THERMAL STUDIES ON SULPHONAMIDE DERIVATIVE COMPLEXES. PART 1. THERMAL BEHAVIOUR OF ACETAZOLAMIDE *-COPPER COMPLEXES

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ABSTRACT

The thermal behaviour of the complexes $CuAcm(NH_3)_3$, $CuAcm(NH_3)_2 \cdot 2H_2O$, *** $CuAcm(NH_3) \cdot H_2O$ and $Cu_3Acm(OH)_4 \cdot 3H_2O$ has been studied by TG and DTA techniques in flowing air and nitrogen atmospheres as well as by IR spectroscopy.

The complexes decompose in two steps: (a) dehydration and/or deammination and (b) pyrolytic decomposition to copper oxides and copper sulphides. The second step is accompanied by an increase in mass and a strong exothermic peak, attributed to the oxidation of copper sulphides to cupric sulphate. Obviously, this oxidation process does not take place in a nitrogen atmosphere.

INTRODUCTION

In recent years, the study of the interactions between transition metal ions and some biological molecules has received increasing attention because of the chemotherapeutic effects shown by some of these complexes. We have initiated studies on the coordination chemistry of the complexes of acetazolamide (Acm) (see formula), a sulphonamide with diuretic properties, and its derivatives [1–3]. In order to augment the chemical information concerning these complexes, we here describe the thermal behaviour of copper(II) complexes of Acm.

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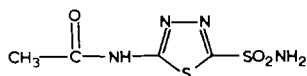
* Acetazolamide (Acm) is 5-acetamido-1,3,4-thiadiazole-2-sulphonamide.
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*** The compound is a dimer of the formula: $[CuAcm(NH_3)_2(OH_2)]_2 \cdot 2H_2O$.

EXPERIMENTAL

Apparatus

Thermogravimetric analyses were made in air and nitrogen atmospheres using Perkin–Elmer 3600 and DTA 1700 instruments at different heating rates (5, 10 and 20°C min^{-1}). The DSC curves were obtained under the same experimental conditions. Peak integration and subsequent enthalpy calculations were performed using the Perkin–Elmer System 7/4 partial area integration program. The latent heat of fusion of pure indium metal ($\Delta H = 28.4$ J g^{-1}) was used for calibration. Thermolytic reactions were obtained with samples varying in weight from 3.0 to 5.0 mg.

IR spectra were obtained using KBr pellets on a Perkin–Elmer 843 spectrophotometer.

Samples

The complexes CuAcm(NH$_3$)$_3$, CuAcm(NH$_3$)$_2 \cdot 2$H$_2$O, CuAcm(NH$_3$)$\cdot$ H$_2$O and Cu$_3$Acm(OH)$_4 \cdot 3$H$_2$O were prepared as previously described [3].

RESULTS AND DISSCUSION

TG, DTG and DTA curves for the complexes are given in Figs. 1–4. Confirmation of the proposed processes was achieved by collection and IR analysis of the compounds evolved, and by visual observation of the colour of the residues.

Thermal decomposition of the copper–acetazolamide complexes takes place in two stages: (a) dehydration and/or deammination, and (b) pyrolytic decomposition.

(a) Dehydration and/or deammination processes

CuAcm (NH$_3$)$_3$

The TG curve (Fig. 1) shows that the complex CuAcm(NH$_3$)$_3$ is stable up to 60°C. Then, deammination occurs in two steps: the first one (60–200°C) involves the loss of two ammonia molecules (exp. 11.0%, calc. 10.2%); the loss of the third ammonia molecule overlaps with the ligand pyrolytic decomposition.

