

Preparation and the Standard Enthalpy of Formation of 2-Amino-4,6-dimethoxypyrimidine and the Related Complexes of Copper

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The complexes of hydrous copper chloride and copper nitrate with 2-amino-4,6-dimethoxypyrimidine (AMP) in the mole ratio of 1:2 were prepared through reflux in alcohol. The compositions of the complexes $\text{Cu(AMP)}_2\text{Cl}_2$ and $\text{Cu(AMP)}_2(\text{NO}_3)_2$ were determined by chemical and elemental analyses. The bonds between Cu^{2+} and AMP were investigated by IR, XPS, ^1H NMR and the structures of the complexes were presumed. The constant-volume combustion energies of the ligand and the complexes, $\Delta_c E$, were determined by a precise rotating bomb calorimeter at 298.15 K. They were (-3340.01 ± 1.54) kJ mol $^{-1}$, (-5684.22 ± 2.24) kJ mol $^{-1}$, and (-6526.47 ± 4.59) kJ mol $^{-1}$. Their standard enthalpies of combustion, $\Delta_c H_m^0$, and standard enthalpies of formation, $\Delta_f H_m^0$, were calculated. They were (-3339.39 ± 1.54) kJ mol $^{-1}$, (-5678.02 ± 2.24) kJ mol $^{-1}$, (-6516.55 ± 4.59) kJ mol $^{-1}$ and (-307.91 ± 1.74) kJ mol $^{-1}$, (-1670.59 ± 2.73) kJ mol $^{-1}$, (-933.27 ± 4.85) kJ mol $^{-1}$.

The pyrimidines as a class are known to possess extraordinary biological properties that are generally distinguished qualitatively by their applications in pesticide, herbicide, bactericide, and medicine intermediates [1]. A survey of these applications and a number of the related variations that were developed recently, such as the extraordinarily effective herbicide of sulfonyl sulfourea, reveals the broad biological importance just because of the wide occurrence of pyrimidines ring systems in these molecules [2]. It has been shown that the medicine intermediates in the complexes of metal ions and pyrimidines could prolong the pharmaceutical activity and effective life, and reduce the damage to mammal [1, 3–8]. When the complexes of Pt or Pd and pyrimidine are employed as medicine additives, they are harmful to human body, especially to some organs such as kidneys, although they are identified as the most effective drugs used to treat cancer by now. If Pt and Pd in these complexes were replaced by such microelements that are necessary for the life as Cu, Zn or Co, *etc.* the toxicity and the side effect of these complexes would be decreased while the power and efficiency of the medicine are preserved.

In the present work, on the basis of the literature [7, 8], the synthesis of 2-amino-4,6-dimethoxypyrimidine (AMP) was ameliorated using triethylbenzylamine chloride (TEBA) as catalyst and the yield was improved. The solid complexes of CuCl_2 and $\text{Cu(NO}_3)_2$ with AMP in the mole ratio 1:2 were pre-

pared in alcohol, the compositions of these complexes were determined by chemical and elemental analyses, and the presumed structures of the complexes were characterized by IR, XPS, and ^1H NMR. The constant volume-combustion energies of the ligand and the complexes were determined by a precise rotating bomb, the standard combustion enthalpies and the standard formation enthalpies were calculated. Clearly the study of the complexes is of substantial practical, as well as theoretical significance.

EXPERIMENTAL

All chemicals and solvents were of anal. grade and used after further purification. Guanidine nitrate and diethyl malonate were made in the chemical factory of Shanghai; phosphorus oxychloride, alcohol, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, $\text{Cu(NO}_3)_2 \cdot 3\text{H}_2\text{O}$, triethylbenzylamine chloride, and sodium methylate were made in the chemical factory of Xi'an.

2-Amino-4,6-dihydroxypyrimidine was synthesized according to Ref. [9]. The white solid product of the yield of 80 %, with the melting point exceeding 330 °C, was obtained.

Referred to Ref. [9], the synthesis method of 2-amino-4,6-dichloropyrimidine was ameliorated by selecting TEBA as catalyst and agitating continually. The straw-yellow product with the yield of 80 % was obtained, m.p. = 224–225 °C which was better than that of the literature (223–225 °C).

