Synthesis and Characterization of Tetrakis(4-oxo-piperidinium ethylene acetal) Bis Sulfate Hexahydrate

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Abstract: Chemical preparation, x-ray characterization, IR spectroscopy and thermal analysis of a new sulfate $(C_7H_{12}O_2NH_2)_4(SO_4)_2 \cdot 6H_2O$, are reported. The atomic arrangement can be described by layers formed by sulfate anions (SO_4^{2-}) and water molecules connected by hydrogen bonds O-H...O. These inorganic layers are developed around *ab* planes at $z = 0$ and $z = 1/2$ and are interconnected by the *H*-bonds created by organic groups. All the hydrogen bonds, the Van der Waals contacts and electrostatic interactions between the different entities give rise to a three-dimensional network in the structure and add stability to this compound. The thermal behaviour and the IR spectroscopic studies of this new sulfate are discussed.

Keywords: Synthesis, X-ray crystal structure, IR spectroscopy, Thermal behavior

Introduction

Piperidine is considered as a lysine specific Maillard reaction product that can be formed from free lysine through decarboxylation and deamination reactions¹. Moreover, some piperidine derivatives are Renin inhibitors with excellent efficacies when administered at low dose to double transgenic rats harboring both the human angiotensinogen and the human Renin gene². Exploration of piperidine as HIV-1 reverse transcriptase inhibitors, with broad potency against resistant mutant viruses³. Furthermore, some piperidinium derivatives displayed strong *in vitro* cytotoxic activity against a panel of cancer cell lines as well as *in vitro* inhibitory activity against the pathogenic microbes mycobacterium tuberculosis and plasmodium falciparum⁴.

In order to research new materials of this kind, we report in this work the preparation and the structural investigation of the non-centrosymmetric, $(\text{C}_7\text{H}_{12}\text{O}_2\text{NH}_2)_4(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$. This compound is a new material resulting from the association of organic and inorganic entities and could be an interesting material in the non-linear optics⁵.

Experimental

Single crystals of the title compound were prepared at room temperature from a mixture of an aqueous solution of sulfuric acid (2 mmol), 1,4-dioxo-8-azaspiro[4.5]decane (4 mmol), ethanol (10 mL) and water (10 mL). Schematically, the reaction can be written as follows:

The resulting solution was evaporated slowly at room temperature for several days until the formation of good prismatic single crystals. The intensity data collection was performed with a CAD4 Enraf Nonius diffractometer. The structure was solved by direct method using the program SHELXS-97⁶ in the WinGX package⁷ and refined by full-matrix least-squares method with the program SHELXL-97⁶. All non-hydrogen atoms were refined isotropically and then anisotropically by full matrix least-square method. The hydrogen atoms were placed geometrically and treated as riding. The parameters used for the x-ray diffraction data collection as well as the strategy used for the crystal structure determination and its final results are reported in Table 1. The main geometrical features of the hydrogen-bond scheme are provided in Table 2.

The infrared spectrum is recorded in the range $4000\text{--}400 \text{ cm}^{-1}$ with a ‘‘PerkinElmer FTIR’’ spectrometer using a sample dispersed in spectroscopically pure KBr pellet. Thermal analysis was performed using the ‘‘Multimodule 92 setaram analyser’’ operating from room temperature up to 450°C at an average heating rate of 5°C min^{-1} .

Table 1. Crystal data and experimental parameters used for the intensity measurements

Empirical formula	$\text{C}_{28}\text{H}_{68}\text{O}_{22}\text{N}_4\text{S}_2$
Formula weight	876.98
T (K)	293
Wavelength ($\text{\AA}$)	0.5608
Crystal system	orthorhombic
Space group	$\text{Pna}2_1$
a ($\text{\AA}$)	22.1849 (10)
b ($\text{\AA}$)	9.928 (2)
c ($\text{\AA}$)	19.160 (3)
Z	4
V ($\text{\AA}^3$)	4220.1(11)
$\rho_{\text{cal.}}$, g cm^{-3}	1.380
F(000)	1888
μ ($\text{AgK}\alpha$)	0.12 mm^{-1}
Crystal size [mm]	$0.35 \times 0.25 \times 0.20$
9478 ($R_{\text{int.}} = 0.0000$)	9478 ($R_{\text{int.}} = 0.0000$)
Unique reflections included [$I > [2\sigma(I)]$]:	3272
$R[F^2 > 2\sigma(F^2)]$	0.063
wR(F^2)	0.181
$\Delta\rho_{\text{min.}}, \Delta\rho_{\text{max}}$	$-0.30, 0.30 \text{ e \AA}^{-3}$
Goodness-of-fit	0.92

