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Thermal behaviour of new Cu(II) complexes with Schiff bases functionalised with 1,3,5-triazine moieties as potential antibacterial agents

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Abstract New complexes of type $[Cu(L^1)_2(OH_2)]\cdot 4H_2O$ (**1**), $[Cu(L^2)(OH_2)]\cdot 0.5H_2O$ (**2**) and $[Cu_3(L^3)_2(OH_2)_3]\cdot 0.5H_2O$ (**3**) were synthesized by [1 + 1], [1 + 2] and [1 + 3], respectively, template condensation of 2,4,6-triamino-1,3,5-triazine and salicylic aldehyde in the presence of copper(II). The features of complexes have been established from microanalytical, IR and UV–Vis data. The thermal analyses have evidenced the thermal intervals of stability and also the accompanying thermodynamic effects. Processes as water elimination and oxidative degradation of the organic ligands were observed. After water elimination, complexes revealed a similar thermal behaviour. The final product of decomposition was copper(II) oxide as powder X-ray diffraction indicated.

Keywords Copper(II) complex · Schiff base · Template condensation · 1,3,5-triazine · Thermal behaviour

Introduction

1,3,5-Triazine motif represents an important building block in medicinal chemistry. These derivatives display a broad range of biological activities, including cytotoxic [1–4], antimalarial [5, 6], anti-Trypanosoma [7, 8], antimicrobial [9, 10], antiviral [11] as well as tumour antiangiogenic activities [12, 13]. The ability of such derivatives to inhibit glucocerebrosidase with potential in Gaucher disease treatment was evidenced recently [14]. Moreover, the potential as anticancer agents resulted from Grb2 (growth factor receptor-bound protein-2, factor that mediates protein–protein interactions in tyrosine kinase signal transduction pathways) inhibition was shown [15].

1,3,5-Triazine derivatives were also widely used as building blocks in order to obtain supramolecular complexes, which posses interesting magnetic behaviour [16, 17]. Furthermore, some of these complexes have demonstrated a very good cytotoxic activity [18–20] or ability to perform the DNA cleavage [21]. Also, complexes with Schiff bases derived from 1,2,4-triazine display antibacterial activities against both Gram-negative and Gram-positive strains [22].

Thermal stability of some complexes with triazine derivatives was also investigated and indicated that after water elimination, the triazine ligand is removed from complex up to 500 °C [23].

In order to improve the antimicrobial activity of Cu(II) complexes with 1,3,5-triazine derivatives, new complexes with such units incorporated in Schiff bases ligands have been synthesized and characterized. The complexes have been characterized by different analytical and spectral methods.

The thermal behaviour of these derivatives was investigated by thermal analysis (TG, DTA) in order to evidence the modifications appeared at heating and also the thermodynamics effects that accompany them.

Experimental

All reagents were of commercial analytical quality and have been used without further purification. Chemical analysis of carbon, nitrogen and hydrogen has been

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performed using a Perkin Elmer PE 2400 analyzer. Copper was determined volumetrically using thiosulfate method.

IR spectra were recorded in KBr pellets with a Bruker Tensor 37 spectrometer in the range 400–4000 cm^{-1}.

Electronic spectra by diffuse reflectance technique, with spectralon as standard, were recorded in the range 200–1500 nm, on a Jasco V670 spectrophotometer.

The heating curves (T, TG and DTA) were recorded using a Labsys 1200 SETARAM instrument, with a sample mass of 6–17 mg over the temperature range of 20–1000 °C, using a heating rate of 10 K/min. The measurements were carried out in synthetic air atmosphere (flow rate 16.66 cm^3/min) using alumina crucibles.

The X-ray powder diffraction patterns were collected on a DRON-3 diffractometer with a nickel filtered Cu K_α radiation ($\lambda = 1.5418$ Å) in 2θ range of 5°–70°, a step width of 0.05° and an acquisition time of 2 s per step.

Synthesis and spectral data of complexes

Synthesis of complexes

To a solution containing 15 mmol copper(II) acetate monohydrate in 50 mL methanol was added 15/30/30 mmol salicylic aldehyde and then a solution obtained by 15/15/10 mmol 2,4,6-triamino-1,3,5-triazine (melamine) dissolution in 50 mL methanol. The reaction mixture was refluxed for 48 h, until a sparingly soluble species was formed. The precipitate was filtered off, washed with ethanol and air-dried.

