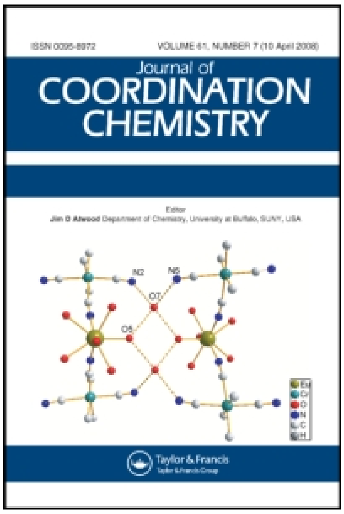

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B. Kaitner[a]; E. Meštrović[a]; N. Paulić[b]; J. Sabolović[b]; N. Raos[b]
[a] Laboratory of General and Inorganic Chemistry, Faculty of Science, University of Zagreb, Croatia [b] Institute for Medical Research and Occupational Health, Zagreb, Croatia

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STEREOCHEMISTRY OF COMPLEXES WITH *N*-ALKYLATED AMINO ACIDS. X. CRYSTAL STRUCTURE AND MOLECULAR MECHANICS CALCULATIONS FOR *BIS(D,L-N,N*-DIMETHYLVALINATO)COPPER(II)

B. KAITNER, E. MEŠTROVIĆ

Laboratory of General and Inorganic Chemistry, Faculty of Science, University of Zagreb, Croatia

N. PAULIĆ, J. SABOLOVIĆ and N. RAOS*

Institute for Medical Research and Occupational Health, Zagreb, Croatia

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The crystal structure of dark red, monoclinic (space group $P2_1/c$) *bis*(*D,L-N,N*-dimethylvalinato)-copper(II) was solved by X-ray diffraction methods and refined to $R = 0.035$. Coordination around copper(II) atom is irregular square-planar with oxygen and nitrogen atoms in *trans* positions [Cu-O = 1.911(2), Cu-N = 2.018(2)Å, O-Cu-N = 84.11(7), O-Cu-N′ = 95.89(7)°]. The structure of the molecule corresponds to the most stable conformation, as predicted by molecular mechanics calculations. MM calculations reproduced (as measured by root-mean-square deviations) the angles around copper(II) to 0.49° and interatomic distances in the molecule to 0.055Å. The MM calculations in the crystal state suggest an influence of packing interactions on molecular conformation.

KEYWORDS: *bis*(*D,L-N,N*-dimethylvalinato)copper(II), copper, X-ray structure, *N,N*-dimethylvaline, molecular mechanics

INTRODUCTION

Copper(II) chelates with *L-N,N*-dimethylvaline and its *D*-isomer have been the central issue in our research on copper complexes with *N*-alkylated α-amino acids.[1] The first molecular mechanics calculations on this class of copper(II) chelates were done in our laboratory in 1983 in an effort to calculate the enantioselectivity effect [difference in Gibbs energy between M(L-ligand)(L-ligand) and M(L-ligand)(D-ligand)] of copper(II) chelates of *N,N*-dimethylvaline[2] as measured in chloroform solution.[3] The discrepancy between theory and experiment (too high a difference in energy between two isomers was obtained by calculations) led us to suppose that it was due to the inability of the molecular mechanics model to reproduce the

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*Author for correspondence.

proposed distortion of the coordination polyhedron.[2] The supposition was confirmed by improvement of the force field parametrization[4] and by solving the crystal structure of *bis*(*L*-*N*,*N*-dimethylvalinato)copper(II).[5] In an attempt to obtain a better reproduction of the observed distortion of the coordination polyhedron of *bis*(*N*,*N*-dimethylvalinato)copper(II) and related compounds a series of novel molecular mechanics models was proposed [a "dummy" atom model (FF2, FF3),[4] models with a distortion coordinate potential (M3, M4, M5)[6,7] and electrostatic models (M6, M7, M8)[8–10]. All of these models were tested on the Cu(II)/*N*,*N*-dimethylvaline system as proof that they reproduce well not only the geometry but also the measured energy.

For *bis*(*D*,*L*-*N*,*N*-dimethylvalinato)copper(II), 21 conformers were proposed, but only the most stable one was expected to appear in the crystal state. All of the force fields yielded the conformer 6-6 (in our notation[2]) as the most stable one, but the calculations of Gibbs energy (assuming also the influence of molecular vibrations on conformer stability) with a recently developed force field disagreed with these findings.[10] In this paper we attempt to put an end to that controversy by solving the crystal structure of the title compound.

