terpretation of this disparate behavior is that the electrochemical reactions involve sufficiently strong electronic coupling so that adiabaticity is achieved in each case; i.e., case 1 behavior is obtained. There are some indications from other measurements that electrochemical reactions can be markedly nonadiabatic, at least for surface–reaction site distances greater than ca. 6–8 Å.[23,41] On the other hand, there is evidence that simple outer-sphere electrochemical processes involving small metal complexes in aqueous media are more adiabatic than for the corresponding homogeneous-phase reactions.[25] Although the precursor-state geometries for such outer-sphere electrochemical processes are not known precisely, it is not unreasonable to envisage the reactant to lie suitably close to the surface so that adiabaticity is achieved. This would especially be the case if the reactant is able to at least partly penetrate the "inner layer" of solvent molecules adjacent to the metal surface.

Despite such uncertainties, the present results provide unusually direct evidence for the importance of orbital-overlap factors in outer-sphere redox reactivity. The differences in k_{ex}^{h} between the $Cp_2Fe^{+/0}$ and $Cp_2Co^{+/0}$, and the $(Cp\text{-}Me_5)_2Fe^{+/0}$ and $(Cp\text{-}Me_5)_2Co^{+/0}$, self-exchange reactions are of particular significance since these pairs of redox couples have structural properties that are otherwise virtually identical. Although such effects may well be prevalent in many other systems, they usually would remain masked by the presence of other obfuscating factors, such as large unknown variations in inner-shell barriers, work terms, and so on when the kinetics of related reactions are compared. It would be worthwhile to evaluate k_{ex}^{h} for other metallocene or arene couples featuring substituents that exert large electronic perturbations on the aromatic rings. The quantitative calculation of electronic matrix coupling elements for these systems using ab initio methods[24] would also be of considerable interest.

Acknowledgment. Some Raman spectroscopic data were obtained by Lam Leung and Dave Gosztola. This work is supported by the Office of Naval Research. The NMR instruments used in this work are supported by National Institutes of Health Grant RR 01077 at Purdue. G.E.M. gratefully acknowledges financial support from a Department of Navy Graduate Research Fellowship.

Registry No. $[(Cp\text{-}Me_5)_2Co]BF_4$, 112840-73-0; $[Cp_2CO]BF_4$, 52314-53-1; $[(CpMe_5)_2Fe]BF_4$, 100021-51-0; $(Cp_2Fe)BF_4$, 1282-37-7; $[(C_6H_6)_2Cr]BF_4$, 11077-48-8; $(Cp\text{-}Me_5)_2Co$, 74507-62-3; Cp_2Co, 1277-43-6; $(Cp\text{-}Me_5)_2Fe$, 12126-50-0; Cp_2Fe, 102-54-5; $(C_6H_6)_2Cr$, 1271-54-1.

(40) Admittedly, the electrochemical kinetics of $Cp_2Fe^{+/0}$ exchange at mercury can only be examined in a few solvents, such as acetonitrile, since the formal potential for this couple is close to, or positive of that for, mercury dissolution in most media. However, measurement of the exchange rate constant for this couple in acetonitrile under conditions as described in ref 1c yielded a value, ca. 5 cm s^{-1}, similar to that obtained for $Cp_2Co^{+/0}$.[1c]

(41) (a) Li, T. T.-T.; Weaver, M. J. *J. Am. Chem. Soc.* **1984**, *106*, 6106. (b) Weaver, M. J.; Li, T. T.-T. *J. Phys. Chem.* **1986**, *90*, 3823.

Infrared Vibrational Circular Dichroism in the Amide III Spectral Region of Peptides

G. M. Roberts, O. Lee, J. Calienni, and M. Diem*

Contribution from the Department of Chemistry, City University of New York, Hunter College, 695 Park Avenue, New York, New York 10021. *Received June 15, 1987*

Abstract: The sensitivity of infrared vibrational circular dichroism (VCD) toward peptide secondary structure has been investigated previously in the amide I, II, and A spectral regions. Here, the first observation of VCD in the amide III vibration is reported in alanyl dipeptides in aqueous solution. Amide I′ and II′ spectral data for the same molecules are presented as well. Since the frequency of the amide III vibration is known to exhibit qualitative conformational sensitivity in infrared and Raman spectra, its VCD is expected to be a probe toward secondary structure as well. The VCD results observed for diastereomeric alanyl dipeptides in the 1200–1500-cm^{-1} region suggest that such a conformational sensitivity of the amide III vibration exists.