Table 2. Hydrogen-bond geometry (Å, °) in (C₇H₁₂O₂NH₂)₄(SO₄)₂·6H₂O

D-H...A	D-H (Å)	H...A (Å)	D...A (Å)	D-H...A (°)
N1-H1A...O4A	0.90	1.77	2.650(14)	165.8
N1-H1A...O4B	0.90	1.88	2.731(15)	157.0
N1-H1B...O6	0.90	2.16	3.015(10)	157.7
N1-H1B...O8	0.90	2.29	3.038(15)	140.2
N2-H2A...O6	0.90	1.88	2.774(9)	174.5
N2-H2B...O1 ⁱ	0.90	1.83	2.718(10)	167.6
N3-H3A...O7B ⁱⁱ	0.90	1.79	2.694(15)	176.3
N3-H3A...O7A ⁱⁱ	0.90	1.96	2.831(14)	163.1
N3-H3B...O1 ⁱⁱⁱ	0.90	1.91	2.786(10)	163.4
N4-H4C...O7A ⁱⁱⁱ	0.90	2.09	2.936(14)	156.3
N4-H4C...O7B ⁱⁱⁱ	0.90	2.30	3.131(16)	153.9
N4-H4C...O8 ⁱⁱⁱ	0.90	2.51	3.252(16)	140.7
N4-H4D...O2B ⁱⁱⁱ	0.90	1.80	2.674(15)	162.6
N4-H4D...O2A ⁱⁱⁱ	0.90	1.84	2.716(18)	163.5
O17-H117...O19	0.851(10)	2.08(3)	2.812(8)	144(4)
O17-H217...O21 ^{iv}	0.851(10)	1.93(4)	2.734(6)	158(9)
O18-H118...O17	0.851(11)	1.975(12)	2.826(5)	178(5)
O18-H218...O4A	0.846(10)	2.04(3)	2.836(19)	157(5)
O18-H218...O2B	0.846(10)	2.28(5)	2.745(17)	115(4)
O19-H119...O20 ⁱ	0.851(10)	1.96(4)	2.766(7)	158(8)
O19-H219...O6	0.845(10)	2.51(4)	3.126(13)	131(5)
O20-H120...O22 ^v	0.846(10)	2.03(2)	2.796(5)	150(4)
O20-H220...O3A	0.850(10)	2.33(5)	3.053(17)	144(6)
O20-H220...O3B	0.850(10)	2.38(2)	3.22(2)	169(4)
O20-H220...O1	0.850(10)	2.57(4)	3.168(5)	128(4)
O21-H121...O3A	0.851(10)	2.19(3)	2.944(18)	148(4)
O20-H220...O3B	0.850(10)	2.38(2)	3.22(2)	118(3)
O21-H221...O8	0.851(10)	1.84(3)	2.655(6)	161(6)
O22-H122...O5	0.850(10)	2.12(4)	2.870(4)	147(7)
O22-H222...O18 ⁱ	0.850(10)	1.98(2)	2.774(6)	156(5)
C5-H5B...O12 ^{vi}	0.97	2.53	3.463(12)	161.6
C11-H11A...O4B ⁱ	0.97	2.28	3.182(17)	155.0
C12-H12B...O10	0.97	2.55	3.503(12)	168.0
C15-H15B...O15 ^{vii}	0.97	2.49	3.455(13)	172.1
C16-H16A...O2A ⁱⁱⁱ	0.97	2.35	3.255(19)	155.7
C23-H23A...O7A ⁱⁱⁱ	0.97	2.53	3.277(16)	133.5
C25-H25B...O7B ⁱⁱⁱ	0.97	2.53	3.322(17)	138.9

