Distortion isomerism of Cu(II) chloride adducts with bis(2-benzimidazolyl)ethane. Synthesis, characterization, X-ray structures and spectroscopy of four different isomers
Albada, G.A. van; Mutikainen, I.; Turpeinen, U.; Reedijk, J.

Citation
Albada, G. A. van, Mutikainen, I., Turpeinen, U., & Reedijk, J. (2007). Distortion isomerism of Cu(II) chloride adducts with bis(2-benzimidazolyl)ethane. Synthesis, characterization, X-ray structures and spectroscopy of four different isomers. *Journal Of Chemical Crystallography, 37*, 489-496. doi:10.1007/s10870-007-9202-0

Version: Publisher's Version
License: Leiden University Non-exclusive license
Downloaded from: https://hdl.handle.net/1887/138112

Note: To cite this publication please use the final published version (if applicable).
Distortion Isomerism of Cu(II) Chloride Adducts with Bis (2-benzimidazolyl)ethane. Synthesis, Characterization, X-ray Structures and Spectroscopy of Four Different Isomers

Gerard A. van Albada · Ilpo Mutikainen · Urho Turpeinen · Jan Reedijk

Abstract 3D structures and spectroscopic properties are reported of four compounds with the ligand bis(2-benzimidazolyl)ethane (hereafter abbreviated as dbz) attached to CuCl₂, all having the general formula [Cu(dbz)Cl₂](Hb)ₓ, (in which Hb = EtOH or MeOH and x = 1/2 or 1). The X-ray crystal structure has been solved from these four slightly different compounds, namely: green α-[CuCl₂(dbz)](C₂H₅OH)₁/₂ (1), the red compound β-[CuCl₂(dbz)](C₂H₅OH)₁/₂ (2), which both have two slightly different units in the unit cell, the red α-[CuCl₂(dbz)](CH₃OH) (3) and a blue–green compound β-[CuCl₂(dbz)](CH₃OH) (4). The geometry around the Cu(II) anion is distorted tetrahedral for all four compounds, with chromophores consisting of two nitrogen atoms of the bidentate chelating dbz molecule and two chloride anions.

The unit cells of compound 1 and 2 consist of two chemically identical, but crystallographically different units, while compounds 3 and 4 each have only one independent CuCl₂(dbz) unit. The major differences are observed in the dihedral angles N₂CuN–Cl₂CuCl, which vary from 29.3 to 77.1° for the four compounds. The differences are related to different packing effects, ring–ring stacking and H-bond interaction, due to the two different alcohols used. In fact these four compounds represent a new range of examples of distortion isomerism in pseudo-tetrahedrally coordinated species. Characterisation of the four compounds has been completed by IR, EPR and LF spectroscopy.

Keywords Copper(II) · Plasticity effect · Crystal structure · Distortion isomerism · Hydrogen bonding

Introduction

The coordination chemistry of the heterocyclic azoles acting as ligands in copper(II) compounds in the context of modelling biological systems has gained much interest in the past decades [1–4]. In this respect bis(2-benzimidazoles) have received much attention for their wide-ranging antivirus activity [5, 6], their importance in selective ion-exchange resins [7, 8] and the possibility to form supramolecular aggregates with d¹⁰ metal ions [9].

So far, spectroscopic and magnetic properties, as well as X-ray structural analysis of a number of mono-, bis-, tetra- and polynuclear copper(II) coordination compounds with bis(2-benzimidazolyl)alkanes and some substituted bis(2-benzimidazolyl)alkanes have been reported by others and by us [10–20].

The copper(II) ion is known to yield in some cases different geometries with the same ligand. This has been coined as “plasticity effect” [21–23] and is believed to results from the Jahn–Teller distortion of the Cu(II) ion. Several ligands are known to yield different (coloured) Cu(II) isomers of the same compound, which have been classified as distortion isomers, a phenomenon known for many years [24–26].

