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Chiral Metal Complexes. 23*. Stereoselective Synthesis of α-Aminoacidates

MICHAEL A. COX, TERENCE J. GOODWIN, PAUL JONES, PETER A. WILLIAMS**
Department of Chemistry, University College, P.O. Box 78, Cardiff CF1 1XL, U.K.

FREDERICK S. STEPHENS and ROBERT S. VAGG**
School of Chemistry, Macquarie University, North Ryde, N.S.W. 2113, Australia

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Abstract

A series of ternary complexes of cobalt(III) containing a chiral linear N_4 tetradentate and either an optically active α-aminoacid or a substituted aminomalonic acid has been synthesised and characterised. A high degree of stereoselectivity is observed for these complexes. The crystal structure of one of these species, Λ-β$_1$-[Co(*R*,*R*-picchxn)(*R*-ABMA)]-$ClO_4 \cdot 1.5H_2O$, where *R*,*R*-picchxn is *N*,*N*′-di(2-picolyl)-1*R*,2*R*-diaminocyclohexane and $ABMAH_2$ is 2-amino-2-benzylpropanedicarboxylic acid, has been determined.

Crystal data: $C_{28}H_{36}N_5ClO_{9.5}Co$ is orthorhombic, space group $P2_12_12_1$, with $a = 12.659(4)$, $b = 14.560(4)$, $c = 34.049(8)$ Å and $Z = 8$. The structure was refined by block-matrix least-squares methods to $R = 0.071$ for 3024 non-zero reflexions.

The complex crystallises with two complex cations in the asymmetric unit. Each cation has a Λ-β$_1$ geometry, and the benzylaminomalonic acid ligand coordinates with an *R* (*pro-S*) absolute configuration. An intramolecular hydrogen bond between a tetradentate secondary amine group and the carboxyl group of the aminoacid is obvious in each cation, and this appears to confer thermodynamic stability on this diastereoisomer.

Decarboxylation of the complexes containing coordinated aminomalonic acids gives corresponding diastereoisomers of aminoacids in high optical yield. The nature of the precursor and final complexes casts some light on the origins of the chiral discriminations important in these species and their reactivity.

Introduction

The use of the reaction involving the decarboxylation of substituted α-aminomalonic acids to yield α-aminoacids is well known and has been applied extensively in the past [1]. Racemic products are obtained which then must be resolved if the optically active aminoacids are required. A considerably more elegant application of this reaction was that of Asperger and Liu [2], who first reported the decarboxylation of α-amino-α-methyl-malonic acid ($AMMAH_2$) coordinated to a chiral Co(III) complex in which the remainder of the coordination sphere was occupied by an optically active linear nitrogenous tetradentate. The reasoning here was that if the overall dissymmetry of the complex could be employed to induce optical activity in the product, then subsequent resolution of the amino acid could be eliminated. It has been shown, however, that the conclusions reached in this early work were based on the incorrect assumption that the starting complexes were formed stereospecifically [3]. A number of other workers have, since that time, investigated similar systems [3–8]. In most cases the degree of chiral induction obtained has not been much greater than 70% with respect to one hand of the aminoacid produced. Furthermore, the mechanism of the decarboxylation of the coordinated precursor has remained in doubt. Different precursors give different directions of asymmetric induction with the same overall hand of the complex [3, 5], and it has been noticed that the optical yield of aminoacidates depends upon the bulkiness of the side group of the aminomalonate and on various, as yet unexplained, solvation phenomena. *N*-Substitution of the optically active tetraamine also exerts an influence on the observed selectivity.

Our interest in this class of reactions arose from the fact that significant chiral discriminations may be measured in systems such as Λ,Δ-[Ru(diimine)$_2$-

*For Part 22 see ref. 26.

**Authors to whom correspondence should be addressed.

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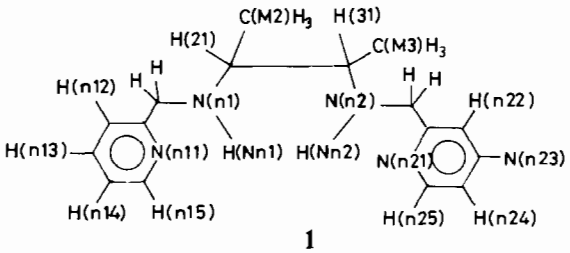
(aa)]$^{n+}$ where diimine is 1,10-phenanthroline, 2,2′-bipyridine or their congeners, and aa is an optically active aminoacidate ligand [9]. Accordingly, we have been able to incorporate the general molecular architecture of these diastereoisomers in Co(III) complexes of nitrogenous tetradentates for use as chiral templates for aminoacid synthesis. This work has resulted in a system which stereospecifically produces alanine in high yield [10]. Encouraged by the initial results we obtained, we have extended our studies to a series of related analogues and their reactions, the results of which we report here. Our results cast new light on the kinds of complexes which can be formed in these ternary systems, and the mechanisms involved in the decarboxylation reactions. Several other aminoacids have been produced in high optical yields, a common intermediate has been discerned in certain reactions, and the general steric requirements of the overall complex with respect to its efficiency in the chiral induction have been established.

Experimental

Synthesis of Starting Complexes and Precursor Ligands

Λ-β-[Co(*R,R*-picchxn)Cl_2]ClO_4·0.5H_2O and Δ-β-[Co(*S,S*-picbn)Cl_2]ClO_4, together with the latter's enantiomer in a separate experiment, were synthesised by following published procedures [11–14]. The *S,S*-picbn* complex had identical, within experimental error, chiroptical properties as that of the complex originally reported by Bosnich and Kneen [12]. *Anal.* Calc. for $C_{16}H_{22}N_4O_4Cl_3Co$: C, 38.5; H, 4.4; N, 11.2. Found: C, 38.0; H, 4.5; N, 11.0%. Characteristic ^{1}H NMR data (DMSO-d_6, saturated solution at 298 K) are *H*(*n*12): d, 7.79; *H*(*n*13): t, 8.25; *H*(*n*14); t, 7.85; *H*(*n*15): d, 9.27; *H*(*n*22): d, 7.66; *H*(*n*23): t, 8.00; *H*(*n*4): t, 7.42; *H*(*n*25): d, 7.02; *H*(21): m, 3.70; *H*(31): m, 2.54; C(M2)H_3: d, 1.16; C(M3)H_3: d, 1.39; *H*(N*n*1): t, 7.23; *H*(N*n*2): t, 7.88 ppm relative to TMS as internal standard. $J_{n12,n13}$, 7.8; $J_{n13,n14}$, 7.5; $J_{n14,n15}$, 5.7; $J_{n22,n23}$, 7.7; $J_{n23,n24}$, 7.5; $J_{n24,n25}$, 5.7; $J_{21,N2}$, 4.2; $J_{21,M2}$, 6.4; $J_{21,31}$, 6.3; $J_{31,M3}$, 6.4 Hz. The spectrum corresponds very closely to that of Λ-β-[Co(*R,R*-picchxn)Cl_2]$^+$ for those analogous protons concerned. The proton numbering scheme is that given in **1**, with N(*n*11), N(*n*1) and N(*n*2) disposed meridionally in the coordination sphere.



1

Λ-β[Co(R,R-picbn)Cl(H_2O)](ClO_4)$_2$

The filtrate from the collected crystals of Λ-β-[Co(*R,R*-picbn)Cl_2]ClO_4 was allowed to stand at room temperature for four weeks during which time a crop of fine red needles crystallised. These proved to be the title compound and were filtered off, washed with a minimum of ice-cold water then acetone and dried at the pump. Yield 8%, based on Co. *Anal.* Calc. for $C_{16}H_{24}N_4O_9Cl_3Co$: C, 33.0; H, 4.2; N, 9.6. Found: C, 33.2; H, 4.1; N, 9.6%. Spectral data, recorded in conc. HCl immediately after dissolution are: λ_{max} = 510 nm, ϵ = 1440 dm^2 mol^{-1} and (CD extrema) $\Delta\epsilon_{556}$ = +1.0, $\Delta\epsilon_{482}$ = +3.0, $\Delta\epsilon_{408}$ = +2.2, $\Delta\epsilon_{360}$ = +4.0 dm^2 mol^{-1}. After 48 h the spectrum had changed to that of the dichloro complex of the same hand. Both the dichloro and chloroaqua complex may be used with equal efficiency for the synthesis of the ternary aminoacidate species.

Aminomalonic acid derivatives

These were obtained using the method of Thanassi [15]. The methyl-substituted compound, $AMMAH_2$, was obtained as the free acid. However, the ethyl analogue, being the precursor for α-aminobutyric acid crystallised from the final solution as the monohydrate form of the potassium hydrogen salt, KAEMAH·H_2O. *Anal.* Calc. for $C_5H_{10}N_1O_5K$: C, 29.6; H, 5.0; H, 6.9. Found: C, 29.4; H, 4.6 N, 6.6%. The compound is NMR pure. Similarly, the benzyl derivative, which corresponds to the prochiral precursor of phenylalanine was isolated as the sesquihydrate of the potassium hydrogen salt, KABMAH·1.5H_2O. *Anal.* Calc. for $C_{10}H_{13}N_1O_{5.5}K$: C, 43.8; H, 4.8; N, 5.1. Found: C, 43.7; H, 4.6; N, 4.9%. This compound too is NMR pure.