Infrared vibrational circular dichroism (VCD) has been observed in the amide I, II, and A vibrations of peptide linkages in a number of poly(amino acids) and various peptides.[1-8] In all but two[7,8] of these reports, the peptides were studied in nonaqueous media. These VCD results, particularly in the amide I region, have demonstrated the conformational sensitivity of VCD and have shown that conformational information derived from VCD is complementary to that obtained from electronic CD for certain small peptides.[5] Consequently, a new view of peptide solution conformation has started to emerge, based on VCD structural information. The structural sensitivity of VCD may be thought of as originating from the coupling of vibrational motions that are a few bonds apart and that are sampled at a very rapid time scale, since VCD is a form of vibrational spectroscopy.

In the following publication, the first observation of amide III VCD of peptides in aqueous solution is reported. The significance of this observation lies in the fact that the frequency shift of the amide III vibration (1250–1350 cm^{-1}) exhibits qualitative peptide conformational sensitivity[9] and consequently has been used to complement crystallographic and electronic CD structural information. Thus, it is likely that the amide III VCD may exhibit sensitivity toward peptide secondary structure. The problem with the amide III vibration is that it is by far less defined in terms of the atomic displacements than other vibrations of the peptide linkage, such as the amide I, II, or A modes. Furthermore, deuteriation of the amide moiety changes the composition of the

(1) Singh, R. D.; Keiderling, T. A. *Biopolymers* **1981**, *20*, 237.
(2) Lal, B. B.; Nafie, L. A., *Biopolymers* **1982**, *21*, 2161.
(3) Sen, A. C.; Keiderling, T. A. *Biopolymers* **1984**, *23*, 1519.
(4) Sen, A. C.; Keiderling, T. A. *Biopolymers* **1984**, *23*, 1537.
(5) Narayanan, U.; Keiderling, T. A.; Bonora, G. M.; Toniolo, C. *Biopolymers* **1985**, *24*, 1757.
(6) Narayanan, U.; Keiderling, T. A.; Bonora, G. M.; Toniolo, C. *J. Am. Chem. Soc.* **1986**, *108*, 2431.
(7) Yasui, S. C.; Keiderling, T. A. *J. Am. Chem. Soc.* **1986**, *108*, 5576.
(8) Paterlini, G. M.; Freedman, T. B.; Nafie, L. A. *Biopolymers* **1986**, *25*, 1751.

(9) Lord, R. C. *Appl. Spectrosc.* **1977**, *31*, 187.

0002-7863/88/1510-1749$01.50/0

amide III vibration significantly more, and in a less predictable manner, than the other amide modes. Therefore, the data presented here had to be obtained in H_2O. In order to test for the feasibility of observing VCD in the amide III region in aqueous solution, one of the simplest chiral dipeptides, alanylalanine, was examined. Diastereomeric forms (i.e., L-Ala-L-Ala and L-Ala-D-Ala) were used to test for the sensitivity of the VCD signal toward changes in molecular structure.

In a previous study, the vibrations of various diastereomeric and isotopically substituted alanyl dipeptides in the 1200–1800-cm^{-1} region were investigated.[10,11] This study led to a detailed vibrational assignment of the vibrations in the amide III spectral region, which contains primarily the methine deformation modes at the chiral carbon atoms and the N–H in-plane deformation of the peptide linkage. Extensive coupling of these vibrations was found, resulting in the postulation of delocalized C*–H/N–H deformation vibrations to describe the mode that is commonly referred to as the "amide III" vibration. This assignment disagrees with previous assignments, which assumed coupling between the N–H deformation and the C–N stretching motion,[12] but agrees with normal coordinate calculations on small alanyl oligomers reported by Krimm.[13] The VCD results presented here substantiate our earlier vibrational results regarding the coupling of C*–H/N–H coordinates and open the possibilities of utilizing the amide III VCD intensities as novel conformational probes in peptides.

