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两个含吡唑环的双核铜配合物的合成、表征及清除自由基活性

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摘要:以三(3,5-二甲基吡唑甲基)胺(TMPzA)及 2,5-噻吩二羧酸为配体合成了 2 个双核 Cu 的配合物[Cu_2(DMPzA)$_2$(TPDC)$_2$]ClO_4 (**1**)和 [Cu_2(TMPzA)$_2$(TPDC)(H_2O)$_2$](ClO_4)$_2$ (**2**)。在 **1** 中,配体 TMPzA 发生裂解,以二(3,5-二甲基吡唑甲基)胺(DMPzA)与 Cu 配位,并在 2 个 Cu 原子之间形成一个大环,2 个 Cu 原子之间的距离为 0.786 84 nm。清除自由基实验发现,配合物 **1** 比 **2** 具有较好的清除自由基活性。

关键词:双核铜配合物;Feton 体系;清除羟基自由基
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Syntheses, Characterization and Radical Scavenging Activity of Two Copper(Ⅱ) Complexes Containing Pyrazoles

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Abstract: By using a tripodal ligand tris (3,5-bimethyl-pyrazolylmethyl)amine (TMPzA) and a bridged ligand thiophenedicarboxylic acid (H_2TPDC), two binuclear copper (Ⅱ) complexes have been synthesized and characterized. It has been found that TMPzA lost an arm and coordinated to copper with di(3,5-bimethyl-pyrazolylmethyl)amine(DMPzA) in complex [Cu_2(DMPzA)$_2$(TPDC)$_2$]ClO_4 (**1**). The structure presented a microcycle with the Cu(1)⋯Cu(1A) distance of 0.786 84 nm. The complex [Cu_2(TMPzA)$_2$(TPDC)(H_2O)$_2$](ClO_4)$_2$ (**2**) is a binuclear structure and with the TMPzA completely. The investigation in Feton system shows that complex **1** has better hydroxyl radicals scavenging property than that of complex **2**. CCDC: 1411232, **1**; 1411233, **2**.

Keywords: binuclear copper(Ⅱ) complexes; Feton system; hydroxyl radicals scavenging

0 Introduction

Oxygen-derived free radicals such as superoxide anion radical ($O_2^{\cdot -}$) and hydroxyl radical (·OH) which can oxidize the proteins, carbonhydrates, nuclein and fats are most active and harmful radicals in organisms[1-2]. The cells and organs would be injured and cause diseases such as coronary heart disease, rheumatoid arthritis and cancer[3] if these radicals cannot be removed just in time[4-6]. So the study of scavenging of oxygen-derived free radicals is more valuable.

It is well-known that free radicals are controlled on human body by some enzymes such as superoxide dismutase and peroxidase[7], but the non-enzymes can also scavenge free radicals and play an important role to protect bodies from free radicals. The poly-functional coordinated polymer and multi-nuclear complexes can be used to scavenge hydroxyl radicals[8-12].

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The hydroxyl radicals can be generated via a redox process from Feton system[13]. Herein, we report two excellent hydroxyl radicals scavenging based on binuclear Cu(Ⅱ) complexes. The two complexes were added to the Feton system to compete the hydroxyl radicals with salicylic acid and the complexes showed good ability and they might be potential hydroxyl radical scavenger.

1 Experimental

1.1 Starting materials and general methods

All commercially available chemicals were of analytical grade and directly used without further purification. Infrared spectra were obtained (KBr disk, 4 000~400 cm^{-1}) using a sp-100 spectrometer. Elemental analyses were performed in a PE240C elemental analyzer. UV-Vis spectra were carried out with a TU-1901 double beam instrument.