Λ-β$_1$ and Λ-β$_2$-[Co(R,R-picchxn)(S-phe)](ClO_4)$_2$·nH_2O

S-Phenylalanine (*S*-pheH, 0.78 g, 4.72 mmol) was added to a stirred solution of Λ-β-[Co(*R,R*-picchxn)Cl_2]ClO_4·½H_2O (0.50 g, 0.94 mmol) in H_2O (30 cm^3) at 60 °C. When it had all dissolved, 1.0 cm^3 of 1.0 M aqueous NaOH was added to the mixture which was cooled to room temperature and diluted five-fold with H_2O. The orange solution was

*picchxn is *N,N′*-di(2-picolyl)-1,2-diaminocyclohexane, picbn is 2,5-diaza-3,4-dimethyl-1,6-di(2-pyridyl)hexane, $AMMAH_2$ is 2-amino-2-methylpropanedicarboxylic acid (α-amino-α-methylmalonic acid or aminomethylmalonic acid), $AEMAH_2$ is 2-amino-2-ethylpropanedicarboxylic acid (aminoethylmalonic acid), $ABMAH_2$ is 2-amino-2-benzylpropanedicarboxylic acid (aminobenzylmalonic acid).

applied to a CM-Sephadex® C-25 cation exchange column (35 × 1.5 cm) in the Na^+ cycle, which was thoroughly flushed with water. Elution was carried out using 0.05 M aqueous $NaClO_4$. Two orange bands separated cleanly and were collected in fractions using an LKB Ultrorac® II fraction collector. Electronic and CD spectral measurements confirmed that each band contained only one isomer. Fractions from the faster moving band were combined, concentrated *in vacuo* at 40 °C to 20 cm^3 and the solution then slowly evaporated over silica gel at room temperature. After a week, the orange crystals of the isomer Λ-β_2-[Co(*R*,*R*-picchxn)(*S*-phe)]$(ClO_4)_2 \cdot 3H_2O$ which had formed were collected at the pump, washed with ice-cold water and air dried. Yield 12.3%. *Anal.* Calc. for $C_{27}H_{40}N_5O_{13}Cl_2Co$: C, 42.0; H, 5.2; N, 9.1; H_2O, 7.0. Found: C, 41.8; H, 5.1; N, 9.3; H_2O, 7%. Spectral data: $\epsilon_{480} = 1770$, $\epsilon_{350} = 2060$ dm^2 mol^{-1} (maxima), $\Delta\epsilon_{534} = -7.9$, $\Delta\epsilon_{482} = +29.7$, $\Delta\epsilon_{347} = -6.3$ dm^2 mol^{-1} (extrema).

In the fractions collected from the slower moving band, fine orange needles crystallised on standing over several days. These correspond to the complex Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-phe)]$(ClO_4)_2$ and were collected at the pump, washed with ice-cold water and air dried. Yield 59.1% (both yields based on Co). *Anal.* Calc. for $C_{27}H_{34}N_5O_{10}Cl_2Co$: C, 45.1; H, 4.8; N, 9.8. Found: C, 45.0; H, 4.7; N, 10.0%. Spectral data: $\epsilon_{479} = 2090$, $\epsilon_{350} = 1530$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{483} = +20.9$, $\Delta\epsilon_{349} = -4.5$ dm^2 mol^{-1} (extrema).

Λ-β_1-[Co(R,R-picchxn)(R-phe)](ClO$_4$)$_2$

This complex was synthesised in a manner analogous to the above, but by substituting *R*-pheH in the first step. The reaction mixture was eluted from the column using 0.05 M aqueous NaCl. Use of a sodium perchlorate solution as eluant caused precipitation of the very insoluble salt of that anion on the resin. The main orange band containing the title isomer was preceeded by an extremely faintly coloured one, which had a CD spectrum characteristic of the Λ-β_2 isomer but was present in insufficient quantities to permit isolation. This isomer distribution is thus somewhat different to that found for the *S*-pheH complexes, but is a general feature of this class of diastereoisomers (*vide infra*). The main orange band eluted was collected in fractions which were shown, as above, to consist of only one isomer in solution. These were combined and sufficient $NaClO_4$ was added to make the solution 0.05 M in ClO_4^- ion. After concentration at 50 °C *in vacuo* to 30 cm^3, the solution was cooled to room temperature and stored over silica gel. Crystals of Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-phe)]$(ClO_4)_2$ were formed over a few hours and these were isolated as described above. Yield 61.3% (based on Co). *Anal.* Calc. for $C_{27}H_{34}N_5O_{10}Cl_2Co$: C, 45.1; H, 4.8; N, 9.8. Found: C, 45.3; H, 4.9; N, 9.6%. Spectral data: $\epsilon_{481} = 2390$, $\epsilon_{350} = 2140$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{499} = +25.4$, $\Delta\epsilon_{352} = -1.1$, $\Delta\epsilon_{304} = +0.5$ dm^2 mol^{-1} (extrema).

Λ-β_1- and Λ-β_2-[Co(R,R-picchxn)(S-abu)](ClO$_4$)$_2$·nH$_2$O

These complexes were synthesised in the same way as the above, substituting *S*-aminobutyric acid (*S*-abuH) for *S*-pheH. Elution was effected using 0.05 M aqueous $NaClO_4$ and crystals of Λ-β_2-[Co(*R*,*R*-picchxn)(*S*-abu)]$(ClO_4)_2 \cdot H_2O$ were obtained from the concentration of fractions of the faster eluting isomer. Yield 4.8%. *Anal.* Calc. for $C_{22}H_{34}N_5O_{11}Cl_2Co$: C, 39.2; H, 5.1; N, 10.4. Found: C, 39.3; H, 4.8; N, 9.9%. Spectral data: $\epsilon_{476} = 1550$, $\epsilon_{346} = 2140$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{537} = -7.9$, $\Delta\epsilon_{485} = +25.3$, $\Delta\epsilon_{348} = -5.4$ dm^2 mol^{-1} (extrema).

From the slower moving band was isolated, in the same way, crystals of Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-abu)]$(ClO_4)_2$. Yield 18.0%. *Anal.* Calc. for $C_{22}H_{32}N_5O_{10}Cl_2Co$: C, 40.3; H, 4.9; N, 10.7. Found: C, 40.0; H, 4.7; N, 10.6%. Spectral data: $\epsilon_{482} = 1950$, $\epsilon_{348} = 1640$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{489} = +17.0$, $\Delta\epsilon_{351} = -4.5$ dm^2 mol^{-1} (extrema).

Λ-β_1-[Co(R,R-picchxn)(R-abu)](ClO$_4$)$_2$·0.5H$_2$O

This complex was prepared as outlined above for the *S* analogue. Elution of the cation exchange column with 0.05 M aqueous $NaClO_4$ developed two orange bands. The faster eluting one, as was the case in the same reaction of the starting complex with *R*-pheH, contained the β_2 diastereomer, but too little was formed to permit its isolation. The larger slower moving band contained only the title isomer, which was isolated as the perchlorate hemihydrate in the usual manner. Yield 38.5%. *Anal.* Calc. for $C_{22}H_{33}N_5O_{10.5}Cl_2Co$: C, 39.7; H, 5.0; N, 10.5. Found: C, 39.7; H, 5.6; N, 10.4%. Spectral data: $\epsilon_{482} = 1650$, $\epsilon_{349} = 1445$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{505} = +20.3$, $\Delta\epsilon_{352} = -1.2$ dm^2 mol^{-1} (extrema).

Δ-β_1-[Co(S,S-picbn)(S-ala)](ClO$_4$)$_2$·2H$_2$O

An aqueous solution (40 cm^3) containing Δ-β-[Co(*S*,*S*-picbn)Cl_2]ClO_4 (0.35 g, 0.7 mmol) was warmed to 40 °C and to it was added *S*-alanine (*S*-alaH, 0.31 g, 3.5 mmol) and 0.7 cm^3 of 1.0 M aqueous NaOH in water (20 cm^3). The reaction mixture was stirred overnight at 40 °C, diluted five-fold with water and chromatographed as above using 0.1 M aqueous $NaClO_4$ as the eluant. Two orange bands developed, the slower of which contained the β_1 isomer alone. Fractions from this band were combined and worked up as above so as to yield fine orange needle crystals of the complex cation as a perchlorate dihydrate salt. Yield 42.5%. *Anal.* Calc. for $C_{19}H_{32}N_5O_{12}Cl_2Co$: C, 35.0; H, 4.9; N, 10.7%. Found: C, 35.0; H, 5.0; N, 10.7%. Spectral data: $\epsilon_{482} = 1930$, $\epsilon_{350} = 1620$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{500} = -20.1$, $\Delta\epsilon_{388} = 2.2$, $\Delta\epsilon_{352} = +1.1$ dm^2 mol^{-1} (extrema). In this

quasi-enantiomeric experiment, compared with the analogues above, we found that the faster moving band contained insufficient material to permit isolation as a crystalline salt. However, CD spectra of fractions collected of this band bore a close resemblance to those of Δ-β_2-[Co(*S,S*-picbn)(*R*-ala)]$^{2+}$ (*vide infra*) and the mirror image of that of the enantiomorphic species Λ-β_2-[Co(trien)(*S*-pro)]$^{2+}$ (trien = 1,4,7,10-tetraazadecane, proH = proline), which has been characterised crystallographically [16, 17].

Δ-β_1- and Δ-β_2-[Co(S,S-picbn)(R-ala)](ClO$_4$)$_2$

This synthesis was carried out as above for the *S*-analogue, and the faster and slower moving bands respectively were shown to contain only the β_2 and β_1 diastereoisomers. From the former the β_2 perchlorate salt was isolated by evaporation of the combined fractions at room temperature over silica gel. Yield 8.6%. *Anal.* Calc. for $C_{19}H_{28}N_5O_{10}Cl_2Co$: C, 37.0; H, 4.6; N, 11.4. Found: C, 37.0; H, 4.7; N, 11.3%. Spectral data: $\epsilon_{475} = 1180$, $\epsilon_{348} = 1340$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{534} = +4.2$, $\Delta\epsilon_{479} = -22.6$, $\Delta\epsilon_{340} = +4.7$ dm^2 mol^{-1} (extrema).

Similar treatment of combined fractions of the slower moving band gave fine orange needles of the β_1 perchlorate salt. Yield 39.1%. *Anal.* Calc. for $C_{19}H_{28}N_5O_{10}Cl_2Co$: C, 37.0; H, 4.6; N, 11.4. Found: C, 37.2; H, 4.8; N, 11.5%. Spectral data: $\epsilon_{482} = 1810$, $\epsilon_{350} = 1470$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{492} = -15.9$, $\Delta\epsilon_{348} = +3.9$ dm^2 mol^{-1} (extrema).