IR (KBr pellet), cm^{-1}: $[Cu(L^1)_2(OH_2)]\cdot 4H_2O$ (**1**): ν(OH), 3446w; $\nu_{as}(NH_2)$, 3469m, 3419m; $\nu_s(NH_2)$, 3336m, 3133m; ν(C=N), 1651m, 1613vs, 1551vs; ν(C–O), 1145w; ν(C–N), 1026w; $[Cu(L^2)(OH_2)]\cdot 0.5H_2O$ (**2**): ν(OH), 3440m, sh.; $\nu_{as}(NH_2)$, 3469m, 3419m; $\nu_s(NH_2)$, 3333m, 3135m; ν(C=N), 1653i, 1611vs, 1574vs; ν(C–O), 1149w; ν(C–N), 1023w; $[Cu_3(L^3)_2(OH_2)_3]\cdot 0.5H_2O$ (**3**): ν(OH), 3341w; ν(C=N), 1653m, 1611vs, 1595s; ν(C–O), 1149w; ν(C–N), 1022w.

Results and discussions

Synthesis and physico-chemical characterization of complexes

In this article, we report the physico-chemical as well as thermal characterization of Cu(II) complexes with Schiff base bearing 1,3,5-triazine moieties. The complexes $[Cu(L^1)_2(OH_2)]\cdot 4H_2O$ (**1**), $[Cu(L^2)(OH_2)]\cdot 0.5H_2O$ (**2**) and $[Cu_2(L^3)_2(OH_2)_3]\cdot 0.5H_2O$ (**3**), respectively, were synthesized by the [1 + 1] (HL^1), [1 + 2] (H_2L^2) and [1 + 3] (H_3L^3) template condensation of 2,4,6-triamino-1,3,5-triazine with salicylic aldehyde in the presence of copper(II) acetate. The chemical analyses are in accord with formulas proposed for complexes. The complexes behave as antimicrobials against some multidrug-resistant germs; these results will be published elsewhere.

The major IR spectral features of complexes (experimental part) indicate that the ligands in anionic form coordinate as chelates. In the complexes spectra bands characteristic for some fragments provided for the Schiff bases both by salicylic aldehyde and 2,4,6-triamino-1,3,5-triazine can be identified. In addition, a new band about 1610 cm^{-1} can be assigned to the $\nu(C = N)$ stretching vibration for the new azomethine bond resulted after condensation. In comparison with the free ligands obtained by organic component condensation, this band is slightly shifted to lower wavenumbers as result of ligands coordination through nitrogen atom of the azomethine group. The stretching bands characteristic for the phenolic group are missing from the spectra but instead the bands assigned to ν(C–O) vibrations are also shifted to lower wavenumbers. This behaviour indicates the ligands deprotonation and coordination through phenolic oxygen atoms [24]. It is to be pointed out that in the spectrum of complex (**3**), the bands' characteristic for the primary amine group is missing. In the characteristic ranges for water, a band or a shoulder about 3400 cm^{-1} can be assigned to ν(OH) stretching vibrations [25].

The electronic spectra of compounds (**1**) and (**2**) show a broad band with maximum about 9200 cm^{-1} and shoulder at higher wavenumbers, pattern characteristic for a trigonal bipyramidal stereochemistry. A band with maximum at 17100 cm^{-1} and a shoulder at lower wavenumbers indicates for complex (**3**) rather a square-pyramidal stereochemistry [26].

The coordination proposed for the new complexes based on these data is presented in Fig. 1.

Thermal behaviour of complexes

The thermal behaviour of complexes was studied in air in 20–900 °C temperature range. The thermal decomposition data are summarized in Table 1.

The TG and DTA curves corresponding to the complex (**1**) indicate that decomposition follows three well-defined steps (Fig. 2).

Thus, the first step of compound thermal transformation starts at 160 °C and consists in an endothermic elimination of water (Table 1). A difference between coordinated or crystallization water molecules was not observed, a behaviour that indicates that the water molecules are involved in strong hydrogen bonds in the compound network. Such behaviour was observed for other complexes as well [27]. The second step, exothermic, is not a single one being an overlapping of at least two processes as DTA

