DALTON
FULL PAPER

Chiral recognition of amino esters by ruthenium porphyrin complexes and crystal structure of {5,10,15,20-tetrakis[*o*-(3,3,3-trifluoro-2-methoxy-2-phenylpropanoylamino)phenyl]porphyrin}-bis(L-valine methyl ester)ruthenium(II) (α,α,β,β isomer)

Christophe Morice,[a] Paul Le Maux,[a] Gérard Simonneaux *[a] and Loic Toupet[b]

[a] *Laboratoire de Chimie Organométallique et Biologique, UMR 6509, Université de Rennes 1, Campus de Beaulieu, 35042 Rennes Cedex, France*
[b] *Groupe Matière Condensée et Matériaux UMR 6626, Université de Rennes 1, Campus de Beaulieu, 35042 Rennes Cedex, France*

Received 22nd June 1998, Accepted 23rd October 1998

Bis(amino ester)ruthenium(II) picket-fence complexes bearing optically active α-methoxy-α-(trifluoromethyl)phenylacetyl residues on both sides of a porphyrin plane (α,β,α,β and α,α,β,β isomers) have been synthesized. These chiral porphyrins have been characterized by UV-visible, IR and ^{1}H, ^{19}F NMR spectroscopy. For the valine methyl ester complex a chiral recognition was observed for the oxidation of the ligand yielding a mixed ligated imino ester/amino ester ruthenium(II) complex with 66% enantiomeric excess. The chiral recognition involving ligated amino ester complexation and oxidation to give imino complexes is discussed. The crystal structure of the complex α,α,β,β-[Ru(P){$(CH_3)_2CHCH(NH_2)CO_2CH_3$}$_2$] {P = 5,10,15,20-tetrakis[*o*-(3,3,3-trifluoro-2-methoxy-2-phenylpropanoylamino)phenyl]porphyrinate} was determined.

Introduction

Since the pioneering work of Cram and co-workers[1–3] and Lehn *et al.*[4] on chiral recognition of amino esters and acids by binaphthyl hosts, several approaches to the design and preparation of new chiral hosts have been reported. Recently, Ogoshi and co-workers[5–12] and Crossley *et al.*[13] utilized the porphyrin rigid framework and a metal co-ordination site as a host which can be seen as a model for the substrate–heme protein interaction. The properties of two metal ions, Rh and Zn, were compared in detail and good enantioselectivity was obtained for valine ester with a chiral zinc porphyrin (D/L = 7.5).[11] Thus it is well known for a chiral molecule to distinguish between the enantiomers of a second species, and that a minimum of three simultaneous interactions must take place between the two species.[12,14]

Our efforts in this area have been largely directed toward the systematic investigation of the reactivity of chiral ruthenium porphyrins.[15–18] For example, we previously described the separation of the enantiomers of chiral phosphines on an optically active ruthenium porphyrin, derived from addition of the Mosher reagent to tetra(aminophenyl)porphyrins.[15] We anticipated that these properties might persist in amino ester ruthenium derivatives. Since amino esters are functionalized substrates, they could better interact with the optically active host. In particular, hydrogen bonding between the carbonyl group of the amino ester and the amide NH group of the chiral pickets might occur. This situation has been shown by Ogoshi and co-workers[11] with doubly bridged chiral porphyrin zinc complexes. Further to complete our understanding of the structures of these ruthenium complexes, detailed spectroscopic investigations were undertaken for derivatives of type 1 [bis-(amino ester)ruthenium porphyrin] and type 2 [(imino ester)-(amino ester)ruthenium porphyrin], using racemic amino acid esters as ligands. The crystal structure of a type 1 complex has also been determined. A comparison with ^{1}H NMR results suggests a general conformation in the bis(amino ester) complexes.

Results

^{19}F NMR Study of the α,β,α,β isomer of bis(amino ester)-ruthenium complexes

For the purpose of chiral recognition, it was decided that the α,β,α,β isomer offered the greater simplicity because the chiral pickets of this atropisomer provide a ruthenium molecule with two topogically identical faces. Confirmation that this was indeed the case came from the observation of the ^{1}H and ^{19}F NMR spectra of the bis(acetonitrile) adduct α,β,α,β-[Ru(P)$(CH_3CN)_2$] **1** {P = 5,10,15,20-tetrakis[*o*-(3,3,3-trifluoro-2-methoxy-2-phenyl-propanoylamino)phenyl]porphyrinate}.[19] The CH_3CN complex displayed only a singlet (δ −68.9) for the CF_3 groups of the four identical pickets. In order to obtain diastereomeric ruthenium porphyrins, the red-purple, six-co-ordinate, low-spin complex α,β,α,β-[Ru(P){$(CH_3)_2$-$CHCH(NH_2)CO_2CH_3$}$_2$] **2** was first prepared from the precursor **1** by treatment with 10 equivalents of racemic valine methyl ester in CH_2Cl_2 at room temperature (12 h, 76% yield). As expected, signals due to equivalent fluorines in the bis(CH_3CN) complex **1** are split in **2** bearing the chiral amino ester (Fig. 1). The signals must represent the LL, LD (two signals) and DD diastereoisomers. Identification of the optically pure isomers has previously been reported.[19] Integration of the four resonances gave a ratio of 1:2:1 for the LL, DL and DD isomers, respectively. Thus, this ratio indicates that the three diastereoisomers are formed in statistical proportions. Moreover the exchange reaction between acetonitrile and amino ester was followed at an intermediate stage by ^{19}F NMR and the spectra of the mixed-ligand acetonitrile–amino ester ruthenium complexes did not show any chiral recognition (Fig. 1). By a procedure similar to that described for valine methyl ester, complexation of the racemic leucine methyl ester gave the bis-(leucine methyl ester) complex **3** with a ^{19}F NMR spectrum showing four signals at δ −69.41 (LL), −69.64 (DL), −69.97 (LL) and −70.05 (DL). Integration of the four resonances gave also a ratio of 1:2:1 for the LL, DL and DD isomers **3**, respectively.

