

A novel chloride and dicyanamide bridged multinuclear copper(I/II) complex derived from N'-(pyridin-2-ylmethylene)benzohydrazide: Crystal structure and antibacterial activity

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Abstract

A novel mixed-valence copper(I/II) coordination complex, $[\text{Cu}^{\text{II}}_2\text{Cu}^{\text{I}}_2(\mu_2\text{-Cl})_2(\mu_{1,5}\text{-dca})_2\text{L}_2]$ (HL = *N'*-(pyridin-2-ylmethylene)benzohydrazide; dca = dicyanamide), has been synthesized and structurally characterized. Single-crystal X-ray diffraction analysis reveals that the complex represents a rare hydrazone-based multinuclear copper assembly featuring the simultaneous incorporation of chloride and dicyanamide bridges. The Cu(II) centers exhibit distorted square-pyramidal coordination geometries, while the Cu(I) centers adopt triangular coordination environments. The μ_2 -chloride bridges generate compact Cu_2 units, and the $\mu_{1,5}$ -dicyanamide ligands further connect the copper centers, resulting in an extended one-dimensional coordination framework. The cooperative bridging strategy of inorganic chloride and nitrogen-rich dicyanamide ligands provides an effective approach for constructing robust mixed-valence copper architectures. Furthermore, the complex exhibits enhanced antibacterial activity compared with the free hydrazone ligand, showing inhibitory effects against several bacterial strains with minimum inhibitory concentration values in the micromolar range. This work highlights the potential of combining multifunctional hydrazone ligands with mixed bridging modes for the development of novel copper coordination materials with biological applications.

Introduction

The rapid emergence of multidrug-resistant bacterial pathogens has significantly reduced the effectiveness of conventional antibiotics, highlighting the necessity of developing alternative antibacterial agents. In recent years, transition metal complexes have attracted increasing attention as potential antimicrobial materials owing to their versatile molecular structures, stable coordination frameworks, and superior bioactivities compared with their corresponding organic precursors [1]. Among various metal-based systems, copper complexes have been extensively studied due to the interesting antibacterial, antifungal, anticancer, and antioxidant potential [2–4].

Schiff bases represent an important class of multifunctional ligands in coordination chemistry because of their facile synthesis, structural diversity, and excellent coordination ability toward transition metal ions [5,6]. As a crucial subclass of Schiff base compounds, hydrazones containing characteristic –CONH–N=CH– moiety have received great interest due to their diverse coordination modes and intrinsic biological activities including antibacterial, antioxidant, anticancer, and enzyme inhibitory effects [7,8].

Copper complexes incorporating Schiff bases or hydrazones as ligands have been widely explored and their biological performance has been shown to be closely related to the coordination environment, ligand framework, nuclearity, and supramolecular organization of the resulting architectures [9,10]. The rational manipulation of bridging ligands and coordination modes provides an effective approach for constructing copper assemblies with diverse structural features and potential bioactivity [11,12].

Among various bridging ligands, dicyanamide (dca, $\text{N}(\text{CN})_2$) has emerged as a versatile building block in coordination chemistry owing to its multiple coordination modes and remarkable ability to assemble metal centers into extended architectures [13]. Depending on the coordination behavior of dca, metal complexes can exhibit a wide range of structural motifs, including discrete polynuclear species, one-dimensional chains, two-dimensional layers, and three-dimensional frameworks [14,15]. In addition, halide ions, particularly chloride, can act as efficient bridging groups to stabilize multinuclear copper assemblies through μ -chloro interactions [16,17]. Copper coordination compounds containing either dicyanamide or chloride bridges have been extensively reported; however, copper complexes simultaneously incorporating hydrazone ligands together with dual chloride and dicyanamide bridging motifs remain largely unexplored. The combination of these two bridging modes may provide a promising strategy for constructing multinuclear copper architectures with enhanced structural rigidity and unique electronic communication between metal centers.

In this work, a novel mixed-valence copper complex, $[\text{Cu}^{\text{II}}_2\text{Cu}_2^{\text{I}}(\mu_2\text{-Cl})_2(\mu_{1,5}\text{-dca})_2\text{L}_2]$, was successfully synthesized using the hydrazone ligand *N'*-(pyridin-2-ylmethylene)benzohydrazide (HL). The complex features a rare dual-bridged coordination framework constructed by the simultaneous incorporation of chloride and dicyanamide bridges. The synthesis, single-crystal structure, spectroscopic characterization, and antibacterial properties of the resulting copper assembly were investigated.

