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4-Alkyloxazolidinedione. VI. The Polymerization of α-Amino Acid *N*-Carboxy Anhydride

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The relationships between the polymerization solvents and the conformation of the polypeptides formed were studied on the basis of the infrared absorption spectra and the X-ray diffraction diagrams of the polymers. Poly-L-α-amino-*n*-butyric acid and poly-L-*n*-valine, prepared in dimethylsulfoxide (DMSO) as a polymerization solvent, formed a β-conformation, but the respective polypeptides obtained in acetonitrile had an α-conformation. The conformational structure of poly-L-α-amino-*n*-butyric acid changed from β to α upon reprecipitation from a solution in dichloroacetic acid with ether. On the other hand, the conformational structure of poly-DL-α-amino-*n*-butyric acid did not change upon reprecipitation from a solution in formic acid and dichloroacetic acid.

In our previous papers in this series, we reported the solvent effect in the polymerization of DL-and L-alanine NCA on the conformation of the formed polypeptides.[1-3] The conformation of the polypeptides was influenced by the polymerization solvent: the polyalanine obtained in acetonitrile had an α-conformation, but the polyalanine obtained in DMSO had a β-conformation.[2] Further relationships between the conformation of the growing chains of poly-L-alanine and poly-L-leucine in DMSO during the polymerization of L-alanine NCA and L-leucine NCA and the polypeptides isolated from DMSO have also been discussed.[4]

The present study will report on the relationships between the conformations of the polypeptides obtained by the polymerization of several kinds of NCA's and the solvents used.

Results and Discussion

Infrared Spectra of L- Configurational polypeptides. The infrared absorption frequencies of the L-configurational polypeptides obtained in acetonitrile and DMSO are shown in Table 1. The spectra of poly-L-α-amino-*n*-butyric acid, poly-L-*n*-valine, poly-L-*n*-leucine, and poly-L-leucine obtained in acetonitrile all gave absorption bands at 1660 cm^{-1}, such bands are characteristic of α-polypeptides.[5] However, the spectra of poly-L-α-amino-*n*-butyric acid and poly-L-*n*-valine obtained in DMSO gave absorption bands at 1635 cm^{-1} and 1535 cm^{-1}, these bands are characteristic of β-conformational polypeptides.[5] These results showed that the L-configurational polypeptides obtained in acetonitrile had an α-conformation, while those obtained in DMSO had a β-conformation. Similar results have been obtained in the polymerization of DL- and L-alanine NCA's. On the other hand, the spectra of each poly-L-valine obtained in acetonitrile and in DMSO gave an absorption band at 1635 cm^{-1} which is characteristic of β-conformational polypeptides.

IR Spectra of DL-Configurational polypeptides. It has been reported that the conformation of poly-DL-alanine obtained in acetonitrile had an α-form and that the one obtained in DMSO had a β-form.[2] However, many polypeptides obtained in acetonitrile and DMSO, such as poly-DL-α-amino-*n*-butyric acid, poly-DL-*n*-valine, poly-DL-*n*-leucine, and poly-DL-valine, showed absorption bands at 1635 cm^{-1} and 1535 cm^{-1}. In the case of the poly-DL-leucine obtained in acetonitrile and DMSO, though,

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Table 1. IR spectra of L-conformational polypeptides

Polymer	Polymerization solvent	$\eta_{sp/c}$ (c=0.5 g/100 cc)	IR absorption bands (cm^{-1})	
			Amide I	Amide II
Poly-L-α-amino-*n*-butyric acid	Acetonitrile (ACN)	0.76 (DCA)	1660	1550
Poly-L-α-amino-*n*-butyric acid	Dimethylsulfoxide (DMSO)	0.43 (DCA)	1635	1535
Poly-L-*n*-valine	ACN	0.18 (DCA)	1660	1545
Poly-L-*n*-valine	DMSO	0.20 (DCA)	1635	1535
Poly-L-valine	ACN	0.11 (TFA)	1635	1545
Poly-L-valine	DMSO	0.13 (TFA)	1635	1545
Poly-L-leucine	ACN	1.20 (H_2SO_4)	1655	1550
Poly-L-*n*-leucine	ACN	0.44 (TFA)	1660	1545

DCA: Dichloroacetic acid. TFA: Trifluoroacetic acid.

the absorption bands of the polymers were found at 1655 and 1545 cm^{-1}.

The IR spectra of polyglycine obtained in acetonitrile was very similar to that of the polyglycine obtained in DMSO. These results are shown in Table 2.