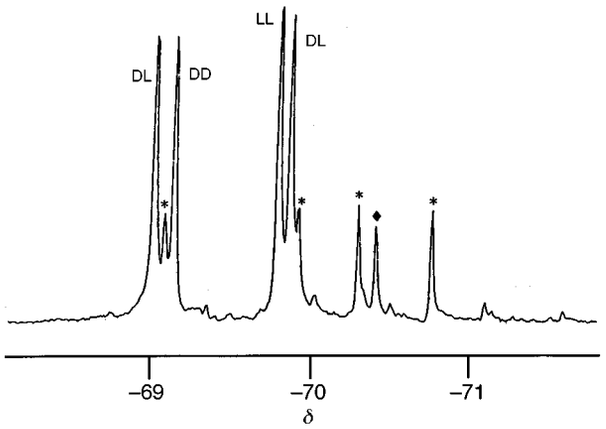


Fig. 1 The ^{19}F NMR spectrum for the diastereoisomeric mixture (LL, DD and DL) of complex **2** resulting from direct exchange from **1** (* = mixed-ligand complex [Ru(P)(CH_3CN){$(CH_3)_2CHCH(NH_2)CO_2CH_3$}], ◆ = **1**.

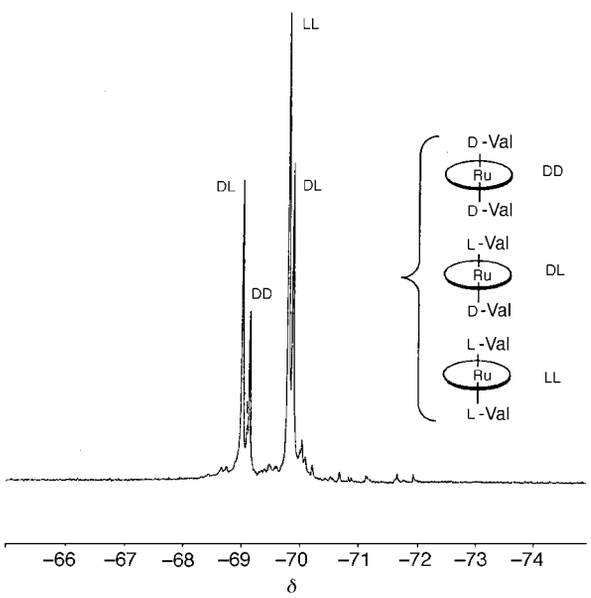


Fig. 2 The ^{19}F NMR spectrum for the diastereoisomeric mixture (LL, DD and DL) of complex **2** resulting from reduction of the dioxoruthenium complex **4**.

However, if a different synthetic route is chosen, *i.e.* addition of an excess of racemic valine methyl ester to the dioxoruthenium complex [Ru(P)O_2] **4**[17] in the presence of zinc amalgam, a 23% enantiomeric excess (e.e.) is found in favor of the L fixation (LL:DL:DD 35:53:12) as shown in the ^{19}F NMR spectrum of the mixture (Fig. 2). This suggests that oxidation is necessary for chiral recognition with these derivatives.

^{19}F NMR Study of the α,β,α,β isomer of (imino ester)(amino ester)ruthenium complexes: chiral recognition

Oxidation of racemic amino esters with chiral complex α,β,α,β-[Ru(P)O_2] **4**[17] (Scheme 1) results in the formation of mixed-ligand (amino ester)(imino ester) complexes α,β,α,β-[Ru(P)-{(R)(CO_2Me)$CHNH_2$}{(R)(CO_2Me)C=NH}] **5**–**8** (Scheme 2). For the purpose of chiral recognition, oxidation of various amino acid methyl esters (10 equivalents) was tested, using previously reported experimental conditions and yielding two isomers. In this case the ^{19}F NMR spectrum of a mixture of the two isomers exhibited four magnetically inequivalent fluorine groups. By its C_2 symmetry, the spectrum of each isomer has two types of fluorine groups. To obtain the stereochemical identity of each isomer, the same reaction was carried out with some pure D- or L-amino acid ester enantiomers.[19] The data are listed in Table 1. First, it appears that the stereoselectivity favors the formation of the L isomer. Secondly, the highest e.e. is obtained with valine methyl ester (66%). Thirdly, the reaction is quite sensitive to the nature of the amino acid ester: no asymmetric induction favoring the formation of one of the isomers was observed with phenylalanine. It should be also underlined that the two isomers obtained in the ratio 83:17 with valine methyl ester can be separated by TLC on silica gel using diethyl ether–hexane (1:3) as eluent. Moreover, exchange of pure D-valine methyl ester isomer complex with pure L-valine methyl ester in dichloromethane (15 equivalents) leads slowly to the formation of the other isomer in a nearly quantitative yield (25 °C, 3 d). Thus the ruthenium–ketimine bond is stronger than the ruthenium–amino ester bond.

Table 1 Data for the oxidation of racemic amino esters with α,β,α,β-[Ru(P)O_2] **4**[17]

Amino ester	% L	% D	e.e.
Alanine (**5**)	55	45	10
Valine (**6**)	83	17	66
Leucine (**7**)	63	37	26
Phenylalanine (**8**)	50	50	0

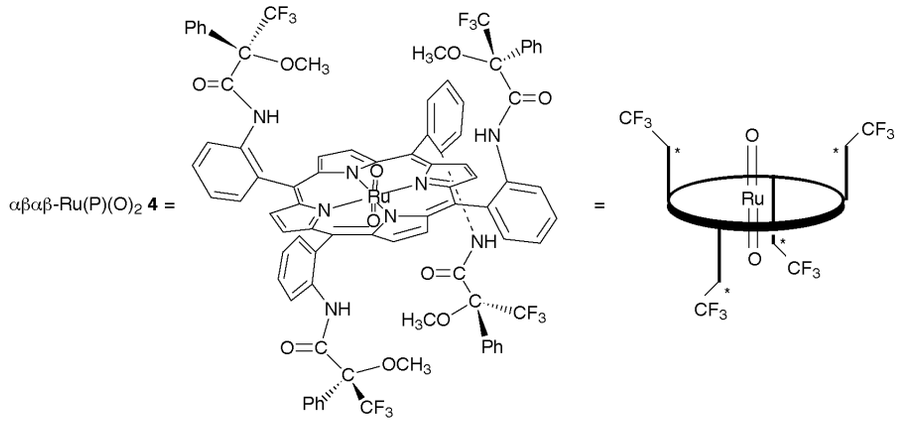
Table 2 Key bond lengths (Å) and angles (°) for complex **9**