Experimental

Materials and measurements

All reagents and solvents were of analytical grade and used as received without further purification. 2-Pyridinecarboxaldehyde and benzohydrazide were purchased from Macklin Chemical Co., Ltd. Copper(II) chloride dihydrate and sodium dicyanamide were obtained from Aladdin Chemical Co., Ltd.

Elemental analyses of carbon, hydrogen, and nitrogen were carried out on a Perkin–Elmer 240C elemental analyzer. Fourier-transform infrared (FT-IR) spectra were recorded using a Nicolet AVATAR 360 spectrophotometer with KBr pellets in the range of $4000\text{--}400\text{ cm}^{-1}$. Electronic absorption spectra were measured on a Lambda 35 UV–vis spectrophotometer. Molar conductivity measurements were performed using a DDS-11A conductivity meter. The ^1H NMR and ^{13}C NMR spectra were recorded on a Bruker 500 MHz NMR spectrometer. Single-crystal X-ray diffraction data for the complex were collected on a Bruker APEX II CCD diffractometer.

Synthesis of *N'*-(pyridin-2-ylmethylene)benzohydrazide (HL)

2-Pyridinecarboxaldehyde (0.010 mol, 1.07 g) was diluted by 30 mL ethanol, to which was added dropwise an ethanolic solution (20 mL) of benzohydrazide (0.010 mol, 1.36 g) with stirring under reflux for 30 min. The solvent was removed by distillation under reduced pressure. The colorless solid was recrystallized from ethanol to obtain crystalline product. Yield: 2.11 g (94%). Elemental analysis (%)

calculated for $C_{13}H_{11}N_3O$: calcd.: C, 69.32; H, 4.92; N 18.66%; found: C, 69.13; H, 5.01; N, 18.55%. ^1H NMR (500 MHz, $CDCl_3$): δ 15.45 (s, 1H, NH), 8.77 (d, 1H, PyH), 8.02 (d, 2H, ArH), 7.95 (d, 1H, PyH), 7.59 (m, 2H, ArH), 7.54 (m, 3H, PyH), 7.41 (s, 1H, CH = N). ^{13}C NMR (126 MHz, $CDCl_3$): δ 164.20, 152.09, 147.60, 137.83, 137.37, 132.83, 131.59, 128.67, 127.24, 125.37, 123.47.

Synthesis of the complex

A mixture of HL (0.10 mmol, 23 mg) and $CuCl_2 \cdot 2H_2O$ (0.20 mmol, 34 mg) was dissolved in ethanol (20 mL) and stirred at room temperature for 30 min. Subsequently, a mixed aqueous/ethanolic solution (V/V = 1:1) of sodium dicyanamide (0.20 mmol, 18 mg) was added slowly to the reaction mixture under continuous stirring. The resulting solution was further stirred at room temperature for 2 h to facilitate the coordination assembly process. After filtration, the clear filtrate was allowed to evaporate slowly at room temperature. After 5 days, well-developed deep-brown prism-shaped single crystals suitable for X-ray diffraction analysis were obtained. The crystals were collected by filtration, washed with ethanol, and dried in air. Yield: 26 mg (57% based on Cu). Elemental analysis (%) calculated for $C_{15}H_{10}ClCu_2N_6O$: calcd.: C, 39.79; H, 2.23; N 18.56%; found: C, 39.92; H, 2.17; N, 18.43%.

Crystal structure determination

Single crystals of the complex suitable for X-ray diffraction analysis were selected and mounted on on a glass fiber of Bruker APEX II CCD area-detector diffractometer equipped with a fine-focus sealed tube and graphite-monochromated Mo K α radiation ($\lambda = 0.71073 \text{ \AA}$). Data were collected at 298(2) K and corrected for Lorentz and polarization effects, as well as linear decay. A multi-scan absorption correction based on ω -scan data was applied. The diffraction data were processed using SMART and SAINT programs [18]. The crystal structure was solved by direct methods and refined by full-matrix least-squares calculations based on F^2 using SHELXL with successive difference Fourier syntheses [19]. All non-hydrogen atoms were refined with anisotropic displacement parameters, whereas hydrogen atoms were introduced at calculated positions and refined using the riding model. Selected crystallographic data and refinement parameters are summarized in Table 1.

