# Note

## Geometrical and optical isomers of the dinickel complexes of two chiral ligands of the N,N′-disubstituted oxamide type: 1D and 2D NMR study

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### Abstract

Two novel chiral dinucleating ligands have been obtained by grafting a methyl substituent onto one and both diamino arm(s) of *N,N′*-bis(4-methyl-5-aza-3-hepten-2-one-7-yl) oxamide ($H_4L^1$), respectively. These ligands, *N*-(4-methyl-6-oxo-3-azahepta-4-enyl)-*N′*-(1,4(2,4)-dimethyl-6-oxo-3-azahepta-4-enyl) oxamide ($H_4L^2$) and *N,N′*-(1,4(2,4)-dimethyl-6-oxo-3-azahepta-4-enyl) oxamide ($H_4L^3$), and their related nickel complexes ($Ni_2L^2$) and ($Ni_2L^3$) exist as a variety of geometrical and optical isomers since, on the one hand, two locations are possible for each substituent and on the other hand, each substituted amino chain comprises an asymmetric carbon. All but one geometrical isomer have been isolated via unequivocal synthetic pathways. Definitive proofs of the existence of all geometrical and optical isomers are gained from an NMR study including 2D spectra and 1D spectra obtained in the presence of a chiral auxiliary. In all cases the five-membered ring resulting from coordination of the diamino moiety of the ligands to the nickel ion adopts a preferred conformation which places the methyl substituent in an axial or pseudoaxial position.

*Key words:* Nickel complexes, Dinucleating ligand complexes, Dinuclear complexes

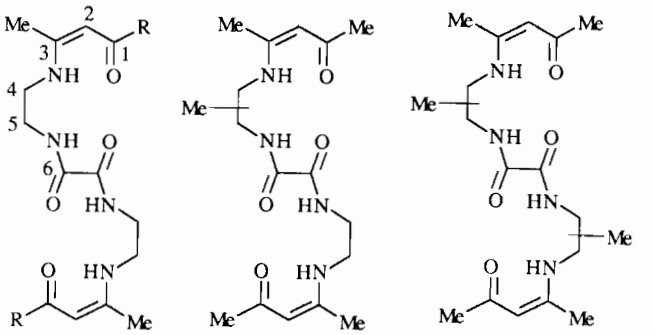
### Introduction

In previous papers [1, 2], we have emphasized the interest of the binucleating ligand *N,N′*-bis(4-methyl-5-aza-3-hepten-2-one-7-yl) oxamide ($H_4L^1$ in Fig. 1) which offers a convenient route to dinuclear complexes.

A way to increase further the interest of this type of ligand and related complexes would be to create supplementary complexing sites in their structure to allow an extension of the number (and eventually nature) of coordinated metal ions. This could be easily performed by grafting a complexing group onto the diamino chain [3]. However this strategy is expected to yield several isomeric species. Indeed the substituent may be located at C(4) (isomer p) or at C(5) (isomer r). Furthermore the substituted carbon, C(4) or C(5), becomes chiral with an *R* or *S* configuration. In addition the five-membered ring resulting from chelation of the diamino chain may adopt a gauche ($\lambda$ or $\delta$) conformation. The present paper is devoted to an NMR study of these stereochemical problems in the case of simple models involving substitution of a proton of the diamino backbone by a methyl group.

The ligands and complexes under study are represented in Fig. 1 together with their unsubstituted counterparts $H_4L^1$ and $Ni_2L^1$. Taking into account the location (p or r) of the methyl groups and the chirality (*R* or *S*) of the asymmetric carbons**, we can expect that:

- each of the geometrical isomers $II_p$ and $II_r$ gives rise to a pair of enantiomers (p*R*, p*S*) and (r*R*, r*S*)
- each of the geometrical isomers $III_{rr}$ and $III_{pp}$ gives rise to a pair of enantiomers (p*R*p*R*, p*S*p*S*) or (r*R*r*R*, r*S*r*S*) and a *meso* form (p*R*p*S*) or (r*R*r*S*) while $III_{pr}$




$H_4L^1$ (R = Me) $Ni_2L^1$ = **I** $(H_4L^2)_p$ $(Ni_2L^2)_p$ = $\mathbf{II_p}$ $(H_4L^3)_{pp}$ $(Ni_2L^1)_{pp}$ = $\mathbf{III_{pp}}$
$H_4L^1$ (R = Et) $Ni_2L^1$ = **I′** $(H_4L^2)_r$ $(Ni_2L^2)_r$ = $\mathbf{II_r}$ $(H_4L^3)_{rr}$ $(Ni_2L^1)_{rr}$ = $\mathbf{III_{rr}}$
$(H_4L^3)_{pr}$ $(Ni_2L^1)_{pr}$ = $\mathbf{III_{pr}}$

Fig 1 Schematic structures of the $H_4L^1$, $H_4L^2$, $H_4L^3$ ligands with the numbering scheme retained for $^1H$ and $^{13}C$ NMR data of the different complexes.

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**The conformation $\delta$ or $\lambda$ of the five-membered chelate ring will not be considered since, as we shall see in the current of this study, it is determined by the chirality of the asymmetric carbon


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yields two pairs of enantiomers (p*R*r*R*, p*S*r*S*) and (p*R*r*S*, p*S*r*R*).