X-Ray-Diffracion Diagrams. The X-ray diffraction pattern of oriented poly-γ-methyl-L-glutamate and poly-L-alanine have been extensively studied.[6-8] The diffraction pattern of oriented poly-γ-methyl-L-glutffmate of the α-form shows very strong peaks at 10.35 Å ($d_{10\bar{1}0}$) and around 4.4 Å. The diffraction diagram of this polymer obtained by the powder method showed strong peaks at 2θ=7.9° (d=10.25 Å) and 19.6° (d=4.4 Å), as is shown in Fig. 1. These peaks agreed with the peaks in the pattern of the oriented polymer, but the other peaks in the diagram were not observed clearly. The X-ray-diffraction pattern of oriented poly-L-alanine of the α-form showed strong peaks at 7.4 Å ($d_{10\bar{1}0}$) and 4.4 Å which belong to the flexible side chain in the polymer.[7] On the other hand, peaks at 4.37 Å (d) and 5.35 Å ($b/2$) have been observed in the poly-L-alanine of the β-form (d is the back-bone

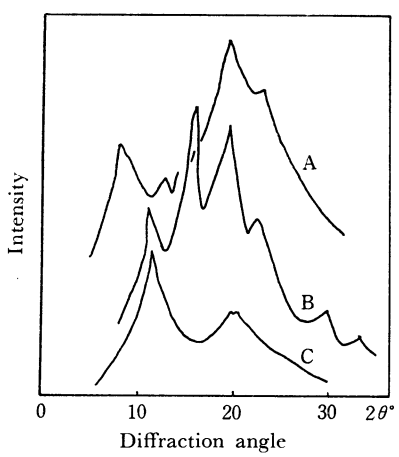

Fig. 1. X-ray diffraction diagrams of poly-γ-methyl-L-glutamate and poly-L-alanine.
A: Poly-γ-methyl-L-glutamate
B: Poly-L-alanine obtained in DMSO
C: Poly-L-alanine obtained in acetonitrile

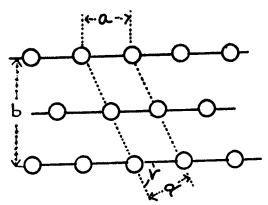

Fig. 2. Diagram showing in plan the packing of hydrogen bonded sheets of poly-L-alanine.

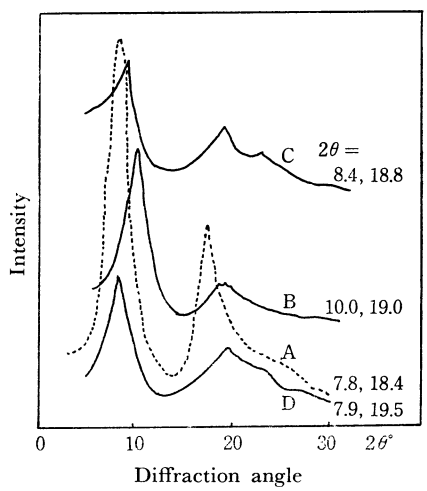

Fig. 3. X-Ray diffraction diagrams of L-conformational polypeptides obtained in acetonitrile.
A: Poly-L-leucine
B: Poly-L-α-amino-*n*-butyric acid
C: Poly-L-*n*-valine
D: Poly-L-*n*-leucine

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8) L. Brown and I. F. Trotter, *Trans. Faraday Soc.*, **52**, 539 (1956).

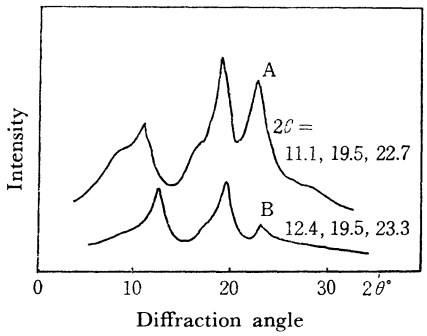

Fig. 4. X-ray diffraction diagrams of poly-L-α-amino-*n*-butyric acid and poly-L-*n*-valine obtained in DMSO.

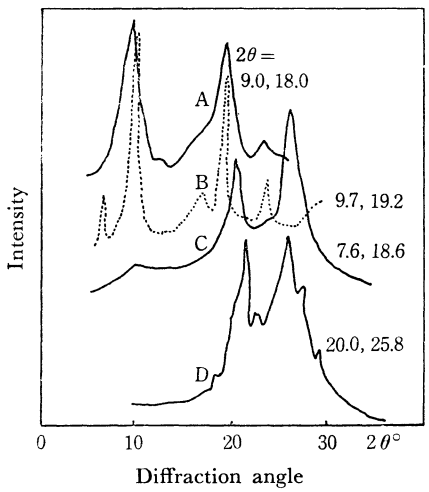

Fig. 5. X-Ray diffraction diagrams of polyglycine and poly-L-valine obtained in DMSO and ACN.
A: Poly-L-valine (ACN)
B: Poly-L-valine (DMSO)
C: Polyglycine (DMSO)
D: Polyglycine (ACN)

