The products were benzhydryl phenyl ketone (29%), presumably from rearrangement of the expected epoxide, and triphenylethylene (31%). The olefin may result from an elimination reaction initiated by attack of hydroxide at the sulfonium site, formation of a methylide, or formation of a cyclic sulfurane.

In a typical experimental procedure the ketone was added to a solution of 1.1 equiv of phenylthiomethyllithium (Dabco) in THF. The reaction times were varied from 2 hr to overnight depending on the reactivity of the ketone. The β-hydroxy sulfides, usually purified by chromatography on silica gel, were treated with a slight excess of trimethyloxonium fluoroborate in methylene chloride until most of the oxonium salt had been consumed (homogeneous solution). Excess 0.5 *N* aqueous sodium hydroxide was added and the two phases were efficiently stirred together overnight. The epoxides thus produced were purified by distillation or by chromatography on silica gel.

Acknowledgment. We are grateful to the National Science Foundation for financial support.

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(13) A. P. Sloan Foundation Fellow, 1971–1973.

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Received February 5, 1973

Asymmetric Deuteration at the α Carbon of L-Aspartic Acid *via* the Template Action of a Dissymmetric Cobalt(III) Complex

Sir:

Stereospecific deuterium labeling of amino acids can be achieved enzymatically as for example with glutamate–oxaloacetate transaminase (aspartate aminotransferase) and glutamate–pyruvate aminotransferase (alanine aminotransferase) which have been used, respectively, to selectively deuterate aspartic acid[1] and glutamic acid[2] at the α carbon. As would be expected the deuteration proceeds with retention of configuration due to the asymmetry of the enzyme active site.

It has been known for some time that certain amino acid and peptide cobalt(III) chelates will undergo deuteration at the α carbon of a glycine or glycine-like chelate ring.[3-5] It was thought that if the deuteration were carried out employing a dissymmetric template such as a resolved *cis*-$Co(en)_2L_2^n$ complex, deuteration with (partial) retention of configuration might be observed. We have previously demonstrated that the diastereomers of $Co(en)_2$(L-aa)$^{2+}$ (aa = aspartate and glutamate chelated through the five-membered ring containing the α carbon as illustrated in Figure 1) will

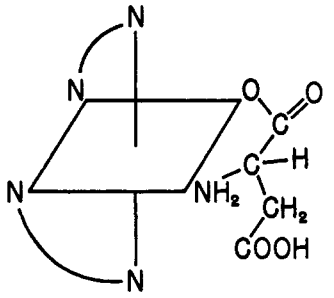

Figure 1. Aspartic acid chelated through the five-membered ring.

selectively deuterate at the α carbon to give the 2-^{2}H amino acids.[4] We have now shown that the deuteration proceeds with at least 77 ± 2% retention of configuration for the aspartic acid complex.

Aspartatobis(ethylenediamine)cobalt(III) perchlorate (1.34 g, 3.00 mmol) was dissolved in 10 ml of deuterium oxide. A mixture of the Na_2CO_3 (0.1 g) and $NaHCO_3$ (0.1 g) was added to bring the pD of the solution to *ca.* 9.5. The solution was allowed to stand at 35° until the pmr signal (a triplet) of the methine proton of the coordinated aspartic acid, Figure 1, was no longer detectable (3 days).[4] The solution was then added to 50 ml of 0.1 *N* HCl, and a solution of 2 g of $NaBH_4$ in 15 ml water was added dropwise until a pH of 7 was attained. The black precipitate was immediately removed by filtration using Celite Filter Aid and washed with a small amount of water. The combined filtrate was diluted to 100 ml with water and loaded on a Bio-Rad AG-1-X4 anion-exchange column (50–100 mesh, 165 mequiv capacity) at a rate of 2–3 ml/min. After rinsing with 1.5 l. of distilled water, the eluting solution was changed to 0.1 *N* HCl. Beginning 25 ml before the eluent became acidic, 150 ml of solution was collected and evaporated to dryness.