Table 1
Crystallographic and experimental data for the complex

Formula	$C_{15}H_{10}ClCu_2N_6O$	Z	4
Formula Weight	452.82	$D_c / (g/cm^{-3})$	1.830
Crystal shape/color	Block/deep brown	μ / mm^{-1}	2.766
Crystal size/mm ³	0.33·0.31·0.28	$F(000)$	900
Crystal system	Monoclinic	θ range/°	1.34–25.50
Space group	$P2_1/c$	Reflections	9419
$a / \text{\AA}$	16.300(2)	Unique reflections	3055
$b / \text{\AA}$	7.595(1)	Observed reflections ($I \geq 2\sigma(I)$)	2445
$c / \text{\AA}$	14.216(2)	Parameters	226
$\alpha / ^\circ$	90	Restraints	0
$\beta / ^\circ$	110.942(2)	Goodness-of-fit on F^2	1.089
$\gamma / ^\circ$	90	$R_1, wR_2 [I \geq 2\sigma(I)]$	0.0374, 0.1097
$V / \text{\AA}^3$	1643.6(3)	R_1, wR_2 (all data)	0.0488, 0.1250

Antimicrobial assay

The antibacterial activities of the compounds were tested against *B. subtilis*, *S. aureus*, *E. coli* and *P. fluorescens* using MH (Mueller–Hinton) medium. The MIC values of the tested compounds were determined by a colorimetric method using the dye MTT [20]. A stock solution of the compounds (150 μM) in DMSO was prepared and graded quantities (75 μM , 37.5 μM , 18.8 μM , 9.4 μM , 4.7 μM , 2.3 μM , 1.2 μM , 0.59 μM) of the tested compounds were incorporated in specified quantity of the corresponding sterilized liquid medium. A specified quantity of the medium containing the compounds was poured into micro-titration plates. Suspension of the microorganism was prepared to contain approximately 10^5 cfu mL^{-1} and applied to micro-titration plates with serially diluted compounds in DMSO to be tested and incubated at 37°C for 24 h and 48 h for bacteria and fungi, respectively. 50 μL of PBS (phosphate buffered saline 0.01 M, pH = 7.4) containing 2 mg of MTT mL^{-1} was added to each well. Incubation was continued at room temperature for 4–5 h. The content of each well was removed, and 100 μL of isopropanol containing 5% 1 M HCl was added to extract the dye. The MIC values were visually determined on each of the micro-titration plates.

Results and discussion

Chemistry

The hydrazone ligand HL was prepared by condensation of equimolar amounts of 2-pyridinecarboxaldehyde and benzohydrazide in ethanol. In the ^1H NMR spectrum of HL, the resonance at $\delta = 15.45$ ppm appears as a singlet and is assigned to the N–H proton, while the singlet at $\delta = 4.41$ ppm corresponds to the azomethine ($-\text{CH}=\text{N}-$) proton. The aromatic protons of the pyridyl and phenyl rings are observed in the range of $\delta = 8.77\text{--}7.54$ ppm.

The formation of the copper complex is mainly governed by the cooperative coordination ability of the aroylhydrazone ligand together with the bridging chloride and dicyanamide (dca) anions. During the self-assembly process, the Cu centers are chelated by the N/O donor atoms of L, whereas chloride and dca ions serve as bridging units to connect adjacent metal centers, ultimately leading to the construction of a multinuclear copper framework (Scheme 1). Notably, partial reduction of Cu(II) to Cu(I) occurs spontaneously during the reaction of CuCl_2 , sodium dicyanamide, and HL in the absence of any external reducing agent. This redox transformation may be attributed to the redox-active hydrazone moiety containing the $-\text{NH}-\text{N}=\text{}$ fragment, which can facilitate ligand-to-metal single-electron transfer upon coordination with Cu(II) ions. In contrast, the dca anion remains electrochemically inactive under these conditions and primarily acts as a linear bridging ligand, contributing to the stabilization and extension of the mixed-valence Cu(I)/Cu(II) coordination framework.