Λ-β_1-[Co(R,R-picchxn)(R-ABMAH)](ClO$_4$)$_2$

An aqueous solution (50 cm^3) of Λ-β-[Co(*R,R*-picchxn)Cl$_2$]ClO$_4$·0.5H$_2$O (1.07 g, 2.0 mmol) and KHABMA·1.5H$_2$O (1.70 g, 6.2 mmol) was adjusted to pH 8.0 with dilute aqueous NaOH, filtered, and the cherry-red solution stirred at room temperature for 30 h. During this time the colour changed to deep orange. The reaction solution was diluted two-fold with water and applied to a Sephadex® (CM C-25, 40 × 2.5 cm) column which was washed with water (30 cm^3) and eluted with 1% (*w/v*) aqueous NaClO$_4$. Only one orange band developed and this was collected in eight 40 cm^3 fractions, all of which had the same CD spectrum (maxima and null dichroic points). These combined fractions were reduced in volume using a rotary evaporator at 30 °C to *ca.* 30 cm^3, whereupon the product crystallised as small orange prisms. These were collected at the pump, washed with 50% aqueous ethanol, then absolute ethanol and air-dried. Yield 47%. The product is very soluble in H$_2$O. *Anal.* Calc. for $C_{28}H_{34}N_5O_{12}Cl_2Co$: C, 44.1; H, 4.5; N, 9.2. Found: C, 44.3; H, 4.5; N, 9.2%. Spectral data: $\epsilon_{485} = 2100$, $\epsilon_{345} = 2115$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{487} = +23.2$, $\Delta\epsilon_{398} = +1.8$, $\Delta\epsilon 350 = -4.5$ dm^2 mol^{-1} (extrema).

Λ-β_1-[Co(R,R-picchxn)(R-AMBA)]ClO$_4$·1.5H$_2$O

In an identical synthetic experiment to the above, the orange band containing the Λ-β_1 diastereoisomer was eluted with 0.05 M aqueous NaClO$_4$ and the whole eluate evaporated to dryness *in vacuo* at 30 °C. The solid residue was dissolved in the minimum amount of cold water and evaporated slowly over silica gel at room temperature. During two weeks acicular crystals of the title complex formed. These were collected at the pump, washed with a minimum of ice-cold water and dried under suction. Yield 30%. *Anal.* Calc. for $C_{28}H_{36}N_5O_{9.5}ClCo$: C, 48.8; H, 5.3; N, 10.2; H$_2$O, 3.9. Found: C, 48.8; H, 5.2; N, 10.5; H$_2$O, 4.2%. The well-formed needles, up to 1 cm in length, proved to be suitable for X-ray crystallographic study after cutting them to a suitable size (*vide infra*).

Λ-β_1-[Co(R,R-picchxn)(R-AEMAH)](ClO$_4$)$_2$·6H$_2$O

Λ-β-[Co(*RR*-picchxn)Cl$_2$]ClO$_4$·0.5H$_2$O (0.54 g, 1.0 mmol) and KHAEMA·H$_2$O (0.61 g, 3.0 mmol) were dissolved in H$_2$O (50 cm^3), the pH of the solution was adjusted to 8.0 using dilute aqueous NaOH, and the mixture was left to stir overnight at room temperature. The resulting orange solution was applied to a Sephadex® column as above, and this was eluted with 0.5% (*w/v*) aqueous NaClO$_4$ until two orange bands had separated. Elution was completed with 1% (*w/v*) aqueous NaClO$_4$. Fractions from the first orange band were shown by circular dichroism spectral measurements to contain only one isomer, and so these were combined, reduced in volume to *ca.* 10 cm^3 using a rotary evaporator, and then were slowly evaporated at room temperature over silica gel. Fine orange needles of the title complex crystallised over several days. These were collected at the pump, washed with a few drops of ice cold water and air dried. The compound loses water of hydration readily when exposed to the air to give an orange microcrystalline powder. Yield 18.0%. *Anal.* Calc. for $C_{32}H_{44}N_5O_{18}Cl_2Co$: C, 34.2; H, 5.5; N, 8.7. Found: C, 34.1; H, 3.9; N, 8.4%. The low H analysis may be attributed to the loss of the volatile crystal lattice water prior to combustion (calc. for dehydrated form: H, 4.0%). Spectral data: $\epsilon_{482} = 2010$, $\epsilon_{348} = 1900$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{491} = +19.5$, $\Delta\epsilon_{353} = -3.9$ dm^2 mol^{-1} (extrema). The faster running band containing this isomer was adjudged to contain the more complex by virtue of its shape and size, but smaller amounts were obtained because of the solubility characteristics of the isolated salt.

Λ-β_1-[Co(R,R-picchxn)(S-AEMAH)](ClO$_4$)$_2$·NaClO$_4$·3H$_2$O

This salt was obtained from the slower-moving minor band developed on the column as noted in the last-mentioned synthesis by using the same methods

as outlined above. It is not hygroscopic, but is very soluble in water and also loses water of crystallisation on prolonged drying. Yield 18.2%. *Anal.* Calc. for $C_{28}H_{38}N_5O_{10}Cl_3NaCo$: C, 31.5; H, 4.4; N, 8.0. Found: C, 31.2; H, 4.4; N, 8.2%. Spectral data: $\epsilon_{482} = 1910$, $\epsilon_{348} = 1735$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{483} = +25.2$, $\Delta\epsilon_{351} = -5.73$ dm^2 mol^{-1} (extrema).

Λ-β$_1$-[Co(R,R-picbn)(R-AMMA)]$^+$ and Λ-β$_1$-[Co-(R,R-picbn)(S-AMMA)]$^+$

A solution of $AMMAH_2$ (0.18 g, 1.3 mmol) in water (5 cm^3) was added to a solution of Λ-β-[Co-(*R,R*-picbn)Cl_2]ClO_4 (0.35 g, 0.7 mmol) in water (10 cm^3), the pH was adjusted to 8.0 with dilute NaOH and the mixture was stirred at room temperature for 15 h. The resulting orange solution was diluted five-fold and chromatographed as above using 0.1 M aqueous $NaClO_4$ as the eluant. Two orange bands developed which had the same general spectral features as those in the previous experiment. The product in the second band had formed in a smaller amount. Attempts to crystallise a solid perchlorate salt from either fraction were unsuccessful. Addition of iodide, triflate or hexafluorophosphate ions similarly failed to give a precipitate in the concentrated fractions. Consequently, the solutions of the complexes containing excess $NaClO_4$ were evaporated to dryness *in vacuo* at 30 °C, dissolved in D_2O and then the excess D_2O removed by azeotroping with ethanol. The NMR spectra of the complexes (see next section) were obtained by redissolving the residues in D_2O. Spectral data were recorded on solutions whose cobalt contents were estimated using AAS spectroscopy. The faster-moving band on the column contained the Λ-β$_1$-[Co(*R,R*-picbn)(*R*-AMMA)]$^+$ diastereoisomer; $\epsilon_{480} = 1980$, $\epsilon_{345} = 1940$ dm^2 mol^{-1} (maxima), $\Delta\epsilon_{488} = +19.7$, $\Delta\epsilon_{389} = +1.6$, $\Delta\epsilon_{350} = -3.7$ dm^2 mol^{-1} (extrema). The slower-moving band containcd thc Λ-β$_1$[Co(*R,R*-picbn)-(*S*-AMMA)]$^+$ diastereoisomer; $\epsilon_{480} = 1950$, $\epsilon_{345} = 1700$ dm^2 mol^{-1} (maxima); $\Delta\epsilon_{474} = +21.2$, $\Delta\epsilon_{350} = -6.2$ dm^2 mol^{-1} (extrema). In subsequent decarboxylation experiments, the solid mixtures of isomers and $NaClO_4$ were used as obtained.

Crystal and Molecular Structure of Λ-β$_1$-[Co(R,R-picchxn)(R-ABMA)]$ClO_4 \cdot 1.5H_2O$

Crystal data

$C_{28}H_{36}N_5Cl_1O_{9.5}Co$, $M_r = 689.0$, orthorhombic, $a = 12.659(4)$, $b = 14.560(4)$, $c = 34.049(8)$ Å, $U = 6275.7$ Å^3, $Z = 8$, $D_c = 1.46$ g cm^{-3}, $F(000) = 2872$, μ(Mo Kα) = 7.2 cm^{-1}. Systematic absences: $h00$ if $h \neq 2n$, $0k0$ if $k \neq 2n$ and $00l$ if $l \neq 2n$; space group $P2_12_12_1$ (No. 19).

Unit cell data were established from precession photographs and were measured accurately by means of a Nicolet XRDP3 four-circle diffractometer [18] using graphite monochromatised Mo Kα radiation. The $\theta/2\theta$ scan technique was used to collect reflexion intensities in the range $3.0 < 2\theta < 45.0°$ with the crystal temperature being maintained at −125 °C. The intensities were corrected empirically for absorption, and of the 4597 independent reflexions obtained 3024 had $I > 3\sigma(I)$ and these were used for the structure determination.

The structure was solved by the heavy atom method. Initial refinement was by full-matrix least-squares calculations with the weight for each reflexion set at unity. The positions of the hydrogen atoms in the ligands were calculated assuming the appropriate geometries of the atoms to which they are attached with bond lengths of 1.0 Å, and they were assigned $B = 2.0$ Å^2. The final structure refinement employed four matrices, these including the parameters for (1) the overall scale and temperature factors, and the positional and thermal parameters for (2) molecule 1, (3) molecule 2, and (4) the perchlorate ions and water molecules. The weights used were $w = (20 + 0.1F + 0.005F^2)^{-1}$. When the maximum shift in any parameter was less than 0.1σ the refinement process was terminated. The final value for R based on all reflexions was 0.071 and $R' = \{(\Sigma w\Delta^2/\Sigma w|F_o|^2)^{1/2}\}$ was 0.095. A final Fourier difference map showed no unusual features.

Calculations were carried out on a FACOM M3405 computer using programs written by F.S.S. Neutral atom scattering factors were taken from 'International Tables for X-Ray Crystallography', [19], with corrections being applied for anomalous dispersion. See also 'Supplementary Material'.

Decarboxylation Experiments

These experiments were carried out using methods similar to those previously descirbed [10]. The entire products of the decarboxylation reactions were dissolved in DMSO-d_6 and their ^{1}H NMR spectra recorded in order to quantify the amounts of each diastereoisomer formed in separate experiments.