EXPERIMENTAL

The ligand, being the racemate of *N*,*N*-dimethylvaline was prepared from *D*,*L*-valine in the same way as *L*-*N*,*N*-dimethylvaline,[5] *i.e.*, by condensation with formaldehyde, followed by catalytic hydrogenation (in ethanol/water (1:1) solution).[11] The product was recrystallized from ethanol/ether (total yield 81%., m.p. 143—144°). The complex was prepared by reaction of copper(II)acetate monohydrate with the sodium salt of the ligand in dichlormethane solution.[12]

Slow evaporation of a water solution of the complex at room temperature, gave *green* crystals, which after prolonged periods in a sealed vesel (exposed to humid air) turned *red* and *blue*, both being suitable for X-ray analysis. The structure of the red modification is reported in this paper; the structure of the blue modification will be reported subsequently.

Crystal structure determination

Crystal data: $C_{14}H_{28}CuN_2O_4$, $M_r = 351.93$, monoclinic, space group $P2_1/c$, $a = 8.118(2)$, $b = 11.507(3)$, $c = 9.819(2)$Å, $\beta = 112.81(2)°$, $V = 845.5(3)$Å^3, $Z = 2$, $D_x = 1.382$ g cm^{-3}, $F(000) = 374$, $\lambda(\text{Mo}K_\alpha) = 0.7093$Å, $\mu(\text{Mo}K_\alpha) = 1.31$ mm^{-1}.

A dark red crystal, dimensions 0.60 × 0.45 × 0.38 mm, was used for the X-ray experiment on a Philips PW1100 diffractometer (upgraded by Stoe) with graphite-monochromated MoK_α radiation. Lattice parameters and their estimated standard deviations were derived from the setting angles of 24 reflections with $20° < 2\theta < 33°$. A total of 2066 intensity maxima were collected in the range $4° < 2\theta < 54°$ using the $\omega/2\theta$ scan mode. After merging of equivalent reflections ($R_{\text{int}} = 0.023$) there were 1455 unique data with $I_{\text{net}} > 2\sigma(I_{\text{net}})$ left. Three high-intensity standard reflections monitored periodically throughout the data collection showed no evidence of crystal decay. The intensities were corrected for Lorentz and polarization effects. Empirical absorption corrections were applied using *DIAFABS*.[13] The structure was solved by the heavy-atom method. The first calculated difference Fourier synthesis based on the copper atom revealed the positions of all non-hydrogen atoms. All hydrogen atoms showed in the δF-map calculated at the end of anisotropic refinement as small positive electron densities. They were calculated in their geometrically expected positions riding on parent carbon atoms [d(C-H) = 0.95Å] and included in structure factor calculations but not refined. The correct spatial orientation of the methyl groups was verified by electron-density contour drawings calculated through the methyl group hydrogen atoms. Refinement by the full-matrix least-squares method converged with $R = 0.035$, $R_w = 0.053$, $S = 1.11$ for 97 variable parameters and $w = 1/(\sigma^2 F_0 + 0.002 F_0^2)$. In the last δF-map the deepest hole was - 0.74 e/Å^3, and the highest peak 0.65 e/Å^3. Atomic scattering factors were taken from the *International Tables for X-ray Crystallography.*[14] All calculations were performed with the *NRCVAX* suite of programs.[15] Table 1 lists final atomic coordinates along with the equivalent isotropic thermal parameters.

Molecular mechanics calculations

The conformational potential (strain energy) was calculated from equation (1) in the general form,

$$V_T = V_b(b) + V_\theta(\theta) + V_\phi(\phi) + V_\chi(\chi) + V_{vW}(r) + V_{el}(r) \qquad (1)$$

where V_b and V_θ are harmonic bond stretching and valence angle potentials dependent on bond lengths and valence angles, respectively; V_ϕ is a torsional potential in the form of a cosine function, and V_χ is a potential dependent on an out-of-plane bending angle χ (calculated in all force fields except FF2 and FF3). Van der Waals potential, V_{vW}, was calculated with Lennard-Jones (M8) or Buckingham functions (rest of the models). In addition, in models M7 and M8 the electrostatic (coulombic) interactions, V_{el}, in the first coordination sphere among the non-bonded atoms were computed, and in model 8 in these interactions all the atoms in the molecule were included. In two models (FF2, FF3)[4] valence angle bending potential among the atoms in the first coordination sphere was explicitly calculated and in the other two models (M7[9] and M8[10]) the interactions in the first

Table 1 Final atomic fractional coordinates (× 10^4) and equivalent isotropic thermal displacement coefficients B_{eq} (Å^2).