Porphyrin–metal			
Ru–N(1)	2.037(6)	Ru–N(3)	2.042(6)
Ru–N(2)	2.032(7)	Ru–N(4)	2.023(7)
N(1)–Ru–N(2)	89.6(3)	N(3)–Ru–N(4)	90.0(3)
N(1)–Ru–N(4)	90.4(3)	N(1)–Ru–N(3)	179.8(3)
N(3)–Ru–N(2)	90.0(3)	N(2)–Ru–N(4)	179.2(3)
Metal–ligand			
Ru–N(9)	2.124(7)	Ru–N(10)	2.136(7)
Porphyrin–metal–ligand			
N(9)–Ru–N(10)	177.9(3)		
N(9)–Ru–N(1)	91.9(2)	N(9)–Ru–N(3)	89.1(2)
N(9)–Ru–N(2)	87.7(3)	N(9)–Ru–N(4)	91.5(3)
N(10)–Ru–N(1)	87.0(2)	N(10)–Ru–N(3)	92.0(2)
N(10)–Ru–N(2)	90.6(3)	N(10)–Ru–N(4)	90.3(3)

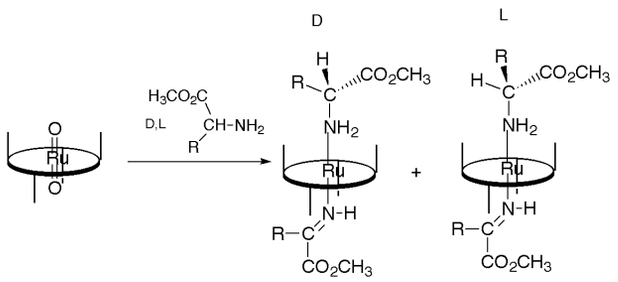
Crystal structure of α,α,β,β-[Ru(P){$(CH_3)_2CHCH(NH_2)CO_2CH_3$}$_2$] **9**

Unfortunately, it was not possible to get suitable crystals for X-ray analysis with the α,β,α,β isomer, only by slow diffusion of hexane in a toluene solution of the α,α,β,β isomer [Ru(P)-{$(CH_3)_2CHCH(NH_2)CO_2CH_3$}$_2$] **9** under argon, over 2 d were suitable crystals obtained. Crystal data and collection procedures are listed in the Experimental section. Fig. 3 shows an ORTEP[20] diagram of **9** and the numbering scheme. Fig. 4 is a side view of the molecule, illustrating a possible hydrogen bonding between the carbonyl ester group and the NH amide group of the picket. In the unit cell there is one solvent toluene.

Key bond lengths and angles for the ruthenium complex are listed in Table 2. The four equivalent Ru–N (pyrrole) distances average to 2.03(1) Å which compares well with the distances of 2.049(5), 2.052(9), 2.041(8), 2.046(9), 2.039(9) and 2.024(5) Å found for [Ru(TPP)(CO)(EtOH)],[21] [Ru(TPP)(CO)(py)],[22] [Ru(TPP)($Ph_2PCH_2PPh_2$)$_2$],[23] [Ru(P)(CO)(THF)],[17] [Ru(TMP)-($PhCH_2NH_2$)$_2$][24] and [Ru(TMCP)(CO)(EtOH)][25] respectively (TPP = 5,10,15,20-tetraphenylporphyrinate, TMP = 5,10,15,20-tetramesitylporphyrinate and TMCP = 5,10,15,20-tetramethylchiroporphyrinate). The Ru–N (NH_2) distances average to 2.125(20) Å and seem reasonable. For example, the comparable distance is 2.129(2) Å in [Ru(TMP)($PhCH_2NH_2$)$_2$].[24]



Scheme 1



Scheme 2 R = CH_3 **5**, $CH(CH_3)_2$ **6**, $CH_2CH(CH_3)_2$ **7** or CH_2Ph **8**.

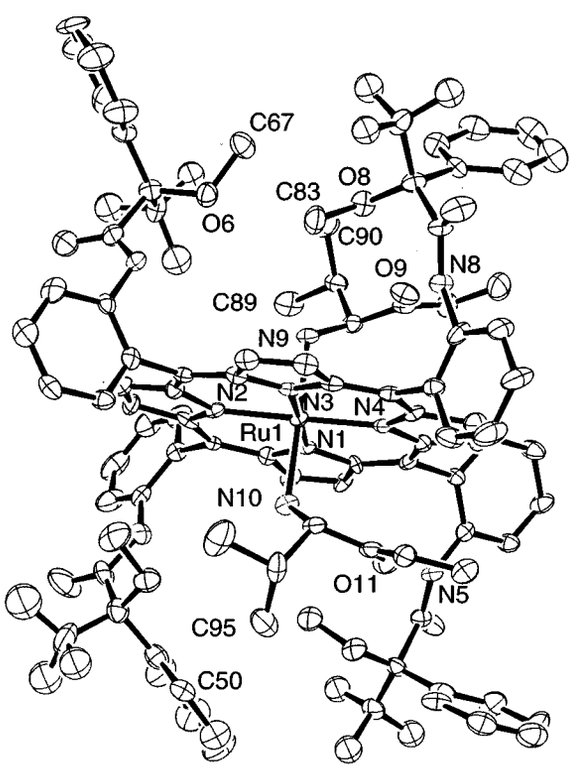


Fig. 3 Molecular structure of the α,α,β,β isomer **9**.