Compared with previously reported copper complexes containing analogous hydrazone ligands, in which chloride or dca anions generally function independently as bridging species, the present complex features an unusual synergistic bridging mode involving the simultaneous participation of both chloride and dca ligands. This distinctive structural characteristic highlights the effectiveness of combining inorganic halide ions with nitrogen-rich pseudohalide ligands for the construction of novel multinuclear copper architectures.

The molar conductivity measurement of the complex was carried out in a 10^{-3} mol L^{-1} DMSO/ H_2O solution (V:V = 1:99). The observed conductivity value of $25 \Omega^{-1} \text{ cm}^2 \text{ mol}^{-1}$ indicates that the complex behaves as a non-electrolyte in solution [21].

Crystal structure description

The molecular structure of the complex is depicted in Fig. 1, and selected bond lengths and angles are summarized in Table 2. Single-crystal X-ray diffraction analysis reveals that the complex crystallizes in the monoclinic space group $P2_1/c$. The structure consists of a mixed-valence multinuclear copper framework constructed through the cooperative bridging action of chloride and dca ligands. The asymmetric unit contains four crystallographically independent copper centers (Cu1, Cu1A, Cu1B, and Cu1C), which are interconnected by μ_2 -chloride and μ -dca bridges to afford an extended multinuclear architecture.

Table 2
Selected bond lengths/Å and angles/° for the complex

Cu1–O1	1.983(3)	Cu1–N2	1.938(3)
Cu1–N1	2.030(3)	Cu1–Cl1	2.2413(10)
Cu1–Cl1A	2.6343(11)	Cu2–N4	1.875(4)
Cu2–N6B	1.937(4)	Cu2–N3	2.013(3)
N2–Cu1–O1	78.50(11)	N2–Cu1–N1	80.26(13)
O1–Cu1–N1	158.68(12)	N2–Cu1–Cl1	162.31(10)
O1–Cu1–Cl1	98.82(8)	N1–Cu1–Cl1	100.85(10)
N2–Cu1–Cl1A	104.81(10)	O1–Cu1–Cl1A	96.67(9)
N1–Cu1–Cl1A	90.51(10)	Cl1–Cu1–Cl1A	92.85(4)
N4–Cu2–N6B	122.54(16)	N4–Cu2–N3	127.91(15)
N6B–Cu2–N3	108.61(15)		
Symmetry codes: A: $-x, 2-y, 1-z$; B: $x, 1+y, z$.			

Each Cu(II) center (Cu1) adopts a distorted square-pyramidal coordination geometry, which is frequently observed for Cu(II) complexes [16,17]. The basal plane is occupied by the pyridyl nitrogen (N1), imine nitrogen (N2), and enolate oxygen (O1) atoms of the hydrazone ligand, together with a chloride ligand (Cl1), while the apical position is occupied by another chloride atom (Cl1A; symmetry code A: $-x, 2-y, 1-z$). The calculated Addison distortion parameter (τ) value of 0.06 confirms the square-pyramidal geometry around the Cu(II) center [22]. The chloride ligand adopts a μ_2 -bridging mode, linking two adjacent Cu(II) ions through a Cu–Cl–Cu angle of $87.15(4)^\circ$, thus forming a compact Cu_2Cl structural motif. The Cu1...Cu1A distance is $3.373(2)$ Å. The Cu–Cl bond lengths and Cu–Cl–Cu bridging angles are comparable to those commonly observed in chloro-bridged copper complexes [16,17], indicating that the chloride ligands adopt a conventional bridging coordination mode.

The Cu(I) center (Cu2) displays a triangular coordination geometry, being coordinated by the imine nitrogen atom (N3) from the hydrazone ligand and two nitrile nitrogen atoms (N4 and N6A) from two independent dca ligands. The Cu(I) atom deviates from the least-squares plane defined by the three donor atoms by $0.108(1)$ Å, indicating a slightly distorted triangular environment. The dca ligand exhibits a $\mu_{1,5}$ -bridging mode, with Cu–N(dca) bond distances ranging from $1.875(4)$ to $1.937(4)$ Å, which is in consistent with the Cu(I)–N(dca) bond distances in Cu(I)-dca compounds [23,24]. The simultaneous involvement of chloride and dca bridges provides multiple connection pathways between copper centers and contributes to the formation of a more robust multinuclear framework. The Cu2...Cu2B separations ($7.595(2)$ Å) mediated by dca bridges are comparable to those reported for related copper dicyanamide

systems [23,24]. These relatively long Cu⋯Cu distances suggesting that no significant Cu•••Cu interaction is present.

