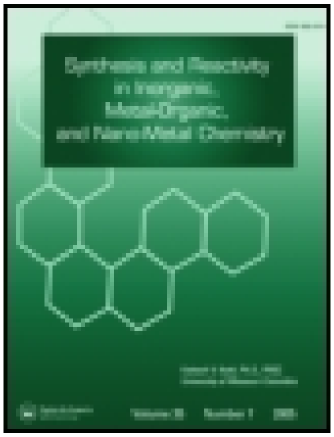
This article was downloaded by: [ECU Libraries]
On: 24 April 2015, At: 12:58
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



CrossMark

Click for updates

Synthesis and Reactivity in Inorganic, Metal-Organic, and Nano-Metal Chemistry
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lsrt20

# Synthesis, Crystal Structure and Biological Property of a Novel Dinuclear Copper(II) Complex

Chao Li[a], Xu-Feng Meng[a], Wei-Ning Li[a], Xin Zhou[a] & Jing-Jun Ma[a]
[a] College of Sciences, Agricultural University of Hebei, Baoding 071001, P. R. China

Accepted author version posted online: 18 Feb 2015.

To cite this article: Chao Li, Xu-Feng Meng, Wei-Ning Li, Xin Zhou & Jing-Jun Ma (2015): Synthesis, Crystal Structure and Biological Property of a Novel Dinuclear Copper(II) Complex, Synthesis and Reactivity in Inorganic, Metal-Organic, and Nano-Metal Chemistry, DOI: 10.1080/15533174.2014.963238

To link to this article: http://dx.doi.org/10.1080/15533174.2014.963238

Disclaimer: This is a version of an unedited manuscript that has been accepted for publication. As a service to authors and researchers we are providing this version of the accepted manuscript (AM). Copyediting, typesetting, and review of the resulting proof will be undertaken on this manuscript before final publication of the Version of Record (VoR). During production and pre-press, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal relate to this version also.

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

# Synthesis, Crystal Structure and Biological Property of a Novel Dinuclear Copper(II) Complex

**Chao Li, Xu-Feng Meng, Wei-Ning Li, Xin Zhou, Jing-Jun Ma***

*College of Sciences, Agricultural University of Hebei, Baoding 071001, P. R. China*

** Corresponding author. Email address: majingjun71@126.com*

## Abstract

The reaction of 2-acetylpyridine, cyclohexylamine and copper(II) perchlorate in methanol resulted in the dinuclear copper(II) complex $[Cu_2L_2]\cdot 2ClO_4$, where L is the monoanionic form of 1-methoxy-1,3-dipyridin-2-ylbutane-1,3-diol. The complex was characterized by elemental analysis and IR spectroscopic method in the solid state. Single crystal X-ray analysis was performed, which indicated that the complex possesses a crystallographic inversion center symmetry. The Cu atom in the complex is in a square pyramidal geometry. Thermal behavior and biological property on the bacteria strains *B. subtilis*, *E. coli*, and *S. aureus* of the complex were studied.

**Keywords** Copper complex, dinuclear complex, crystal structure, thermal behavior, antibacterial activity.

## INTRODUCTION

Transition metal complexes with various organic ligands have been reported to possess interesting biological properties, such as bacterial, antifungal and antitumor activities.[1-4] In general, the complexation of organic ligands with most transition metal atoms influences their antibacterial activities.[5-7] In recent years, copper complexes have been extensively used in antibacterial agents.[8-10] At this point of view and in continuation of work on the study of metal complexes, herein we report a novel dinuclear copper complex, $[Cu_2L_2]\cdot 2ClO_4$, where L is the monoanionic form of 1-methoxy-1,3-dipyridin-2-ylbutane-1,3-diol.