As expected, the ruthenium atom surrounded by six nitrogens is in an essentially octahedral environment with the ruthenium in the porphyrin plane. The angle (N9–Ru–N10) for the two axial ligands is essentially linear with an observed value of 177.9(3)°; N–Ru–N angles for the porphyrin are in the range of 90 ± 0.5°. Nevertheless, the porphyrin is fairly distorted with N (porph)–Ru–N (NH_2) angles in the range 87–92°. The conformation of the axial ligand is closer to an eclipsed than to a staggered conformation. The ester group seems to be in a fairly parallel plane to the macrocycle. Moreover, the model proposed

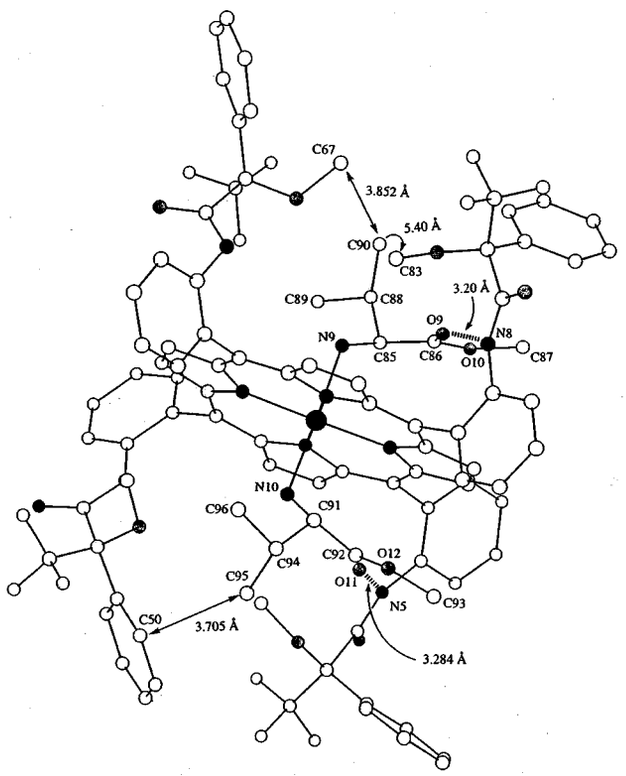


Fig. 4 A side view of the molecule **9**, illustrating possible hydrogen bonding between the carbonyl ester group and the NH amide group of the picket.

by Ogoshi and co-workers,[11] with a geometry optimized by a MOPAC version, is quite similar to the crystal structure (see below).

In common with other picket-fence porphyrin structures,[26] atoms of the chiral pickets can be affected with high thermal motion. Since the structure was determined at 120 K the coordination sphere is reasonably precisely defined and without disorder. The structure shows also general agreement for the pickets with results obtained from ^{1}H NMR experiments. Inspection of Fig. 4 shows that OCH_3 groups are located above the porphyrin plane. Such a situation was previously suggested from the high field position of the methoxy group in the ^{1}H NMR spectrum. More important, a possible hydrogen bond between one of the amide NH of each side of the porphyrin and the carbonyl group of the ligand can be proposed (the two distances C=O · · · HN are 2.24 and 2.33 Å). This situation was also detected with valine methyl ester and a quite similar chiral porphyrin by Ogoshi and co-workers,[11] on the basis of their NMR results.

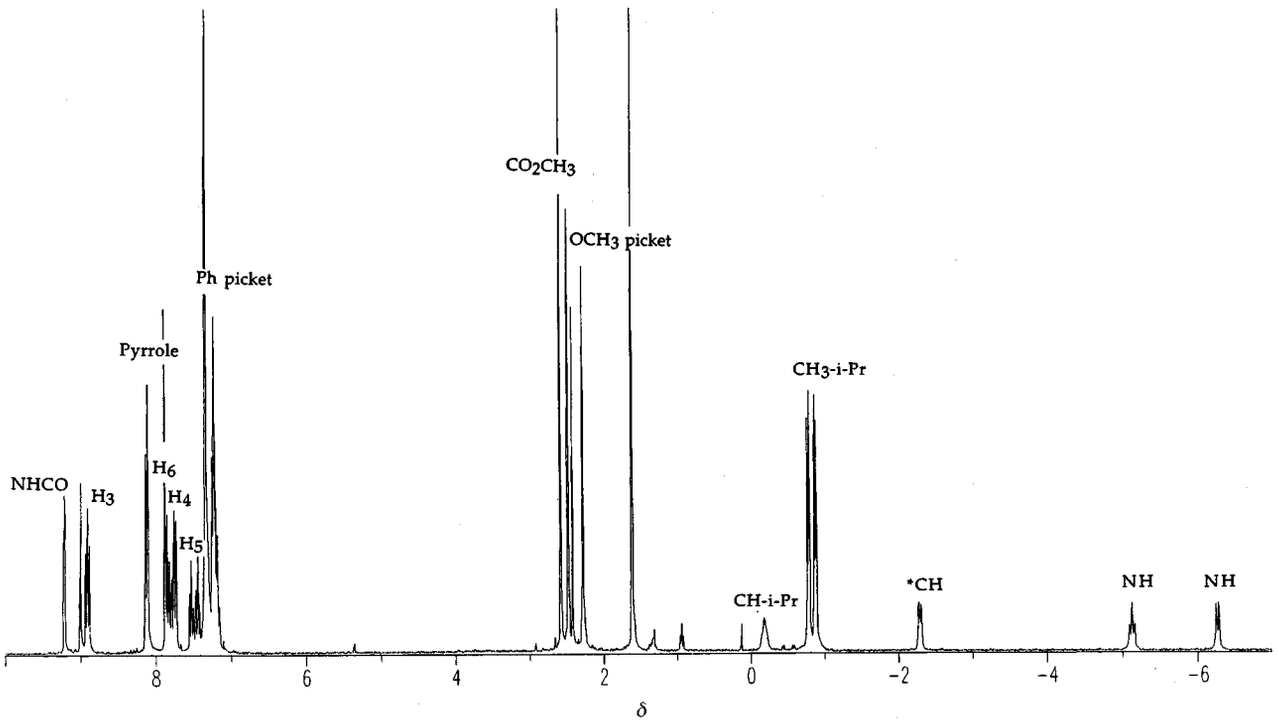


Fig. 5 ^{1}H NMR Spectrum of the α,α,β,β isomer **9**.

