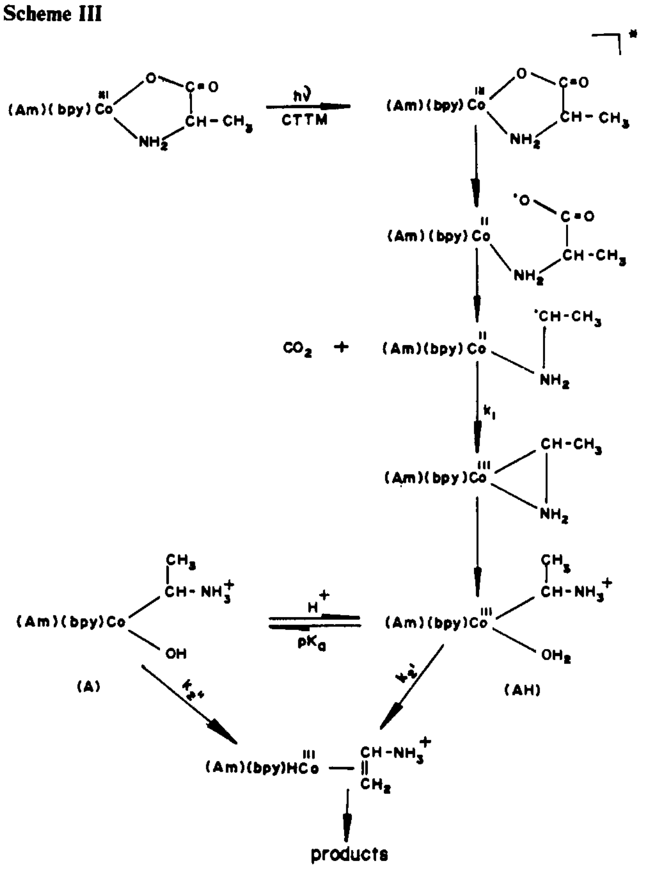
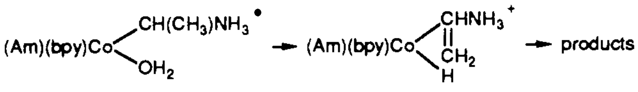
Scheme III

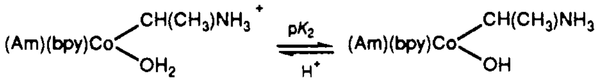


In the case of alanine-coordinated complex ions **3** and **5** the decomposition of the alkyl complex (bpy)(Am)Co–CH(CH_3)NH_3^+ produced photochemically obeys first-order kinetics and the presence of methyl group on the α-carbon atom of the amino acid alters the nature of the decomposition, which differs from that for the glycine complex (bpy)(Am)$CoCH_2NH_3^+$:



$$(Am)(bpy)Co\begin{matrix}CH(CH_3)NH_3^{+}\\OH_2\end{matrix} \rightarrow (Am)(bpy)Co\begin{matrix}CHNH_3^{+}\\ \| \\ CH_2\\ H\end{matrix} \rightarrow \text{products}$$

Hydride transfer from a β-carbon to a metal is well-known in aqueous medium.[31] The rate constant for the decomposition of (bpy)(Am)Co–CH(CH_3)NH_3^+ as a function of pH (Figure 5b) indicates a pK_a around 2.6, which is assigned to the dissociation of coordinated water (reaction 3). A general mechanism (Scheme III) is proposed for the formation and decay of the organocobalt complexes formed from cobalt(III)–bipyridine complexes containing α-alanine.



$$(Am)(bpy)Co\begin{matrix}CH(CH_3)NH_3^{+}\\OH_2\end{matrix} \underset{H^+}{\overset{pK_2}{\rightleftharpoons}} (Am)(bpy)Co\begin{matrix}CH(CH_3)NH_3^{+}\\OH\end{matrix} \qquad (3)$$