Experimental Section

Samples utilized in this investigation were commercially available (L-Ala-L-Ala, D-Ala-D-Ala, L-Ala-D-Ala, D-Ala-L-Ala) from Chemical Dynamics Corp. or Research Plus, Inc., and were used without further purification.

CD in the 190–250-nm region was obtained at isoelectronic pH using a commercial circular dichrograph (Jobin-Yvon Mark V) interfaced to an Apple computer. Sample concentrations were 0.1 mg/mL, and path lengths of 0.05 mm were used.

The Raman data shown have been discussed in detail.[11] Sample concentrations for the Raman spectra were 1 M.

All infrared and VCD data were obtained on a recently completed infrared dichrograph.[14] This instrument is a dispersive unit based on large-aperture ($f/4$) optics throughout. The light source is a 2400 K Nernst source (Artcor Corp.), which is imaged into the entrance slit of a 32-cm focal length Czerny–Turner monochromator (Instruments, SA, Model HR320), equipped with a 120 groove/mm grating. All reflecting surfaces, including the grating, are gold coated for maximum reflectance, and all transmitting elements are broad-band antireflection coated, unless the materials have low indices of refraction. Light modulation is accomplished by a ZnSe photoelastic modulator (Hinds International), operating at 31.2 kHz and providing quarter-wave retardation up to nearly 20 μm. In addition, the light is chopped at 79 Hz via an externally stabilized mechanical chopper (Laser Precision Corp.).

After the sample, which is usually contained between CaF_2 plates with a 15-μm Teflon spacer, the light is detected by a HgCdTe detector (Infrared Associates, Model HCT80) with a D^* of 3×10^{10}, operated at 77 K. Electronically, the VCD signal is obtained via a double-demodulation technique, utilizing a Princeton Applied Research (PAR) Model 124A lock-in amplifier to monitor the signal at 31.2 kHz and demodulating its output at 79 Hz by a PAR Model 5207 lock-in amplifier. This latter amplifier is interfaced to a computer (AT&T Model 6300 PC), which also controls the monochromator, the modulator, and another digital lock-in amplifier. The output of the PAR 5207 is normalized digitally via division by the total sample transmission.

Sample volumes required are about 5 μL. Sample concentrations were 1 M (in H_2O) for the amide III spectral region and 0.5 M (in D_2O) for the amide II′ and amide I′ regions. Further details of the data acquisitions are given in the figure captions.

Results and Discussion

Before a detailed vibrational and VCD discussion of the alanyl peptide results is possible, a short review of the vibrations in the 1200–1700-cm^{-1} spectral region of alanine itself is appropriate. These data, which are summarized in Table I, are taken from ref 14 and 15. The two vibrations at 1307 and 1355 cm^{-1} are assigned to the two C*–H deformations, which are degenerate in a symmetric molecule such as $CHCl_3$. These vibrations disappear upon deuteriation of the C*–H moiety, and appear as a distinct group frequency in most species containing a single, chirally perturbed C*–H group if coupling with energetically similar vibrations is not possible. These deformation vibrations exhibit opposite sign in the infrared VCD spectra, as might be expected from vibrations resulting from a perturbed degenerate state. The other alanine vibrations in the spectral region of interest at 1379, 1409, and 1462 cm^{-1} were assigned via isotopic substitution studies to the methyl symmetric deformation, the carboxylic anion symmetric stretching, and the methyl antisymmetric deformation modes, respectively.[15] The methyl deformation modes show no detectable VCD intensities.

Next, the vibrational spectra of the alanyl dipeptides in the 1200–1700-cm^{-1} region will be discussed. Raman frequencies of the dipeptides are summarized in Table II. The following assignments are based on the Raman data of six isotopically substituted dipeptides.[10,11] In D_2O, the amide I′ band (the prime denotes vibrations of the deuteriated peptide linkage) is observed in the Raman spectra at ca. 1670 cm^{-1}, with the antisymmetric carboxylic anion stretching mode at 1590 cm^{-1} (cf. Figure 1,