The DTA curve shows an undefined broad endothermic region from 40 to 150°C and an endothermic peak between 150 and 200°C ($\Delta H = 112.0$ kJ mol^{-1}). From the temperature range and the low ΔH value [4,5] it is not clear if the loss of the third ammonia molecule is included in these endothermic processes. On the other hand, the next event in the DTA curve
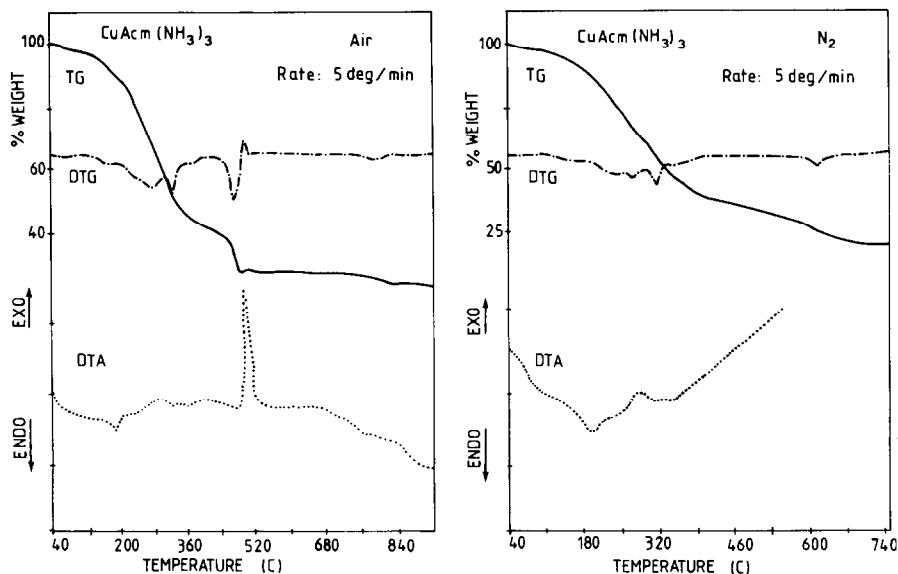
Fig. 1. TG, DTG and DTA thermograms for CuAcm(NH$_3$)$_3$ in air and N$_2$ at 5°C min^{-1}.

does not begin until 265°C, which probably corresponds to the start of the decomposition. Finally, as deammination begins at low temperatures, it appears that at least one of the ammonia molecules is not coordinated with the metal ion.
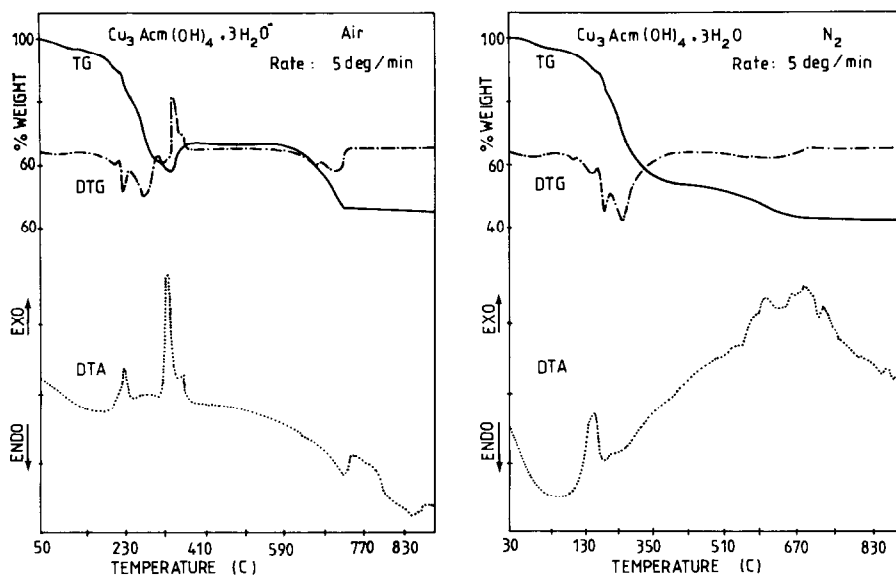