Atom	*x/a*	*y/b*	*z/c*	B_{eq}*
Cu	0	0	0	2.12(2)
O1	912(2)	- 1463(1)	- 312(2)	3.1(1)
O2	2304(2)	- 3047(1)	865(2)	3.6(1)
N	327(2)	- 683(2)	1981(2)	2.5(1)
C1	1701(3)	- 2079(2)	872(2)	2.4(1)
C2	1877(3)	- 1501(2)	2330(2)	2.3(1)
C3	3711(3)	- 917(2)	3080(2)	3.3(1)
C4	5177(4)	- 1830(3)	3617(3)	5.1(1)
C5	4126(5)	- 12(2)	2122(6)	5.2(2)
C6	528(6)	157(2)	3175(4)	4.6(2)
C7	- 1298(3)	- 1388(3)	1731(3)	4.5(1)

*B_{eq} is the mean of the principal axes of the thermal ellipsoid.

coordination sphere were computed with coulombic potential. In all models the coordination around copper is regarded to consist of four real ligand atoms (N and O) and two apically placed "dummy" atoms, denoted as X. The general overlay of parameters for all models, except for M8 (M8-kr47 parameter set was used in our calculations),[10] was presented in ref. 16.

The calculations in the crystal state were based on the use of the convergence function for the acceleration of the summation of intermolecular terms.[17—19] Calculations were performed with the CFF program.[19,20]

Root-mean-square deviations were calculated from (*2*),

$$\mathrm{rms}(\Delta\chi) = \left[\frac{1}{N}\sum_{i=1}^{N}(\Delta\chi_i)^2\right]^{1/2} \qquad (2)$$

where χ stands for six valence angles defining the copper coordination, rms($\Delta\theta$), or for all intramolecular distances among the non-hydrogen atoms, rms(Δr).

RESULTS AND DISCUSSION

An *ORTEP*II[21] view of the *bis(D,L-N,N*-dimethylvalinato)copper(II) molecule is displayed in Figure 1. The structure is built up of discrete molecules held together by normal van der Waals interactions. The molecule lies in a special position with the metal atom at an inversion centre. The copper atom has irregular square-planar coordination with oxygen and nitrogen atoms in *trans* positions. The discrepancy of the Cu-O [1.911(2)Å] and Cu-N [2.018(2)Å] bond distances and interatomic

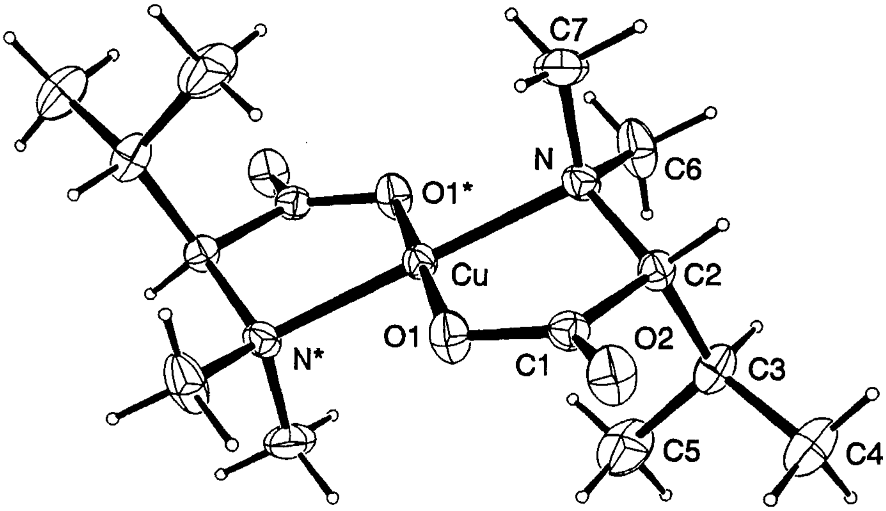

Figure 1 An *ORTEP*II drawing of the *bis*(*D,L-N,N*-dimethylvalinato)copper(II) molecule with the crystallographic atom numbering scheme and thermal displacement ellipsoids at 30% probability level. Small open circles represent the hydrogen atoms. Symmetry code (*): −x, −y, −z.

