Helical Configuration of Poly(iminomethylenes). Screw Sense of Polymers Derived from Optically Active Alkyl Isocyanides\textsuperscript{1,2}

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ABSTRACT: The synthesis of three poly(iminomethylenes), \([\text{RN}=-\text{C}<]_n\), from optically active isocyanides is described. The group \(R\) includes \((R)-(\text{CH})_3\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_3)\), \((R)-(\text{CH})_2\text{CHCH}(\text{CH}_3)\), and \((R)-\text{n-C}_6\text{H}_{11}\text{CH}(\text{CH}_3)\).

These polymers show atropisomerism, that is, stereoisomerism due to restricted rotation about single bonds,\textsuperscript{4} and represent a rare case of this kind of isomerism in polymers.\textsuperscript{5} They have a helical configuration and consequently are chiral. Poly(tert-butyliminomethylene) has been completely resolved by column chromatography.\textsuperscript{26} The support consisted of glass beads coated with poly[(S)-sec-butyliminomethylene].

This resolution of poly(tert-butyliminomethylene) into enantiomers shows that polymerization of a nonchiral isocyanide gives a racemic mixture of \(P\) and \(M\) screws. However, when the monomer is one enantiomer of a chiral isocyanide, its polymer will be a mixture of diastereoisomers, and \(P\) and \(M\) screws will not be formed in equivalent amounts.

In a previous paper\textsuperscript{8} we compared the optical rotation values of various chiral isocyanides with those of their corresponding polymers. This comparison strongly supports the hypothesis that optically active isocyanides do indeed polymerize screw sense selectively. The screw sense of the various polymers was tentatively deduced from the optical rotation values. From the polymerization mechanism, rules were derived by means of which the screw sense can be predicted when an optically active isocyanide is polymerized by nickel(II).

Optical rotation values have been used frequently to draw conclusions about conformations of polymer chains in solution.\textsuperscript{9} However, in the present system one should be cautious about doing this, because poly(iminomethylenes) are highly rigid rod polymers.\textsuperscript{10} The rigid environment in the system \((R^*\text{N}=\text{C}<)\) might considerably affect the conformation of \(R^*\) and thus its contribution to the optical rotation. Therefore, when going from monomer to polymer the change in the optical rotation value is not necessarily due to the conformation of the polymer main chain exclusively.

More reliable information can be expected from circular dichroism (CD) data. Many of the polymers which we synthesized earlier had chromophores in their side chains. These chromophores might interfere with the helically arranged \(C=\text{N}\) chromophores of the main chain. These polymers are therefore less suitable for CD spectral analysis. Poly(iminomethylenes) derived from optically active alkyl isocyanides do not have additional chromophores and are more appropriate for a CD study. One such polymer, poly(sec-butyliminomethylene), was synthesized earlier.\textsuperscript{7} Its CD spectrum could not be recorded because of its complete insolubility in organic solvents. Yet its screw sense could be derived from the resolution process of poly(tert-butyliminomethylene).\textsuperscript{7} In this paper we describe the synthesis of three additional poly(alkyliminomethylenes) prepared from optically active alkyl isocyanides, compounds 4a–c of Scheme I. These polymers are soluble in apolar organic solvents. Their CD spectra are compared with the spectrum of poly(tert-butyliminomethylene) (4d) and spectra of model compounds.

Results and Discussion

Synthesis. For the synthesis of polymers 4a–c as well as for their model compounds 5a–c one requires optically active amines as starting materials (Scheme I). 2-Octanamine (1a) was resolved through fractional crystallization of its bitartrate from water. After 12 crystallizations \(^1\mathrm{H}\) NMR shift experiments showed that 1a was optically pure with \([\alpha]_\text{D}^{2578} = -6.92\textsuperscript{25}$. The absolute configuration of this enantiomer has been established to be \(R\).\textsuperscript{11} (R)-3-Methyl-2-butanamine (1b) and (R)-4-methyl-2-pentanamine (1c) were prepared from the amino acids L-valine and L-leucine, respectively, as outlined in Scheme II.