Fig. 2. TG, DTG and DTA thermograms for Cu$_3$Acm(OH)$_4$·3H$_2$O in air and N$_2$ at 5°C min^{-1}.
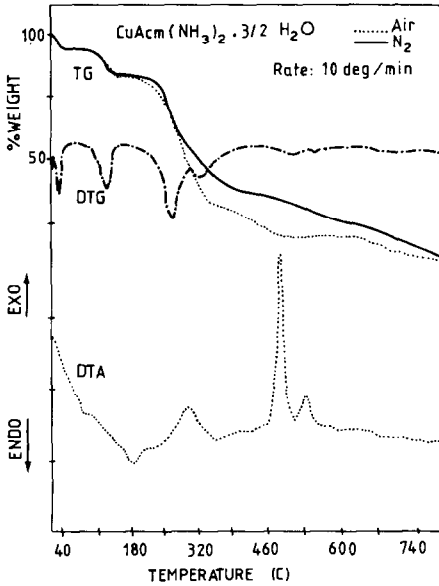
Fig. 3. TG, DTG and DTA thermograms for $CuAcm(NH_3)_2 \cdot 2H_2O$ in air at $10°C$ min^{-1} and TG thermogram in N_2 at $10°C$ min^{-1}.

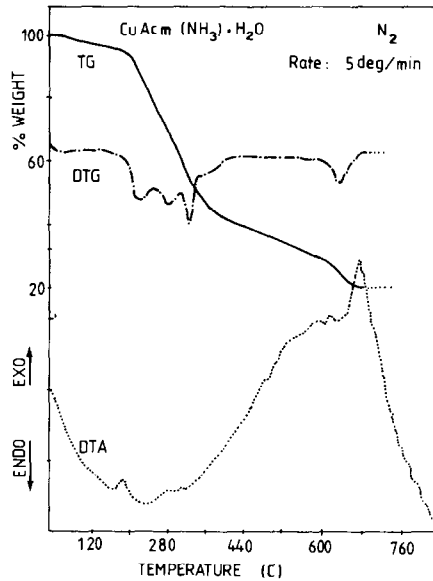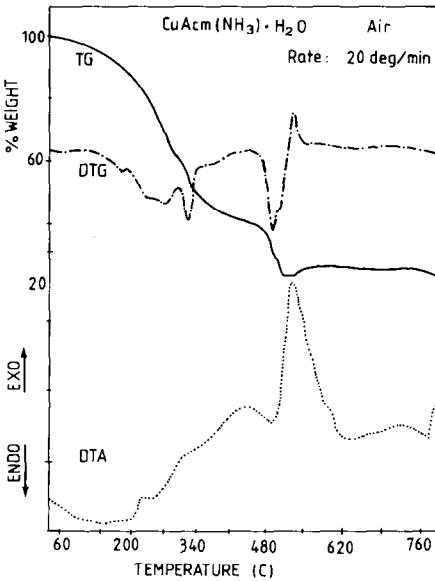
Fig. 4. TG, DTG and DTA thermograms for $CuAcm(NH_3) \cdot H_2O$ in air at $20°C$ min^{-1} and N_2 at $5°C$ min^{-1}.
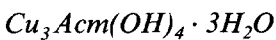
$Cu_3Acm(OH)_4 \cdot 3H_2O$

Dehydration of the $Cu_3Acm(OH)_4 \cdot 3H_2O$ complex takes place in two consecutive steps (Fig. 2). The first weight loss, observed in the TG curve

between 40 and 210°C, corresponds to the liberation of the three water molecules (calc. 10.1%, exp. 11.0%). The expected endothermic behaviour for this process appears in the DTA curve in the same temperature range. The second step, between 210 and 230°C, is attributed to the condensation of the OH groups (calc. 6.8%, exp. 5.8%). The DTA curve shows an exothermic peak, which is the combination of an endothermic peak corresponding to the dehydration and an exothermic peak of higher energy assigned to a structural change associated with the condensation process [6].
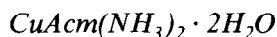
$CuAcm(NH_3)_2 \cdot 2H_2O$