Since enantiomers cannot be distinguished by NMR spectroscopy performed in an achiral medium this type of study would lead to the observation of two sets of signals for each of the **III** complexes. However, they would be attributable to *rac* and *meso* forms in the case of $III_{rr}$ and $III_{pp}$ but to two diastereoisomeric pairs of enantiomers in the case of $III_{pr}$. A complete resolution of all the optical isomers results from the use of a chiral auxiliary [4].

Although steric and conformational effects in mononuclear complexes of quadridentate ligands (Schiff bases deriving from salicylaldehyde, 2,4-pentanedione and macrocycles), have been widely investigated, few studies have been devoted to dinuclear complexes [5–13].

## Experimental

*Synthesis of ligands and complexes*

Reagents and solvents used were commercially available reagent quality. The $H_4L^1$, $HL^4$, $HL^5$ and $H_2L^8$ ligands were prepared according to published methods [1, 14, 15]. The methods used to prepare $(H_4L^2)_p$, $(H_4L^2)_r$, $(H_4L^3)_{pp}$, $(H_4L^3)_{rr}$ and $(H_4L^3)_{pp+rr+pr}$ are outlined in Fig. 2 which contains also a schematic representation of the precursors $HL^4$, $(HL^6)_r$, $H_2L^7$ and $H_2L^8$.

*$HL^6$*

While the preparation exactly paralleled that of $HL^4$ but making use of 2,2-diaminopropane instead of diaminoethane, the resulting product was a mixture of p and r isomers. Typically, to 1,2-diaminopropane (10 ml) in $CHCl_3$ (100 ml) was slowly added a $CHCl_3$ solution (50 ml) of 2,4-pentanedione (12 g) with stirring, overnight. The aqueous phase was then discarded and the solvent removed to leave a yellow oil, which was used without further purification

The r isomer $(HL^6)_r$ was obtained by demetallation (dimethylglyoxime) of $[Ni(L^6)_rPy]ClO_4$ (Py = pyridine). This complex was prepared by reacting in ethanol a mixture of $(HL^6)$ (r + p), pyridine, triethylamine with $Ni(ClO_4)_2 \cdot 6H_2O$ in stoichiometric amounts, as previously described for $[NiL^4Py]ClO_4$ [16]. NMR spectra and an X-ray structural determination [17] showed that the precipitate appearing at the end of the reaction is only composed of the remote isomer.

*$H_4L^{1'}$*

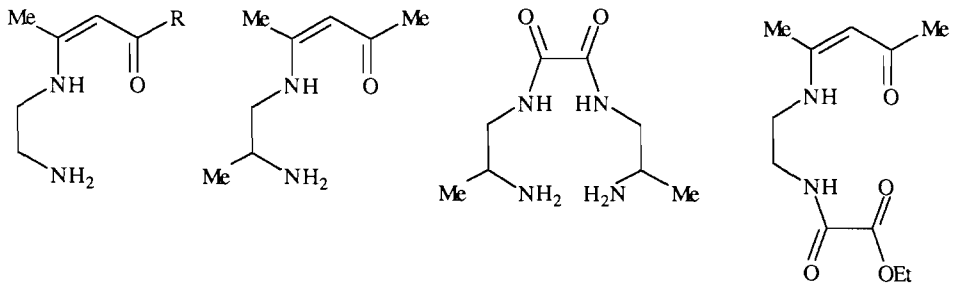
To a stirred solution of diethyloxalate (1 g) in $CH_2Cl_2$ (20 ml) was added $HL^5$ (2.14 g). The solution was refluxed for 15 min. After cooling, the resulting white powder was filtered off and dried (1.8 g, 72% yield). *Anal.* Calc. for $C_{18}H_{30}N_4O_4$: C, 59.0; H, 8.2; N, 15.3. Found: C, 58.7; H, 8.0; N, 15.0%.

*$(H_4L^2)_p$*

To $H_2L^8$ (1 g) in $CH_2Cl_2$ (20 ml) was added an excess of 1,2-diaminopropane (0.6 g). Refluxing the solution for 15 min yielded a white precipitate which was filtered off and dried. This precipitate (0.8 g) was poured again into $CH_2Cl_2$ (20 ml) with 2,4-pentanedione (0.4 g) and refluxed for 30 min. After cooling the white powder was filtered off, washed with $CH_2Cl_2$ and dried (0.7 g, 70% yield).

*$(H_4L^2)_r$*

A solution of $(HL^6)_r$ (1 g) and $H_2L^8$ (1.6 g) in $CH_2Cl_2$ (20 ml) was stirred for one day at ambient temperature. Addition of diethyl ether precipitated a white powder which was filtered off and dried (1.2 g, 55% yield).




$HL^4$ (R = Me) $(HL^6)_r$ $H_2L^7$ $H_2L^8$
$HL^5$ (R = Et)

$H_2L^8$ + 1,2-dp + acacH = $(H_4L^2)_p$
$(HL^6)_r + H_2L^8 = (H_4L^2)_r$
$H_2L^7$ + acacH = $(H_4L^3)_{pp}$
$(HL^6)_r$ + ox = $(H_4L^3)_{rr}$
$(HL^6)_{r+p}$ + ox = $(H_4L^3)_{pp+rr+pr}$
1,2-dp = 1,2-diaminopropane; acacH = 2,4-pentanedione; ox = diethyl-oxalate.

Fig 2 Reaction schemes and ligands used in the synthesis of $H_4L^2$ and $H_4L^3$ ligands

*Anal* Calc. for $C_{17}H_{28}N_4O_4$: C, 58.0; H, 7.9; N, 15.9. Found: C, 57.5; H, 8.1; N, 15.7%.