^{1}H NMR Spectra of complex 9

The ^{1}H NMR experiments on complex **9** show general agreement with the structural results. The proton on the Cα carbon is in close contact with the porphyrin ring, and thus appears at high field (δ −2.36). In contrast, the methoxy group of the ligand is far away from the porphyrin and much less shielded (δ 3.74). The alkyl side chain is also located in the shielding area but to a lesser extent than the CHα. Such a situation was previously described for amino acid complexation on porphyrin cobalt derivatives on the basis of NMR results.[27] The ^{1}H NMR spectrum of **9** is shown in Fig. 5. Noticeable upfield shifts occur for the amino protons, since each NH proton is shielded by the porphyrin ring. This result confirms the ligation of the amino group. The large chemical shift difference noted between the two diastereotopic NH protons is ascribed to the absence of nitrogen inversion due to the metal complexation. The coupling constants between these two protons and the CH are different, yielding an ABX system. Furthermore the CHα proton of L-valine methyl ester was also found to be shifted upfield. This indicates that this proton is also very close to the porphyrin ring. The chemical shifts of free and ligated L-valine methyl ester are summarized in Table 3. These results are quite similar to those previously reported by Gaudemer and co-workers.[27] These authors suggest an eclipsed conformation for N–CH and N–M bonds. Using a Karplus relationship relating the *J* values to the dihedral angle between the N–H and C–H bonds yielded a value of 160°. This result agrees with the proximity of Hα of the porphyrin ring and is confirmed by the crystal structure (see above).

Table 3 ^{1}H NMR data of free and complexed (**9**) valine methyl ester

L-Val-OCH_3	δ_{free}	$\delta_{complex}$	$\Delta\delta = \delta_{complex} - \delta_{free}$
NH_2	1.55	−6.33, −5.19	−7.88, −6.74
OCH_3	3.74	2.51	−1.23
C*H	3.31	−2.36	−5.67
$(CH_3)_2CH$	2.04	−0.24	−2.28
$(CH_3)_2$	0.98, 0.92	−0.95, −0.85	−1.93, −1.77 (or −1.87, −1.83)

Discussion

High valent oxoruthenium complexes of porphyrins have received recent attention because of their relevance to the biological activation of oxygen by haemoproteins.[28–33] By using a sterically encumbered porphyrin (tetramesitylporphyrin), Groves and Quinn[28] isolated the first monomeric dioxoruthenium(VI) species whereas, more recently, dioxoruthenium(VI) complexes with non-sterically encumbered porphyrins were prepared in good yields in co-ordinating solvents (methanol and ethanol).[31,32] In connection with our studies on molecular recognition by chiral ruthenium porphyrins,[15–18,33] we previously described the isolation and characterization of the first optically active *trans*-dioxoruthenium(VI) porphyrin complexes.[33] Further, the oxidation of racemic benzylmethylphenylphosphine was investigated in order to examine the mechanism of oxygen transfer.[17] The source of the stereoselectivity observed in the oxidation reaction was attributed mainly to the preferred mode of the initial binding of the chiral phosphine to a possible oxoruthenium(IV) porphyrin intermediate, similar to that previously reported with ruthenium tetramesitylporphyrin.[30] Thus, with phosphorus derivatives, the oxygen transfer seems weakly selective but the stereoselectivity of the complexation (phosphine *S*) is almost completely under kinetic control. In contrast, the results reported herein with amino esters show that complexation does not give any chiral recognition and that oxidation of racemic valine ester by dioxoruthenium porphyrins can be quite selective.

Chiral recognition of amine complexation by metalloporphyrins is of current interest and is a challenging subject in biomimetic chemistry. Good results have been obtained with chiral zinc porphyrins[9–13] under thermodynamic control whereas absence of chiral recognition was reported with cobalt porphyrins.[34] Surprisingly, amino ester complexation on ruthenium porphyrins also failed to differentiate one enantiomer from the other. This was unexpected because excellent chiral recognition was observed with phosphine under kinetic control, using the same ruthenium porphyrin.[15] Beside the co-ordination of the amino group, a hydrogen bond between the NH (of the chiral

picket) and the ester carbonyl group and the steric interaction of the amino ester alkyl chain with the porphyrin ring are plausible in these ruthenium complexes.

As in Ogoshi's system, with zinc complexes,[12] the main attractive interactions between the host and the guest molecules is co-ordination of the amino group to the metal. In ruthenium porphyrins the metal–ligand bond is stronger than in zinc compounds and no ligand exchange is observed for the bis(amino ester)ruthenium complexes. This first interaction leads to conformational restrictions of the guest, as was previously reported for cobalt[27] and zinc[11] porphyrins, and shown in the solid state by the crystal structure of complex **8**. Addition of a second interaction such as hydrogen bonding would result in further conformational restriction which may occur on the Ru–NH_2 bond rotation. This second interaction seems to be essential for chiral recognition.[11] Whereas the crystal structure determination may suggest a weak hydrogen bonding in the ruthenium derivatives, ^{1}H NMR spectroscopy of bis(amino ester)-ruthenium complexes does not show such a bond in solution. This observation could explain why no chiral recognition occurs in the amino ester complexation on ruthenium picket fence porphyrins. Moreover, the absence of conformational restriction of the pickets probably decreases steric interactions with the amino ester side chains, which seem necessary to improve chiral recognition.