A distinctive structural feature of this complex is the coexistence of two independent bridging pathways. The μ_2 -chloride ligands connect Cu(II) centers through Cu–Cl–Cu interactions, whereas $\mu_{1,5}$ -dca ligands link Cu(I) centers through terminal nitrile nitrogen atoms. Consequently, the copper centers are interconnected through both chloride- and dca-mediated pathways, giving rise to a rigid mixed-valence Cu(I)/Cu(II) coordination framework. In the crystal lattice, the discrete $[\text{Cu}^{\text{II}}_2\text{Cu}^{\text{I}}_2\text{I}_2(\mu_2\text{-Cl})_2\text{L}_2]$ units are further linked by $\mu_{1,5}$ -dca ligands to generate one-dimensional chains extending along the *b* axis. These chains are additionally stabilized by weak intermolecular C–H⋯N hydrogen-bonding interactions involving C6–H6⋯N5ⁱ (C6–H6 = 0.93 Å, H6⋯N5ⁱ = 2.57 Å, C6⋯N5ⁱ = 3.38 Å, and $\angle\text{C6–H6}\cdots\text{N5}^i = 146(3)^\circ$; symmetry code: *i* = 1 – *x*, – 1 – *y*, – *z*).

Antimicrobial activity

The antibacterial activities of HL and the copper complex were assessed by determining the minimum inhibitory concentrations (MICs) against four bacterial strains, including *Bacillus subtilis*, *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas fluorescens*, with kanamycin and penicillin G employed as reference antibiotics (Table 3). Compared with the free ligand HL, the copper complex exhibited significantly enhanced antibacterial activity against all tested strains, indicating that metal coordination plays an important role in improving the biological efficacy of the ligand.

Table 3
Minimum inhibitory concentrations (MICs, μM) of HL, the copper complex and reference antibiotics against tested bacterial strains

Tested material	<i>B. subtilis</i>	<i>S. aureus</i>	<i>E. coli</i>	<i>P. fluorescens</i>
The complex	1.2	2.3	4.7	37.5
HL	18.8	9.4	37.5	> 150
Kanamycin	0.6	2.3	4.7	4.7
Penicillin G	2.3	4.7	> 150	> 150

The complex showed comparable inhibitory effects to kanamycin against *S. aureus* and *E. coli*, with MIC values of 2.3 and 4.7 μM , respectively. Moreover, it displayed stronger antibacterial activity than penicillin G toward the Gram-positive strains, whereas penicillin G exhibited no detectable inhibitory effect against the tested Gram-negative bacteria under the investigated conditions. Although kanamycin showed superior activity against *P. fluorescens*, the copper complex still demonstrated markedly improved antibacterial performance compared with HL and penicillin G.

The enhanced antibacterial activity of the complex may be associated with the chelation-induced modification of the ligand properties. Coordination with the copper center can alter the electronic characteristics and hydrophobicity of HL, thereby facilitating interaction with bacterial cell membranes and improving cellular uptake [25]. These results suggest that metal coordination provides an effective strategy for enhancing the antibacterial properties of hydrazone-based ligands.

Conclusion

In summary, a mixed-valence hydrazone-based copper(I/II) coordination compound containing both Cu(I) and Cu(II) centers has been successfully constructed. The Cu(II) ions adopt distorted square-pyramidal coordination geometries, whereas the Cu(I) ions exhibit triangular coordination environments. The coexistence of dicyanamide-based nitrogen bridges and chloride linkers provides a cooperative bridging mode for the assembly of a multinuclear copper framework. The μ_2 -chloride bridges generate compact Cu₂ structural motifs, while the $\mu_{1,5}$ -dicyanamide ligands further propagate the copper arrangement, resulting in an extended and robust coordination architecture. The complex exhibits notable antibacterial activity against *Bacillus subtilis*, *Staphylococcus aureus*, and *Escherichia coli*, with MIC values ranging from 1.2 to 4.7 $\mu\text{mol L}^{-1}$. This study expands the structural diversity of hydrazone-based copper coordination compounds and highlights the importance of combining different bridging ligands for the construction of multinuclear metal architectures with potential biological applications.

