**Magnesium Anthranilate Dihydrate**

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Magnesium, Hexa(aquo) Complex of Magnesium, Anthranilate Anion

The reaction mixture of magnesium chloride with two equivalents of potassium anthranilate [K+ Anth-] in water gives on cooling to 0 °C a 60% yield of a precipitate which after drying in a vacuum has the composition [Mg(H₂O)₆]₂[Anth]₂ (1). Recrystallization from hot water affords an octahydrate identified as [Mg(H₂O)₆][Anth]₂(H₂O)₂ (2) in a single crystal X-ray diffraction study. Contrary to findings for the related calcium, strontium and barium compounds, in the magnesium compound the anthranilate anions are not part of the coordination sphere of the metal atom. Thermal degradation of 1 or 2 at 125 °C gives the anhydrous product [Mg[A nth]₂]. 3. An alternative preparative route employed in previous studies gave only anhydrous material. The result of the present investigation confirms the outstanding stability of the hexa(aquo) complex of magnesium, as compared to the hydrates of the larger alkaline earth metals, in the presence of potential bio-ligands.

**Introduction**

Magnesium salts play a central role as cofactors for most enzymes that participate in the biochemistry of nucleic acids [1–5]. The outstanding stability of the hexahydrate dication [Mg(H₂O)₆]²⁺, as compared to the hydrates of the other three metal ions most common in biological systems (sodium, potassium and calcium), is responsible for the superior template function of magnesium ions in aqueous solution under physiological conditions. However, in many cases the mode of action of Mg²⁺ on the molecular level is not perfectly understood, and few model complexes are available where structural information gives a clue as to the details of the binding sites at the substrates.

Recent structural work on magnesium complexes of amino acids [6,7] has revealed the modes of chelate interaction for L-aspartic and L-glutamic acid which are known to be the prominent binding sites for magnesium in proteins. This information is also of key importance for an understanding of the mechanism of many biominalization processes [8]. Complementary studies focused on complexes with β-glutamate [9], citrate [10], and orotate ligands [11].

Current interest has also been oriented towards the coordination chemistry of alkali and earth alkaline salts of salicylic [12] and anthranilic acid (A, B) which are ubiquitous constituents of biological systems and – in the case of B – precursors of important amino acids such as tryptophan. The two aromatic hydroxy- and amino-benzoic acids are also important models for the coordination chemistry of humic acids [13].

While the stoichiometry, structure and stability of calcium, strontium, and barium anthranilates could recently be established [14], open questions remained regarding the nature of the magnesium salts of anthranilic acid. Hill and Curran reported the precipitation of a magnesium bis-anthranilate from aqueous solution [15], but the elemental analysis and the IR and UV/Vis spectra were inconclusive. Murugavel et al. also obtained this product and confirmed that the material is anhydrous and insoluble in water, but could not determine its structure [14]. This result was unexpected, because magnesium ions – more than their heavier congeners – are known to trap water molecules in almost all their complexes with bio-ligands.

In this paper we present an account of our own current studies and of the successful structural characterization of magnesium anthranilates obtained via a slightly different preparative route.

**Results**

Potassium anthranilate (K+Anth-) is prepared by neutralization of anthranilic acid (A nthH) with potassium hydroxide in water at 20 °C. Upon addition of an aqueous solution of magnesium chloride (molar ratio K₂Mg = 2:1) and cooling to 0 °C a pale-brown crystalline precipitate appears in ca. 60%, which slowly loses crystal water when stored at room temperature. The vacuum-dried product has the composition of the hexahydrate [Mg(H₂O)₆][A nth]₂ (1, by elemental analysis).

In previous attempts to prepare magnesium anthranilate, magnesium chloride and A nthH in a water/methanol mixed solvent were treated with aqueous ammonia. This procedure affords an in-

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soluble anhydrous material of the composition \(\text{Mg(Anth)}_2\) of unknown structure \([14,15]\).

The product obtained in the present study (1) can readily be redissolved in hot water and crystallized (at 20 °C) to give single crystals of an octahydrate (2) \(\text{Mg(Anth)}_2\left(\text{H}_2\text{O}\right)_8\) which is to be formulated as \([\text{Mg(H}_2\text{O)}_6][(\text{Anth})_2]\left(\text{H}_2\text{O}\right)_2\) (2, by X-ray crystallography, below). Compound 2, which is probably identical with the primary product, but of higher purity, also has a high water vapour pressure and looses two of the eight water molecules when air-dried or exposed to vacuum.

On heating of the hexahydrate 1 to 125 °C the water content is reduced to the anhydrous \(\text{Mg(Anth)}_2\) (3, by elemental analysis). This dehydration was followed by thermogravimetric analysis, which confirmed the loss of 6 \(\text{H}_2\text{O}\) in the narrow range of 105–125 °C. According to the TGA diagram, the dehydrated residue is stable to 415 °C as already noted by earlier workers [14].

All salts (1–3) were investigated by IR-spectroscopy, but the spectra showed only small variations in the individual band characteristics. The samples of 1 and 2 exhibit the absorptions of crystal water, but these gradually disappear upon transition to 3 (125 °C). The IR spectrum of the anhydrous material has been published, as have UV/Vis and NQR data [14–16].