The TG and DTA curves of $CuAcm(NH_3)_2 \cdot 2H_2O$ show two well-separated thermal events (Fig. 3). The first (30–70°C), of about 9.0% mass loss, corresponds to the elimination of 1/2 mol of water and and 1 mol of ammonia (calc. 10.2%). The second (70–160°C) is due to the removal of one water and one ammonia molecule (calc. 10.2%, exp. 10.5%). The DTA curve, with two endothermic peaks centred at 80 and 180°C respectively, is consistent with the thermogravimetric results. The preceding assignment has been made according to the X-ray crystal structure of the compound [3], which indicates that only one water molecule and one ammonia molecule are coordinated to the Cu(II) ion (bond lengths: $Cu-OH_2 = 2.011$ Å and $Cu-NH_3 = 2.012$ Å). The enthalpies of these two steps are 27.7 and 161.1 kJ mol^{-1} respectively. The low value of the first ΔH and the high value of the second, as well as the temperature ranges, are in agreement with the loss of uncoordinated molecules in the first stage and of coordinated ligands in the second.

In the three compounds studied, the deammination and dehydration processes are identical in nitrogen and in air atmospheres.

$CuAcm(NH_3) \cdot H_2O$

The TG curve of the $CuAcm(NH_3) \cdot H_2O$ complex indicates that the dehydration and deammination occur between 40 and 220°C in two overlapping processes (calc. 10.9%, exp. 10.7%). The removal of water and ammonia is accompanied in the DTA curve by a weak endothermic region over the temperature range 40–200°C and an exothermic peak centred at 216°C in air atmosphere and at 195°C in nitrogen atmosphere ($\Delta H = -15.8$ kJ mol^{-1}). The assignment of this exothermic peak is difficult. If it were due only to the ammonia elimination, it would not be exothermic. On the other hand, the temperature range is too low to correspond to ligand degradation, as almost all Acm complexes start decomposition at about 240–260°C [5]. So, the presence of this exothermic peak suggests that a structural change occurs simultaneously with the deammination of the complex.

(b) Pyrolytic decomposition

From TG curves and IR spectra of the samples collected at different temperatures, two different behaviours can be observed: one for complexes

with a ligand metal ratio of 1 : 1 in air and N_2 and for the $Cu_3Acm(OH)_4 \cdot 3H_2O$ in N_2, and another for the $Cu_3Acm(OH)_4 \cdot 3H_2O$ in air.

In the three former compounds, the first stage of the ligand degradation gives a copper–thiadiazole derivative characterized by a broad strong IR band over 1400 cm^{-1} and a medium one at around 600 cm^{-1}, which can be attributed to the st(NCS) vibrations typical of compounds such as the thiadiazoles [7,8]. Furthermore, the carbonyl and sulphonyl bands have disappeared [1,3]. In the next step, a mixture of Cu_2S and CuS is formed (the relative amount of each depending on the starting material). On the other hand, pyrolysis of the $Cu_3Acm(OH)_4 \cdot 3H_2O$ complex leads to a mixture $CuSO_4$ and Cu_2S in flowing air, while in nitrogen, as with the other three compounds, a copper–thiadiazole derivative is formed.

After formation of these mixtures, the TG curves of the four compounds in dynamic air show an increase in weight. As this increase is not observed in nitrogen atmosphere, we propose that it is due to an oxidation process of the sulphides to copper(II) sulphate and copper(II) oxide [9]. Then the sulphate decomposes to give CuO, which is finally transformed to the more thermally stable Cu_2O.

This hypothesis is consistent with the IR spectra of the samples taken before and after the increase in mass. Furthermore, DTA curves in air atmosphere present a very strong exothermic peak in the temperature range of the proposed oxidation reactions, whereas under nitrogen atmosphere no exothermic event is observed, suggesting a relation between the increase in weight and liberation of energy.