The carboxylic function of the latter compounds was esterified and subsequently reduced to the hydroxymethyl group with LiAlH\(_4\). We found it convenient to attach a benzoyl group to the NH\(_2\) group of 6, as this facilitates the isolation of alcohol 9 from the reaction mixture.\textsuperscript{12} This benzoyl group is converted into a benzyl group during the reduction process. The latter group was removed by hydrogenolysis with palladium-on-carbon. The unprotected alcohol 10 was treated with HBr in acetic acid to give 11. In this reaction a small amount of bromine was added as a catalyst. The bromide 11 was subjected to hydrogenolysis in an aqueous...
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Table I

<table>
<thead>
<tr>
<th>R</th>
<th>[M]_23,4°/deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>(R)-t-C,H_5,C,H(CH_3)</td>
</tr>
<tr>
<td>b</td>
<td>(R)-(CH_3)_2 CHCH(CH_3)</td>
</tr>
<tr>
<td>c</td>
<td>(R)-(CH_3)_2 CHCH(CH_3)</td>
</tr>
<tr>
<td>d</td>
<td>(CH_3)_2 C</td>
</tr>
</tbody>
</table>

In chloroform: 3, c 1.1-1.9; 4, c 0.25-0.8; 5, c 0.9-2.3. 

a Per repeating unit RN=C. 

b Taken from ref 2, M helix.

Sodium acetate-acetic acid buffer with palladium-on-carbon as catalyst. After workup the desired amines were isolated as their HCl salts. It follows from Scheme II that, when we start from the L-amino acids the absolute configuration of the amines 1b and 1c is R.

Scheme I

\[
\text{RN}=\text{CH}(\text{CH}=\text{NH})\text{CHOH} \rightarrow \text{RNH}_2 \rightarrow \text{RNHCHO} \rightarrow \text{RN}=\text{C} \rightarrow (\text{RN}=\text{C})_n
\]

a, R = (R)-t-C,H_5,C,H(CH_3) 
b, R = (R)-(CH_3)_2 CHCH(CH_3) 
c, R = (R)-(CH_3)_2 CHCH_2 CH(CH_3) 
d, R = (CH_3)_2 C

Scheme II

\[
\text{R'=CH(NH}_2\text{COOH} \rightarrow \text{R'CH(NH}CO\text{OPh})\text{COOH} \rightarrow \text{R'CH(NH}CO\text{OPh})\text{COOCH}_3 \rightarrow \text{R'CH(NH}_2\text{CHCH}_2\text{OH} \rightarrow \text{R'CH(NH}_2\text{CH}_2\text{OH} \rightarrow \text{R'CH(NH}_2\text{CH}_2\text{Br} \rightarrow \text{RNH}_2
\]

6e, R' = (CH_3)_2 CH, valine 

f, R' = (CH_3)_2 CHCH_2 leucine

Upon treatment with an excess of ethyl formate the amines 1a-c afforded the N-formyl derivatives 2a-c (Scheme I). The isocyanides 3a and 3c were obtained in 85 and 70% yield, respectively, by dehydration of the corresponding formamides with phosphorus oxychloride at low temperatures. Compounds 3b was prepared in 86% yield, using p-toluenesulfonyl chloride and quinoline as dehydrating agent. The latter procedure is the preferred one for relatively volatile isocyanides. We assume that racemization does not occur in either procedure. With regard to the former procedure this assumption is based on our observation that retention occurs in molecules even more sensitive to racemization than the isocyanides described here. With respect to the second procedure, it is known that optically active sec-butyl isocyanide retains its configuration under reaction conditions similar to those applied by us. The infrared absorption spectra of compounds 3a-c showed characteristic isocyanide stretching vibrations at approximately 2140 cm\(^{-1}\). At 578 nm the isocyanides have negative optical rotations (Table I). Their structures were confirmed by \(^{1}H\) NMR.

