



Synthesis, Characterization, Crystal Structure and Interaction with DNA of Cobalt(II) Complex

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(Received: 29 February 2012;

Accepted: 7 January 2013)

AJC-12661

A cobalt(II) complex with the composition $[\text{Co}(\text{DMAP})_2(\text{bipy})(\text{H}_2\text{O})_2]$ (HDMAP = 3,4-dimethoxyphenyl acetic acid, bipy = 4,4'-bipyridine), was synthesized under hydrothermal conditions from $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$ and 3,4-dimethoxyphenyl acetic acid together with 4,4'-bipyridine and characterized by IR spectra and thermal behaviour. The crystal structure of the complex was determined by X-ray crystallography. It crystallizes in the monoclinic system, space group $C2/c$ with $a = 2.57437(9)$ nm, $b = 1.14108(4)$ nm, $c = 0.98716(3)$ nm, $\beta = 92.683(2)^\circ$, $V = 2.89667(17)$ nm³, $Z = 4$. In addition, the interaction of the complex with DNA was also investigated *via* the ethidium bromide fluorescence displacement experiments by detecting the fluorescence intensity of the complex-EB-DNA mixture. CCDC: 859086.

Key Words: Cobalt(II) complex, 3,4-Dimethoxyphenylacetic acid, 4,4'-Bipyridine, Crystal structure, DNA binding.

INTRODUCTION

The design and synthesis of coordination complexes have been absorbed considerable attention due to their diversity structures with 4,4'-bipyridine linker¹⁻³ and hydrogen bond can also play an important role in forming motifs structures⁴⁻⁶. Divalent transition metal complexes were studied by some researchers⁷⁻⁹. Although mixed-ligand complexes of acid with phenanthroline and bipyridine or related ligands were prepared and well-characterized, metal complexes with other ligands are still rare¹⁰.

It is well-known that DNA is a useful target for many anticancer drugs and the effectiveness mainly depends on the mode and affinity of the binding between the drugs and DNA¹¹. It is reported that the transition metal complexes can interact non-covalently with nucleic acids and act as active anticancer drugs¹² in the mode of intercalation, groove binding or external electrostatic binding¹³⁻¹⁵, so the research concerning the interaction of transition metal complexes and DNA interested many researchers over the past decades¹⁶⁻¹⁸. In this paper, we report the synthesis, characterization, crystal structure and DNA binding properties of cobalt(II) complex $[\text{Co}(\text{DMAP})_2(\text{bipy})(\text{H}_2\text{O})_2]$.

EXPERIMENTAL

Basic Co(II) sulfate heptahydrate, 3,4-dimethoxyphenyl acetic acid, 4,4'-bipyridine, ethidium bromide and calf thymus DNA (CT-DNA), the other chemicals and reagents were of analytical reagent grade and were used without further purifi-

cation. *Tris*-(hydroxymethyl) aminomethane-HCl (*tris*-HCl) buffer was prepared using deionized and sonicated twice-distilled water. All the experiments regarding the binding and cleavage of DNA using the complex were carried out in *tris*-buffer (pH, 7.2).

The IR spectra were recorded on a Nicolet NEXUS 670 FT-IR spectrometer (4000-400 cm⁻¹) with KBr discs. Thermogravimetric analysis was carried out on a Mettler-Toledo TGA/SDTA 851° thermal analyzer in the range 30-800 °C at a heating rate of 10 °C/min under air condition. The fluorescence spectra were detected by a Perkin Elmer LS 55 fluorophotometer. X-ray diffraction was performed on a Bruker APEXII CCD diffractometer.

Syntheses: 3,4-Dimethoxyphenylacetic acid (0.392 g, 2 mmol) and 4,4'-bipyridine (0.312 g, 2 mmol) was added to a mixed solution of ethanol (30 mL) and water (15 mL) with $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$ (0.562 g, 2 mmol) under stirred conditions at room temperature. Some red single crystals suitable for X-ray structure analysis were obtained about 19 days later.

