of TFA, then pipetting them into glass vials (10 mm diameter, 30 mm deep) containing methanol (2.0 mL). The vials were located in a specially prepared wooden block with the locating holes at the same distance apart as the wells on the reaction block, so

facilitating transfers using the multichannel pipet. The precipitates were allowed to settle, the solvent removed by pipet or by decantation and the polymers dried in the vials in a vacuum oven. They were then reanalyzed by SEC or by intrinsic viscosity. The results, summarized in 8, show that the precipitated products usually consisted of >99% polymer and had slightly greater molecular weights than the crude products. The precipitated copolymers whose preparations are summarized in entries 1–3 were also analyzed by  $^1\text{H}$  NMR spectroscopy to determine the percentages of the different constituents. The results indicate that the compositions are within 3% of the original feedstock proportions. Another aspect worth noting is that the precipitated products were, with one exception, white powders. The exception was the product whose preparation is summarized in entry 3 and it remained light brown in color. The yields of precipitated product were all >70%. Considering the scale on which they were prepared and precipitated this is considered satisfactory.

Having established a satisfactory precipitation procedure, the products prepared by the polymerizations summarized in Table 1 were precipitated similarly from dichloromethane into methanol and the  $T_m$  values were determined by DSC. The results are summarized in Table 1. Consistent with the fact the products were copolymers, each product had just one  $T_m$ . The values decrease gradually from 60 °C for pure poly(hexamethylene adipate) (4) to 54 °C for the 25/75 composition and then gradually increase again to 89 °C for the pure polyundecanoate (3). The fact the  $T_m$ s of the copolymers are less than those of the main corresponding homopolymer probably reflects the fact that disorder in the copolymers makes packing less efficient.

After each Teflon block had been used for six or more libraries a problem emerged. This was that the blocks slowly distorted and eventually were no longer a snug fit in the Büchi oven. This prompted us to fabricate further blocks. These were aluminum blocks each with 36 wells (3 rows of 12), each well lined with a Teflon cup (7 mm diameter, 10 mm deep) that protruded 4 mm above the surface of the block: see the Supporting Information. This arrangement has the advantages of a permanently rigid snug-fitting block with excellent heat transfer properties combined with the nonstick properties of Teflon reaction vessels. The fact the Teflon cups protruded above the surface of the block makes cross contamination between reactions/products less likely. Similar blocks were fabricated for use on the shelves of a conventional oven. They had flat bottoms and close-fitting aluminum lids to shield the samples: see Supporting Information.

To test these new lined blocks a series of 50/50 copolymers were prepared on ca. 90 mg scale by heating the appropriate MCOs at 250 °C for 3 h with 0.1 mol % of di-*n*-butyltin oxide or at 300 °C for 2 h with 1 mol % di-*n*-butyltin oxide. The polymerizations are summarized in Table 9. At the end of the reaction period the products were cooled to ambient temperature. Using a multichannel pipet the products were dissolved in dichloromethane containing 1% v/v of TFA, then precipitated into methanol. The products were allowed to settle then the solvent was decanted off. The products were washed 3 times with methanol and dried at 65 °C under vacuum. The final products from entries 1 and 2 were

analyzed by SEC, and  $^1\text{H}$  and  $^{13}\text{C}$  NMR spectroscopy. They consisted of >99.5% polymer. The  $M_w$ s were 26 200 and 27 900, the dispersities were 2.2 and 2.0, the copolymer compositions were essentially the same as the feedstocks, and the copolymers were random. The final products from entries 3 and 4 were analyzed by  $^1\text{H}$  NMR spectroscopy and intrinsic viscosities were measured. The copolymer compositions were essentially the same as the feedstocks and the intrinsic viscosities indicated the products had significant molecular weights. Thus, the various polymeric products had very similar properties to those of the corresponding products in the earlier experiment, indicating that the lined block is an effective way to synthesize copolyesters by ED-ROPs. This type of block has since proved to be entirely satisfactory in all our ongoing HT research.

## Conclusions

Several conclusions can be drawn from the results.

1. Copolyesters can be synthesized in an HT manner on about a 90 mg scale and in high yield using ED-ROPs. This involves taking mixtures of appropriate MCOs and heating them together at 250–300 °C under neat conditions with a small amount of a transesterification catalyst. The method works well with esters derived from aliphatic or aromatic acids and alcohols, but it does not work well with esters derived from phenols. This limitation might be overcome in future by optimizing the choice of catalyst.

2. Typically  $M_n$  was > 10 000 and  $M_w$  > 25 000. Higher values could almost certainly be obtained by using longer reaction times, but this might in some cases lead to product decomposition.