Instrumentation and Analyses

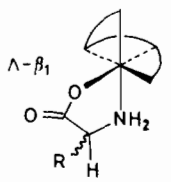
C, H and N analyses were carried out by Mrs A. Dams of the Department of Chemistry, Cardiff. Water of hydration analyses were performed using a Stanton Redcroft TG-750 thermobalance. **Caution**: temperatures must be kept below 120 °C due to the risk of explosion of the perchlorate salts. Electronic and CD spectral measurements were carried out using a Perkin-Elmer SP8000 and Jobin Yvon CNRS Dichrographe III spectrophotometer, respectively. Atomic absorption spectroscopy (AAS) measurements were made with a Varian AA-275 spectrometer using aqueous solutions of Λ-β-[Co(*R,R*-picbn)Cl_2]ClO_4 as standards. All CD and electronic spectra were recorded in aqueous solutions at 298 K except where specifically noted. The 360 MHz ^{1}H

TABLE I. Characteristic ^{1}H NMR Data for the Complexes β-[Co(tetradentate)(aminoacidate)]$^{2+}$

Measured δ or *J*	Complex[a]								
	A	B	C	D	E	F	G	H	I
H(*n*12)	7.90	7.92	7.94	7.91	7.89	7.90	7.84	7.86	7.88
H(*n*13)	8.33	8.34	8.36	8.34	8.35	8.36	8.29	8.32	8.31
H(*n*14)	7.80	7.89	7.89	7.89	7.90	7.90	7.87	7.88	7.88
H(*n*15)	8.08	8.26	8.23	8.24	8.41	8.41	8.72	9.03	8.94
H(*n*22)	7.76	7.64	7.78	7.74	7.81	7.81	7.74	7.69	7.66
H(*n*23)	8.17	8.17	8.18	8.15	8.15	8.16	8.11	8.13	8.09
H(*n*24)	7.54	7.54	7.57	7.55	7.48	7.48	7.44	7.55	7.46
H(*n*25)	6.97	7.02	7.04	7.02	7.26	7.22	7.26	7.18	7.11
$J_{n12,n13}$	7.8	7.9	7.7	7.8	7.7	7.5	8.3	7.8	7.8
$J_{n13,n14}$	7.5	7.6	7.5	7.6	7.5	7.5	7.3	7.5	7.5
$J_{n14,n15}$	5.5	5.6	5.6	5.7	5.5	5.6	5.7	5.6	5.6
$J_{n22,n23}$	7.2	8.0	7.9	7.8	7.7	7.7	7.6	7.8	7.8
$J_{n23,n24}$	7.4	8.0	7.6	7.7	7.8	7.7	7.7	7.7	7.6
$J_{n24,n25}$	5.9	5.5	5.7	5.6	5.8	6.0	5.8	5.8	5.7
H(N*n*2)	6.92	8.12	6.90	7.49	[c]	[c]	[c]	7.80	7.81
H(N3)	6.85	7.02	6.81	6.90	[c]	[c]	[c]	7.46	7.42
H_α[b]	3.43	3.19	3.46	[h]	2.98	3.91	3.70	3.25	3.26
Ar–*H*[b]	7.16–7.29	7.06–7.27							7.20–7.39
N*H*[b]	6.15	5.58	6.01	6.90	[c]	[c]	[c]	6.75	6.73
N*H*′[b]	4.08	5.44	4.44	5.21	[c]	[c]	[c]	4.40	4.53
H(21)[d]					3.30	3.41	3.63		
H(31)					2.79	2.80	2.91		
C(M2)H_3					1.27	1.27	1.38		
C(M3)H_3					1.55	1.55	1.52		
CH_3[b]			0.76[e]	0.99[f]	1.39	1.16	1.49	1.09[g]	
$J_{21,M2}$					6.3	6.3	6.5		
$J_{31,M3}$					6.5	6.5	6.5		
$J_{21,31}$					5.6	5.7	5.7		
J_{α,CH_3}[b]					6.9	7.4	7.0		

[a]A = Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-phe)]$^{2+}$; B = Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-phe)]$^{2+}$; C = Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-abu)]$^{2+}$; D = Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-abu)]$^{2+}$; E = Δ-β_1-[Co(*S*,*S*-picbn)(*R*-ala)]$^{2+}$; F = Δ-β_1-[Co(*S*,*S*-picbn)(*R*-ala)]$^{2+}$; G = Δ-β_2-[Co(*S*,*S*-picbn)(*R*-ala)]$^{2+}$; H = Λ-β_2-[Co(*R*,*R*-picchxn)(*S*-abu)]$^{2+}$; I = Λ-β_2-[Co(*R*,*R*-picchxn)(*S*-phe)]$^{2+}$. Spectra of A–D, H & I were measured in DMSO-d_6, spectra E–G were measured in D_2O. Chemical shifts (δ) in ppm relative to internal standard, coupling constants in Hz. [b]Amino acidate resonances and coupling constants. [c]Exchanged. [d]For numbering scheme in picbn ligand backbone, see **1**. [e]Triplet, *J* = 7.2 Hz. [f]Triplet, *J* = 7.6 Hz. [g]Triplet, 7.8 Hz. [h]Obscured by HDO peak.

NMR spectra were recorded at 298 K on a Bruker WM 360 instrument in DMSO-d_6 or D_2O solutions using TMS or DSS, respectively, as internal standards.



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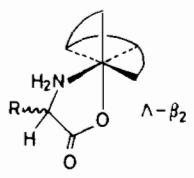

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Results and Discussion

Synthesis of Complexes

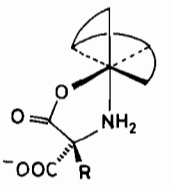
For complexes containing tetradentates with two-fold symmetry of the type used in this work, the coordination sphere may be completed in two ways using an unsymmetrical bidentate, such as an aminoacidate, when the β configuration is adopted. These two geometries, designated β_1 and β_2, are depicted in **2** and **3**, where the absolute configuration of the complex at the metal centre is Λ. Previous ^{1}H NMR studies [14, 20] complemented by X-ray crystallographic determinations on related species [21] have shown how these coordination modes may be distinguished spectroscopically. To summarise briefly, we point out that the position of the *H*(*n*15) resonance in the β_1 form, by virtue of its being somewhat shielded by the coordinated carbonyl group, is found about 1 ppm upfield compared with its position in the analogous β_2 isomer. This pattern of chemical shifts is preserved

in both *R*- and *S*-aminoacid complexes. In addition, characteristic CD spectra are also obtained [14]. This same pattern of results has been used to distinguish between the pairs of diastereoisomeric complexes made in the present work. Electronic and CD spectral data are given in the 'Experimental' section above, and diagnostic ^{1}H NMR data for the complexes β-[Co(tetradentate)(*R*,*S*-aminoacidate)]$^{2+}$ are listed in Table I. It should be noted that considerable stereoselectivity is obtained during the synthesis of these complexes.

Only Λ-β_1 and Λ-β_2 diastereoisomers are formed in these cases when Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$^+$ is reacted with *R*- or *S*-aminoacids in aqueous solutions under the conditions employed. Furthermore it is found that the β_1 isomers are always made in far greater amounts, as judged by yields of complexes eluted from the chromatographic columns. Reported yields given in the 'Experimental' section, it should be remembered, refer to the amounts of solid complexes isolated, and these are of course subject to differential solubility phenomena. In the reactions of Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$^+$ with *R*-pheH and *R*-abuH, negligible amounts of β_2 diastereoisomers are formed. This is probably due to non-bonded steric interactions between the amino acid side-group and the tetradentate [14].

Analogous stereoselectivity is found in the reactions of Λ-β-[Co(*S*,*S*-picbn)Cl_2]$^+$ with *R*- and *S*-alaH, although in the enantiomeric sense. It is evident that the optically active picbn ligand also coordinates stereospecifically to Co(III) when the coordination sphere is completed by bidentates, as found here, or by unidentates as originally found by Bosnich and Kneen [12] and subsequently confirmed in every respect by us.

Replacement of the aminoacidate ligand in these complexes by an alkyl- or arylaminomalonic acidate function leads to a further isomeric complication. This is because of the fact that in both β_1 and β_2 cases a new chiral centre is generated in the previously prochiral terdentate when it coordinates as an α-aminoacidate. The four possibilities, the absolute configurations of the N(*n*1) and N(*n*2) atoms being fixed for chiral picchxn and picbn, are shown in **4**–**7** for complexes of overall Λ stereochemistry. For these cases, the pro-*R* or pro-*S* designations refer to the absolute configurations of aminomalonate were the pendant carboxyl group to be replaced by a proton to give the corresponding aminoacidate. Thus in **4**, Λ-β_1-(*pro-S*), retention of stereochemistry during decarboxylation would give the *S*-aminoacid (for all cases in this work, *cf.* cysteine) even though the absolute configuration of the coordinated aminomalonic acid is in fact *R* by application of the usual Cahn–Ingold–Prelog rules.



Λ-β_1-(pro-S)

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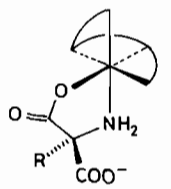

Λ-β_1-(pro-R)

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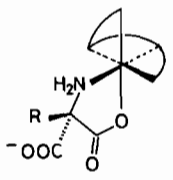

Λ-β_2-(pro-R)

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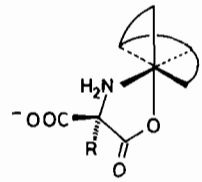

Λ-β_2-(pro-S)

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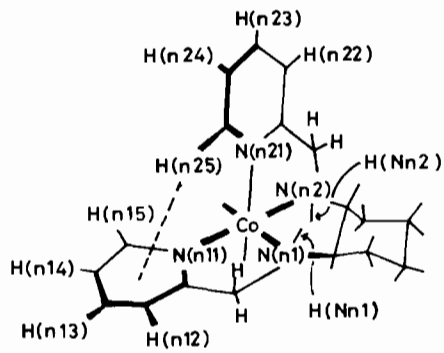
Here, and previously [10], we find stereoselective coordination of aminomalonic acidate ligands in the ternary Co(III) complexes. When Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$^+$ is reacted with $AMMAH_2$ in aqueous solution at pH 8, only one diastereoisomer is formed [10]. It has a ^{1}H NMR spectrum characteristic of a β_1 complex and a CD spectrum which closely resembles that of Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-ala)]$^{2+}$. On this basis it was assigned the structure* shown in **4**. Support for this assignment is also found in the NMR spectrum with respect to the unusually low resonance position for H(N3) which could be explained by a hydrogen-bonding interaction between this proton and the pendant carboxylic acid group. This interaction is only possible for the *pro-S* diastereoisomer with β_1 coordination geometry, as shown in **8** (^{1}H NMR numbering scheme for selected protons also shown). This assignment now is shown



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to be correct in all aspects by the determination of the crystal and molecular structure of the analogous complex Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-ABMA)]$ClO_4 \cdot 1.5H_2O$ (*vide infra*).