Table I. Vibrational Frequencies,[a] Assignment, and VCD Intensities of L-Alanine in Aqueous Solution in the 1200–1700-cm^{-1} Region

obsd freq, cm^{-1}	IR intens,[b] A	VCD intens,[b] $\Delta A \times 10^5$	assignment[c]
1307	0.14	5.3	δ(C*–H)
1355	0.15	−5.5	δ(C*–H)
1379	0.10		$\delta^s(CH_3)$
1409	0.23	1.8	$\nu^s(CO_2^-)$
1462	0.10		$\delta^{as}(CH_3)$
1590			$\nu^{as}(CO_2^-)$

[a] The frequencies are taken from the Raman data of ref 15. [b] Infrared absorption and VCD intensities are presented in absorbance, rather than extinction units, since the path length is not known accurately (c = 1 M (H_2O), path length ≈15 μm). [c] Symbols used: δ, deformation; ν, stretch; s, symmetric; as, antisymmetric.

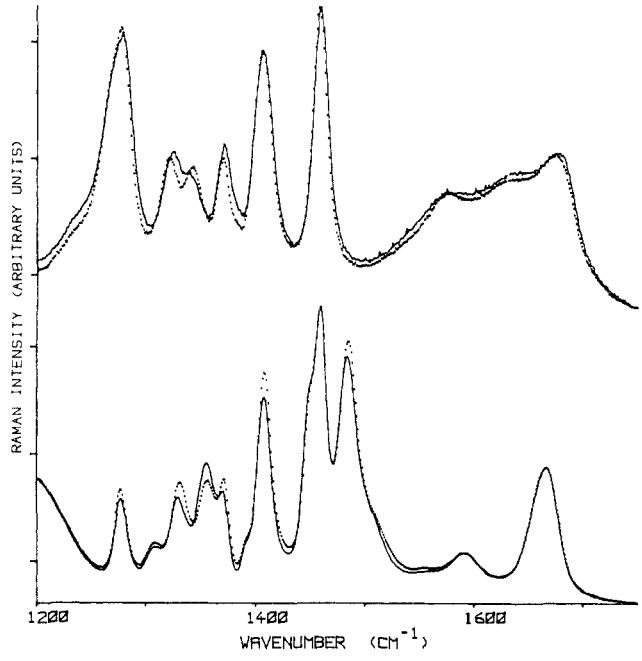

Figure 1. Raman spectra of L-Ala-L-Ala Raman spectra (solid trace) and D-Ala-L-Ala (dotted trace) in H_2O (top) and D_2O (bottom). Detailed experimental conditions are given in ref 11.

(10) Oboodi, M. R.; Alva, C.; Diem, M. *J. Phys. Chem.* **1984**, *88*, 501.
(11) Diem, M.; Alva, C.; Oboodi, M. R. *Biopolymers* **1984**, *23*, 1917.
(12) Miyazawa, T.; Shimanouchi, T.; Mizushima, S. I. *J. Chem. Phys.* **1958**, *29*, 611.
(13) Krimm, S.; Bandekar, J. *Biopolymers* **1980**, *19*, 1.
(14) Diem, M.; Roberts, G. M.; Lee, O.; Barlow, A. *Appl. Spectrosc.*, in press.
(15) Diem, M.; Polavarapu, P. L.; Oboodi, M. R.; Nafie, L. A. *J. Am. Chem. Soc.* **1982**, *104*, 3329.

Table II. Vibrational Frequencies,[a] Assignment, and VCD Intensities[b] of Alanylalanine in Aqueous Solution in the 1200–1700-cm^{-1} Region

L-Ala-L-Ala			L-Ala-D-Ala			
obsd freq, cm^{-1}	IR intens, A	VCD intens, $\Delta A \times 10^5$	obsd freq, cm^{-1}	IR intens, A	VCD intens, $\Delta A \times 10^5$	assignment
1280	0.15	1.8	1280	0.15	−1.3	*c*
1325	0.06	−0.7	1322	0.05		*c*
1340	0.03		1343	0.03	0.4	*c*
1372	0.2		1372	0.2		$\delta^s(CH_3)$
1407	0.34		1407	0.34		$\nu^s(CO_2^-)$
1460	0.2		1460	0.19		$\delta^{as}(CH_3)$
1590[d]	0.65	−0.5	1590[d]	0.65	0.5	$\nu^{as}(CO_2^-)$
1665[d]	0.45		1665[d]	0.45		amide I′

[a] The frequencies are taken from the Raman data of ref 15. [b] Cf. comment *b* of Table I; c = 1 M, path length ≈15 μm. [c] Coupled N–H/C_C*–H/C_N*–H deformation; cf. text. [d] D_2O data; c = 0.5 M, path length ≈15 μm.

bottom traces, and Table II). These two modes are masked by the strong water deformation vibration for solutions in H_2O (cf. Figure 1, top traces).

