

## Chiral Promesogenic Monomers Inducing One-Handed, Helical Conformations in Synthetic Polymers

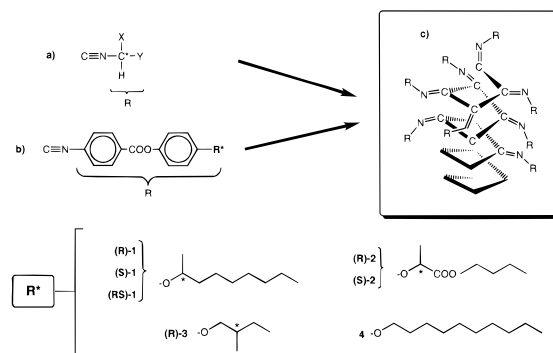
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The synthesis and study of optically active polymers whose chirality is based on a helical main-chain conformation have generated wide interest across a broad range of scientific disciplines.<sup>1</sup> As a consequence, the preparation of synthetic chiral macromolecules with helical structures and the understanding and control of the different mechanisms governing the induction of an excess of one helical sense might have far-reaching implications in biology and biomolecular materials.<sup>2</sup>

Polymers with exclusively helical conformational chirality can only be obtained when isotacticity and atropisomerism are simultaneously present in their structures, that is, when their repeating units have the same stereochemistry, and the rigidity of the polymer backbone and/or sterical repulsion of the side groups prevent random coil-like conformations.<sup>1b</sup> Synthetic polymers with such chiral conformations may show a high optical activity if an excess of a one-handed helical conformation exists. This has been attained for only very few cases; for example, with chloral,<sup>3</sup> bulky substituted methacrylates,<sup>1,4</sup> isocyanates,<sup>5</sup> and isocyanides,<sup>6</sup> along with some substituted  $\pi$ -conjugated polymers.<sup>7</sup> Noteworthy are the results achieved with isocyanides since the stereochemistry of their polymerizations has been studied in great detail.<sup>8</sup> Optically active polyisocyanides, with an excess of a one-handed helical conformation, can be obtained by direct polymerization of chiral isocyanides with the general formula depicted in Figure 1a.<sup>8</sup> In all these polymerizations, the chiral moiety responsible for the stereoselectivity is joined directly (or very close) to polymerizable isocyanide groups. This proximity encourages the inserting monomers with a stereogenic center configuration (*R* or *S*) to approach to one side of the reactive adduct, thereby generating a unique helical sense (plus, *P*, or minus, *M*) in the growing polymer.



**Figure 1.** (a) Example of a typical chiral isocyanide with a stereogenic center immediately attached to the N atom of the polymerizable group which gives rise to an excess of a one-handed helical conformation through a “classical” asymmetric induction mechanism. (b) Chiral and achiral isocyanide monomers **1–4**, with stereogenic centers located far from the polymerizable groups, in which the long-distance asymmetric induction of polymeric, helical, main-chain conformations has been observed. (c) Polyisocyanide backbone showing a usual 4/1 helical conformation with a *P* helix sense.

A very different approximation to helical superstructures is based on chiral liquid crystal materials exhibiting cholesteric or tilted smectic mesophases (namely  $S_C^*$ ,  $S_F^*$ , and  $S_I^*$ ).<sup>9</sup> In this case a helical sense is induced by very weak interactions whose origin lies in the chirality of the molecules. The presence of this macroscopic structure makes these materials interesting for applications, e.g. those derived from their thermotropic properties.

During our investigations, we sought to combine both types of approaches in order to obtain new helical superstructures and, simultaneously, to advance the knowledge of the mechanism of their formation. With this aim in mind, we synthesized new polyisocyanides whose monomeric isocyanide constituents are based on structures rather classical in the liquid crystals field. Thus, a phenyl benzoate has been chosen to be the rigid part of the molecule, and a chiral terminal tail such as (*R*)-2-octanol has been selected (Figure 1b). In this communication we describe some of the most relevant results obtained so far from our investigations.