X-ray crystallography: A red block-like crystal of the complex with dimensions of 0.316 mm × 0.218 mm × 0.125 mm was used for structural determination. Diffraction data were collected on a Bruker APEXII CCD diffractometer by using graphite monochromated MoK_α radiation ($\lambda = 0.071073$ nm). The structure was solved by direct methods with SHELXS-97¹⁹ and refined on the F^2 by full-matrix least-squares method with SHELXL-97²⁰. All non-hydrogen atoms were refined anisotropically. The hydrogens on carbon were placed in calculated positions in the riding model approximation

and the H atoms of water were located in difference Fourier synthesis maps. Experimental details for X-ray data collection are presented in Table-1 and the selected bond lengths and angles are listed in Table-2. CCDC No. 859086 of the complex contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from the Cambridge crystallographic data centre.

TABLE-1
CRYSTALLOGRAPHIC DATA FOR 1

Formula	C ₃₀ H ₃₄ CoN ₂ O ₁₀
Formula weight	641.52
Temperature (K)	296(2)
Wavelength (nm)	0.071073
Crystal system	Monoclinic
Space group	C2/c
a (nm)	2.57437(9)
b (nm)	1.14108(4)
c (nm)	0.98716(3)
β (°)	92.683(2)
Volume (nm ³)	2.89667(17)
Z	4
Calculated density (g/cm ³)	1.471
Absorption coefficient (mm ⁻¹)	0.655
F(000)	1340
Crystal size (mm)	0.316 × 0.218 × 0.125
Theta range for data collection (°)	1.95 to 27.64
Limiting indices	-33 ≤ h ≤ 31, -14 ≤ k ≤ 14, -12 ≤ l ≤ 12
Reflections collected / unique	12972 / 3368 [R(int) = 0.0226]
Completeness to theta = 27.64 (%)	99.9
Max. and min. transmission	0.921 and 0.834
Refinement method	Full-matrix least-squares on F ²
Data / restraints / parameters	3368 / 0 / 197
Goodness-of-fit on F ²	1.033
Final R indices [I > 2σ(I)]	R1 = 0.0320, wR2 = 0.0874
R indices (all data)	R1 = 0.0389, wR2 = 0.0923
Largest diff. peak and hole (e.nm ⁻³)	402 and -266

TABLE-2
SELECTED BOND LENGTHS (nm) AND ANGLES (°)

Bond	Dist.	Bond	Dist.
Co(1)-O(1W)	0.20984(12)	C(7)-O(1)	0.1235(2)
Co(1)-O(1W) ⁱ	0.20984(12)	C(7)-O(2)	0.1270(2)
Co(1)-O(2) ⁱ	0.21048(11)	C(1)-N(1)	0.13353(19)
Co(1)-O(2)	0.21048(11)	N(2)-C(6)	0.13338(19)
Co(1)-N(2)	0.21570(18)	N(1)-C(1) ⁱ	0.13353(19)
Co(1)-N(1) ⁱⁱ	0.21800(18)	N(1)-Co(1) ⁱⁱⁱ	0.21800(18)
C(6)-N(2)	0.13338(19)		
Angle	(°)	Angle	(°)
O(1W)-Co(1)-O(1W) ⁱ	173.99(7)	N(2)-Co(1)-N(1) ⁱⁱⁱ	180.0
O(1W)-Co(1)-O(2) ⁱ	89.87(5)	N(2)-C(6)-C(5)	123.41(16)
O(1W) ⁱ -Co(1)-O(2) ⁱ	90.00(5)	O(1)-C(7)-O(2)	124.52(16)
O(1W)-Co(1)-O(2)	90.00(5)	O(1)-C(7)-C(8)	119.57(16)
O(1W) ⁱ -Co(1)-O(2)	89.87(5)	O(2)-C(7)-C(8)	115.83(16)
O(2) ⁱ -Co(1)-O(2)	177.54(6)	N(1)-C(1)-C(2)	123.21(16)
O(1W)-Co(1)-N(2)	93.00(3)	C(7)-O(2)-Co(1)	128.58(11)
O(1W) ⁱ -Co(1)-N(2)	93.00(3)	C(6)-N(2)-C(6) ⁱ	117.42(19)
O(2) ⁱ -Co(1)-N(2)	91.23(3)	C(6)-N(2)-Co(1)	121.29(10)
O(2)-Co(1)-N(2)	91.23(3)	C(6) ⁱ -N(2)-Co(1)	121.29(10)
O(1W)-Co(1)-N(1) ⁱⁱ	87.00(3)	C(1)-N(1)-C(1) ⁱ	117.14(19)
O(1W) ⁱ -Co(1)-N(1) ⁱⁱ	87.00(3)	C(1)-N(1)-Co(1) ⁱⁱⁱ	121.43(10)
O(2) ⁱ -Co(1)-N(1) ⁱⁱ	88.77(3)	C(1) ⁱ -N(1)-Co(1) ⁱⁱⁱ	121.43(10)
O(2)-Co(1)-N(1) ⁱⁱ	88.77(3)		