*$(H_4L^3)_{pp}$*

To a stirred solution of 1,2-diaminopropane (5 ml) in diethyl ether (80 ml) was added dropwise a diethyl ether solution (40 ml) of diethyloxalate (2 ml). A white precipitate of $H_2L^7$ appeared, it was filtered 3 h later and dried (1,8 g, 70% yield). 0.5 g of $H_2L^7$ and 2,4-pentanedione (0.6 g) in $CH_2Cl_2$ (30 ml) were stirred overnight at ambient temperature. Concentration and addition of diethyl ether yielded a white precipitate which was filtered off and dried (0.7 g, 78% yield).

*$(H_4L^3)_{rr}$*

A solution of $(HL^6)_r$ (1 g) and diethyloxalate (0.47 g) in $CH_2Cl_2$ (15 ml) was stirred at ambient temperature for 24 h. The white precipitate was filtered off, washed with water and dried (0.95 g, 40% yield).

*$(H_4L^3)_{pp+rr+pr}$*

A solution of $(HL^6)_{p+r}$ (5 g) and diethyloxalate (2.34 g) in ethanol (50 ml) was gently refluxed for 1 h. Evaporation of the solvent gave an oil which was poured into diethyl ether (50 ml) and stirred, giving a white precipitate which was filtered off and dried (6.4 g, 55% yield).

Obviously, these three samples gave quite similar analytical results. *Anal.* Calc. for $C_{18}H_{30}N_4O_4$: C, 59.0; H, 8.2; N, 15.3. Found: C, 58.7; H, 8.3, N, 15.0%.

*Complexes*

The same procedure was used for all the complexes. Typically, to 0.5 g of ligand in methanol (20 ml) was first added a twofold equivalent amount of nickel acetate tetrahydrate followed by 0.8 ml of triethylamine. The mixture was gently refluxed for 30 min, then cooled. The orange–red precipitate was filtered off, washed with methanol, diethyl ether and dried (40 to 50% yield). *Anal.* **I'**, $Ni_2L^{1'}$: Calc. for $C_{18}H_{26}N_4Ni_2O_4$: C, 45.0; H, 5.4; N, 11.7. Found: C, 45.0, H, 5.6; N, 11.4%. **II**, $Ni_2L^2$: Calc. for $C_{17}H_{24}N_4Ni_2O_4$: C, 43.8; H, 5.2; N, 12.0. Found: C, 43.2; H, 5.3; N, 11.7%. **III**, $Ni_2L^3$: Calc. for $C_{18}H_{26}N_4Ni_2O_4$: C, 45.0; H, 5.4; N, 11.7. Found: C, 44.8; H, 5.4, N, 11.5%.

*Physical measurements*

Microanalyses were performed by the Service de Microanalyse du Laboratoire LCC, Toulouse

1D NMR spectra were acquired at 200.13 or 250.13 MHz for $^1H$, at 50.32 or 62.89 MHz for $^{13}C$ on Bruker AC200 or WM250 spectrometers. 1D proton spectra were acquired using at least 16K complex data points and a spectral width of 1400 Hz. 1D $^{13}C$ spectra using $^1H$ broadband decoupling $\{^1H\}^{13}C$ and gated $^1H$ decoupling with selective proton irradiation during acquisition were performed with the Bruker WM250 apparatus, using 16K complex data points, a spectral width of 16 000 Hz and a recycling delay of 1 s Data have been zero-filled to 32K prior to transformation

2D $^1H$ COSY and NOESY experiments using standard programs were performed on the Bruker WM250 apparatus. The data were collected with 2K complex data points in $\tau_1$ dimension using a spectral width of 1400 Hz and a mixing time of 1 s for NOESY experiments. 512 experiments with spectral width of 700 Hz were recorded and zero-filled to 1 K in $\tau_2$ dimension. For each $\tau_1$ value, 40 to 64 scans were signal averaged using 10 s of recycling delay 2D pulse-field gradient HMQC $^1H$–$^{13}C$ correlation using the PFG-HMQC standard program were performed on a Bruker AMX500 spectrometer*. The spectra were collected with 2K complex data points in $\tau_2$ using a spectral width of 5000 Hz. 256 experiments with spectral width of 20 000 Hz were recorded and zero-filled to 4K in $\tau_1$ dimension. For each $\tau_1$ value two scans were signal averaged. Squared-sinebell apodization in both dimensions were applied prior to transformation. All measurements were made at room temperature.

## Results and discussion

As described in 'Experimental', we succeeded in obtaining pure samples of the different isomers, $(H_4L^2)_p$, $(H_4L^2)_r$, $(H_4L^3)_{pp}$ and $(H_4L^3)_{rr}$, and their related nickel(II) complexes. Consideration of the reactions schemes reported in Fig. 2 shows that the unequivocal synthesis relies on the availability of two precursors, $(HL^6)_r$ and $(H_2L^7)$, which comprise methyl substituent(s) grafted on the amino chain at well-defined position(s) remote from either the pentanedione or the oxamide moieties. Indeed reacting 2,4-pentanedione with 1,2-diaminopropane yields a mixture of $(HL^6)_r$ and $(HL^6)_p$ but, if the reaction is performed in the presence of nickel(II) ions, the only final product isolated is a complex of the remote isomer $[Ni(L^6)_rB]^+$ or $[Ni(L^6)_rX]$ (B is an auxiliary ligand such as Py and $X = N_3^-$). The ligand $(H_2L^7)$ is the only product formed in the reaction of 1,2-diaminopropane with diethyloxalate. The selectivity encountered in both cases is likely due to a lower reactivity of the $NH_2$ group adjacent to the methyl substituent and/or steric effects resulting from interactions of this methyl group with other substituents. We failed to isolate a pure sample of $(H_4L^3)_{pr}$ but NMR evidence points to the presence of these species in the mixture resulting from the reaction of $(HL^6)_p + (HL^6)_r$ with diethyloxalate.