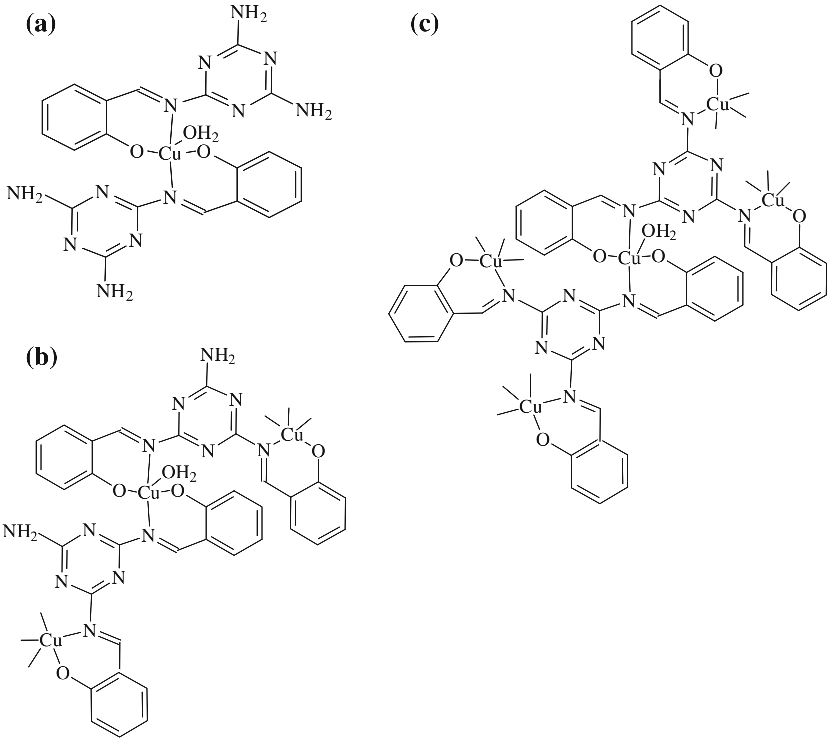

Fig. 1 The proposed coordination for [**a** Cu(L^1)$_2$(OH_2)]·$4H_2O$ (**1**), **b** [Cu(L^2)(OH_2)]·$0.5H_2O$ (**2**) and **c** [Cu_2(L^3)$_2$(OH_2)$_3$]·$0.5H_2O$ (**3**)

Table 1 Thermal behaviour data (in synthetic air atmosphere) for complexes

Complex	Step	Thermal effect	Temperature range/°C	Δm_{exp}/%	Δm_{calc}/%
[Cu(L^1)$_2$(OH_2)]·$4H_2O$ (**1**)	1.	Endothermic	160–219	14.3	14.7
	2.	Exothermic	219–353	29.7	29.8
	3.	Exothermic	353–525	42.4	42.5
	Residue CuO			13.6	13.0
[Cu(L^2)(OH_2)]·$0.5H_2O$ (**2**)	1.	Endothermic	64–140	1.9	2.1
	2.	Endothermic	140–200	4.1	4.3
	3.	Exothermic	200–380	43.2	43.1
	4.	Exothermic	360–830	31.6	31.7
	Residue CuO			19.2	18.8
[Cu_3(L^3)$_2$(OH_2)$_3$]·$0.5H_2O$ (**3**)	1.	Endothermic	60–147	0.5	0.8
	2.	Endothermic	147–205	4.4	4.8
	3.	Exothermic	205–380	48.5	48.3
	4.	Exothermic	380–820	26.2	26.3
	Residue CuO			20.4	19.8

curve indicates. This step corresponds to the partial oxidative degradation of Schiff base L^1. Next step, exothermic also, corresponds to oxidative degradation of remaining organic part. This consists in at least two processes according to DTA curve profile. The final product is CuO as powder X-ray diffraction indicates (ASTM 5-661) (found/calcd. overall mass loss: 80.8/81.2).

For the complex (**2**), the water molecule are stepwise eliminated namely the crystallization one up to 140 °C while the coordination one in 140–200 °C temperature range, both steps being endothermic (Fig. 3). This behaviour was revealed to other complexes also [28, 29]. The third step, exothermic, is not a single one being an overlap of at least three processes as both TG and DTA curves indicate. This step corresponds to the partial Schiff base L^2 oxidative degradation. Next step, exothermic also, corresponds to the rest of organic part oxidative degradation and consists in at least four processes (according to DTA curve profile) and leads also to CuO as final product (found/calcd. overall mass loss: 80.8/81.2).