Symmetry codes: (i): -x+1,y,-z+3/2; (ii): x,y+1,z; (iii): x,y-1,z

RESULTS AND DISCUSSION

IR spectra: The appearance of two medium bands at 3286 cm⁻¹ for ν(OH) and 826 cm⁻¹ for δ(OH) suggest the presence of coordinated water in the complex. The weak peaks 3061 cm⁻¹ of the complex are assigned to the C-H stretching vibrations. The characteristic frequencies of the ν_{as} (-COO⁻) and ν_s (-COO⁻) are at 1606 and 1414 cm⁻¹, respectively. The conspicuous stretching vibrations of the hydroxyl disappear in spectra of the complex and the absorption frequency of carbonyl and C=N bonds significantly decrease. These data clearly show the formation of the complex, consistent with the results of the X-ray crystallography analyses.

Crystal structure of the complex: The structure of the complex is shown in Figs. 1 and 2, which shows that the cobalt(II) is octahedrally coordinated by two 3,4-dimethoxyphenylacetic anions, two bipy and two coordinated water molecules. The 4,4'-bipyridine ligand is a bridging ligand between two cobalt centres, which acts as a monodentate ligand *via* the N atom, while the ligand has one carboxylate groups, behaving as a monodentate site through the deprotonated O atom. The octahedral plane is built up by a pair of 3,4-dimethoxyphenylacetic anions using carboxylate oxygen atoms and by a pair of neutral 4,4'-bipyridine molecules using pyridine ring nitrogen atoms in trans positions. The axial positions are occupied by water molecules.

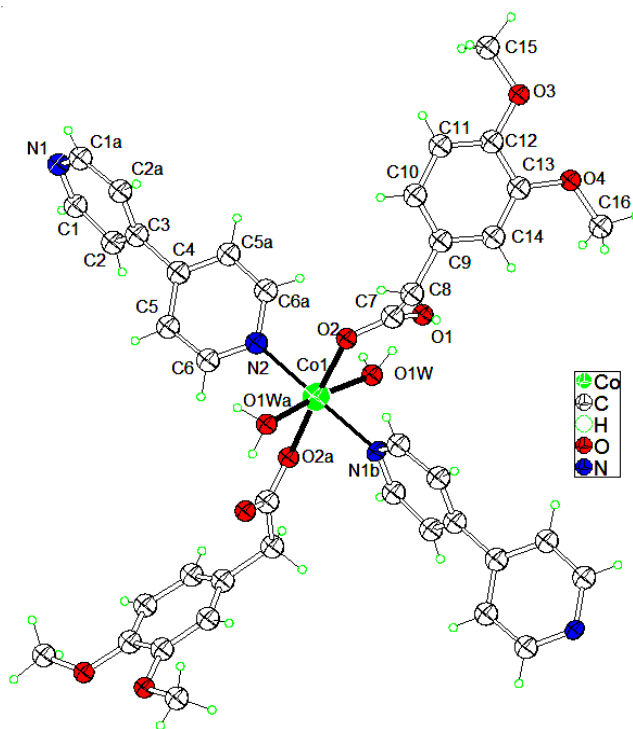


Fig. 1. Molecular structure of the title complex. Displacement ellipsoids are drawn at the 30% probability level

Intramolecular hydrogen bonding interactions involving an axial coordinated water molecule and disordered carboxylic oxygen atoms stabilize the molecular structure. The packing plot is shown in Fig. 3. The most significant forces contributing the formation and stabilization of the crystal packing are intermolecular interactions O-H...O hydrogen bonds and weak