## EXPERIMENTAL

### Materials and Methods

2-Acetylpyridine and cyclohexylamine were purchased from Merck and Fluka, and used as received. Copper perchlorate was prepared by the reaction of basic cupric carbonate with perchloric acid in aqueous solution. All other chemicals and solvents used in this work are of analytical grade available commercially and used without further purification. Elemental analyses (carbon, hydrogen and nitrogen) of the complex were obtained from a Carlo ERBA Model EA 1108 analyzer. Infrared spectrum was performed by using a KBr pellet on a Jasco-5300 FT-IR spectrophotometer. Solution electrical conductivity was measured with a DDS-11A conductivity meter.

### Synthesis of $[Cu_2L_2]\cdot 2ClO_4$

2-Acetylpyridine (0.01 mol, 1.21 g) and cyclohexylamine (0.01 mol, 0.99 g) were reacted in methanol (15 mL) at room temperature for 30 min. Then, copper perchlorate (0.01 mol, 3.88 g) and $NH_4BF_4$ (0.01 mol, 1.05 g) in methanol (10 mL) were added slowly to the above stirred solution. The final mixture was stirred at room temperature for another 30 min to give a blue solution. The solution was filtered to remove some microdirty, and left to slow evaporate in air. A few days later, small block-shaped single crystals were obtained. Yield: 2.75 g (63%). Anal. Calcd. for $C_{15}H_{17}ClCuN_2O_7$ (%): C, 41.29; H, 3.93; N, 6.42. Found: C, 41.13; H, 4.02; N, 6.55. IR data ($cm^{-1}$, KBr): 3391, 1609, 1571, 1491, 1474, 1445, 1376, 1218, 1097, 863, 783, 757, 623, 553, 525, 479, 429, 345.

### X-ray Crystallography

A well-shaped X-ray quality crystal of the complex was pick up under a microscope and investigated in a diffraction experiment at 298(2) K on a Bruker Apex II diffractometer with monochromated Mo KŬ radiation ($\lambda$ = 0.71073 Å) obtained from a graded multilayer X-ray optics. The structure was solved by direct method with SHELXS-97,[11] and refined with full-matrix least-squares techniques on $F^2$ with SHELXL-97.[11] The C- and O-bonded hydrogen atoms were calculated in an idealized geometry, riding on their parent atoms, with distances restrained to 0.93ï 0.97 Å for Cï H and 0.93 Å for Oï H. The perchlorate anion is disordered over two sites with occupancies of 0.64(2) and 0.36(2). The crystal data and refinement parameters are listed in Table 1.

### Antibacterial Assay

The antibacterial activities were tested against *B. subtilis*, *E. coli*, and *S. aureus* using Mueller-Hinton medium. The MICs (minimum inhibitory concentrations) of the test compounds were determined by a colorimetric method using the dye MTT [3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide]. A stock solution of the synthesized compound (50 εg $mL^{-1}$) in

DMSO was prepared and quantities of the test compounds were incorporated in specified quantity of sterilized liquid Mueller-Hinton medium. A specified quantity of the medium containing the compound was poured into microtitration plates. A suspension of the microorganism was prepared to contain approximately $10^5$ cfu $mL^{-1}$ and applied to microtitration plates with serially diluted compounds in DMSO to be tested and incubated at 37 °C for 24 h. After the MICs were visually determined on each of the microtitration plates, 50 εL of PBS (phosphate buffered saline 0.01 mol $L^{-1}$, pH 7.4: $Na_2HPO_4 \cdot 12H_2O$ 2.9 g, $KH_2PO_4$ 0.2 g, NaCl 8.0 g, KCl 0.2 g, distilled water 1000 mL) containing 2 mg of MTT/mL was added to each well. Incubation was continued at room temperature for 4-5 h. The content of each well was removed and 100 εL of isopropanol containing 5% 1 mol $L^{-1}$ HCl was added to extract the dye. After 12 h of incubation at room temperature, the optical density (OD) was measured with a microplate reader at 550 nm. The antibiotics kanamycin and penicillin were used as standard drugs. The observed MIC values are given in Table 3.