Crystals of \([\text{Mg(H}_2\text{O)}_6][(\text{Anth})_2]\left(\text{H}_2\text{O}\right)_2\) (2) are monoclinic, space group \(\text{P2}_1/c\) with \(Z = 2\) formula units in the unit cell. The structure is composed of a hexa(aquo)magnesium cation, the metal atom of which resides on a center of inversion, and two anthranilate anions and two water molecules, each pair related by symmetry (Fig. 1). The components are engaged in a network of hydrogen bonds (Table 1). A prominent intra-anionic hydrogen bond spans the amino and the carboxylate group of each anthranilate unit (N1-H1–O4). All other hydrogen bonds of the anions involve at least one magnesium-bound water molecule, and the two interstitial water molecules are also associated with water molecules of the hexa(aquo)magnesium dication (O1-H12–O6', O3-H32–O6').

The dications and water molecules form layers separated by layers of anthranilate anions (Fig. 2). The structure of the magnesium anthranilate 1 is entirely different from the structures of the calcium, strontium and barium compounds, which crystallize as tri- (Ca, Sr) or monohydrates (Ba), respectively. With the heavier earth alkaline metals, the anions are part of the ligand sphere of the dications, while in the magnesium salts the integ-

Table 1. Hydrogen bonding in \([\text{Mg(H}_2\text{O)}_6][(\text{Anth})_2]\left(\text{H}_2\text{O}\right)_2\) (2).

<table>
<thead>
<tr>
<th>D-H-A</th>
<th>d(D-H) ([\text{A}])</th>
<th>d(H...A) ([\text{A}])</th>
<th>d(D...A) ([\text{A}])</th>
<th>Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>O6-H61-O4</td>
<td>0.852</td>
<td>1.890</td>
<td>167.41</td>
<td>2.728</td>
</tr>
<tr>
<td>O6-H61-O5</td>
<td>0.776</td>
<td>1.998</td>
<td>162.43</td>
<td>2.748</td>
</tr>
<tr>
<td>O1-H11-O5</td>
<td>0.813</td>
<td>1.984</td>
<td>168.69</td>
<td>2.786</td>
</tr>
<tr>
<td>O1-H12-O6</td>
<td>0.842</td>
<td>1.885</td>
<td>174.30</td>
<td>2.786</td>
</tr>
<tr>
<td>O2-H21-O4</td>
<td>0.829</td>
<td>1.935</td>
<td>177.52</td>
<td>2.764</td>
</tr>
<tr>
<td>O2-H22-O1</td>
<td>0.826</td>
<td>2.012</td>
<td>172.25</td>
<td>2.833</td>
</tr>
<tr>
<td>O3-H31-O5</td>
<td>0.865</td>
<td>1.889</td>
<td>170.15</td>
<td>2.746</td>
</tr>
<tr>
<td>O3-H32-O6</td>
<td>0.785</td>
<td>1.977</td>
<td>166.67</td>
<td>2.747</td>
</tr>
<tr>
<td>N1-H1-O4</td>
<td>0.896</td>
<td>1.994</td>
<td>132.28</td>
<td>2.680</td>
</tr>
</tbody>
</table>

a) \(x+1, y, z\); b) \(-x, -y+1, -z\); c) \(x+1, -y+0.5, z+0.5\); d) \(-x+1, -y+1, -z+1\); e) \(-x, -y+1, -z+1\); f) \(x, y, z\); g) \(x, -y+1.5, z+0.5\).
Fig. 2. Cell plot of $\text{[Mg(H}_2\text{O)}_6\text{]}^2+$, showing the layers of anthranilate anions separated by layers of the dications and water molecules.

rity of the $\text{[Mg(H}_2\text{O)}_6\text{]}^2+$ octahedron is strictly conserved. This result is consistent with findings for many magnesium salts with bio-relevant cations in aqueous solution and in crystalline phases.

**Experimental Section**

The experiments were carried out in bidistilled water under an atmosphere of nitrogen. All reagents were commercially available. Standard glassware and equipment was used throughout.

Anthranilic acid (2.06 g, 15 mmol) is neutralized with potassium hydroxide (0.84 g, 15 mmol) in 30 ml of bidistilled water at 20 °C. The reaction mixture is filtered, its pH adjusted to 6 with small amounts of anthranilic acid and added to a solution of magnesium chloride (1.52 g, 7.5 mmol) in 7.5 ml of water. A pale-brown precipitate is formed which dissolves on heating to reflux. Upon cooling to 20 °C a yellow solid is obtained (2.17 g, 61% yield). Heating of the product to 100 °C (but not beyond) or exposing it to a vacuum at 20 °C leaves a solid with a lower content of crystal water: Calculated for the hexahydrate $\text{C}_14\text{H}_{28}\text{MgN}_2\text{O}_{12}$, $M=440.69$, monoclinic, $a=9.4416(2)$, $b=11.7701(3)$, $c=9.5330(2)$, $\beta=107.417(1)^\circ$, space group $P2_1/c$, $Z=2$, $V=1010.82(4)$ A$^3$, $\mu(\text{Mo-K}_\alpha)=1.53$ cm$^{-1}$, 37052 measured and 2318 unique reflections $|F_{\text{int}}|=0.059$, $wR_2=0.0845$, $R=0.0381$ for 2318 reflections $|F_{\text{obs}}|$ and 173 parameters. The function minimized was $wR^2=\sum[w(F_{\text{obs}}^2-F_{\text{calc}}^2)^2]/\sum[w(F_{\text{obs}}^2)]^{1/2}$; $w=1/\sigma(F_{\text{obs}}^2)+(ap)^2+bp$; $p=(F_{\text{obs}}^2+2F_{\text{calc}}^2)/3$; $a=0.0277$, $b=0.51$. Residual electron density 0.275/-0.242 A$^{-3}$. Thermal parameters and complete tables of interatomic distances and angles have been deposited with the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, U.K. The data are available on request quoting CCDC-178447.

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