In our earlier research with the ligand bis(2-benzimidazolyl)propane (abbreviated as tbz), two different Cu(II) compounds, of formula [Cu(tbz)Cl₂], were obtained, i.e. a red isomer with a (distorted) tetrahedral geometry and a
polymeric green isomer containing two different copper(II) sites, each distorted from square planar [14]. With a methyl substituent on different positions on the alkyl chain of tbz a number of copper(II) halide compounds were synthesized, however, no distortion isomers were reported in these cases [19].

In the present study a few other examples dealing with four CuCl₂ distortion isomers are reported with the ligand bis(2-benzimidazolyl)ethane (abbreviated as dbz) having the general formula [Cu(dbz)Cl₂][Hb]ₓ (in which Hb = EtOH or MeOH and x = 1/2 or 1). The X-ray crystal structure has been solved from four different compounds, the green a-[CuCl₂dbz](C₂H₅OH)½ (1) [27], the red β-[CuCl₂dbz](C₂H₅OH)½ (2), the red α-[CuCl₂dbz] (CH₃OH) (3) and the blue–green compound β-[CuCl₂dbz](CH₃OH) (4). The characterization was further done by spectroscopic methods and EPR. This study is a rare case of distortion isomerism in which four different CuCl₂ compounds with the same ligand is fully characterized, also by X-ray crystallography.

**Experimental section**

General

C, H, N determinations were performed on a Perkin Elmer 2400 Series II analyzer. Ligand field spectra were obtained on a Perkin-Elmer Lambda 900 spectrophotometer, using the diffuse reflectance technique, with MgO as a reference. X-band powder EPR spectra were obtained on a Jeol RE2x electron spin resonance spectrometer using DPPH (g = 2.0036) as a standard. FTIR spectra were obtained on a Perkin Elmer Paragon 1000 FTIR spectrophotometer equipped with a Golden Gate ATR device, using the reflectance technique (4,000–300 cm⁻¹, res. 4 cm⁻¹).

| Table 1 | Crystal and refinement data |
|---------|-----------------------------|
| Compound | 1   | 2   | 3   | 4   |
| CCDC deposit nr. |     |     |     |     |
| Molecular formula | C₁₆H₁₆Cl₂Cu₂N₈O | C₁₆H₁₆Cl₂Cu₂N₈O | C₁₆H₁₆Cl₂Cu₂N₈O | C₁₆H₁₆Cl₂Cu₂N₈O |
| Molecular weight | 839.59 | 839.59 | 428.79 | 428.79 |
| T (K) | 173(2) | 173(2) | 173(2) | 173(2) |
| Crystal system | Triclinic | Triclinic | Triclinic | Monoclinic |
| Space group | P-1 | P-1 | P-1 | P2(1)/c |
| a (Å) | 12.306(2) | 9.2620 | 8.265(2) | 6.982(1) |
| b (Å) | 12.757(2) | 12.660(3) | 9.082(2) | 13.802(3) |
| c (Å) | 13.742(3) | 15.457(3) | 12.331(2) | 18.579(4) |
| α (°) | 67.27(3) | 89.55(3) | 100.80(3) | 90.0 |
| β (°) | 63.76(3) | 88.44(3) | 95.33(3) |
| γ (°) | 84.65(3) | 78.72(3) | 94.57(3) | 90.0 |
| V (Å³) | 1776.9(9) | 1776.8(9) | 878.0(3) | 1785.7(6) |
| Z | 2 | 2 | 2 | 4 |
| D(FOO) (Mg m⁻³) | 1.569 | 1.569 | 1.622 | 1.595 |
| µ (mm⁻¹) | 1.539 | 1.539 | 1.561 | 1.535 |
| Crystal size (mm) | 0.20 × 0.25 × 0.25 | 0.30 × 0.10 × 0.07 | 0.20 × 0.20 × 0.04 | 0.25 × 0.13 × 0.13 |
| Colour, shape | green, block | red, plate | blue-green, block |
| θ range (°) | 2.9–27.5 | 2.8–27.0 | 3.16–27.50 | 2.20–27.55 |
| Number of reflections collected | 28,173 | 28,194 | 13,257 | 27,031 |
| Number of unique reflections | 8110 (Rint = 0.037) | 7457 (Rint = 0.065) | 4010 (Rint = 0.083) | 4092 (Rint = 0.1494) |
| Number of ref. parameters | 444 | 487 | 228 | 227 |
| S (Goodness of fit) | 0.95 | 1.048 | 1.009 | 0.991 |
| Final R indices [I > 2σ(I)] | R1 = 0.0294 | R1 = 0.0558 | R1 = 0.0518 | R1 = 0.0686 |
| wR2 = 0.0731 | wR2 = 0.1313 | wR2 = 0.1177 | wR2 = 0.1622 |
| R indices (all data) | R1 = 0.0437 | R1 = 0.0895 | R1 = 0.0901 | R1 = 0.1404 |
| wR2 = 0.0749 | wR2 = 0.1488 | wR2 = 0.1310 | wR2 = 0.1940 |
| Largest difference min, max (e Å⁻³) | −0.59, 0.51 | −0.99, 1.04 | −0.82, 0.70 | −0.58, 1.26 |