Cobalt–carbon bond stability has been studied[4,16,32] by generating the cobalt(III)–alkyl complexes, by the reaction of the pulse radiolytically produced free radicals such as $^{\bullet}CH_2OH$, $^{\bullet}CH_2CHO$, $^{\bullet}CH(CH_3)OH$, $^{\bullet}CH(OH)CH_2OH$, and $^{\bullet}CH_2COCH_3$, and looking at their decomposition. In the present study the stability of the cobalt–carbon bond is studied by producing aminoalkyl radicals photochemically, which is more difficult to generate in pulse radiolysis experiments. The present study illustrates the possibilities for further investigation of the products formed and the mechanistic details of the reactions of unstable organocobalt complexes using different amino acids and related biologically important ligands which could provide clues to vitamin B_{12} metabolism.

Acknowledgment. We wish to thank the CSIR, New Delhi, for granting a research fellowship to E.N. throughout the course of this investigation. The research work reported here is partially supported by the DST-SERC Thrust Area program and by the UGC-COSIST program.

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Predictions and Methods of Separation of Racemic Bidentate Ligands via Stereoselective Ligand Exchange Reactions

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The technique of molecular mechanics has been applied to the prediction of isomer distributions of several complexes of chiral quadridentate amine ligands in conjunction with some optically active bidentate substrates. Specifically, the systems reported comprise the cobalt(III) and nickel(II) complexes of *N*,*N'*-bis[2(*S*)-2-pyrrolidinylmethyl]ethane-1,2-diamine (*S*,*S*-epm) and *N*,*N'*-bis[2(*S*)-2-pyrrolidinylmethyl]propane-1,3-diamine (*S*,*S*-ppm) in combination with the chiral bidentate ligands propane-1,2-diamine, (pn) 2-pyrrolidinylmethanamine (pam), and alanine (ala). Agreement between all predicted and observed isomer ratios was within 5%. The experimentally determined enantiomer ratios were as follows: $[Co(S,S\text{-ppm})(pn)]^{3+}$, 49/51 *R*-pn/*S*-pn; $[Ni(S,S\text{-ppm})(pn)]^{2+}$, 57/43 *R*-pn/*S*-pn; $[Ni(S,S\text{-ppm})(pam)]^{2+}$, 44/56 *R*-pam/*S*-pam; $[Ni(S,S\text{-epm})(pn)]^{2+}$, 43/57 *R*-pn/*S*-pn; $[Ni(S,S\text{-epm})(pam)]^{2+}$, 70/30 *R*-pam/*S*-pam. Various experimental methods are reported for the determination of chiral separation.

Introduction

Many different approaches may be adopted in the pursuit of optically pure reagents. If direct synthetic methods such as asymmetric syntheses cannot be performed, then enantiomeric separation of racemic mixtures must be undertaken. This approach may take several forms, including fractional crystallization of diastereomers (with optically pure counterions),[1] conglomerate crystallization,[2] and various forms of chromatographic separation incorporating both chiral mobile and stationary phases.[3]

Separation of racemic mixtures based on stereoselective ligand exchange reactions specifically involves coordination of chiral substrate molecules to a chiral matrix host.[4] The relative sta-

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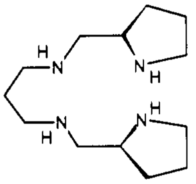
bilities of the diastereomeric adducts at equilibrium determines the degree of selectivity. It is this technique in particular which has interested us, and in earlier work[5–7] we have been concerned with accurate predictions, via molecular mechanics, of equilibrium isomeric mixture ratios of cobalt(III) complexes. Having confirmed by experiment that isomeric distributions of these systems could be predicted, we have applied the same technique to the design of chiral matrix systems that will promote enantioselective ligand exchange reactions.

