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THERMAL STUDIES ON PURINE COMPLEXES. IV. THERMAL BEHAVIOUR OF SOME TETRACHLOROAURATES OF XANTHINE DERIVATIVES

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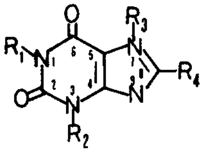
ABSTRACT

Gold compounds $[LH_2^+][AuCl_4]$ (where LH = theophylline, theobromine, 3,8-dimethylxanthine, caffeine and 1,3,8-trimethylxanthine) were prepared in acid medium, and characterized on the basis of IR, ^{1}H-NMR and magnetic studies. The thermal behaviour of these salts was studied using TG, DTG and DSC techniques. Heats of dehalogenation were calculated from DSC curves. These heats fluctuate between 81.8 and 184 3 kJ mole^{-1}.

INTRODUCTION

The importance of metal–nucleic acid and peptide–metal–nucleic acid interactions in living systems has stimulated considerable research in the area of metal interactions with nucleic acid constituents [1–5]. For this reason and following the thermal studies on compounds containing metal ions and xanthine derivatives [6–8], in the present paper, we report the synthesis, characterizations and thermal behaviour of five new compounds of Au(III), with the xanthine derivatives, theophylline (TH), theobromine (TBH), 3,8-dimethylxanthine (DMH), caffeine (C) and 1,3,8-trimethylxanthine (TMH). The molecular structures of these xanthinic derivatives are as shown.



R_1, R_2 = CH_3, $R_3 R_4$ = H (TH)
R_2, R_3 = CH_3, $R_1 R_4$ = H (TBH)
R_2, R_4 = CH_3; R_1, R_3 = H (DMH)
R_1, R_2, R_3 = CH_3; R_4 = H (C)
R_1, R_2, R_4 = CH_3, R_3 = H (TMH)

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EXPERIMENTAL

Materials

Theophylline (TH), theobromine (TBH) and caffeine (C) were purchased from Carlo Erba. 3,8-Dimethylxanthine (DMH) and 1,3,8-trimethylxanthine (TMH) were synthesized according to the methods described in the literature [9,10]. The isolated products were purified and characterized. The values found for the melting points of DMH and TMH (363 and 235°C, respectively) are in accordance with bibliographic data [9,10]. All the results obtained in the characterization of DMH and TMH are in agreement with their molecular structures. All the inorganic products used were of analytical reagent grade.

Methods

Chemical analysis of C, H and N was realized in a Carlo Erba model 1106 microanalyzer. The determination of Au(III) was carried out gravimetrically.

Infrared spectra of the compounds studied were recorded in KBr medium, in the region 4000–200 cm^{-1}, using a Beckmann 4250 spectrophotometer. Using samples in polyethylene pellets, IR spectra were obtained in the 600–200 cm^{-1} region.

The ^{1}H-NMR spectra of the xanthine derivatives and its Au(III) compounds, were recorded on a Hitachi–Perkin-Elmer model R-600 FT-NMR spectrometer, using dimethyl sulfoxide-d_6 as solvent and TMS as internal standard.

TG studies were carried out in a Mettler TG-50 thermobalance, using samples varying in weight from 7.4 to 13.7 mg and at a heating rate of 10°C min^{-1}. The DSC curves were recorded in a Mettler differential scanning calorimeter model DSC-20 at a heating rate of 5°C min^{-1}. The TG and DSC studies were carried out in an atmosphere of pure air.

Preparation of the compounds

Compounds of the type $[LH_2^+][AuCl_4]$ (where LH_2^+ = protonated xanthinic base) were obtained by mixing solutions of 0.012 M HCl, containing 6×10^{-4} mole of xanthine derivative and 6×10^{-4} mole of $[HAuCl_4]$. After a few hours, yellow precipitates appeared, which were filtered, washed consecutively with water and ethanol and dried with ether. Their chemical analysis and colour were as given.

$[TH_2^+][AuCl_4]$ (yellow): calcd. C = 16.2%, H = 1.7%, N = 10.8%, Cl = 27.3%, Au = 37.9%; found C = 16.5%, H = 1.7%, N = 10.9%, Cl = 27.1%, Au = 39.2%.

$[TBH_2^+][AuCl_4]$ (yellow): calcd. C = 16.2%, H = 1.7%, N = 10.8%, Cl =

27.3%, Au = 37.9%; found C = 16.0%, H = 1.7%, N = 10.9%, Cl = 27.1%, Au = 39.2%.

$[DMH_2^+][AuCl_4]\cdot 0.5\ H_2O$ (yellow): calcd. C = 15.9%, H = 1.9%, N = 10.6%, Cl = 26.9%, Au = 37.2%; found C = 16.2%, H = 1.7%, N = 10.6%, Cl = 27.1%, Au = 37.5%.