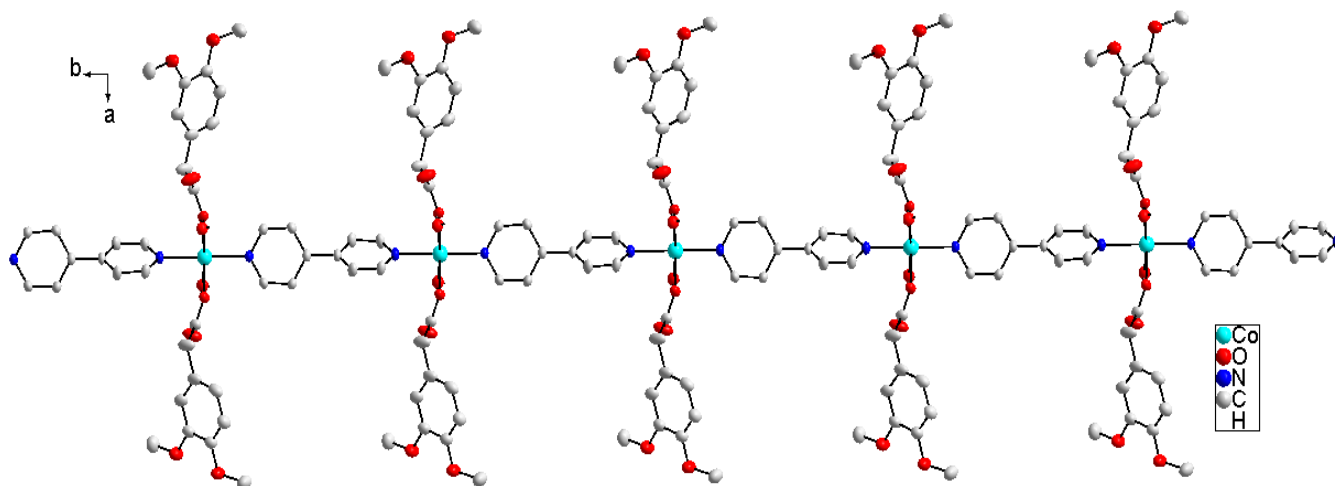


Fig. 2. A perspective view of the title compound along the c axis. H atoms have been omitted for clarity