O-Cu-N bond angles [84.11(7) and 95.89(7)°] (Table 2) is characteristic of copper(II)-amino acid chelates and was found in *bis*(*L*-*N*,*N*-dimethylvalinato)-copper(II) as well as in the crystal structures of other anhydrous copper complexes with different*N*-substituted amino acids.[5,22–24] The chelate ring exhibits the conformation of an open envelope with the nitrogen atom on the flap and a dihedral angle 36.6(2)° between the least-squares planes calculated through Cu,O1,C1,C2 and Cu,N,C2. Displacement of the N atom from the least-squares plane through the Cu,O1,C1,C2 is 0.617(3)Å. The amino acid isopropyl residual occupies the axial position as was observed in copper complexes with *N*,*N*-dimethylvaline[5] and *N*,*N*-dimethylisoleucine.[22] There is very good agreement between the bond lengths found in this structure and those determined in the structure of *bis*(*L*-*N*,*N*-dimethylvalinato)copper(II).[5] On the contrary, such good agreement is not observed

Table 2 Interatomic distances (Å), valence angles (°) and selected torsion angles (°)

Internal coordinate	Experimental value	Theoretical value M8	M8(c)[a]
Cu-O1	1.911(2)	1.913	1.903
Cu-N	2.018(2)	2.023	2.016
O1-C1	1.300(2)	1.290	1.286
O2-C1	1.218(3)	1.215	1.215
N-C2	1.501(3)	1.500	1.502
N-C6	1.479(3)	1.492	1.491
N-C7	1.485(3)	1.490	1.488
C1-C2	1.534(3)	1.561	1.552
C2-C3	1.536(3)	1.552	1.551
C3-C4	1.520(4)	1.534	1.532
C3-C5	1.526(5)	1.536	1.535
O1-Cu-N	84.11(7)	84.80	84.93
O1-Cu-N*	95.89(7)	95.20	95.07
Cu-O1-C1	115.1(1)	116.3	116.9
Cu-N-C2	104.4(1)	105.7	106.6
Cu-N-C6	116.3(2)	116.2	115.5
Cu-N-C7	106.1(2)	101.3	101.5
C2-N-C6	113.8(2)	113.7	113.4
C2-N-C7	107.9(2)	110.9	110.6
C6-N-C7	107.8(2)	108.3	108.5
O1-C1-O2	123.6(2)	123.3	123.0
O1-C1-C2	115.7(2)	115.9	115.0
O2-C1-C2	120.7(2)	121.7	122.0
N-C2-C1	107.0(2)	107.5	107.6
N-C2-C3	114.0(2)	116.7	116.9
C1-C2-C3	111.1(2)	110.1	109.8
C2-C3-C4	110.3(2)	111.3	111.4
C2-C3-C5	114.1(2)	114.2	114.3
C4-C3-C5	110.8(3)	110.1	110.2
N-Cu-O1-C1	- 15.8(1)	- 9.5	- 4.8
O1-Cu-N-C6	156.4(2)	152.0	147.8
O1-C1-C2-N	29.2(1)	29.5	29.7
N-C2-C3-C4	170.7(2)	174.3	169.2
Cu-O1-C1-C2	- 3.8(1)	- 8.9	- 12.9
Cu-N-C2-C3	85.5(1)	90.7	93.5

[a] Calculated in the crystal state with cut-out-limit of 14Å and convergence constants with values of 0.2, 0.2 and 0.0 Å^{-1} for Coulomb, dispersion and repulsive summation terms, respectively. Calculated parameters of crystal lattice: a = 7.730, *b* = 10.957, *c* = 9.350Å, β = 107.77°, *V* = 754.1Å^3.