The amide II′ vibration is observed as a strong peak at 1480 cm^{-1}, whereas the amide II vibration is not observed at all in the Raman spectra. The symmetric CO_2^- stretching (1407 cm^{-1}), the antisymmetric methyl deformation (1460 cm^{-1}), and the symmetric methyl deformation (1372 cm^{-1}) vibrations occur nearly unchanged from the alanine monomer.

The next vibrations to lower frequency are the methine and the N–H deformation modes. In the alanyl dipeptides, one expects to observe four C*–H deformation vibrations, two from each Ala residue. Indeed, in the Raman spectra of L-Ala-L-Ala in D_2O, all four vibrations are observed at 1276 and 1329 cm^{-1} for the acid terminal methine deformations (henceforth referred to as the C_C*–H) and at 1305 and 1355 cm^{-1} for the C_N*–H deformations, where the subscript C and N denote acid and amine terminal residues, respectively. The shift of the C_C*–H vibrations is not unexpected, since any substitution at the nitrogen atom (even deuteriation of the $-NH_3^+$ group) causes similar shifts toward lower frequencies.[15]

For L-Ala-L-Ala in H_2O, however, the spectrum in this region is drastically different. Detailed isotopic studies revealed that the "uncoupled" N–H deformation, which occurs at 1336 cm^{-1} in L-Ala-*d*-L-Ala-*d*[11] mixes heavily with two of the four C*–H deformations. Thus, the strong band at ca. 1279 cm^{-1}, which had previously been assigned[16] to the amide III vibration, is a superposition of the "uncoupled" C_C*–H deformation at 1266 cm^{-1} and a highly coupled vibration at 1281 cm^{-1}, which consists of the N–H, one C_C*–H, and one C_N*–H deformation coordinates. The two bands observed in the Raman spectra at 1325 and 1340 cm^{-1} are assigned to the other two linear combinations of the three coupling coordinates, namely the N–H and the two C*–H deformations at the two chiral carbon atoms.

It is these two vibrations at 1325 and 1340 cm^{-1} that show distinct frequency and intensity differences between the L–L and the D–L (or L–D) diastereomers in the Raman spectra (cf. Figure 1, top traces) as well as in the infrared absorption spectra (cf. Figure 2, bottom). The differences are attributed to different coupling between these interacting coordinates due to geometric differences. Thus, the VCD of these vibrations was of particular interest, since such coupling should manifest itself in distinct VCD features.

This assumption turned out to be correct. Large VCD signals were observed for both the L–L and the L–D diastereomers in the 1280–1350-cm^{-1} region (cf. Figure 2). The most predominant VCD feature of L-Ala-L-Ala is located under the composite peak at 1280 cm^{-1}. It is sensitive to the chirality of the acid terminal alanine residue, for it changes sign between L-Ala-L-Ala and L-Ala-D-Ala. The distinctly negative VCD feature at 1325 cm^{-1} in L-Ala-L-Ala coincides with the lower frequency peak observed in the Raman spectrum whereas in L-Ala-D-Ala, the VCD exhibits a positive band coinciding with the higher frequency (1340 cm^{-1}) Raman band. It is interesting to note that only one of the two vibrations at 1325/1340 cm^{-1} shows VCD in each of the diastereomers and that the sign of their VCD signals is opposite.