*The authors are greatly indebted to Dr M Piotto from Bruker Spectrospin France for his kind collaboration

*Analysis of the $^1H$ and $^{13}C$ NMR spectra*

*Ligands $H_4L^2$ and $H_4L^3$*

Due to the severe overlaps in the 1–4 ppm area no attempts were made to perform a complete analysis of the ligand spectra. In keeping with our aim, the main interest of these spectra is restricted to the fact that they afford a straightforward characterization of the location of the methyl substituent. Indeed the enamino and amido N*H* signals which appear in dmso-$d_6$ solutions around 10.5 and 9 ppm, respectively, display a multiplicity (triplet with $J=6.0$ Hz or doublet with $J=9.5$ Hz) characteristic of the nature ($CH_2$ or CHMe) of the adjacent groups. In accordance with a complete deprotonation of the ligands, these signals are lacking in the spectra of the complexes.

*Complexes $II_p$, $II_r$, $III_{rr}$ and $III_{pp}$*

Let us first consider the $^{13}C$ spectra for which attribution of the various resonances is straightforward except for C(1)$CH_3$ and C(3)$CH_3$. This difficulty is easily relieved by considering **I'**. Finally the assignments retained for the isolated complexes ($Ni_2L^1$, $Ni_2L^{1'}$, $Ni_2L^2{}_p$, $Ni_2L^2{}_r$, $Ni_2L^3{}_{pp}$ and $Ni_2L^3{}_{rr}$) are quoted in Table 1. The signals do not show any unexpected multiplicity.

In the $^1H$ spectra, the main difficulty in attributing the signals is also related to the methyl groups since up to four signals are observed between 1.13 and 1.85 ppm. A coherent proton decoupling off-resonance performed by centring the decoupler frequency at 1.10 ppm and then at 1.87 ppm while observing the $^{13}C$ spectra allows a straightforward attribution to the $^1H$ methyl resonances from the known $^{13}C$ assignments. The data are quoted in Tables 2 and 3.

In complexes $\mathbf{II}_r$ and $\mathbf{II}_p$, the two halves of the molecule are inequivalent. As expected the main differences are related to the diamino chains which give an $A_2X_2$ spectrum for the unsubstituted moiety and an $ABCX_3$ spectrum for the substituted moiety. Furthermore the $\delta$ values characterizing the $ABCX_3$ depend on the location, C(4) or C(5), of the methyl substituent as does, more surprisingly, C(3)$CH_3$ with a $\delta$ value of 1.82 ppm in $\mathbf{II}_r$, and 1.88 ppm in $\mathbf{II}_p$ while we observe a value of 1.85 ppm in the unsubstituted moiety.

The two geometrical isomers $\mathbf{III}_{rr}$ and $\mathbf{III}_{pp}$ display characteristic spectra which differ in the related $\delta$ values and in the multiplicity of the signals attributed to the methyl group of the amino chain. Indeed two doublets are observed for C(5)$CH_3$ in $\mathbf{III}_{rr}$ while C(4)$CH_3$ in $\mathbf{III}_{pp}$ gives a single doublet. The two doublets are unambiguously attributable to the *rac*-(*RR*,*SS*) and *meso*-(*RS*) forms of $\mathbf{III}_{rr}$ since a sample prepared from *S*-diaminopropane gives one signal at $\delta=1.145$ ppm. Seemingly, in the case of $\mathbf{III}_{pp}$, the unequivalence is too slight to be observed. Furthermore if a chiral auxiliary, (*S*)−(+)−2,2,2-trifluoro-1-(9-anthryl)-ethanol, is added to a solution of $\mathbf{III}_{rr}$, the multiplicity of all the signals is increased. The most conspicuous effects are related to C(5)$CH_3$ and C(2)*H* which give four doublets and four singlets, respectively (Table 4). These two sets of clearly resolved signals are conclusive of the presence of the four diastereoisomers (r*R*, r*R*, s*S*), (r*S*, r*S*, s*S*), (r*S*, r*R*, s*S*) and (r*R*, r*S*, s*S*) which result from the interaction of the reagent(s) of chirality *S* with the *rac* and *meso* forms of $\mathbf{III}_{rr}$. Less convincing data are obtained in the case of $\mathbf{III}_{pp}$ since a four-time multiplicity is not achieved for any of the signals. As before, the largest effects concern the C(4)$CH_3$ and C(2)*H* resonances which appear as two doublets and two singlets, respectively (Table 4).