The monomers were polymerized at room temperature by 0.1-1.0 mol % of nickel chloride either in methanol or without solvent. The yields of isolated polymer ranged from 60 to 95%. Polymers 4a-c were pale yellow. They were soluble in petroleum ether, benzene, toluene, chlorinated hydrocarbons, and tetrahydrofuran and insoluble in alcohols and water. Filtered and initially clear solutions of 4b were unstable and gave deposits of polymer when allowed to stand for a short time. This behavior prevented the determination of the intrinsic viscosity of this compound. Polymers 4a and 4c showed intrinsic viscosities \([\eta]\) varying from 0.05 to 0.45 dL/g (toluene, 30.00 °C). In order to obtain an impression of the molecular weights corresponding to these viscosities we determined a Mark–Houwink relation. To this end a sample of racemic 2-isocyanooctane was prepared as indicated for the optically active compound 3a. This racemic monomer was polymerized by nickel chloride under various conditions to give polymers having intrinsic viscosities from 0.43 to 1.6 dL/g (toluene, 30.00 °C). Their weight-average molecular weights were determined by light scattering and were found to vary from 65000 to 140000. The ratio of \(M_w/M_n\) (gel permeation chromatography) for these polymers was about 6. From these data on the unfractionated samples the Mark–Houwink equation \([\eta] = 1.4 \times 10^{6} M_w^{0.75}\) was derived. Applying this equation to our optically active polymers 4a and 4c, we estimate that their viscosity-average molecular weights range from 20000 to 70000.

Compounds 4a-c showed a distinct N=C stretching vibration in the infrared spectrum at about 1630 cm\(^{-1}\). The UV spectra in hexane solution revealed a weak shoulder at about 310 nm (\(e \approx 60 \text{ L}(\text{mol} \cdot \text{cm})^{-1}\)) due to the n–π* transition of the N=C chromophore. This shoulder is at the onset of a much stronger absorption band which has its maximum in the far-UV region. The CD spectra of the polymers were recorded in hexane and are presented in Figure 1. The optical rotation values are given in Table I.

As low molecular weight model compounds for our polymers we chose the N-nepenthenylene derivatives of amines 1, compounds 5, were synthesized. These compounds were selected because they can easily be prepared from pivaldehyde and 1,15,18 Moreover, with these imines the problem of aldol-type condensation is avoided because an
α-CH group, such as that in 12, is absent. Also the formation of tautomeric enamine is prevented

\[ \text{CH} = \text{CH} = \text{N} \rightarrow \text{C} = \text{CH} = \text{NH} \]

Furthermore, it is advantageous for our CD study that imines of type 5 have the $E$ configuration exclusively. Compounds 5 showed an N=C stretching vibration in the infrared at 1667 cm$^{-1}$. The UV and CD spectra of these compounds were recorded in the same solvent as used for the corresponding polymers. The parameters are given in Table II. The optical rotation values are listed in Table I.

**CD Spectra.** Both the UV and CD spectra of the model compounds 5 show a band at approximately 248 nm (Table II). This band can be attributed to the $n-\pi^*$ transition of the N=C group. Our ($R$)-imines show a simple, negative Cotton effect at the wavelength indicated. This result is in line with the ORD spectrum of pentylidene-sec-butylamine, measured by Bonnett,17 which also shows a negative Cotton effect at 245 nm.

In polymers 4a-c the $n-\pi^*$ transition of the N=C group in the UV spectrum is shifted some 50 nm toward longer wavelength. The CD (Figure 1) in the region of 240–380 nm corresponds to this transition. At wavelengths $\lambda < 240$ nm the spectra are complicated by the onset of effects due to a transition of relatively high energy, most probably the $\pi-\pi^*$ transition of the N=C group. In the polymers both the chiral center in the side chain and the helical structure of the main chain will induce rotational power in the N=C chromophore.22 The contribution by the chiral side chain reveals itself in the CD spectra (Figure 1) as a relatively large negative band with a maximum $\Delta\epsilon$ value at about 260 nm. The helicity of the main chain is manifested as a positive "couplet",23 the positive part of which is visible as a band at about 325 nm. Such a positive couplet is also found in the CD spectrum of ($M$)-poly(tert-butyliminomethylene) (4d). For comparison this spectrum is included in Figure 1. From the similarity of the couplets we conclude that polymers 4a-c are predominantly in the $M$-helical configuration. The rotation data for these polymers (Table I) show appreciable shifts to positive values compared to the rotations of the model imines. This behavior suggests a dextrorotatory contribution by the helices. The combination of $M$-screw sense and dextrorotation is in line with what was found earlier for poly(tert-butyliminomethylene).2