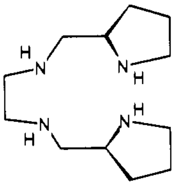
The chiral matrices employed in this work are nickel(II) and cobalt(III) complexes of the chiral ligands *S,S*-ppm and *S,S*-epm. The syntheses of both quadridentate amine ligands have been reported,[8,9] and in one instance a cobalt(III) complex of *S,S*-ppm was employed in an enantioselective epimerization of some coordinated amino acids.[10] We have been concerned with enantioselective separations rather than syntheses, and specifically three different experimental methods for racemate separation are reported herein. In each case the experimental determination has been accompanied by a molecular mechanics prediction of the isomer distributions.

Experimental Section

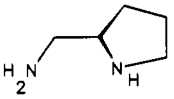
Syntheses. The ligands *N,N'*-bis[2(*S*)-2-pyrrolidinylmethyl]ethane-1,2-diamine (*S,S*-epm) and *N,N'*-bis[2(*S*)-2-pyrrolidinylmethyl]propane-1,3-diamine (*S,S*-ppm) were prepared from literature syntheses.[8,9] The synthesis of (*S*)-2-pyrrolidinylmethanamine (*S*-pam) from L-proline has been reported,[11] but an improved[12] synthesis was employed for the present study. The same synthesis was employed in order to obtain *rac*-pam; however, *rac*-proline was used as the precursor. The complexes *trans*-[Co(*S,S*-ppm)Cl_2](ClO_4),[8] [Ni(*S,S*-ppm)]$(ClO_4)_2$,[13] and [Ni(*S,S*-epm)]$(ClO_4)_2$[9] were prepared as described in the literature. All other chemicals were obtained commercially.



ppm



epm



pam

(i) Precipitation of the Substrate Complex. (*N,N'*-Bis[2(*S*)-2-pyrrolidinylmethyl]ethane-1,2-diamine)(propane-1,2-diamine)nickel(II) Perchlorate, [Ni(*S,S*-epm)(pn)]$(ClO_4)_2$. To a solution of [Ni(*S,S*-epm)]$(ClO_4)_2$ (0.518 g, 1.07 mmol) in a minimum volume of ethanol (ca. 20 mL) was added 2 equiv of racemic pn (0.183 mL, 2.14 mmol). An immediate color change from yellow to purple occurred. The volume of the solution was reduced to ca. 5 mL; the resultant purple precipitate was collected by filtration. The precipitate was thoroughly washed with diethyl ether until no pn could be detected in the washings (by addition of a small amount of aqueous Cu^{2+}_{aq} to afford a purple solution).

(*N,N'*-Bis[2(*S*)-2-pyrrolidinylmethyl]ethane-1,2-diamine)(2-pyrrolidinylmethanamine)nickel(II), [Ni(*S,S*-epm)(pam)]$^{2+}$. This compound was prepared in a manner identical to that for [Ni(*S,S*-epm)(pn)]$(ClO_4)_2$, except the quantities were [Ni(*S,S*-epm)]$(ClO_4)_2$ (0.242 g, 0.5 mmol) and pam (0.1 g, 1.0 mmol).

The precipitated complex of [Ni(*S,S*-epm)(L)]$(ClO_4)_2$ (L = pn, pam) was dissolved in water (250 mL) and charged on a column of Sephadex C-25 cation-exchange resin (Na^+ form). Washing with 0.1 M $NaClO_4$ (pH 8–9) removed the free amine substrate. The ligand solution was evaporated under reduced pressure to dryness at room temperature.

The residues were suspended in 1,2-dichloroethane (5 mL) and triethylamine (3 mL). Excess (*R*)-methoxy(trifluoromethyl)phenylacetyl chloride (*R*-MTPA) (~0.5 g) was added, and the suspension was refluxed for 3 h. The mixture was evaporated to dryness, the solid was suspended in 10 mL of diethyl ether/1 M HCl (1/1), and then the mixture was filtered. The aqueous and organic phases were separated, and the aqueous phase was extracted twice with diethyl ether. The ether phases were combined, washed with 0.2 M sodium hydroxide solution, and dried over anhydrous Na_2SO_4. The solution was evaporated to an oil, which was analyzed by ^1H NMR spectroscopy.