Symmetry codes: (i) $x+1/2, -y+1/2, z$; (ii) $-x+2, -y+1, z+1/2$; (iii) $-x+3/2, y+1/2, z+1/2$; (iv) $x, y+1, z$; (v) $x-1/2, -y-1/2, z$; (vi) $x-1/2, -y+1/2, z$; (vii) $x+1/2, -y+3/2, z$

Results and Discussion

Crystal description

Asymmetric unit of the title compound is built up from two sulfate anions, four organic cations and six water molecules. Its geometrical configuration is depicted in the Figure 1. The atomic arrangement of the title compound is characterized by the existence of inorganic layers, generated by the periodic motif $[\text{S}_2\text{O}_8(\text{H}_2\text{O})_6]^{4-}$. These layers cross the unit cell parallel

to the (a, b) plane at $z=0$ and $z=1/2$ (Figure 2). Between these layers, separated by a distance of 9.580 Å, organic cations establish hydrogen bonds to interconnect the different anions. The SO_4^{2-} ions are bonded to the water molecules through single, bifurcated and trifurcated O-H...O hydrogen bonds.

Figure 1. ORTEP Drawing showing the asymmetric unit of $(\text{C}_7\text{H}_{12}\text{O}_2\text{NH}_2)_4(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ with the atom-labelling scheme. Displacement ellipsoids are drawn at the 30% probability level. H atoms are represented by spheres of arbitrary radii

Figure 2. Projection of $(\text{C}_7\text{H}_{12}\text{O}_2\text{NH}_2)_4(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ structure along the b axis

The title compound contains distorted tetrahedral SO_4^{2-} anions, so four oxygen atoms (O2, O3, O4 and O7) are distorted over two sets in 0.5:0.5 ratio. The sulfate ion S1O_4^{2-} is disordered over two sites related by rotation around the S1-O1 bond in an “umbrella” type of disorder (only three of four oxygen atoms are disordered), a similar case has been observed in the structure of tris(diisopropylammonium) hydrogensulfate sulfate⁸. In the other sulfate ion S2O_4^{2-} , the oxygen atom O7 is disordered over two positions (O7A and O7B) with equal occupancy. We can notice that the presence of the disordered tetrahedral encourages the formation of bifurcated and trifurcated hydrogen bonds.

Four independent 4-oxo-piperidinium ethylene acetal cations are identified in crystal structure. Interatomic bond lengths and angles in these entities spread within the ranges [1.325(12)-1.573(13) Å] and [102.2(8)-113.8(8)°], respectively. These values are similar to those obtained for the same organic group in other compound⁹. The organic cations are localized in the interlayer spacing and arranged in the same direction. The organic molecule contains two rings joined at the carbon atom. The first ring presents a planar part that contains two oxygen atoms with a mean plane deviation of 0.045 Å, while the second one exhibits a chair conformation.

All the amino hydrogen atoms are involved in N-H...O hydrogen bonding, as well as weak C-H...O interactions. In the N-H...O bonds, the H...O bond lengths are in the range 1.77-2.51 Å and the H...O distances in the C-H...O bonds are in the 2.28 - 2.55 Å range (Table 2). The adjacent layers interact via N-H...O and C-H...O hydrogen bonding along the b-axis to form 3D network.

There are six crystallographically independent water molecules O(17), O(18), O(19), O(20), O(21) and O(22) in this atomic arrangement. They interconnect the sulfate anions and the organic groups via hydrogen bonds. The cohesion forces in this compound are assured by electrostatic interactions, van der Waals contacts and hydrogen bonds (O-H...O, N-H...O and C-H...O).

Thermal Behavior

Figure 3 shows both TG and DTA thermograms of the hybrid compound heated from room temperature to 450 °C at 5 °C min⁻¹. From these curves, we deduce that the thermal decomposition occurs in two stages. The first one corresponds to the removal of the six water molecules (weight loss calculated 12.31%, observed 12.19%) in the temperature range 50-115 °C. This is related to the endothermic peak on the DTA curve at 91 °C. The force of the hydrogen bonds in the network explains the removal of the water molecules in this large temperature range. The endothermic peak at 149 °C is assigned to a phase transition. In order to detect the phase transition and to examine the nature of this transformation, DSC measurements have been undertaken. A result of calorimetric study is represented in Figure 4, which represents the diagram obtained during heating and cooling scans a recently prepared crystals of (C₇H₁₂O₂NH₂)₄(SO₄)₂·6H₂O. The diagram shows the appearance of the peak of the phase transition only in the heating cycle at 155 °C. That proves that the phase transition is irreversible.