3. As expected for ED-ROPs, the polydispersity indices were generally close to 2.0. In cases where they were higher, it was probably due to the catalyst being poorly soluble in the feedstock so that synthesis took place at different locations in the mixture under slightly different conditions. At each location the polydispersity would be close to 2.0 but the  $M_w$ s would differ, so that taken overall the dispersity was >2.0. This could problem could probably be avoided by using catalysts that are totally soluble in the feedstock, for example, polymers similar to the target polymers with catalyst-type end-groups. Lower PDIs were obtained after the polymers had been precipitated.

4. While the copolymerizations generally gave random copolymers, in some cases using shorter reaction periods there was clear evidence, from  $^{13}\text{C}$  NMR spectroscopy, that, as expected, nonrandom copolymers were formed initially. With longer reaction times these polymers became random.

5. Attempts were also made to synthesize copolymers by mixing together the two homopolymers and heating with a catalyst. These reactions were successful in a few instances, but generally, they were not. This is probably because the homopolymers were not miscible. Mixing MCOs and reacting them together is a much more successful approach, probably because most pairs of MCOs used mix to some extent on heating and so readily reacted together to give immediately cyclic co-oligomers and copolymers.

6. Three types of reaction blocks were used. Initially 10 small sample tubes were mounted in an aluminum

**Table 9.** Synthesis of 50/50 Copolymers Using an Aluminium Block with Teflon Wells<sup>a</sup>

entry	MCOs reacted		reaction conditions			repeat unit composition of polymeric product <sup>b</sup>		molecular weight <sup>c</sup> (Mw × 10 <sup>-3</sup> ) or intrinsic viscosity <sup>d</sup>	PDI (Mw/Mn)
			temp (°C)	time (h)	Yield (%)	(RU/mol %)	(RU/mol %)		
1	7	8	250	3	78	3/49	4/51	27.9	2.2
2	8	9	250	3	81	4/50	1/50	26.2	2.2
3	9	10	300	2	84	1/50	2/50	0.73	
4	10	11	300	2	77	2/51	5/49	0.66	

<sup>a</sup> Polymerizations were carried out under a nitrogen atmosphere for with 0.1 mol % of di-*n*-butyltin oxide as the catalyst. The final reaction mixture was dissolved in dichloromethane/TFA (99 vols to 1 vol) and precipitated into methanol. The solvent was decanted off and the polymer dried then analyzed by SEC. <sup>b</sup> Measured by <sup>1</sup>H NMR spectroscopy on the precipitated product. <sup>c</sup> By SEC analysis relative to polystyrene standards. <sup>d</sup> Estimated using an Ubbelohde viscometer at 25 °C with TFA as solvent.<sup>37</sup>

block, then Teflon blocks with 36 wells drilled into the block were used, but most satisfactory is an aluminum block with 36 wells lined with Teflon cups was used: see the figure in the Supporting Information. These had the benefit of good heat transfer, nonstick reaction vessels and, due to their high sides, minimal opportunity for cross contamination of the samples.

The above study paves the way for the future preparation of larger polyester libraries, of both copolymers and terpolymers, and studies of their structure–property relationships.

## Experimental Section

**General Methods.** These have been given previously.<sup>25</sup>

**Source of polymers.** Polymers **1**, **2**, **4**, and **5** were purchased from the Aldrich Chemical Co. Polymer **3** was prepared from 11-bromundecanoic acid as described previously.<sup>39</sup> Polymer **6** was prepared by the interfacial polymerization of adipoyl chloride with bisphenolA in aqueous sodium hydroxide.<sup>40</sup> Details of their molecular weights or intrinsic viscosities are given in Table 1.

**Preparation of MCOs by CDP.** The CDPs of polymers **1**, **2**, **3**, and **5** are described in the literature (see Table 1 for references). The reactions were repeated. Poly(hexamethylene adipate) (**4**) was subjected to CDP in the same manner as polyundecanoate (**2**).<sup>28</sup> Polymer **6** was subjected to CDP in the same manner as polymer **3** but using tetra-*n*-butylammonium tetraphenylborate as catalyst. The compositions of the various products are summarized in Table 1.

**Typical HT Polymer Syntheses.** As described in the text, three types of reaction blocks were used. The procedures are described in the text in some detail. In each case the glass vial/reaction well was loaded with the relevant MCOs (total weight about 90 mg) and the catalyst added as a 5% solution in dichloromethane. The solvent was allowed to evaporate off at 35 °C and ambient pressure before the block was placed in a cold cylindrical Büchi distillation oven. The oven was partially evacuated then filled with dry nitrogen through three cycles. The oven was then heated to the required temperature and for the required time. In each case, the reaction temperature was measured by a thermometer present in the oven. The products were either analyzed by SEC or the intrinsic viscosities were measured. NMR spectra and, in selected cases, the Tgs and/or Tms of the products were measured. If necessary the products were (re)precipitated in a HT manner as described in the text.

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**Supporting Information Available.** Selected examples of the <sup>13</sup>C NMR spectroscopic evidence for copolymers being random or not random, together with photographs of the final reaction blocks. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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