Declarations

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Author Contribution

Zhong-Lu You. Conception, supervision, writing. Zheng-Wei Wu: Writing the main manuscript, and biological assay. Hao-Jie Yuan: Chemical synthesis and characterization. Hao-Dong Zhang: Chemical synthesis and characterization. Jia-Yan Dai: Chemical synthesis and characterization. Lv-Shan Zhou: Validation, methodology, investigation.

Data availability

No datasets were generated or analysed during the current study.

References

1. Das B, Sathyanarayan S, Gupta P (2025) Dalton Trans 54:10178
2. Moreno-Narváez ME, González-Sebastián L, Colorado-Peralta R, Reyes-Márquez V, Franco-Sandoval LO, Romo-Pérez A, Cruz-Navarro JA, Manozca-Dosman IV, Aragón-Muriel A, Morales-Morales D (2025) Inorganics 13:38
3. Ngece K, Khwaza V, Paca AM, Aderibigbe BA (2025) Antibiotics-Basel 14:516
4. Alhussaini MS, Alyahya AAI, Al-Ghanayem AA (2025) Dyes Pigm 243:113040
5. Sinhapitiya P, Tennakoon S, Weeraratne IADK (2025) Admet Dmpk 14:3214
6. Iacopetta D, Catalano A, Ceramella J, Mariconda A, D'Amato A, Checconi P, Aquaro S, Longo P, Sinicropi MS (2025) Molecules 30:207
7. Bufarwa SM, El-Sefait RM, Thbayh DK, Belaidi M, Al-Shemary RK, Abdusamea RM, El-Ajaily MM, Fiser B, Bader HA, Saleh AA, Bufarwa MM (2025) Rev Inorg Chem 45:105
8. Czyzewska I, Mazur L, Popiolek L (2024) Chem Biol Drug Des 104:e14590
9. Azam T, Ahmad Z, Shakoor B, Arshad U, Farooq A, Ghazanfar U, Mahmood S, Shafiq N, Moveed A, Metouekel A, Elossaily GM, Bourhia M, Bin Jordan YA, Ali H, Hefnawy M (2026) J Mol Struct 1372:146586
10. Kahraman S, Hepokur C, Erci F, Erkan S, Cetin S, Kose M, Kurtoglu M (2025) Polyhedron 269:117393
11. Middya P, Roy D, Chattopadhyay S (2023) Inorg Chim Acta 548:121377
12. Pradhan A, Haldar S, Mallik KB, Ghosh M, Bera M, Sepay N, Schollmeyer D, Ghatak SK, Roy S, Saha S (2019) Inorg Chim Acta 484:197
13. Du M, Zhao XJ, Batten SR, Ribas J (2005) Cryst Growth Des 5:901
14. Mal D, Adhikary C, Rentschler E, Miyashita Y, Okamoto KI, Koner S (2007) Polyhedron 26:736
15. Mal D, Sen R, Adhikary C, Miyashita Y, Okamoto KI, Bhattacharjee A, Gütlich P, Koner S (2008) J Coord Chem 61:3486
16. Devi RKB, Devi SP, Singh RKB, Singh RKH, Swu T, Devi WR, Singh CB (2014) J Coord Chem 67:891
17. Gao YJ, Ji YF, Ding S, Liu ZL, Tang JK (2011) Z Anorg Allg Chem 637:2300
18. Bruker, SMART and SAINT (2002) Bruker AXS Inc., Madison
19. Sheldrick GM (2008) Acta Crystallogr A64:112
20. Meletiadis J, Meis JFGM, Mouton JW, Donnelly JP, Verweij PE (2000) J Clin Microbiol 38:2949
21. Geary WJ (1971) Coord Chem Rev 7:81
22. Addison AW, Rao TN, Reedijk J, van Rijn J, Verschoor GC (1984) J Chem Soc Dalton Trans 1349
23. Batten SR, Harris AR, Jensen P, Murray KS, Ziebell A (2000) J Chem Soc Dalton Trans 3829
24. Nandy M, Shit S, Dhal P, Rizzoli C, Gomez-Garcia CJ, Mitra S (2015) J Coord Chem 68:916
25. Searl JW, Smith RC, Wyard SJ (1961) Proc Phys Soc 78:1174.