(ii) Reversible Substrate Coordination to the Chiral Matrix Charged on an Ion-Exchange Resin. (*N,N'*-Bis[2(*S*)-2-pyrrolidinylmethyl]propane-1,3-diamine)(propane-1,2-diamine)nickel(II), [Ni(*S,S*-ppm)(pn)]$^{2+}$. To a solution of [Ni(*S,S*-ppm)]$(ClO_4)_2$ (0.249 g, 0.5 mmol) in ethanol/water (100 mL, 4/1) was added a slurry of Sephadex C-25 cation-exchange resin (ca. 30 mL). To this mixture was added a 2/1 excess of racemic pn (0.085 mL, 1.0 mmol) to afford a purple complex bound to the resin. The mixture was allowed to equilibrate over 2 h at room temperature. The suspension was filtered and washed with ethanol until no pn could be detected in the filtrate.

(*N,N'*-Bis[2(*S*)-2-pyrrolidinylmethyl]propane-1,3-diamine)(2-pyrrolidinylmethanamine)nickel(II), [Ni(*S,S*-ppm)(pam)]$^{2+}$. This compound was prepared in a fashion identical to that of [Ni(*S,S*-ppm)(pn)]$^{2+}$ with quantities of [Ni(*S,S*-ppm)]$(ClO_4)_2$ (0.249 g, 0.5 mmol) and pam (0.1 g, 1 mmol).

The Sephadex resin, including [Ni(*S,S*-ppm)(L)]$^{2+}$ (L = pn, pam), was washed with water (50 mL, pH 8–9) four times. The complex immediately became yellow, with the substrate passing into the aqueous phase. The washings were combined and evaporated to an oil. The mixture of ligands was reacted with *R*-MTPA as described above.

(iii) Destruction of the Chiral Matrix. (*N,N'*-Bis[2(*S*)-2-pyrrolidinylmethyl]propane-1,3-diamine)(propane-1,2-diamine)cobalt(III), [Co(*S,S*-ppm)(pn)]$^{3+}$. To a solution of *trans*-[Co(*S,S*-ppm)Cl_2](ClO_4) (0.469 g, 1.0 mmol) in methanol (250 mL) was added racemic propane-1,2-diamine (0.172 mL, 2.0 mmol). The solution was refluxed for 20 h and then diluted to 500 mL and charged on a column (10 × 2 cm) of Sephadex C-25 cation-exchange resin (Na^+ form). A single yellow band was removed with 0.2 M sodium chloride solution, and this was evaporated to dryness. The above mixture of [Co(*S,S*-ppm)(pn)]$^{3+}$ and NaCl was dissolved in hydrochloric acid (20 mL, 1 M), and ca. 2 g of granulated zinc amalgam was added. The solution was stirred at 60 °C for 3 h, which afforded a pink solution of Co^{2+}_{aq}, free *S,S*-ppm, and pn. Precipitation of cobalt(II) was achieved by addition of excess sodium sulfide (ca. 2 g) in a well-ventilated fume hood. The solution was stirred at 60 °C for 15 min and then filtered. The filtrate was stirred vigorously at 60 °C for 1 h to eliminate hydrogen sulfide fumes and then evaporated to dryness. The residues were reacted with *R*-MTPA as described above.

Physical Methods. The ^1H NMR spectra of all samples in [$^2H_6$]dimethyl sulfoxide solution were recorded with a Varian Gemini 300-MHz spectrometer. Integration of the N–H(amide) resonances of the diastereomeric mixture formed by coupling of the amine substrate and optically pure *R*-MTPA determined the enantiomer ratio. Relevant reference spectra of the MTPA adducts of *R*- and *S*-pn were reported in an earlier publication.[7] The ^1H NMR spectra of the *R*-MTPA adducts of *R*- and *S*-pam in [$^2H_6$]DMSO exhibit triplets at δ 8.53 and 8.57 ppm each with coupling constants of 6 Hz. Note that both pn and pam may react with MTPA at either amine nitrogen.