TABLE 1. Chemical shifts $\delta$ $^{13}C$ (ppm) vs. TMS

| | $CH_3$ | | | | $CH_2$ | | CH | | | C | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1[a] | 3 | 4 | 5 | 4 | 5 | 2 | 4 | 5 | 1 | 3 | 6 | 7 |
| **I** | 23.77 | 20 21 | | | 57 08 | 43 00 | 100.42 | | | 175 83 | 165.25 | 168 42 | 168.42 |
| **I'** | 11 91[b]<br>30 88[c] | 20.42 | | | 57.58 | 43 09 | 98 71 | | | 180 29 | 166.02 | 168 87 | 168.87 |
| $\mathbf{II}_p$ | 23 78 | 20 08<br>18.90 | 22 42 | | 57 02 | 43.04<br>49 27 | 100.48 | 62.51 | | 175 88 | 165.08 | 168.81 | 168 23 |
| $\mathbf{II}_r$ | 23.80 | 20 11 | | 19 48 | 57.00<br>64.09 | 43 02 | 100.41 | | 49.57 | 175 91 | 165.32 | 169.08 | 168.23 |
| $\mathbf{III}_{pp}$ | 23.66 | 19.09 | 22 68 | | | 49.26 | 100.49 | 62 92 | | 175 98 | 164.25 | 169.73 | 169.73 |
| $\mathbf{III}_{rr}$ | 23.64 | 20.26 | | 19.38 | 64.49 | | 100 37 | | 49.90 | 175 79 | 165.98 | 169.05 | 169.05 |
| **III**[d] | 23.64<br>23.59 | 19 08<br>20 24 | 22.64<br>22.57 | 19.34<br>19.41 | 64.58<br>64.46 | 49.25<br>49.31 | 100.47<br>100.32 | 62.88 | 49.85<br>50.03 | 175 91<br>175 76 | 164.22<br>165.98 | | 169.77<br>168 77 |

[a]The numbering scheme is as described in Fig 1. [b]$CH_3$ resonance [c]$CH_2$ resonance [d]$\mathbf{III}=\mathbf{III}_{pp}+\mathbf{III}_{rr}+\mathbf{III}_{pr}$

TABLE 2 Chemical shifts $\delta$ $^1$H (ppm) vs TMS

| | $CH_3$ | | | | $CH_2$ | | | | CH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1[a] | 3 | 4 | 5 | 4 | | 5 | | 2 | 4 | 5 |
| | | | | | $(H_A)$[b] | $(H_B)$[b] | $(H_A)$[b] | $(H_B)$[b] | | $(H_C)$[b] | $(H_C)$[b] |
| **I** | 1.803 | 1 832 | | | 3 209 | | 2.748 | | 4 870 | | |
| $\mathbf{II}_p$ | 1 755 | 1 849[c] | | | 3.218[c] | | ~2 70[c,d] | | 4.909[c] | 3.470 | |
| | | 1 878 | 1 327 | | | | ~2 70[c,d] | 2 365 | 4 871 | | |
| $\mathbf{II}_r$ | 1.755 | 1.849[c] | | | 3.222[c] | | | 2.680[c] | 4.909 | | |
| | | 1 821 | | 1.139 | 3 357 | 2 827 | | | 4.909 | | 3 100 |
| $\mathbf{III}_{pp}$ | 1 751 | 1 883 | 1 333 | | | | 2 675 | 2.376 | 4.874 | 3.512 | |
| $\mathbf{III}_{rr}$ | 1.764 | 1.822 | | 1.141 | 3.348 | 2 815 | | | 4 909 | | 3.100 |
| | | | | 1.126 | | | | | | | |
| **III**[f] | 1.751 | 1 822 | 1 331 | 1.153 | 3.358 | 2 826 | 2 672 | 2.376 | 4 873 | 3 510 | 3.103 |
| | 1 761 | 1.881 | | 1.141[e] | 3 348 | 2.816 | | 2.364 | 4 908 | 3.498 | 3.096 |
| | | | | 1 127 | | | | 2 348 | | | |

[a]The numbering scheme is described in Fig 1. [b]The protons of the diamino chain are labelled according to the scheme N–C($H_A$)($H_B$)–C′($H_C$)($CH_3$)–N with $\delta(H_A) > \delta(H_B)$. [c]Related to the unsubstituted moiety of the complex. [d]Overlapping signals. [e]Practically twice as intense as the nearby signals. [f]$\mathbf{III} = \mathbf{III}_{pp} + \mathbf{III}_{rr} + \mathbf{III}_{pr}$.

TABLE 3. Coupling constants $^nJ$(H–H) (Hz) in the amino chains N–$CH_AH_B$–$C(CH_3)H_C$–N

| | $^2J(H_A–H_B)$ | $^3J(H_C–CH_3)$ | $^3J(H_B–H_C)$ | $^3J(H_A–H_C)$ |
|---|---|---|---|---|
| $\mathbf{II}_{pp}$ | 13.6 | 6.5 | ⩽0 5 | 6.2 |
| $\mathbf{II}_{rr}$ | 13 0 | 6.3 | 2 6 | 6.8 |
| $\mathbf{III}_{pp}$ and p part of $\mathbf{III}_{pr}$ | 13.5 | 6.5 | ⩽0 5 | 6.1 |
| $\mathbf{III}_{rr}$ and r part of $\mathbf{III}_{pr}$ | 13 1 | 6 4 | 2.5 | 6 7 |