Scheme

Scheme 1 is available in the Supplementary Files section.

Figures

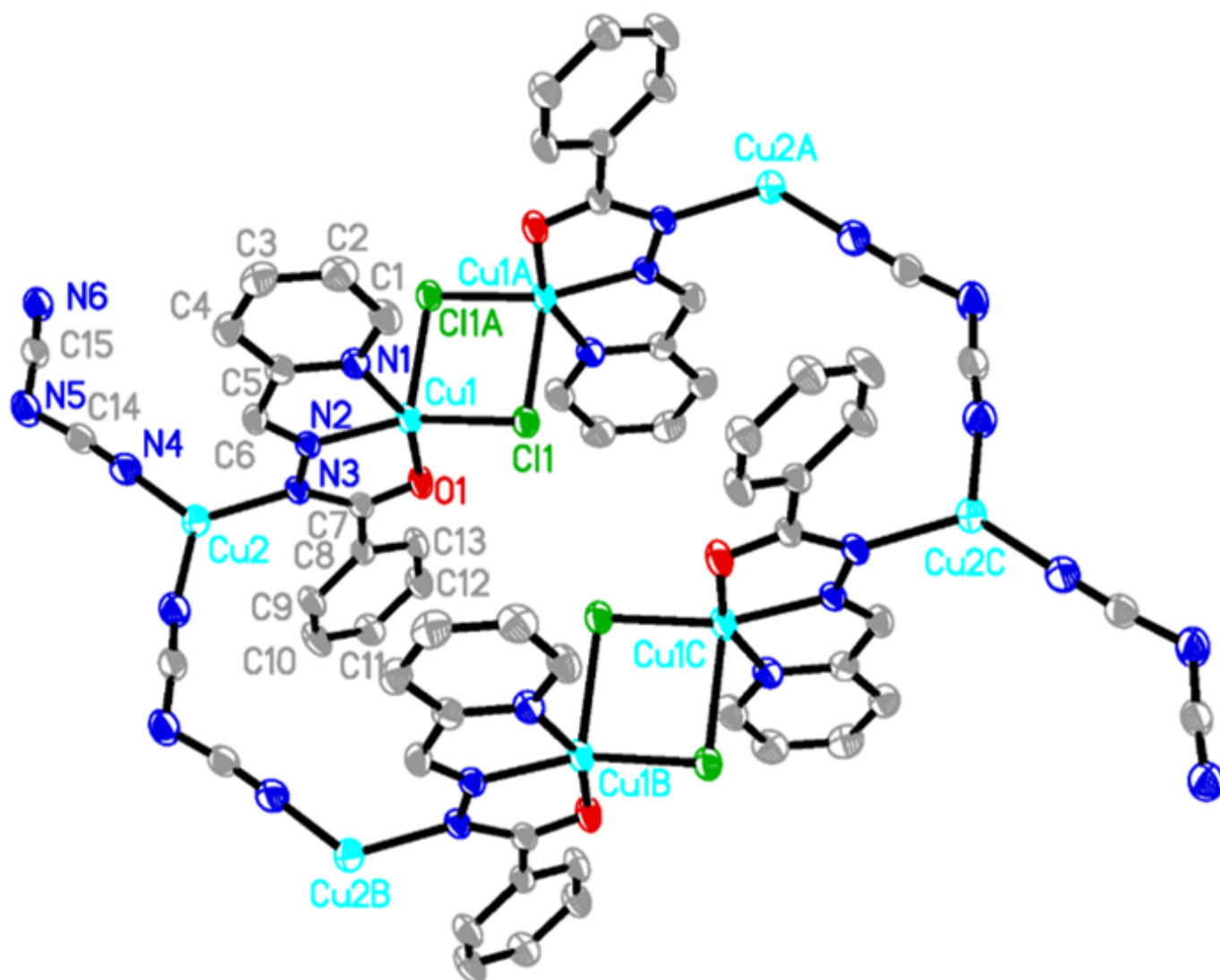


Figure 1

Molecular structure of the complex. Displacement ellipsoids for non-hydrogen atoms are drawn at the 30% probability level. Symmetry codes: A: $-x, 2-y, 1-z$; B: $x, 1+y, z$.