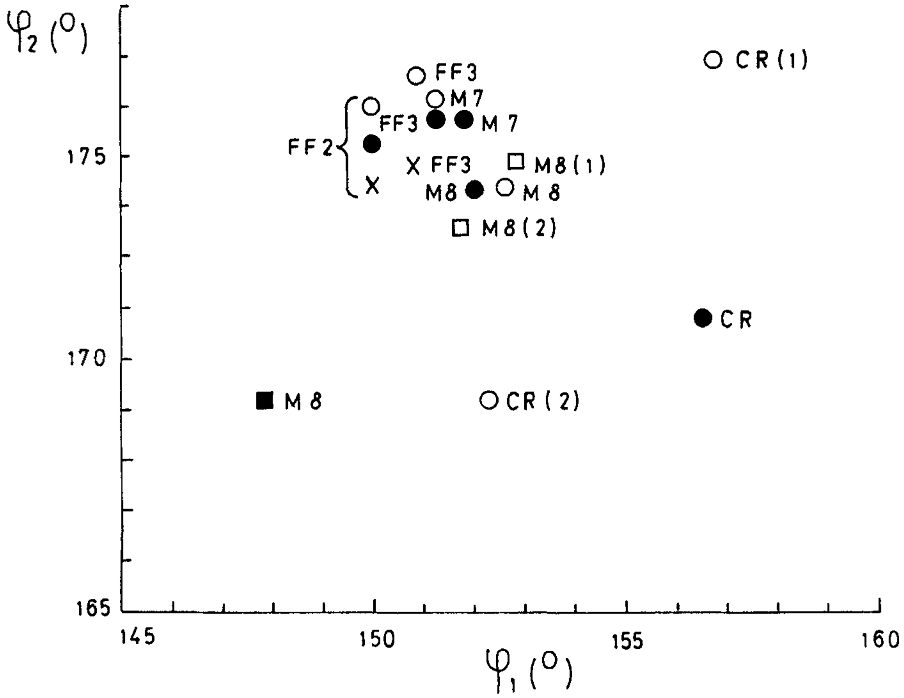

Figure 2 Crystal (CR) and theoretical (FF2, FF3 *etc.*) structures of *bis*(*D,L-N,N*-dimethylvalinato)copper(II), full symbols, and its *LL*-isomer, open symbols, within the frame of torsion angles ϕ_1 (O1-Cu-N-C6) and ϕ_2 (N-C2-C3-C4). The results of calculations *in vacuo* are marked as circles, and the results of calculation in the crystal state as squares. The results of calculation on isolated rings (*mono*-complex) are denoted with an X.

for the valence and torsion angles. There are no *inter*molecular contacts closer than 3.392Å (C2-H. . .O2^i); symmetry code (i): x, -y -0.5, z+0.5.[25]

The conformation of both chelate rings is the same by definition and equal to the conformation of *LL*-isomer[5], *i.e.*, 6-6 according to our notation.[2] This conformation corresponds to the conformer with the lowest conformational energy as obtained with all models checked so far.[2,4–10] Theoretical models reproduced unequally the angles around copper [rms(Δθ) = 0.49° (FF3), 0.57° (FF3a, M8), 0.69° (M8c), 1.59° (M7), 2.41° (FF2), 2.45° (FF2a)]. This result was not quite unexpected because force field FF2 yielded generally the poorest results with respect to reproduction of copper(II) coordination geometry and was unable, in the case of high distortion, to yield a physically sound minimum.[26] A difference in reproduction of overall molecular geometry was also observed [rms(Δr) = 0.055Å (FF3a), 0.073Å (FF2a), 0.074Å (FF3, M7), 0.119 (M8)Å, 0.179Å (M8c)] but was not so model-dependent. It is interesting to note that the explicit calculations of interangular interactions (in the *bis*-complex) did not improve the reproduction of molecular geometry, because calculations on isolated rings (*mono*-complex) yielded results of the same precision [rms(Δr) = 0.045Å (FF3a), 0.068Å (FF3)].

A plot of the molecular structures within the frame of the two most critical torsion angles (describing the conformation of chelate ring and side chain, Fig. 2) showed that *all* crystal structures converge to the virtually same theoretical structure after energy minimization. This appears to be independent of the interactions among the chelate rings (*c.f.*, *LL*-, *DL*-isomer or *mono*-complex) and force field used. MM calculations in the crystal state of the *LL*-isomer gave a structure close to the one obtained by *in vacuo* calculations [M8(1) and M8(2), Fig. 2]. On the contrary, the calculations on the *DL*-isomer in the crystal state yielded a molecular geometry quite different to both the X-ray and *in vacuo* structures (Fig. 2). An explanation for such an anomaly can be found in the symmetry properties of the *DL*-isomer. Namely, it is incapable of compensating for steric strain imposed by close contact of surrounding molecules and by distorting the coordination polyhedron (centre of inversion must be preserved); the molecule distorts by changing the geometry of the chelate rings. This phenomenon (two types of distortion) is frequently observed in related compounds, such as with sterically hindered copper chelates with Schiff bases,[27] but it has not been explicitly discussed. The explanation of the observed phenomen calls therefore for further research.