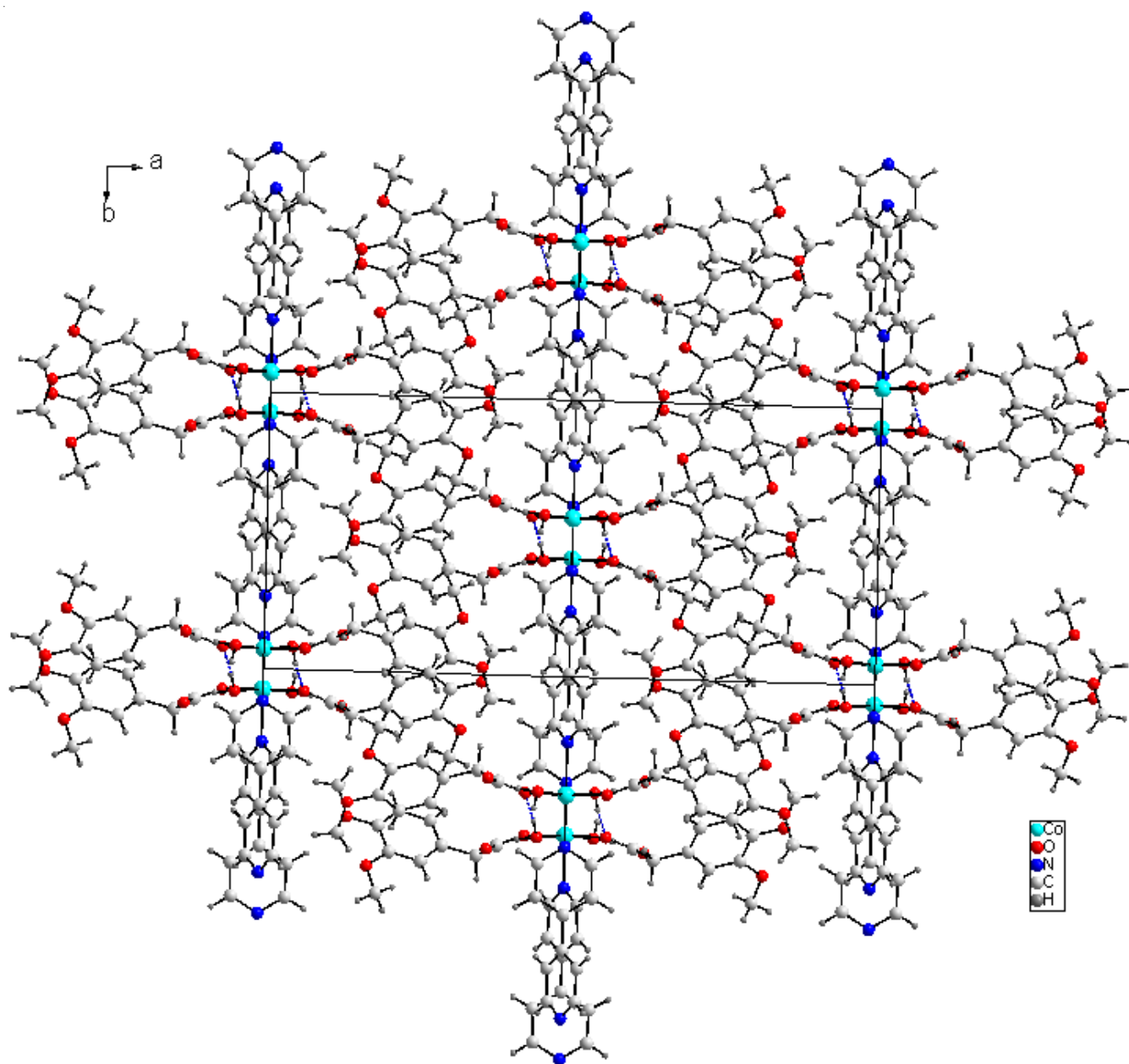


Fig. 3. Packing plot of the complex

π - π aromatic interactions from bipy molecules and aromatic rings of the ligands.

Thermal behaviour: The TG curve of the complex indicates that the thermal decomposition can be roughly divided into two stages (Fig. 4). The first step is dehydration with a weight loss of 5.57 %, which corresponds to the loss of two water molecules in the temperature range 101-136 °C (calcd. 5.61 %); the second step has a weight loss of 81.64 % in the range of 181-366 °C, corresponding to the loss of three ligands (calcd. 82.71%). The remaining mass of 11.93 % is corresponding to the residue CoO (calcd. 11.68 %).

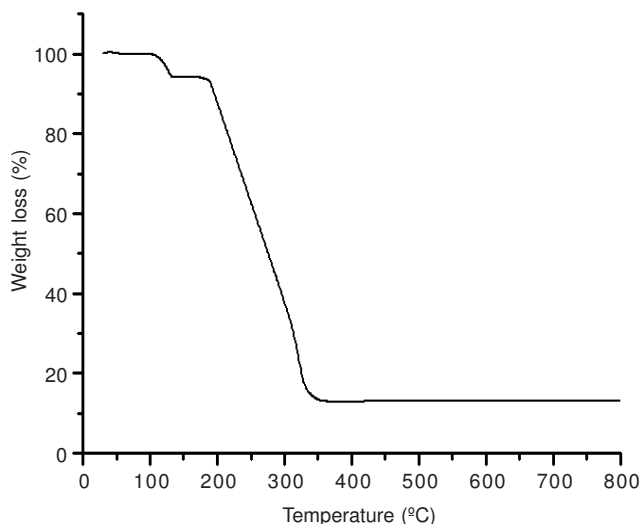


Fig. 4. TG curve of the complex

Spectroscopic studies of the interactions with DNA:

Fluorescence spectroscopic results are presented in Fig. 5, the fluorescence intensities of ethidium bromide bound to CT-DNA at 591 nm show remarkable decreasing trends with the increasing concentration of the complex, indicating that some ethidium bromide molecules are released into solution after the exchange with the complex which resulted in the fluorescence quenching of ethidium bromide. The quenching of ethidium bromide bound to DNA by the complex is in agreement with the linear Stern-Volmer equation: $I_0/I = 1 + K_{sq}r^{21}$, where I_0 and I represent the fluorescence intensities in the absence and presence of quencher, respectively. K_{sq} is a linear Stern-Volmer quenching constant, r is the ratio of the concentration of quencher and DNA. In the quenching plots (insets in Fig. 5) of I_0/I versus r , K_{sq} values are given by the slopes. The K_{sq} value for the complex is 0.8333.