*A drafting error in the original report [10] gave the false impression that the structure of the tetradentate is based on 1,3-diaminopropane. We correct that error here.

TABLE II. Characteristic ^{1}H NMR Data for the Complexes β-[Co(tetradentate)(aminomalonate)]$^+$

Measured δ or J	Complex[a]					
	A[b]	B	C	D	E	F
H(n12)	7.88	7.72	7.89	7.75	7.89	7.83
H(n13)	8.30	8.12	8.31	8.20	8.34	8.14
H(n14)	7.86	7.46	7.73	7.66	7.90	7.76
H(n15)	8.21	7.55	8.22	7.98	8.39	8.21
H(n22)	7.74	7.70	7.73	7.77	7.79	7.81
H(n23)	8.13	8.13	8.13	8.16	8.13	8.29
H(n24)	7.53	7.39	7.53	7.54	7.46	7.47
H(n25)	7.04	6.88	7.04	6.97	7.20	7.20
$J_{n12,n13}$	7.3	7.4	7.9	7.1	8.0	6.8
$J_{n13,n14}$	8.2	7.4	8.7	7.8	8.1	7.7
$J_{n14,n15}$	5.4	5.3	6.6	6.6	6.4	5.2
$J_{n22,n23}$	7.7	6.9	7.8	7.1	7.4	7.5
$J_{n23,n24}$	7.9	7.4	7.1	7.9	7.3	8.2
$J_{n24,n25}$	5.6	5.7	5.7	6.7	6.6	5.7
H(Nn1)	6.76	6.87	6.75	6.74	[d]	[d]
H(Nn2)	11.09	10.91	10.93	6.96	[d]	[d]
CH_3[c]	1.16		0.50[j]	0.80[k]	1.40	1.62
NH[c]	5.85	6.26	5.72	6.20	[d]	[d]
NH'[c]	4.90	4.21	4.46	4.78	[d]	[d]
C(M2)H_3[e]					1.31[f]	1.29[h]
C(M3)H_3					1.58[g]	1.56[i]
Ar–H[c]		6.90–7.01				

[a]A = Λ-β_1-[Co(R,R-picchxn)(R-AMMA)]$^+$; B = Λ-β_1-[Co(R,R-picchxn)(R-ABMA)]$^+$; C = Λ-β_1-[Co(R,R-picchxn)(R-AEMA)]$^+$; D = Λ-β_1-[Co(R,R-picchxn)(S-AEMA)]$^+$; E = Λ-β_1-[Co(R,R-picbn)(R-AMMA)]$^+$; F = Λ-β_1-[Co(R,R-picbn)(S-AMMA)]$^+$. Spectra of A–D were measured in DMSO-d_6, spectra D and E were measured in D_2O. Chemical shifts (δ) are in ppm relative to internal standard; coupling constants are in Hz. [b]Data taken from ref. 10. [c]Aminomalonate resonances and coupling constants. [d]Exchanged. [e]For the numbering scheme of the picbn ligand backbone see **1**. [f]Doublet, J = 6.2 Hz. [g]Doublet, J = 6.3 Hz. [h]Doublet, J = 6.2 Hz. [i]doublet, J = 7.3 Hz. [j]Triplet, J = 7.1 Hz. [k]Triplet, J = 7.6 Hz.

A similar pattern of results to the above is found in reactions of the starting complex with the aminomalonic acid precursor of pheH. When K(HABMA)·1.5H_2O is reacted with Λ-β-[Co(R,R-picchxn)Cl_2]$^+$ under the same conditions as above chromatographic studies show again that only one diastereoisomer is formed. It may be isolated as the diperchlorate salt of the protonated cation or as the sesquihydrate of the perchlorate salt of the conjugate base of the cation. Its NMR spectrum in DMSO-d_6 is quite analogous to that of the AMMAH$_2$ species (Fig. 1, Table II), as are the electronic and CD spectra of the diperchlorate form ('Experimental'). Any remaining doubts as to its stereochemistry are dispelled by the determination of its structure, as discussed below.

In contrast to the absolute stereospecificity found in the reactions of Λ-β-[Co(R,R-picchxn)Cl_2]$^+$ with the alanine and phenylalanine precursors, two diastereoisomers are formed in the reaction of the α-aminobutyric acid precursor KHAEMA·H_2O in aqueous solution. Chromatographic separation of the reaction mixture gave two orange bands on the column, and from which two isomeric salts were isolated. The major isomer, which eluted more slowly, is the analogue of the two mentioned above, namely Λ-β_1-[Co(R,R-picchxn)(R-AEMA)]$^+$. CD and ^{1}H NMR spectral data for this species are given in the 'Experimental' and Table III, respectively. Its lower-field NMR spectrum is also shown in Fig. 1 for comparison.

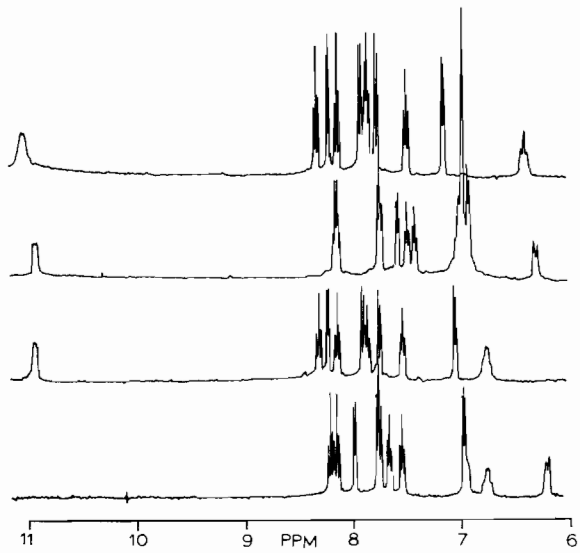


Fig. 1. 360 MHz ^{1}H NMR spectra in DMSO-d_6 of (a) Λ-β_1-[Co(R,R-picchxn)(R-AMMA)]$^+$; (b) its R-ABMA analogue; (c) its R-AEMA analogue; (d) Λ-β_1-[Co(R,R-picchxn)(S-AEMA)]$^+$.

The minor isomer has a ^{1}H NMR spectrum which is quite different from that of Λ-β_1-[Co(R,R-picchxn)(R-aa)]$^+$ (where aa represents AMMA, ABMA or AEMA in this case), but its absolute configuration is indeed Λ. This is quite as expected in view of the stereosospecific form of β-coordination always observed for the tetradentate, and the ^{1}H NMR spectrum of the complex ('Experimental' and Table II) indicates that it too is unquestionably a β_1 diastereoisomer. Hence the only structure possible for this species is that shown in **5**, *i.e.* Λ-β_1-[Co(R,R-picchxn)(S-AEMA)]$^+$. This was isolated as a $NaClO_4$ adduct of the protonated complex cation. Particularly noteworthy is the fact that the H(Nn2) resonance of this complex is shifted significantly upfield compared with that of the R-AEMAH$_2$ diastereoisomer. This no doubt is due to the fact that the pendant carboxylic group is no longer in a favourable position to form the appropriate internal hydrogen bond. The reasons that both possible β_1 isomers form in this case are as yet unclear, but this pattern of

TABLE III. Final Atomic Coordinates (fractional × 10^4) for Non-hydrogen Atoms with Estimated Standard Deviations in Parentheses

	x	*y*	*z*
Co(1)	1530.0(17)	4158.0(14)	1596.5(6)
N(111)	2709(11)	3560(9)	1851(4)
N(11)	751(10)	3230(9)	1862(4)
N(12)	217(10)	4553(9)	1365(4)
N(121)	1619(11)	3457(8)	1109(4)
N(13)	1444(12)	5059(8)	2028(3)
O(181)	2312(9)	5099(8)	1342(3)
O(182)	2691(10)	6579(8)	1330(3)
O(191)	846(10)	7408(8)	1975(4)
O(192)	49(9)	6293(7)	1653(4)
C(17)	1802(14)	5990(11)	1897(4)
C(18)	2317(13)	5915(11)	1502(4)
C(19)	826(14)	6629(11)	1853(5)
C(110)	2571(13)	6414(11)	2204(5)
C(131)	3572(14)	5889(12)	2258(5)
C(132)	3725(15)	5312(12)	2585(5)
C(133)	4686(18)	4891(15)	2634(6)
C(134)	5504(16)	5026(16)	2402(7)
C(135)	5387(15)	5566(17)	2090(6)
C(136)	4404(16)	5988(15)	2009(6)
C(111)	2446(12)	2999(11)	2146(5)
C(112)	3193(14)	2506(12)	2340(6)
C(113)	4249(15)	2555(15)	2238(6)
C(114)	4505(16)	3115(13)	1933(6)
C(115)	3731(14)	3612(11)	1753(6)
C(116)	1278(13)	2992(10)	2242(4)
C(11)	−405(12)	3501(12)	1887(5)
C(12)	−625(13)	3882(11)	1483(5)
C(13)	−1746(14)	4277(13)	1467(6)
C(14)	−2536(14)	3546(14)	1597(6)
C(15)	−2256(14)	3081(14)	1975(5)
C(16)	−1153(13)	2739(13)	2003(5)
C(121)	976(16)	3779(13)	824(6)
C(122)	945(19)	3420(16)	457(5)
C(123)	1563(19)	2637(18)	377(6)
C(124)	2271(18)	2307(12)	676(6)
C(125)	2270(16)	2727(12)	1048(5)
C(126)	366(14)	4617(14)	943(5)
Co(2)	−110.1(14)	4438.5(14)	3975.4(6)
N(211)	−1444(11)	4190(9)	4224(4)
N(21)	266(12)	3251(10)	4182(4)
N(22)	1304(11)	4496(10)	3765(4)
N(221)	501(13)	5107(10)	4412(4)
N(23)	−687(11)	3986(9)	3479(4)
O(281)	−506(9)	5608(7)	3784(3)
O(282)	−1151(10)	6388(7)	3276(3)
O(291)	−248(10)	5175(9)	2561(4)
O(292)	885(9)	4511(9)	2978(3)
C(27)	−903(13)	4772(11)	3204(5)
C(28)	−863(13)	5678(11)	3435(5)
C(29)	−11(16)	4838(11)	2885(5)
C(210)	−1972(12)	4642(11)	2995(5)
C(231)	−2922(12)	4594(12)	3276(5)
C(232)	−3444(16)	5401(13)	3383(6)
C(233)	−4296(15)	5389(18)	3638(6)
C(234)	−4628(18)	4587(27)	3787(7)
C(235)	−4117(20)	3764(17)	3686(7)
C(236)	−3256(13)	3802(12)	3424(5)
C(211)	−1580(14)	3332(11)	4336(5)
C(212)	−2438(16)	3057(16)	4562(6)
C(213)	−3194(18)	3690(16)	4660(7)
C(214)	−3044(16)	4575(18)	4540(6)
C(215)	−2158(16)	4835(14)	4322(6)
C(216)	−760(16)	2690(12)	4207(5)
C(21)	1151(13)	2873(11)	3942(5)
C(22)	1899(14)	3672(12)	3896(6)
C(23)	2788(15)	3380(13)	3606(6)
C(24)	3388(17)	2546(15)	3754(7)
C(25)	2568(18)	1766(14)	3823(7)
C(26)	1682(15)	2049(12)	4119(7)
C(221)	1361(14)	5599(14)	4308(6)
C(222)	1800(17)	6239(15)	4550(7)
C(223)	1309(20)	6405(16)	4899(8)
C(224)	430(19)	5908(17)	5013(6)
C(225)	36(17)	5198(12)	4765(5)
C(226)	1798(15)	5371(11)	3907(6)
Cl(1)	3676.1(43)	4233.2(35)	4890.5(14)
O(11)	3760(14)	4844(13)	4597(4)
O(12)	3683(21)	3330(13)	4731(6)
O(13)	4506(22)	4273(16)	5168(7)
O(14)	2853(22)	4470(22)	5137(10)
Cl(2)	5598.2(53)	2418.8(47)	784.6(18)
O(21)	4927(15)	3029(14)	984(5)
O(22)	6101(15)	1775(13)	1048(5)
O(23)	4934(18)	1874(16)	505(6)
O(24)	6431(14)	2979(12)	576(5)
O(w1)	1693(10)	1193(9)	2859(4)
O(w2)	3795(12)	6016(10)	660(4)
O(w3)	199(16)	3091(10)	5035(4)