Figure 1 shows that the maximum $\Delta\epsilon$ value of the positive CD band at 320–340 nm varies for the three polymers. If we assume that the main-chain helical configuration (apart from the $M$ or $P$ sense) is highly similar in polymers 4a-c, this $\Delta\epsilon$ value is a measure of the $M$-screw excess. We have calculated this excess from the maximum $\Delta\epsilon$ values, taking the $\Delta\epsilon$ of completely resolved poly(tert-butyliminomethylene) as the calibration value (Table III). Actually, for an accurate calculation the contributions made by the helical main chain24 and the chiral side chain should be considered separately. However, this is not really possible since the latter contribution is difficult to quantify for two reasons: (a) the lower wavelength region of the CD spectrum is disturbed by the effects on high-energy transitions and (b) the conformation of the side chain is unknown. This conformation is not necessarily similar to that in compounds 5, because both systems have a different steric environment. Therefore, the side-chain contribution cannot simply be taken from the model compounds. We have made the approximation that the $\Delta\epsilon$ values at longer wavelength are exclusively determined by the couplet. Thus, the numbers of Table III should be considered as useful only within the present series of polymers. They are probably lower limits.

The data in Table III show that the excess of $M$ screws diminishes with decreasing bulkiness of $R'$, as expressed by the $\lambda$ steric constant25 or approximately the Taft steric parameter.26 The $P$ excess in the polymer of ($R$)-sec-butyl isocyanide ($R' = \text{C}_3\text{H}_7$), which we synthesized earlier, fits into this series. We will try to explain this result in terms of the polymerization mechanism.

It was suggested earlier that polymerization of isocyanides by nickel(II) chloride proceeds via a circular sequence of insertion reactions around the nickel center ("merry-go-round" mechanism). The reaction starts from the square-planar complex Ni(CNR)$_4$.$^2$ The complex $\pi$ back-bonding from nickel to the isocyanide ligands is very small. The terminal carbon atom of such a ligand is

<table>
<thead>
<tr>
<th>Table III</th>
<th>CD and Optical Rotation Data of Polymers [(R)$\cdot$R'CH$\cdot$CHN=C&lt;]$_n$ and of (t-C$_4$H$_n$N=C&lt;)$_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R'$</td>
<td>$\Delta\epsilon_{max}^a$</td>
</tr>
<tr>
<td>C$_4$H$_n$</td>
<td>0.400</td>
</tr>
<tr>
<td>n-C$<em>4$H$</em>{13}$</td>
<td>0.115</td>
</tr>
<tr>
<td>i-C$_4$H$_9$</td>
<td>0.125</td>
</tr>
<tr>
<td>(t-C$_4$H$_7$N)$_n$</td>
<td>0.20</td>
</tr>
</tbody>
</table>

$^a$ $\Delta\epsilon_{max}$ of positive band at 300–400 nm. $^b$ Difference between the molar optical rotation value of polymer 4 and that of model compound 5. $^c$ ee = enantiomeric excess of indicated screw, assuming complete stereoregular polymerization. $^d$ See ref 25. $^e$ Taft steric constant. See ref 26. $^f$ See ref 7.
easily attacked by a nucleophile X− (e.g., Cl−) giving rise to ion 13 (Scheme III). In 13 the carbanion \( C^− \) is attached coordinatively to the nickel center. Its plane is approximately perpendicular to the C2C4C4 plane for steric reasons. There is free rotation around the bonds from Ni to C2, C3, and C4, but not around that to C1. Carbon atom C1 has gained in nucleophilicity. As a nucleophile it is able to attack a neighboring isocyancide carbon. This attack is facilitated when a new ligand enters apically from above and coordinates to the nickel. The direction of attack determines the screw sense. Continuing the sequence C1 → C2 → C3 in a merry-go-round fashion, a right-handed helix is obtained. In a similar way the sequence C1 → C4 → C3 results in a left-handed helix.