Molecular Mechanics. Molecular mechanics calculations were performed with the strain energy minimization program MOMEC87.[14] The model and force field have been reported.[15] The strain energies in each structure were minimized until the shift in each atomic Cartesian coordinate was less than 0.001 Å. Trial coordinates for the calculations were obtained by constructing the complex with the graphics program SMILE.[16] Plots of refined structures were produced with ORTEP.[17]

The predicted isomer and conformer ratios were calculated from the minimized strain energies of each refined structure using eqs 1 and 2,

$$N_i = e^{-E_i/RT}/Q_T \qquad (1)$$

$$Q_T = \sum e^{-E_i/RT} \qquad (2)$$

where E_i is the strain energy relative to the lowest energy structure. Lists

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of calculated strain energies for all of the present systems have been supplied as supplementary material.

Results and Discussion

It has been our aim, both in the present study and in other areas of coordination chemistry,[18] to predict structural and thermodynamic properties of systems with molecular mechanics prior to performing the actual experiment. Such an approach may, if correctly carried out, obviate the need for an experiment if the predicted results do not meet the original goals of the work. One can then make adjustments to the model in order to improve its performance. Obviously much time and effort may be saved in preparative chemistry if this procedure is followed judiciously. In other words, the systematic design of an efficient chiral matrix for racemate separation based on ligand exchange must be accompanied by quantitative predictions preceding the experimental determination.

The various reactivities and stabilities of the present systems necessitated different approaches to the experimental determination of chiral separation. The complexes containing $[\mathrm{Ni}(S,S\text{-ppm})]^{2+}$ as a chiral matrix formed octahedral adducts that were reasonably stable in aqueous alcohol, whereas the closely related $[\mathrm{Ni}(S,S\text{-epm})]^{2+}$ did not bind either pn or pam to any noticeable extent in the presence of water. A similar reluctance of $[\mathrm{Ni}(S,S\text{-epm})]^{2+}$ to form octahedral complexes has been noted previously.[10] The racemate separation experiment was therefore conducted in alcohol for the $[\mathrm{Ni}(S,S\text{-epm})]^{2+}$ chiral matrix, with virtually quantitative precipitation of the octahedral substrate complex occurring upon addition of the substrate. It is of critical importance that all diastereomers of the octahedral adduct are precipitated and not merely the least soluble isomers. Hydrolysis of the octahedral complex was rapid upon dissolution in water. Separation of the square planar complex from the free substrate was achieved by cation-exchange chromatography. A somewhat different approach was possible with the $[\mathrm{Ni}(S,S\text{-ppm})]^{2+}$ system. The square planar precursor complex was charged on an ion-exchange resin, and then addition of a 2-fold excess of the substrate (either pn or pam) resulted in a bound octahedral adduct and a separate fraction containing the uncoordinated excess ligand. The excess ligand was removed by washing the resin with alcoholic base. The remaining octahedral complex was hydrolyzed rapidly with aqueous base, which afforded the bound fraction of the substrate.