*Complex $III_{pr}$*

As previously noted, we did not succeed in isolating a pure sample of $\mathbf{III}_{pr}$. Nevertheless the $^1$H and $^{13}$C spectra of **III** obtained from $(H_4L^3)_{pp+rr+pr}$ as described in 'Experimental' afford convergent proofs of the existence of this species. The $^1$H spectrum of **III** comprises ten clusters of signals (Fig. 3 and Table 2). This pattern is roughly consistent with the simultaneous presence of $\mathbf{III}_{pp}$ and $\mathbf{III}_{rr}$. However a closer examination shows that several clusters are more complex than expected for a mixture of $\mathbf{III}_{pp}$ and $\mathbf{III}_{rr}$ alone. The highest multiplicity affects the C(5)$CH_3$ resonance which appears in the undecoupled spectrum as a pseudo-quintuplet. Selective irradiation of the cluster centred at 3 1 ppm causes the pseudo-quintuplet to merge into a pseudo-triplet with unequal separations (3.0 and 3.6 Hz) of the components and a central signal twice as intense as the lateral signals. Besides, we know from 2D experiments (*vide infra*) that the C(5)$CH_3$ protons are only coupled with the related C(5)*H* so that we

TABLE 4. Influence of a chiral auxiliary ((*S*)-(+)-2,2,2-trifluoro-1-(9-anthryl)-ethanol) on the chemical shifts $\delta(^1H)$ (ppm)[a]

| | | Without auxiliary | With auxiliary |
|---|---|---|---|
| $\mathbf{III}_{pp}$ | C(4)$CH_3$ | 1.333 | 1.183, 1.228 |
| | C(2)*H* | 4 874 | 4 772, 4.790 |
| $\mathbf{III}_{rr}$ | C(5)$CH_3$ | 1.126, 1.141 | 1.065, 0.976, 0 946, 0 923 |
| | C(2)*H* | 4 909 | 4.827, 4.812, 4 782, 4.725 |
| **III**[c] | C(4)$CH_3$ | 1.331 | 1 241[b], 1.227, 1.184, 1.171[b] |
| | C(5)$CH_3$ | 1.127, 1.141, 1.141[b], 1.153[b] | 1.136[b], 1.099[b], 1 065, 1 032[b] |
| | | | 0 986, 0.961[b], 0.945, 0.924 |
| | C(2)*H* | 4.908, 4.873 | 4.854, 4.829, 4.817, 4.808[b], |
| | | | 4 785, 4 775, 4.754, 4 692[b] |

[a]All the solutions contain ~0.02 mM of complex in 0.5 cm$^3$ of $CDCl_3$ and, eventually, 0 1 mM of chiral reagent. [b]Attributable to $\mathbf{III}_{pr}$. [c]$\mathbf{III} = \mathbf{III}_{pp} + \mathbf{III}_{rr} + \mathbf{III}_{pr}$.

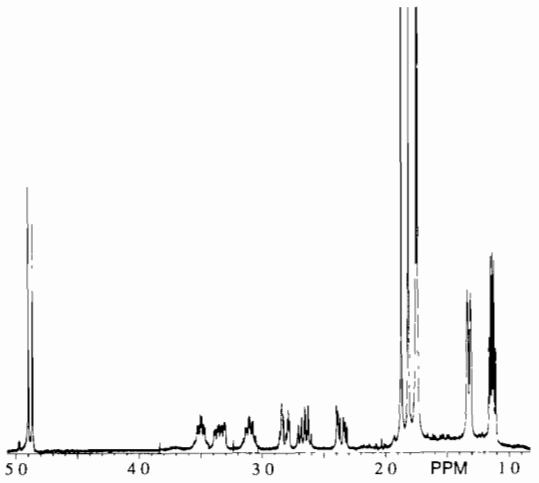



Fig 3 1D $^1$H NMR spectrum of ($\mathbf{III}_{pp}+\mathbf{III}_{rr}+\mathbf{III}_{pr}$) in $CD_2Cl_2$

suggest that the pseudo-triplet results from the presence of four singlets, two of them being fortuitously degenerate. The signal at 1.127 ppm and one of the degenerate signals (1.141 ppm) are obviously attributable to the *rac* and *meso* forms of $\mathbf{III}_{rr}$ and we suggest that the two remaining signals (1.141 and 1.153 ppm) are due to the two diastereoisomeric pairs (p*R*, r*R*; p*S*, r*S*) and (p*R*, r*S*; p*S*, r*R*) of $\mathbf{III}_{pr}$. This assumption is supported by the spectral pattern observed for the C(4)C$H_3$ and C(5)C$H_3$ resonances after addition of the chiral auxiliary. From a comparative study of the spectra obtained with and without decoupling the related C(4)*H* and C(5)*H*, it results that we have two partly overlapping multiplets. The first one lies from 0.90 to 1.15 ppm and comprises eight doublets while the second extends from 1 10 to 1.24 ppm and contains four doublets (Table 4). Clearly the eight doublets arise from the presence of the eight expected diastereoisomers; (r*R*, r*R*, s*S*), (r*S*, r*S*, s*S*), (r*R*, r*S*, s*S*) and (r*S*, r*R*, s*S*) from $\mathbf{III}_{rr}$ and (p*R*, r*R*, s*S*), (p*S*, r*S*, s*S*), (p*R*, r*S*, s*S*) and (p*S*, r*R*, s*S*) from $\mathbf{III}_{pr}$. Obviously $\mathbf{III}_{pp}$ does not contribute to this multiplet. As yet noted for the isolated $\mathbf{III}_{rr}$ complex, the multiplicity of C(4)C$H_3$ is lower than expected. It may be noted that eight signals are observed for C(2)*H* while the resonances of C(1)C$H_3$ and C(3)C$H_3$ comprise six clearly resolved signals and several ill-defined shoulders.