A quantitative amino acid analysis (Beckman 121C automatic amino acid analyzer) showed that the sample consisted of 0.12 g (0.9 mmol) of aspartic acid, a 30% yield based on the original amount of complex taken for deuteration (product is retained by the filtrate after reduction). From this information and comparison of the ORD curves obtained for the sample and a standard sample of L-aspartic acid, the aspartic acid obtained from the deuterated $Co(en)_2$(L-asp)$^{2+}$ was found to consist of 79% L and 21% D isomer. A repeat of the deuteration and isolation yielded 75% L and 25% D. The ORD and CD data were obtained with a JASCO Model ORD/UV-5 with CD attachment. The CD spectra were also recorded on a Cary Model 61 recording spectropolarimeter.[6] The pmr spectra were recorded on a Varian A-60 spectrometer with sodium 2,2-dimethyl-2-silapentane-5-sulfonate (TMS*) employed as an external standard.

Figure 2 summarizes the circular dichroism (CD) spectra obtained before and after deuteration of Λ-$Co(en)_2$(L-Asp)$^{2+}$.[7] If complete retention of configura-

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(4) J. I. Legg, and J. Steele, *Inorg. Chem.*, **10**, 2177 (1971).
(5) D. A. Buckingham, L. G. Marzilli, and A. M. Sargeson, *J. Amer. Chem. Soc.*, **89**, 5133 (1967).
(6) Although the analytical data obtained for the isomers agreed with previously obtained data, the Δε of the CD maxima were not identical (ref 4). Therefore, the spectra of the isomers used in this study were recorded on a Cary 61 and found to be in agreement with the spectra obtained with the JASCO. We are grateful to Professor B. L. Vallee of the Harvard Medical School for the use of the Cary 61.
(7) The absolute configurations of these complexes have been tentatively assigned, ref 4. However, the reasoning presented here is independent of these assignments. The IUPAC nomenclature, *Inorg. Chem.*, **9**, 1 (1970), is used.

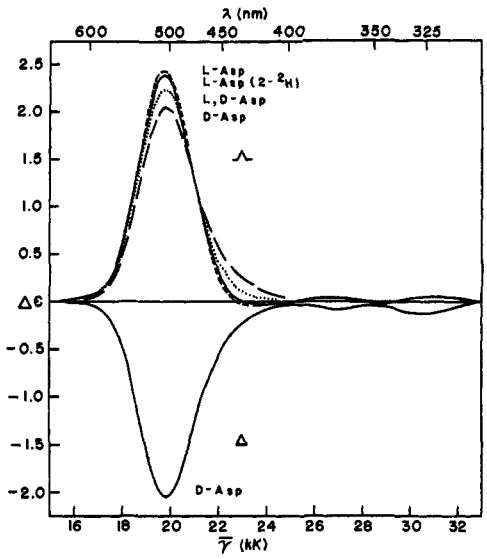

Figure 2. Circular dichroism spectra of various isomers of $Co(en)_2(asp)^{2+}$. For spectra shown with positive maxima at 507 nm: (- - - -) Λ(L) isomer before deuteration, (——) same isomer after deuteration, (· · · ·) Λ(L,D) isomer, (— — —) Λ(D) isomer.

tion had been obtained, the CD spectra should have been indistinguishable (assuming isotope effects to be negligible). However, that partial retention of configuration has been obtained can be seen from the following argument. In Figure 2 is also shown the spectrum obtained for Δ-$Co(en)_2$(L-Asp)$^{2+}$.[4] The mirror image of this isomer is Λ-$Co(en)_2$(D-Asp)$^{2+}$. Its CD spectrum can be obtained by mirroring the spectrum of the Δ isomer through the $\Delta\epsilon = 0$ axis and is shown in Figure 2. The spectrum thus generated would be that obtained if the L-aspartic acid had *inverted* in configuration during the deuteration (Λ(L) → Λ(D)). If total racemization had occurred (Λ(L) → Λ(D,L)), a CD spectrum representing an average between that of Λ-$Co(en)_2$(L-Asp)$^{2+}$ and Λ-$Co(en)_2$(D-Asp)$^{2+}$ would have been obtained, Figure 2. As can be seen in the figure, this spectrum has a lower $\Delta\epsilon$ than the spectrum obtained after deuteration of the Λ(L) isomer. Thus, partial retention of configuration is strongly indicated. The degree of racemization can be calculated from the relative $\Delta\epsilon$ values for the maxima at 507 nm to be 20% (90% L- and 10% D-amino acid).