\[
R = \sum |F_o| - |F_c| / \sum F_o, \text{ w}_n = \left( \sum |F_o| - |F_c| \right)^2 / \sum w|F_o|^2 \\
R_w = \left( \sum w|F_o| - |F_c| \right)^2 / \sum w|F_o|^2 \\
\text{where} F_o = \max (|F|), F_c = \max (|F|)
\]

\[R = P ||F_o|| - |F_c| / \sum |F_o|, R_w = P \sum w|F_o| - |F_c| / \sum w|F_o|^2 \]
Synthesis of the coordination compounds

The compounds were prepared according to the following general procedure: 1.2 mmol of CuCl₂ and 1.2 mmol of the ligand dbz were each dissolved in 10 ml of methanol or ethanol. The Cu(II) salt solution was then added slowly to the ligand solution and filtered to remove any undissolved material. Usually after a few days the products separated as a mixture of red and green crystals for the ethanol solution or red and blue–green crystals for the methanol solution. The different coloured crystals were separated manually for spectroscopic measurements and X-ray crystallography.

Changing the Cu/ligand ratio appeared to have a small effect on the crystallisation of the different coloured products, but it was not possible to synthesize these isomers completely separately. Satisfactory elemental (C, H, N) analysis were obtained.

Crystal structure determination and refinement

A crystal was selected and mounted to a glass fiber using the oil-drop method; data were collected on a Nonius KappaCCD diffractometer (graphite-monochromated Mo-Kα radiation). The intensity data were corrected for Lorentz and polarization effects, for absorption and for extinction. The structures were solved by direct methods. The programs COLLECT [28], SHELXS-97 [29], SHELXL-97 [30] were used for data reduction, structure solution and structure refinement, respectively. Refinement of $F^2$
Table 2  Selected bond lengths (Å) and angles (°) for the four compounds