Figure 3. DTA and TG curves of (C₇H₁₂O₂NH₂)₄(SO₄)₂·6H₂O

Figure 4. DSC curves obtained upon heating and cooling of $(\text{C}_7\text{H}_{12}\text{O}_2\text{NH}_2)_4(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$

The second process related to the others endothermic peak observed in the DTA at 227, 242 and 269 °C correspond to a degradation of the obtained phase in a wide temperature range [200–300 °C].

IR spectroscopy

The infrared absorption spectrum of the title compound reported in Figure 5 shows vibrations band characteristic of the organic cation, the SO_4^{2-} anion and the water molecule. The assignment attempts are based on previous results encountered in the literature^{10,11} and on the predictions of group theoretical analysis. Multiple bands extending from 3400 to 2500 cm^{-1} are observed in the IR spectrum. These bands are due to the symmetric and asymmetric stretching modes of H_2O , NH_2 , CH_2 and OH ⁹. Frequencies in the range 1700–1300 are attributed to $\delta(\text{H}_2\text{O})$, $\delta(\text{NH}_2)$, $\delta(\text{CH}_2)$ and $\delta(\text{OH})$ ⁹ bending vibrations.

Figure 5. Infrared absorption spectrum of $(\text{C}_7\text{H}_{12}\text{O}_2\text{NH}_2)_4(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$

Various valency and bending vibration bands, whose number and positions are between 1200 and 300 cm^{-1} , are both characteristic of a sulfate anion. The isolated SO_4^{2-} tetrahedron with an ideal T_d symmetry has four vibrational modes: the non-degenerate symmetric stretching mode $\nu_1(A_1)$; the doubly degenerate bending mode $\nu_2(E)$; the triply asymmetric stretching mode $\nu_3(F_2)$ and the triply degenerate asymmetric bending mode $\nu_4(F_2)$. All the modes are Raman active, whereas only ν_3 and ν_4 are active in the IR. These modes are observed at 981, 451, 1104, and 614 cm^{-1} , respectively¹². In the crystal, the SO_4^{2-} anion occupies lower site symmetry C_1 , a result the IR inactive modes ν_1 and ν_2 may become active and the degeneracy of ν_2 , ν_3 and ν_4 modes may be removed. The degenerate ν_2 mode of the ion is found to be split into two components around 441 and 451 cm^{-1} . Appearance of this IR inactive mode can be due the symmetry lowering of the SO_4^{2-} ion from T_d to C_1 . The ν_3 mode appears as three bands at 1018, 1047 and 1125 cm^{-1} . The ν_4 mode is also observed as three bands at 492, 590 and 620 cm^{-1} . The non-degenerate stretching mode ν_1 appears as one band at 944 cm^{-1} .

Supplementary material

Crystallographic data (CIF) for the structure reported in this paper have been deposited in the Cambridge crystallographic data centre as supplementary materials No CCDC 802225. Copies of the data can be obtained, free of charge, on application to the CCDC, 12 Union Road, Cambridge CB12EZ, UK

Conclusion

The use of the protonated 4-oxo-piperidinium ethylene acetal as organic cation in the sulfate matrix leads to a new hybrid compound of the chemical formula $(\text{C}_7\text{H}_{12}\text{O}_2\text{NH}_2)_4(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$. Crystal structure of this compound was found to be built by infinite layers of SO_4^{2-} and water molecules parallel to the ab planes around $z=0$ and $z=1/2$. Between these layers the organic cations are located. Both inorganic and organic components perform different interactions (electrostatic, H -bonds and van der Waals) to stabilize the three-dimensional network. When heated, the compound loses the crystallization water molecules at 91 °C. By heating further, the compound exhibits a degradation of the organic entities confirmed by the obtained carbon black residue at the end of the experiment.

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