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Finally, combining the results above and of Ref. [10], the white crystal of AMP was collected. The yield of AMP was beyond 80 %, and its melting point is in the range of 97.0—97.5 °C.

Melting point of the compounds was measured with WRS-1A digital melting-point apparatus. Cu^{2+} content was determined by iodimetry, Cl^- by the Fajans' method and C, H, N contents were determined on a Perkin—Elmer 2400 type elemental analyzer. The IR spectra (KBr pellets) were obtained on a Bruker EQ UINOX-550 spectrophotometer in the 400—4000 cm^{-1} region. XPS were taken on an ESCA PHI-5400 X-ray photoelectron spectrophotometer using $\text{MgK}\alpha$ radiation, the C_{1s} electron in benzene was used as the internal standard, $\text{BE} = 284.6$ eV, and the accuracy of the measured BE value was +0.1 eV. The NMR spectra of the compounds were measured with a Varian Unity INOVA-400 nuclear magnetic resonance spectrometer using TMS as the reference sample and $\text{C}_2\text{D}_5\text{OD}$ as the solvent.

The constant-volume combustion energies of the compounds were determined by a precise rotating bomb calorimeter [11]. The main experimental procedures were described in Ref. [10]. The initial temperature was regulated to $(25.0000 \pm 0.0005)^\circ\text{C}$, and the initial oxygen pressure was 2.5 MPa. The correct value of the heat exchange was calculated according to the Linio—Pyfengdelel—Wsawa formula [9]. The calorimeter was calibrated with benzoic acid of 99.999 % purity. It had an isothermal heat of combustion at 298.15 K of $(-26434 \pm 3) \text{ J g}^{-1}$. The energy equivalent of calorimeter was determined to be $(17936.01 \pm 9.08) \text{ kJ K}^{-1}$. The analytical methods for final products (gas, liquid, and solid) were the same as those in Ref. [12].

Complexes

For preparation of the complex *I*, 0.93 g of the ligand and 0.52 g of $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ were weighed out, and separately dissolved in 15 cm^3 and 10 cm^3 of alcohol. When the solution of $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ was warmed for a few minutes on a hot plate, the solution of the ligand was added dropwise into the solution of salt. Under the condition of reflux, the reaction proceeded further for 3 h. After evaporating a part of solvent, the precipitant appeared, and the reaction mixture was allowed to cool slowly to room temperature, followed by suction filtration. In order to remove the reminder of the ligand and salt, it was necessary for the reaction mixture to be rinsed thoroughly with hot alcohol and distilled water. An infrared heat lamp was employed to serve the drying of the product. Finally, the green product of the yield of 75.6 % with the melting point of 162.0—162.1 °C was obtained. The complex *II* was prepared according to the procedures used for the complex *I* above. The purity of the complexes was greater than 99.9 % checked by HPLC. The analytical results

of the composition of these complexes are presented as follows. For *I*, $w_i(\text{calc.})$: 14.29 % Cu, 15.95 % Cl, 32.41 % C, 4.08 % H, 18.90 % N; $w_i(\text{found})$: 13.98 % Cu, 15.94 % Cl, 32.91 % C, 4.18 % H, 19.20 % N. For *II*, $w_i(\text{calc.})$: 11.90 % Cu, 28.91 % C, 3.64 % H, 22.51 % N; $w_i(\text{found})$: 11.24 % Cu, 29.41 % C, 3.73 % H, 22.03 % N. The compositions of the complexes *I* and *II* were identified as $\text{Cu}(\text{AMP})_2\text{Cl}_2$ and $\text{Cu}(\text{AMP})_2(\text{NO}_3)_2$.

RESULTS AND DISCUSSION

IR spectra of the ligand and the complexes are shown in Figs. 1—3. It is obvious from the infrared spectra of the compounds that there are differences between the main characteristic absorption peaks of the complexes and those of the ligand [13, 14]. Compared with the characteristic absorption peaks of the ligand, the characteristic absorptions of $\text{C}=\text{N}$ and $\text{C}-\text{N}$ in the ring of pyrimidine, as well as those of stretching vibration and bending vibration of $\text{N}-\text{H}$ connected with the ring, have the shifts of 27 cm^{-1} , 14 cm^{-1} , 12 cm^{-1} , and 16 cm^{-1} for the complex *I* and of 18 cm^{-1} , 15 cm^{-1} , 12 cm^{-1} , and 14 cm^{-1} for the complex *II*. In addition, the stretching vibration and bending vibration of $\text{C}-\text{H}$ in the place of β of