isomer distribution is mirrored in the reaction of $AMMAH_2$ with Λ-β-[Co(*R*,*R*-picbn)Cl_2]$^+$.

In this latter case, unlike the reaction of $AMMAH_2$ with Λ-β_1-[Co(*R*,*R*-picchxn)Cl_2]$^+$, two diastereoisomers again are produced. Their CD and electronic spectral data ('Experimental') indicate that they too are Λ-β_1 analogues of the Λ-β_1-[Co(*R*,*R*-picchxn)(*R*- or *S*-AEMA)]$^+$ species, and ^{1}H NMR spectral data (Table II) support these assignments. Unfortunately, the latter needed to be recorded in D_2O solution because of the presence of excess $NaClO_4$ (see 'Experimental'), and hence the downfield *H*(N3) resonance of the Λ-β_1-[Co(*R*,*R*-picbn)-(*R*-AMMA)]$^+$ ion is not observed due to its rapid exchange for a deuteron. Nevertheless, the electronic and CD spectral characteristics of these two diastereoisomers permit an unequivocal assignment of their respective stereochemistries. Indeed, the retention of their Λ-β_1 forms after decarboxylation both provides strong support for their structural assignments as well as an insight into the mechanism involved when using these complexes to produce chiral amino acids.

The Crystal and Molecular Structure of Λ-β$_1$-[Co-(R,R-picchxn)(R-ABMA)] ClO$_4$·1.5H$_2$O

The solution of the structure of this complex was crucial to the unequivocal establishment of the stereochemical course of the synthetic reactions reported here and earlier [10].

It is worthy of note that the conclusions that were drawn concerning the nature of this and related species, in terms of absolute configurations and complex ligand geometry, are correct in every respect. An unusual feature of the structure is the fact that two complex cations, and hence also three molecules of water of crystallisation, together make up the crystallographic asymmetric unit. Final atomic positions for all atoms are given in Tables III and IV. The calculated positions of the hydrogen atoms have been included because of their special relevance to the NMR spectral studies of this complex and of related ones.

TABLE IV. Atomic Parameters (coordinates: fractional $\times 10^3$) for Hydrogen Atoms

	x	y	z
H(112)	297	210	256
H(113)	480	220	238
H(114)	525	316	184
H(115)	394	404	154
H(122)	49	370	25
H(123)	151	232	12
H(124)	276	179	62
H(125)	274	249	126
H(132)	314	521	278
H(133)	477	446	286
H(134)	620	473	246
H(135)	600	568	191
H(136)	432	636	176
H(212)	−251	240	465
H(213)	−384	351	481
H(214)	−358	505	461
H(215)	−206	549	424
H(222)	246	658	447
H(223)	159	690	507
H(224)	8	605	527
H(225)	−56	479	485
H(232)	−320	600	327
H(233)	−466	597	371
H(234)	−524	457	397
H(235)	−436	316	379
H(236)	−289	322	335
H(N13a)	190	485	225
H(N13b)	70	510	212
H(110a)	276	705	212
H(110b)	220	644	246
H(116a)	111	346	245
H(116b)	105	237	233
H(126a)	77	519	88
H(126b)	−34	463	81
H(11)	−47	401	208
H(12)	−56	338	128
H(13a)	−180	482	165
H(13b)	−191	447	119
H(14a)	−324	385	163
H(14b)	−258	307	139
H(15a)	−237	353	219
H(15b)	−274	254	201
H(16a)	−100	254	228
H(16b)	−106	220	182
H(N11)	80	268	169
H(N12)	2	517	147
H(N23a)	−136	365	353
H(N23b)	−17	356	336
H(210a)	−208	517	281
H(210b)	−194	406	284
H(216a)	−68	218	440
H(216b)	−94	243	394
H(226a)	258	529	392
H(226b)	163	588	372
H(21)	87	270	368
H(22)	221	383	416
H(23a)	329	390	357
H(23b)	246	323	335
H(24a)	375	270	401
H(24b)	392	235	356
H(25a)	294	121	393
H(25b)	223	161	357
H(26a)	200	221	438
H(26b)	116	154	415
H(N21)	53	333	446
H(N22)	129	450	347

(continued)

TABLE IV. *(continued)*

For Hydrogen atoms B = 2.0 Å^2

A view of the packing arrangement of all molecular units in one unit cell is shown in Fig. 2. It is evident that a three-dimensional hydrogen bonding network involving the water molecules, perchlorate anions and donor–acceptor atoms in the complex cations exists in the crystal. See also 'Supplementary Material'.

Perspective views [23] of the two complex cations in the asymmetric unit are shown in Fig. 3, together with the atomic labelling scheme. It is readily seen that only very minor structural differences serve to distinguish between the two cations By way of illustration, selected bond lengths and angles for the pair are listed in Table V. There are no unusual structural features.

However in terms of the results reported elsewhere in this paper, there are several points worthy of comment. Firstly, it is true that both cations have a Λ-β$_1$ geometry and that the aminomalonic acid coordinates with an absolute configuration of *R* (*i.e., pro-S*). Secondly, the internal hydrogen bond that had been proposed on the basis of ^{1}H NMR studies [10] is indeed observed for both cations. For the two molecules (n = 1 and 2) the interatomic

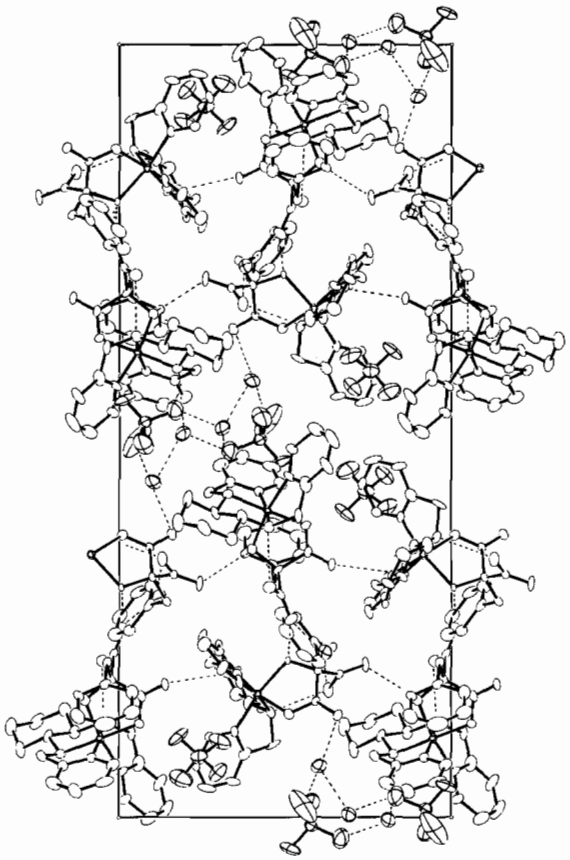


Fig. 2. The packing of the molecular contents of the unit cell of $\Lambda\,\beta_1$-[Co(*R*,*R*-picchxn)(*R*-ABMA)]$ClO_4 \cdot 1.5H_2O$ projected down the *a* axis. Proposed hydrogen bonds are represented by broken lines.

distances O(*n*91)·····N(*n*2) are 2.72(2) and 2.73(2) Å, respectively. Furthermore, the N(*n*2)–H(N*n*2) bonds are almost colinear with these two O····N directions.

This internal hydrogen bond apparently serves to stabilise the observed *R*-aminomalonate coordination in the Λ-β_1 diastereoisomer over its alternative *S* bonding form. Thus, as has been mentioned elsewhere, an explanation is provided for the far greater proportion of the former complex formed in this (stereospecific) case and in related synthetic reactions. A similar three-point attachment of coordinated $AMMAH_2$ has been found in three other related complexes [6, 20]. All three complexes possess a β coordination geometry for the linear aliphatic tetramines employed, and β_2 coordination for the aminomethylmalonate. It has been suggested [20] that binding modes of $AMMAH_2$ other than β_2 would be less stable by virtue of steric interactions between the tetradentate and the coordinated aminomalonate. We can discern no justifiable reason for this claim, and it is possible that electronic rather than steric discriminations play at least as important a role in these kinds of species.