| Compound          | (1)       | (2)       | (3)       | (4)       |
|-------------------|-----------|-----------|-----------|-----------|
| Cu1A–Cl1A        | 2.2664(7) | 2.304(3)* | 2.265(1)  | 2.279(2)  |
| Cu1A–Cl1         | 2.402(2)* |           |           |           |
| Cu1A–Cl2A        | 2.2367(8) | 2.152(3)* | 2.255(1)  | 2.234(2)  |
| Cu1A–Cl2         | 2.319(3)* |           |           |           |
| Cu1A–N2A         | 1.988(2)  | 1.801(5)  | 2.013(3)  | 1.996(5)  |
| Cu1A–N4A         | 2.004(2)  | 2.116(5)  | 1.976(3)  | 2.007(4)  |
| Cu1B–Cl1B        | 2.2724(9) | 2.356(2)  |           |           |
| Cu1B–Cl2B        | 2.2371(8) | 2.208(1)  |           |           |
| Cu1B–N2B         | 1.9765(17)| 1.843(3)  |           |           |
| Cu1B–N4B         | 1.973(2)  | 2.141(4)  |           |           |
| Cl1A–Cu1A–Cl2A   | 95.62(4)  | 104.8(1)* | 94.17(4)  | 94.11(6)  |
| Cl1–Cu1A–Cl2     | 95.43(9)* |           |           |           |
| Cl1A–Cu1A–N2A    | 148.80(7) | 109.2(2)* | 128.9(1)  | 156.8(1)  |
| Cl1A–Cu1A–N4A    | 91.21(6)  | 128.3(1)* | 100.48(9)| 90.5(1)   |
| Cl1–Cu1A–N4A     | 104.4(1)* | 116.1(2)* | 96.9(1)   | 93.7(1)   |
| Cl2A–Cu1A–N2A    | 94.22(6)  | 116.1(2)* | 105.7(2)* |           |
| Cl2–Cu1A–N2A     | 105.7(2)* |           |           |           |
| Cl2A–Cu1A–N4A    | 151.33(7) | 99.1(2)*  | 146.38(9)| 161.3(1)  |
| Cl2–Cu1A–N4A     | 138.6(2)* |           |           |           |
| N2A–Cu1A–N4A     | 94.17(8)  | 99.8(2)   | 97.1(1)   | 89.1(2)   |
| Cl2B–Cu1B–N4B    | 140.55(7) | 98.2(1)   |           |           |
| N2B–Cu1B–N4B     | 94.68(8)  | 90.9(2)   |           |           |
| Cl1B–Cu1B–N4B    | 103.32(7) | 140.0(1)  |           |           |
| Cl1B–Cu1B–Cl2B   | 98.64(4)  | 95.53(6)  |           |           |
| Cl1B–Cu1B–N2B    | 132.13(7) | 103.4(1)  |           |           |
| Cl2B–Cu1B–N2B    | 94.33(7)  | 137.8(1)  |           |           |

Hydrogen bonds:

| D–H    | H···A | D–A | D–H···A |
|--------|------|-----|--------|
| O1–H1A–Cl1B [–1–x, –y, –z] | 0.84 | 2.31 | 3.146(2) | 173 |
| N1A–H1AA–Cl2B [x,1 + y, –1 + z] | 0.88 | 2.28 | 3.147(2) | 169 |
| N3A–H3AA–Cl1A [–1–x, 1–y, –1–z] | 0.88 | 2.56 | 3.248(2) | 136**|
| N3A–H3AA–O1 [–1–x,1–y, –1–z] | 0.88 | 2.43 | 3.131(3) | 138**|
| NIB–HIBA–Cl2A [1 + x, y, z] | 0.88 | 2.54 | 3.262(2) | 140 |
| N3B–H3BA–O1 [1 + x, y, z] | 0.88 | 1.98 | 2.830(3) | 162 |

Structure (2):

| O16–H16A–Cl1 [1–x, 1–y, 1–z] | 0.84 | 2.28 | 2.778(9) | 119 |
| N1A–H1AC–Cl1B | 0.88 | 2.43 | 3.210(5) | 148 |
| N3A–H3AA–O3 [x, 1 + y, z] | 0.88 | 2.05 | 2.917(11)| 167 |
| N1B–HIBC–O1 [1–x, 1–y, 1–z] | 0.88 | 1.95 | 2.778(9) | 156 |
| N3B–H3BA–Cl2B [1–x, 2–y, 1–z] | 0.88 | 2.61 | 3.369(4) | 145 |

Structure (3):

| O16–H16A–Cl1 [1–x, 1–y, 1–z] | 0.84 | 2.37 | 3.175(3) | 160 |
| N1–H1C–O16 | 0.88 | 2.03 | 2.853(5) | 154 |
| N3–H3AA–Cl2 [1 + x, y, z] | 0.88 | 2.60 | 3.406(4)| 153 |

Structure (4):

| N(1)–H(1A)–O(18) [1–x, 2–y, 1–z] | 0.88 | 1.98 | 2.776(7) | 150 |
was done against all reflections. All non-hydrogen atoms were refined anisotropically. The ethanol molecule and the Cl atoms coordinated to the Cu1A atom in compound (2) were found in disordered positions. These disordered atoms were refined in the two positions with population parameter 0.5. All H atoms were introduced in calculated positions and refined with fixed geometry with respect to their carrier atoms. Crystallographic data are presented in Table 1.