The ability to establish intermolecular stereoselective interactions between the studied isocyanides were evaluated for the stereoisomers of 4'-(1-methylheptoxy)phenyl 4-isocyanobenzoate, **1** (Figure 1b), using the cholesteric liquid crystal induced circular dichroism (LCICD) technique.<sup>10,11</sup> For our study we used *p*-methoxybenzylidene-*p'*-(*n*-butyl)aniline (MBBA) as the nematic host, since it has strong structural and conformational resemblances to the studied isocyanide **1**. The pitch and helix sense of such an induced chiral nematic mesophase can be determined by using the circular dichroism (CD) spectrum of a properly oriented sample.<sup>12</sup> Thus, the LCICD technique, using this compound as the nematic host, shows that isocyanides (*R*)-**1** and (*S*)-**1** cause *M* and *P* helical senses, respectively, in the chiral nematic phases resulting from the mixture of the compounds. On the contrary, the racemate (*RS*)-**1** does not induce a chiral nematic phase in the nematic host. Therefore, the presence of a stereogenic center in **1** with *R* (or *S*) configuration preferentially induces an *M* (or *P*) conformation in the two aromatic rings of the phenyl benzoate group which are thus able to establish intermolecular stereoselective interactions leading to chiral supramolecular organizations with an (*M* or *P*) helical sense.

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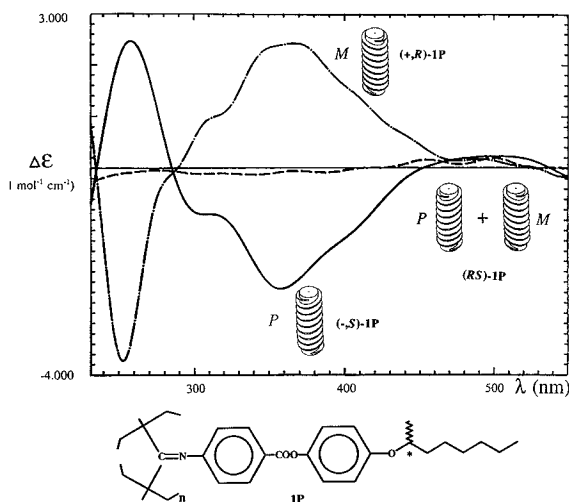
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**Table 1.** Chiroptical Data (Specific Optical Rotations and CD Differential Molar Absorptivities) of Polyisocyanides Derived from Monomers **1**–**4**<sup>a</sup>

monomer	$[\alpha]_{546}^b$ (deg)	$\Delta\epsilon^c$ (L mol <sup>-1</sup> cm <sup>-1</sup> )	screw sense of helix
( <b>R</b> )- <b>1P</b>	+236	+2.42	<i>M</i>
( <b>S</b> )- <b>1P</b>	-216	-2.34	<i>P</i>
( <b>RS</b> )- <b>1P</b>	0 <sup>d</sup>	0 <sup>d</sup>	<i>M</i> + <i>P</i>
( <b>R</b> )- <b>2P</b>	+526	+4.93	<i>M</i>
( <b>S</b> )- <b>2P</b>	-564	-5.17	<i>P</i>
( <b>S</b> )- <b>3P</b>	+53	+0.51	<i>M</i>
<b>4P</b>	0 <sup>d</sup>	0 <sup>d</sup>	<i>M</i> + <i>P</i>

<sup>a</sup> Polymerization conditions: solvent, CH<sub>2</sub>Cl<sub>2</sub>; catalyst, NiCl<sub>2</sub>·6H<sub>2</sub>O (1 mol %); 48 h at room temperature. Weight-averaged molecular weights (*M<sub>w</sub>*) and polydispersities (*Q*) of the polymers were determined by GPC to be (4.3–5.5) × 10<sup>4</sup> Da and 1.3–1.7, respectively, on the basis of a calibration of polystyrene standards and using THF as eluent at 30 °C. <sup>b</sup> Specific optical rotations of the polymers measured in CHCl<sub>3</sub> (c, 6–10 g L<sup>-1</sup>) at 25 °C. <sup>c</sup> CD differential molar absorptivities measured in CHCl<sub>3</sub> at 363 nm and at 25 °C. <sup>d</sup> Polymer without optical activity.

**Figure 2.** CD spectra of polyisocyanides (+,**R**)-**1P**, (-,**S**)-**1P**, and (**RS**)-**1P** in CHCl<sub>3</sub> at 25 °C showing their prevailing helix senses.