$[CH^+][AuCl_4]\cdot 2\ H_2O$ (yellow): calcd. C = 16.8%, H = 2.6%, N = 9.8%, Cl = 24.9%, Au = 34.5%; found C = 16.9%, H = 2.9, N = 10.1%, Cl = 26.2%, Au = 33.7%.

$[TMH_2^+][AuCl_4]\cdot 2\ H_2O$ (yellow): calcd. C = 16.8%, H = 2.6%, N = 9.8%, Cl = 24.9%, Au = 34.5%; found C = 17.1%, H = 2.3%, N = 10.3%, Cl = 26.1%, Au = 35.1%.

RESULTS AND DISCUSSION

The IR data of the isolated compounds are tabulated in Table 1, together with those corresponding to xanthinic bases [11,12]. The new bands due to protonation of the bases in the 3200–2700 cm^{-1} range, were assigned to $\overset{+}{N}-H$ stretching.

The protonation of these xanthine derivatives probably occurs in all cases in the N_9 position. Likewise, the IR spectra of these Au(III) compounds show shifts to higher wavenumber of the bands corresponding to stretching vibrations $\nu(C{=}C)$ and $\nu(C{=}N)$, compared with the position of these bands in the free xanthine derivatives. These shifts are attributed to the protonation, since an increase in the electron density at the carbon atoms adjacent to the protonated nitrogen has been calculated theoretically for some nitrogen heterocyclic molecules [13]. Finally, all the compounds isolated present a new band in the 350–355 cm^{-1} range, which was assigned to $\nu(Au-Cl)$ in the $[AuCl_4]^-$ square-planar anion [14].

The square-planar nature of the $[AuCl_4]^-$ anion was confirmed by magnetic measurements, because the Au(III) compounds isolated are not paramagnetic.

^1H-NMR spectra of the $[LH_2^+][AuCl_4]$ compounds in DMSO-d_6 show a downfield shift of the signals, corresponding to the protons bonding to C(8) [15,16], compared with the positions of those signals in the free bases, which is compatible with the positive character on the imidazole ring due to protonation [17]. The previous data suggest that these compounds are salts, in which the charge of the $[AuCl_4]^-$ anion is neutralized by a molecule of protonated xanthine derivative. These salts are similar to that obtained in the reaction between hypoxanthine and $[AuCl_4]^-$ [18].

Figures 1 and 2 show TG and DSC plots of these new gold compounds. The thermal behaviour of these compounds consist of three major processes: (i) dehydration, (ii) dehalogenation and (iii) decomposition of the anhydrous and dehalogenated compounds to metallic gold.

TABLE 1

Infrared data for the $[LH_2][AuCl_4]$ compounds
All values are in cm^{-1}

Substance	ν(O–H)	ν(N–H)	ν(C=O)	ν(C=C)	ν(C=N)	ν(Au–Cl)
Theophylline (TH)		3120	1715 1665	1605	1560	
$[TH_2][AuCl_4]$		3200–2700 [a]	1700 1640	[b]	1580	350
Theobromine (TBH)		3120	1700 1675	1600	1550	
$[TBH_2][AuCl_4]$		3200–2700 [a]	1700 [c]	1650	1570	352
3,8-Dimethyl-xanthine (DMH)	3470	3150 3040	1705 1660	1600	1565	
$[DMH_2][AuCl_4]$ 0.5 H_2O	3580(as) 3485(sym)	3200–2700 [a]	1705 1675	1585	1565	350
Caffeine (C)			1700 1650	1595	1540	
$[CH][AuCl_4]\cdot 2\ H_2O$	3460	3200–3100 [a]	1710 1675	1575	1550	355
1,3,8-Trimethyl xanthine (TMH)		3180	1700 1630	1590	1550	
$[TMH_2][AuCl_4]\cdot 2\ H_2O$	3560(as) 3415(sym)	3200–2700 [a]	1715 1680	1610	1580	355

[a] Few bands.
[b] Not observed due to overlapping with the carbonyl bands.
[c] Broad band.

(i) Dehydration processes

The compounds of DMH, C and TMH contain water of crystallization. Dehydration of these compounds occurs in one step, in the temperature ranges 150–180, 55–100 and 60–140°C, respectively. The expected endothermic behaviour for the dehydration process associated with these compounds has been observed from DSC curves in most temperature ranges. The dehydration temperatures, observed weight losses, calculated weight losses and dehydration enthalpies, calculated from the DSC curves in Fig. 2, are given in Table 2.