Finally, with reference to this particular complex, it is apparent that a hydrophobic interaction between the phenyl ring of the aminomalonate and the adjacent pyridyl ring of the tetradentate ligands is present in each complex cation. Data concerning these planar fragments are presented in Table VI. These interactions may be of particular importance with respect to the isomeric distribution found upon acid-catalysed decarboxylation of Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-ABMAH)]$^{2+}$, as discussed below.

TABLE V. Selected Bond Lengths and Angles with Estimated Standard Deviations in Parentheses

	n = 1	*n* = 2		*n* = 1	*n* = 2
(a) Distances (A)					
Co(*n*)–N(*n*11)	1.933(13)	1.924(14)	Co(*n*)–N(*n*21)	1.950(13)	1.937(14)
Co(*n*)–N(*n*1)	1.903(14)	1.926(14)	Co(*n*)–N(*n*2)	1.928(14)	1.930(14)
Co(*n*)–N(*n*3)	1.973(12)	1.954(13)	Co(*n*)–O(*n*81)	1.900(11)	1.891(11)
C(*n*8)–O(*n*81)	1.31(2)	1.28(2)	C(*n*9)–O(*n*91)	1.21(2)	1.24(2)
C(*n*8)–O(*n*82)	1.23(2)	1.22(2)	C(*n*9)–O(*n*92)	1.29(2)	1.27(2)
C(*n*8)–C(*n*7)	1.50(2)	1.54(2)	C(*n*9)–C(*n*7)	1.55(2)	1.57(2)
N(*n*3)–C(n7)	1.50(2)	1.50(2)	C(*n*7)–C(*n*10)	1.56(2)	1.54(2)
(b) Angles (°)					
N(*n*11)–Co(*n*)–N(*n*1)	82.4(6)	83.6(6)	N(*n*21)–Co(*n*)–N(*n*2)	81.9(6)	83.8(6)
N(*n*1)–Co(*n*)–N(*n*2)	87.7(6)	86.9(9)	N(*n*3)–Co(*n*)–O(*n*81)	83.6(5)	84.6(5)
N(*n*11)–Co(*n*)–N(*n*2)	169.6(6)	170.4(6)	N(*n*21)–Co(*n*)–N(*n*1)	93.6(5)	94.2(6)
N(*n*21)–Co(*n*)–N(*n*3)	169.9(5)	168.9(6)	N(*n*21)–Co(*n*)–O(*n*81)	87.7(5)	85.3(6)
N(*n*1)–Co(*n*)–O(*n*81)	178.7(5)	178.5(6)	N(*n*1)–Co(*n*)–N(*n*3)	95.1(5)	96.0(6)
N(*n*11)–Co(*n*)–N(*n*21)	95.8(6)	96.2(6)	N(*n*2)–Co(*n*)–N(*n*3)	93.4(6)	92.3(6)
N(*n*11)–Co(*n*)–N(*n*3)	90.5(6)	89.4(6)	N(*n*2)–Co(*n*)–O(*n*81)	92.7(5)	94.5(6)
N(*n*11)–Co(*n*)–O(*n*81)	97.3(5)	95.1(5)			

(continued)

TABLE V. *(continued)*

	$n = 1$	$n = 2$		$n = 1$	$n = 2$
Co(n)–N(n3)–C(n7)	111(1)	111(1)	Co(n)–O(n81)–C(n8)	118(1)	119(1)
O(n81)–C(n8)–O(n82)	121(2)	126(2)	O(n91)–C(n9)–O(n92)	124(2)	126(2)
O(n81)–C(n8)–C(n7)	116(1)	115(1)	O(n91)–C(n9)–C(n7)	121(2)	118(2)
O(n82)–C(n8)–C(n7)	123(1)	119(2)	O(n92)–C(n9)–C(n7)	115(1)	117(2)
N(n3)–C(n7)–C(n8)	110(1)	109(1)	C(n8)–C(n7)–C(n9)	108(1)	106(1)
N(n3)–C(n7)–C(n9)	109(1)	110(1)	C(n8)–C(n7)–C(n10)	111(1)	112(1)
N(n3)–C(n7)–C(n10)	110(1)	111(1)	C(n9)–C(n7)–C(n10)	109(1)	109(1)

TABLE VI. Least-squares Planes Data

Plane No.	Atoms defining plane	l	m	n	p
(a) Least-squares planes and their equations given by $lX + mY + nZ - p = 0$ where X, Y and Z are atomic coordinates in A					
1	N(111), C(111)–C(115)	0.1292	0.7515	0.6469	8.4148
2	C(131)–C(136)	0.2959	0.7870	0.5414	12.2373
3	N(211), C(211)–C(215)	0.5027	0.1944	0.8423	12.3813
4	C(231)–C(235)	0.6231	0.1115	0.7761	7.0754
Planes	Dihedral angle	Centroid–centroid			
(b) Dihedral angles (°) and centroid–centroid distances (A) between planes					
1–2	11.5	3.858			
3–4	9.2	3.807			
Centroid ring	Plane	Distance			
(c) Perpendicular distances (A) between the centroid of each aromatic ring and its interacting plane					
1	2	3.419			
2	1	3.666			
3	4	3.446			
4	3	3.357			

Decarboxylation Experiments

Decarboxylation of the precursor complexes containing coordinated aminomalonic acid derivatives so as to yield the corresponding α-aminoacidates were carried out in such a way as to permit the estimation of the optical yields of the aminoacids by reference to the ^{1}H NMR spectra of their previously prepared complexes with the same tetradentate ligands coordinated to Co(III). Integration by weighing of expanded sections of the spectra of pairs of diastereoisomers containing signals clearly due to the individual isomers previously established gave the ratios of chiral aminoacids listed in Table VII. In general, the decarboxylation reactions were carried out at 70 °C in a thermostatted bath in aqueous 1.13 mol dm^{-3} HCl during two hours. Separate experiments were carried out using 0.113 and 2.26 mol dm^{-3} HCl, and with the temperature varied between 50 and 90 °C. In all cases the same respective ratios of aminoacid-containing diastereoisomers were formed. A similar lack of sensitivity of the ratios was found in earlier [10] experiments, although we find here that prolonged heating of the complexes (>5 h) causes some decomposition of the products. In particular, Λ-β_1 diastereoisomers containing the *R*-aminoacids were observed to decompose faster than the corresponding *S* forms under the same reaction conditions.

In all cases studied here, using either *R,R*-picchxn or *R,R*-picbn as the chiral 'template' ligand, high chiral inductions are found in the reactions leading to coordinated aminoacidates. We first would wish to draw attention to the results found for alanine synthesis using complexes containing both tetradentates. Decarboxylation of Λ-β_1-[Co(*R,R*-picchxn)(*R*-AMMAH)]$^{2+}$ [10] gives a ratio of *R*-ala:*S*-ala of

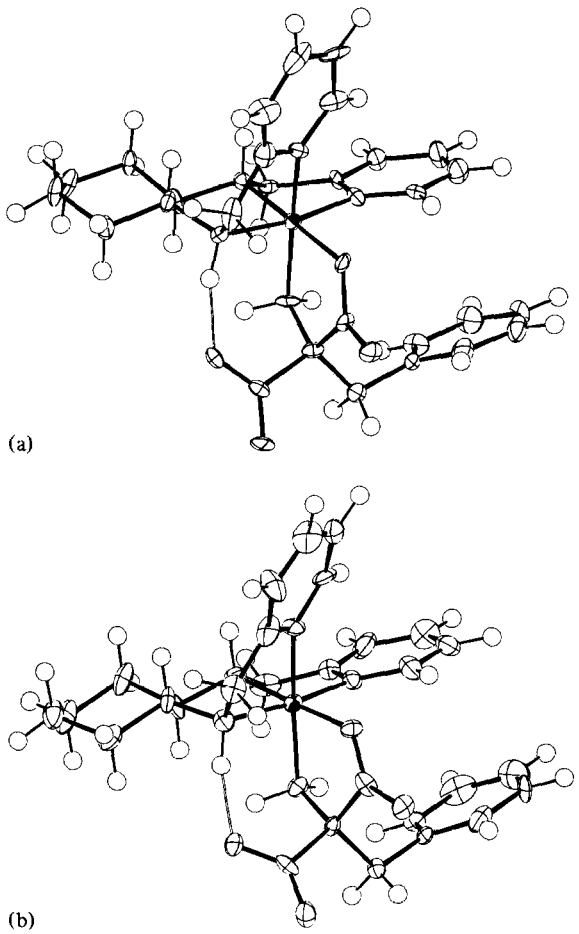
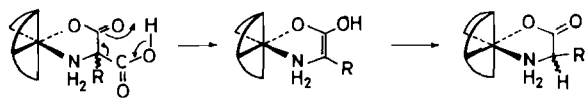


Fig. 3. Perspective drawings of the two crystallographically distinct cations of Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-ABMA)]$^+$ for molecules (a) $n = 1$, and (b) $n = 2$. Non-hydrogen ellipsoids are scaled to include 35% probability.

89:11. Since the same ratio of products is formed in the decarboxylation of Λ-β_1-[Co(*R*,*R*-picbn)(*R*-AMMAH)]$^{2+}$, within experimental error, it is evident that the overall molecular architecture of the complexes, and concomitant solvation effects which we comment upon further below, is of central importance in determining the chiral inductions observed. The nature of the optically active fragment in the backbone of the tetradentate is not important, and serves merely to lock the overall geometry of the precursor and final product complexes.