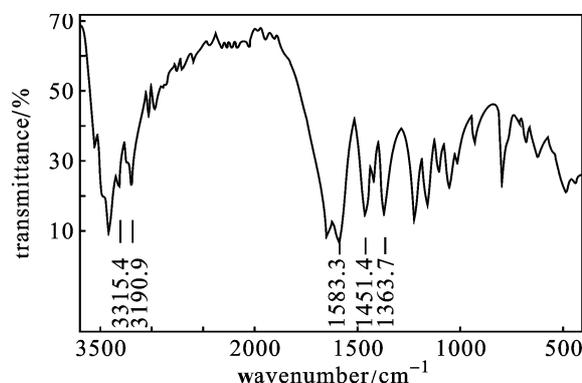


Fig. 1. IR spectra of AMP.

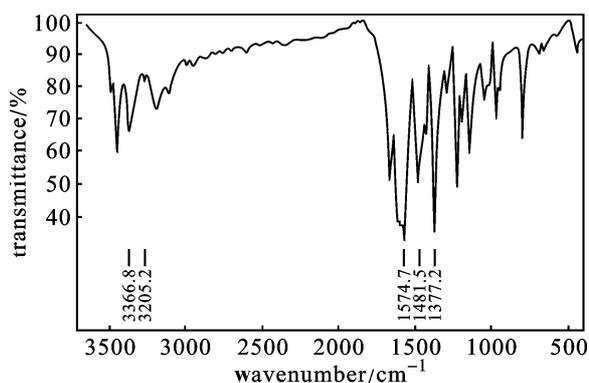


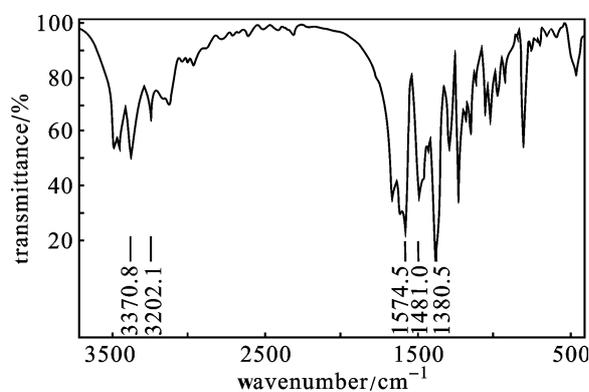
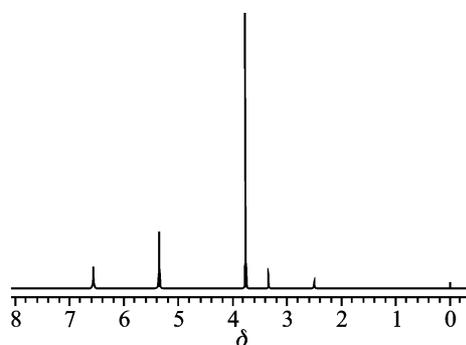
Fig. 2. IR spectra of the complex *I*.

Table 1. Binding Energy Data/eV

Compound	N _{1s} (amino)	N _{1s} (the ring of pyrimidine)	N _{1s} (nitric acid)	Cl _{2p_{3/2}}	Cu _{2p_{3/2}}
AMP	400.1	398.2	–	–	–
CuCl ₂ · 2H ₂ O	–	–	–	199.1	935.2
Cu(NO ₃) ₂ · 3H ₂ O	–	–	407.0	–	935.5
<i>I</i>	399.7	399.9	–	198.9	935.8
<i>II</i>	399.2	398.8	407.1	–	935.9

Table 2. Chemical Shifts and Peak Areas of the Main Groups for AMP, *I*, and *II*