The polymerization of the isocyanide (**R**)-**1** with NiCl<sub>2</sub> in CH<sub>2</sub>Cl<sub>2</sub> affords the corresponding polymer (Figure 1), (+)-poly-{4'-[(**R**)-1-methylheptoxy]phenyl 4-isocyanobenzoate}, (+,**R**)-**1P**, which exhibits a large positive optical rotation and a strong CD absorption signal as shown in Table 1 and in Figure 2. The rather large values of both chiroptical measurements, as well as their signs, are remarkable since they are 2 order of magnitude larger and opposite in sign to those shown by the monomeric precursor (**R**)-**1**. Both facts suggest that the optical activity of the resulting polyisocyanide (+,**R**)-**1P** must be attributed to a main-chain helical conformation with a prevailing screw sense rather than a configurational chirality due to its side groups. Moreover, it can be concluded that the polyisocyanide (+,**R**)-**1** has a prevailing *M*-helical conformation on the basis of the sign of the excitonic couplet observed in its CD spectrum (Figure 2).<sup>13</sup> Therefore, the chiral carbon atom of (**R**)-**1** is able to induce asymmetric polymerization although it is located several angstroms away from the reactive isocyanide group. In order to confirm this interesting phenomenon, we have also studied the polymerizations of (**R**)-**1** and those of its antipode (**S**)-**1** and of the racemate (**RS**)-**1**. CD spectra of polymers, derived from isocyanide monomers (**R**)-**1** and (**S**)-**1**, are nearly mirror images of each other (Figure 2) and are indicative of enantiomers with opposite helicities. In contrast, no significant CD signal was observed for the polymer obtained from the racemate (**RS**)-**1**. The CD signals, therefore, permit the assignment of the

prevailing helical senses *M* and *P* to polymers (+,**R**)-**1P** and (-,**S**)-**1P**, respectively, and a racemic nature (*M* + *P*) to (**RS**)-**1P**. The results of these polymerizations, which are summarized in Table 1, also confirmed that the long-distance asymmetric induction phenomenon took place.

Agreement between the helical senses of the synthetic polymers and those of the corresponding supramolecular organizations of the induced cholesteric phases has been found, thus suggesting similar self-assembling processes for both chiral induction phenomena.

In order to confirm these results, we have also studied the polymerizations of other substituted isocyanides structurally related to the isocyanide **1**. Table 1 shows the results achieved for isocyanides (**R**)-**2**, (**S**)-**2**, (**S**)-**3**, and **4** (Figure 1b), which were polymerized under similar conditions to those used for (**R**)-**1**. Long-distance induction of predominantly one-handed helical conformation was again observed for the chiral isocyanides assayed, but they occurred to different degrees depending on the characteristics of the stereogenic center. From chiroptical data of the studied polyisocyanides, it is clear that the replacement of the *n*-hexyl substituent of the asymmetric carbon in **1** by a *n*-butyloxycarbonyl substituent, as in **2**, does not cause any change in the preference of the helix sense, and furthermore, it produces an increase in the degree of such a preference, as revealed by the increase in the rotation of the chiroptical signals. In contrast, the removal of the asymmetric carbon from the β- to the γ-position in the substituent of the phenyl ring inverts the sense of the prevailing helix and diminishes the degree of its preference, as observed for the isocyanide (**S**)-**3**. This behavior is in accordance to the alternance rules *Sol-Rel*, *Sed-Rod* (*S*, *R*, absolute configuration of the stereogenic center; *o*, *e*, odd or even position of the stereogenic center with regard to the phenyl ring; *l*, *d*; levo- or dextro- sense of the helical ordering) of Gray and McDonnell<sup>14</sup> that relate the supramolecular helical senses with the stereogenic centers for cholesteric liquid crystals, and which are also applicable to helicoidal smectics.<sup>15</sup> On the other hand, no preference in helical sense occurs when the asymmetric carbon is missing from the skeleton of the monomer, as observed for the achiral isocyanide **4**.

Studies using chiral tails with the stereogenic center in positions different to the β-position and several other mesogenic cores have been carried out. In all cases agreement between the chiral induction in liquid crystal mixtures and the helical handedness of the polymer derivative has been found. Results described here provide indirect experimental evidence about a possible mechanism that operates during the long-distance asymmetric induction. According to this mechanism, the chiral information contained in the stereogenic center of the monomer is transferred toward the polymerizable group of the monomer, via the chiral conformation adopted by the two rings of the moderately rigid phenyl benzoate moiety. In this way the monomer develops two differentiated diastereomeric faces in the surroundings of polymerizable isocyanide groups. These are able to interact stereoselectivity with the growing species leading to an excess of one screw sense in the resulting polymer, as in the supramolecular organization observed in the LCICD experiments. Further studies in order to validate such long-distance asymmetric induction mechanism are in progress.

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