1.2 Synthesis of $[Cu_2(DMPzA)_2(TPDC)_2]ClO_4$ (1) and $[Cu_2(TMPzA)_2(TPDC)(H_2O)_2](ClO_4)_2$ (2)

A colorless aqueous solution of 2,5-Thiophenedicarboxylate (17.2 mg, 0.1 mmol, deprotonated by reacting with NaOH) was added to a 10 mL acetonitrile solution of $Cu(ClO_4)_2\cdot 6H_2O$ (74.2 mg, 0.2 mmol) and TMPzA (68.2 mg, 0.2 mmol) with stirring for 30 min, filtered and allowed to evaporate at room temperature. Green rectangular crystals of **1** and blue needle crystals of **2** were deposited after a few days, which were separated and air-dried. Yield: 40% for **1**; 30% for **2** (based on copper). Anal. Calcd. for **1** ($C_{36}H_{41}ClCu_2N_{10}O_{12}S_2$, %): C, 41.84; H, 3.96; N, 13.56. Found (%): C, 41.72; H, 4.03; N, 13.67. Calcd. for **2** ($C_{42}H_{60}Cl_2Cu_2N_{14}O_{14}S$, %): C,41.48; H,4.94; N,16.13. Found (%): C,41.29; H,4.85; N,16.07. IR data (cm^{-1}) for **1**: 3 434(m), 2 925(w), 1 639(m), 1 585(s), 1 554 (m), 1 529(m), 1 420(w), 1 318(m), 1 234(w), 1 121(s), 1 061(m), 808(w), 774(w), 625(w). For **2**: 3 435(s), 2 925(w), 1 627(s), 1 557(m), 1 468(w), 1 393(m), 1 349 (m), 1 121(vs), 797(w), 727(w), 624(w).

1.3 Crystal structure determination

The X-ray diffraction measurements for **1** and **2** were performed on Bruker SMART APEX Ⅱ CCD diffractometer with graphite-monochromatized Mo $K\alpha$ radiation (λ=0.071 073 nm) by using φ-ω scan mode at 100(2) K for **1** and 296(2) K for **2**. The absorption corrections were applied using SADABS program[14]. All structures were solved by direct methods and refined by full matrix least-square on F^2 using SHELXTL program package[15]. All non-hydrogen atoms were refined with anisotropic displacement parameters. All the hydrogen atoms bonded to carbon atoms were placed in calculated positions and treated in a riding-model approximation. The hydrogen atoms of the H_2O in complex **2** were located in a difference Fourier map. In complex **1**, the part of one DMPzA molecule (N3, N3A, N4, N4A, N5, N5A, C12, C12A, C13, C13A, C14, C14A, C15, C15A, C16, C16A, C17, C17A, C18 and C18A) were disordered by refining over two sides with occupancy of part 21.00 and −21.00. The crystal data and details of structural determination for the complex **1** and **2** are presented in Table 1.

CCDC: 1411232, **1**; 1411233, **2**.

Table 1 Crystallographic data and details for complexes 1 and 2

Complex	1	2
Empirical formula	$C_{36}H_{43}ClCu_2N_{10}O_{12}S_2$	$C_{42}H_{60}Cl_2Cu_2N_{14}O_{14}S$
Formula weight	1 032.44	1 215.08
Crystal system	Monoclinic	Orthorhombic
Space group	*P*2/*n*	*Pca*2$_1$
a / nm	1.328 3(4)	1.924 8(5)
b / nm	0.820 7(2)	0.775 6(2)
c / nm	2.274 0(6)	3.541 9(9)
β / (°)	106.602(5)	
V / nm^3	2.375 5(11)	5.287(2)

Continued Table 1

Z	2	4
D_c / (g·cm^{-3})	1.443	1.526
Absorption coefficient /mm^{-1}	1.105	1.021
F(000)	1 060	2 520
θ range for data collection / (°)	2.80~25.01	2.63~25.01
Max. and min. transmission	0.817 5 and 0.785 1	0.821 8 and 0.806 5
Limiting indices	$-15 \leqslant h \leqslant 15, 0 \leqslant k \leqslant 9, 0 \leqslant l \leqslant 27$	$-22 \leqslant h \leqslant 22, -8 \leqslant k \leqslant 9, -42 \leqslant l \leqslant 31$
Reflection collected, unique	4 173, 4 173 (R_{int}=0.021 9)	24 600, 7 784 (R_{int}=0.094 3)
Data, parameter [$I>2\sigma(I)$]	4 173, 394	7 784, 701
GOF on F^2	1.061	1.017
R_1, wR_2 [$I>2\sigma(I)$]	0.054 3, 0.155 2	0.064 1, 0.132 0
R_1, wR_2 (all data)	0.066 5, 0.162 9	0.159 1, 0.170 0
Largest difference peak and hole / (e·nm^{-3})	1 020, −580	466, −286