Results and discussion

Description of the crystal structures

A thermal ellipsoid plot, together with the numbering scheme for the four compounds is shown in Figs. 1–4, for compounds 1 to 4, respectively. The selected bond lengths and bond angles are given in Table 2.

The structure of compounds 1 and 2 contains two chemically almost identical, but crystallographically independent, CuCl₂-dbz units and one non-coordinating ethanol molecule, which is present in a disordered position for compound 2. In compound 2 also one of the two units contains the two chloride atoms in disordered positions, which appears to be related to the hydrogen-bonding interaction with the disordered ethanol. Compounds 3 and 4 have only one crystallographic unit and one non-coordinating methanol molecule.

Each copper(II) atom is tetrahedrally surrounded by two nitrogens of the chelating bidentate ligand and two chloride anions. The Cu–N distances vary from 1.801(5) to 2.141(4) Å and the Cu–Cl distances vary from 2.152(3) to 2.279(2) Å (the disordered Cu–Cl distances are not considered), which are normal distances for CuCl₂ tetrahedral compounds. The smallest tetrahedral angles (N–Cu–N) of the 7-membered chelate ring differs from 89.12(18)° to 99.8(2)° in the four compounds. Structural comparison of the four compounds is given in Table 3. The fact that in compound 2 the Cl atoms in one of the units is disordered makes it somewhat difficult to compare these compounds with each other.

One of the important differences is the dihedral angle between the Cl–Cu–Cl and the N–Cu–N planes in the four compounds (see Table 3). These tetrahedral angles differ significantly from the tetrahedral angles reported for the copper(II) halide compounds with tbz and methylated tbz (dihedral angles 62.52 and 65.43°); values of 90° would be expected for undistorted tetrahedral geometry, so the present compounds are more close to tetrahedral than the tbz or methylated tbz compounds, perhaps also influenced by the fact that tbz and methylated tbz compounds forms an eight-membered chelate ring [19], while the present compounds forms a seven-membered chelate ring.

The lattice structure is additionally stabilized by stacking between the benzimidazole groups of different units (Ring–Ring distances are 3.552, 3.416, 3.500, 3.451 Å, for compounds 1 to 4, respectively). An extensive hydrogen bond system is present between the N–H of the ligand and the chloride ions; between the N–H and the oxygen atom of the alcohol molecule and between the oxygen atom of the alcohol molecule and the chloride ions. Details of the H bonds are given in Table 2. This great variety in H bonds is likely to be responsible for the different distortion isomers found.

Ligand field and infrared spectroscopy

The diffuse reflectance spectra of the powdered solids are given in Table 4, together with the EPR values. The compounds 1 to 3 show the typical tetrahedral-type ligand field spectrum of a very broad (split) band with a centre around 12.0–9.7 × 10³ cm⁻¹, whereas compound 4 has a very broad band centred around 15.0 × 10³ cm⁻¹, which are known to be in the common range of absorptions for (square-planar distorted) tetrahedral copper(II) compounds [14, 19, 31].

The infrared spectra of the four compounds show only some differences in the characteristic benzimidazole C–H bending vibrations in the 700–800 cm⁻¹ area. The benzimidazole-CH bending vibrations between 750–720 cm⁻¹ are known to be very sensitive to structure differences and orientations of the benzene part of the molecule in the lattice [32]. In the dbz free ligand the imidazole bending vibration is observed at 775 cm⁻¹ and the benzimidazole CH-out-of-plane bending at 750 and 739 cm⁻¹ [32a].