## RESULTS AND DISCUSSION

### Synthesis and Characterization

Massa and coworkers reported a mononuclear copper(II) complex with the Schiff base ligand derived from pyridine-2-carbaldehyde with cyclohexylamine.[12] In the present work, we used 2-acetylpyridine and cyclohexylamine as the starting material, to form a Schiff base ligand cyclohexyl-(1-pyridin-2-ylethylidene)amine. The Schiff base ligand was further reacted with copper perchlorate in the presence of $NH_4BF_4$. To our surprise, the ligand transferred to 1-methoxy-1,3-dipyridin-2-ylbutane-1,3-diol during the reaction and crystallization. The complex was obtained as single crystals, stable in air and soluble in polar organic solvents such as ethanol, methanol, DMF, and DMSO. Elemental analyses of the complex are consistent with the general molecular formula proposed by single crystal X-ray determination. The molar conductivity of the complex in absolute methanolic solution confirms the 1:1 electrically nature.[13]

**Description of the Crystal Structure of the Complex**

Figure 1 gives the ORTEP diagram with atomic labeling scheme of the complex. Selected bond lengths and angles are given in Table 2. The complex possesses a crystallographic inversion center symmetry, and the asymmetric unit of the complex contains a dinuclear copper complex cation and two disordered perchlorate anions. The Cu···Cu distance is 2.985(1) Å. In the complex cation, two of the monoanionic four-dentate ligands wrap the Cu atoms with coordination of two pyridine nitrogen atoms and two oxygen atoms in a distorted square pyramidal coordination, which is proved by the Űreference (Ű= 0.24).[14] One phenolic hydroxyl is deprotonated on complexation, and acts as a bridging group, while the other one is kept in neutral. The distortion of the square pyramidal coordination mainly comes from the tensile force of the four-membered chelate ring Cu1-O6-Cu1A-O6A and five-membered chelate rings Cu1-N2-C1-C6-O7 and Cu1-N3A-C10A-C9A-O6A. The apical O7 atom forms coordinate bond angles in the range of 76.0(1)-108.5(2)° with the basal donor atoms N2, N3, O6 and O6A. The two *trans* angles in the basal plane of the square pyramidal coordination differ by 8.0(2) and 22.5(2)° from the ideal values. The coordinate bond values are with normal ranges as compared to other similar copper(II) complexes.[15-18]

The molecular packing structure of the complex is shown in Figure 2. The perchlorate anions are linked to the complex cations through intermolecular O7ï H7D···O1 hydrogen bonds [O7ï

H7D = 0.93 Å, H7D···O1$^{\#1}$ = 2.28 Å, O7···O1$^{\#1}$ = 2.89(1) Å, O7ï H7D···O1$^{\#1}$ = 123°; symmetry code for #1: 1 ï *x*, ï *y*, 1 ï *z*].

## Thermal Behavior

Thermogravimetric analysis of the complex was carried out in the temperature range 50ï 800 °C at a heating rate of 10 °C min$^{-1}$. The TG curve of the complex is given following degradation scheme (Figure 3). The complex decomposes from 180 °C to 520 °C. The final residue is CuO. The observed residue of 16.5% is close to the calculated value of 18.0%.

## Antibacterial Activity

From Table 3, the copper complex has medium activity against *E. coli,* and strong activities against *B. subtilis* and *S. aureus*. Especially for *S. aureus*, the complex has even stronger activity than the reference drugs Penicillin and Kanamycin. The complex has stronger activity against *E. coli* than Penicillin, but weaker than Kanamycin. As for *B. subtilis*, the activity of the complex is slightly weaker than the two reference drugs.

## CONCLUSIONS

A novel dinuclear copper(II) complex was synthesized by the reaction of 2-acetylpyridine, cyclohexylamine, copper perchlorate and $NH_4BF_4$ in methanol at room temperature. The ligand underwent an interesting transformation. The reaction mechanism may be further studied by organic and catalytic researchers. The complex has effective antibacterial activities on the strains *B. subtilis*, *E. coli*, and *S. aureus*.