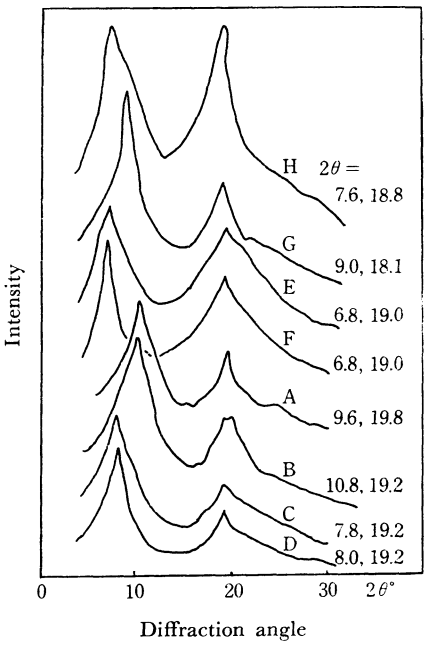

Fig. 6. X-Ray diffraction diagrams of DL-conformational polypeptides.
A: Poly-DL-α-amino-*n*-butyric acid (ACN)
B: Poly-DL-α-amino-*n*-butyric acid (DMSO)
C: Poly-DL-*n*-valine (ACN)
D: Poly-DL-*n*-valine (DMSO)
E: Poly-DL-*n*-leucine (ACN)
F: Poly-DL-*n*-leucine (DMSO)
G: Poly-DL-valine (ACN)
H: Poly-DL-valine (DMSO)

spacing and *b* is twice the side-chain length, as is shown in Fig. 2.[8]) The diffraction diagram of the poly-L-alanine obtained by the powder method (Fig. 1) also showed peaks at $2\theta=11.9°$ ($d=7.4$ Å) and 19.9° in the α-form and at $2\theta=16.6°$ ($d=5.35$ Å), 20.3° ($d=4.37$ Å) and 11.9° in the β-form.

The Diagrams of L-Configurational Poly-

Table 2. IR spectra of DL-configurational polypeptides

Polymer	Polymerization solvents	$\eta_{sp/c}$ ($c=0.5$ g/100 cc)	IR absorption bands (cm^{-1})	
			Amide I	Amide II
Poly-DL-α-amino-*n*-butyric acid	ACN	0.92 (DCA)	1635	1535
Poly-DL-α-amino-*n*-butyric acid	DMSO	0.22 (DCA)	1635	1535, 1515
Poly-DL-*n*-valine	ACN	0.20 (DCA)	1640	1535
Poly-DL-*n*-valine	DMSO	0.20 (DCA)	1640	1535
Poly-DL-*n*-leucine	ACN	0.40 (DCA)	1635	1545
Poly-DL-*n*-leucine	DMSO	0.23 (DCA)	1635	1545
Poly-DL-leucine	ACN	0.23 (DCA)	1655	1545
Poly-DL-leucine	DMSO	0.23 (DCA)	1655	1545
Poly-DL-valine	ACN	0.11 (DCA)	1635	1535
Poly-DL-valine	DMSO	0.11 (DCA)	1635	1515
Polyglycine	ACN	0.30 (TFA)	1635	1515
Polyglycine	DMSO	0.31 (TFA)	1635	1515

peptides. X-Ray-diffraction diagrams obtained by the powder method of poly-peptides consisting of L-configurational α-amino acid obtained by polymerization in acetonitrile are shown in Fig. 3. All these diagrams showed two peaks like those of poly-DL- and poly-L-alanine obtained in acetonitrile. On the other hand, the diagrams of poly-L-α-amino-*n*-butyric acid and poly-L-*n*-valine obtained in DMSO showed three or four peaks, like those of poly-L-alanine obtained in DMSO with the β-form.[2] These patterns are shown in Fig. 4. The diagram of poly-L-α-amino-*n*-butyric acid showed peaks at $2\theta=12.4°$, 19.5,° and $2\theta=23.3°$, while that of poly-L-*n*-valine showed peaks at $2\theta=11.1°$, 19.5°, and $2\theta=22.7°$.

For polyglycine and poly-L-valine, the infrared spectra were not affected by the polymerization solvent used, but the diagrams of both these polymers were different from each other (Fig. 5). Diffraction diagrams obtained by the powder method of almost DL-configurational polypeptides showed two strong peaks in spite of the fact that these polypeptides showed β-conformational spectra. These results are shown in Fig. 6.

Reprecipitation Treatment of the polymers. It has been reported that poly-DL- and L-alanine are changed from the α- to the β-form when treated in dichloroacetic acid and in formic acid.[2] Poly-L-α-amino-*n*-butyric acid was changed from the β- to the α-form by treatment in dichloroacetic acid. However, poly-DL-α-amino-*n*-butyric acid did not change its conformation upon treatment with formic acid and dichloro acetic acid. These conclusions are based on the infrared spectra and X-ray-diffraction diagrams.

Experimental

The NCA's used in this study were prepared in a high purity (chlorine content less than 0.02%) by a method reported previously.[1] The polypeptides were also prepared by a method reported previously.[1] The results are shown in Tables 1 and 2.

The X-ray-diffraction diagrams and IR spectra were obtained as has been reported previously.[2]

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