In our earlier studies, we assumed that the group SMLC in 13 (the relative steric requirements of the substituents are denoted by small (S), medium (M), and large (L)) is predominantly in the Z position, (Z)-13. This assumption was probably correct, since at that time we had ligands \( C^−(X) = NCR^+_RR^3 \) in which one of the substituents R1, R2, or R3 could coordinate to nickel and in this way favor a Z position. The present monomers do not have such additional ligand properties. Therefore, we must now take into account both the Z and E isomers of polymerization intermediate 13. It is known that, in comparable metal complexes as well as in imines, the \( E / Z \) ratio varies with temperature, solvent, and substituents.

Let us consider conformation (Z)-13. The competition between the attack by C1 on C2 and on C4 will depend on the relative energies of the respective transition states. These energies will be related to the steric interactions within the transition states. With regard to these interactions, the relative sizes and the arrangement of the substituents on the chiral carbon atom of ligand C1 are of interest. In the case under consideration, S = H, M = CH3, and L = R1. We have positioned the substituent L pointing away from the largest impediment in the transition state, viz., the nickel center. Attack by C1 will preferentially occur at the least hindered side, i.e., in (Z)-13 on C2. A \( P \) screw will be formed (rate constant \( k_P \)).

For intermediate (E)-13 we have to consider which of the two substituents on C1, namely, nickel center or X, will interfere more severely with L in the transition state. In our opinion this will be X since this group is placed in a cis position with respect to SMLC. Reasoning in a similar way as indicated for (Z)-13 one can derive that an M screw will be formed from (E)-13 (rate constant \( k_M \)).

What will be the influence of \( R^1 (=L) \) on the rate constants \( k_P \) and \( k_M \) and on the equilibrium constant \( K \)? Since \( R^1 \) is far away from the reaction centers (C1−C2 in (Z)-13 and C1−C4 in (E)-13) the effects of \( R^1 \) on \( k_P \) and \( k_M \) will be relatively small. However, the effect on the equilibrium constant \( K \) will be relatively larger. With a sterically more demanding \( R^1 \) (in Table III reading from top to bottom) the equilibrium will shift to the right since in (E)-13 the steric interactions are less severe than in (Z)-13. Thus, the preference for \( M \) helices will increase in the same direction.

**Experimental Section**

**Analytical Techniques.** Infrared (IR) spectra were recorded on a Perkin-Elmer 297 spectrophotometer. Ultraviolet (UV) spectra were obtained on a Perkin-Elmer 200 spectrophotometer. CD spectra were recorded on a high-field NMR spectrometer. This instrument measures the differential absorbance (\( A/A \)) with a sensitivity better than \( 1 \times 10^{-6} \). Optical rotations were measured on a Perkin-Elmer 241 polarimeter. \( ^1H \) and \( ^13C \) NMR spectra were obtained on a Varian EM390 instrument. Chemical shifts (\( \delta \)) are given in ppm downfield from internal tetramethylsilane. Abbreviations used are s = singlet, d = doublet, t = triplet, m = multiplet, and br = broad.

Elemental analyses were carried out by the Element Analytical Section of the Institute for Organic Chemistry TNO, Utrecht, The Netherlands, under the supervision of W. J. Buis. Melting points were determined on a Mettler FP5/FP51 photoelectric melting point apparatus. Solution viscosity data were obtained with a Cannon-Ubbelohde viscometer.

Weight-average molecular weights were measured on a Fica 50 automatic light scattering photometer. Gel permeation chromatography was performed in the Department of Chemical Technology, Enschede University of Technology.