## ACKNOWLEDGMENTS

The authors are grateful to Hebei Key Laboratory of Bioinorganic Chemistry and College of Sciences of Agricultural University of Hebei for financial support.

## SUPPLEMENTARY MATERIAL

CCDC 980234 contains the supplementary crystallographic data for the complex. The data can be obtained free of charge *via* http://www.ccdc.cam.ac.uk/conts/retrieving.html, or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; or e-mail: deposit@ccdc.cam.ac.uk.

## REFERENCES

1. Siddiqi, Z.A.; Khalid, M.; Kumar, S.; Shahid, M.; Noor, S. Antimicrobial and SOD activities of novel transition metal complexes of pyridine-2,6-dicarboxylic acid containing 4-picoline as auxiliary ligand. *Eur. J. Med. Chem.* **2010**, *45*, 264-269.
2. Tumer, M.; Koksal, H.; Sener, M.K.; Serin, S. Antimicrobial activity studies of the binuclear metal complexes derived from tridentate Schiff base ligands. *Transition Met. Chem.* **1999**, *24*, 414-420.
3. Singh, D.P.; Kumar, K.; Sharma, C. Antimicrobial active macrocyclic complexes of Cr(III), Mn(III) and Fe(III) with their spectroscopic approach. *Eur. J Med. Chem.* **2009**, *44*, 3299-3304.
4. Patil, S.; Claffey, J.; Deally, A.; Hogan, M.; Gleeson, B.; Mendez, L.M.M.; Muller-Bunz, H.; Paradisi, F.; Tacke, M. Synthesis, cytotoxicity and antibacterial studies of *p*-methoxybenzyl-substituted and benzyl-substituted *N*-heterocyclic carbeneï silver complexes. *Eur. J. Inorg. Chem.* **2010**, 1020-1031.
5. Singh, N.P.; Srivastava, A.N. Synthesis, characterization and antimicrobial studies of novel binuclear transition metal complexes of Schiff base derived from 1-amino-5-methyl-2,6-pyrimidine-dione and 2,3-butanedione. *Asian J. Chem.* **2013**, *25*, 533-537.
6. Shaabani, B.; Khandar, A.A.; Dusek, M.; Pojarova, M.; Mahmoudi, F. Synthesis, crystal structure, antimicrobial activity and electrochemistry study of chromium(III) and copper(II) complexes based on semicarbazone Schiff base and azide ligands. *Inorg. Chim. Acta* **2013**, *394*, 563-568.

7. Singh, K.; Kumar, Y.; Puri, P.; Kumar, M.; Sharma, C. Cobalt, nickel, copper and zinc complexes with 1,3-diphenyl-1H-pyrazole-4-carboxaldehyde Schiff bases: Antimicrobial, spectroscopic, thermal and fluorescence studies. *Eur. J. Med. Chem.* **2012**, *52*, 313-321.
8. Liu, Z.-C.; Wang, B.-D.; Yang, Z.-Y.; Li, Y.; Qin, D.-D.; Li, T.-R. Synthesis, crystal structure, DNA interaction and antioxidant activities of two novel water-soluble Cu(2þ) complexes derivated from 2-oxo-quinoline-3-carbaldehyde Schiff-bases. *Eur. J. Med. Chem.* **2009**, *44*, 4477-4484.
9. Dhanaraj, C.J.; Nair, M.S. Synthesis, characterization, and antimicrobial studies of some Schiff-base metal(II) complexes. *J. Coord. Chem.* **2009**, *62*, 4018-4028.
10. Valent, A.; Milnik, M.; Hudecova, D.; Dudova, B.; Kivekas, R.; Sundberg, M.R. Copper(II) salicylideneglycinate complexes as potential antimicrobial agents. *Inorg. Chim. Acta* **2002**, *340*, 15-20.
11. Sheldrick, G.M. A short history of SHELX. *Acta Crystallogr.* **2008**, *A64*, 112-122.
12. Massa, W.; Dehghanpour, S.; Jahani, K. Structure-dependent spectroscopic and redox properties of copper(I) complexes with bidentate iminopyridine ligands. *Inorg. Chim. Acta* **2009**, *362*, 2872-2878.
13. Geary, W.J. Use of conductivity measurements in organic solvents for characterisation of coordination compounds. *Coord. Chem. Rev.* **1971**, *7*, 81-122.
14. Addison, A.W.; Rao, T.N.; Reedijk, J.; van Rijn, J.; Verschoor, G.C. Synthesis, structure, and spectroscopic properties of copper(II) compounds containing nitrogenï sulphur donor ligands; the crystal and molecular structure of aqua[1,7-bis(N-methylbenzimidazol-2-yl)-2,6-dithiaheptane]copper(II) perchlorate. *J. Chem. Soc., Dalton Trans.* **1984**, *7*, 1349-1356.