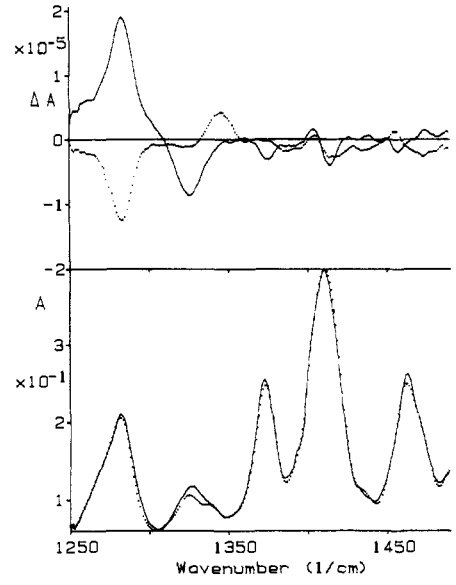

Figure 2. Infrared absorption (bottom) and VCD (top) spectra of L-Ala-L-Ala (solid trace) and L-Ala-D-Ala (dotted trace) in H_2O in the amide III spectral region. VCD spectra are corrected for instrument base line. Data acquisition conditions: scan speed, 50 cm^{-1}/min; time constant, 1 s; number of scans, 10; slits, 2 mm; band-pass, 4–6 cm^{-1}, depending on wavelength (nine-point smoothing).

The observed VCD intensities confirm the strong coupling between the N–H deformation and the C*–H deformations. It appears that the intensity at 1280 cm^{-1} is due to the coupled N–H/C_C*–H/C_N*–H coordinate, and not to the uncoupled C_C*–H deformation at 1266 cm^{-1}, since there is no indication of a low-frequency component in the VCD peak. One of the peaks at 1325/1340 cm^{-1} shows an intensity patterns reversal between the L–L and L–D diastereomers: in the L–L form, the 1325-cm^{-1} band is negative, whereas the high-frequency peak is positive in the L–D diastereomer. A simple interpretation of a coupled oscillator involving three near-degenerate coordinates was attempted but did not produce a useful model. Thus, a quantitative interpretation will require a normal coordinate analysis and intensity model calculations.

It is not possible to decouple the vibrational modes, as was done in the previous Raman work, by simply exchanging the proton in the N–H group. This is because the D_2O deformation vibration masks the spectral region up to about 1350 cm^{-1}.

None of the other vibrations in the 1250–1750-cm^{-1} spectral region exhibit significant differential intensities. The most intense feature observed outside the amide III region is the antisymmetric CO_2^- stretching mode at ca. 1590 cm^{-1}. Its VCD intensity is very small ($\Delta A/A \approx 1 \times 10^{-5}$ (cf. Figure 3), which is about the detection limit of the Hunter College VCD unit). The sign of the VCD of this vibration is, as expected, determined by the chirality of the acid terminal alanine residue; that is, the L–L and the D–L diastereomers exhibit the same sign VCD in this band. In Figure 3, the VCD of the L–L and the L–D species is shown for better

(16) Koenig, J. L. *J. Polym. Sci. Part D* **1972**, *6*, 59.

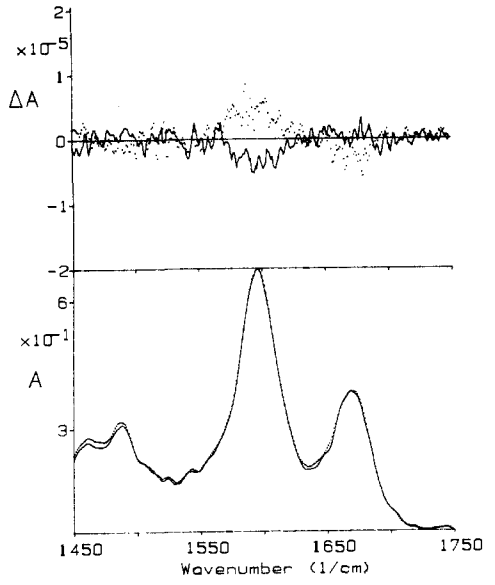

Figure 3. Infrared absorption (bottom) and VCD (top) spectra of L-Ala-L-Ala (solid trace) and L-Ala-D-Ala (dotted trace) in D_2O in the amide I′ and II′ spectral region. VCD spectra are corrected for instrument base line. Data acquisition conditions: scan speed, 50 cm^{-1}/min; time constant, 1 s; number of scans, 10; slits, 2 mm; band-pass, 4–6 cm^{-1}, depending on wavelength.

clarity. Neither the methyl deformations (at 1379 and 1462 cm^{-1}), the amide II′ at 1485 cm^{-1}, nor the CO_2^- symmetric stretching mode at 1409 cm^{-1} shows any significant VCD intensity.