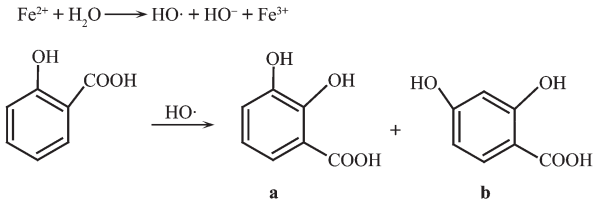
1.4 Hydroxyl radical-scavenging essay

1.4.1 Generation and trapping of hydroxyl radicals

The hydroxyl radicals were generated by the well-known Fenton reaction using hydrogen peroxide and ferrous sulfate[16]. If the salicylic acid is added to the Fenton reaction system, the characteristic absorption bands at 504 nm will appear due to the hydroxyl radicals trapped and the products (a) and (b) formed, the reaction occurring as Scheme 1[17]. The UV absorbance at 504 nm will decrease when the complexes which can scavenge the hydroxyl radical were added to the solution. That means we can determine the radical-scavenging activities of the complexes by measuring the absorbance of 504 nm.

1.4.2 Hydroxyl radical-scavenging rate measurement

The $FeSO_4$ solution (2 mL, 1.8 mmol·L^{-1}) was mixed with salicylic acid solution (2 mL, 1.8 mmol·L^{-1}) in five 10 mL volumetric flasks, then the solution of the two complexes with different concentrations was added to the mixture, respectively. After shaking, 1 mL H_2O_2 was added and the final volume was made up to 10 mL with double distilled water. The solutions were transferred to the cell for the absorption measurement at 504 nm on a TU-1901 spectrophotometer with the temperature 37 ℃, the time 30 min and the pH 7.38. The absorption data of **a** and **b** (Scheme 1) by the action of the complexes with various concentrations can be obtained. The hydroxyl radical-scavenging activity was calculated.



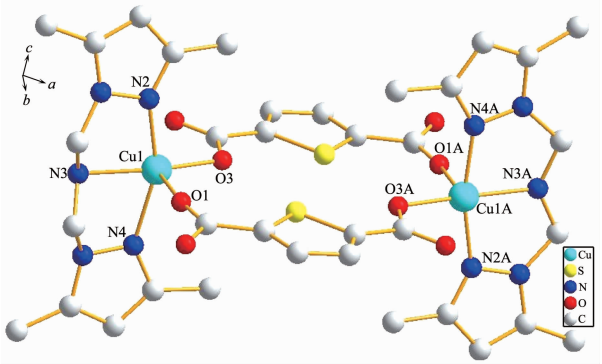
Scheme 1

2 Results and discussion

2.1 Descriptions of crystal structures

2.1.1 Crystal structure of $[Cu_2(DMPzA)_2(TPDC)_2]ClO_4$ (**1**)

Complex **1** crystallizes in the monoclinic space group $P2/n$ and has an independent molecule in the centrosymmetric unit, as shown in Fig.1. The tripodal ligand TMPzA lose a pendant arm and turn to DMPzA with the N atom of amine protonated partially, the possible mechanism has been discussed in our previous works[18]. The molecular structure of **1** consists



Hydrogen atoms and one perchlorate anion have been omitted for clarity; Symmetry codes: A: $-x+1, -y+1, -z+1$