15. Li, Y.-M.; Zhang, J.-J.; Fu, R.-B.; Xiang, S.-C.; Sheng, T.-L.; Yuan, D.-Q.; Huang, X.-H.; Wu, X.-T. Three new cubane-like transition metal complexes of di-2-pyridyl ketone in gem-diol form: Syntheses, crystal structures and properties. *Polyhedron* **2006**, *25*, 1618-1624.
16. Telfer, S.G.; Parker, N.D.; Kuroda, R.; Harada, T.; Lefebvre, J.; Leznoff, D.B. Helicates, boxes, and polymers from simple pyridine-alcohol ligands: the impact of the identity of the transition metal ion. *Inorg. Chem.* **2008**, *47*, 209-218.
17. Boudalis, A.K.; Raptopoulou, C.P.; Psycharis, V.; Abarca, B.; Ballesteros, R. Ferromagnetism in $Cu^{II}_4$ and $Co^{II}_4$ complexes derived from metal-assisted solvolysis of di-2,6-(2-pyridylcarbonyl)pyridine: Syntheses, structures, and magnetic properties. *Eur. J. Inorg. Chem.* **2008**, 3796-3781.
18. Georgopoulou, A.N.; Raptopoulou, C.P.; Psycharis, V.; Ballesteros, R.; Abarca, B.; Boudalis, A.K. Ferromagnetic $Cu(II)_4$, $Co(II)_4$, and $Ni(II)_6$ azido complexes derived from metal-assisted methanolysis of di-2,6-(2-pyridylcarbonyl)pyridine. *Inorg. Chem.* **2009**, *48*, 3167-3176.

Table 1. Crystallographic data for the complex

| | |
|---|---|
| Chemical formula | $C_{15}H_{17}ClCuN_2O_7$ |
| Formula weight | 436.3 |
| Crystal system | Monoclinic |
| Space group | $P2_1/n$ |
| Unit cell dimensions | |
| $a$ (Å) | 10.315(2) |
| $b$ (Å) | 12.416(2) |
| $c$ (Å) | 13.964(2) |
| $\beta$ (°) | 97.494(2) |
| V (Å$^3$) | 1773.2(6) |
| Z | 4 |
| $\rho$ (g cm$^{-3}$) | 1.634 |
| $\mu$ (mm$^{-1}$) | 1.423 |
| $T_{\min}$, $T_{\max}$ | 0.7838, 0.7940 |
| Reflections collected | 9371 |
| Reflections unique | 3466 |
| Reflections observed [$I > 2\sigma(I)$] | 2339 |
| Parameters | 274 |
| Restraints | 101 |
| $R_1$, $wR_2$ [$I > 2\sigma(I)$] | 0.0518, 0.1383 |
| $R_1$, $wR_2$ (all data) | 0.0847, 0.1549 |

| | |
|---|---|
| Goodness-of-fit on $F^2$ | 1.045 |
| Highest peak and deepest hole (e Å$^{-3}$) | 0.667, ï 0.612 |