In these particular reactions, inversion of absolute configuration of the chiral carbon atom in the coordinated AMMAH$^-$ ligand occurs. More significantly, retention of absolute configuration at this carbon atom is observed in the decarboxylation of Λ-β_1-[Co(*R*,*R*-picbn)(*S*-AMMAH)]$^{2+}$ to give again the same ratio of *R*-ala:*S*-ala in the products. This result means that in the decarboxylation of both *R*- and *S*-AMMAH diastereoisomers, the reaction must proceed through a common intermediate. The natural conclusion to be drawn from this finding, coupled with the fact that the product isomer distribution is not dependent on proton concentration or temperature over the range studied, is that the course of the decarboxylation of these and the chiral inductions found are a consequence of thermodynamic rather than kinetic influences, as had earlier been suggested for the Λ-β_1-[Co(*R*,*R*-picchxn)(AMMAH)]$^{2+}$ case [10]. Job and Bruice [3] have suggested that the mechanism of the decarboxylation proceeds via a cyclised transition state involving an *enol* intermediate, as shown in **9**–**11**. This supposes that the uncoordinated carboxylic group is lost during the reaction, although it should be mentioned that there is no firm evidence to suggest that this is truly the case.



9 **10** **11**

If, however, this mechanism is correct and the thermodynamic distribution of product diastereoisomers is found, then the addition of a proton to either side of the intermediate coordinated *enol* in **10** is stereoselective. It also might be mentioned in passing that this mechanism is akin to that usually ascribed to the base-catalysed epimerisation of amino-acids coordinated to Co(III), as shown in **12** and **13**.

TABLE VII. Ratios of Coordinated *R*- and *S*-Amino Acids Produced in the Decarboxylation Experiments

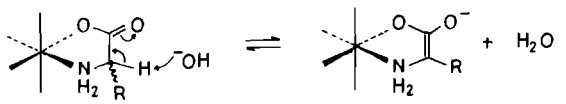
Starting complex[a]	Amino acid produced	*R*-amino acid: *S*-amino acid
Λ β_1-[Co(*R*,*R*-picchxn)(*R*-AMMAH)]$^{2+}$	alaH	89.0:11.0 ± 0.5[b]
Λ-β_1-[Co(*R*,*R*-picbn)(*R*-AMMAH)]$^{2+}$	alaH	89.2:10.8 ± 1.5
Λ-β_1-[Co(*R*,*R*-picbn)(*S*-AMMAH)]$^{2+}$	alaH	88.3:11.7 ± 2.0
Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-AEMAH)]$^{2+}$	abuH	83.1:16.8 ± 2.7
Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-AEMAH)]$^{2+}$	abuH	84.2:15.8 ± 1.3
Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-ABMAH)]$^{2+}$	pheH	24.2:75.8 ± 3.1

[a]In acid solution the protonated complex must predominate ([H$^+$] ≥ 0.113 mol dm^{-3}; see text). [b]Data taken from ref. 10.

TABLE VIII. Ratios of *S*-:*R*-aminoacidate formed on Decarboxylation of Λ-β_2-[Co(tetradentate)(*S*-aminomalonateH)]$^{2+}$ Under Various Conditions

Tetradentate[a]	*S*-aa:*R*-aa[b]			
	alaH	valH	pheH	leuH
2*S*,9*S*-Me_2trien[c]	65:35	36:64		
2*S*,9*S*-Pr_2trien[c]	69:31			
3*S*,8*S*-Me_2trien	56:44	28:72(22:78)		
2*S*,10*S*-Me_2-2,3,2-tet	54:46	22:78(16:84)	39:61(50:50)	41:59(44:56)
3*S*,9*S*-Me_2-2,3,2-tet	55:45(45:55)	13:87(9:91)	35:65(23:77)	

[a]2*S*,9*S*-Me_2trien is 2*S*,9*S*-diamino-4,7-diazadecane, 2*S*,9*S*-Pr_2trien is 3*S*,10*S*-diamino-5,8-diaza-2,11-dimethyldodecane, 3*S*,8*S*-Me_2trien is 1,4,7,10-tetraaza-3*S*,8*S*-dimethyldecane, 2*S*,10*S*-Me_2-2,3,2-tet = 2*S*,10*S*-diamino-4,8-diazaundecane, 3*S*,9*S*-Me_2-2,3,2-tet is 1,4,8,11-tetraaza-3*S*,9*S*-dimethylundecane. [b]Values in brackets are for decarboxylation experiments carried out at reflux temperature in methanolic 1.0 M HCl. Other values are for the same reactions in aqueous 1.0 M HCl. [c]Values for these complexes from ref. 3. All other values are from ref. 5.



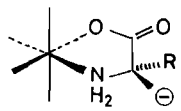
12 13

The same pattern of stereoselectivity is found for the pair of diastereoisomers Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-AEMAH)]$^{2+}$ and Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-AEMAH)]$^{2+}$. In both cases coordinated abuH is produced in high optical yield, with the same ratio *R*-abuH:*S*-abuH equal to 84:16. Inversion of configuration of the aminomalonate is found for the former isomer, and retention for the latter. This result is particularly significant with respect to other factors which have been suggested to be important in these kinds of reactions in that the side chain of the aminoacid is somewhat more bulky than in $AMMAH_2$ or alaH analogues.

Yamaguchi *et al.* [5] have studied similar reactions on related complexes and have compared their results with the earlier ones of Job and Bruice [3] with respect to the formation of alaH, pheH, valine (valH) and leucine (leuH) from appropriate precursors. Their results are collected together in Table VIII. In all cases tabulated, the complex which was decarboxylated was the Λ-β_2-[Co(tetradentate)(*S*-aminomalonateH)]$^{2+}$ ion. Other decarboxylations of complexes containing the tetradentate 1,7-bis(2*S*-pyrrolidyl)-2,6-diazaheptane were carried out with appreciable chiral inductions, but since mixtures of diastereoisomers containing the precursors were not separated [5] these results are not included. On the basis of the results in the Table, it is concluded that the planar *enol* intermediate suggested to be formed in **9**–**11** would not explain the different stereoselectivities found for the different aminoacids produced. Since the degree of retention of absolute configuration of the carbon atom in the coordinated aminomalonates decreases in the order

$APMAH_2 > ABMAH_2 > ABuMAH_2 > AMMAH_2$

($APMAH_2$ and $ABuMAH_2$ being the precursors of valH and leuH respectively) it was thought that the preference for retention depends upon the bulkiness of the side chain of the aminoacid or aminomalonic acid precursor. Thus an intermediate in which the α-carbon of the aminomalonate retains, at least partially, a tetrahedral character was invoked, as shown in **14**. In this connection it is worth recalling



14

that the rate of exchange of the α-hydrogen atom of *S*-aspartic acid and *S*-glutamic acid coordinated to Co(III) is faster than the rate of epimerisation of the chiral centre [24]. In this case too a partially tetrahedral configuration of the carbanion intermediate, retanining the original absolute configuration of the aminoacid, must be invoked to explain the experimental observations. In other words, the intermediate must have the partial characteristics of both **13** and **14**.

The above explanation is a plausible one at first glance, but a closer scrutiny of the reported results, and ours, does not support it. Firstly, the results reported in Table VII show marked solvation effects. Indeed no selectivity in the formation of pheH is found in reactions carried out in acidic methanol, and the direction of the inversion/retention ratio is reversed in the same conditions with respect to the formation of alanine (with 2*S*,10*S*-Me_2-2,3,2-tet and 3*S*,9*S*-Me_2-2,3,2-tet respectively). Yamaguchi *et al.* [5, 25] have measured equilibrium constants for eqn. (1) by the epimerisation method for the aminoacids alaH, valH, pheH and leuH with N_4 being 2*S*,10*S*-Me_2-2,3,2-tet and 3*S*,9*S*-Me_2-2,3,2-tet (except

$$\Lambda\text{-}\beta_2\text{-}[Co(N_4)(S\text{-aa})]^{2+}_{(aq)} \rightleftharpoons \Lambda\text{-}\beta_2\text{-}[Co(N_4)(R\text{-aa})]^{2+}_{(aq)} \quad (1)$$

for the ternary complex with leuH). Except for the valine complexes, the thermodynamically stable diastereoisomer contained the *S*-aminoacidate. Measured chiral discrimination energies varied from between 1.16 and 1.73 kJ mol^{-1} for the pairs of diastereoisomers. With the ternary valine complexes, those containing *R*-valH were more stable by 0.31 and 2.21 kJ mol^{-1} for the above two tetradentates respectively, with all measurements being made at 40 °C. On the basis that the stereoselectivities found in some decarboxylations were the reverse of those found in the epimerisation equilibrium experiments, a thermodynamic origin for the chiral discriminations observed in the former was ruled out [5]. This conclusion may not strictly be correct, since the temperatures of the two sets of experiments were some 30 °C different and the one was carried out under basic conditions whereas the other was carried out in acid solution. Thus the two series of results are not comparable. Furthermore, because the magnitudes of the chiral discrimination energies are so small, they may easily be accounted for by temperature and solvation effects which already had been shown to be important in these systems (*vide supra*). We note as well that a kinetic explanation for the results would appear to completely contradict the findings concerning the products formed upon decarboxylation of Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-AEMAH)]$^{2+}$, Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-AEMAH)]$^{2+}$, and their $AMMAH_2$ analogues in the ternary Co(III) complexes containing *R*,*R*-picbn.

We are forced to conclude therefore that the stereoselectivities we observe are the result of chiral discriminations of thermodynamic origin. All of our results may be explained by the formation of an intermediate which does retain the tetrahedral character of the chiral carbon of the aminomalonate, but that its absolute configuration represents the distribution of aminoacidate products formed. Subtle steric, solvation and hydrophobic bonding effects, quite consistent with the isomer distributions found, may all then play a part in determining the relative stabilities of diastereoisomeric intermediates. This subtlety reflects that found in the related systems Λ,Δ-$[Ru(diimine)_2(aa)]^{n+}$ [9].

We also find a marked stereoselectivity reflected in the products of decarboxylation of Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-ABMAH)]$^{2+}$ and that the absolute configuration of the coordinated precursor is retained overall during the reaction. A delicate interplay of discriminatory forces is no doubt responsible for the observed distribution of products. In this case the intermediate with the *pro-S* configuration might be stabilised by hydrophobic stacking interactions between the benzene ring of the precursor and the adjacent pyridyl ring of the tetradentate, as observed in the structure of Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-ABMA)]$ClO_4 \cdot 1.5H_2O$ (*vide supra*), an arrangement which is not possible for its diastereoisomeric congener. Further experiments to explore this possibility are in progress.

Supplementary Material

Lists of observed and calculated structure factors, anisotropic thermal parameters (21 pages), proposed hydrogen bond parameters and a comprehensive table of bond lengths and angles have been deposited with the Editor.

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