In contrast, oxidation of the amino acid methyl ester to the imino complex proceeds with chiral recognition. We have previously discussed the mechanism of the formation of imino ester complexes.[19] It was suggested that the dehydrogenation of the ligand amino ester in the corresponding imino ester may occur *via* an intramolecular redox reaction from a ruthenium(IV) bis(amino ester) intermediate. Several groups have proposed a similar mechanism for the dehydrogenation of chelated aminoruthenium complexes.[35–38] Our electrochemical study is also consistent with the possible role of the bis(amino ester)ruthenium(IV) complex in the mechanism of these dehydrogenation reactions. Thus it should be noted that imino ester/amino ester ruthenium(II) porphyrin complexes can be obtained either by electrochemical oxidation of the amino ester complex or by chemical oxidation of amino esters with the high valent dioxoruthenium complex.[19] Since (i) the complexity of such reactions has very recently been demonstrated with ruthenium hexamine complexes[39] and (ii) metal chelation has probably a dramatic effect on the reactivity of amino esters toward oxidation, the present results do not allow us to clarify the stereochemical aspects of the oxidation and further details of the reaction mechanism remain to be elucidated. Nevertheless, the diastereoselectivity observed in the formation of the imino complex may principally occur in this dehydrogenation since the amino ester complexation appears not to be stereoselective. The selectivity observed in the formation of the bis(valine methyl ester)ruthenium(II) porphyrin, starting from the ruthenium(VI) dioxo complex and zinc amalgam (e.e. = 23%) may occur from residual oxidation. A stereochemical study of electrochemical oxidation of co-ordinated racemic amino ester derivatives will be reported in a subsequent publication.

Conclusion

The structure reported herein is a good stucturally characterized compound which may be useful for understanding heme protein–amino acid interactions. A similar stereochemistry is expected for six-co-ordinate low-spin complexes where one of the axial ligands is replaced by a nitrogenous base such as found in cytochrome f. Thus the three-dimensional structure of the membrane-embedded cytochrome f from turnip chloroplast has recently been reported with an unprecedented axial heme iron ligand: the amino terminus of the polypeptide chain.[40]

Experimental

Materials and syntheses

The complex $[Ru_3(CO)_{12}]$ was prepared from $RuCl_3$ and CO as previously reported;[41] mCPBA (*m*-chloroperbenzoic acid; ACROS, 75%) was used as received. The solvents were distilled under argon before use. We previously reported the syntheses of optically active α,β,α,β- and α,α,β,β-[Ru(P)(CO)] isomers.[16] The syntheses of the bis(acetonitrile), bis(amino ester) and mixed (amino ester)(imino ester) complexes with the α,β,α,β isomer have been previously reported when the amino ester is the pure L isomer.[18,19] The reactions of the racemic form of the ligand with the α,β,α,β isomer and the complexation of L-valine methyl ester to the α,α,β,β isomer are described below.

Reactions between the α,β,α,β isomer and racemic amino acid methyl esters

α,β,α,β-[Ru(P){(R)(CO_2Me)CHNH_2}$_2$] complexes [R = CH(CH_3)$_2$ 2 or $CH_2CH(CH_3)_2$ 3. The complex [Ru(P)(CH_3CN)$_2$] **1** (10 mg, 5.8 μmol) was dissolved under argon in CH_2Cl_2 (3 ml). Racemic valine methyl ester (7.5 μl, 58 μmol) was added *via* a syringe and the mixture stirred for 12 h at 40 °C. The reaction was followed by TLC and visible spectrometry. The brown-orange solution was dried under vacuum. The residue was dissolved in $CDCl_3$ and transferred under argon to a NMR tube. ^{19}F NMR: δ ($CDCl_3$) −69.01 (DL), −69.14 (DD), −69.78 (LL) and −69.86 (DL) (CF_3). Integration of the four resonances gave a ratio of 1:2:1 for the LL, DL and DD isomers, respectively. Identification of the isomers has previously been reported.[19] By a procedure similar to that described for valine methyl ester, complexation of the racemic leucine methyl ester gave a ^{19}F NMR spectrum with four signals at δ −69.41 (LL), −69.64 (DL), −69.97 (LL) and −70.05 (DL). Integration of the four resonances gave a ratio of 1:2:1 for the LL, DL and DD isomers **3**, respectively (yield: 80% for **2** and **3**).

A solution of racemic valine methyl ester (8 μl, 60 μmol) in dichloromethane (5 ml) was added under argon to a Schlenk flask containing [Ru(P)O_2] **4** (10 mg, 6 μmol) and zinc amalgam. The mixture was stirred for 2 h at room temperature. The reaction was followed by TLC and visible spectrometry. The mixture corresponding to the four diastereoisomers of complex **2** was purified by TLC on silica gel using diethyl ether–hexane (1:2) as eluent, extracted from the silica gel with diethyl ether and dried under vacuum. The residue was dissolved in $CDCl_3$ and transferred under argon to a NMR tube. ^{19}F NMR: δ ($CDCl_3$) −69.01 (DL), −69.14 (DD), −69.78 (LL) and −69.86 (DL) (CF_3). Integration of the four resonances gave a ratio of 3.5:5.3:1.2 for the LL, DL and DD isomers, respectively (e.e.: 23%; yield: 85%).

α,β,α,β-[Ru(P){(R)(CO_2Me)CHNH_2}{(R)(CO_2Me)C=NH}] complexes [R = CH_3 5, CH(CH_3)$_2$ 6, $CH_2CH(CH_3)_2$ 7 or CH_2-Ph, 8]. *Preparation and separation of the two isomers of complex* **6**. In a Schlenk flask, DL-valine methyl ester (50 μl, 480 μmol) was added under argon with a syringe to a solution of complex **1** (80 mg, 48 μmol) in dichloromethane (8 ml). The reaction was followed by TLC which showed the disappearance of the brown complex **1** in favor of a mixture of two green complexes **6L** and **6D**. After 2 h of stirring the solution volume was reduced and the two isomers were separated by chromatography over silica gel under argon (eluent diethyl ether–hexane, 1:3) to afford **3** as a green-brown solid powder in 80% yield (36 mg). Thin layer chromatography on silica gel using diethyl ether–hexane (1:3) as eluent gave excellent separations of two compounds in ratio 83:17, respectively the L and D isomer, with the D isomer moving slowly (e.e.: 66%).