Fig.1 Molecular structure of complex **1**

Table 2 Selected bond lengths (nm) and angles (°) in 1

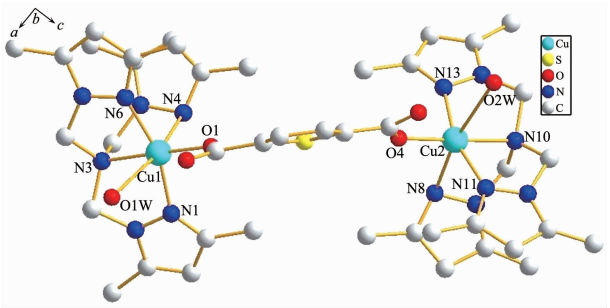
Cu(1)-O(3)	0.192 4(3)	Cu(1)-N(4)	0.214 5(4)	Cu(1)-O(1)	0.232 3(3)
Cu(1)-N(2)	0.197 6(4)	Cu(1)-N(3)	0.202 7(4)	Cu(1A)-O(3A)	0.192 4(3)
Cu(1A)-N(4A)	0.192 9(4)	Cu(1A)-O(1A)	0.232 3(4)	Cu(1A)-N(3A)	0.205 6(4)
Cu(1A)-N(4A)	0.197 7(4)				
O(3)-Cu(1)-N(2)	99.45(14)	O(3)-Cu(1)-N(3)	160.3(4)	N(2)-Cu(1)-N(3)	83.0(4)
O(3)-Cu(1)-N(4)	100.4(5)	N(2)-Cu(1)-N(4)	158.2(5)	N(3)-Cu(1)-N(4)	75.4(6)
O(3)-Cu(1)-O(1)	104.30(13)	N(2)-Cu(1)-O(1)	89.67(14)	N(3)-Cu(1)-O(1)	95.2(4)
N(4)-Cu(1)-O(1)	94.1(6)	N(4A)-Cu(1A)-N(2A)	165.48(12)	N(4A)-Cu(1A)-N(3A)	82.7(5)
O(3A)-Cu(1A)-N(3A)	174.0(4)	N(2A)-Cu(1A)-N(3A)	81.2(3)	N(3A)-Cu(1A)-N(4A)	84.3(5)
N(4A)-Cu(1A)-O(1A)	89.3(3)	N(3A)-Cu(1A)-O(1A)	81.7(4)	O(3A)-Cu(1A)-N(4A)	94.8(3)
O(3A)-Cu(1A)-N(2A)	99.5(11)	O(3A)-Cu(1A)-O(1A)	104.3(9)		

Symmetry codes: A: $-x+1, -y+1, -z+1$

of two Cu(Ⅱ) ions bridged through two Thiophenedicarboxylate molecular resulting in a microcycle with the intramolecular Cu(1)⋯Cu(1A) distance of 0.786 84 nm. The copper ions are coordinated with two $N_{pyrazole}$ atoms, one N_{amine} from a DMPzA molecule and two $O_{carboxyl}$ atoms from two H_2DPC molecules, forming a distorted square pyramidal geometry. The Cu-N_{amine} is somewhat longer than Cu-$N_{pyrazole}$ and it is consistent with this class of complexes. The three N atoms (N2, N3, N4) and O3 define the bottom plane with the Cu atoms protrude out from it by 0.006 75 nm. The Cu1-O1 bond occupy the axial site and is significantly longer than other bonds may be due to the strain of the carboxylate ligand and the Jahn-Teller effect from the copper atom. Selected bond lengths and angles for **1** are listed in Table 2.

2.1.2 $[Cu_2(TMPzA)_2(TPDC)(H_2O)_2](ClO_4)_2$ (**2**)

Be different from **1**, the tripodal ligand TMPzA in **2** has not decomposed and coordinate to the Cu atoms with three $N_{pyrazole}$ atoms and one N_{amine} atom, as shown in Fig.2. The two Cu(Ⅱ) ions are also linked by the H_2TPDC ligand and form a centrasymmetric structure. Each Cu ion is coordinated by four N atoms from TMPzA, one O atom form H_2TPDC and one O atom from H_2O molecule, forming a distorted octahedral coordination geometry. The three $N_{pyrazole}$ atoms and O from H_2O are located at the equatorial plane of Cu center, while the N_{amine} and $O_{carboxyl}$ atoms are located at the apical positions. The most distinguished feature of **2** lies in the Cu-N_{amine} (Cu1-N3 0.206 4(7) nm; Cu2-N10 0.207 8(7) nm) bond lengths are significantly shorter than the Cu-$N_{pyrazole}$ (Cu1-N4 0.235 9(6) nm; Cu2-N8 0.238 0(7) nm) bonds, which is very rare in this class of complexes. Selected bond lengths and angles for **2** are listed in Table 3.