The inert nature of chiral matrices based cobalt(III) complexes presented a different problem. The formation of the hexaamine adduct was quite slow, and complete complexation of the chiral matrix was not always a simple procedure. In particular it was difficult to determine whether a genuine equilibrium between substrate and the chiral matrix had been established. If one could be sure that the ligand substitution reaction went to completion, then analysis of either the excess ligand or the fraction that was bound to the chiral matrix should lead to the same overall result. In cases where incomplete complexation occurred, the method of analyzing the uncomplexed fraction is clearly not meaningful, since it would not only contain some partially resolved ligand but also an unknown amount of racemic ligand. Therefore, analysis of the bound fraction was always the more reliable method in determination of the degree of separation. We have addressed the problems inherent to the equilibration of cobalt(III) hexaamine complexes in earlier publications,[5-7] and we are satisfied that the present results reflect a genuine equilibrium between substrate and chiral matrix. Recovery of the $[\mathrm{Co}(S,S\text{-ppm})\mathrm{Cl}_2]^+$ chiral matrix following the separation was not possible, and complete ligand dissociation was necessary in order to analyze the degree of racemate separation. The syntheses of S,S-ppm and of S,S-epm are rather expensive and tedious so it was not reasonable to pursue at length the cobalt(III) chemistry of these systems. For this reason, only one example of chiral separation with a cobalt(III) complex was pursued, and the study concentrated on the reversible nickel(II) systems.

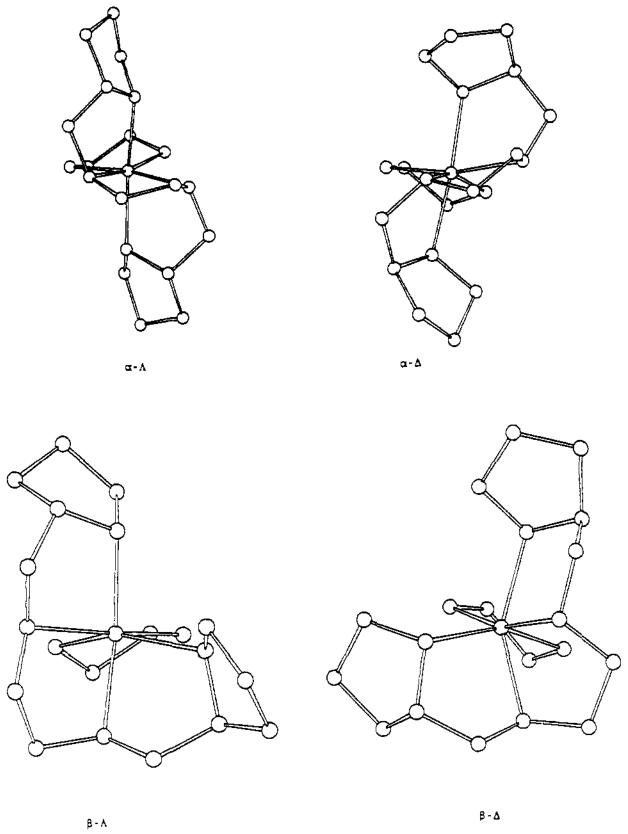

Figure 1. The four cis geometric isomers of an octahedral complex of S,S-epm.

The chiral matrix complex must exhibit two reactive coordination sites in cis positions if introduction of the substrate is to be facile. In the present systems, there are four geometric isomers that meet this requirement, and these isomers are shown in Figure 1, where complexes of S,S-epm are given. The same nomenclature applies for complexes of S,S-ppm. The two symmetrical (C_2) α isomers, Λ and Δ, differ in that the pyrrolidinyl rings are oriented toward and away from the substrate molecule on the complex, respectively. The asymmetric β isomers (Λ and Δ) are also shown in Figure 1. When a racemic mixture of a bidentate is introduced to the complex, there are four possible isomers for each geometry described above; i.e., both enantiomers may bind in two ways (for the α isomers these two positions are symmetry related). One must also consider the conformational freedom of both the quadridentate matrix ligand and the substrate. Each pyrrolidinyl ring possesses two conformations, exo and endo where the methylene group trans to the bond connecting the two chirotopic atoms (C and N) may be on either side of the plane defined by the remaining four atoms comprising the pyrrolidinyl ring. The five-membered chelate ring that contains the connecting ethylene group in S,S-epm may adopt a λ or δ conformation. The analogous six-membered chelate ring in S,S-ppm may adopt a number of conformations, but the chair conformer is clearly the most stable and has invariably been observed in crystal structures of complexes of S,S-ppm,[19-21] thus allowing one to neglect other possibilities. The substrates similarly possess conformational freedom, via the λ and δ conformers of pn and the exo and endo conformers of pam. When all of these combinations are considered, the number of possible isomers (including conformers) of $[\mathrm{M}(S,S\text{-epm})(\mathrm{L})]^{n+}$ (L = pn, pam) is 192 and for $[\mathrm{M}(S,S\text{-ppm})(\mathrm{L})]^{n+}$ the total is 96. This is certainly an awesome prospect if one wishes to repeat such calculations on a variety of systems. Fortunately, one can eliminate