**Poly[(R)-N-Formyl-2-octanamine (2a).** This compound was obtained in quantitative yield from 1a and from a 25% excess of ethyl formate, according to a standard procedure. \( ^1H \) NMR (CDCl3) \( \delta \) 8.00 (s, 1 H, CHO), 7.75 (d, 1 H, NH), 3.90 (m, 1 H, CH), 1.1–1.5 (m, 10 H, CH2), 1.10 (d, 3 H, CH3), 0.85 (t, 3 H, CH3).

**Poly[(R)-2-Octanaminomethylmethane (4a).** To a stirred solution of 14 mg (0.060 mmol) of NiC12·6H2O in 5 mL of methanol was added at ambient temperature 2.35 g (16.9 mmol) of POCl3 in 10 mL of methylene chloride. The reaction mixture was stirred at 0 °C for 1 h. Subsequently, the temperature was raised to 20 °C and the water was added slowly (foaming) while stirring. After the mixture had been stirred for a further 15 min, it was diluted with water and extracted with methylene chloride. After drying over sodium sulfate and evaporation of the solvent, the residue was distilled under diminished pressure: yield 3.80 g (85%) of 3a; bp 73–74 °C (8 mm) \( \delta \) 15.3 (3.1, chloroform); \( IR \) (KBr) 1635 (N=C) cm−1. Anal. Calcd for C12H22N2O: C, 69.0; H, 10.4; N, 10.5. Found: C, 68.6; H, 10.1; N, 10.3. The polymer contains a small amount of \( O \); compare also ref 33 and 34.

**N-Benzoyl-L-valine (7e) and N-Benzoyl-L-valine methyl ester (8e)**. These compounds were prepared from 1a, (6e, 7e, 8e, Fluka), according to standard procedures.

**N-Benzoyl-L-valine (9e).** This compound was prepared from 8e with an excess of LiAlH4 in boiling diethyl ether.

**Poly[(S)-2-Amino-3-methyl-2-butane (2c).** This compound was prepared from 2a by hydrogenation in excess 25% methanol-ether: \( mp \) 120 °C (lit. \( mp \) 118–119 °C); \( [\alpha]_D^{20} +14.5° \) (c 2.0, water) \( \delta \) 11.4° (c 1.9, methanol).

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at 115 °C for 20 h.34 In the HBr salt of 1le was used directly for
the synthesis of 1b.

(R)-3-Methyl-2-butylanime (1b). An amount of 19 g (77
mmol) of 1le was subjected to catalytic reduction with 1 g of 10%
 palladium-on-carbon in a solution of 15 mL of acetic acid and
20 g of sodium acetate in 100 mL of water. After stirring for 4 h
at room temperature and 1 atm of H₂ pressure, the calculated
amount of H₂ was consumed. Subsequently, the catalyst was
removed by filtration. The filtrate was rendered alkaline with
an excess of NaOH and extracted with ether. After drying over
KOH, HCl gas was led into the ether layer. The flocculent precipitate
was filtered off by filtration and recrystallized from acetone–ether: yield 8.8 g (93%) of the HCl salt of 1b; mp 216-217 °C
(lit.13 mp 205 °C); [α]2591 –2.25° (0.7, methanol); [α]2591 +3.25°, [α]2591 +3.68° (0.3, water) [lit.15 [α]2591 +3.5° (6.5, water)]; 1H NMR (CDCl₃) δ 3.15 (1 H, CH₃), 1.95 (m, 1 H, CH₂), 1.28 (d, 3 H, CH₃), 1.06 and 0.98 (2d, 6 H, (CH₃)₂).

(R)-N-Formyl-3-methyl-2-butylanime (2b). Amine 1b was
liberated from its HCl salt with an excess of aqueous NaOH and
formylated as indicated for the synthesis of 2a: [α]2591 +7.0° (1.2, chloroform); 1H NMR (CDCl₃) δ 4.07 (1 H, CH), 3.15 (1 H, CH₃), 2.90 (m, 1 H, CH), 1.03 (d, 3 H, CH₃), 0.75-1.60 (16, H, remaining H's).