Table 2. Selected bond lengths (Å) and angles (°) for the complex

| | | | |
|---|---|---|---|
| Bond lengths (Å) | | | |
| Cu1ï O6A | 1.904(3) | Cu1ï O6 | 1.948(3) |
| Cu1ï N3A | 1.973(4) | Cu1ï N2 | 1.978(4) |
| Cu1ï O7 | 2.238(3) | | |
| Bond angles (°) | | | |
| O6ï Cu1ï O6A | 78.43(14) | O6Aï Cu1ï N3A | 81.87(15) |
| O6ï Cu1ï N3A | 157.55(15) | O6ï Cu1ï N2A | 172.04(16) |
| O6ï Cu1ï N2 | 93.85(15) | N3ï Cu1ï N2A | 106.07(17) |
| O6ï Cu1ï O7A | 101.24(13) | O6ï Cu1ï O7 | 85.99(13) |
| N3ï Cu1ï O7A | 108.48(15) | N2ï Cu1ï O7 | 76.04(14) |

Symmetry code for A: 1 ï *x*, ï *y*, 1 ï *z*.

Table 3. MIC values (ε g mL$^{-1}$) of the tested compounds

| | *B. subtilis* | *E. coli* | *S. aureus* |
|---|---|---|---|
| The complex | 1.56 | 12.5 | 0.78 |
| Penicillin | 0.78 | >100 | 3.13 |
| Kanamycin | 0.39 | 6.25 | 1.56 |

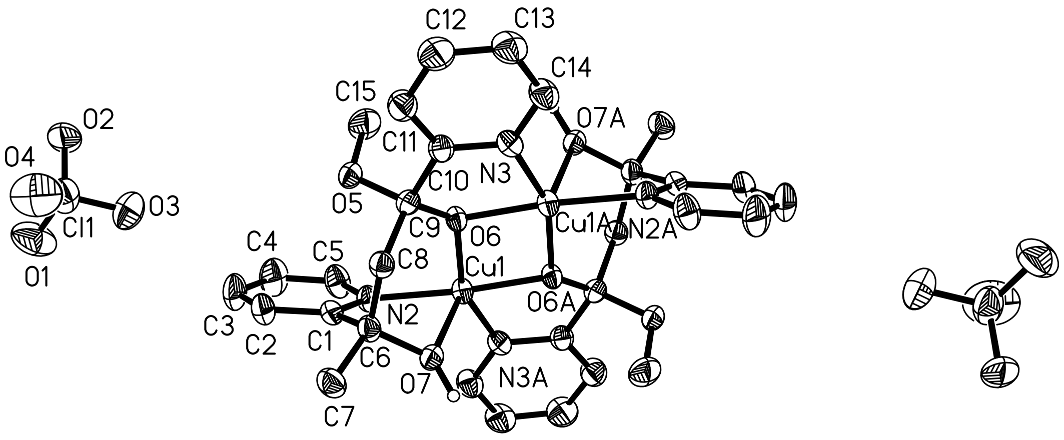


Figure 1. Molecular structure of the complex with the atom labeling scheme. All non-hydrogen atoms are represented at 30% probability thermal ellipsoids. Only the major components of the disordered perchlorate anions are shown.