The attributions reported in Table 2 are further supported by COSY and NOESY 2D experiments performed on a sample of **III**. With reference to the 1D spectrum represented in Fig. 3, a COSY chart shows two series of connections between the clusters without any connection between the series. These connections:

(i) (Me, 1.1 ppm)↔($H_C$, 3.1 ppm); ($H_C$, 3 1 ppm)↔($H_B$, 2.8 ppm) and ($H_B$, 2.8 ppm)↔($H_A$, 3.3 ppm)

(ii) (Me′, 1.3 ppm)↔($H'_C$, 3 5 ppm); (Me′, 1.3 ppm)↔($H'_A$, 2.7 ppm); ($H'_C$, 3 5 ppm)↔($H'_B$, 2.4 ppm) and ($H'_A$, 2.7 ppm)↔($H'_B$, 2.3 ppm)

confirm the presence of two main types of amino chains which, from NOESY data , differ by the location of the methyl substituent. Indeed we observe NOESY connectivities between, on the one hand, the clusters centred at 1.88 and 3.50 ppm, respectively, and, on the other hand, the clusters centred at 1.82 and 2.81 ppm, respectively. This clearly corroborates that the clusters at 1.88 and 1.82 ppm are due to the C(3)C$H_3$ protons in $\mathbf{III}_{pp}$ (or in the p part of $\mathbf{III}_{pr}$) and in $\mathbf{III}_{rr}$ (or in the r part of $\mathbf{III}_{pr}$), respectively, while the clusters at 3.50 and 2.81 ppm must be attributed to the methine protons C(4)*H* in $\mathbf{III}_{pp}$ (or p part of $\mathbf{III}_{pr}$) and to one type ($H_B$) of the methylenic protons C(4)$H_2$ in $\mathbf{III}_{rr}$ (or r part of $\mathbf{III}_{pr}$).

The $^1$H decoupled $^{13}$C spectrum of **III** shows twenty-three separate signals whereas a mixture of $\mathbf{III}_{rr}+\mathbf{III}_{pp}$ is expected to give, at most (Table 1), eighteen signals. This discrepancy is strongly reminiscent of that observed for the $^1$H spectra and both are consistent with the presence of $\mathbf{III}_{pr}$ in the mixture. A firm and complete attribution of the $^{13}$C resonances is deduced from a comparison with the $\mathbf{III}_{rr}$ and $\mathbf{III}_{pp}$ spectra, from a consideration of the multiplicity of the signals in the $^1$H-coupled $^{13}$C spectrum and from a $\delta^1$H–$\delta^{13}$C correlation experiment which points to connections between the various clusters of $^1$H signals and the $^{13}$C signals (Fig. 4). The resulting assignments are quoted in Table 1. It appears that to each carbon nucleus of the diamino chains, except C(4)*H*, correspond two slightly different signals. This indicates that each amino chain, N–C(4)(Me)H–C(5)$H_2$–N and N–C(4)$H_2$–C(5)(Me)H–N, occurs in the mixture under two forms. In keeping with the feeble differences observed, it may

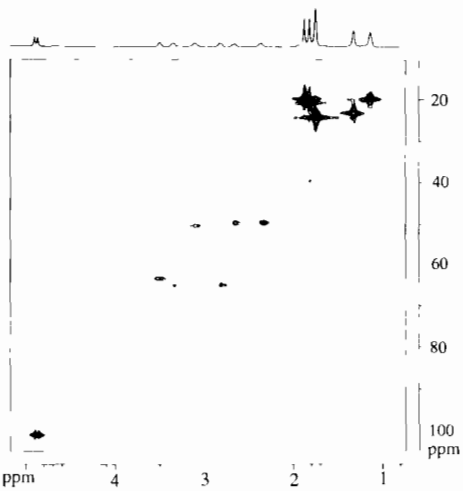



Fig. 4. 2D NMR $^1$H–$^{13}$C correlation chart for ($\mathbf{III}_{pp}+\mathbf{III}_{rr}+\mathbf{III}_{pr}$) in $CD_2Cl_2$.

be assumed that each pair of forms results from the association of one chain either with itself to give $\mathbf{III}_{rr}$ or $\mathbf{III}_{pp}$ or with the other type of chain to give $\mathbf{III}_{pr}$