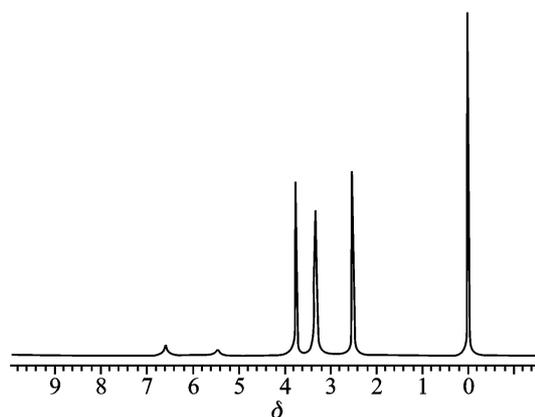
Compound	Chemical shift, δ		
AMP	3.757 (s, 6H, —OCH ₃)	5.347 (s, 1H, =CH [–])	6.563 (s, 2H, —NH ₂)
<i>I</i>	3.762 (s, 12H, —OCH ₃)	5.421 (s, 2H, =CH [–])	6.559 (s, 4H, —NH ₂)
<i>II</i>	3.790 (s, 12H, —OCH ₃)	5.752 (s, 2H, =CH [–])	6.679 (s, 4H, —NH ₂)

**Fig. 3.** IR spectra of the complex *II*.**Fig. 4.** ¹H NMR spectra of AMP.

the pyrimidine ring shift 51 cm^{–1} and 44 cm^{–1}, separately. Based on the analyses above, it is shown that for the ligand the nitrogen atom of the amino group and one of the nitrogen atoms of the pyrimidine coordinate to Cu²⁺ in bidentate fashion. The vibration of Cl[–] in the complex *I* occurs in the fingerprint region of 200–4000 cm^{–1}, which is difficult to show in the recorder. As for the characteristic absorption of NO₃[–], it has a little shift after the ligand coordinates to Cu²⁺. This indicates that NO₃[–] does not participate in coordination to Cu²⁺.

Consulting Ref. [15], the binding energy data of the internal shell electron for the main atoms of the compounds obtained from XPS spectra of the complexes are listed in Table 1.

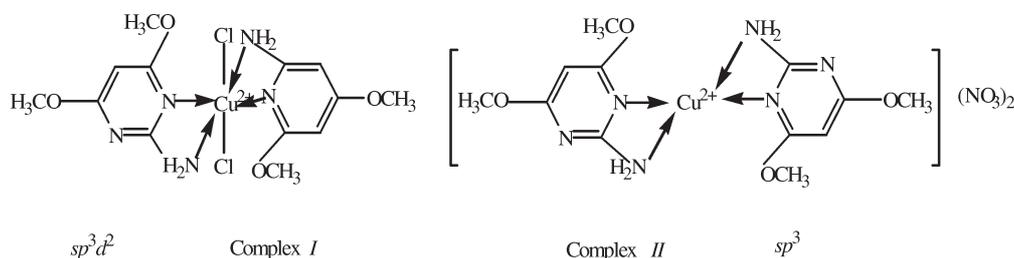
Three conclusions could be drawn from the analyses of the binding data. 1. Comparing the binding energy of N_{1s} of the amino group and that of N_{1s} of the pyrimidine ring, there are changes for those of the complexes, which show that nitrogen atom of the amino group and one of the nitrogen atoms in the pyrimidine coordinate to Cu²⁺. The decrease of the binding energy could be interpreted that rather amount of feedback of *d* electrons existing in the co-

**Fig. 5.** ¹H NMR spectra of the complex *I*.

ordination bond of N → Cu²⁺ leads to the increase of the electron cloud density of N_{1s}. 2. The binding energy of Cl[–] for the complex *I* distinctly changes while that of NO₃[–] in the complex *II* does not, due to which it is assumed that Cl[–] coordinates to Cu²⁺, and NO₃[–] does not. 3. For the complexes *I* and *II*, the binding energy of Cu²⁺ has changes of 0.6 eV and 0.4 eV and the ranges of the differences are not wide,