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Table I. Calculated and Experimentally Determined Ratios of the Complexed Enantiomeric Substrates at Equilibrium

		calcd ratio		exptl ratio	
chiral matrix	substrate	% *S*	% *R*	% *S*	% *R*
Co(III)/ppm	pn	55	45	51	49
	pam	64	36		
	ala	33	67		
Co(III)/epm	pn	78	22		
	pam	39	61		
Ni(II)/ppm	pn	44	56	43	57
	pam	53	47	56	44
Ni(II)/epm	pn	62	38	57	43
	pam	27	73	30	70

some isomers from the calculation by performing a preliminary analysis with a simple bidentate ligand, such as ethane-1,2-diamine, which narrows the number of geometric isomers to four (α-Λ, α-Δ, β-Λ, β-Δ). It was found that, for like conformers, the strain energies of β-Δ-[Co(L)(en)]$^{3+}$ (L = *S,S*-epm and *S,S*-ppm) were at least 20 kJ mol^{-1} less stable than their corresponding β-Λ isomers. Energy differences as great as these dictate that the β-Δ isomers would never be observed experimentally so further calculations with these isomers were not pursued. In addition, it has been found that formation of the symmetrical α isomers of [M(*S,S*-ppm)(en)]$^{n+}$ are similarly quite unstable (with respect to β-[M(*S,S*-ppm)(en)]$^{n+}$), due primarily to a nonbonded interaction between a methylene hydrogen bound adjacent to the pyrrolidinyl ring and another hydrogen atom bound to the central carbon of the six-membered chelate ring. Similar results have been found in studies of other cobalt(III) complexes containing six-membered chelate rings, where it has been generally found that such complexes will prefer to exhibit *meridonal* rather than *facial* arrangements of adjacent triamine residues.[22] Nevertheless, linear triamine ligands possessing six-membered chelate rings do adopt facial *geometries*,[23,24] but it has been as a result of the accompanying tridentate ligand forcing this geometry.

The experimentally determined isomer ratios are in excellent agreement with those predicted by molecular mechanics calculations (Table I). It is interesting that the chiral matrix Ni(II) complexes of *S,S*-ppm and *S,S*-epm exhibited opposite selectivities; i.e., [Ni(*S,S*-epm)]$^{2+}$ showed a preference for *S*-pn and *R*-pam, whereas [Ni(*S,S*-ppm)]$^{2+}$ was selective toward *R*-pn and *S*-pam. The origins of this reversal are rather difficult to trace. The minimized strain energies of the 10 most stable isomers of [Ni(*S,S*-ppm)(pam)]$^{2+}$ were within ca. 1.5 kJ mol^{-1} of each other. Within this group of isomers there was a roughly equal distribution of *R*- and *S*-pam so a rather poor enantioselectivity was resultant. On the other hand, the [Ni(*S,S*-epm)(pam)]$^{2+}$ system displayed genuine selectivity, where the strain energy of the most stable *R*-pam isomer was some 3 kJ mol^{-1} less than the most stable *S*-pam adduct. There was also a reversal in the selectivities toward pn of [Ni(*S,S*-ppm)(pn)]$^{2+}$ compared with [Co(*S,S*-ppm)(pn)]$^{3+}$. It should be said that both systems were rather indiscriminant toward the incoming bidentate so further discussion of this apparent anomaly does not seem warranted.