By a procedure similar to that described for valine methyl ester, reaction of other racemic amino acid methyl esters (leucine, alanine, phenylalanine) with complex **4** gave the expected

mixture of the two isomers which showed a ^{19}F NMR spectrum with four signals, two for the D isomer and two for the L isomer. Integration of the four resonances gave the ratio of the two isomers. In these cases the reactions were followed by TLC and visible spectrometry but no attempts at purification were undertaken. Identification of the compounds is based on previous results obtained with the pure enantiomeric form of the amino esters.[18]

Synthesis of bis(amino ester) complex α,α,β,β-[Ru(P){$(CH_3)_2$-$CH(CO_2Me)CHNH_2$}$_2$] 9

The synthesis of this compound was undertaken in two steps, using the dioxoruthenium derivative as an intermediate. The latter was not isolated, due to its instability, but used directly *in situ*. The complex α,α,β,β-[Ru(P)(CO)(THF)][16] (40 mg, 23 μmol) and 14 mg (81 μmol) of mCPBA were stirred for 5 min in CH_2Cl_2 (2 ml). The solution was filtered under argon into another Schlenk flask containing a solution of L-valine methyl ester (30 μl, 230 μmol) and zinc amalgam in dichloromethane (5 ml). The mixture was stirred for 3 h at room temperature and then was filtered under argon. The solvent was removed under vacuum. The resulting brown-orange solid was dissolved in 2 ml of toluene after which crystallization by addition of hexane afforded brown crystals suitable for X-ray analysis (32 mg, 70% yield). ^1H NMR ($CDCl_3$): δ −6.33 (d, 2 H, J = 10.4, NH), −5.19 (t, 2 H, J = 10, NH), −2.36 (dd, 2 H, CH), −0.95 (d, 6 H, J = 7, CH_3 of i-Pr), −0.85 (d, 6 H, J = 7, CH_3 of i-Pr), −0.24 (m, 2 H, CH of i-Pr), 2.51 (s, 6 H, CO_2CH_3), 2.41 (s, 6 H, OMe picket), 2.20 (s, 6 H, OMe picket), 7.05–7.20 (m, 20 H, Ph picket), 7.37 (t, 2 H, J = 7, H-5 of *meso*-Ph), 7.45 (t, 2 H, J = 7, H-5 of *meso*-Ph), 7.67 (d, 2 H, J = 7, H-6 of *meso*-Ph), 7.78 (d, 2 H, J = 7, H-6 of *meso*-Ph), 7.69 (t, 2 H, J = 7, H-4 of *meso*-Ph), 7.77 (t, 2 H, J = 7, H-4 of *meso*-Ph), 8.83 (d, 4 H, J = 7, H-3 of *meso*-Ph), 7.80 (s, 2 H, H of pyrrole), 8.03 (s, 2 H, H of pyrrole), 8.05 (dd, 4 H, J = 5 Hz, H of pyrrole), 8.92 (s, 2 H, NHCO) and 9.14 (s, 2 H, NHCO). ^{19}F NMR ($CDCl_3$): δ −69.91 (s, 2 CF_3) and −69.94 (s, 2 CF_3). VIS (CH_2Cl_2): λ_{max} (nm) 406 (Soret), 506 and 523.

Physical measurements

The UV-visible spectra were recorded on an Uvikon 941 spectrophotometer in dichloromethane, infrared spectra in KBr on a Nicolet 205 FT-IR spectrophotometer and NMR spectra in $CDCl_3$ on a Bruker AC 300P [300 (^1H) and 280 MHz (^{19}F)] or 200DPX spectrometer [200 (^1H) and 188 MHz (^{19}F)].

Crystal stucture determination

The X-ray study was carried out on a CAD4 ENRAF-NONIUS diffractometer using graphite monochromatized Mo-Kα radiation. The cell parameters were obtained by fitting a set of 25 high-θ reflections. Crystals of the compound were obtained as reported in results. Atomic scattering factors were from ref. 42. The calculations were performed on a Silicon Graphics Indy computer with the MOLEN package[43] for data reduction and with SHELXL 97[44] for stucture determination and refinement.

Crystal data for $C_{103}H_{94}F_{12}N_{10}O_{12}Ru$ 9. M_r = 1992.89, orthorhombic, space group $P2_12_12_1$, a = 15.199(3), b = 16.372(4), c = 37.318(5) Å, V = 9286(4) Å^3, Z = 4, D_c = 1.425 Mg m^{-3}, λ(Mo-Kα) = 0.71073 Å, μ = 2.63 cm^{-1}, F(000) = 4096, T = 120 K.

The data collection [$2\theta_{max}$ = 54°, scan ω–2θ = 1, t_{max} = 60 s, range h 0–16, k 0–19, l 0–44, intensity controls without appreciable decay (0.3%)] gave 8777 reflections without the intensity controls and 6156 independent reflections with $I > 2.0\sigma(I)$. After Lorentz- polarization corrections the structure was solved with SHELXL 97 which revealed the non-hydrogen atoms of the structure. After anisotropic refinement the hydrogen atoms were found with a Fourier difference synthesis. With the complete set of reflections (8777), R = 0.1108, R' = 0.1241. The whole structure was refined by the full-matrix least-squares technique [on F^2; x, y, z, $\beta_{i,j}$ for Ru, C, O, F and N atoms; and x, y, z fixed for hydrogen atoms; 1244 variables and 6155 observations ($I > 2\sigma(I)$]; with the resulting R = 0.0464, R' = 0.1041 and S_w = 1.006 (residual $\Delta\rho$ < 0.56 e Å^{-3}). The absolute structure was determined [Flack parameter 0.00(4) refined using twin and basf (batch scale factors) options].

CCDC reference number 186/1213.

See http://www.rsc.org/suppdata/dt/1998/4165/ for crystallographic files in .cif format.