At this point, a qualitative summary of the observed VCD intensity in this and other peptides is appropriate. It appears that nearly all peptide VCD observed to date is due to either of two mechanisms: In the C–H stretching region, all large signals have been due to methine stretching vibrations, which derive their intensity from large charge redistributions during the vibration (the "ring-current mechanism" of VCD).[17] In peptides which showed large C*–H stretching VCD, such as L-Ala-L-Ala, the signal all but disappeared upon deuteriation of the two methine protons.[18]

The other mechanism contributing to previously observed infrared VCD of peptides is that of coupling of identical transitions in a polymeric molecule. This mechanism is responsible for all amide A, amide I, and amide II VCD in poly(amino acids) and peptides studied by Nafie and Keiderling.[1-8] It was noted before that the amide I VCD nearly disappears as the peptide size goes below the tetrapeptide levels, since coupling of the transitions decreases. The VCD data presented here further confirm the correctness of this earlier observation, since no amide I′ or amide II′ VCD was observed in the dipeptides.

Thus, it appears that the chiral perturbation of a symmetric vibrational chromophore (such as CH_3, CO_2^-, or even a peptide linkage) is too small to produce significant VCD intensity and that most observed VCD is due to a coupled oscillator or a ring-current mechanism. In the case of a coupled oscillator, the coupling may be between identical groups in a polymeric unit, or energetically similar vibrations in close proximity, such as the N–H/C–H deformations described above.

The VCD results presented here give no indication for the presence of more than one conformer for each of the peptides in aqueous solution. On the basis of the VCD stretching intensities of the C*–H stretching motion, Nafie and co-workers[17] have postulated a fairly stable, intramolecularly hydrogen-bonded conformer with low flexibility which can enhance a vibrational ring current. The electronic CD spectra substantiate this view of only one predominant conformer, since only one major signal is observed in L-Ala-L-Ala at ca. 197 nm ($\Delta\epsilon/\epsilon = -3.5 \times 10^{-2}$ in water). This signal is much more intense and exhibits sign opposite the CD of L-Ala, which is centered at 207 nm with $\Delta\epsilon/\epsilon = 8.1 \times 10^{-4}$. The electronic CD changes sign when the acid terminal residue is exchanged against a D-Ala residue. This behavior is similar to the amide III VCD and to the C–H stretching VCD[19] in alanylglycine and glycylalanine, where the chirality of the acid terminal amino acid determines the vibrational optical activity.

Conclusion

The observation of the amide II VCD in peptides, which is due to heavily coupled vibrations involving the N–H deformation and the C*–H deformations on the adjacent residues, is possible in aqueous solution. An interpretation of the observed VCD in terms of detailed vibrational assignments has been presented. This interpretation is far more complicated than that of other amide vibrations, which are less delocalized and, consequently more amenable to an assignment based on group frequencies. Furthermore, the VCD of the localized vibrations (e.g., the amide I mode) can be interpreted in terms of a simple coupled oscillator model, whereas the amide III region will require detailed normal coordinate and VCD intensity calculations for a quantitative interpretation. Nevertheless, a significant amount of structural information appears to be contained in this spectral region, as evidenced by a comparison of the VCD of diastereomeric alanyl peptides.

Acknowledgment. Financial support from the National Institute of General Medical Science (Grant GM28619), the National Science Foundation (Grant CHE86-07934), and several PSC–CUNY faculty research awards is gratefully acknowledged.

Registry No. L-Ala, 56-41-7; L-Ala-L-Ala, 1948-31-8; L-Ala-D-Ala, 3695-80-5.

(17) Freedman, T. B.; Nafie, L. A. in *Topics in Stereochemistry*; Eliel, E. L.; Wilen, S. H., Ed.; Wiley: New York, 1987; pp 17, 114.
(18) Nafie, L. A.; Diem, M., unpublished results.
(19) Diem, M.; Gotkin, P. J.; Kupfer, J. M.; Nafie, L. A. *J. Am. Chem. Soc.* **1978**, *100*, 5644.