An earlier reported[10] epimerization of an isomerically pure sample of β-Λ-[Co(*S,S*-ppm)(*R*-ala)]$^{2+}$ afforded a 82/18 ratio of coordinated *R*- to *S*-alanine at equilibrium. In this work, we have considered all isomers of the complex whereas the previous study was restricted to the two possible products of the epimerization reaction, i.e. β-Λ-[Co(*S,S*-ppm)(*S*-ala)]$^{2+}$ and β-Λ-[Co(*S,S*-ppm)(*R*-ala)]$^{2+}$, where the alanine amino group was cis to both pyrrolidinyl groups. We have also considered the isomers where the carboxyl group is cis to the pyrrolidinyl groups and found the overall selectivity to be 67/33 *R*/*S*.

The chiral matrix ligands *S,S*-ppm and *S,S*-epm could conceivably be modified in order to reduce their conformational and geometrical isomerism. The five-membered chelate ring comprising the ethylene group bridging the two pyrrolidinyl groups in complexes of *S,S*-epm may adopt either a λ or δ conformation. If this conformation could be fixed, then the total number of conformers would be immediately halved. This could be achieved by substituting optically pure *trans*-cyclohexane-1,2-diamine for ethane-1,2-diamine, and this ligand is in fact known.[10] It was found during the course of this study that λ and δ conformers of particular isomers of [M(*S,S*-epm)(L)]$^{n+}$ often displayed drastically different selectivities; e.g., the λ conformer was selective but the δ conformer was not. Moreover, fixing the conformer often favored an α instead of a β geometry of the coordinated quadridentate. Specifically, the selectivity of the [Co(*S,S*-epm)(pn)]$^{3+}$ system was found to be strongly dependent on the conformation of the five-membered chelate ring defined by *S,S*-epm. When this chelate ring is held in the λ conformation, the α-Λ isomer is more than 7 kJ mol^{-1} more stable than the β-Λ isomer, which would dictate that the ratio of α-Λ-[Co(*S,S*-epm)(pn)]$^{3+}$ to β-Λ-[Co(*S,S*-epm)(pn)]$^{3+}$ would be ca. 95 to 5%. Moreover, the α-Λ isomer overwhelmingly favors coordination of *S*-pn over *R*-pn (91 to 9%). Therefore, the opportunity exists to constrain the matrix ligand in order to force the ligand into a highly selective geometry.

Conclusions

It has been shown that the employment of molecular mechanics calculations as a predictive tool may lead to the design of chiral matrix systems that may be applied to the separation of racemic mixtures of simple bidentate ligands. Of the systems presented herein, the [Ni(*S,S*-epm)(L)]$^{2+}$ complexes were the most effective. Nevertheless the [Ni(*S,S*-ppm)(L)]$^{2+}$ systems may be more applicable to larger scale separations. The greater stability of the octahedral adducts of [Ni(*S,S*-ppm)]$^{2+}$ in aqueous solution, and within an ion-exchange resin matrix, compared with [Ni(*S,S*-epm)]$^{2+}$ presents the opportunity for the partially resolved substrates to be continually separated through several cycles in order to achieve optical purity.

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Registry No. (±)-pn, 10424-38-1; (±)-pam, 123654-27-3; [Ni(*S,S*-epm)](ClO$_4$)$_2$, 139347-45-8; [Ni(*S,S*-ppm)](ClO$_4$)$_2$, 59187-66-5; *trans*-[Co(*S,S*-ppm)Cl$_2$](ClO$_4$), 59202-14-1.

Supplementary Material Available: Tables of minimized strain energies of all isomers calculated in this work (7 pages). Ordering information is given on any current masthead page.

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