Hydrogen atoms and two perchlorate anions have been omitted for clarity

Fig.2 Molecular structure of complex **2**

2.2 Hydroxyl radical-scavenging studies

The absorbance with various concentrations of complexes **1** and **2**, A_i, are summarized in Table 4 and the radical-scavenging rates after adding complexes are shown in Fig.3. The radical-scavenging rate (η) is calculated by the equation: $\eta=1-\frac{A_i}{A_0}$ and the plots of hydroxyl radical-scavenging rate vs the extent of complexes used can be made from the data, where A_0 (A_0=0.533 5) represents the absorbance of the reaction system without any complex. It is found that the greater the concentration of **1** and **2**, the

Table 3　Selected bond lengths (nm) and angles (°) in 2

Cu(1)-O(1)	0.189 0(6)	Cu(1)-N(1)	0.200 3(7)	Cu(1)-N(6)	0.201 3(6)
Cu(1)-N(3)	0.206 4(7)	Cu(1)-N(4)	0.235 9(6)	Cu(1)-O(1W)	0.272 4(5)
Cu(2)-O(4)	0.191 6(6)	Cu(2)-N(13)	0.198 3(6)	Cu(2)-N(11)	0.198 4(7)
Cu(2)-N(10)	0.207 8(7)	Cu(2)-N(8)	0.238 0(7)	Cu(1)-O(2W)	0.266 5(5)
O(1)-Cu(1)-N(1)	97.9(3)	O(1)-Cu(1)-N(6)	100.2(3)	N(1)-Cu(1)-N(6)	161.0(3)
O(1)-Cu(1)-N(3)	178.6(2)	N(1)-Cu(1)-N(3)	80.8(3)	N(6)-Cu(1)-N(3)	81.1(3)
O(1)-Cu(1)-N(4)	96.8(2)	N(1)-Cu(1)-N(4)	95.8(2)	N(6)-Cu(1)-N(4)	87.7(2)
N(3)-Cu(1)-N(4)	83.0(2)	O(1)-Cu(1)-O(1W)	95.5(12)	N(1)-Cu(1)-O(1W)	85.4(9)
O(1W)-Cu(1)-N(3)	84.9(9)	O(1W)-Cu(1)-N(6)	87.3(11)	N(4)-Cu(1)-O(1W)	167.4(10)
O(2W)-Cu(2)-N(10)	86.3(9)	O(4)-Cu(2)-N(13)	95.9(3)	O(4)-Cu(2)-N(11)	100.9(3)
N(13)-Cu(2)-N(11)	162.1(3)	O(4)-Cu(2)-N(10)	178.4(2)	N(13)-Cu(2)-N(10)	82.5(3)
N(11)-Cu(2)-N(10)	80.7(3)	O(4)-Cu(2)-N(8)	97.3(2)	N(13)-Cu(2)-N(8)	94.8(3)
N(11)-Cu(2)-N(8)	89.3(3)	N(10)-Cu(2)-N(8)	82.6(3)	O(2W)-Cu(2)-N(11)	87.0(11)
N(8)-Cu(2)-O(2W)	168.8(10)	O(2W)-Cu(2)-O(4)	93.8(12)	N(13)-Cu(2)-O(2W)	85.6(9)

Table 4　Hydroxyl radical-scavenging of 1 and 2

$c_{complex}$ / (μg·mL^{-1})	A_i for **1**	η_1 / %	A_i for **2**	η_2 / %
2	0.504 1	5.14	0.517 0	2.77
4	0.387 7	27.33	0.391 2	26.67
8	0.291 8	45.30	0.292 2	45.23
12	0.204 9	61.59	0.222 3	58.33
20	0.117 1	78.05	0.120 6	77.39

lower the absorbance of **a** and **b** in the reaction system and the higher the hydroxyl radical-scavenging rate. Moreover, the radical-scavenging rate of **1** is somewhat higher than that of **2**, which may be due to the different coordination environment of Cu ions. In complex **1**, the Cu ions are five-coordinated with a potential coordination site that can combine with the hydroxyl radical while the Cu ions in complex **2** are six-coordinated.