These infrared vibrations in compound 1 are observed at 761, 753, 750, 744 and 736 cm⁻¹; the two red compounds,
2 and 3 have almost the same pattern, bands at 761, 753, 746, 733 cm⁻¹ (compound 2) and 762, 753, 747, 733 cm⁻¹ (for compound 3). The blue–green compound 4 has a pattern of three vibrations at 764, 757 and 752 cm⁻¹. The ligand N–H stretches vary for each of the compounds (3,464–3,000 cm⁻¹), which is related to their hydrogen bonding situation [34]. The bands are, however, too broad to allow a study with comparison of H-bond distances, also because of the lattice EtOH and MeOH OH-stretching vibrations, which occur in the same region.

**EPR**

X-band EPR spectra of polycrystalline powders of the complexes were recorded at room temperature and 77 K. The resolution did not improve very much upon cooling to 77 K. As shown in Table 2 the compounds show an axial \( S = 1/2 \) signal with a \( g_\perp \) at 2.11–2.07 and an unresolved \( g_\parallel \) value in the range of 2.23–2.32. EPR measurements as frozen solutions (DMSO/MeOH mixtures) resulted in resolved spectra with \( g_\perp \) of 2.07, \( g_\parallel \) 2.32 and \( A_\parallel \) between 12.7–14.4. These values differ from the earlier reported CuCl₂-(tbz) compounds which show in similar solutions a trigonal-bipyramidal geometry; perhaps some dmso is coordinating to the metal of the CuCl₂-(tbz), thereby changing the spectral parameters [14]. The \( g \) values obtained are nevertheless in the usual range for copper in a (distorted) tetrahedral environment [14, 16, 19, 21].

**Conclusion**

The present study has provided four new samples of Cu(II) distortion isomeric compounds with the ligand dbz. So far only a few examples of CuCl₂-based distortion isomers are known which have been fully characterized by X-ray analysis [14, 26d, h], and the present species are the first examples in which four different compounds of the same ligand and metal salt and the same chromophore are fully characterized by X-ray crystallography. All compounds exhibit a more or less distorted tetrahedral environment and a seven-membered chelate ring is formed. The tetrahedral angles (N–Cu–N) of the chelate rings are close to the calculated value (101.3°) for 7-membered chelate rings [33].

The difference in the dihedral angles for the various isomers can be understood on the basis of different hydrogen bonding due to the fact of two different solvents and differences in packing due to ring–ring stacking, thereby illustrating that the energy differences are small. Another interesting fact is that in compound (2) the
Supplementary material

Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publications no. CCDC: 602249, 602250, 602251 and 602252, for compounds 1 to 4, respectively. Copies of the data can be obtained free of charge on application to The Director, CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: int code +44(1223)336-033, E-mail: deposit@ccdc.cam.ac.uk).

Acknowledgements The work described in the present paper has been supported by the Leiden University Study group WFMO (Werkgroep Fundamenteel Materialen Onderzoek). Financial support and coordination by the FP6 Network of Excellence “Magma-net” (contract number 515767) is kindly acknowledged.