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SUPPLEMENTARY MATERIAL

Full lists of H atom positions, anisotropic thermal parameters and observed and calculated structure factors are available from N.R. upon request.

References

1. N. Paulić and N. Raos, *J. Coord. Chem.*, **31**, 181 (1994).
2. N. Raos and Vl. Simeon, *Croat. Chem. Acta*, **56**, 79 (1983).
3. V.A. Davankov, S.V. Rogozhin, A.A. Kurganov and L. Ya. Zhuchkova, *J. Inorg. Nucl. Chem.*, **37**, 369 (1975).
4. N. Raos and Vl. Simeon, *Croat. Chem. Acta*, **58**, 127 (1985).
5. B. Kaitner, B. Kamenar, N. Paulić, N. Raos and Vl. Simeon, *J. Coord. Chem.*, **15**, 373 (1987).
6. J. Sabolović, N. Raos and Kj. Rasmussen, *Croat. Chem. Acta*, **62**, 495 (1989).
7. J. Sabolović and N. Raos, *Polyhedron*, **9**, 1277 (1990).
8. J. Sabolović and N. Raos, *Polyhedron*, **9**, 2419 (1990).
9. J. Sabolović, *Polyhedron*, **12**, 1107 (1993).
10. J. Sabolović and Kj. Rasmussen, *Inorg. Chem.*, **34**, 1221 (1995).
11. R.E. Bowman and H.H. Stroud, *J. Chem. Soc.*, 1342 (1950).
12. C.P. Nash and W.P. Schaefer, *J. Amer. Chem. Soc.*, **91**, 1319 (1969).
13. N. Walker and D. Stuart, *Acta Crystallogr.*, **A39**, 158 (1983).
14. *International Tables for X-ray Crystallography*, Vol. IV, Table 2.2B, (Kynoch Press, Birmingham, 1974); Present distributor: Kluwer Academic Publishers, Dordrecht, The Netherlands.

15. E.J. Gabe, Y. Le Page, J.-P. Charland, F.L. Lee and P.S. White, *J. Appl. Crystallogr.*, **22**, 384 (1989).
16. N. Raos, S.R. Niketić and Vl. Simeon, *J. Inorg. Chem.*, **16**, 1 (1982).
17. D.E. Williams, *Acta Cryst.*, **A27**, 452 (1971).
18. D.E. Williams, *Acta Cryst.*, **A28**, 629 (1972).
19. Kj. Rasmussen, "*Potential Energy Functions in Conformational Analysis*", *Lecture Notes in Chemistry*, Vol. 37, (Springer-Verlag, Berlin, 1985).
20. S.R. Niketić and Kj. Rasmussen, "*The Consistent Force Field: A Documentation*", *Lecture Notes in Chemistry*, Vol. 3, (Springer-Verlag, Berlin, 1977); Kj. Rasmussen, S.B. Engelsen, J. Fabricius and B. Rasmussen,*The Consistent Force Field: Development of potential energy functions for conformational analysis*, Recent Experimental and Computational Advances in Molecular Spectroscopy (Proceedings of the NATO Advanced Study Insitute on Molecular Spectroscopy, Ponta Delgada, São Miguel, Açores, Portugal 1992), R. Fausto, Ed., NATO ASI Series C: Mathematical and Physical Sciences, Vol. 406, (Kluwer Academic Publishers, Dordrecht 1993), pp. 381–419.
21. C.K. Johnson, *ORTEP*II, Report ORL-5138. Oak Ridge National Laboratory, Tennessee, USA (1976).
22. B. Kaitner, N. Paulić and N. Raos, *J. Coord. Chem.*, **22**, 269 (1991).
23. B. Kaitner, G. Ferguson, N. Paulić and N. Raos, *J. Coord. Chem.*, **26**, 105 (1992).
24. B. Kaitner, G. Ferguson, N. Paulić and N. Raos, *J. Coord. Chem.*, **29**, 247 (1993).
25. T. Steiner and W. Seanger, *J. Amer. Chem. Soc.*, **115**, 4540 (1993).
26. N. Raos, *Croat. Chem. Acta*, **67**, 515(1994).
27. A.P. Polishchuk, M. Yu. Antipin, T.V. Timofeeva, Yu. T. Struchkov, Yu. G. Galyametdinov, I.V. Ovchinnikov, *Kristallografiya,* **31**, 466 (1986).