References

1 E. P. Kyba, M. G. Siegel, L. R. Sousa, G. D. Y. Sogha and D. J. Cram, *J. Am. Chem. Soc.*, 1973, **95**, 2691.
2 S. C. Peacock, L. A. Domeier, F. C. A. Gaeta, R. C. Helgeson, J. M. Timko and D. J. Cram, *J. Am. Chem. Soc.*, 1978, **100**, 8190.
3 M. Newcomb, J. L. Toner, C. Helgeson and D. J. Cram, *J. Am. Chem. Soc.*, 1979, **101**, 4941.
4 J. M. Lehn, J. Simon and A. Moradpour, *Helv. Chim. Acta*, 1978, **61**, 2407.
5 H. Ogoshi, K. Saita, K. I. Sakurai, T. Watanabe, H. Toi and Y. Aoyama, *Tetrahedron Lett.*, 1986, **27**, 6365.
6 Y. Aoyama, A. Yamagishi, M. Aqakawa, H. Toi and H. Ogoshi, *J. Am. Chem. Soc.*, 1988, **110**, 4076.
7 Y. Aoyama, M. Aqakawa, A. Yamagishi, H. Toi and H. Ogoshi, *J. Am. Chem. Soc.*, 1990, **112**, 3145.
8 M. Mizutani, T. Ema, T. Yoshida, Y. Kudora and H. Ogoshi, *Inorg. Chem.*, 1993, **32**, 2072.
9 M. Mizutani, T. Ema, T. Tomita, Y. Kudora and H. Ogoshi, *J. Chem. Soc., Chem. Commun.*, 1993, 520.
10 M. Mizutani, T. Ema, T. Tomita, Y. Kudora and H. Ogoshi, *J. Am. Chem. Soc.*, 1994, **116**, 4240.
11 Y. Kuroda, Y. Kato, T. Higashioji, J. Hasegawa, S. Kawanami, M. Takahashi, N. Shiraishi, K. Tanabe and H. Ogoshi, *J. Am. Chem. Soc.*, 1995, **117**, 10950.
12 H. Ogoshi and T. Mitzutani, *Acc. Chem. Res.*, 1998, **31**, 81.
13 M. J. Crossley, L. G. Mackay and A. C. Try, *J. Chem. Soc., Chem. Commun.*, 1995, 1925.
14 W. H. Pirkle and T. C. Pochapsky, *J. Am. Chem. Soc.*, 1987, **109**, 5975.
15 P. Le Maux, H. Bahri and G. Simonneaux, *J. Chem. Soc., Chem. Commun.*, 1991, 1350.
16 P. Le Maux, H. Bahri and G. Simonneaux, *Tetrahedron*, 1993, **49**, 1401.
17 P. Le Maux, H. Bahri, G. Simonneaux and L. Toupet, *Inorg. Chem.*, 1995, **34**, 4691.
18 C. Morice, P. Le Maux and G. Simonneaux, *Tetrahedron Lett.*, 1996, **37**, 6701.
19 C. Morice, P. Le Maux, C. Moinet and G. Simonneaux, *Inorg. Chim. Acta*, 1998, **273/1–2**, 142.
20 C. K. Johnson, ORTEP, Report ORNL-5138, Oak Ridge National Laboratory, Oak Ridge, TN, 1976.
21 J. J. Bonnet, S. S. Eaton, G. R. Eaton, R. H. Holm and J. A. Ibers, *J. Am. Chem. Soc.*, 1973, **95**, 2141.
22 R. G. Little and J. A. Ibers, *J. Am. Chem. Soc.*, 1973, **95**, 8583.
23 R. G. Ball, G. Domazetis, D. Dolphin, B. R. James and J. Trotter, *Inorg. Chem.*, 1981, **20**, 1556.
24 A. Bailey and B. R. James, *Chem. Commun.*, 1996, 2343.
25 M. Mazzanti, M. Veyrat, R. Ramasseul, J. C. Marchon, I. Turowska-Tyrk, M. Shang and W. R. Scheidt, *Inorg. Chem.*, 1996, **35**, 3733.
26 See, for example, G. B. Jameson, F. S. Molinaro, J. A. Ibers, J. P. Collman, J. I. Brauman, E. Rose and K. S. Suslick, *J. Am. Chem. Soc.*, 1980, **102**, 3224 and refs. therein.
27 E. Mikros, F. Gaudemer and A. Gaudemer, *Inorg. Chem.*, 1991, **30**, 1806.
28 J. T. Groves and R. Quinn, *Inorg. Chem.*, 1984, **23**, 3846.
29 J. T. Groves and R. Quinn, *J. Am. Chem. Soc.*, 1985, **107**, 5790.
30 J. T. Groves and K. H. Ahn, *Inorg. Chem.*, 1987, **23**, 3831.
31 W. H. Leung and C. H. Che, *J. Am. Chem. Soc.*, 1989, **111**, 8812.
32 J. S. Huang, C. H. Che and C. H. Poon, *J. Chem. Soc., Chem. Commun.*, 1992, 161.
33 P. Le Maux, H. Bahri and G. Simonneaux, *J. Chem. Soc., Chem. Commun.*, 1994, 1287.
34 D. Toronto, F. Sarrazin, J. Pécaut, J.-C. Marchon, M. Shang and R. Sheidt, *Inorg. Chem.*, 1998, **37**, 526.
35 P. Bernhard and A. M. Sargeson, *J. Am. Chem. Soc.*, 1989, **111**, 597.

36 M. J. Ridd and F. R. Keene, *J. Am. Chem. Soc.*, 1981, **103**, 5733.
37 F. R. Keene, M. J. Ridd and M. R. Snow, *J. Am. Chem. Soc.*, 1983, **105**, 7075.
38 M. Yamaguchi, K. Machiguchi, T. Mori, K. Kikuchi, I. Ikemoto and T. Yamagishi, *Inorg. Chem.*, 1996, **35**, 143.
39 P. Bernhard, D. J. Bull, H. B. Bürgi, P. Osvath, A. Raselli and A. Sargeson, *Inorg. Chem.*, 1997, **36**, 2804.
40 S. E. Martinez, D. Huang, A. Szczepaniak, W. A. Cramer and J. L. Smith, *Structure*, 1994, **2**, 95.
41 C. R. Eady, P. F. Jackson, B. F. G. Johnson, J. Lewis, M. C. Malatesta, M. McPartlin and W. J. H. Nelson, *J. Chem. Soc.*, *Dalton Trans.*, 1980, 383.
42 *International Tables for X-Ray Crystallography*, Kynoch Press, Birmingham, 1974, vol. IV.
43 B. A. Frenz, MOLEN, Molecular Structure Determination Package, ENRAF-NONIUS, Delft, 1990.
44 G. M. Sheldrick, SHELXL 97, Program for crystal structure refinement, University of Göttingen, 1997.

Paper 8/04704I