CuAcm(NH₃)₃

The TG curve shows that the ligand pyrolysis of $CuAcm(NH_3)_3$ is a three-stage process. The first step, contiguous with the loss of the third ammonia molecule as previously indicated, finishes above 350°C. At this temperature, the species which remains must be a derivative of the thiadiazole ring. The observed weight percentage of the residue is 45.1% and that calculated for the tentative empirical "Cu–C$_2$N$_2$S" is 44.0%.

This stage of the pyrolytic decomposition is accompanied by an exothermic peak in the DTA curve between 265 and 320°C ($\Delta H = -70.0$ kJ mol^{-1}). In the following step, degradation of the ring occurs to give a mixture of copper(I) and copper(II) sulphides at 480°C (exp. 25.8%; calc. for Cu_2S 23.6%, and for CuS 28.5%). The TG curve then indicates an increase in weight. IR spectra of the samples taken at this temperature indicate that cupric oxide is not present among the products produced during these processes. As cuprous sulphide oxidation to cupric sulphate requires copper oxide formation, we propose that it is the cupric sulphide which is transformed to the sulphate. Consequently, at 520°C, the temperature with maximum weight after the rise, the products obtained are cupric sulphate with cuprous sulphide. The DTA curve shows a very strong
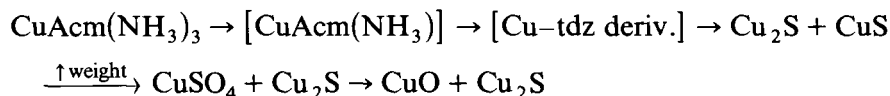
exothermic event composed of several effects between 470 and 530°C which is consistent with the exothermic nature of the preceding oxidation reactions ($\Delta H = -622.2$ kJ mol^{-1}).

The TG curve in the temperature range 520–600°C is nearly horizontal. From 760°C, the weight falls until 820°C, and then stabilizes. The final residue at 900°C is cuprous sulphide and cupric oxide (exp. 22.5%; calc. for Cu_2S 23.6%, and calc. for CuO 23.5%). Cupric oxide should have been formed by decomposition of $CuSO_4$ through the reaction [9]
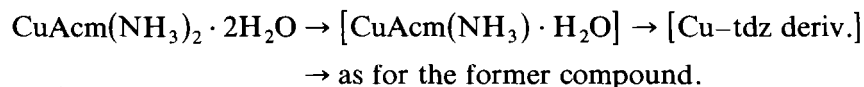
$$CuSO_4 \rightarrow CuO + SO_2 + 0.5O_2$$
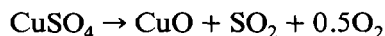
In N_2, the decomposition processes are similar, although slower than in flowing air. Because there are no oxidation reactions in nitrogen, the final residue is Cu_2S (exp. 23.5%, calc. 23.6%).

The following scheme summarizes the thermal decomposition of the compound in air

$$CuAcm(NH_3)_3 \rightarrow [CuAcm(NH_3)] \rightarrow [Cu-tdz\ deriv.] \rightarrow Cu_2S + CuS$$
$$\xrightarrow{\uparrow weight} CuSO_4 + Cu_2S \rightarrow CuO + Cu_2S$$

$CuAcm(NH_3)_2 \cdot 2H_2O$

The thermal pyrolysis of the $CuAcm(NH_3)_3 \cdot 2H_2O$ complex is similar to the preceding one. The DTA curve in air atmosphere shows the characteristic exothermic peak of the ligand decomposition between 230 and 355°C, and the strong exothermic event in the temperature range 450–540°C corresponding to the oxidation. The thermal degradation of the compound in N_2 is the same as in air, although, as observed in the other cases, the ligand degrades more slowly and there is no oxidation process.