Table 3. The Experimental Results for Combustion Energies of AMP, *I* and *II*

Compound	No.	Mass of sample <i>m/g</i>	Calibrated heat of combustion wire q_c/J	Calibrated heat of acid containing nitrogen q_n/J	Calibrated $\Delta T/K$	Combustion energy of sample $-\Delta_c E/(J g^{-1})$
AMP	1	0.77961	12.60	67.17	0.9369	21530.39
	2	1.03304	12.60	89.38	1.2400	21509.09
	3	1.90079	12.60	78.28	1.0912	21560.98
	4	1.00319	12.60	86.60	1.2038	21501.25
	5	1.01272	12.60	87.42	1.2179	21509.37
	6	1.00303	12.60	86.58	1.2040	21509.15
	mean					
<i>I</i>	1	1.04940	9.90	267.32	0.7604	12779.23
	2	0.96142	12.60	259.08	0.6979	12784.50
	3	1.03259	12.60	278.27	0.7505	12801.34
	4	1.01072	12.60	272.37	0.7327	12767.54
	5	1.04230	12.60	280.88	0.7557	12770.37
	6	1.00791	12.60	271.61		12787.69
	mean					
<i>II</i>	1	1.13521	12.60	49.60	0.8323	13142.87
	2	1.03178	12.60	35.14	0.7523	13078.30
	3	1.10030	12.60	43.03	0.8048	13115.82
	4	1.07489	12.60	42.03	0.7850	13095.92
	5	1.05302	12.60	41.18	0.7693	13099.87
	6	1.09941	12.60	42.99	0.8045	13121.69
	mean					

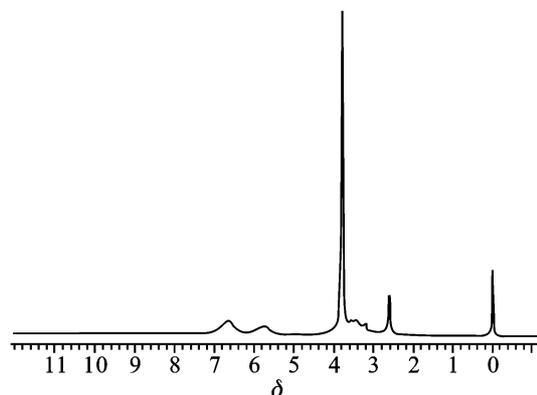
**Formula 1.** Presumed structures of complexes *I* and *II*.

which illustrates certain degree of feedback bond existing in the coordination bond. It is coincidental that the conclusion corresponds to the result of the analysis of infrared spectrum.

^1H NMR spectra of the ligand and the complexes are depicted in Figs. 4–6. The chemical shifts for the main group are illustrated in Table 2. Combining the data of these two sources, four of nitrogen atoms coordinate to Cu^{2+} for the complexes *I* and *II*.

Based on the analytical results above, it is assumed that Cu^{2+} in the complexes *I* and *II* hybridizes separately in sp^3d^2 and sp^3 , with the coordination number of 6 and 4. The structures of the complexes are presumed in Formula 1.

Standard enthalpies of formation of ligand and complexes were studied. The determination method of constant-volume combustion energy for the sample was the same as the calibration of the calorimeter with benzoic acid. The combustion energies of the samples

**Fig. 6.** ^1H NMR spectra of the complex *II*.

were calculated by the formula

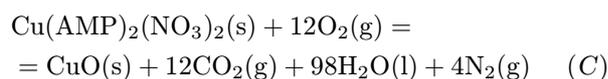
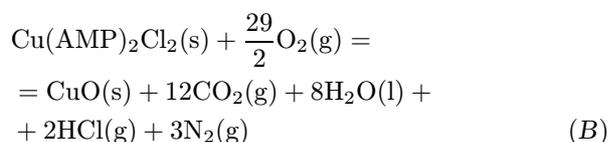
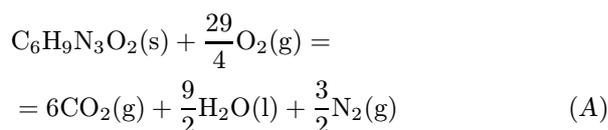
$$\Delta_c E(s) = \frac{W\Delta T - aG - 5.983 \text{ J cm}^{-3} \cdot b}{m} \quad (1)$$

Table 4. Combustion Energies, Standard Enthalpies of Combustion, and Standard Enthalpies of Formation of AMP, I, and II