The decomposition of complex (**3**) comprises also four steps and starts with water elimination, in two well-defined

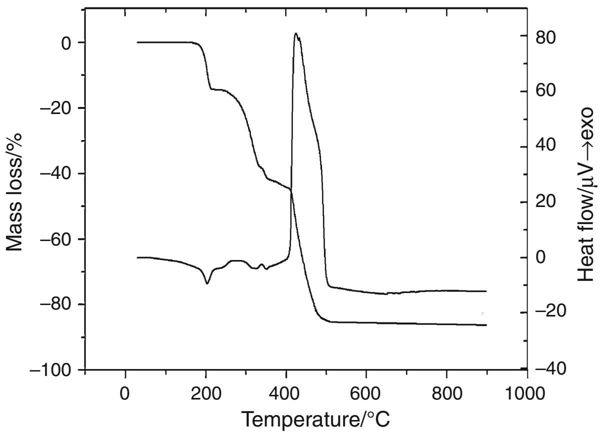

Fig. 2 TG and DTA curves for $[Cu(L^1)_2(OH_2)]\cdot4H_2O$ (**1**)

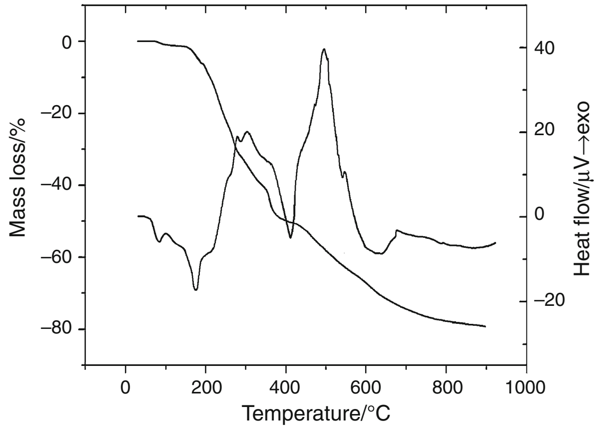

Fig. 3 TG and DTA curves for $[Cu(L^2)(OH_2)]\cdot0.5H_2O$ (**2**)

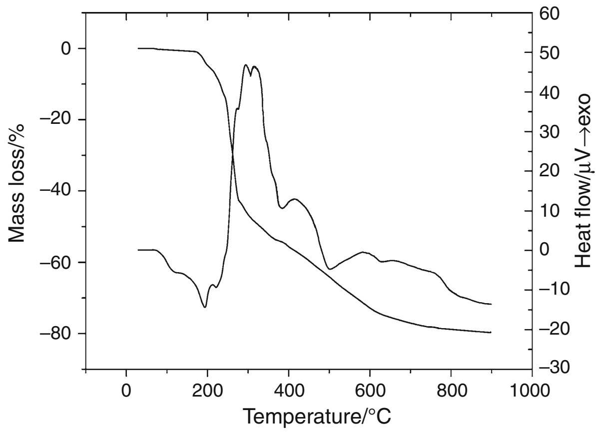

Fig. 4 TG and DTA curves for $[Cu_2(L^3)_2(OH_2)_3]\cdot0.5H_2O$ (**3**)

endothermic processes. First process that occurs at low temperatures (Fig. 4) corresponds to crystallization water elimination, while the second one up to 205 °C is associated with the removal of the coordination water.

The thermal oxidative degradation of the anhydrous species starts immediately and comprises two steps. The third step occurs in three exothermic processes as both TG and DTA profile indicate. Again the mass loss indicates a partial degradation of the Schiff base L^3. More overlapped processes that lead to a broad and not well-structured DTA signal can be noticed in the last step. Finally, the oxidative degradation leads to CuO in accord with the overall mass loss (found/calcd: 79.6/80.2).

Conclusions

Three novel Cu(II) complexes with Schiff bases resulted in [1 + 1], [1 + 2] and [1 + 3] template condensation of 2,4,6-triamino-1,3,5-triazine with salicylic aldehyde were synthesised and characterized in order to obtain new effective antimicrobial agents.

The modifications in the IR spectra of ligands are in accord with the condensation process and indicate the coordination as chelating ligands through azomethine nitrogen and phenolic oxygen atoms in anionic form. Electronic spectra are characteristic for a square-pyramidal or trigonal bipyramidal stereochemistry.

Thermal decomposition of complexes allowed establishing the number and nature of water molecule, the composition of complexes and also the intervals of thermal stability. The thermal degradation occurs in three or four steps. After water elimination in one or two well-defined events, the complexes suffer oxidative degradation in two steps leading to copper(II) oxide as final product.

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