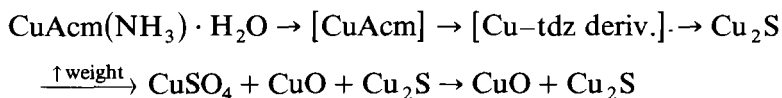The following scheme summarizes the thermal decomposition of the compound in air

$$CuAcm(NH_3)_2 \cdot 2H_2O \rightarrow [CuAcm(NH_3) \cdot H_2O] \rightarrow [Cu-tdz\ deriv.]$$
$$\rightarrow \text{as for the former compound.}$$

$CuAcm(NH_3) \cdot H_2O$

From the TG curve of $CuAcm(NH_3) \cdot H_2O$, a mass loss between 200 and 360°C is observed which is attributed, as before, to the formation of a copper–thiadiazole derivative (exp. 47.3%, calc. 49.0%). The DTA curve shows an exothermic peak in the temperature range 265–345°C, which corresponds to the beginning of the ligand decomposition as previously observed in the Acm complexes ($\Delta H = -21.0$ kJ mol^{-1}). The second and third steps take place between 345 and 490°C and between 490 and 532°C. At 532°C, the principal product obtained is cuprous sulphide (exp. 23.5%, calc. 23.7%). Whereas for the $CuAcm(NH_3)_3$ compound a mixture of Cu(I)

and Cu(II) sulphides was proposed, here the percentages suggest that Cu_2S is the most important component. Furthermore, after the oxidation processes, IR spectra of the residue at around $640°C$ show the presence of CuO, consistent with the oxidation of Cu_2S. The mass increase for this compound is about 4.3%. The products at $640°C$ are $CuSO_4$, CuO and Cu_2S. Although there is no direct evidence for the presence Cu_2S, all the Cu_2S cannot have been transformed because the theoretical percentage of weight would be 37.0% and the observed in only 27.8%. Therefore, Cu_2S oxidation is partial. The expected exothermic behaviour for the mass increase processes associated with this complex is observed from the DTA curve in a similar temperature range as was seen in the other two complexes (490–610$°C$ with a $\Delta H = -490.0$ kJ mol^{-1}).

Moreover, in air, the DTA curve between 700 and 780$°C$ exhibits an endothermic event ($\Delta H = 43.2$ kJ mol^{-1}). The IR spectra of the samples taken at these temperatures and the absence of this peak in this region in the nitrogen DTA curve, suggest that it could be associated with the decomposition of $CuSO_4$ to CuO.

The final residue at 900$°C$ is cuprous sulphide and cupric oxide (exp. 24.9%; calc. for CuO 24.9%, and for Cu_2S 23.7%). In dinitrogen, the final residue is cuprous sulphide (exp. 24.9%, calc. 23.7%).

The following scheme summarizes the thermal decomposition of the compound in air

$$CuAcm(NH_3) \cdot H_2O \rightarrow [CuAcm] \rightarrow [Cu\text{--}tdz \text{ deriv.}] \rightarrow Cu_2S$$

$$\xrightarrow{\uparrow \text{weight}} CuSO_4 + CuO + Cu_2S \rightarrow CuO + Cu_2S$$

$Cu_3Acm(OH)_4 \cdot 3H_2O$

The thermal pyrolysis of $Cu_3Acm(OH)_4 \cdot 3H_2O$ starts with the condensation of the OH groups. The corresponding exothermic peaks in the DTA curve occur between 175 and 240$°C$ and between 250 and 302$°C$ ($\Delta H = -177.0$ and -35.6 kJ mol^{-1} respectively). The IR spectrum of the sample collected at 240$°C$ shows the partial formation of $CuSO_4$ as well as a weak band at around 1400 cm^{-1}. The stoichiometry of the compound and the IR spectra suggest that in this complex $CuSO_4$ must originate not only from oxidation of the thiadiazole ring but also directly from the sulphonamido group.