Compound 5b: bp 72 °C (60 mm); [α]2591 –50.3° (2.1, hexane)
and [α]2591 –49.0° (0.9, chloroform); IR (neat) 1668 (N≡C) cm⁻¹;
1H NMR (CDCl₃) δ 7.41 (1 H, =CH), 2.68 (m, 1 H, CH), 1.6
(9, 3 H, t-C₃H₇), 1.05 (s, 9 H, t-C₃H₇), 1.03 (d, 3 H, CH₃), 0.77 and
0.85 (2d, 6 H, (CH₃)₂).

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tion for the Advancement of Pure Research (ZWO). We
thank Mr. H. Bokhorst for measuring the molecular
weights.

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Optically Active Polymapholytes Derived from L- and D-Carblylalanyl-L-histidine1,2

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ABSTRACT: Two optically active polymers with the general structure [CN=CH(CH3)C(O)NHCH(COOH)CH2Im]+, were prepared by the polymerization of L- and D-carblylalanyl-L-histidine with catalytic amounts of nickel(II) chloride. The monomers were synthesized from the dipeptides L- and D-alanyl-L-histidine by converting the amino group of these compounds into an isocyano function. The polymer from D-alanyl-L-histidine has a pKₐ(ImH⁺) of 8.4. It shows a polyelectrolyte viscosity behavior. Its molar rotation is [M]²⁰⁰很好 = 0°. Its CD spectrum has a couplet indicative of a right-handed helix. The other polymer has a pKₐ(ImH⁺) of 9.4 and a nonpolypelectrolyte viscosity behavior. Its [M]²⁰⁰很好 = +1025°. The CD spectrum contains a single positive band, which does not provide information about the screw sense.

Enzymes combine high catalytic activity with high selectivity. Certain polymeric model systems, called synthetic enzymes, have equal or even greater activity. Striking examples are the ethylenimine-based systems developed by Klotz et al. and very recently by Kunitake et al. The success in this field contrasts sharply with the little progress that has been made in imitating the enantioselectivity of enzymes. In our opinion there is a lack of appropriate chiral polymers which can be tested as enantioselective catalysts. We are currently investigating whether poly(isocyanides), more properly called poly(iminomethylenes), [RN=CH]ₙ, are useful as such polymers. These compounds are attractive for two reasons. First, they are readily obtainable from the monomeric isocyanides, RN=CH, with nickel chloride or a nickel(II) complex as catalyst. These monomers in turn can be prepared in great variety from the corresponding amines. Second, poly(iminomethylenes) have a stable helical structure. Left-handed and right-handed helices of poly(tert-butyliminomethylene) have been separated by resolution. Preferential formation of one screw occurs in the polymerization of one enantiomer of a chiral monomer.

In previous papers we reported on the synthesis and catalytic activity of imidazole-containing poly(iminomethylenes) such as poly(carbylhistidine), I, which could be models for hydrolytic enzymes. We were unable to get I in optically active form because its carboxyl- and imidazole-protected monomer suffered from a rapid racemization.

Results and Discussion

Synthesis. As far as we are aware, isocyanides derived from dipeptides containing histidine and other amino acids. The synthesis and physical properties of two polymers derived from such isocyanides, viz., poly(L-carblylalanyl-L-histidine) and poly(D-carblylalanyl-L-histidine), are described in this paper. Their catalytic activity in the hydrolysis of chiral esters will be described elsewhere.

Prior to the coupling of the amino acids, the carbonyl group of histidine and the amino group of alanine were protected as the methyl ester and the formamide group, according to Scheme 1. From the synthesis of I we learned that it is necessary to protect the imidazole nucleus before converting the N-formyl function into an isocyano function. Dicyclohexylcarbodiimide in acetonitrile/N,N-dimethylformamide was used as coupling agent.

From the synthesis of I we learned that it is necessary to protect the imidazole nucleus before converting the N-formyl function into an isocyano group. We chose the p-toluensulfonyl (Tos) group as an imidazole protecting group in 4. This group is easily introduced and can be removed under mild conditions, as we found recently. Moreover, a p-toluensulfonyl group lowers the basicity of the imidazole nucleus, which reduces the chance of

(37) Reference 35, p 316.