(ii) Dehalogenation processes

The dehalogenation of the anhydrous compounds starts in all cases in the 175–230°C region of the DTG curves. Under the experimental conditions used in the present work, the four chlorine atoms are eliminated in one step as Cl_2 except for the theophylline compound in which dehalogenation

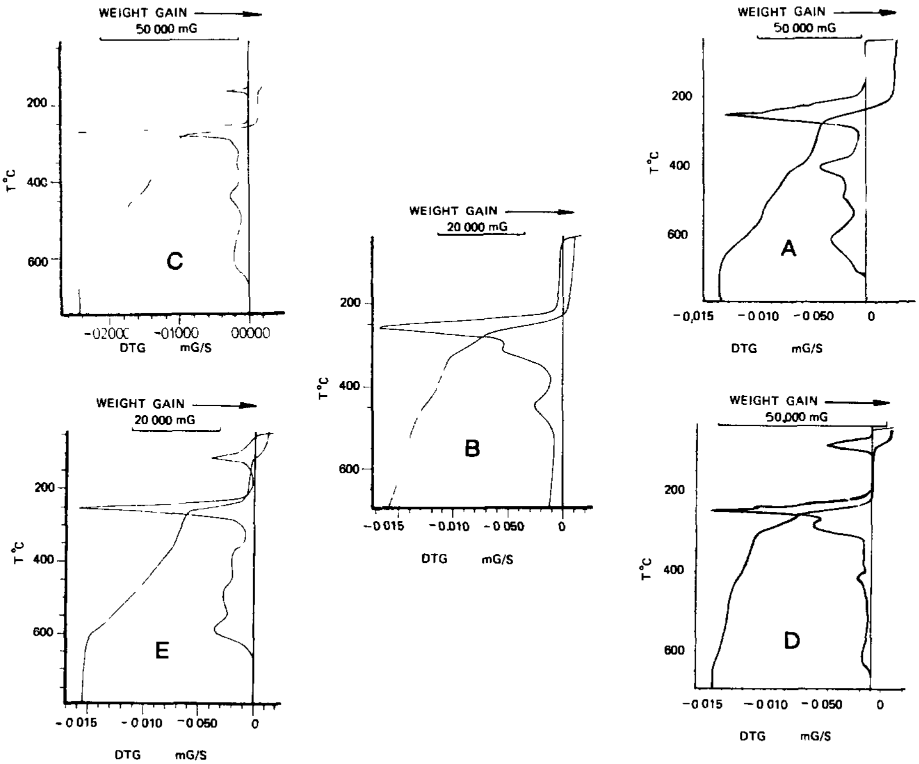

Fig. 1 TG and DTG plots of A, $[AuCl_4][TH_2]$, B, $[AuCl_4][TBH_2]$, C, $[AuCl_4][DMH_2]\cdot0.5\ H_2O$; D, $[AuCl_4][CH]\cdot2\ H_2O$; E, $[AuCl_4][TMH_2]\ 2\ H_2O$

apparently occurs in two steps as can be observed from its DSC curve. It seems probable that, in the first step, one HCl molecule is lost and, in the second step, the remaining three chlorine atoms are eliminated as Cl_2.

For these processes, the observed and calculated weight losses, dehalogenation temperatures and dehalogenation enthalpies are indicated in Table 3. The order obtained for the dehalogenation enthalpies for DMH, C and TMH compounds is analogous to that indicated in Table 2 for the dehydration enthalpies.

(iii) Pyrolytic processes

All the compounds isolated, the dehydrated and dehalogenate intermediates decompose showing exothermic effects in the DSC curves, which must be attributed to the combustion of the organic matter. In all cases, the final residue was Au°: this was corroborated by IR spectroscopy. The thermogravimetric and DSC data for these pyrolytic processes are given in Table 4.

From the foregoing results, we have proposed the following thermal degradation schemes for the new Au(III) compounds isolated.