Compound	$-\Delta_{c,\text{compound}(s)}E/(\text{kJ mol}^{-1})$	$-\Delta_{c,\text{compound}(s)}H_m^0/(\text{kJ mol}^{-1})$	$-\Delta_{f,\text{compound}(s)}H_m^0/(\text{kJ mol}^{-1})$
AMP	3340.01±1.54	3339.39±1.54	307.91±1.74
I	5684.22±2.24	5678.02±2.24	1670.59±2.73
II	6526.47±4.59	6516.55±4.59	933.27±4.85

where $\Delta_c E(s)$ denotes the constant-volume combustion energy of the samples, W is the energy equivalent of the RBC-III-type calorimeter (in J K^{-1}), ΔT the correct value of the temperature rising, a the length of actual Ni—Cr wire consumed (in cm), G the combustion enthalpy of Ni—Cr wire for ignition (0.9 J cm^{-1}), 5.983 the formation enthalpy and solution enthalpy of nitric acid corresponding to 1 cm^3 of $0.1000 \text{ mol cm}^{-3}$ solution of NaOH (in J cm^{-3}), b the volume in cm^3 of consumed $0.1000 \text{ mol dm}^{-3}$ solution of NaOH, and m the mass in g of the sample. The results of the calculations are given in Table 3.

The standard combustion enthalpy of the compounds, $\Delta_c H_m$, was referred to the combustion enthalpy change of the following ideal combustion reaction at 298.15 K and 101.325 kPa.



The standard combustion enthalpies of the samples were calculated by the following equations

$$\Delta H_{m,c} = \Delta E_c + \Delta nRT \quad (2)$$

$$\Delta n = n_g(\text{products}) - n_g(\text{reactants}) \quad (3)$$

where n_g is the total amount of substance of gases present as products or reactants, $k = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$, $T = 298.15 \text{ K}$. The results of the calculations are given in Table 4.

The standard enthalpies of formation of the samples, $\Delta_f H_m^0$, were calculated by Hess' law according to the following thermochemical equations

$$\begin{aligned} \Delta_{f,\text{AMP}(s)}H_m^0 &= \left[6\Delta_{f,\text{CO}_2(\text{g})}H_m^0 + \frac{9}{2}\Delta_{f,\text{H}_2\text{O}(\text{l})}H_m^0 \right] - \\ &- \Delta_{c,\text{AMP}(s)}H_m^0 \end{aligned} \quad (4)$$

$$\begin{aligned} \Delta_{f,\text{Cu}(\text{AMP})_2\text{Cl}_2(\text{s})}H_m^0 &= \left[\Delta_{f,\text{CuO}(\text{s})}H_m^0 + \right. \\ &+ 12\Delta_{f,\text{CO}_2(\text{g})}H_m^0 + 8\Delta_{f,\text{H}_2\text{O}(\text{l})}H_m^0 + \end{aligned}$$

$$\left. + 2\Delta_{f,\text{HCl}(\text{g})}H_m^0 \right] - \Delta_{c,\text{Cu}(\text{AMP})_2\text{Cl}_2(\text{s})}H_m^0 \quad (5)$$

$$\begin{aligned} \Delta_{f,\text{Cu}(\text{AMP})_2(\text{NO}_3)_2(\text{s})}H_m^0 &= \left[\Delta_{f,\text{CuO}(\text{s})}H_m^0 + \right. \\ &+ 12\Delta_{f,\text{CO}_2(\text{g})}H_m^0 + 9\Delta_{f,\text{H}_2\text{O}(\text{l})}H_m^0 \left. \right] - \\ &- \Delta_{c,\text{Cu}(\text{AMP})_2(\text{NO}_3)_2(\text{s})}H_m^0 \end{aligned} \quad (6)$$

where $\Delta_{f,\text{CuO}(\text{s})}H_m^0 = -155.23 \text{ kJ mol}^{-1}$, $\Delta_{f,\text{CO}_2(\text{g})}H_m^0 = -393.51 \pm 0.13 \text{ kJ mol}^{-1}$, $\Delta_{f,\text{H}_2\text{O}(\text{l})}H_m^0 = (-285.83 \pm 0.042) \text{ kJ mol}^{-1}$, $\Delta_{f,\text{HCl}(\text{g})}H_m^0 = (-92.31 \pm 0.03) \text{ kJ mol}^{-1}$ [16]. The detailed list of the results of the calculations is presented in Table 4.

As shown in Table 4, if thermostabilizations of the complexes are compared with that of the ligand, their values decrease in the order $\text{Cu}(\text{AMP})_2\text{Cl}_2$, $\text{Cu}(\text{AMP})_2(\text{NO}_3)_2$, AMP, which relates with the structures of the substances.

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