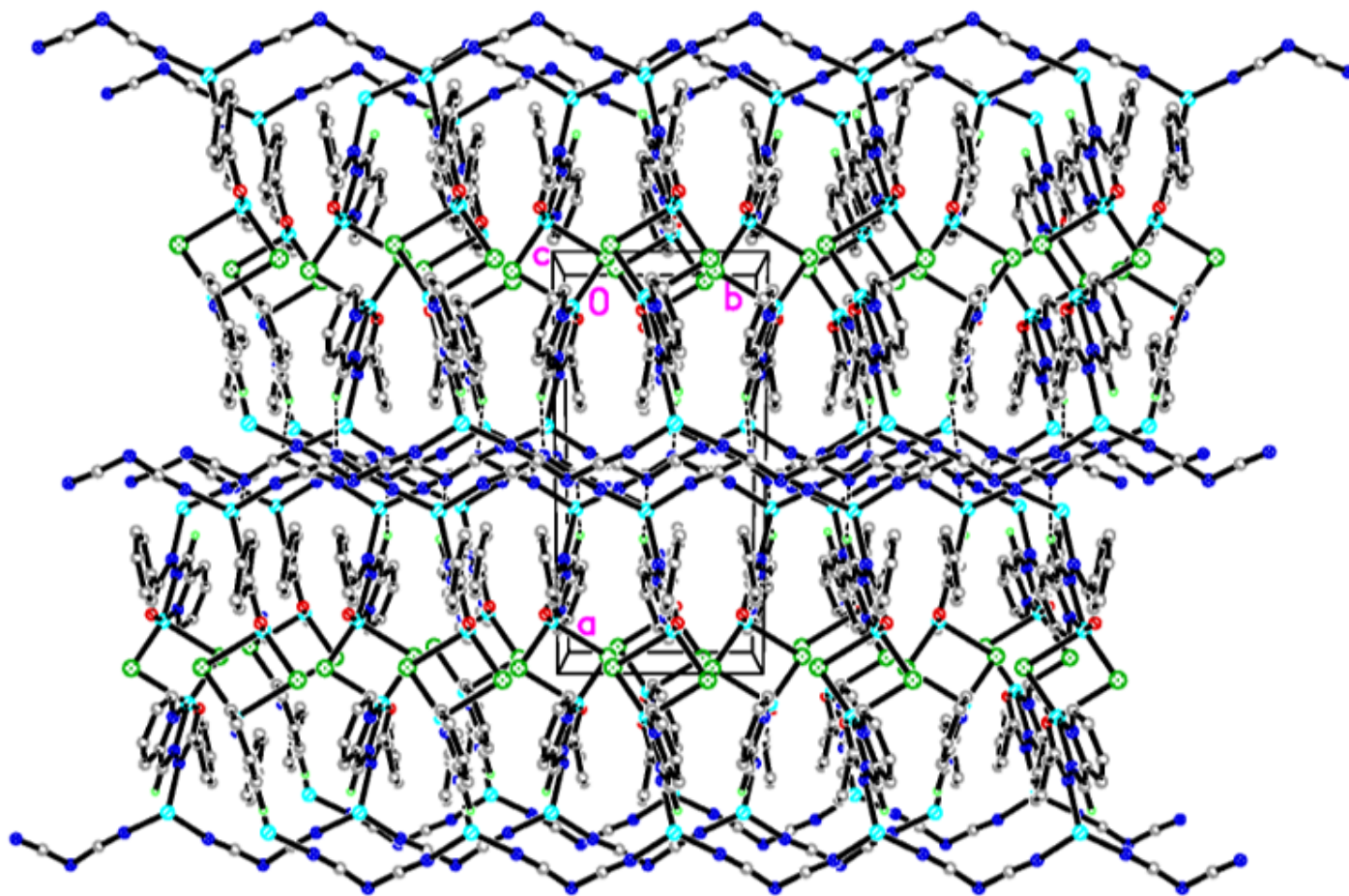


Figure 2

Molecular packing structure of the complex, viewed along *c* axis. Hydrogen bonds are shown as dashed lines.

Supplementary Files

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- [scheme1.png](#)