References

1. Reedijk J (1987) In: Wilkinson G, Gillard RD, McCleverty JA (eds) Comprehensive coordination chemistry, Pergamon Press, 2:73
2. Bouwman E, Driessen WL, Reedijk J (1990) Coord Chem Rev 104:143
3. Sorrell TN (1989) Tetrahedron 45:3
4. Zanello P, Tamburini S, Vigato PA, Mazzochini GA (1987) Coord Chem Rev 77:165
5. Çakir B, Büyükbingöl E, Uççu Ü, Abbasoglu U (1988) J Fac Pharm Gazi 5:71
6. Roderick WR, Nordeen CW Jr, Esch AM, Appell von RN (1972) J Med Chem 15:655
7. Hoom HJ, Joode P de, Driessen WL, Reedijk J (1995) React Funct Polym 27:223
8. Berkel PM van, Dijkstra DJ, Driessen WL, Reedijk J, Sherrington DC (1995) React Funct Polym 28:39
9. Piquet C, Bünnii J-CG, Bernardinelli G, Hopfgartner G, Williams AF (1995) J Alloys Comp 225:324
10. Bernardinelli G, Kübel-Pollak A, Rüttimann S, Williams AF (1992) Chimia 46:155
11. Bernardinelli G, Kübel-Pollak A, Rüttimann S, Williams AF (1993) Zeitschrift Kristallogr 203:132
12. Abada GA van, Lakin MT, Veldman N, Spek AL, Reedijk J (1995) Inorg Chem 34:4910
13. Abada GA van, Smeets WJJ, Spek AL, Reedijk J (1997) Inorg Chim Acta 260:151
14. Abada GA van, Smeets WJJ, Spek AL, Reedijk J (1999) Inorg Chim Acta 288:220
15. Abada GA van, Smeets WJJ, Veldman N, Spek AL, Reedijk J (1999) Inorg Chim Acta 290:105
16. Abada GA van, Smeets WJJ, Spek AL, Reedijk J (2000) Inorg Chim Acta 299:35
17. Abada GA van, Veldman N, Spek AL, Reedijk J (2000) Chem Crystallogr 30:69
18. Abada GA van, Riggio I, Mutikainen I, Turpeinen U, Reedijk J (2000) Chem Cryst 30:793
19. Riggio I, Abada GA van, Ellis DD, Mutikainen I, Spek AL, Turpeinen U, Reedijk J (2001) Polyhedron 20:141
20. Abada GA van, Mutikainen I, Riggio I, Turpeinen U, Reedijk J (2002) Polyhedron 21:141
21. Hathaway BJ (1987) In: Wilkinson G, Gillard RD, McCleverty JA (eds) Comprehensive coordination chemistry, vol 5, Pergamon, Oxford
22. Gaszó J, Bersuker IB, Garaj J, Kabesőva M, Kohout J, Langfelderová H, Melník M, Šerát M, Valach F (1976) Coord Chem Rev 19:253
23. Palaniandavar M, Butcher RJ, Addison AW (1996) Inorg Chem 35:467
24. Gaszó J (1974) Pure Appl Chem 38:279
25. Melník M (1982) Coord Chem Rev 42:279
26. (a) Haddad SF, Pickardt J (1993) Transition Met Chem 18:377; (b) Foley J, Tyagi J, Hathaway BJ (1984) J Chem Soc, Dalton Trans 1; (c) Baran P, Koman M, Valigura D, Mrozínski J (1991) J Chem Soc, Dalton Trans 1385; (d) Kelly PF, Slawin AMZ, Waring KW (1997) J Chem Soc, Dalton Trans 2853; (e) Pajunen A, Smolander K, Belinski H, Melník M, Kabesőva M, Gazsó J (1978) J Alloys Comp 45:233; (f) Glass RS, Sabahi M, Hojjatie M, Wilson GS (1987) Inorg Chem 26:2196; (g) Haanstra WG, Donk WAW van der, Driessen WL, Reedijk J, Wood JS, Drew MGB (1990) J Chem Soc, Dalton Trans 3123; (h) Langfelderová H, Macásková L, Melník M, Kabesőva M, Gaszó J (1978) Z Anorg Allg Chem 445:233.
30. Sheldrick, GM (1997) SHELXL-97 Program for the Refinement of Crystal Structures University of Göttingen, Germany
31. Lever ABP (1984) Inorganic electronic spectroscopy, 2nd Ed, Elsevier, Amsterdam
32. (a) Drolet DP, Manuta DM, Lees AJ, Katnani AD, Coyle GJ (1988) Inorg Chim Acta 146:173; (b) Boinnard D, Cassoux P, Petrouleas V, Savariault J-M, Tuchagues J-P (1990) Inorg Chem 29:4114; (c) Cordes MM, Walter JL (1968) Spectrochim Acta 24A:1421
33. Broughton V, Bernardinelli G, Williams AF (1998) Inorg Chim Acta 275:276–279
34. Bellamy LJ, Owen AJ (1969) Spectr Chim Acta 25A:329