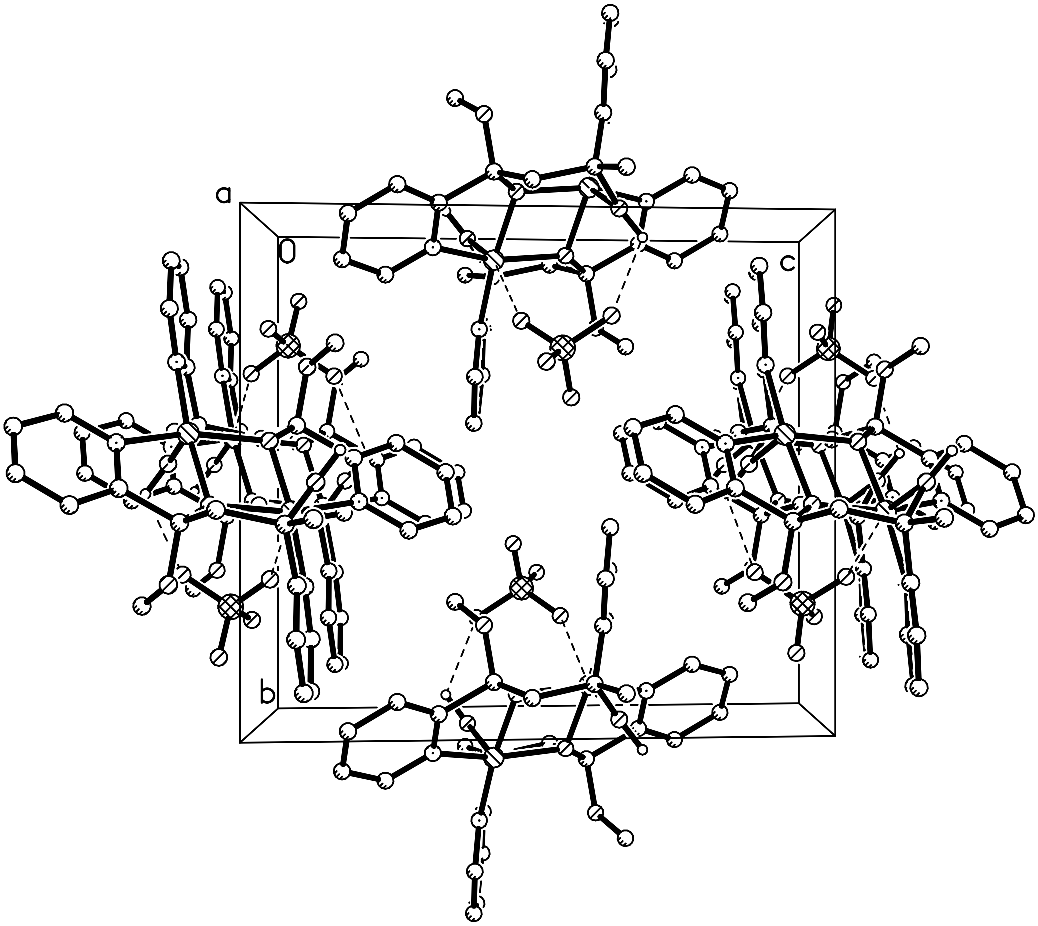


Figure 2. Packing structure of the complex. Hydrogen bonds are shown as thin dashed lines.

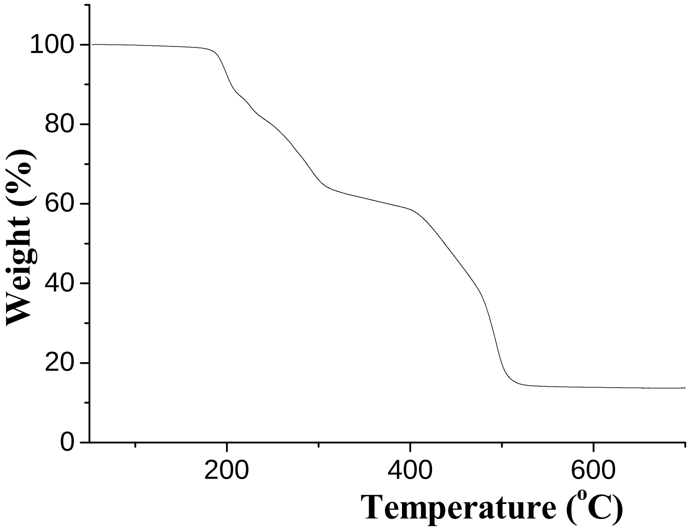


Figure 3. DT curve of the complex.