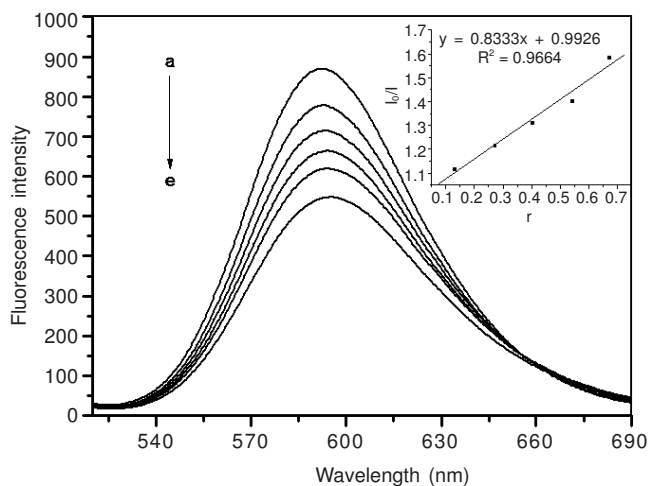


Fig. 5. Emission spectra of EB-DNA system in the absence and presence of the complex. $\lambda_{ex} = 251$ nm, $C_{EB} = 1.25 \times 10^{-7}$ mol L⁻¹, from a to e: $r = C_{complex}/C_{DNA} = 0, 0.13, 0.27, 0.40, 0.54, 0.67$, respectively

REFERENCES

- O. Castillo, J. Alonso, U. García-Couceiro, A. Luque and P. Román, *Inorg. Chem. Commun.*, **6**, 803 (2003).
- J.L. Manson and J.A. Schlueter, *Inorg. Chim. Acta.*, **357**, 3975 (2004).
- C. Biswas, S. Chattopadhyay, M.G.B. Drew and A. Ghosh, *Polyhedron*, **26**, 4411 (2007).
- W.-Y. Wan and E.J. Milner-White, *J. Mol. Biol.*, **286**, 1633 (1999).
- M.M. Babu, S.K. Singh and P. Balaran, *J. Mol. Biol.*, **322**, 871 (2002).
- D. Sun, N. Zhang, Q.-J. Xu, G.-G. Luo, R.-B. Huang and L.-S. Zheng, *J. Mol. Struct.*, **969**, 176 (2010).
- S.-M. Ying, J.-G. Mao, Y.-Q. Sun, H.-Y. Zeng and Z.-C. Dong, *Polyhedron*, **22**, 3097 (2003).
- N. Lah, I.K. Cigic and I. Leban, *Inorg. Chem. Commun.*, **6**, 1441 (2003).
- Z.-W. Yu, M.-H. He, W. Zhang and P. Sun, *Chin. J. Struct. Chem.*, **29**, 1301 (2010).
- H.-Q. Li, H.-D. Xian and G.-L. Zhao, *J. Rare. Earth*, **28**, 7 (2010).
- B.A. Chabner and T.G. Roberts, *Nat. Rev. Cancer*, **5**, 65 (2005).
- M. Navarro, E.J. Cisneros-Fajardo, A. Sierralta, M. Fernández-Mestre, P. Silva, D. Arrieche and E. Marchán, *J. Biol. Inorg. Chem.*, **8**, 401 (2003).
- L. Strekowski and B. Wilson, *Mutat. Res.*, **623**, 3 (2007).
- C.-Y. Zhou, J. Zhao, Y.-B. Wu, C.-X. Yin and P. Yang, *J. Inorg. Biochem.*, **101**, 10 (2007).
- F. Gao, H. Chao, F. Zhou, Y.-X. Yuan, B. Peng and L.-N. Ji, *J. Inorg. Biochem.*, **100**, 1487 (2006).
- Q.-Q. Zhang, F. Zhang, W.-G. Wang and X.-L. Wang, *J. Inorg. Biochem.*, **100**, 1344 (2006).
- R. Indumathy, S. Radhika, M. Kanthimathi, T. Weyhermuller and B.U. Nair, *J. Inorg. Biochem.*, **101**, 434 (2007).
- A. Arslantas, M. Sozmen and H. Necefoglu, *Asian J. Chem.*, **22**, 1709 (2010).
- G.M. Sheldrick, SHELXS-97. Program for the Solution of Crystal Structures. University of Göttingen, Germany (1997).
- G.M. Sheldrick, SHELXL-97. Program for the Refinement of Crystal Structures. University of Göttingen, Germany (1997).
- J.R. Lakowicz and G. Weber, *Biochemistry*, **12**, 4161 (1973).