## Conclusions

From the data quoted in Tables 1 and 2, it appears that the $^{1}H$ and $^{13}C$ chemical shifts afford clear distinctions between the geometrical isomers, $\mathbf{III}_{pp}$ and $\mathbf{III}_{rr}$, and provide evidence for the existence of $\mathbf{III}_{pr}$. As for the optical isomers, in achiral medium we can differentiate between the *rac* and *meso* forms of $\mathbf{III}_{rr}$ and between the diasteroisomeric pairs (p*R*, r*R*; p*S*, r*S*) and (p*R*, r*S*; p*S*, r*R*), of $\mathbf{III}_{pr}$. As expected, characterization of all the enantiomers can be only performed in the presence of a chiral auxiliary. It may be noted that the most significant differences between geometrical isomers on the one hand and optical isomers on the other hand are observed for the nuclei of the diamino chains. Before propounding a rationalization of these effects, let us consider the coupling constant values characterizing the protons of the diamino chains (Table 3). It is generally accepted that the vicinal coupling constants $^{3}J(HH)$ in a $-C(H_A)(H_B)-C(H_C)R-$ fragment depend on electronic and geometric parameters [18] In closely related compounds such as $\mathbf{III}_{pp}$, $\mathbf{III}_{rr}$ and $\mathbf{III}_{pr}$, the significant parameters are the dihedral angles $\theta_{AC}$ and $\theta_{BC}$ so that the $^{3}J$ values provide significant information on the conformation of the five-membered chelate rings. The values observed in the present work, i.e. $^{3}J_{BC} \leqslant 0.5$ Hz, $^{3}J_{AC} \sim 6.1$Hz for $\mathbf{III}_{pp}$ and the p moiety of $\mathbf{III}_{pr}$ and $^{3}J_{BC} = 2.5$ Hz, $^{3}J_{AC} \sim 6.7$ Hz for $\mathbf{III}_{rr}$ and the r moiety of $\mathbf{III}_{pr}$ considered together with data obtained for similar complexes [19, 20] lead to the conclusion that in any case the five-membered ring adopts a preferred conformation placing the methyl group in axial position. In quadridentate Schiff bases involving a methyl substituted diamino fragment, the methyl substituent is reported to be axial [5, 6]. Therefore, according to the chirality, *R* or *S*, of the asymmetric carbon C(4/5), the chelate ring is in a $\delta$ or $\lambda$ *gauche* conformation. It is also concluded that the $H_A$ nucleus characterized by a chemical shift larger than that of $H_B$ is the axial methylenic proton.

The slight differences between the coupling constants of $\mathbf{III}_{pp}$ and $\mathbf{III}_{rr}$ (and the related moieties of $\mathbf{III}_{pr}$) are likely due to feeble but significant distortions of the chelate ring which depend on the position of the methyl substituent. From the Karplus equation it can be shown that when going from C(4) to C(5), the methyl group moves away from its axial position. This suggests that the axial location of $C(4/5)CH_3$ is due to a non-bonded interaction with $C(3)CH_3$. The steric constraint, large when the substituent is fixed on C(4), would be partly relieved on moving to C(5) allowing a trend of the methyl group towards an equatorial location. This rationale is consistent with the chemical shifts pattern. It is generally accepted that protons in a sterically compressed environment experience low-field shifts. Actually we observe (Table 2) that $C(4/5)CH_3$, $C(4/5)H$ and $C(3)CH_3$ display higher chemical shift values in $\mathbf{III}_{rr}$ than in $\mathbf{III}_{pp}$ while the reverse occurs for the methylenic protons ($H_A$ and $H_B$). These trends could be reinforced by the magnetic anisotropy of the C=O groups of the oxamide moiety which is expected to increase the shielding of $C(5)CH_3$ and $C(5)H$ in the r (or rr) isomer more than that of $C(4)CH_3$ and $C(4)H$, respectively, in the p (or pp) isomer. This effect could also explain why $C(5)CH_3$ and $C(5)H$ give separate signals for, on the one hand, the *rac* and *meso* forms of $\mathbf{III}_{rr}$ and, on the other hand, the two diastereoisomeric pairs of $\mathbf{III}_{pr}$ whereas single signals are observed in the case of $C(4)CH_3$ and $C(4)H$.

## References


1 J.P. Costes, F. Dahan and J.-P Laurent, *J Chem Soc, Dalton Trans*, (1989) 1017
2 J.-P. Costes and J -P Laurent, *Inorg. Chem*, *28* (1989) 2234
3 J.-P. Costes, J -M. Dominguez-Vera and J.-P. Laurent, *29th ICCC, Lausanne, Switzerland, 1992*
4 D J Cram and J.L. Mateos, *J Am Chem Soc., 81* (1959) 2756
5 B Bosnich, *J Am Chem Soc*, *90* (1968) 627
6 R S. Downing and F.L Urbach, *J Am Chem Soc*, *91* (1969) 5977; *92* (1970) 5861.
7 R L. Farmer and F.L Urbach, *Inorg Chem*, *9* (1970) 2562.
8 M. Calligaris, G. Nardin and L Randaccio, *J Chem Soc., Dalton Trans*, (1973) 419.
9 C. Busetto, F. Cariati, A. Fusi, M Gullotti, F. Morazzoni, A Pasini, R. Ugo and V. Valenti, *J Chem Soc, Dalton Trans*, (1973) 754.
10 M Gullotti, L Casella, A Pasini and R Ugo, *J. Chem Soc., Dalton Trans.*, (1977) 339
11 J. Hanzlik, A Puxeddu and G Costa, *J Chem Soc, Dalton Trans*, (1977) 542.
12 A. Pasini, M Gullotti and R Ugo, *J Chem Soc., Dalton Trans.*, (1977) 346
13 M. Gullotti, A. Pasini, G.M Zanderighi, G. Ciani and A. Sironi, *J Chem Soc, Dalton Trans*, (1981) 902.
14 G. Cros and J.-P Costes, *C R. Acad. Sci., Ser. B, 173* (1982) 294
15 J.-P Costes and M I. Fernandez-Garcia, *Inorg Chim Acta, 173* (1990) 247
16 J.-P Costes, *Transition Met Chem*, *10* (1985) 185.
17 J -P Costes and J.-P. Laurent, unpublished results.
18 M. Barfield and W.B. Smith, *J Am Chem Soc.*, 114 (1992) 1574, and refs. therein.
19 T. Ito and D.H. Busch, *Inorg. Chem*, *13* (1974) 1770.
20 L.E Erickson, J.E. Sarneski and C.N Reilley, *Inorg Chem., 14* (1975) 3007.