The degradation of the ligand, completed at 340$°C$, gives a mixture of cupric sulphate and cuprous sulphide (calc. 56.8%, exp. 58.0%), whereas in the preceding Cu–Acm complexes, $CuSO_4$ is formed later (at temperatures above 500–600$°C$) by the oxidation of the sulphides. The presence of the sulphate ion has been confirmed by IR spectroscopy. Formation of the cuprous sulphide has been proposed for several reasons: the IR spectrum at 340$°C$ indicates that there is neither ligand nor oxide bands and so cupric

sulphide must have been formed; the existence of the sulphide at this temperature is necessary to explain the next increase in mass; furthermore, as initially there are only two sulphur atoms and three copper atoms, it is not possible for all the copper to be present as $CuSO_4$ and CuS; and finally, the calculated percentages are in good agreement with the experimental ones.

In the next stage (340–365°C) the cuprous sulphide is completely oxidised and the cupric sulphate partially decomposes, producing a significant increase in mass (10.4%) (exp. 69.4%, calc. for $3/2CuSO_4 + 3/2CuO$ 67.3%). The IR spectrum of a sample obtained at about 400°C shows strong bands at 1250, 1150, 1050 and 1000 cm^{-1} and two medium bands at 610 and 500 cm^{-1}, indicating the presence of $CuSO_4$ and CuO respectively, in the residue [10]. The oxidation process shows two exothermic peaks in the DTA curve in the temperature range 302–390°C ($\Delta H = -879.0$ kJ mol^{-1}) with maxima at 331 and 367°C respectively.
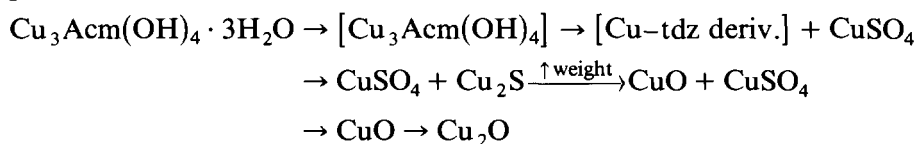
Between 361 and 600°C, the weight remains essentially unchanged. Then decomposition of $CuSO_4$ takes place. Above 730°C, all the $CuSO_4$ has been transformed to CuO (calc. 44.8%, exp. 45.1%), which is slowly reduced to Cu_2O [11] to give a mixture of copper oxides at 1000°C.

In the DTA curve, two endothermic peaks are observed between 660 and 710°C ($\Delta H = 311.0$ kJ mol^{-1}), as occurs in the case of $CuAcm(NH_3) \cdot H_2O$, which is due to decomposition of the sulphate to cupric oxide, and between 795 and 900°C ($\Delta H = 599.0$ kJ mol^{-1}), due to the formation of cuprous oxide.

Pyrolytic decomposition of the compound in N_2 gives a mixture which contains a copper–thiadiazole derivative characterized by the 1400–1500 cm^{-1} IR band. The number of Cu(II) ions bonded to this thiadiazole residue is not clear. The TG percentages at 350°C are consistent with a mixture of copper–thiadiazole derivative and copper sulphides (i.e. calculated for copper–thiadiazole derivative and cuprous sulphide 57.4%, exp. 55.0%).

The final reddish black residue at 830°C is composed of cuprous oxide and sulphide (cal. 43.0%, exp. 41.8%).

The final scheme summarizes the thermal decomposition of the compound in air

$$Cu_3Acm(OH)_4 \cdot 3H_2O \rightarrow \left[Cu_3Acm(OH)_4\right] \rightarrow \left[Cu-tdz\ deriv.\right] + CuSO_4$$
$$\rightarrow CuSO_4 + Cu_2S \xrightarrow{\uparrow weight} CuO + CuSO_4$$
$$\rightarrow CuO \rightarrow Cu_2O$$

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