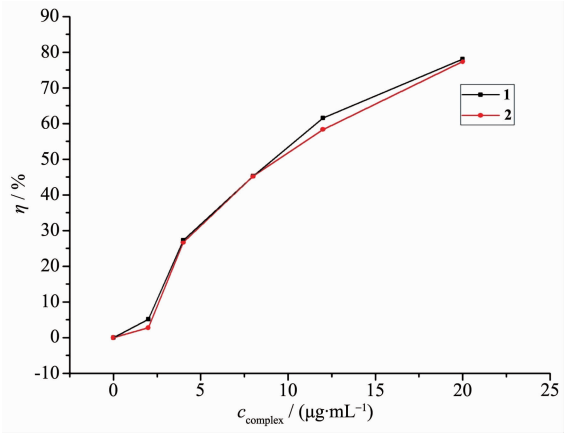


Fig.3　Hydroxyl radical-scavenging rate of **1** and **2**

3　Conclusions

Two binuclear copper(Ⅱ) complexes containing polyamine and bridged carboxyl ligands were prepared and characterized. In two complexes, the copper ions have square-pyramidal geometry and were bridged by the carboxyl ligand via the oxygen atoms in monodentate mode. The radical-scavenging activity of the two complexes was determined and the results indicate that two complexes present excellent radical-scavenging activities.

References:

[1] JIANG Lin-Ling(蒋林玲), LI Bao-Lin(李宝林), WANG Li(王丽). *J. Anal. Sci. Technol.*(分析科学学报), **2008**,**24**(2):212-214

[2] Tavadyan L A, Sedrakyan G Z, Minasyan S H, et al. *Transition Met. Chem.*, **2004**,**29**(6):684-696

[3] Mittler R. *Trends Plant Sci.*, **2002**,**7**:405-410

[4] Halliwell B, Gutteridge J M C. *Free Radicals in Biology and Medicine*. Oxford: Clarendon Press, **1989**:110

[5] Vasquez J, Kalyanaraman B, Kennedy M C. *J. Biol. Chem.*, **2000**,**275**:14064-14069

[6] Harman D. *Free Radicals in Molecular Biology, Aging and Disease*. New York: Raven Press, **1984**:1-12

[7] Fattman C L, Schaefer L M, Oury T D. *Free Radical Biol. Med.*, **2003**,**35**(3):236-256

[8] Giokas D L, Vlessidis A G, Evmiridis N P. *Anal. Chim. Acta*, **2007**,**589**(1):59-65

[9] Naughtona D P, Grootveld M. *Bioorg. Med. Chem. Lett.*, **2001**,**11**:2573-2575

[10]Senthil Raja D, Paramaguru G, Bhuvanesh N S P, et al. *Dalton Trans.*, **2011**,**40**:4548-4559

[11]Raja D S, Bhuvanesh N S P, Natarajan K. *Dalton Trans.*, **2012**,**41**:4365-4377

[12]Manikandan R, Viswanathamurthi P, Velmurugan K, et al. *J. Photochem. Photobiol. B*, **2014**,**130**:205-216

[13]Yan F F, An P D, Ying P H. *Chin. Chem. Lett.*, **2009**,**20**: 1235-1240

[14]Sheldrick G M. *SADABS*, University of Göttingen, Germany, **1996**.

[15]Sheldrick G M. *SHELX*-97, *Program for the Solution and the Refinement of Crystal Structures*, University of Göttingen, Germany, **1997**.

[16]Suttor H C, Winterbourn C C. *Free Radical Biol. Med.*, **1989**,**6**:53-60

[17]LI Yan(李艳), GONG Shi-Lei(巩士磊), CHE Ying(车影), et al. *Chin. J. Appl. Chem.*(应用化学), **2015**,**32**(8):948-954

[18]Yang H, Tang Y, Shang Z F, et al. *Polyhedron*, **2009**,**28**: 3491-3498