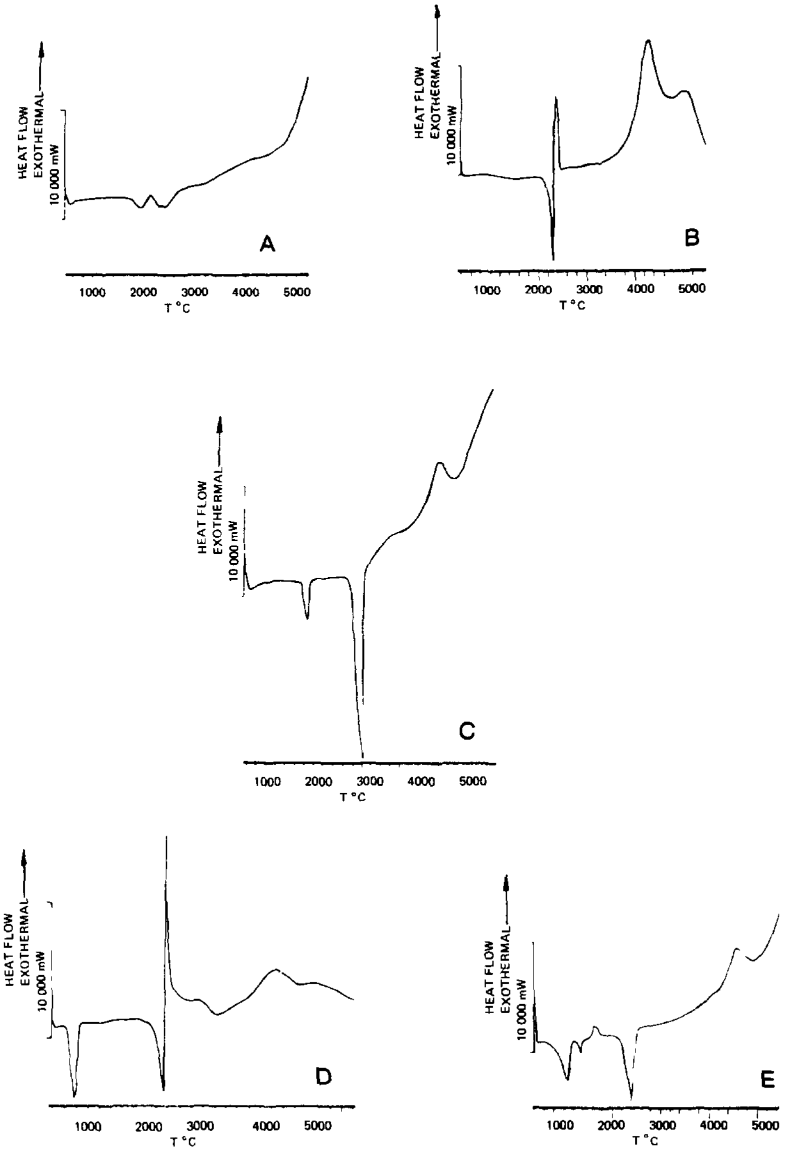

Fig 2 DSC curves of A, $[AuCl_4][TH_2]$, B, $[AuCl_4][TBH_2]$, C, $[AuCl_4][DMH_2]$ 0 5 H_2O, D, $[AuCl_4][CH]$ 2 H_2O; E, $[AuCl_4][TMH_2]$ 2 H_2O

For the theophylline compound

$$[TH_2^+][AuCl_4] \xrightarrow{\text{Endo}} [TH][AuCl_3] + HCl \xrightarrow{\text{Endo}} \xrightarrow{\text{Exo}} Au + 1.5\ Cl_2 + \text{pyrolysis products}$$

For the remaining Au(III) compounds

$$[LH_2^+][AuCl_4] \xrightarrow{\text{Endo}} \xrightarrow{\text{Exo}} Au + 2\ Cl_2 + \text{pyrolysis products}$$

TABLE 2

TG and DSC data for the dehydration of some $[LH_2][AuCl_4]$ complexes

Compounds	Dehydration temp (°C)	Weight loss (%)		ΔH dehydrat (kJ mole^{-1} H_2O)
		Found	Calcd	
$[DMH_2][AuCl_4]\cdot0$ 5 H_2O	163.6	1 5	1 70	51.7
$[CH][AuCl_4]$ 2 H_2O	74 9	5 9	6 32	48 0
$[TMH_2][AuCl_4]$ 2 H_2O	106.8	6 2	6 32	34 1

TABLE 3

Thermogravimetric and DSC data for the prepared compounds in the dehalogenation processes

Substance	Weight loss (%)		Temperature peak, DSC (°C)	ΔH dehalog (kJ mole^{-1})
	Found	Calcd		
$[TH_2][AuCl_4]$	26 6	27.31	192 6 242 4	19 5 [a] 62 3 [b]
$[TBH_2][AuCl_4]$	27 6	27 31	229 0	98 4
$[DMH_2][AuCl_4]\cdot0$ 5 H_2O	25.8	26 85	269 6	184 3
$[CH][AuCl_4]\cdot2$ H_2O	25 1	24 92	230 8	133 0
$[TMH_2][AuCl_4]$ 2 H_2O	25 3	24 92	238 6	126 5

[a] Elimination of an HCl molecule

[b] Elimination of three chlorine atoms

TABLE 4

Thermogravimetric and DSC data for the pyrolytic processes

Substance	Metal residue (%)		DSC peak temperature (°C) Exo
	Found	Calcd	
$[TH_2][AuCl_4]$	38 8	37.87	> 350
$[TBH_2][AuCl_4]$	38 7	37.87	420, 500
$[DMH_2][AuCl_4]$ 0.5 H_2O	38.6	37.22	440, > 500
$[CH][AuCl_4]\cdot2$ H_2O	33 7	34 55	240, > 400
$[TMH_2][AuCl_4]$ 2 H_2O	34.7	34 55	445, > 500

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