In order to check these observations the aspartic acid was removed from the complex by reduction with $NaBH_4$[8] to give labile Co(II). Ion-exchange chromatography was used to separate the aspartic acid from the residual products. Although only a 30% yield was obtained, this was sufficient for characterization of the amino acid. The pmr spectrum of the aspartic acid thus obtained, Figure 3, shows that the amino acid is still deuterated at the α carbon since the methine triplet of the nondeuterated acid located between 5 and 4 ppm is absent. It is important to note that the reduction method employed does not appreciably exchange hydrogen (deuterium) at the α carbon which strongly suggests that the configuration about that carbon is retained during this process. The ORD spectrum obtained for the α carbon deuterated amino acid revealed that 77 ± 2% retention of configuration had been obtained. This sets a lower limit to the value of 90% calculated from analysis of the CD spectra of the deuterated and nondeuterated diastereoisomer.

(8) We are grateful to Professor A. Sargeson for suggesting the use of $NaBH_4$ in this step.

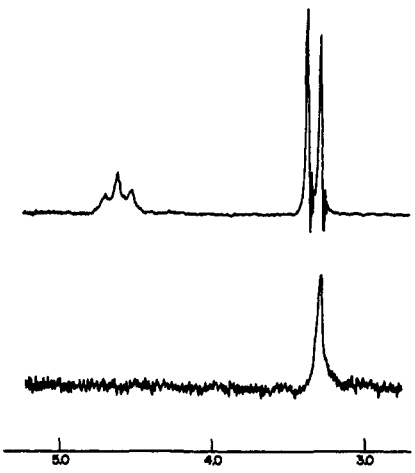

Figure 3. The pmr spectrum of the aspartic acid isolated from the reduction of $Co(en)_2([2\text{-}^2H]asp)^{2+}$ (lower) and of undeuterated aspartic acid (upper).

In contrast it is of interest to note that proton exchange and mutarotation rates for the corresponding alanine and valine complexes were essentially the same.[5] However, the conditions (*e.g.*, pD's >11) were not the same as those employed in this study. It is conceivable that in the aspartic acid complex the presence of a basic component on the side chain may lead to the preference of a particular diastereomeric form for the intermediate. The proposed mechanism for the deuteration involves the formation of a carbanion intermediate stabilized by resonance with the enolate form.[3c] This would bring about racemization unless the ^2H_2O molecule attacked the α carbon preferentially from one side. Such a situation could arise if the side chain interacted preferentially with the complex. A similar "three-point attachment" theory has been employed to account for the dissymmetric action of enzymes on substrates lacking chiral centers. The possibility of such an interaction in this and similar complexes has been discussed previously.[3e,4] To further investigate this hypothesis we are studying the deuteration of various other chelated amino acids.

Acknowledgments. We gratefully acknowledge support for this research through grants from the National Institutes of Health (GM 18983-01), National Science Foundation (GP-34490X), and the Petroleum Research Fund, administered by the American Chemical Society. J. I. L. is also grateful for a National Institutes of Health Special Fellowship, 1972–1973, for study at the Harvard Medical School.

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Received February 13, 1973

Buffer Catalysis in Epoxide Hydrolyses

Sir:

Interest in epoxide hydrolyses has recently been stimulated by the discovery that epoxides are interme-